



6GNTN

D3.9 SOFTWARE DEFINED PAYLOAD AND ITS SCALABILITY

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Abstract	This document describes the work carried out to define the loads used for NTN 6G. Based on the system definition, trade-offs propose preliminary solutions for the main components of the 6G. NTN.

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EXECUTIVE SUMMARY

This document is dedicated to the definition of the payloads of the various nodes of the 6G NTN network, i.e. GEO, LEO, VLEO and HAPS.

In this final version of the document, the hardware solutions for the payload are outlined with the objective of providing global coverage thru several nodes. This definition takes into account the multi-layer 3D architecture, which is even at the base of the 6G NTN definition. The payload design is an iterative process encompassing all tasks in Work Package (WP3), involving several parameters from constellation definition to terminal characterization. The design of payload solutions is proposed based on the trade-offs on for GEO to VLEO constellations as well as for AERIALS.

Firstly, the definition of the elements of the 6G NTN network, their assigned roles, and the nature of the links between them, based on the objectives outlined in Tasks 2.1, 2.2, and 2.4, have been proposed in collaboration with system definition Task 3.1. This has enabled us to advance and propose potential payload solutions through iterative performance evaluations.

These solutions are mainly:

- GEO constellations (Ku or Ka band)
- Satellite payloads for LEO and VLEO constellations in C band and LEO constellation in Q/V bands.
- HAPS/AERIALS: payloads for UAV solutions in S Band.

The payloads include INL (Inter Node Links), ISL (Inter Satellite Links), Feeder links, as well as user links.

These evaluations allowed to define possible solutions for each of the previously defined payloads, justifying the directions taken. Solutions are also assessed in the context of evolving technologies and the considerable uncertainties associated with future needs. The objective of scalability is also addressed, to overcome this context of uncertainties and imagine their adaptability. Nevertheless, reference solutions (VLEO, LEO constellations, HAPS, RF and interlinks, feeder links) that are likely to evolve with maturity of thinking are proposed to perform the analyses defined in the other tasks (RIC management, System definition, constellation sizing ...) and then gives feedback to progress on this research work. Moreover a part is devoted for Navigation question more precisely on solution for positioning based on 6G NTN which is one of the additional feature envisaged.

TABLE OF CONTENTS

<i>Disclaimer</i>	2
<i>Copyright notice</i>	2
1 INTRODUCTION	23
1.1 SCOPE AND OBJECTIVES.....	23
1.1.1 Scope: Task 3.3 in the context of the study	23
1.1.2 6G NTN vision.....	23
1.1.3 Objectives	24
1.2 Document structure	25
2 STATE OF ART & CHALLENGES & METHODOLOGY	26
2.1 STATE OF ART: FROM 5G NTN SYSTEM currently in design to the next evolution of NTN SYSTEM.....	26
2.1.1 Context of 6G NTN: state of art and design /constellation in progress 4G 5G.....	26
2.1.2 6G NTN: “unified Network “2030 / AI / ultra-connected word / sustainability / technology evolution: impact on payload definitions.....	27
2.1.3 Future context: Tendency users/ satellites enabling technology: vision 6G NTN	28
2.2 NETWORK AND NODES: CHALLENGES	29
2.2.1 Deterministic and flexible nodes	29
2.2.2 Overview on GEO, LEO, AERIALS : axis of focus.....	29
2.2.3 Scalability: Flexibility / adaptability / evolution/ sustainability.....	30
2.2.4 Payload designs /challenges.....	30
2.3 METHODOLOGY APPLIED.....	31
3 SYSTEM 6G NTN	34
3.1 DESCRIPTION OF THE 6G NTN SYSTEM.....	34
3.1.1 Definition of the system.....	34
3.1.2 Frequency plan	36
3.1.3 Terminal definition.....	38
3.1.4 Gateways Definition	41
3.1.5 Scalability of the system (NTN): concept	41
4 DESCRIPTION OF THE PAYLOADS ASSOCIATED TO THE NODES (THE MAIN FUNCTIONALITIES EXPECTED)	43
4.1 GEO CONSTELLATION (DETERMINISTIC).....	43
4.1.1 Mission definition.....	43
4.1.2 GEO satellite Payload.....	45
4.1.3 User Link (1).....	46
4.1.4 Feeder Link (7).....	47
4.1.5 ISL RF Link(11).....	47
4.1.6 INL to HAPS (Q/V band) (4).....	47
4.1.7 OISL to GEO SAT (5).....	47

4.2	<i>LEO CONSTELLATION- C-BAND payload (reference case Case A)</i>	48
4.2.1	<i>Mission objectives</i>	48
4.2.2	<i>C band Payload description</i>	49
4.2.3	<i>User link (C-Band) trade-off</i>	50
4.2.4	<i>Solution C-band Analysis</i>	67
4.2.5	<i>Link Budget</i>	75
4.2.6	<i>System level performance of the proposed C-band (use case of Metropolitan France)</i>	80
4.2.7	<i>Observations</i>	94
4.2.8	<i>Satellite C-band performances (case A)</i>	96
4.3	<i>Investigation on improvement in C-Band constellations</i>	99
4.3.1	<i>Introduction</i>	99
4.3.2	<i>VLEO constellation at 350 km (case B)</i>	100
4.3.3	<i>Antenna Performances</i>	103
4.3.4	<i>LEO Satellite C-BAND Enhanced performances (Case C)</i>	107
4.4	<i>Synthesis of the solutions A,B,C</i>	108
4.4.1	<i>Synthesis of the 3 solutions</i>	108
4.4.2	<i>Performances and target objectives defined in [24]</i>	110
4.4.3	<i>Conclusion</i>	112
4.5	<i>LEO CONSTELLATION PAYLOAD Q/V</i>	114
4.5.1	<i>Q/V frequency band</i>	114
4.5.2	<i>Mission description</i>	114
4.5.3	<i>Payload description</i>	115
4.5.4	<i>User link (Q/V-Band)</i>	116
4.5.5	<i>Solution Q/V band Analysis</i>	121
4.5.6	<i>Link Budget</i>	132
4.5.7	<i>Satellite Q/V band performances</i>	136
4.6	<i>LEO constellation Satellite design</i>	141
4.7	<i>UAV PAYLOAD (HAPS) (FLEXIBLE)</i>	143
4.7.1	<i>HAPS and Drones as a Station</i>	143
4.7.2	<i>Mission descriptions</i>	144
4.7.3	<i>Payload functionalities</i>	150
4.7.4	<i>User Links S band (HIBS)</i>	151
4.7.5	<i>Solution S band Analysis</i>	154
4.7.6	<i>Link Budget</i>	161
4.7.7	<i>User Links Q/V band</i>	167
4.8	<i>FEEDER LINK LEO GATEWAY</i>	167
4.8.1	<i>Introduction</i>	167
4.8.2	<i>Trade-off and solution orientation</i>	168
4.8.3	<i>Frequency band</i>	170

4.8.4	<i>Feeder Links of the NTN mission</i>	171
4.8.5	<i>Feeder Solution (architecture)</i>	172
4.8.6	<i>Link Budget</i>	173
4.9	INL : LEO FEEDER SAT to HAPS	174
4.9.1	<i>Introduction</i>	174
4.9.2	<i>Solution orientation</i>	175
4.9.3	<i>Link Budget</i>	177
4.10	ISL RF LEO to GEO	178
4.10.1	<i>Introduction</i>	178
4.10.2	<i>Solution orientation</i>	179
4.10.3	<i>Frequency band selection</i>	179
4.10.4	<i>Antenna Architecture trade-off</i>	180
4.10.5	<i>Link Budget</i>	182
5	SCALABILITY	185
5.1	<i>Scalability of payload design</i>	185
5.2	<i>Scalability at payload level</i>	185
5.3	<i>connectivity aspect and fonctionnal split implementation</i>	186
5.4	<i>Scalability: incremental number of payloads</i>	188
5.5	<i>Payloads scalability over coverage</i>	191
5.5.1	<i>Coverage of each payload</i>	191
6	NAVIGATION CAPABILITIES OF THE PAYLOADS	193
6.1	<i>Introduction</i>	193
6.2	<i>Enlarged beam</i>	193
6.3	<i>Conclusion</i>	197
7	CONCLUSION /PERSPECTIVE /NEXT STEP	198
8	REFERENCE	200
9	APPENDICES	209
9.1	<i>FRONT-ENDS DEFINITION</i>	1
9.2	<i>GENERAL TRADE-OFF</i>	1
9.3	<i>NUMEROLOGY</i>	3
9.4	<i>C-BAND payload</i>	4
9.4.1	<i>CASE A – C band LEO</i>	4
9.4.2	<i>Metropolitan France</i>	21
9.4.3	<i>CASE B – C band VLEO</i>	49
9.4.4	<i>CASE C C-BAND</i>	57
9.5	<i>Q/V band payload</i>	71
9.5.1	<i>Antenna performances</i>	71
9.5.2	<i>Downlink Q/V band link budget</i>	73

9.5.3 Uplink A/V band link budget76

LIST OF FIGURES

FIGURE 1-1: 6G-NTN PERT CHART – FOCUS ON TASK 3.3	23
FIGURE 1-2 G-NTN 3D NETWORK CONCEPT. [1]	24
FIGURE 2-1 ILLUSTRATION OF THE METHODOLOGY (APPLICABLE TO LEO CONSTELLATION	32
(1) : TASK 3.1. (2) : TASK 3.4. (3) : TASK 3.2	32
FIGURE 3-1 SYSTEM ARCHITECTURE 1 & 2.....	35
FIGURE 3-2 TABLE RESUME OF THE TERMINALS DEFINITION.....	39
FIGURE 3-3 TERMINALS CBAND HANDELD PERFORMANCES	40
FIGURE 3-4 PERFORMANCES OF THE DIFFERENT TYPE OF TERMINALS	40
FIGURE 3-5 QV_NTN_1 TERMINAL PERFORMANCES.....	41
FIGURE 3-6 RESUME OF THE PERFORMANCES HYPOTHESIS FOR QV_NTN_1 TERMINAL 41	41
FIGURE 4-1 LEO COVERAGE USER LINK (MULTISPOTS).....	43
FIGURE 4-2 AREA OF COVERAGE OF A GEO SATELLITE.....	44
FIGURE 4-3 EXAMPLE: EARTH COVERAGE WITH 3 SATELLITES (SAT1 SAT2 SAT3) CELLS OF 900 KMS	44
FIGURE 4-4 EXEMPLE COVERAGE COMPATIBILITY GEO COVERAGE (CELL = 900 KM, NB=284) AND LEO COVERAGE (CELL=45KM, NB=499).....	45
FIGURE 4-5 GEO CONSTELLATION AND THE LINKS	46
FIGURE 4-6 EXEMPLE CONSTELLATION.....	48
FIGURE 4-7 PAYLOAD C-BAND FONCTIONNALITIES.....	49
FIGURE 4-9 NUMEROLOLGY FR1 USED FOR C-BAND.....	50
FIGURE 4-10 EXEMPLE OF COVERAGE SEEN AT DIFFERENT ALTITUDE OF A COVERAGE OF ELMIN OF 30°, CELL SIZE OF 50 KM	51
FIGURE 4-11 PARAMETERS DEFINING THE CONSTELLATION	52
FIGURE 4-12 EARTH COVERAGE ANGLE VERSUS SATELLITE ALTITUDE.....	53
FIGURE 4-13 ILLUSTRATION OF SCAN ANGLE DUE TO GRATING LOBES.....	53
FIGURE 4-14 RE SIZE VERSUS ELMIN AND ALTITUDE TO AVOID GRATING LOBES.....	54
FIGURE 4-15 FREESPACE LOSSES (DELTA NADIR-EDGE).....	55
FIGURE 4-16 SCAN LOSSES (DELTA NADIR-EDGE).....	55
FIGURE 4-17 TOTAL FSL+SC.....	55
FIGURE 4-18 DIRECTIVITY 2 ANTENNA SIZE.....	56
FIGURE 4-19 ANGLE α VERSUS EL_{MIN}	56
FIGURE 4-20 COMMUNICATION TYPE DEFINITION	57
FIGURE 4-21 RTT VERSUS EL_{MIN} AND SATELLITE ALTITUDE.....	58
FIGURE 4-22 NUMBER OF SATELLITE NEEDED VERSUS ALTITUDE AND ELMIN.....	58
FIGURE 4-23 NUMBER OF SATELLITES OF THE CONSTELLATION	59
FIGURE 4-24 COVERAGE DEFINITION FOR TRADE-OFF	59

FIGURE 4-25 NUMBER OF CELL VERSUS CELL SIZE/AND COVERAGE EL _{MIN}	60
FIGURE 4-26 VIEW OF THE CELLS	61
FIGURE 4-27 ANTENNA SIZES USED FOR TRADE-OFF FINALIZATION	61
FIGURE 4-28 BEAM POINTING BY PHASE PLANE ONLY RE 512, 1056 & 1536 RE	62
FIGURE 4-29 EXEMPLE OF COVERAGE WITH CELLS OF 22.5 KM	63
FIGURE 4-30 ANTENNE 512 RE 0.741λ : directivity min and max over cell at nadir and edge 64	64
FIGURE 4-31 ANTENNE 1056 RE 0.741λ : directivity min and max over cell at nadir and edge 65	65
FIGURE 4-32 ANTENNE 1536 RE 0.741λ : directivity min and max over cell at nadir and edge 66	66
FIGURE 4-33 NUMBER OF CELL VERSUS CELL SIZE AND SATELLITE ALTITUDE	67
FIGURE 4-34 COVERAGE OF LEO-C BAND	67
FIGURE 4-35 PAE VS OBO SHAPES COMPARISON BETWEEN CLASS-AB (BLUE) AND DOHERTY (RED) HPA DESIGNS (TAS-F DESIGN, C-BAND, GAN)	68
FIGURE 4-36 PAYLOAD ARCHITECTURE 1 (SERVICE SATELLITE).....	69
FIGURE 4-37 PAYLAOD ARCHITECTURE 2 (SERVICE SATELLITE).....	70
FIGURE 4-38 RADIATING ELEMENT DIAGRAM 0.741λ (RX).....	71
FIGURE 4-39 ANTENNA DEFINIITON.....	71
ANTENNA RE POSITIONNING.....	ERROR! BOOKMARK NOT DEFINED.
ANTENNA RE POSITIONNING.....	72
FIGURE 4-40 ANTENNA GEOMETRY	72
FIGURE 4-41 BEAM FORMING TECH. & BEAM SHAPE.....	73
FIGURE 4-42 BEAM PERFORMANCES DIRECTIVITY 0.741λ (Rx)	73
FIGURE 4-43 BEAM PERFORMANCES DIRECTIVITY 0.65λ (Tx).....	74
FIGURE 4-44 GRATING LOBES POSITION VERIFICATIONS.....	74
FIGURE 4-45 CONSTANTS AND HYPOTHESIS	75
FIGURE 4-46 RESUME OF THE TERMINAL PERFORMANCES(UE)	75
FIGURE 4-47 SATELLITE PARAMETERS FDD CASE (UE_1 & UE_2)	76
FIGURE 4-48 SATELLITE PARAMETERS TDD CASE (UE_3 & UE_4)	77
FIGURE 4-49 UE HYPOTHESIS (UE_1).....	78
FIGURE 4-50 UE HYPOTHESIS (UE_2).....	78
FIGURE 4-51 UE HYPOTHESIS (UE_3).....	79
FIGURE 4-52 UE HYPOTHESIS (UE_4).....	79
FIGURE 4-53 COMPARISON OF THROUGHPUT IN TYPICAL CASE FOR THE 4 UE TYPE IN BANDE C	80
FIGURE 4-54 TERRESTRIAL COVERAGE MAP OF METROPOLITAN FRANCE RETRIEVED FROM [132].....	81
FIGURE 4-55 NTN CELL VISUALISATION A VISUALIZATION OF A SNAPSHOT OF THE CONSTELLATION AND BEAM ASSIGNMENT TO NTN CELLS WITHIN METROPOLITAN FRANCE GIVEN THE PARAMETERS OF TABLE 3TABLE 2 USING FRF=3. GREEN,	

YELLOW AND BLUE CIRCLES INDICATE THE THREE DIFFERENT CELL COLORS. RED SQUARES INDICATE THE LOCATION OF THE LEO SATELLITES, AND WHITE LINES THEIR ORBIT TRACES.	82
FIGURE 4-56 POPULATION DISTRIBUTION OF METROPOLITAN FRANCE RETRIEVED FROM [133].....	83
FIGURE 4-57 POPULATION DISTRIBUTION OF NTN USERS WITHIN METROPOLITAN FRANCE.....	83
FIGURE 4-58 THE SOCIAL-MEDIA CENTRIC USER TRAFFIC PROFILE (2022).....	84
FIGURE 4-59 DATA VOLUME DISTRIBUTION OVER THE DAY AND BUSY HOUR RECTANGULAR APPROXIMATION. CONTRIBUTIONS FROM DOWNLINK AND UPLINK ARE ALSO SHOWN.	85
FIGURE 4-60 MOBILE DATA TRAFFIC PER SMARTPHONE (GB PER MONTH) AND ITS EVOLUTION IN TIME (P. 17 OF [134][16]).	85
FIGURE 4-61 BLER PERFORMANCE OF THE FIRST HARQ TRANSMISSION OF MCS = {0...20} FOR A NTN TDL C, LOS, RURAL ENVIRONMENT, ELEVATION ANGLE 80° AS SPECIFIED IN TABLE 6.7.2-7A OF [16].	87
FIGURE 4-62 BLER PERFORMANCE (ADJUSTED FOR A 10% BLER TARGET) OF MCS = {0...20} FOR A NTN TDL C, LOS, RURAL ENVIRONMENT, ELEVATION ANGLE 80°, BW=33.3MHZ (100MHZ WITH FRF=3).	87
TABLE 1 PARAMETERS OF SIMULATED “TYPICAL UE” CHARACTERISTICS.....	88
TABLE 2 PARAMETERS OF SIMULATED LEO CONSTELLATION ([25])	88
FIGURE 4-63 VISUALIZATION OF THE SIMULATED LEO CONSTELLATION OF TABLE 2..	89
TABLE 3 PARAMETER VALUES	91
FIGURE 4-64 FREQUENCY REUSE SCHEMES, FRF=1, AND FRF=3, SEE TABLE 6.1.1.1-5 OF 3GPP 38.821[17].....	91
TABLE 4 SYSTEM LEVEL SIMULATION PARAMETERS	92
TABLE 5 PERFORMANCE SUMMARY.....	93
FIGURE 4-65 VIEW OF THE COVERAGE OVERLAP WITH ELVATION ANGLE [25].....	96
FIGURE 4-66 NUMBER OF SATELLITES AND ASSOCIATED CELLS TO COVER [25]	96
FIGURE 4-67 SELECTED CELLS IN (BROWN).....	97
FIGURE 4-68 CAPACITY PER BEAM VERS NUMBER OF ACTIVE BEAMS	97
FIGURE 4-69 EIRP FLUX DENSITY VERSUS NUMBER OF ACTIVE BEAMS	98
FIGURE 4-70 DOWNLINK THROUGHPUT TOTAL CAPACITY OF A SATELLITE VERS NUMBER OF ACTIVE BEAMS.....	98
FIGURE 4-71 VARIATION OF THE THROUGHPUT WITH RANDOM SELECTION OF 60 BEAMS	99
FIGURE 4-72 UPLINK THROUGHPUT VERSUS NUMBE OF ACTIVE BEAMS.....	99
FIGURE 4-73 COVERAGE PARAMETERS LEO AND VLEO.....	101
FIGURE 4-74 IMPACT OF ALTITUDE CHANGE IN ANGLE VIEW	101
FIGURE 4-75 COVERAGE AND RE-ADJUSTEMENT FOR VLEO.....	102
FIGURE 4-76 RE SIZE REDUCTION FOR VLEO.....	102
(1536 RE, 48 BLOCS OF 32 RE SUB-PANNELS)	103
FULL REGENERATIVE PAYLOAD	103

FIGURE 4-77 ANTENNA FOOTPRINT & ARCHITECTURE	103
FIGURE 4-78 C-BAND NUMEROLOGY	103
FIGURE 4-79 CAPACITY PER BEAM VERS NUMBER OF ACTIVE BEAMS	104
FIGURE 4-80 EIRP FLUX DENSITY VERSUS NUMBER OF ACTIVE BEAMS	104
FIGURE 4-81 DOWNLINK THROUGHPUT TOTAL CAPACITY OF A SATELLITE VERS NUMBER OF ACTIVE BEAMS	105
FIGURE 4-82 VARIATION OF THE THROUGHPUT WITH RANDOM SELECTION OF 60 BEAMS 105	
FIGURE 4-83 UPLINK THROUGHPUT VERSUS NUMBE OF ACTIVE BEAMS.....	106
FIGURE 4-84 UPLINK THROUGHPUT FOR RANDOM SET OF BEAMS	106
FIGURE 4-85 60 ACTIVE BEAMS ISSUED FROM OPTIMIZATION.....	108
FIGURE 4-86 SYNTHESIS OF THE PÊRFOMANCE OF THE 3 SOLUTIONS (AT MAX THROUGHPUT)	109
FIGURE 4-87 COMPARISON BETWEEN CASE, A , B AND C FOR UE_1.....	109
FIGURE 4-88 PAYLOAD BUDGETS CASE A.....	110
FIGURE 4-89 PAYLOAD BUDGET CASE B	110
FIGURE 4-90 PAYLOAD BUDGET CASE C	110
FIGURE 4-91 SYNTHESIS OF INVESTIGATIONS (SEE APPENDIX 9.4.4).....	111
FIGURE 4-92 MAX DIRECTIVITY VERSUS DEPOINTING ANGLE	111
FIGURE 4-93 EARTH COVERAGE.....	115
FIGURE 4-94 PAYLOAD Q/V-BAND FONCTIONNALITIES	116
FIGURE 4-95 NUMEROLOLY FR2 USED FOR Q/V-BAND.....	116
TABLE 6 : OVERVIEW OF INTEGRATED CIRCUIT TECHNOLOGY PORTFOLIO AND PRELIMINARY TRADE-OFF TRENDS FOR Q/V BAND APPLICATIONS	119
FIGURE 4-96 MAX DIRECTIVITY ANTENNA TRADE-OFF.....	120
FIGURE 4-97 FUNCTIONNAL DESCRIPTION SATELLITE /PAYLAODS	123
FIGURE 4-98 ARCHITECTURE 1 :V BAND RX ANTENNA SYSTEM.....	124
FIGURE 4-99 ARCHITECTURE 2 : V BAND RX ANTENNA SYSTEM.....	124
FIGURE 4-100 ARCHITECTURE 1 : Q BAND TX ANTENNA SYSTEM.....	124
FIGURE 4-101 ARCHITECTURE 2: Q BAND TX ANTENNA SYSTEM.....	125
FIGURE 4-102 ANTENNA LATTICE	126
FIGURE 4-103 SATELLITE ANTENNA RADIATING ELEMENT GAIN	126
FIGURE 4-104 RADIATING ELEMENT DIAGRAMS FOR Q/V BAND (DIRECTIVITY).....	126
FIGURE 4-105 ANTENNA PANNEL	127
FIGURE 4-106 ANTENNA PERFORMANCES 512 RE IN DEPOINTING (DYN.=12 DB)	128
FIGURE 4-107 ANTENNA PERFORMANCES 512 RE IN DEPOINTING (DYN.=12 DB)	128
FIGURE 4-108 ANTENNA PERFORMANCES 512 RE IN DEPOINTING (DYN.=6 DB)	129
FIGURE 4-109 BEAM PERFORMANCES IN DEPOINTING 6DB	129
FIGURE 4-110 512 RE 12 DB AMPLITUDE & 6 DB AMPLITUDE.....	129

FIGURE 4-111 PERFORMANCE OF ANTENNA WITH SLIGH ANGLE	130
FIGURE 4-112 OPTIMISATION OF COVERAGE OF EACH ANTENNA	131
FIGURE 4-113 GRATING LOBES.....	132
FIGURE 4-114 CONSTANTS AND HYPOTHESIS	132
FIGURE 4-115 ELEMENTARY ELEMENT PERFORMANCES SATELLITE	133
FIGURE 4-116 ELEMENTARY ELEMENT PERFORMANCES TERMINAL	133
FIGURE 4-117- RADIATING ELEMENT MODEL 0.741λ	133
FIGURE 4-118 TERMINAL ANTENNA PERFORMANCES.....	134
FIGURE 4-119 SATELLITE HYPOTHESIS.....	135
FIGURE 4-120 UE HYPOTHESIS	136
FIGURE 4-121 OPTIMUM DISTRIBUTION OF 28 BEAMS (PER DRA)	137
FIGURE 4-122 CAPACITY PER BEAM VERS NUMBER OF ACTIVE BEAMS	137
FIGURE 4-123 EIRP FLUX DENSITY VERSUS NUMBER OF ACTIVE BEAMS	138
FIGURE 4-124 EIRP DENSITY VERSUS NUMBER OF ACTIVE BEAMS.....	138
FIGURE 4-125 DOWNLINK THROUGHPUT TOTAL CAPACITY OF A SATELLITE VERS NUMBER OF ACTIVE BEAMS.....	139
FIGURE 4-126 VARIATION OF THE THROUGHPUT WITH RANDOM SELECTION OF 28 BEAMS.....	139
FIGURE 4-127 UPLINK THROUGHPUT VERSUS NUMBE OF ACTIVE BEAMS.....	140
FIGURE 4-128 UPLINK THROUGHPUT FOR RANDOM SET OF BEAMS	140
FIGURE 4-129 FEEDER SATELLITE & USERS SATELLITE (ARCH. 2).....	141
FIGURE 4-131 SATELLITE DESCRIPTION C-BAND CASE A B & C.....	142
FIGURE 4-132 SATELLITE DESCRIPTION Q/V-BAND.....	143
FIGURE 4-133 EXEMPLE OF ANTENNA SOLUTIONS PROPOSED	145
FIGURE 4-134 EXEMPLE OF ANTENNA SOLUTIONS PROPOSED IN [122]	146
FIGURE 4-135 HAPS CHARACTERISTICS & PARAMETERS	147
FIGURE 4-136 CELLS DEFINITIONS	148
FIGURE 4-137 COVERAGE IMPACT VERSUS HAPS ALTITUDE AND CELLS SIZE	149
FIGURE 4-138 NTN CELL AND TN SECTOR COVERAGE COMPATIBILITY.....	150
FIGURE 4-139 GEO CONSTELLATION AND THE LINK (USER, INTERNODES, FEEDER) ..	150
FIGURE 4-140 LINK DESCRIPTION FROM A HAPS	150
FIGURE 4-141 NUMEROLOLY FR1 USED FOR Q/V-BAND.....	151
FIGURE 4-142 ALTERNATIVE FREQUENCY BAND	151
FIGURE 4-143 DRA SIZING.....	152
FIGURE 4-144 MAX/MIN DIRECTIVITY ANTENNA TRADE-OFF	153
FIGURE 4-145 DIRECTIVITY MIN COMPARISON.....	153
FIGURE 4-146 ANTENNA ARRAY GEOMETRY.....	154
FIGURE 4-147 FUNCTIONNAL DESCRIPTION HAPS/PAYLOAD	155
The beamforming will be based on a DBFN.	155

FIGURE 4-148 HAPS PAYLOAD ARCHITECTURE S BAND.....	155
FIGURE 4-149 ANTENNA LATTICE.....	156
FIGURE 4-150 RADIATING ELEMENT DIAGRAMS FOR S BAND (DIRECTIVITY).....	156
FIGURE 4-151 CORRESPONDENCE BETWEEN CELL DEFINITIONS (SATELLITE & HAPS) AND NESTINGS.....	157
FIGURE 4-152 BEAM ON COVERAGE COMPOSED OF CELLS OF 5.625 KM.....	157
FIGURE 4-153 BEAM ON COVERAGE COMPOSED OF CELLS OF 11.25 KM.....	158
FIGURE 4-154 BEAM ON COVERAGE COMPOSED OF CELLS OF 22.5 KM.....	158
FIGURE 4-155 BEAM ON COVERAGE COMPOSED OF A CELL OF 45 KM	159
FIGURE 4-156 ANTENNA PERFORMANCES 30 RE	159
FIGURE 4-157 FLUX DENSITY LIMITS TO PROTECT MOBILE (IMT) SERVICES.....	160
FIGURE 4-158 PFD LIMITS.....	161
FIGURE 4-159 CONSTANTS AND HYPOTHESIS	161
FIGURE 4-160 ELEMENTARY ELEMENT PERFORMANCES HAPS	161
FIGURE 4-161 ELEMENTARY ELEMENT PERFORMANCES TERMINAL (BEST CASE)	161
FIGURE 4-162 HAPS HYPOTHESIS	163
FIGURE 4-163 UE HYPOTHESIS	164
FIGURE 4-164 UPLINK BUDGET	165
FIGURE 4-165 PERFORMANCES EVALUATION IN DIFFERENT CONFIGURATIONS.....	166
FIGURE 4-166 DOWNLINK LINK BUDGET	167
FIGURE 4-167 NEWTON BASED STEERABLE ANTENNA.....	169
FIGURE 4-168 CASSEGRANIAN BASED STEERABLE ANTENNA	170
FIGURE 4-169 FREQUENCY BAND FOR THE FEEDER LINK.....	170
FIGURE 4-170 COVERAGE AREA OF A FEEDER SATELLITE	171
FIGURE 4-171 GATEWAY PERFORMANCES.....	172
FIGURE 4-172 FEEDER HYPOTHESIS.....	172
FIGURE 4-173 FRONT END ARCHITECTURE FEEDER.....	173
FIGURE 4-174 RESUME OF FEEDER HYPOTHESIS	173
FIGURE 4-175 LINK BUDGET UPLINK.....	174
FIGURE 4-176 LINK BUDGET DOWNLINK	174
FIGURE 4-177 INTERNODE LINK	175
FIGURE 4-178 PERFORMANCES HAPS ANTENNA AND FEEDER SATELLITE	175
FIGURE 4-179 FREQUENCY BAND.....	176
FIGURE 4-180 SATELLITE ANTENNA FEEDER SYNTHESIS	176
FIGURE 4-181 HAPS ANTENNA	177
FIGURE 4-182 UPLINK LINK BUDGET.....	178
FIGURE 4-183 DOWNLINK BUDGET.....	178
FIGURE 4-184 DISTANCE BETWEEN A LEO SAT AND GEO SATELLITE.....	179

FIGURE 4-185 FREQUENCY FOR ISL RF (DATA ITU).....	180
FIGURE 4-186 EXEMPLE OF ARCHITECTURE (BI-POLARIZATION FULL FLEXIBLE/FULL DUPLEX) TWO POLARIZATIONS	180
FIGURE 4-187 EXEMPLE OF LINKS.....	181
FIGURE 4-188 EXEMPLE OF ARCHITECTURE ONE POLARIZATION /ONE FREQUENCY/ POLARIZATION DISCRIMINATION (F1 OR F2).....	181
FIGURE 4-189 EXEMPLE OF LINK (F=F1 OR F2).....	181
FIGURE 4-191 EXEMPLE ANTENNA PERFORMANCE FOR TWO APERTURES	182
FIGURE 4-192 EXEMPLE OF THROUGHPUT ACHIEVABLE.....	183
FIGURE 4-193.....	183
FIGURE 5-1 DESCRIPTION OF THE LINKS	187
FIGURE 5-2 ARCHITECTURE : SPLIT OPTION RU-DU AND CU-DU	188
FIGURE 5-3 EXEMPLE OF SCALABILITY OF THE PAYLOADS	189
FIGURE 5-4 INCREASE IN CAPACITY	190
FIGURE 5-5 COMPATIBILITY OF COVERAGE AND CELL SIZE.....	191
FIGURE 5-6 ILLUSTRATION OF SHAPING COVERAGE OVER A ZONE	192
FIGURE 6-1 SUPERPOSITION OF THE SATELLITES (COVERAGE EL MIN 45°, 10 S HANDOVER) (-.- DASHED- LINE :POSITION OF FRANCE METROPOLITAN COVERAGE)	193
FIGURE 6-2 EXTENSION OF EACH SATELLITE COVERAGE	194
FIGURE 6-3 COVERAGE EXTENSION (C-BAND CASE C)	194
FIGURE 6-4 WIDE BEAM 26.1° ELMIN (55.1° DEPOINTING ANGLE FROM SATELLITE)....	195
FIGURE 6-5 SUPERPOSITION OF WIDE BEAM GENERATED BY THE ANTENNA COVERAGE 26.1°	196
FIGURE 6-6 NUMBER OF SATELLITE THAT SUPERPOSE ITS COVERAGEVERS LONG/LAT	196
FIGURE 6-7 % OF SURFACE COVERED BY AT LEAST 4 SATELLITES.....	197
FIGURE 9-1 TABLE RESUME OF THE FRONT-ENDS DEFINITION	3
FIGURE 9-2 GENERAL TRADE-OFF TABLE	2
FIGURE 9-3 EXTRACT NUMEROLOGY 3GPP TR 38.811 V15.4.0 [16]	3
FIGURE 9-4 RX BEST PERFORMANCE CASE (PHASE ONLY)	5
FIGURE 9-5 RX TYPICAL CASE (12 DB AMPLITUDE/PHASE)	6
FIGURE 9-6 COMPARISON RX : BEST PERFORMANCE (PHASE ONLY) & TYPICAL CASE (AMPLITUDE/PHASE 12 DB)	6
FIGURE 9-7 TX BEST CASE (PHASE ONLY CENTER OF CELL)	7
FIGURE 9-8 TX BEST CASE (PHASE ONLY EDGE OF CELL)	8
FIGURE 9-9 TX TYPICAL CASE (12 AMPLITUDE/PHASE EDGE OF CELL)	9
FIGURE 9-10 COMPARISON BETWEEN THE 3 BEAMFORMING TECHNIQUES	9
FIGURE 9-11 POWER HYPOTHESIS (CASE A) FRONT-END TX	10
FIGURE 9-12 DOWNLINK BUDGET CASE A NOMINAL CASE (UE_1).....	10

FIGURE 9-13 DOWNLINK BUDGET CASE A NOMINAL CASE (UE_2).....	11
FIGURE 9-14 DOWNLINK BUDGET CASE A NOMINAL CASE (UE_3).....	11
FIGURE 9-15 DOWNLINK BUDGET CASE A NOMINAL CASE (UE_4).....	12
FIGURE 9-16 DOWNLINK BUDGET CASE A BEST CASE (UE_1)	12
FIGURE 9-17 DOWNLINK BUDGET CASE A BEST CASE (UE_2)	13
FIGURE 9-18 DOWNLINK BUDGET CASE A BEST CASE (UE_3)	13
FIGURE 9-19 DOWNLINK BUDGET CASE A BEST CASE (UE_1)	13
FIGURE 9-20 DOWNLINK BUDGET (UE_1) WORST CASE INDOOR 10 DB ATTENUATION	14
FIGURE 9-21 DOWNLINK BUDGET (UE_2) WORST CASE INDOOR 10 DB ATTENUATION.....	14
FIGURE 9-22 DOWNLINK BUDGET (UE_3) WORST CASE INDOOR 10 DB ATTENUATION	15
FIGURE 9-23 DOWNLINK BUDGET (UE_4) WORST CASE INDOOR 10 DB ATTENUATION	15
FIGURE 9-23 RX FRONT END HYPOTHESIS CASE A.....	15
FIGURE 9-24 UPLINK BUDGET BEST CASE (UE_1)	16
FIGURE 9-25 9-26 UPLINK BUDGET BEST CASE (UE_2).....	16
FIGURE 9-27 UPLINK BUDGET BEST CASE (UE_3)	17
FIGURE 9-28 UPLINK BUDGET BEST CASE (UE_4)	17
FIGURE 9-29 UPLINK BUDGET FOR 1 PRB CASE UE_1 (TO SIMPLIFY).....	18
FIGURE 9-30 UPLINK BUDGET FOR 1 PRB CASE UE_2.....	18
FIGURE 9-31 UPLINK BUDGET FOR 1 PRB CASE UE_3.....	19
FIGURE 9-32 UPLINK BUDGET FOR 1 PRB CASE UE_4.....	19
FIGURE 9-33 UPLINK BUDGET WORST CASE (UE_1) 7 DB MAX ATTENUATION	20
FIGURE 9-34 UPLINK BUDGET WORST CASE (UE_2) 10 DB MAX ATTENUATION	20
FIGURE 9-35 UPLINK BUDGET WORST CASE (UE_3) 7 DB AND 9 DB MAX ATTENUATION	21
FIGURE 9-36 UPLINK BUDGET WORST CASE (UE_4) 10 DB MAX ATTENUATION	21
FIGURE 9-37 HYPOTHESIS	50
FIGURE 9-38 TX BEAMS FOOTPRINT (DIFFERENT BEAM FORMING)	51
FIGURE 9-39 BEAM FORMING TX BEAMS RESUME	52
FIGURE 9-40 RX BEAMS FOOTPRINT (DIFFERENT BEAM FORMING).....	52
FIGURE 9-41 BEAM FORMING RX BEAMS RESUME.....	53
FIGURE 9-42 POWER HYPOTHESIS CASE B	54
FIGURE 9-43 DOWNLINK BUDGET NOMINAL CASE (UE_1)	54
FIGURE 9-44 DOWNLINK BUDGET BEST CASE (UE_1).....	55
FIGURE 9-45 DOWNLINK BUDGET WORST CASE (UE_1).....	55
FIGURE 9-46 RX FRONT END HYPOTHESIS CASE A.....	56
FIGURE 9-47 UPLINK BUDGET BEST CASE (UE_1)	56
FIGURE 9-48 UPLINK BUDGET FOR ONE PRB (UE_1).....	56
FIGURE 9-50 RESIZING FOR RE	57

FIGURE 9-51 SIZING TRADE-OFF TESTS	57
FIGURE 9-52 ANTENNA OF 1504 RE	58
FIGURE 9-53 ANTENNA OF 2048 RE	59
FIGURE 9-54 ANTENNA OF 2048 RE	59
FIGURE 9-55 ANTENNA OF 3008 RE	60
FIGURE 9-56 ANTENNA OF 4080 RE	60
FIGURE 9-57 ANTENNA SIZE INCREASE 1056 TO 1520 RE	61
FIGURE 9-58 NEW CELL DISCRETIZATION.....	61
FIGURE 9-59 COMPARISON DRA 1056 RE AND 1520 RE ON CELL OF 45 KM ($EL_{MIN}=45^\circ$) .	62
FIGURE 9-60 DRA 1056 RE : COMPARISON BETWEEN PERFORMANCES RX ON 45 KM AND 21 KM CELLS	62
FIGURE 9-61 DRA 1056 RE : COMPARISON BETWEEN PERFORMANCES ON 45 KM AND 21 KM CELLS	64
FIGURE 9-62 COMPARISON BETWEEN RX DRA 1056 & 1520 ON CELLS OF 21 KM.....	64
FIGURE 9-63 COMPARISON BETWEEN RX DRA 1056 & 1520 ON CELLS OF 21 KM.....	65
FIGURE 9-64 UPLINK PERFORMANCE OF DRA 1520 RE ON (MAX ACHIEVABLE THROUGHPUT)	66
FIGURE 9-65 SATELLITE RX FRONT END HYPOTHESIS IN DIRECTIVITY TO REACH 2 MBPS IN UPLINK.....	66
FIGURE 9-66 UPLINK LINK BUDGET 2 MBPS	67
FIGURE 9-67 POWER TX CASE C	67
FIGURE 9-68 DOWNLINK BUDGET NOMINAL CASE (UE_1)	68
FIGURE 9-69 DOWNLINK BUDGET BEST CASE (UE_1).....	68
FIGURE 9-70 DOWNLINK BUDGET WORST CASE (UE_1).....	69
FIGURE 9-71 UPLINK BUDGET BEST CASE (UE_1)	69
FIGURE 9-72 UPLINK BUDGET FOR ONE PRB (UE_1).....	69
FIGURE 9-73 UPLINK BUDGET WORST CASE (UE_1) 8 AND 9 DB ATTENUATION	70
FIGURE 9-74 PERFORMANCES DIRECTIVITY BEAM TX	72
FIGURE 9-75 PERFORMANCES DIRECTIVITY BEAM RX.....	73
FIGURE 9-76 POWER HYPHESIS (53 W PER DRA).....	73
FIGURE 9-77 DOWNLINK BUDGET NOMINAL CASE (4 BEAMS CENTER BEAM)	74
FIGURE 9-78 DOWNLINK LINK BUDGET BEST CASE ALL POWER IN ONE BEAM	75
FIGURE 9-79 DOWNLINK LINK BUDGET WORST CASE 10 DB ATTENUATION	76
FIGURE 9-80 SATELLITE RX FRONT END HYPOTHESIS.....	76
FIGURE 9-81 UPLINK BUDGET NOMINAL CASE (1 PRB)	77
FIGURE 9-82 UPLINK BUDGET BEST CASE (MAXIMISATION OF UPLINK)	78
FIGURE 9-83 UPLINK BUDGET WORST CASE (10 DB ATTENUATION)	79

LIST OF TABLES

ABBREVIATIONS

3GPP	3rd Generation Partnership Project
AFSR	Array fed shaped reflector Antenna
AI	Artificial Intelligence
ASIC	Application-specific integrated circuit
BH	Beam Hopping
BLER	Block error rate
BS	Base station
BVLoS	Beyond Visual Line of Sight
BW	Bandwidth
CAGR	Compound annual growth rate
C2	Command and Control
C2CSP	C2 Link communication service provider
CDL	Lustered delay line
CMOS	Complementary metal-oxide semiconductor
CoW	Cell on Wheels
CQI	Channel quality indicator
CSI	Channel state information
C-SWaP	Cost Size Weight and Power
DRA	Direct radiating array
EASA	European Union Aviation Safety Agency
EOC	End of coverage
EC	Earth coverage
E2E	End-to-end
FAFR	fed array focal Reflector antenna
FR	First Responder
FSL	Free space losses
FPGA	Field programmable Gate Array

GEO	Geostationary Earth Orbit
GaN	Gallium Nitride (amplifier)
gNB	Next-generation Node-B
GNSS	Global Navigation Satellite Systems
GSO	Geostationary orbit
HAPs	High Altitude Platform (station)
HARQ	Hybrid automatic repeat request
HPA	High power amplifier
HTS	High throughput service
HV	Host Vehicle
IoT	Internet of Things
IMT	International Mobile Telecommunications
INL	Inter-node link
ISL	Inter-satellite link
LMBA	Load-Modulated Balanced Amplifier Design
LEO	Low Earth Orbit
LNA	Low Noise Amplifier
LoS	Line of Sight
MCS	Modulation and coding scheme
MFCN	Mobile/Fixed Communications Networks
MEO	Medium Earth Orbit
MFPB	Multiple feed per beam
MIMO	Multiple inputs multiple outputs
MNO	Mobile Network Operator
NGSO	non-geostationary orbit
NLoS	Non-Line of Sight
NR	New Radio
NTN	Non-Terrestrial Network

OBO	Output backoff
OOBE	Out-of-Band Emission
PAE	Power added efficiency
PAPR	Peak-to-Average Power Ratio
PCB	Printed circuit board
PRB	Physical resource Block
PPDR	Public Protection and Disaster Relief
PTT	Push-To-Talk
QoE	Quality of Experience
QoS	Quality of Service*
RAAN	right ascension of ascending node
RE	Radiating element
Rel	Release
RIC	Radio Intelligent Controller
RTT	Round trip time
SAR	Search and Rescue
SC	Scan losses
SFPB	Single feed per beam
SI	Study Item
SIP	System in package
SIR	Signal to interference ratio
SINR	Signal to interference ratio
SNR	Signal to noise ratio
SON	Self-organizing networks
TDL	Tapped delay line
TN	Terrestrial Network
TR	Technical Report
TS	Technical Specifications

UAM	Urban Air Mobility
UAV	Uncrewed Aerial Vehicle
UAV-C	UAV controller
UC	Use case
UE	User Equipment
vLEO	Very low Earth Orbit
VLoS	Visual Line of Sight
VNF	Virtualized Network Function
VR	Virtual reality
VTOL	Vertical take-off and landing
WI	Work Item
WP	Work package

1 INTRODUCTION

1.1 SCOPE AND OBJECTIVES

1.1.1 Scope: Task 3.3 in the context of the study

Task 3.3 is part of the WP3 Architecture Design and Trade-offs itself is one of the 6G NTN Workpackage . The interaction between the tasks have been presented in the figure Figure 1-1 :

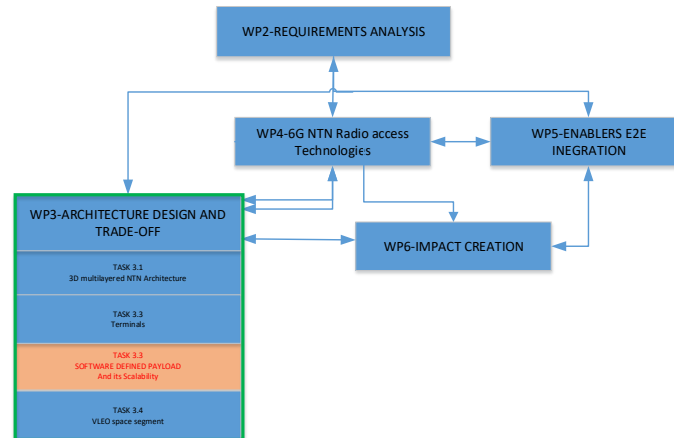


FIGURE 1-1: 6G-NTN PERT CHART – FOCUS ON TASK 3.3

In this document, we focus on WP3 Architecture design and trade-off and more particularly on task 3.3, which deals with payloads definition associated to each node of the 6G NTN. Task 3.3 interacts directly with the others task of this WP 3, the system definition (task 3.1), terminal definition (task 3.2) and constellation definition (task 3.4). This WP3 is in interaction with the other WP's as mentioned in the Figure 1-1 and defined in [1].

As mentioned in [1] the aim is to help build the system 6G NTN based on a global vision of what the future system could be and define the axis of progress and investigations to achieve to make it a reality in the schedule of the deployment of the 6G network. To carry out this project, several aspects of the system will need to be considered before a concrete vision of the system can be drawn up and the payloads of the network elements defined. On the other hand, we also need to establish the long-term feasibility (technological maturity) of the payloads, to be able to propose a system. This document presents the preliminary payloads definitions.

1.1.2 6G NTN vision

These recent years, several early work [2]-[15] has focused on imagining what the system could be and the vision converge in the version of a 3D systems composed of nodes defined in different layers and interconnected in such a way to cover a large domain of connection with different users evolving around the earth/sea or in the atmosphere layer (planes, unmanned users aerials).

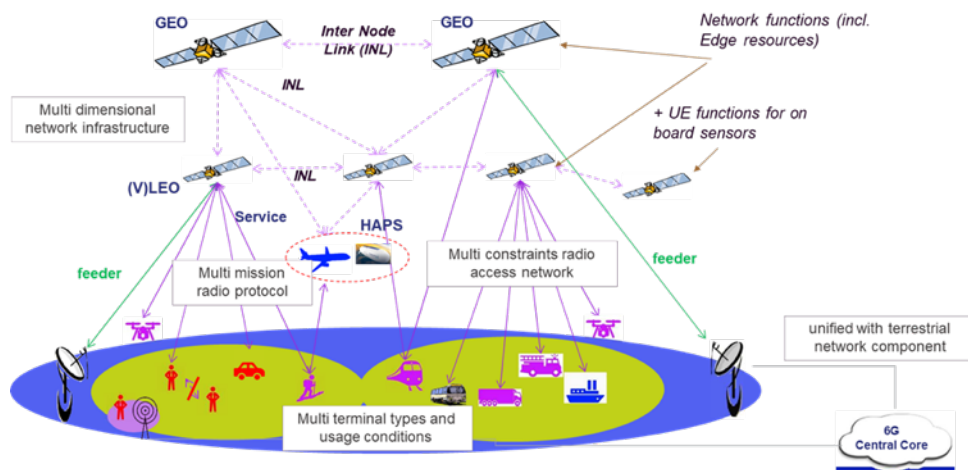


FIGURE 1-2 G-NTN 3D NETWORK CONCEPT. [1]

All the different nodes that integrate everything from the outset, ensure continuity, are robust and have self-organizing capacity, enabling communication both between them and between UEs, and all this while adapting to needs.

Preliminary work has focused on imagining what the system might look like, and this is the start of the 5G implementation and discussions on integrating NTN into 5G ([16],[18]). The context here is to anticipate and define from the outset the integration of NTN as a building block for 6G at its infancy.

As far as multiple elements are concerned in this system, the impact is to define the payloads of the elements making up the proposed system. Each Element, in our terminology “nodes” have a payload, i.e., materials and component which ensure dedicated functions. As nothing is set in stone, we must carry out this research activity with all the elements that make up the system. The task is far from straightforward, since it involves building permanent interaction with all aspects of 6G NTN, both the equipment (users) and the operating procedures to be standardized.

Thus, from WP2 where the main preliminary requirements are addressed, it should be remembered that this WP in particular needs to be run in parallel, as the elements are interconnected and have an impact on the whole. On the one hand, to define the system on the basis of feasibility, thanks to constant feedback between tasks (on orientations based on preliminary analyses) and, on the other hand, to go into a little more detail on each element as a component and interacting to constitute this system (constellations, terminals and payloads). This work will provide feedback on the architecture, consolidating choices or specifying points to which greater importance should be attached in subsequent studies, and thus progress towards a possible 6G NTN system.

1.1.3 Objectives

The aim of this document is to focus on the definition of the nodes (and their payloads) that make up the NTN part of 6G system, as described in D3.5 (Task 3.1) [19]. It focuses on the performance of the payloads, and more specifically on the performance of the User link. These architecture-related performances will define the maximum capacity that the RF-ISL and Optical-ISL Interlink as well as the Feeder link must support. The aim is to estimate the satellite sizing parameters and the size of the constellation. The definition of a constellation is not direct, so a second/third iteration of the work will be needed to reorient the design and refine the choice in interrelation with the other specific tasks of this 6G NTN study [19-27] in order to converge on a feasible solution.

1.2 DOCUMENT STRUCTURE

This document is divided into different sections that synthesize the work carried out during the first part of this research activity.

The document is composed of different parts:

The first part will begin with the context, the state of art, clarify the challenges, and give the methodology applied during this study. The two system architectures proposed in task 3.1 will be revisited, supplemented by the definitions that will be extensively used throughout this document. These definitions pertain to the aspects covered in this document. Following the system-level definition, the functionalities of each node type (GEO, LEO C, LEO Q/V, HAPS) will be addressed.

Starting with the trade-off analysis of the main nodes and their definitions. In this section, we will also present the methodology and the philosophy applied in this study.

The third part will focus on defining the system, considering inputs such as terminals and gateways characteristics and identify the payloads to be developed (with scalability in mind). Moving on to the fourth part, we will describe the payloads associated with the nodes and delve into link definitions. After this section, we will focus on the dimensioning aspect of the main challenging payloads for deterministic nodes—specifically, satellites for LEO, VLEO constellations in the C-band and Q/V band—and provide performance analysis through link budgets, and satellites performances.

The fourth part will explore flexible nodes, including an investigation into a possible HAPS design and proposed dimensioning.

A fifth Section will be devoted to ISL and INL link dimensioning, offering solutions in terms of payload.

In addition, the sixth part is devoted to navigation, one of the features envisaged for the 6G NTN.

Moreover, in the seventh part we will discuss the concept of scalability based on the previously defined parameters. To support the analyses, part eight includes additional calculations and investigation results that will allow for the adaptation of guidelines if necessary according to market and technological developments. The conclusion will outline the next steps and detail the points to be addressed and consolidated in the next phase of the work.

2 STATE OF ART & CHALLENGES & METHODOLOGY

2.1 STATE OF ART: FROM 5G NTN SYSTEM CURRENTLY IN DESIGN TO THE NEXT EVOLUTION OF NTN SYSTEM

2.1.1 Context of 6G NTN: state of art and design /constellation in progress 4G 5G

So far, the space component has proved its clear advantage as a means of communication between remote areas, both in terms of implementation and in ensuring complementarity and also redundancy for terrestrial systems. Standardization studies have already been carried out in the context of integrating 5G in the NTN [27]-[30].

NTN systems based on big constellations such as Starlink © have been launched and several planned for future implementation [8]. They address the market for fixed terminals at fixed locations or on moving platforms. However, in terms of mobility, the systems developed in GEO such as EchoStar© and Inmarsat © or the systems in LEO such as Globalstar© and Iridium ©, have gained in performance in recent years and are widely used for fixed or large mobile terminal (planes and ships) with relatively high-speed requirements. Nevertheless, or direct to device service (handsets), the solutions remain limited compared with terrestrial 5G NR systems and need the use of specific and proprietary handsets.

The direct-to-device market has emerged since few years. So, the aim of the next step is to bring direct telephony services to a wider market at an affordable cost and with improved performance, revolutionizing connectivity (system and technology) between all types of terminals everywhere, especially in remote areas, and eliminating dead zones on sea and land.

Several previous studies are currently underway in this sense [28], the aim being to develop common standards enabling the same types of terminal connectable to the NTN and TN (Terrestrial Networks). This unification is one of the objectives of this study. In that context, the future 6G NTN is envisaged and the main guidelines and orientations are described in doc 3.5 (task 3.1). Thus, the future 6G NTN system is under investigation [32-35]. The NTN system is composed of Nodes and links. It will allow not only to connect a user equipped with a standard handset (direct-to-device) but also a variety of terminals (IOT and broadband internet services) in a diversity of frequency bands.

Among the state of art of the constellation [28-31], several constellations are in progress:

Starlink direct to device [29]: provides direct-to-handheld 4G (LTE) service in L-S band. The first deployment provides a limited capacity short message service, and it is projected to be enhanced up to provide high throughput connectivity in the next versions.

Space mobile AST[30]: developed a system in Lower frequency band of FR1 band direct to handheld in LTE 4G. The first breadboard has been launched and tested successfully.

Lynk Global [31]: provides service in 4G FR1 frequency band without any modification in the handset. The service is operational with limited throughput.

These three constellations do not necessitate any modifications of standard handheld. Nevertheless, their capacity is limited and most of the payloads are non-regenerative and are supposed to carry data to a gateway and to process data and manage the system.

In that context several new actors listed in [28] have announced their intention not only in the 5G NTN deployment but also for the next 6G NTN. More recently, several new actors have clearly declared their intentions in the new generation of space networks.

2.1.2 6G NTN: “unified Network “2030 / AI / ultra-connected word / sustainability / technology evolution: impact on payload definitions

The purpose of the 6G network is to be a unified system which allows to connect several types of UEs through the standardized interfaces. After identifying the UEs and their associated terminals, the objective of task 3.4 [25], in the present Task 3.3, the purpose is to propose solutions to the 6G NTN under definition. In other words, this implies a consistent approach that integrates reflection on payload design (associated with node definitions) in parallel with the development of the new system. The system definition is further consolidated through enabling technology and analysis, all aimed at assessing the relevance of the choices made. By sharing the effort equitably between the system components, the goal is to converge toward an overall efficient system in terms of performance.

Since each task has its own development and contributes to the system definition (Task 3.1), which evolves continuously during the study, a predefined set of parameters (hypotheses) has been established for each deliverable. These parameters are then assessed and consolidated through analysis and updated. The primary objective at the deliverable stage is to provide key performance indicators for the system. It's important to note that the overall system performance is directly influenced by the performance of the payload. Therefore, special attention has been devoted to analyzing the payload's performance subject of this work.

The term “performances” includes the link performances as well as several Key performances Indicator listed below:

- coverage: seamless with TN. Fill the gap regions uncovered by TN in earth and on sea.
- capacity delivered
- reliability
- interconnections efficiency: the ability of each node to connect to the other nodes
- new services offered: large panel of services described in doc [21] of Task 2.1
- cost efficiency: manufacturing, launches, operational services
- scalability
- sustainability

In terms of equipment, it will require suitable techniques and well-informed technological choices. This applies to all elements of the network. Each choice has its own advantages and

drawbacks, which should be optimized in the utilization of the various elements. Thus, it is about proposing solutions as diverse as the payloads of GEO, LEO, and VLEO satellite constellations, as well as for UAVs (AERIALS, drones, etc.), integrating the ability to establish efficient connections. All of this in the context of sustainability concerns.

2.1.3 Future context: Tendency users/ satellites enabling technology: vision 6G NTN

The 6G NTN will not be a classical system in terms of resource management. As we approach a new definition of a system, however complex, it will have to take into account the trend and emergence of new technologies in components performances [32]-[33] and also on performances managements such as AI, RIC, edge computing [34]-[37]. Systems have a natural tendency to become more complex, and the tools used to process them are also undergoing advances designed to cope with this complexity. Announced several years ago, AI will have a major impact on technical applications, opening up a number of new avenues for development and system operations. The main challenges are to anticipate the availability of technology in order to be efficient, and to take the opportunities & possibilities offered in terms of system management, at the risk of being left behind.

Every network works because it thinks in terms of a network, which means connecting everything and managing functionalities (link capacity and data processing) on a global scale.

In this context, a number of research projects and studies have been carried out. This means that nodes must be designed to optimize these new functionalities and support their integration.

RIC and AI Edge computing make extensive use of OISL [39]-[43] and have widely distributed computing and memory capacities. In that perspective , several project focusing on sustainability [44] take advantage of space for locating data center in orbit [45]-[47], even if the carbon impact have to be evaluated in the sense of operation and cost in manufacturing balancing the power consumption by solar array , refueling capacity of the satellite and others.

All these trends have been identified as a potential source of improvement but remain to be demonstrated as the concept is in an evaluation phase. At present, it's only just being envisaged, and developments and studies on the subject are still in their infancy. In terms of payloads, consideration must be given to these possibilities. The impact this may have on the design of payloads associated with nodes is as follows:

- providing a communication link for users: flexible coverage
- providing intensive interconnectivity links
- include computing/processing capabilities (distributed for edge computing), storage.
- include the ability to allow incremental capacity to respond to market evolution
- ensure security, reliability and resilience of the system

All of the features listed above shall be performed in a context of sustainability: impact on expanding life duration / upgrading and recyclability ...including not only at payload level but also at system level (reusable launchers, refueling possibilityetc)

2.2 NETWORK AND NODES: CHALLENGES

2.2.1 Deterministic and flexible nodes

As described in D3.5 [17], two types of nodes are envisaged: Deterministic nodes and Flexible nodes. The deterministic nodes are predictable in time and have a role frozen in time. They act as an element of the basis of the skeleton of the overall system. The flexible nodes are a local extension of the global deterministic network. In addition to the deterministic system composed of nodes that are fixed in time, additional flexible nodes could be added locally or at points in the system to allow for capacity improvements or new functionalities (sensing, positioning, etc.), if not to compensate for possible system failures.

The deterministic nodes are completely predictable and include devices enabling the connection to the other nodes and/or interfaces to connect users, and may also include communication, sensing or positioning functions. Thus, they could include:

- in space: constellations of satellites (GEO/MEO/LEO/VLEO)
- on earth: a network of ground stations (Gateways)

The flexible nodes are generally flying objects commonly classified as “aerials”. These elements will enable functions to be carried out either to enhance locally the capacity to meet a local need or to ensure other functions such as inspections (sensing), measurements of physical parameters, or infrastructure monitoring.

- evolving in-atmosphere: HAPS, Drones ...
- on earth: mobile ground stations (gateways).

2.2.2 Overview on GEO, LEO, AERIALS : axis of focus

The GEO constellation is not a challenge in terms of technological evolution. Most of the modern payloads evolve to reconfigurable design and their integration on the new 6G NTN context will only ensure the connectivity links and the evolution of waveform and interface standards, for example. This is not the case for LEO constellation and for AERIALS where the aim is to define new functionalities. To define them, we will need to carry out trade-offs with the objectives fixed by this project [1]. Thus, for instance for AERIALS, several studies are underway on this subject [48]-[50], but the diversity of approaches to defining them, and the diversity of AERIALS (UAV) built on the basis of balloons or drones, make the task a tedious one; in our case, it will be a question of identifying solutions that integrate harmoniously into the system being defined (as HAPS which are one of the main components of the system).

A "networked" system only makes sense if the elements that make up it are connected to each other in an efficient way [51]. The two techniques used to establish these connections are either in RF or in optics. Both methods have seen growth in recent years, as evidenced by numerous articles on the subject [52]-[56] for LEO constellation and for HAPS interlinks [57]. In Task 3.3, we will focus specifically on RF links, while optical links are addressed in document [19].

2.2.3 Scalability: Flexibility / adaptability / evolution/ sustainability

The scalability of a system or infrastructure is defined as its ability to adapt to changing in demand (generally increasing with time) and evolution (extension of the market). Scalability at payload level means matching this system-level functionality. Although the performance and functionality of payloads have a direct impact on this key performance factor, it is important to emphasize that it is at system level that it can be assessed. Because it also depends on how the system is built, and whether scalability is also considered at system level. Thus, the characteristics of the payloads of each node shall be seen in relation/interaction with system response. This means designing payloads in relation to the system definition, so that this notion is clearly considered.

The payload shall be designed in such a way to allow several functionalities identified and defined in D3.5 of task 3.1[19].

. By concept, scalability is a characteristic of the system itself. Although it also impacts the way in which the elements that make it up are designed. To achieve this goal, it is necessary to take into account the design of payloads, which must be capable of providing scalability at the level of each node. The system itself must be flexible enough to achieve this goal.

Scalability is measured in terms of its ability to adapt without too “much effort”. Is the system reactive or not to an unexpected demand? This last term is to be evaluated in terms of cost, which may ultimately be the consequence of modifications required for upgrades, redistribution of network capacity via payloads (increased distribution of resources in real time).

2.2.4 Payload designs /challenges

The system consists of several elements (nodes). Each node definition depends on the other nodes definitions. In that context the overall nodes shall constitute an optimized system in a just-tailored need which itself is not yet defined. Moreover, the system shall be organized in such a way it is able to adjust in time or flexible in its performances management. Moreover, to constitute the system and make it operational, the deployment schedule could have an impact so that the system shall be operational progressively. This means that the design of the nodes must inherently incorporate a future vision of potential demand evolution.

An analysis of the potential needs at this stage requires an extensive market analysis, which is beyond the scope of this present study. Nevertheless, an analysis based on the population has been proposed in [25] of task 3.4 and will be used for quantifying the performances of the system design and consequently readjust the performances of the payloads in a next iteration.

The task quickly becomes complex, especially as it involves many elements whose choices are likely to have an impact on the overall cost of the system..

It is crucial to base all solutions on accessible and sufficiently mature technology to offer the most efficient system possible. This requires evaluating what might be feasible by the time the system is deployed. In other words, it involves conducting a state-of-the-art review and assessing potential developments in the coming years or those that could be implemented immediately to make this technology accessible

In the case of constellations composed of NGSO (Non-Geostationary Satellite Orbit) satellites, each node experiences varying demand (user link) due to its motion and do not see a fixed

coverage during its orbit cycle. Consequently, satellite payloads must be flexible, i.e., capable of handling demand fluctuations throughout an orbit while maintaining optimal performance (active beam forming and power management). Given the complexity of managing parameters during satellite movement, the trend is towards payloads based on software-defined technology that can generate adjustable beams to ensure coverage according to demand. This involves refreshing the pointing towards the edge cell coverage and generating beams as needed, with an optimization of capacity over the beams.

Proper dimensioning (avoiding over-dimensioning, which incurs costs) is crucial. Additionally, considering the typical lifespan of satellites (generally 7-10 years) and the uncertain market trends (pending complete market assessment), we need a vision for payload concepts. These concepts should be flexible, easily reprogrammable to adapt to demand, and manageable at the constellation level, either through incremental upgrades or reprogramming. It's essential to recognize that not all payloads will be identical, since in GEO (Geostationary Earth Orbit), LEO (Low Earth Orbit), or even aerial systems the constraints are not identical.

The goal is to propose solutions with well-justified orientations and choices in the development of payload concepts. An ideal case only in term of functional performance is no longer the only consideration; sustainability focus introduces strong constraints and the emergence of AI, as mentioned earlier, introduce new possibilities for more efficient network management, even if its capacity to provide an advantage is still in its infancy. Furthermore, when translating these concepts into potential equipment and future materials, it becomes evident that integrating all these requests is inherently ambitious.

2.3 METHODOLOGY APPLIED

Defining the elements that make up a system is no easy task. The system's performance depends on the performance of its component parts, and vice versa. The methodology for doing this can only be iterative. In this paragraph, we describe the main lines of the approach adopted to advance in this study.

All this while keeping in mind performance and functionality objectives and specifications, as well as those concerning sustainable development, which remains one of the priorities to be taken into account in this project.

Consequently, the approach adopted is the following:

- ➔ Define the terminal list (UE equipment and terminals), derivation from the trade-off between the elements specification and the requirements
- ➔ System definition to payloads: iterative process as everything is linked: objective to feedback into the system definition (in term of complexity): to evaluate the cost of the overall system and its performance only some guidelines could be applied and shall be verified at the end. The evaluation could result in the opposite of expected. Each element shall be designed in a context to be inserted
 - A preliminary iterative process for evaluating the impact of each choice on the overall system.
 - The analyses first are focused on the main parameters: consistency in the choice of the link, functionality of each node and key performances for dimensioning the system.

In system design, each component contributes to overall performance. Sometimes, increasing the complexity of individual nodes can simplify the overall system, while simplifying nodes can complicate system management. Ultimately, the goal is to balance these constraints to create a system that meets future needs.

The 6G NTN system is a complex system by itself, as it is in fact made up of interconnected sub-systems. Thus, sub-systems can be isolated to a certain extent for optimization: for example, constellation design.

The logic is outlined below:

- ➔ Definition of the constellation of LEO C-band and Q/V band ➔ issued from contribution to the architecture/constellation definition with a major orientation to reduce the complexity of each node: two system architectures have been proposed to evaluate the performance of the global system. In this framework, the challenge is to simplify the payload and separate the function
- ➔ One architecture is based on minimizing the number of satellites, resulting in satellites with complex payloads.
- ➔ The second architecture is based on simplifying the payloads of the two satellites, but with a larger number of satellites.
- ➔ Evaluation of the number of launches required in each case remains the objective at the end of the studies.
- ➔ In each case the feedback will be given to see if one will result in a better compromise than the other, and of course to see the full impact of both systems: time to orbit, service, scalability, short- and medium-term capacity, system robustness.
- ➔ Considering all the constraints and uncertainties that still need to be resolved is a complex task. The first step is to check the feasibility of the first dimensioning and to identify weaknesses and shortcomings, then in phase two to focus attention on these parameters to improve them

The FIGURE 2-1 shows the iterative process to converge to a preliminary solution

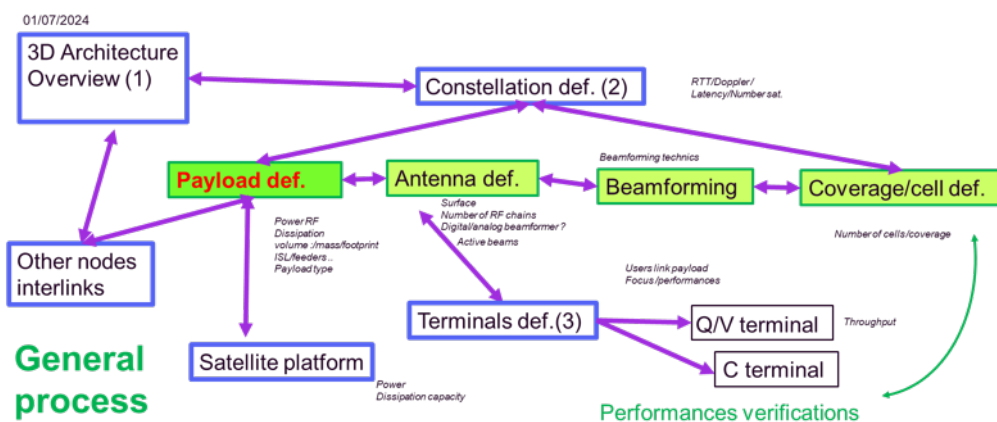


FIGURE 2-1 ILLUSTRATION OF THE METHODOLOGY (APPLICABLE TO LEO CONSTELLATION)

(1) : TASK 3.1. (2) : TASK 3.4. (3) : TASK 3.2

As mentioned in the FIGURE 2-1, the work in task 3.3 is in interactions on several collaborative discussions and interactions between Task 3.1, 3.2 and 3.4. The inputs and preliminary definitions on the payloads sizing parameters are constantly in relations with the system definition, constellation definition and terminal definition. The synthesis of this work allowed to converge to a status on all the elements in each task.

3 SYSTEM 6G NTN

3.1 DESCRIPTION OF THE 6G NTN SYSTEM

3.1.1 Definition of the system

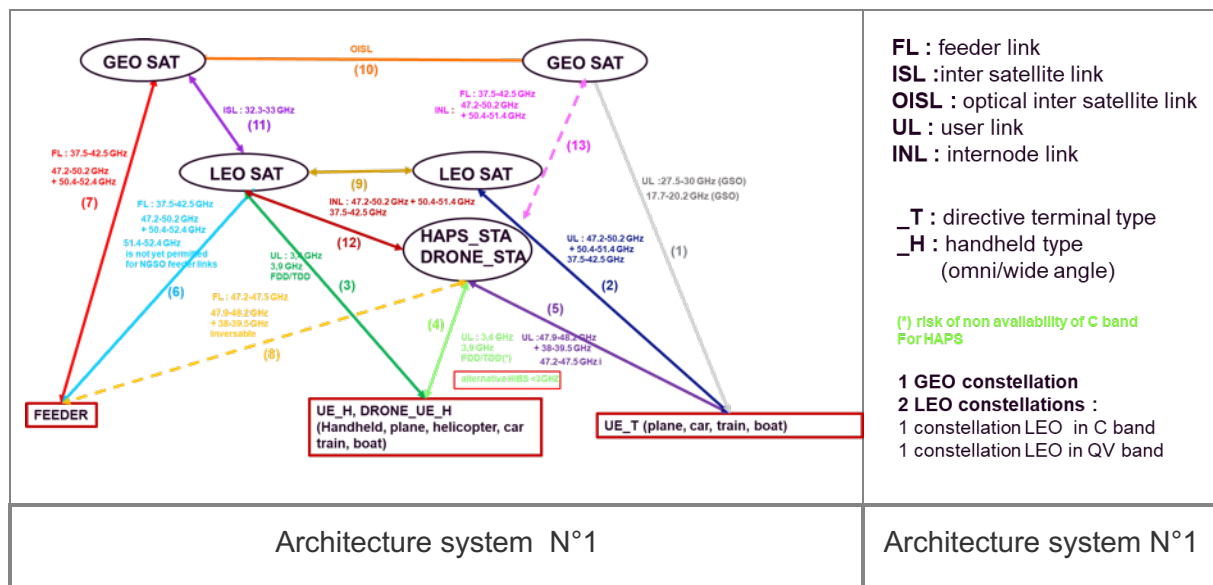
The definition of the 6G NTN system is based on investigations already envisaged and initiated in preliminary studies [2]-[15]. This gives us an overall vision of the objectives in broad outline as recalled in numerous articles [32]-[35]. To build this system, it is also necessary to associate elements of long-term feasibility, as the deployment date is more or less defined (2030-2035). In the first phase, therefore, we need to lay the foundations for what could be envisaged in terms of hardware, and then consolidate and refine them as outlined in the first chapter.

Although the main elements and their functionalities have been defined, there is some freedom as regards the possibilities offered. In this chapter, we will see the consolidation of what was proposed in [19].

The objective of this chapter is to identify the payload to investigate from the system description in 3.1 in [19].

Recall of the system foreseen main nodes definitions:

The 6G NTN is a global unified system composed of certain number of nodes Flexibles and deterministic nodes [Ref. D3.5 Task 3.1 [19]] as recalled previously.



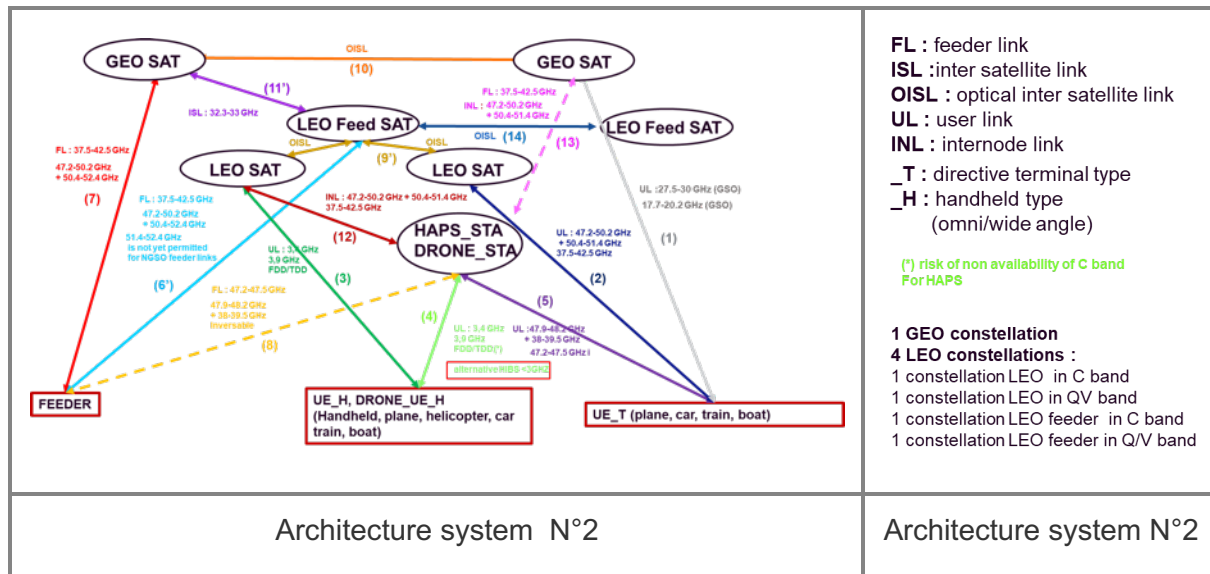


FIGURE 3-1 SYSTEM ARCHITECTURE 1 & 2

Two system architectures have been proposed (FIGURE 3-1): a baseline (architecture 1) and an optional one (architecture 2). The two architectures have to be evaluated. All these architectures are composed of Nodes and Links. The Nodes could be a constellations of satellites or single nodes. The links could be Users link, Feeder link, or ISL/INL.

User link is the link between the nodes and an UE (vehicle-mounted terminal, handled, etc).

The Feeder link is a link between the nodes and a Gateway on earth. It establishes the connection to the ground network to transfer data to the core network on earth.

These architectures are based on nodes linked between them. Among the nodes we can distinguish the:

- Deterministic nodes : GEO constellation, LEO constellations ..
- Flexible nodes : HAPS, DRONES ...etc.

The inter nodes links (INL) are Optical or RF.

The user links are in RF.

Difference between architecture 1 & 2 :

Between architecture 1 (conventional approach) and architecture 2 (distributed approach), the main difference lies in the presence of an additional “constellation feeder satellite” layer in the second architecture. The first architecture is a rather classical approach, while the second proposes a different way of proceeding. The idea of this additional layer is to concentrate a certain number of functions in this layer in order to simplify the payloads of the other nodes. This idea is based on the efficiency and capacity of OISL links in term of throughput and are well adapted to interlink in space. A number of assumptions are made in order to assess the relevance of this latest architecture in terms of cost. In the following chapter the impact on the payload design will be evaluated.

In terms of payloads, the following nodes and links will be examined:

- C and Q/V constellation satellites and HAPS, User links and OISL/ISL/Feeder links

- for GEO satellites, ISL link only will be studied in this document, the only links from GEO to other GEO is based on OISL and reported in document D3.5 of task 3.1.

The impact on architecture 1 & 2 will be mentioned.

Remark : in some cases (LEO and VLEO) the alternative to architecture 2 is proposed and noted as architecture 2'. The latter is a variant of architecture 2 but with extreme lightening of the User constellation. The objective displayed is to search for ways to reduce the complexity of each node in order to reduce costs.

3.1.2 Frequency plan

3.1.2.1 Frequency plan users links

The analysis on possible frequency band that could be candidate for the 6G NTN are proposed in documentation of task 2.5 [20]. The main values are recalled hereafter :

-The frequency plan for User link are in C-band and in Q/V band and in HIBS band for the Aerials.

Users link in Q/V band (LEO constellation) :

Downlink: 37.5 – 42.5 GHz (Q-band).

Uplink: 47.2 – 50.2 GHz and 50.4 – 51.4 GHz (V-band).

User link in C band (LEO constellation) :

Downlink : NTN satellite communications could potentially use TN TDD (Time Division Duplex) frequency bands n77 (3,300 – 4,200 MHz) / n78 (3,300 – 3,800 MHz).

Uplink : NTN satellite communications could potentially use the upper frequency spectrum (around 6 GHz) or lower frequency spectrum (e.g., UL n255 or UL n256).

User link in S band (HAPS) : several band could be possible around 2 GHz in HIBS defined band.

3.1.2.2 Frequency plan for ISL and INL

This chapter gives the spectrum bands for non-user system links. It analyse the two case of architectures N°1 and N°2.

This section identifies and provides justification for the frequency bands chosen for links within the system dedicated to network functions, i.e. not dedicated to user links.

1- Architecture 1

In this architecture, a 3-layer approach is implemented with a GEO, LEO and HAPS component

a. Ground-node links:

i. GEO node

The proposed band in the Q/V range is supported by a FSS global ITU allocation: 37.5-42.5 GHz (space-to-Earth) and 47.2-50.2 GHz + 50.4-52.4 GHz (Earth-to-space). The band 51.4-52.4 GHz is limited to Feeder

links using stations of a diameter of 2.4m minimum. This band provides the required spectrum availability and leaves the Ka band for user connectivity.

ii. LEO node

The proposed band in the Q/V range is supported by a FSS global ITU allocation: 37.5-42.5 GHz (space-to-Earth) and 47.2-50.2 GHz + 50.4-51.4 GHz (Earth-to-space). There is the potential that the 51.4-52.4 GHz band also becomes available for NGSO feeder-links at ITU WRC-27 under agenda item 1.3.

GSO arc protection applies as per ITU Radio Regulations Article 22.2.

iii. HAPS/Drone node

The proposed band is based Fixed Service allocations identified for HAPS use on a global basis in the bands 38-39.5 GHz (RR 5.550D), 47.2-47.5 GHz and 47.9-48.2 GHz (5.552A). Specific PFD limits apply on ground for HAPS-to-ground links, and at borders for ground-to-HAPS links to protect incumbent services (see ITU Resolutions 122 and 168). The band 31-31.3 GHz maybe an alternative option if its bandwidth is sufficient.

b. Inter-node links:

i. GEO-GEO alternatives to OISL

The allocations in the inter-satellite service for telecom missions in the 20-100 GHz range are: 22.55-23.55 GHz, 24.45-24.75 GHz, 32.3-33 GHz, 54.25-58.2 GHz, 59-71 GHz. Given the incumbent use of the 22.55-23.55 GHz, its use is not recommended for GSO-GSO links. Within the above ranges, the following allocations are specifically suitable from a regulatory point of view for GSO-GSO links: 54.25-58.2 GHz and 59-71 GHz.

ii. GEO-LEO and LEO-LEO alternatives to OISL

The inter-satellite bands usable to/from LEO orbit are 22.55-23.55 GHz, 24.45-24.75 GHz, 32.3-33 GHz and 59.3-71 GHz. The band 22.55-23.55 GHz is used by several systems. Their protection may impose bandwidth or availability limitations. The band 32.3-33 GHz may be a more interesting option (little incumbent use, relatively large bandwidth). Bands above 59.3 GHz have technological challenges.

iii. GEO/LEO-HAPS

For establishing links between a satellite (LEO or GEO) to/from HAPS, the HAPS is considered as an Earth station from a regulatory point of view. The FSS allocations in Q/V band seem appropriate since HAPS are flying above most atmospheric disturbances. The recommended range are 37.5-42.5 GHz (space-to-Earth); 47.2-50.2 GHz and 50.4-51.4 GHz (Earth-to-space). The latter two uplink bands use for ESIMs (Earth Station In Motion) may be further facilitated by WRC-27 under Agenda Item 1.1.

2- Architecture 2

In this architecture, besides the GEO and HAPS component as in architecture 1, the LEO layer is split in two sub-layers: one dedicated to radio access functions to users, while the other supports network functions. These two LEO sub-layers are respectively named LEO user SAT for access, and LEO feeder SAT for network functions.

a. Ground-node links:

i. GEO node

Same as in architecture 1 but GEO linked to LEO feeder SAT

ii. LEO user SAT node

Not Interconnected (between same nodes) pass through the LEO feeder SAT node.

- iii. HAPS/Drone node
Same as is architecture 1

b. Inter-node links:

- i. GEO-GEO alternatives to OISL
Same as in architecture 1
- ii. GEO-LEO user SAT, LEO user SAT-LEO user SAT and LEO user SAT-LEO feeder SAT
Same as in architecture 1 for GEO-LEO and LEO-LEO alternatives to OISL
- iii. GEO/LEO SAT-HAPS
Same as in architecture 1

3- Architecture 2'

In this alternative architecture of architecture 2, the LEO user satellite ensure only a link to LEO feeder SAT. All the others links pass through the LEO, feeder satellite. This point will be detailed in

3.1.3 Terminal definition

In order to establish a preliminary dimensioning, it is necessary to have an idea of the variety of terminals and of their targeted performances. The definition of the terminals is subject of the dedicated task 3.2 [26] and not yet fully established. The technological maturity of terminal has to be consolidated for instance in Q/V band and is the task of WP3.2.

Nonetheless, before assessing the feasibility of the terminals, it is necessary to define specific performance targets. This allows us to establish the link budget and evaluate system performance, while keeping in mind that these assumptions may evolve during the project. Based on heritage on existing handheld performances, a list of terminal types have been identified with their targeted performances (for initial objectives issued from the proposal [1] for FR2 terminals (Q/V band) and based on existing terminals for the FR1 (C-band).

Nevertheless, before assessing the feasibility of terminals and, more precisely, consolidate the achievable performance, it is essential to establish a link budget and evaluate system performance during the design phase, even if it is subject to evolution during project discussions. Based on a heritage list of terminal types, those within targeted performances have been identified. These targets are issued from initial proposals for FR2 terminals (Q/V band) and existing terminals for FR1 (C-band).

Moreover, in addition to terminal types, there are also different terminal classes with performance options (consumer, professional, mobile, vehicle mounted...etc.) which increase the number of cases to consider.

We recall in this document a list of terminals that have been identified and referenced, these terminals definition will be updated during this research work. But nevertheless, the objective is to start the dimensioning at a first level in order to identify some bottleneck in the definition of the NTN and have a feedback to make evolve the performance targets.

The different cases have to be taken into account as mentioned on the table of the below :

UE performance in C band (smartphone)	FDD mode	TDD mode
Antenna gain (typical), Note 2	-5 dB	-5 dB
Antenna gain (NTN optimized) (Note 3)	-2 dB	-2 dB
Noise figure (typical)	7 dB	5.5 dB
Tx power with dual antenna collocated (Note 1)	26 dBm	26 dBm
Note 1: SAR constraints (duty cycle) may reduce the Tx power on FDD, but likely not to affect the Tx power performance in TDD		
Note 2: due to the multiplicity of bands supported and the number of switches/filters of the RF front end. Non coherent combining		
Note 3: using beam forming techniques based on coherent combining between the two co located antenna		

FIGURE 3-3 TERMINALS CBAND HANDELD PERFORMANCES

The table of the FIGURE 6 shows the expected performances for the future handheld. Two types of handheld have been identified according to their operating mode. In our case where we have identified the different types of terminals and declined according to their uses, the table below summarizes the performance. The 3 types of C-band terminals are the C_NTN_1, C_NTN_2 and C_NTN_3.

	FDD MOD		
	GAIN	Power	NF
	dBi	dBm	dB
C_NTN_1	-5	26	7
<i>C_NTN_2</i>	-2	26	7
<i>C_NTN_3</i>	-2	26	7
	TDD MOD		
	GAIN	Power	NF
	dBi	dBm	dB
<i>C_NTN_1</i>	-5	26	5.5
<i>C_NTN_2</i>	-2	26	5.5
<i>C_NTN_3</i>	-2	26	5.5

FIGURE 3-4 PERFORMANCES OF THE DIFFERENT TYPE OF TERMINALS

The functioning mode FDD or TDD is not yet defined and the possibility for NTN is under study.

3.1.3.1 Q/V band terminal performances

Q/V band terminal are identified by QV_NTN_1 & QV_NTN_2 which correspond respectively to two class of terminal. The WP3.3 terminals are entirely devoted for the study of performances of the future Terminal are WP3.2. Nevertheless the performances of these two terminals are proposed as a target and have been used for establish the link budget et Q/V

constellation performances. For the analysis we focus on one type of terminal QV_NTN_1 standard terminal which is subject to be used most largely and it will be the less

Terminal	Antenna	FREQ GHz	Size (ϕ) m	nb element	directivity			Gain	
					nadir	EI 45°	losses	nadir	EI 45°
					dBi	dBi	dB	dBi	dBi
	QRx	40	0.12	512	33.3	31.8	1.5	31.8	30.3
	VTx	50	0.09	512	33.3	31.8	2.0	31.3	29.8

FIGURE 3-5 QV_NTN_1 TERMINAL PERFORMANCES

TERMINAL	QV_NTN_1	
FDD Mod		
Front-end Rx		
Losses	L =	1.5 dB
LNA	NF =	4 dB
Tant	Tant =	140 K
G/T	=G+L-29.45	dB/K
G/T	=D-29.45	dB/K
Front-end Tx		
Losses	L =	2 dB
Power	P=	4 dBW

FIGURE 3-6 RESUME OF THE PERFORMANCES HYPOTHESIS FOR QV_NTN_1 TERMINAL

3.1.4 Gateways Definition

The Gateway are generally cassegrenian based antenna capable of tracking capabilities. The Gateway could be in several bandwidth in Ka or Q/V band for GEO and LEO constellation. In Q/V band the frequency band availability is 5GHz and 3 GHz so that high throughput could be achieved. The performances in Q/V band are given in the table of chapter 4.8.4.1.

The performances will depend on the choice of the amplifier and of the LNA, as well as the antenna diameter. According to the need, it will be adjusted in order to optimize le cost.

Gateways must be to be able to follow the satellite, both to cope with its movement and to ensure transfer to another satellite when its coverage is beyond its field of vision. To be able to perform this active pointing function, they could be mechanically steerable at varying speeds, or electronically pointable. One requires a passive antenna mounted on a pointing mechanism and the second an active antenna capable of generating electronically steerable beams. The efficiencies of the latter are low, making them unsuitable for the NTN 6G, which aims for low cost and low energy consumption; the mechanically steerable passive antenna therefore remains the best solution.

The objective is also to reduce the number of gateway needed for the next 6G NTN system always in the perspective to an overall cost reduction.

3.1.5 Scalability of the system (NTN): concept

The 6G NTN will be designed to be scalable effectively with payloads. Its flexible nodes enable quick and targeted increases in system capacity, contributing to overall scalability.

It must be noticed that there is no constraint to increase capacity by increasing the numbers of nodes. The constellation could be enhanced by a more dense deployment (increase the number of plane and insert more satellites per plane) and proceed by :

- reducing the coverage per satellite
- overlap the coverage of the satellites

Moreover, the scalability concept has been integrated natively in the system design by overlapping the coverage by several satellites. This feature is taken into account in the design of the payload.

4 DESCRIPTION OF THE PAYLOADS ASSOCIATED TO THE NODES (THE MAIN FUNCTIONALITIES EXPECTED)

4.1 GEO CONSTELLATION (DETERMINISTIC)

The GEO constellation is composed at least of 3 satellites to ensure a full coverage of the earth at an altitude of 36000 Km. The GEO constellation in NTN ensure use cases based on multicast and broadcast services and delay insensitive traffic requests.

4.1.1 Mission definition

Generally, the GEO mission could be broadcast or multispot missions. Most of the missions are in Ku or Ka band and converge multibeam coverage (HTS). In the context of the 6G NTN, the role of the GEO satellite has to be defined. The waveform and also the satellite's interconnection to the other nodes needs to be clarified. One of the roles of the GEO satellite could be to give a resilience to the system as a backup in case of failure, and thus to secure the overall system. Due to the high altitude, the performances in term of latency could be not compatible with some use cases. Nevertheless, the advantage of GEO is that with just a few satellites, a near-complete visibility of the earth could be achievable. The throughput achieved is interesting for broadband applications with fixed terminals. In order to ensure connectivity everywhere around the earth (except very high latitudes), at least 3 satellites are necessary (see FIGURE 4-1. and FIGURE 4-3). Each satellite could cover a large coverage or some regional coverage according to the power available on the satellite which limits his capacity. A number of satellites could be co-located in order to fulfill the needs (see FIGURE 4-2). In the concept for 6G NTN, the role of GEO satellite could be to ensure a minimum of connectivity capacity with the other nodes as defined in the previous chapter (see FIGURE 3-1).

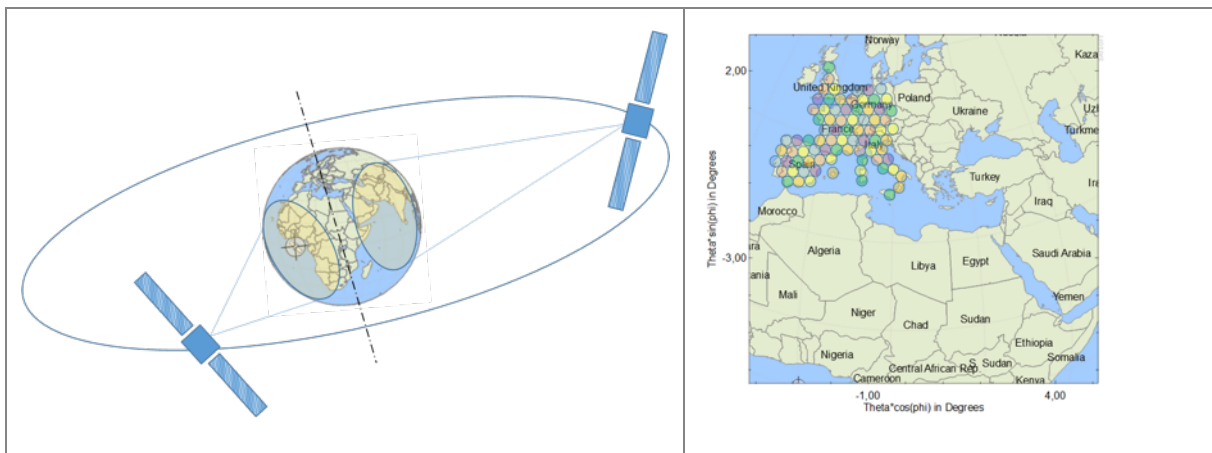


FIGURE 4-1 LEO COVERAGE USER LINK (MULTISPOTS)

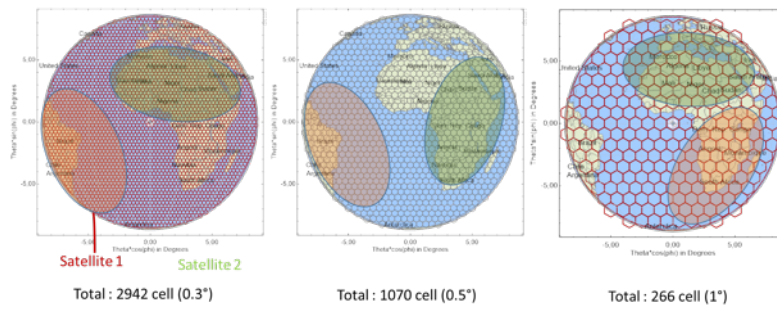


FIGURE 4-2 AREA OF COVERAGE OF A GEO SATELLITE

In FIGURE 4-2, the earth seen from geostationary orbit is proposed for different angular resolutions to define cells. This resolution will depend on the size of the satellite antenna to be taken into account. In the context of 6G, this is based on fixed ground cells. There is currently no standard definition or size for such cells. The aim is to possibly propose something consistent and compatible with the choice of cells in LEO and for UAV in conjunction with TN.

In case of fixed cell, an exemple of 900 km cell is given in FIGURE 4-3.

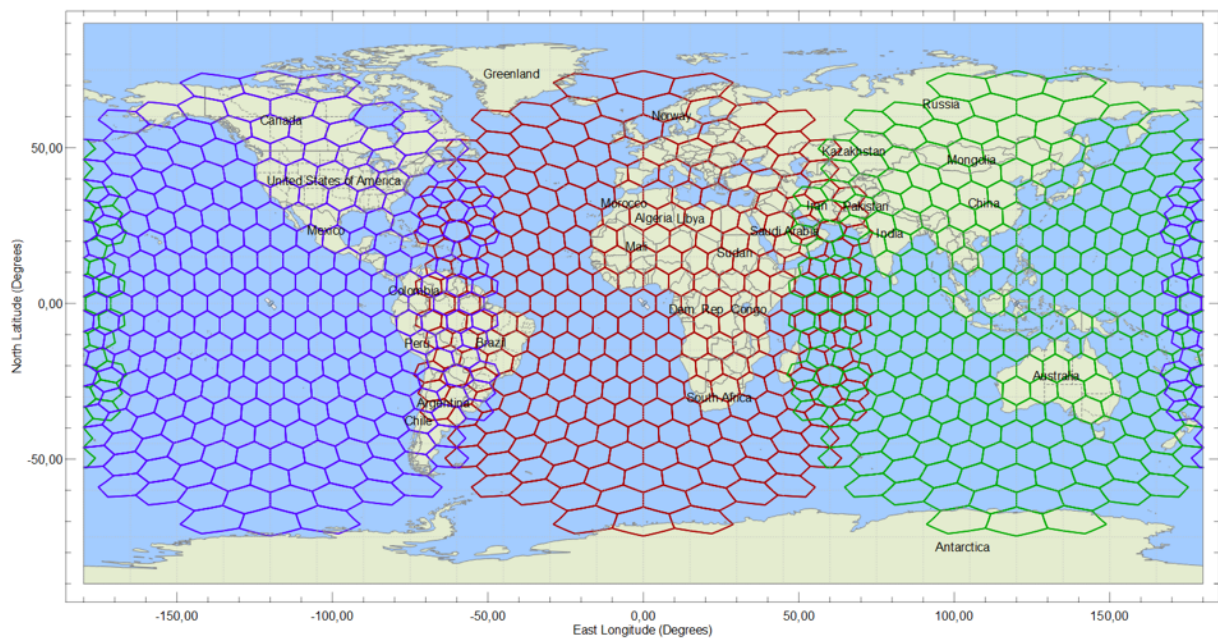


FIGURE 4-3 EXAMPLE: EARTH COVERAGE WITH 3 SATELLITES (SAT1 SAT2 SAT3) CELLS OF 900 KMS

The geo-satellite could be a multibeam mission defined on terrestrial fixed cells and will be part of the 6G NTN. The frequency band could be as the one used in Ku or Ka. The terminals will be directly integrated the modem for the new 6G waveform when established.

The missions will be constituted of cells of same size (by definition fixed as it is geostationary satellite). As previously stated, the performance metrics and the services must be defined, even though some have already been identified, such as resiliency/redundancy to the nominal system and HTS services.

Thus, it could be possible to imagine a compatibility between GEO and LEO cell as illustrated by the FIGURE 4-4. For instance, the LEO coverage could be a subdivision 1/20 of GEO coverage.

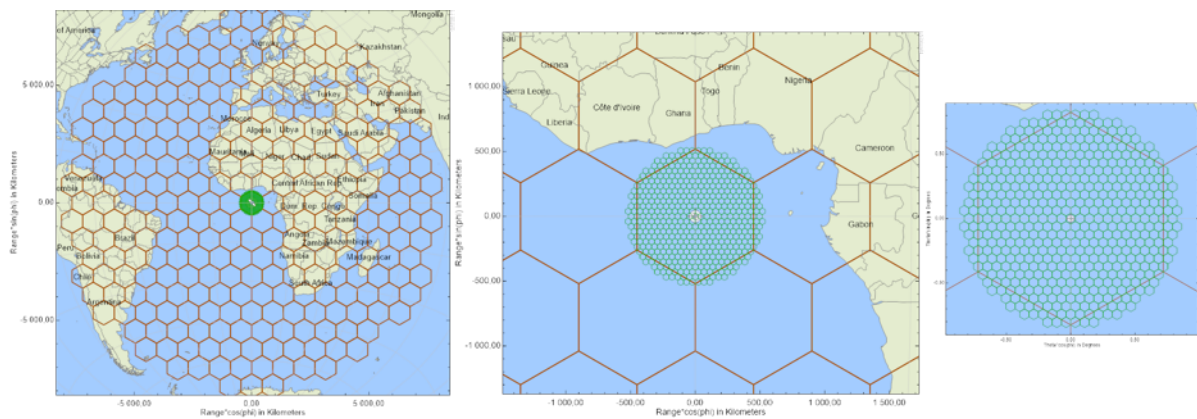


FIGURE 4-4 EXEMPLE COVERAGE COMPATIBILITY GEO COVERAGE (**CELL = 900 KM, NB=284**) AND LEO COVERAGE (**CELL=45KM, NB=499**)

4.1.2 GEO satellite Payload

4.1.2.1 Next generation payload for GEO

In the 6G-NTN case, the payload shall be able to generate multiple beams. The next generation of payload is based on flexible antenna associated with software defined payload and is based on DTP (digital transparent processor) and DBF (digital beam forming) technology [58]-[70]. At term, thus, it will be an evolution of the existing and ugraded payload design, with improvements towards the NR waveform and protocol in order to be integrated in the 6G NTN. Additional equipment should also be integrated to ensure the links to the other nodes (OISL and ISL).

The terminals shall also evolve to be able to function directly in NR and its evolution in 6G. Certainly a phases of double waveforms will be needed to ensure a smooth transition on the intermediate time.

Terminal typical in Ka/Ku: typically the performance of the terminals are the following:

EIRP : between 44 to 52 dBW

G/T : between 7dB/K to 15 dBK

4.1.2.2 Payload functionalities

The FIGURE 4-5 gives a schematic view of the functionalities associated to the node (GEO Satellite). These functionalities are common for the two architectures in investigation.

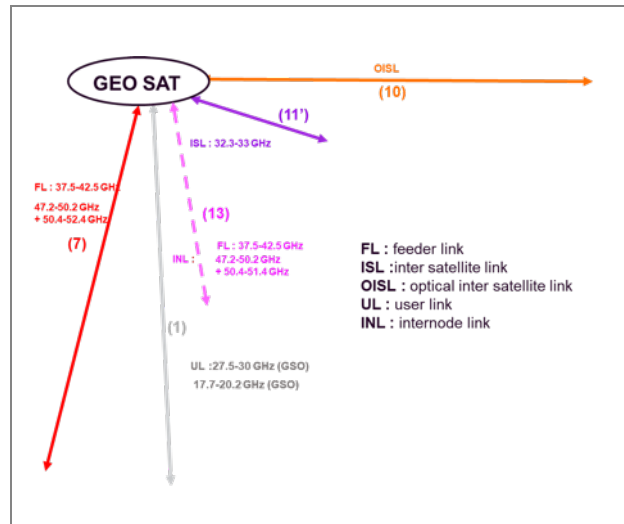


FIGURE 4-5 GEO CONSTELLATION AND THE LINKS

Each GEO satellite payload is composed of 5 LINKS:

(1) : Users link multibeam

(7) : Feeder link (Q/V band)

(10) : OISL LINK between GEO satellite see D3.5 [20]

(13) : interlink with an HAPS

(11') : Interlink with a LEO satellite

4.1.3 User Link (1)

- A user link in Ka band ou Ku (1): could be a multiple beams antenna covering an earth area. Generally, the antenna could be active or passive and is composed of a focal array and reflector or a focusing element (lens).

- Several solution exists and are used in that context. Some of the techniques developed in recent years are based on active antennas combined with a shaped reflector, such as SFPB, MFPB, and AFSR (Array fed shaped Reflector) [71]-[73].

The design of the GEO constellation remains classical, the tendency is to have a coverage composed of multi-spots.

- ➔ Convergence of missions towards multispot in Ka and Ku with new-generation DTPs [58] basis of software defined payloads.
- ➔ One satellite can cover 1/3 of the Earth at 36,000 km, but 3 satellites may be not enough for global coverage but for multispot coverage, the area of coverage per satellite is limited as illustrated in FIGURE 4-2. Multispot also means power: the Beam Hopping process is set up to manage capacity over the entire coverage area. Currently in DVB, the transition to NR is being studied in the context of 5G and in the future candidate [26].

- Compatibility with the Ka frequency bands and those used for the LEO constellations currently under development, and protection of the Orbital arc being studied in this context [74]–[77].

4.1.4 Feeder Link (7)

-The Feeder Link to Gateway (7) could be in Ka band or Q/V band, the last one are the more selected options

- Feeder to Gateway links are more and more provided in Q/V band. Similarly, compatibility must be ensured with LEO constellations which may operate in Q/V.
- Reflector type antenna, normally steerable as Gregorian or Cassegrain antenna are used or steerable Multifeed and reflector system.
- At least 2 feeders links for LEO constellations in order to ensure the handover between two satellites.

4.1.5 ISL RF Link(11)

-ISL to LEO satellite (Ka band) or LEO Feeder Satellite (11)

- Reflector type antenna steerable (follow the LEO satellite motion) / DRA not envisaged the relative speed remains low so that classical mechanical steerable antenna is sufficient at this level.

4.1.6 INL to HAPS (Q/V band) (4)

- Reflector type antenna steerable (follow HAPS) / DRA not envisaged the relative speed remains low and the DRA is not justified for this link and moreover it will not be efficient.

4.1.7 OISL to GEO SAT (5)

- For ensure sufficient throughput at a distance between 40 000 Km to 80 000 Km (5) The OISL will be used.

The dimensioning of the OISL will be addressed in the document 3.5 [19].

4.2 LEO CONSTELLATION- C-BAND PAYLOAD (REFERENCE CASE CASE A)

4.2.1 Mission objectives

C-band

C band frequencies could become available for NTN use based on a future MSS frequency allocation to be decided in an ITU World Radio Conference. WRC-2031 is the earliest credible opportunity for such decision. As an alternative, or in the interim, NTN systems may be authorized under national framework, on the basis on non-interference, non-protection see document [20].

4.2.1.1 Coverage

The purpose of the 6G NTN is to cover any point on the surface of the earth and in the atmosphere. The best way to do it with a reasonable effort and with sufficient performance is to use LEO constellation as a basis of this requirement. The considered LEO mission consists of full earth surface coverage (almost everywhere as a target), well suited to provide low latency with a reasonable throughput (link budget). Each coverage area of the satellite is decomposed in cells of identical size. The cells are of fixed earth cells type. Thus, the LEO constellation is composed of several satellites, each one ensuring part of the full coverage of the earth. The satellite coverage of two adjacent satellites shall overlap in order to ensure a connectivity between these two adjacent satellites during the handover phase (see doc task 3.4 [25]).

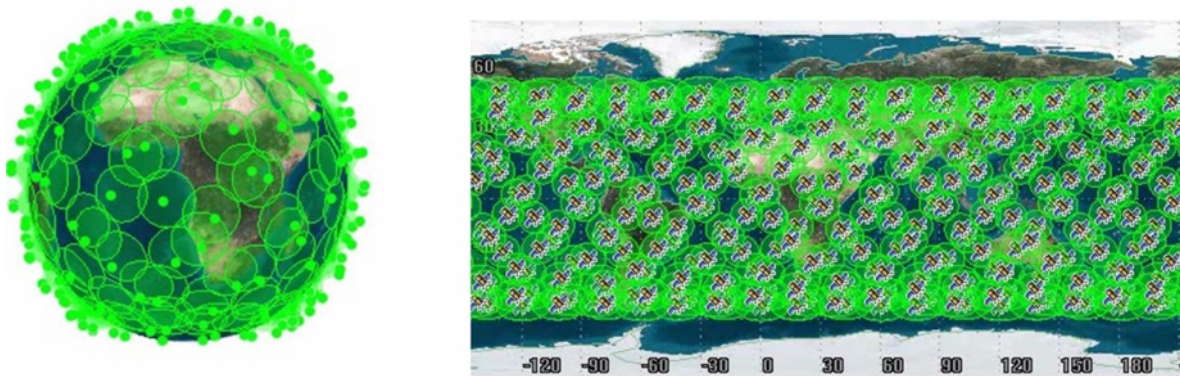


FIGURE 4-6 EXEMPLE CONSTELLATION

4.2.1.2 Main guideline in constellation definition

The orientations and guidelines to define a constellation are the following :

The coverage ensured by each satellite payload is composed of cells. The cells and the coverage shall be defined in a right combination between the size of cell and the size of the antenna with the following objectives:

- ➔ Optimize the RTT (Round Trip Time): impact on altitude / coverage ELmin (minimum elevation)

- ➔ Number of satellites: impact on cost /size/ power consumption/dissipation
- ➔ Full coverage: impact on coverage size per sat / number of cells: constellation size/power
- ➔ Flexibility in capacity enhancement by satellite by densifying the number of satellite: impact on cost and dimensioning to allow upgrading
- ➔ Sustainability : global efficiency : manufacturing / power consumption / ...materials
- ...

In the next chapters, the process is the following :

- Identify all the functions of the satellites (interlinks, feeder links, users links)
- Focus on the user link dimensioning :
 - o Define an elevation (EL) per coverage and define antenna size/cell definition
 - o Evaluate each satellite capacity and then dimension the required link capacity and then envisage a first level of power consumption and dissipation capacity.
 - o Evaluate the performance achievable over a local theater (metropolitan France) and evaluate max capacity of the constellation

4.2.2 C band Payload description

The Figure 4-7 shows the links that the satellite should ensure in the two case of the 2 proposed architectures .

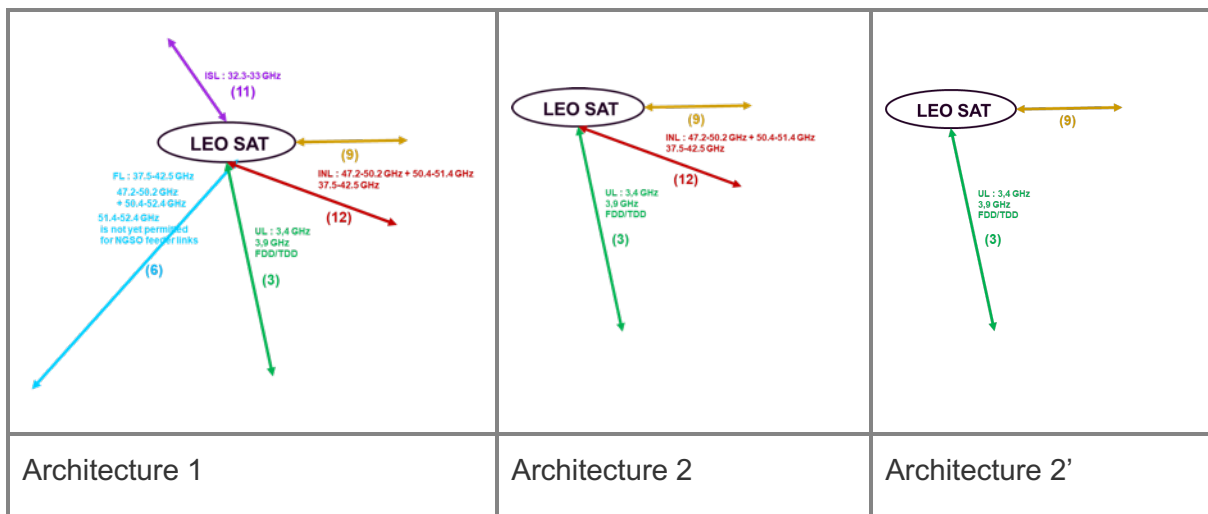


FIGURE 4-7 PAYLOAD C-BAND FONCTIONNALITIES

Between the two architectures the difference remains on the absence of 2 links on the LEO SAT of architecture 2. Thus in that last case, a maximum power could be devoted to the User link, which allow to optimize the capacity of the overall constellation in term of service. An alternative is also envisaged in Architecture 2' which is a to suppress any other link than user link and feeder satellite link. The objective is also to evaluate the extreme simplification impact on the cost of the constellation.

List of payload functionalities (links) for the two architectures are described below :

(3) User link C band

(6) Feeder link in Q/V band

(12) Interlink between the LEO satellite and an Aerial nodes in Q/V band

(9) OISL link to the other identical satellite LEO (architecture 1) or with a Feeder LEO satellite in architecture 2.

(11) ISL link with a GEO satellite in Ka band.

These functionalities (links) could/shall be redounded or multiplied to ensure the connectivity with the other nodes. The number of each one according to the architecture are given in the table in FIGURE 4-8.

	Architecture 1	Architecture 2	Architecture 2'
USER SATELLITE			
C-Band DRA	1	1	1
Ka band ISL to GEO (Ka)	1	0	0
Q/V band INL to HAPS	1	1	0
OISL	4	2	2
Q/V band Feeder	2	0	0
FEEDER SATELLITE			
OISL	N/A	4 to 8	4 to 8
Q/V band INL to HAPS	N/A	0	1
Q/V band Feeder	N/A	2	2
Ka band ISL to GEO (Ka)	N/A	1	1

FIGURE 4-8 Number of antenna according to the architecture (1, 2 and 2')

The FIGURE 4-8 gives the number of antenna on each User satellite according to the two architectures. The payloads of architecture 2 will be less complex. Indeed, the feeder link function and ISL to GEO link is implemented at the Feeder satellite level (see FIGURE 3-1). It should be remembered that each Feeder satellite performs the feeder link function for multiple User satellites.

4.2.3 User link (C-Band) trade-off

4.2.3.1 Frequency band & Numerology

The frequency band foreseen for the C band is subject to proposition in the document 3.5 [20] and is recalled in the table below:

ID	Used Frequency		Channel Bandwidth		PRB						PRACH	
	Uplink Sat Rx / UE Tx	Downlink Sat Tx / UE Rx	Uplink Sat Rx / UE Tx	Downlink Sat Tx / UE Rx	Uplink Sat Rx / UE Tx	Downlink Sat Tx / UE Rx	Number of carriers	SCS bandwidth	PRB bandwidth	Number of PRB	PRACH bandwidth	
	GHz	GHz	MHz	MHz	kHz	kHz	-	kHz	kHz	-	kHz	
C	C2	3,9	3,4	100	100	360	360	12	30	360	273	3600

FIGURE 4-9 NUMEROLOGY FR1 USED FOR C-BAND

The choice of the numerology refers to document [25].

A bandwidth of 100 MHz for Rx and Tx are considered. The frequency band have not yet been defined and will be adjusted later on [20].

4.2.3.2 Trade-off

To define a constellation where the exact target in term of capacity is not defined yet, is not straightforward, it is necessary to define a way to perform a trade-off.

Coverage definition:

The choice of coverage is based on preliminary work [16]-[18] and is defined by the coverage seen by the satellite considering a given minimum elevation angle. This coverage is broken down into cells. These cells have a hexagonal shape to ensure continuity between them and are defined by a size in km on the ground. All cells are identical. The solution of fixed earth cell has been chosen as opposed to earth moving cells [16] as the best solution in term of cell identification management. The question remains to define the minimum elevation for the coverage and cell size to suit requirements in coherence with payload feasibility and optimization. The FIGURE 4-10 gives some examples of coverage.

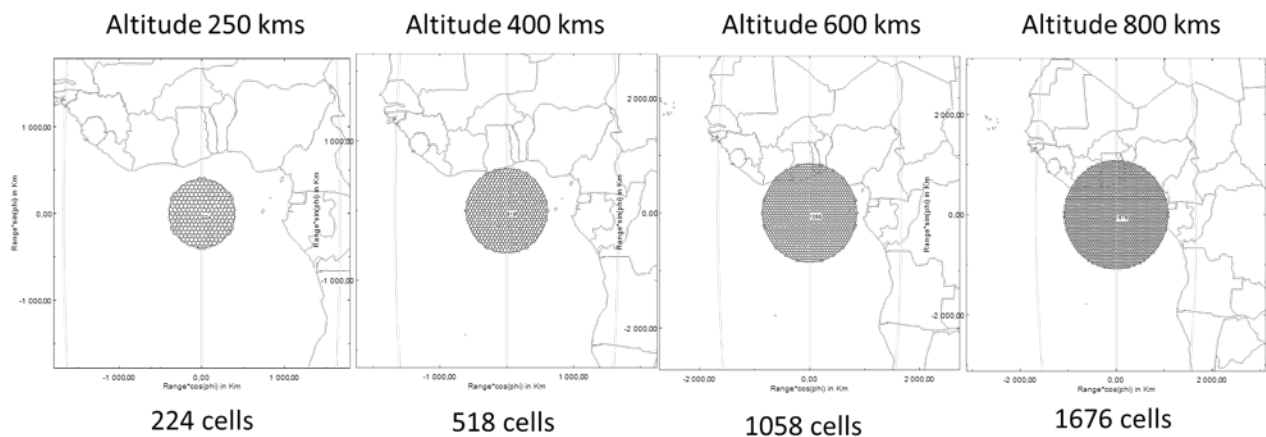


FIGURE 4-10 EXEMPLE OF COVERAGE SEEN AT DIFFERENT ALTITUDE OF A COVERAGE OF ELMIN OF 30°, CELL SIZE OF 50 KM

Antenna and payload architecture orientation:

The constellation is based on satellite with payload including a DRA type antenna; in our case, the DRA type antenna associated with a beamformer is the best choice to generate a multibeam antenna [63]-[67] in a large field of view. Other solutions based on an active array (array associated with a beam former) combined with a focusing element (reflector, lens, etc.) are very effective, but naturally limit the accessible field of view and are unable to cover low elevations <70°. The number of beams is important and also the objective is to maximize the coverage ensured by one satellite maximizing the scan angle in order to reduce the constellation size. The antenna systems based on focal array and optics do not allow to cover large angular area and are well suited only for GEO.

To generate multiple beams, the payload will be based on a multiple beam former. Several options could be envisaged based on an ABFN (analog beam former) or a DBFN (digital beam former) or a HBFN (hybrid beamformer). A HBFN is based on a combination of an analog and a digital beamformer. The selection among them depend on several points:

- Technological maturity
- Bandwidth to process
- Power consumption

- Number of beam to manage

The main advantage of the DBFN is the ability to generate beam theoretically without any limit. In practice, the constraint on the processing capacity will nevertheless limit this number. The ABFN complexity limit the number of beam and do not offer a full flexibility as with the DBFN.

In our case, the orientation is to cover area composed of a huge number of cells. According to the number of beam to manage, the DBFN should be chosen in C-band at least where the maturity of the components will allow to envisage without any objection for the 6G NTN.

A first-level multi-parameter trade-off is required to define the constellation. The first step is to define the constellation, and more specifically the parameters defining the antenna in conjunction with coverage and cell size and satellite altitude. The next chapter details the trade-off performed to define the constellation (additional information in Appendices, FIGURE 9-2)

4.2.3.3 Definition of the parameters

Trade-off have been performed taking into account all the important parameters (shown in FIGURE 4 11) involved in defining the antenna. In FIGURE 4 11, these parameters are described and defined hereafter. The best compromise of these parameters will be used to size the antenna and consequently the payload.

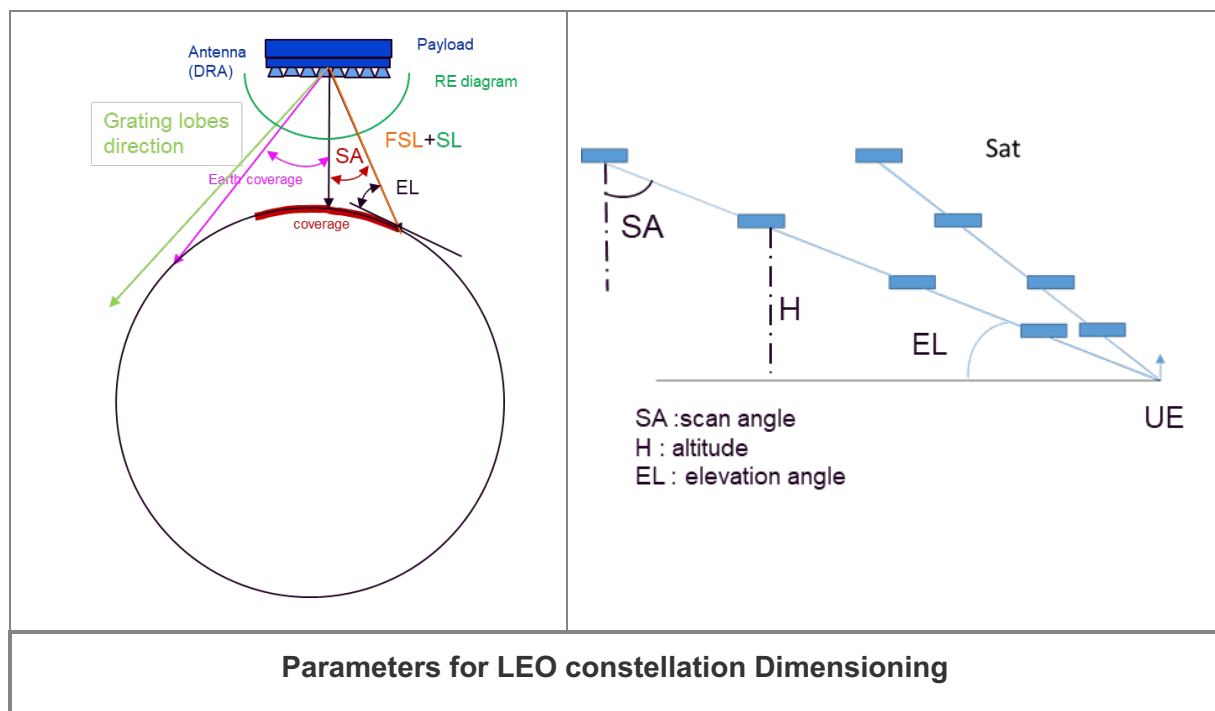


FIGURE 4-11 PARAMETERS DEFINING THE CONSTELLATION

SA : scan angle max to ensure a pointing from satellite to a cell at the edge of the coverage. Measured from satellite nadir direction

H : altitude min of the satellite : the altitude have an impact on satellite constellation and on the Doppler shift. The lower the altitude, the higher the speed.

EL: elevation min seen by an UE

EC : earth coverage angle seen by the satellite. When pointing an antenna at the cell to the edge of the coverage, the objective is to keep the grating lobes outside the earth coverage.

RTT : round trip time : time taken by the signal to travel 2x (UE to Gateway distance) , by supposing that the Gateway – is at the edge of the coverage.

Doppler shift : maximum Doppler shift the frequency signal between a UE at nadir and a UE.

Grating lobes angle: depend on the lattice of the radiating element of DRA type antenna. The lattice of a radiating element is defined in the FIGURE 4-13.

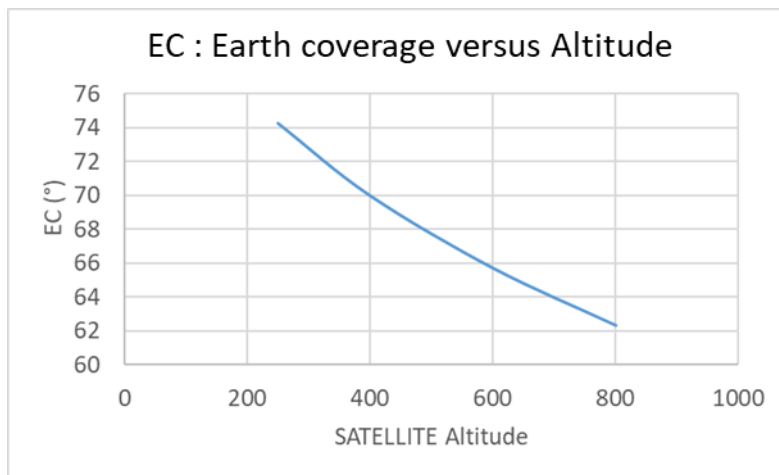


FIGURE 4-12 EARTH COVERAGE ANGLE VERSUS SATELLITE ALTITUDE

The Earth’s edge seen by the satellite increases conversely with its altitude. This means that the scan angle from the satellite could be limited when the altitude is low for a given antenna’s radiating element (RE) size. Consequently, as the grating lobes are dependent on the lattice, the larger the scan angle, the smaller the size of the RE must be. As a consequence, the SC will decrease, but the number of elements needed to achieve a certain level of gain will increase complexifying the payload. Even if the link budget is favorable at lower altitudes, it will not compensate for the free-space loss (FSL) through an increase in antenna gain.

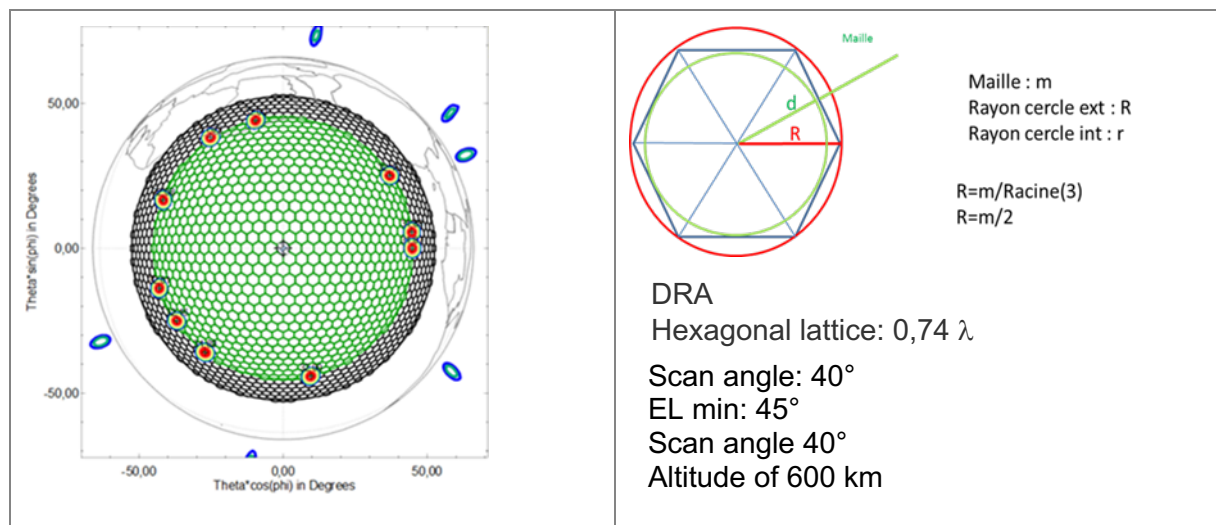


FIGURE 4-13 ILLUSTRATION OF SCAN ANGLE DUE TO GRATING LOBES

The table in FIGURE 4-14 gives the maximum value for the size of the RE in order to avoid the grating lobes on the earth surface. The lattice chosen is hexagonal in order to limit the grating lobes . A square lattice will be not favorable in the diagonal direction.

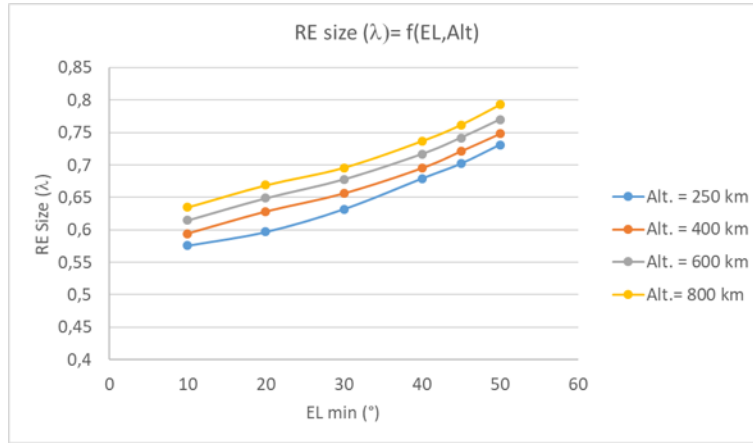


FIGURE 4-14 RE SIZE VERSUS ELMIN AND ALTITUDE TO AVOID GRATING LOBES

FSL : free space losses depending on the distance of the antenna to UE. The maximum distance is the distance from the satellite to the edge of the coverage.

SL : scan losses is the losses in directivity due to the radiating element radiation pattern when the pointing angle increase. This scanlosses is important with the size the radiating element (more directive).

Trade-off : coverage , ELmin , Altitude:

Impact on FSL and SL :

Depend only on the size of the RE and the distance from the satellite to UE

On these computations the losses are calculated for a UE at the edge compared to a UE at the center of the coverage. The size of the radiating element have been adjusted in order to keep the grating lobes outside the earth coverage.

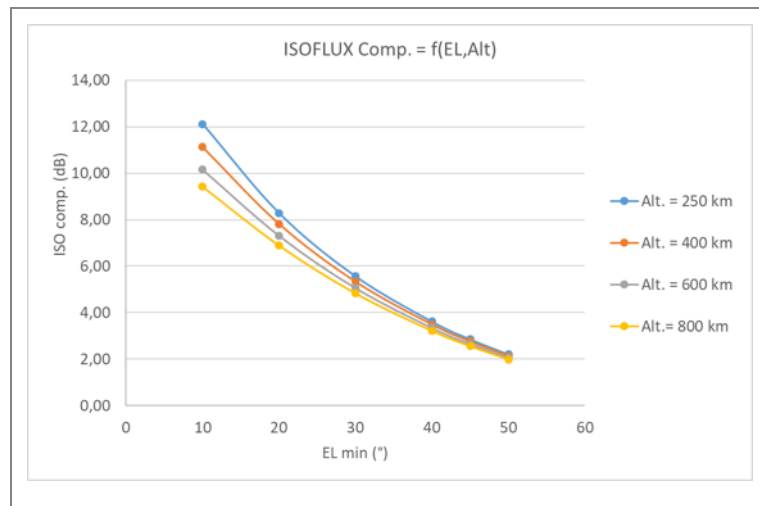


FIGURE 4-15 FREESPACE LOSSES (DELTA NADIR-EDGE)

The FSL is the losses due to the distance between the UE and the satellite and consequently depend on Elevation angle and satellite altitude (see FIGURE 4-15).

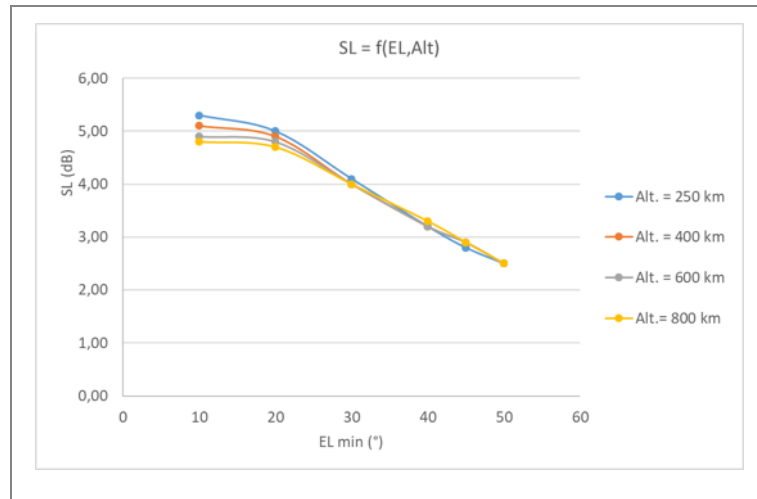


FIGURE 4-16 SCAN LOSSES (DELTA NADIR-EDGE)

The scan losses is directly linked to the diagram of the RE diagram (see FIGURE 4-16).

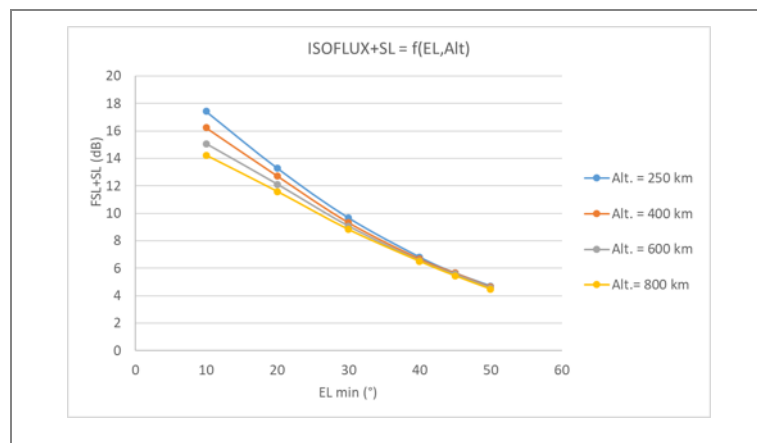


FIGURE 4-17 TOTAL FSL+SC

The total losses (SC+FSL) will be high for coverage of low EL_{min} (FIGURE 4-17). This double penalty due to an increase of distance and decrease in scan angle have to be compensated. It means that the performance of the link budget could become problematic compared to the nadir. The objective is to choose an acceptable value so as not to create too much speed variation during handover between two satellites. In Tx (Downlink), it can be partially compensated by increasing the power on the edge beams. In Rx (Uplink), the satellite antenna can't be compensated, so we need to ensure that G/T performance is sufficient to ensure the link.

Performances in directivity for two antenna apertures : the purpose is to estimate the directivity of two antenna sizes of diameter 1.75 m and 2 m in order to estimate the maximum directivity. These directivities include the scan losses.

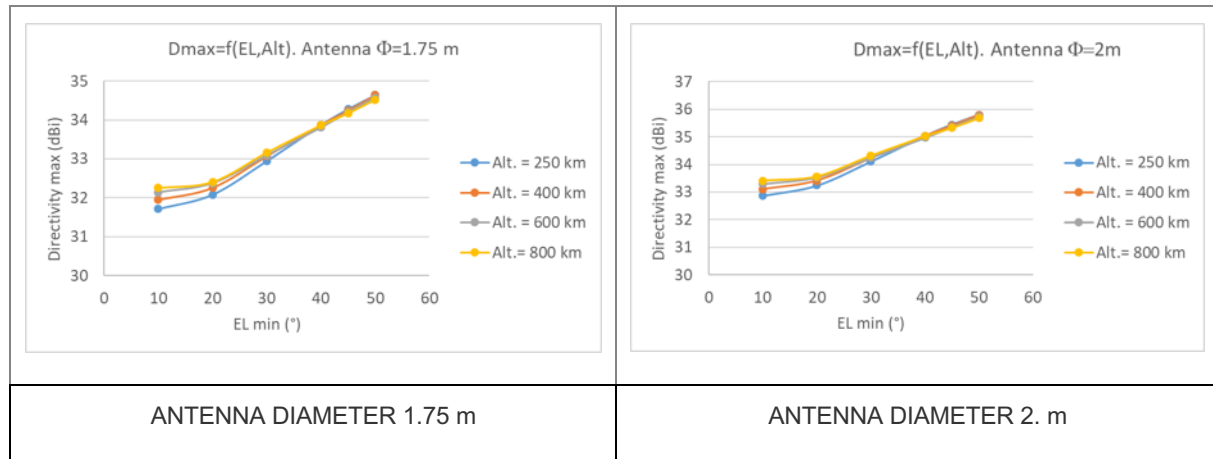


FIGURE 4-18 DIRECTIVITY 2 ANTENNA SIZE

The level of directivity ranges from a maximum of 34.5 dBi to 31.7 dBi at low elevation with an antenna of 1.75 m of aperture diameter and between 35.8 dBi to 33 dBi with an antenna of 2. m of aperture diameter.

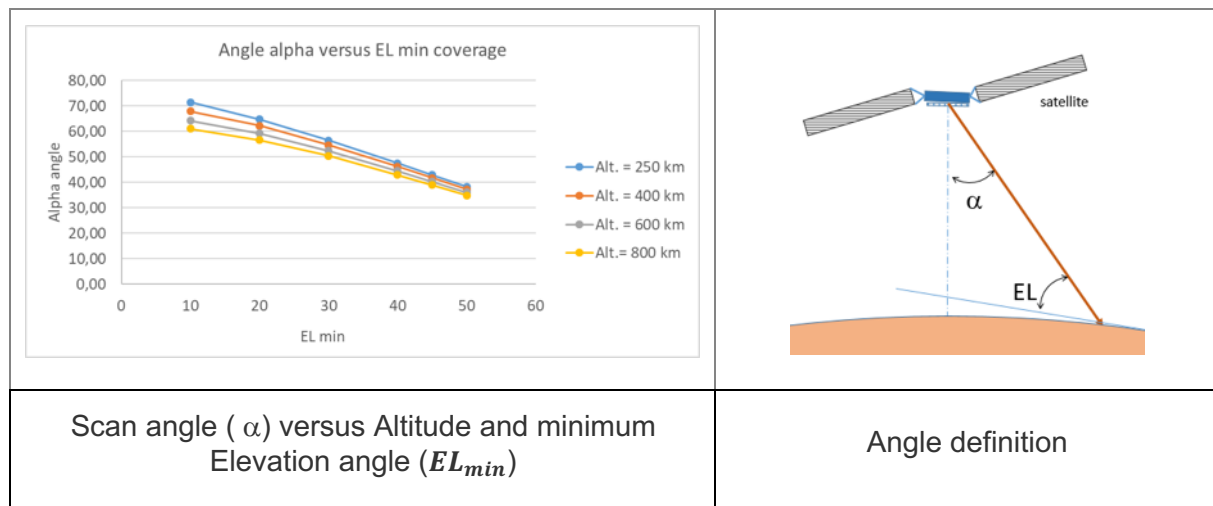


FIGURE 4-19 ANGLE α VERSUS EL_{MIN}

These figures give a preliminary value in order to verify the link budget, the exact surface shall be adjusted according to the antenna accommodation.

The Round-Trip Time (RTT) for Architecture 1 is calculated based on the time required for the signal to travel the following distances: from the User Equipment (UE) to the satellite, from the satellite to the gateway, from the gateway back to the satellite, and finally from the satellite back to the UE. This calculation is done in the worst-case scenario, as illustrated in FIGURE 4-20 (B)

the definition of the communication type is the following :

- Mesh**: Communications within the constellation between terminals.
- **Star**: Convergence of all communications from the constellation towards the Packet Data Network (Internet) on the ground and core network.

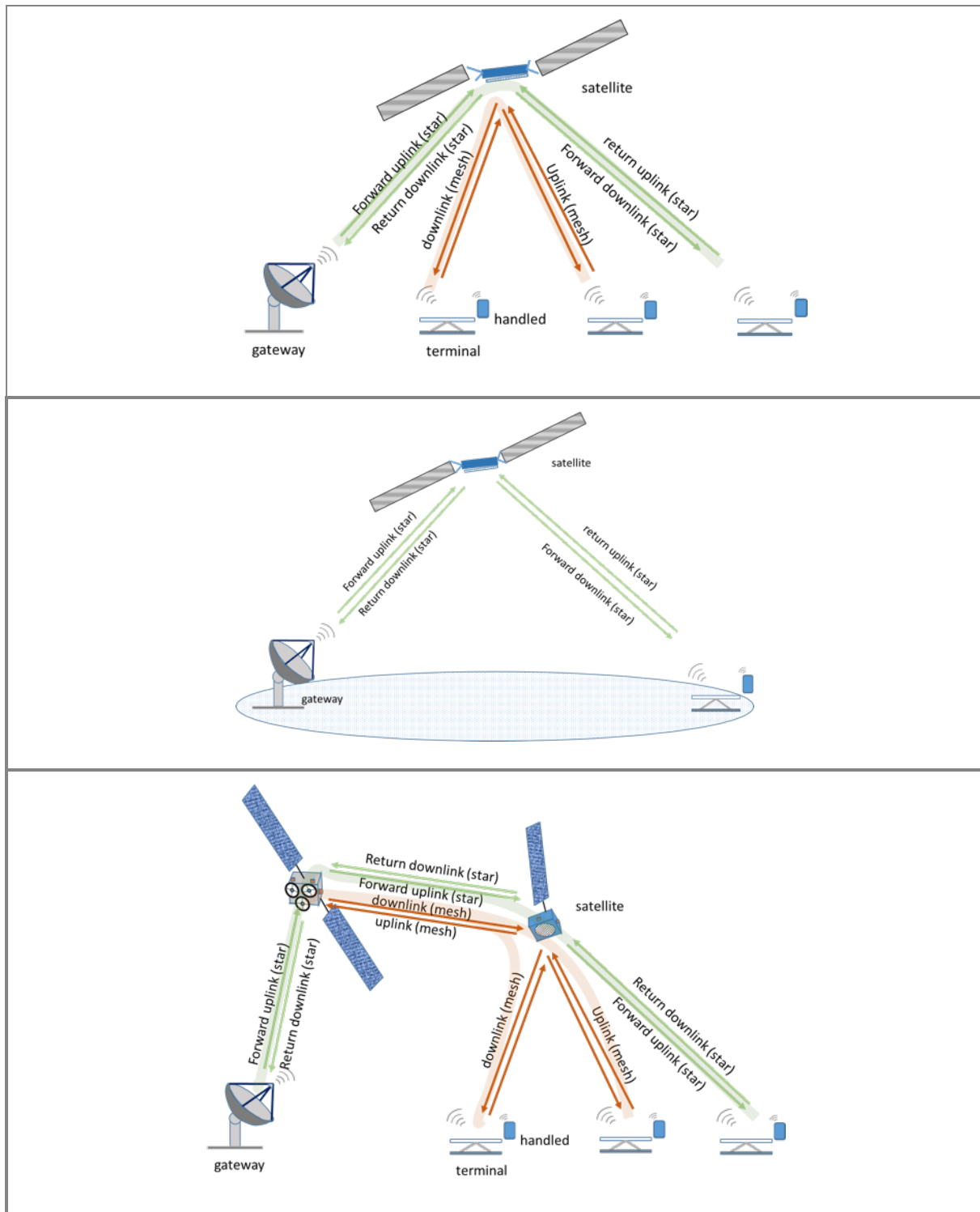


FIGURE 4-20 COMMUNICATION TYPE DEFINITION

The FIGURE 4-21 give the RTT computed for different satellite altitude (see doc 3.4 for details).

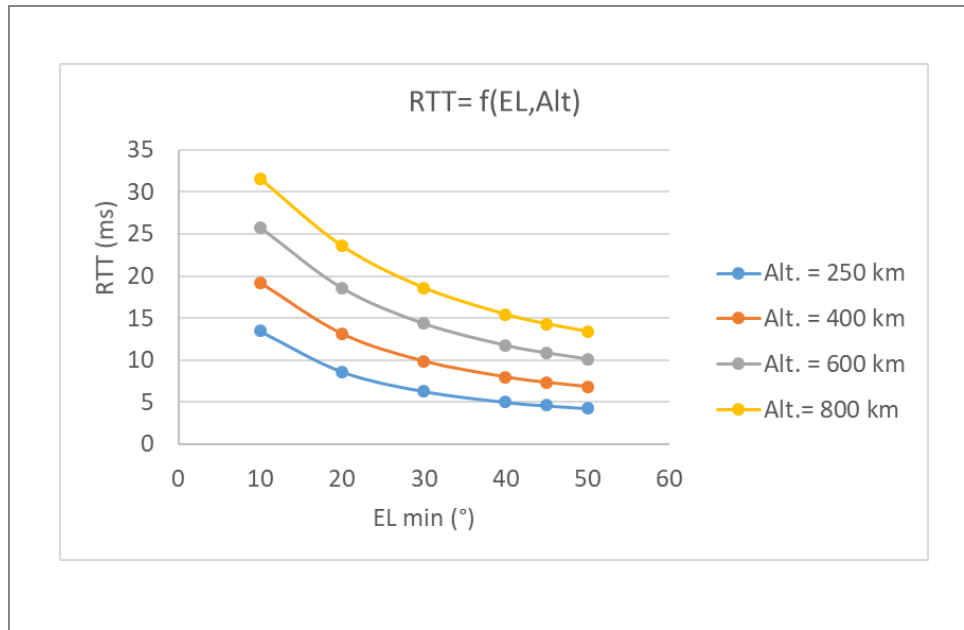


FIGURE 4-21 RTT VERSUS EL_{min} AND SATELLITE ALTITUDE

To ensure certain services, low latency is essential. However, constellations cannot achieve the very low latency levels possible with terrestrial networks. The objective for NTN is to achieve a maximum of 10 ms [22]. In the case of architecture 2, the RTT will be adjusted to by adding the time needed to the distance between the LEO satellite and the feeder satellite. The real latency shall be estimated with the contribution of the payload even if it remains low. Some values are given in [19] on the requirements according to the Quality of Service (QoS). The document detailed the requested latency with the associated service. The service which requires less than 5ms necessitates low altitude constellation and high value of EL_{min} .

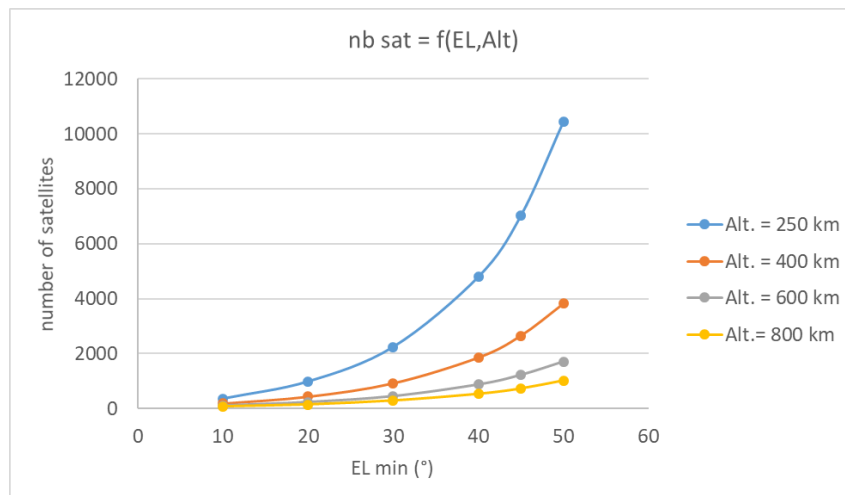


FIGURE 4-22 NUMBER OF SATELLITE NEEDED VERSUS ALTITUDE AND EL_{min}

The number of satellite needed increase conversely with altitude for a given EL_{min} .

For example, achieving a RTT of 5ms requires a minimum elevation angle of 45° with 7,000 satellites at an altitude of 250 km.

Two cases have been investigated for the handover (10s visibility of two satellites) and 2 satellites always in visibility.

Number of satellites versus (EL_{min} and Altitude)				
1 Satellite visible, 2 satellites during 10s min for handover				
	altitude (km)			
EL_{min} (°)	250km	400km	600km	800km
10	360	180	104	72
20	984	432	228	144
30	2244	920	448	286
40	4794	1856	874	527
45	7015	2652	1222	720
50	10434	3818	1710	1008

Number of satellites (EL_{min} and Altitude)				
2 satellite in visibility				
	altitude (km)			
EL_{min} (°)	250km	400km	600km	800km
10	672	350	208	144
20	1794	816	429	279
30	3960	1716	855	540
40	7920	3348	1628	1003
45	11088	4625	2225	1360
50	15611	6450	3090	1886

2 satellites in visibility during 10s min	2 satellites in visibility (always)
---	-------------------------------------

FIGURE 4-23 NUMBER OF SATELLITES OF THE CONSTELLATION

To ensure handover between two LEO satellites, it's crucial to have an overlapping coverage of the two satellites for a certain period. The most convenient case is to ensure always a visibility of the satellite. The second case requires almost the double number of satellites.

Trade-off issues on number of cell for a given Altitude 600 km and $EL_{min} = 45^\circ$:

The coverage is defined by cells as illustrated in the FIGURE 4-22

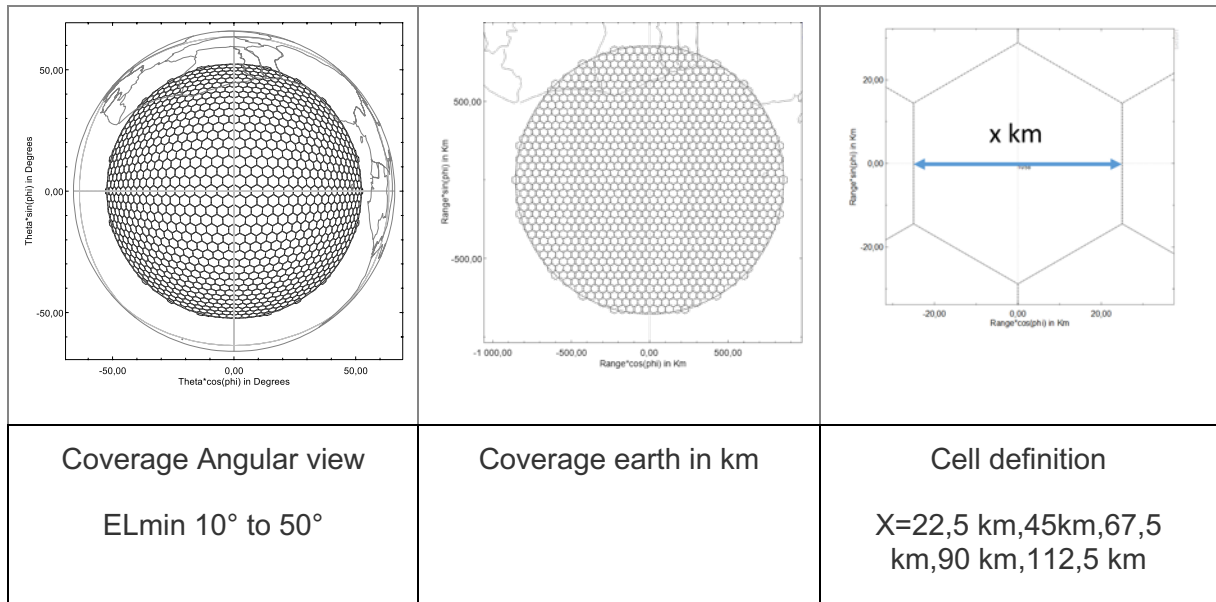


FIGURE 4-24 COVERAGE DEFINITION FOR TRADE-OFF

The trade-off on the sensinty analysis on these parameters are given in the figure below :

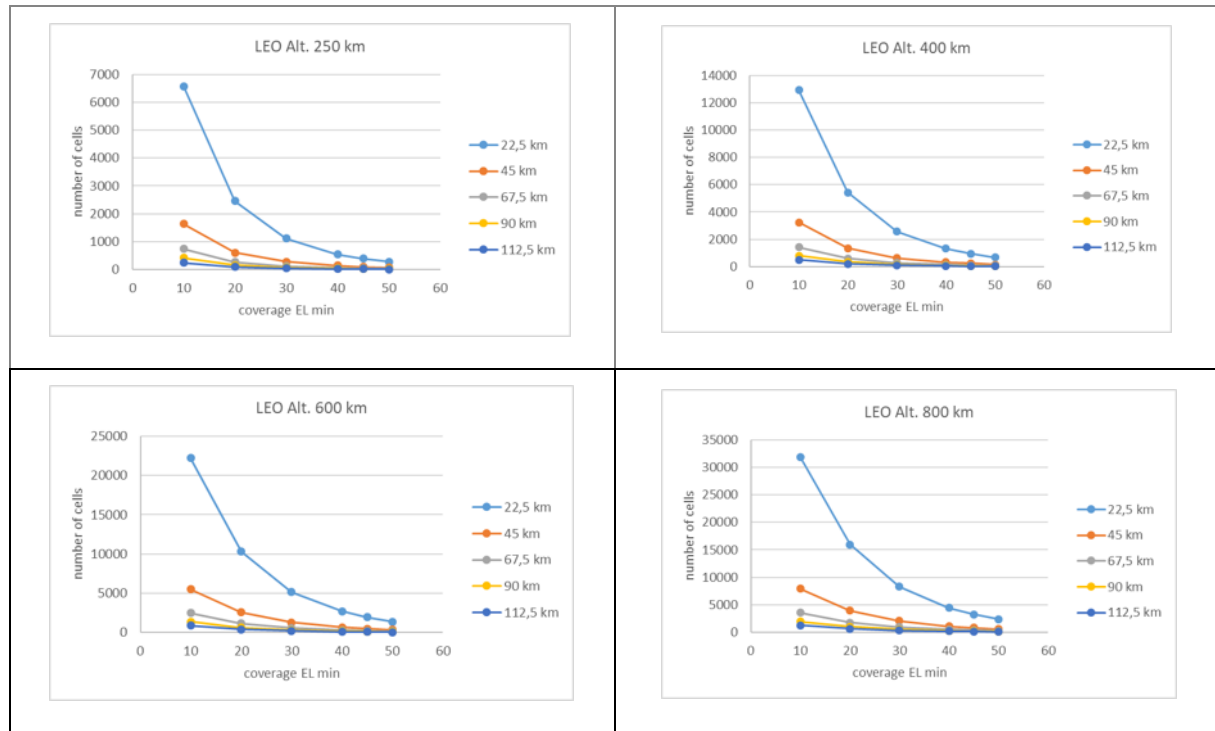


FIGURE 4-25 NUMBER OF CELL VERSUS CELL SIZE/AND COVERAGE EL_{MIN}

The number of cells can increase significantly depending on the chosen EL_{min} for coverage. Since each cell is associated with a beam, the number of beams that a single satellite must cover is a crucial parameter. This determines the number of active beams, the beam hopping factor, and consequently, the power requirements of the payload. Additionally, the size of each cell will dictate the size of the antenna (beam width).

The analysis show that the best solution that are issued from the sensitivity analysis are:

- a coverage of EL_{min} of 45° (limit the impact of the FSL+SL, SC, and a RE size of 0.741λ)
- an altitude of 600 km,
- 2 satellites in visibility during a time lapse of 10 s
- an RTT of around 10 ms
- a number of satellites (max of 1500 satellites)

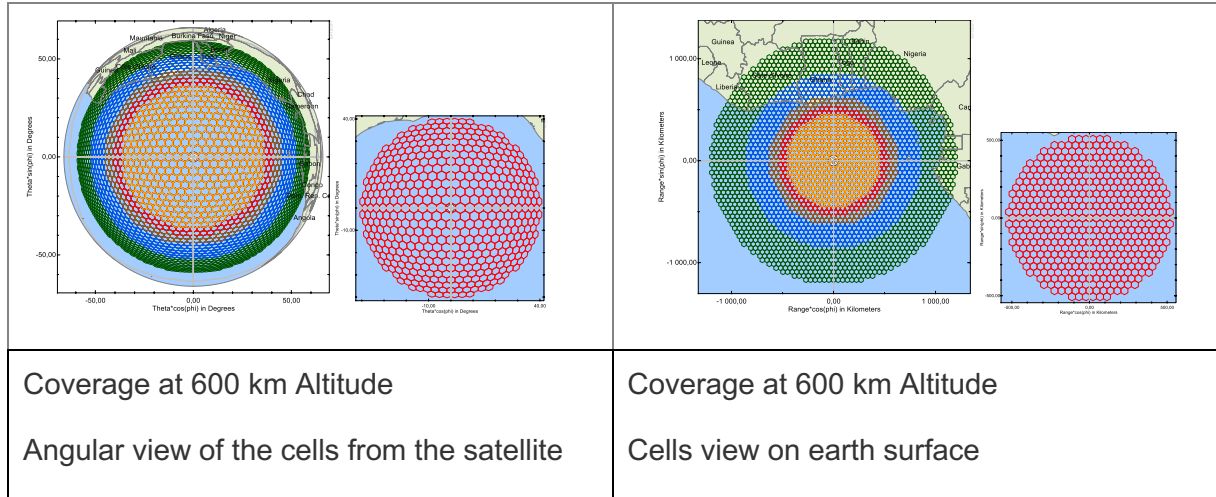


FIGURE 4-26 VIEW OF THE CELLS

4.2.3.4 Trade off on the antenna size /cell size beamforming techniques :

The altitude, coverage have been selected, now it is necessary to define the cells size and the antenna size based on the number of RE that compose the antenna and the power of each satellite.

To do that, a trade-off have been performed on cell size in conjunction with antenna size and beamforming techniques. The antenna sizes investigated are illustrated in figure

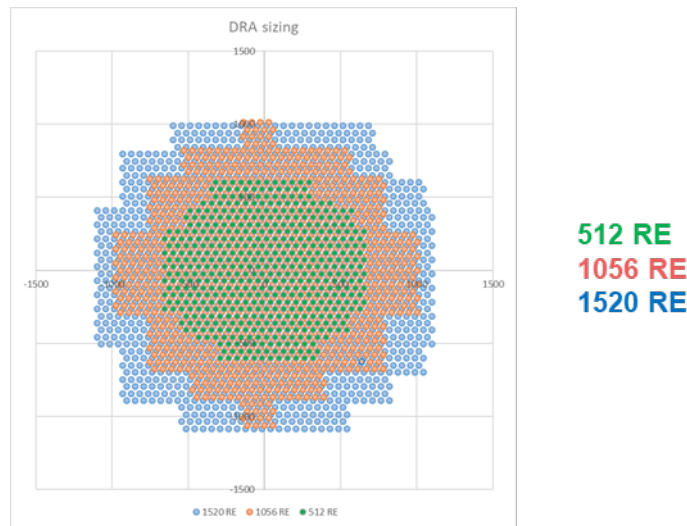


FIGURE 4-27 ANTENNA SIZES USED FOR TRADE-OFF FINALIZATION

The figure show the beam forming in phase only according to the size of the cell at nadir and at the edge.

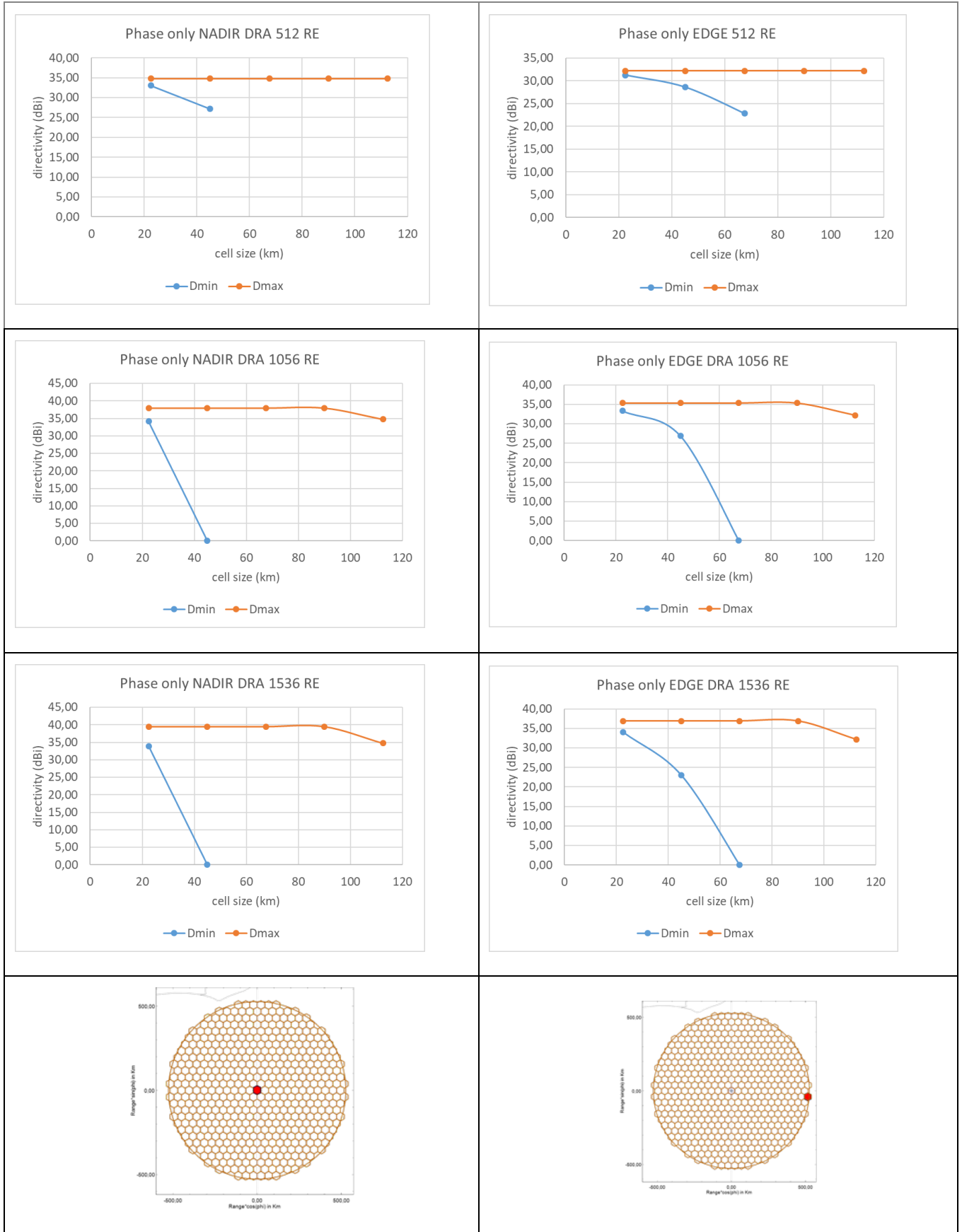


FIGURE 4-28 BEAM POINTING BY PHASE PLANE ONLY RE 512, 1056 & 1536 RE

The choice of the beamforming technique based solely on phase (phase plane slope control) is easier to implement at the payload level and maximizes efficiency. If amplitude is used in beamforming, the beam can be more finely adjusted, but the use of attenuation results in a loss of efficiency, this is due to the fact that the amplifier functioning point is not at his optimum.

Ensuring a service only with beam pointing is not sufficient to ensure a D_{\min} at the EOC (edge of coverage) unless taking a small size of cells 22,5 km. Chose a size of cell of 22,5 km means having 1984 cells over a coverage of $E_{\min} 45^\circ$ (see FIGURE 4-29). This solution is not envisaged for a question of number of beams to generate instantaneously. Even if a high BH (beam hopping) factor is applied it will induce a reduction in throughput finally. Moreover, the size of the cell is small compared to the capacity to position accurately the satellite without a sufficient effort in term of means. It will require sophisticated stabilizing system and also additional RF sensor and beacons on earth to reduce the error budgets. Despite the effort, it will remains a part of uncertainties budget that will be corrected.

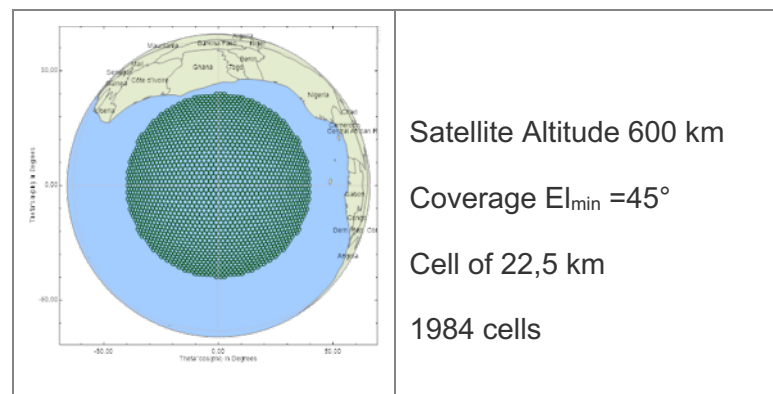


FIGURE 4-29 EXEMPLE OF COVERAGE WITH CELLS OF 22.5 KM

4.2.3.5 Beamforming by phase law adjustment / amplitude + phase variations (amplitude 6 dB, 12 dB and 40 dB)

The beamforming have been performed for a cell placed at the nadir and at the edge (best and worst case). The objective is also to look at the minimum and the maximum value of the directivity in order to evaluate the level of roll-off (maximum and minimum over the cell). The best solution will be to have a directivity that is around 30 dBi with a roll-off of 3dB.

The objective is to increase as possible the size of the cells in order to reduce the number of beam to manage.

ANTENNA 512 RE :

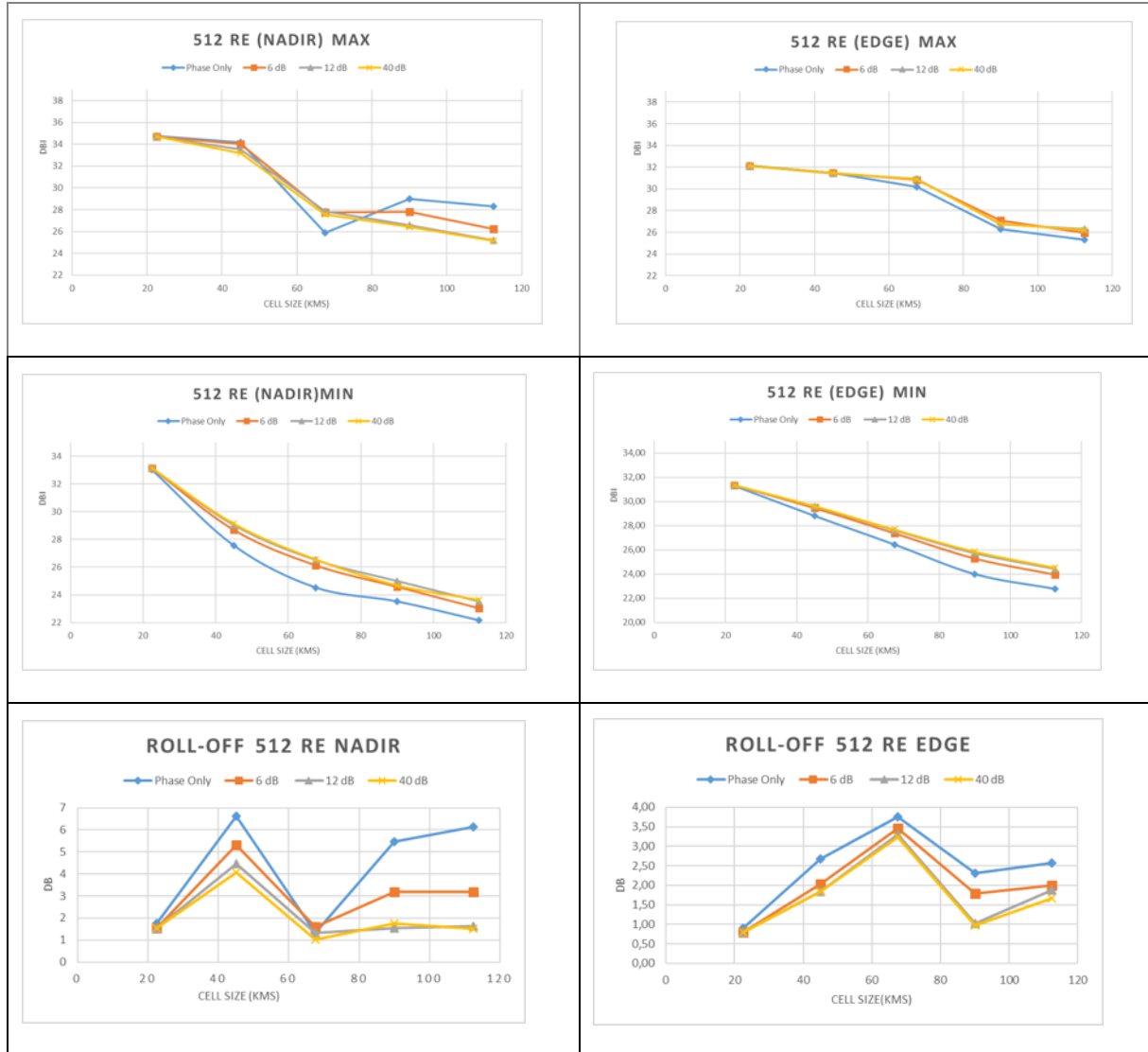


FIGURE 4-30 ANTENNE 512 RE 0.741λ : directivity min and max over cell at nadir and edge

The solution under investigation is 30dBi min. The cell size shall be lower than 45 km. To maintain a roll off of 3 dB, with a cell size of 45 km with an adjustment in beamforming according to the position of the cell is required.

At nadir: an attenuation of 40 dB is needed (even a extinguish of certain number of elements) to have a roll-off of 3-4dB and directivity min of 29 dBi.

At edge: beamforming in phase only is needed to have a roll-off of 2.6 dB and a directivity min of 29 dBi.

This solution could be advantageous for maintaining a constant directivity value across the cells.

ANTENNA 1056 RE :



FIGURE 4-31 ANTENNE 1056 RE 0.741λ : directivity min and max over cell at nadir and edge

In the case of an antenna of 1056 RE and a cell size of 45 km, the minimum directivity is 30 dBi at nadir and greater than 30dBi at the edge (according to the beamforming technic used). It means that the FSL could be compensated at edge.

At nadir: phase only beam forming could be sufficient and the roll-off is around 2dB with a directivity of 29dBi. With a Amplitude of phase of 6 dBi, at nadir the performance will gain 1 dB in directivity with 1dB of roll-off.

At edge: beamforming in amplitude and in phase with almost 6 dB will allow to reach 31 dBi

This solution is interesting because the directivity with beamforming allows to increase the performance at edge where the requirement is stringent and could allow to compensate for the FSL.

ANTENNA 1536 RE :

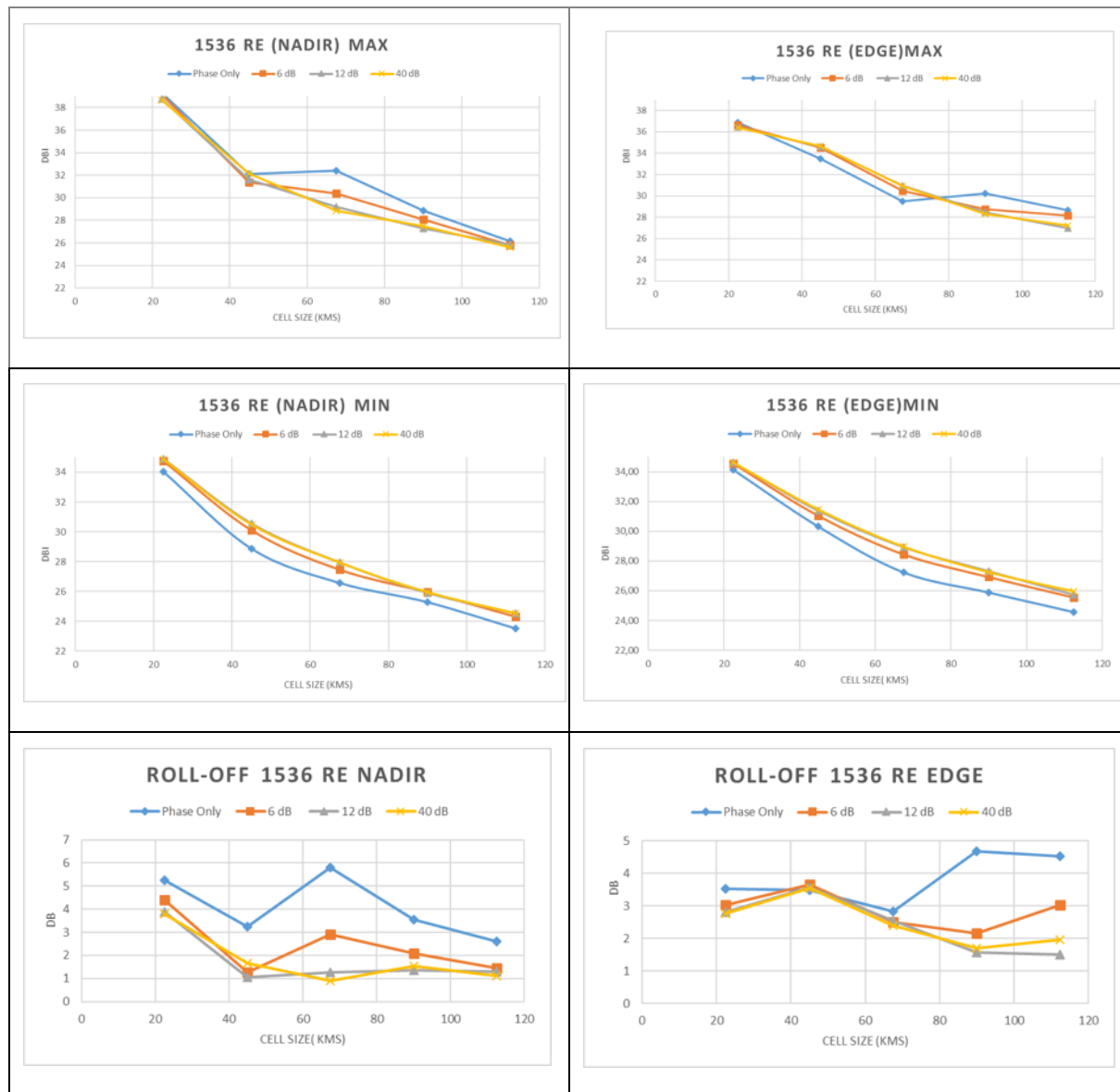


FIGURE 4-32 ANTENNE 1536 RE 0.741λ : directivity min and max over cell at nadir and edge

In the case of 1536 RE with a cell of 45 km. The minimum directivity is 30 dBi at nadir and greater than 30dBi at the edge (according to the beamforming technique used). It means that the FSL could be compensated at edge as for the 1056 RE case.

At nadir: phase only beam forming could be sufficient and the roll-off is around 3dB with a directivity of almost 29 dBi. beamforming in amplitude and phase with almost 6 dB dynamic will allow, at nadir, to gain 1 dB in directivity with 1dB of roll-off.

At edge: beamforming in amplitude and phase with almost 6 dB dynamic will allow to reach 31 dBi.

This solution of 1536 RE is not sufficiently interesting in terms of directivity compared to the 1056 RE case due to the drastic increase in number of element by 50%.

The choice will be to consider the case of 1056 Elements, with RE size of 0.741 λ in an hexagonal lattice.

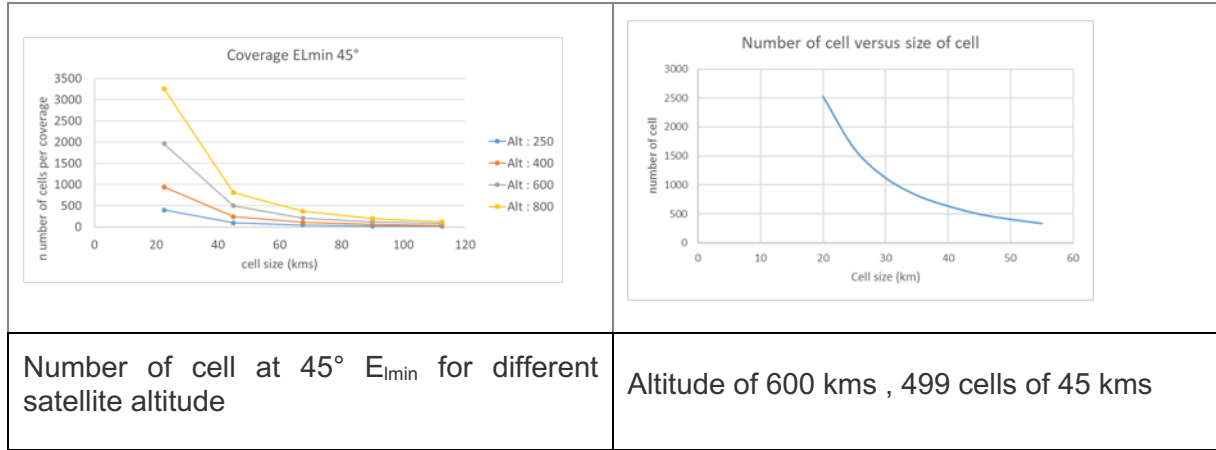


FIGURE 4-33 NUMBER OF CELL VERSUS CELL SIZE AND SATELLITE ALTITUDE

The solution has been defined based on the previous trade-off. The next step is to determine if more precise analyses confirm this choice. We will then explore the achievable performance in greater detail and refine the solution if necessary.

4.2.4 Solution C-band Analysis

The coverage has been chosen: 45 E_{Lmin}

Cell size of 45 km (499 cells to cover the 45° E_{Lmin} coverage)

Satellite altitude: 600 km

Number of radiating elements : 1056

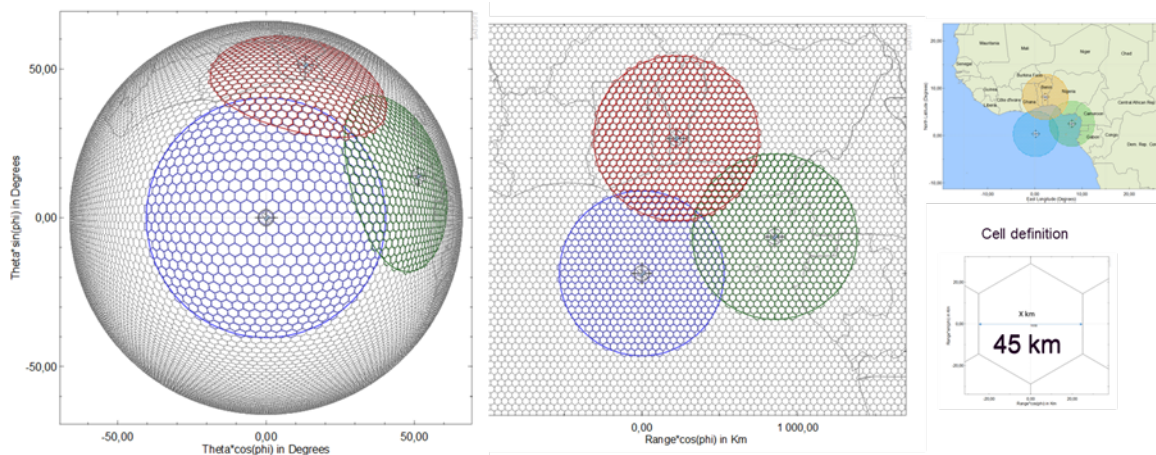


FIGURE 4-34 COVERAGE OF LEO-C BAND

-The RE size 0.741λ

-Payload based on a distributed DBFN

4.2.4.1 Technology focus C-BAND

For C-band DRA Front-ends, there is a need for large number of highly integrated HPA delivering medium power, in the order of few watts at saturation.

At these frequencies and power levels, huge progress, pushed by the 5G developments, have been made in the past few years for the development of very efficient HPA for micro-cells and massive-MIMO antennas [80] [81].

If LDMOS technology still dominates the ground station market for its cost advantage, the recent introduction of GaN transistors provides still higher efficiencies, especially using short gate length technologies. Moreover, besides high power densities and high efficiency levels, their particular properties such as low intrinsic capacitances and high operating voltages have eased the design of very wide band Doherty amplifiers (up to 30 or 40% fractional BW) with high PAE up to 6dB OBO or more [79]-[80].

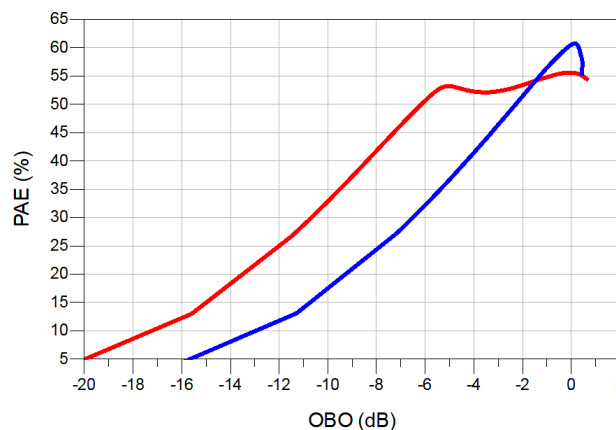


FIGURE 4-35 PAE VS OBO SHAPES COMPARISON BETWEEN CLASS-AB (BLUE) AND DOHERTY (RED) HPA DESIGNS (TAS-F DESIGN, C-BAND, GAN)

Other techniques have been considered to achieve high PAE such LMBA [5][6], Envelope Tracking [7][8], SPA-D, etc. and are especially considered when there is a need for high PAE at still higher OBO than 6dB. In the same trend to achieve higher flexibility -higher OBO, higher bandwidth or both- with the Doherty combination concept, the Doherty architecture has also been improved by the addition of staged peaking branches (multi-stage Doherty), the combination with envelope tracking at gate or drain[9], or with the replacement of the input combiner by a digitally assisted dual-input [88].

These techniques are however more complex to implement, often need additional digital circuits and are consequently reserved to very specific and demanding operational cases.

Another development direction is the output combiner and output path losses minimization, to achieve still higher PAE in the “classical” Doherty domain (up to 6dB OBO). Very original and efficient air-combiner has been proposed by [89], but the need for very selective cavity filters at HPA output in space applications may prevent its applicability. The other ways of improvement are technological. In this field, again, many improvements have been done in the past few years, in particular in the transistor technologies intrinsic performance, the integration of output combiner with the active device into a single SiP package [80], and the improvement of thermal management, with “top-side cooling” packages [90], in which the active parts are flip-chipped to provide another thermal conducting path than the PCB which usually have poor thermal performance.

A last point to improve Tx performance is a system approach with a global optimization of the antenna system performance, such as shown in [91] where an optimization of DPD digital processing demand is performed in a massive MIMO antennas ; which implies a totally different design approach with the use of system level simulators able to provide fast and accurate performance prediction of antenna with several tens of radiating elements and as many power amplifiers. For this reason and because usual “circuit” models can no more be used as leading to prohibitive simulation times, the development of behavioral models and simulators is an important R&D topic [92].

For the digital part, FPGAs form the basis of the architectures, and digitizing circuits for these frequency bands are available on the market, but need to be spatialized; some efforts in this direction have been made to consider their extended use for the constellation [93]-[97]. The major problem with existing and planned FPGAs is that they consume a lot of energy. A trade-off will have to be made between an ASIC solution (more restrictive in terms of flexibility, but low power consumption) and an FPGA (very flexible, but higher power consumption).

4.2.4.2 Payload architecture

The payload is constituted of an antenna with associated payloads based on a DBFN, for architecture 1 and architecture 2.

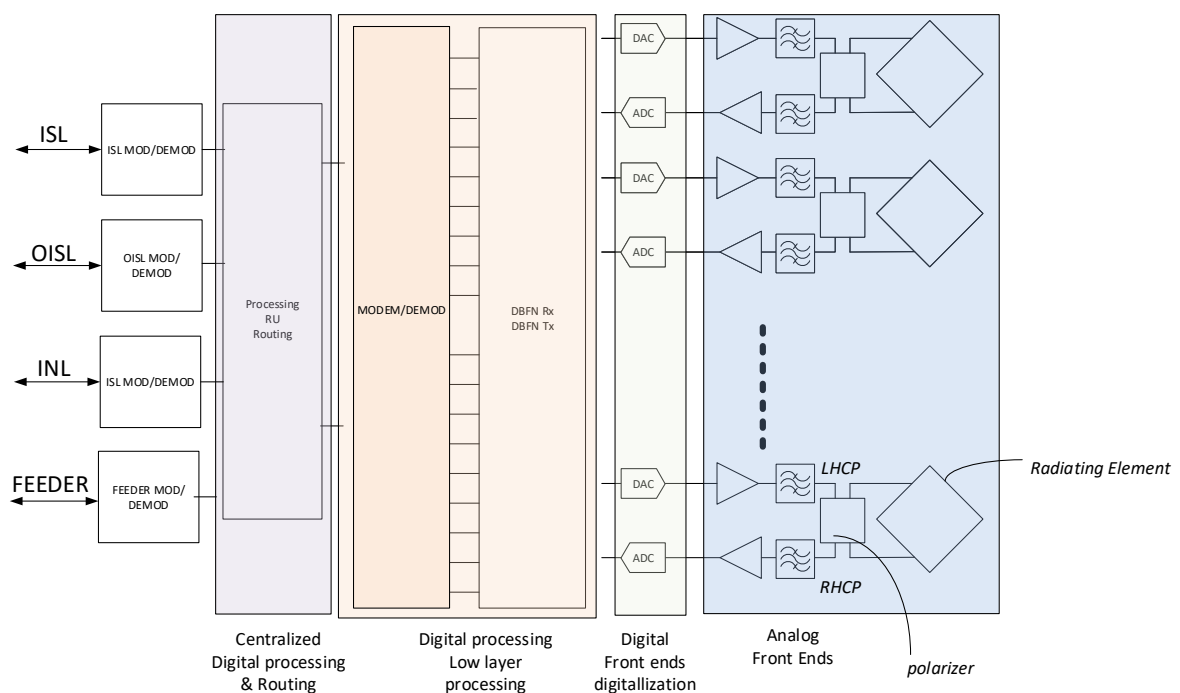


FIGURE 4-36 PAYLOAD ARCHITECTURE 1 (SERVICE SATELLITE)

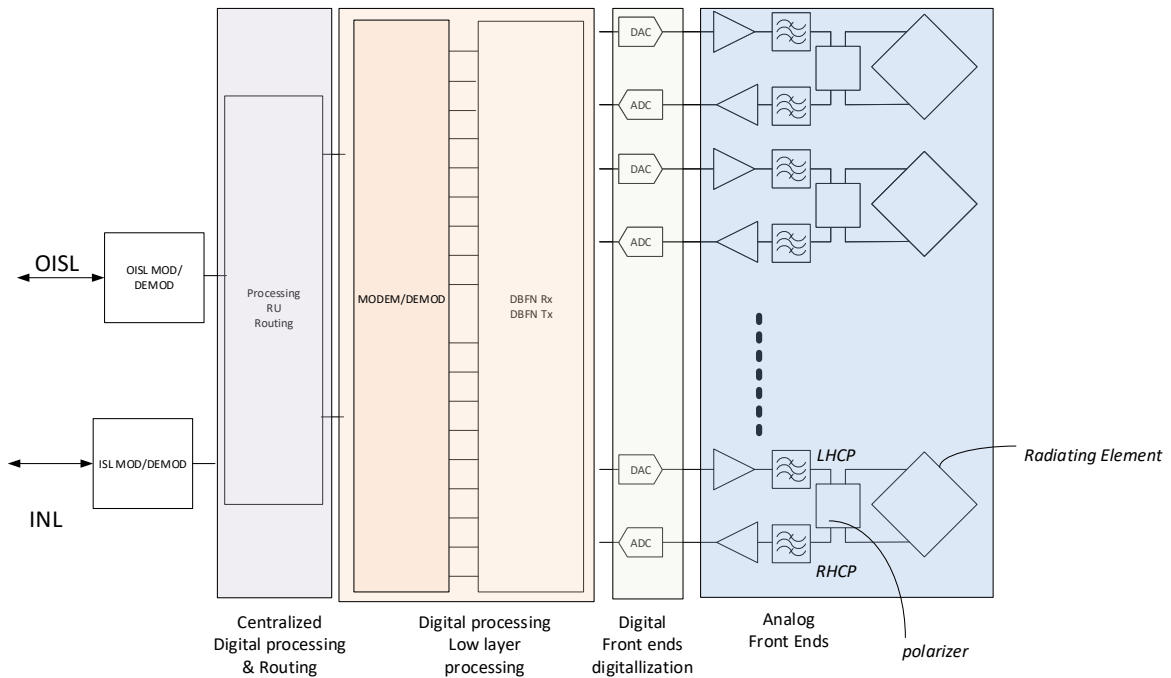


FIGURE 4-37 PAYLAOD ARCHITECTURE 2 (SERVICE SATELLITE)

The antenna is composed of Rx/Tx radiating elements connected to filters and amplifier section (analog Front-end). This front end part could be regrouped by block of 4, 8, 16 amplifiers connected to the digitalization part; the arrangement will depend on the first processing part ensured by ADC/DAC connected to an ASIC or a FPGA. The processing part complexity will depend on the split option used for the processing stack. Moreover In the case of architecture 1, the payloads include as mentioned in the FIGURE 4-36 the Feeder link, ISL link in addition of OISL link only present in the architecture 2. The main advantage of the architecture 2 is in one hand to concentrated the power available to the user link and simplify the complexity of the payload and consequently the cost. As illustrated in FIGURE 4-37 , the others links are ensured by the feeder satellite which concentrates one part of the processing capacity of several satellite (4 users satellites) and the other links (feeder and ISL to GEO for instance.)

These two payloads shall be evaluated in term of cost and the advantage of one compared to the second shall be quantified.

In architecture 2' the INL link is suppressed from architecture 2 and transferred to Feeder Satellite.

4.2.4.3 Radiating Elements

As mentionned in the satellite antenna radiating elements is Rx/Tx :

The polarization is RHCP or LHCP 1 polarization for Rx and 1 polarization for Tx

The circular polarization is well suited to LEO constellation for several reasons. In case of linear polarization, It will be difficult to maintain the polarization constant toward an UE. It is preferred to use circular polarization at satellite antenna and consider a polarization loss of 3 dB with an UE in linear polarization. Some UE terminals could be proposed in circular polarization which allow to gain 3 dB.

The optimisation of the constellation could not accurately been estimated with a theoretical model with do not be representative at off-axis performances. It is necessary to have a realistic model which is close enough to a probable design; in that purpose a existing model have been taken for the optimisation.

The diagramm in Directivity of a 0.741λ radiating element is presented in the FIGURE 4-38.

The efficiency taken is 90%. The technology could be type circular ring patch, cross-dipoles etc. Several solutions to generate the circular polarization exist [98]-[99] and the most appropriate technology will be used in conjonction of the easiness of connectivity. The research of compacity of the all assemblies is one of the main objectives of the payload design.

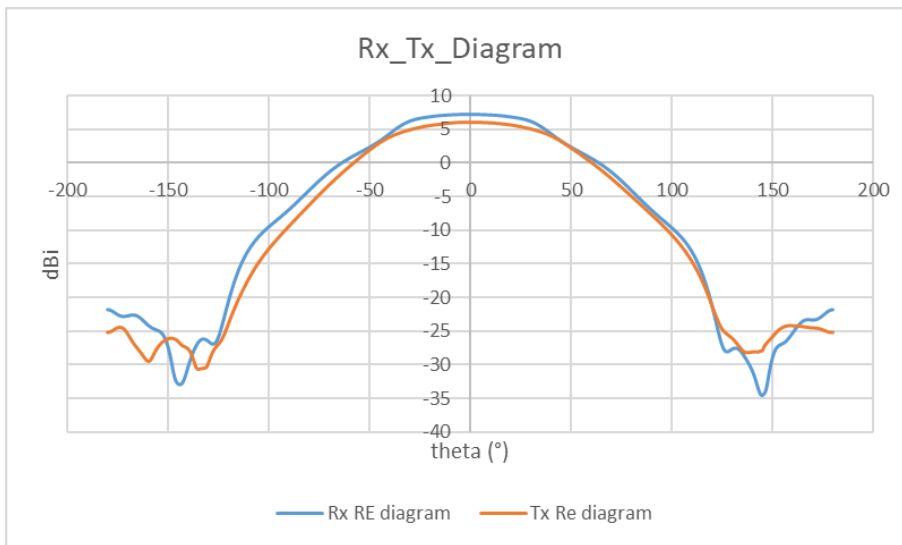


FIGURE 4-38 RADIATING ELEMENT DIAGRAM 0.741λ (RX)

Resume performances GAIN with a losses of 2 dB which includes the connectivity, radiating element and filters losses.

4.2.4.4 Antenna definition

The antenna definition is resumed in the table of the table below :

Satellite							NADIR MAX			EDGE MAX EL 45°		
							directivity	perthes 2dB	Gain	directivity	perthes 2dB	Gain
							dBi	dB	dBi	dB	dB	dBi
			diametre		nb ELEMENTS		5,89	2	3,89	4,39	2	2,39
radiating element	3,4	C Tx	0,055575	m	1		7,09	2	5,09	5,58	2	3,58
	3,9	C Rx	0,055575	m	1							
		Nfsat	9	dB								
							NADIR MAX			EDGE MAX EL 45°		
							directivity	perthes 2dB	Gain	directivity	perthes 2dB	Gain
							dBi	dB	dBi	dB	dB	dBi
satellite			diametre		nb ELEMENTS		36,13	2	34,13	34,63	2	32,63
antenne	SATELLITE	3,4	1,95	m	1056		37,32	2	35,32	35,82	2	33,82
		3,9	1,95	m	1056							

FIGURE 4-39 ANTENNA DEFINIITON

The antenna comprises 1056 elements arranged to form a flat panel (see

Antenna accommodation in pannel of 16 RE	ANTENNA RE POSITIONNING
--	-------------------------

FIGURE 4-40). In view of the layout requirements of the modules and association blocks, it is offered in blocks of 16 RE. This is a cross-polarized Rx/Tx antenna.

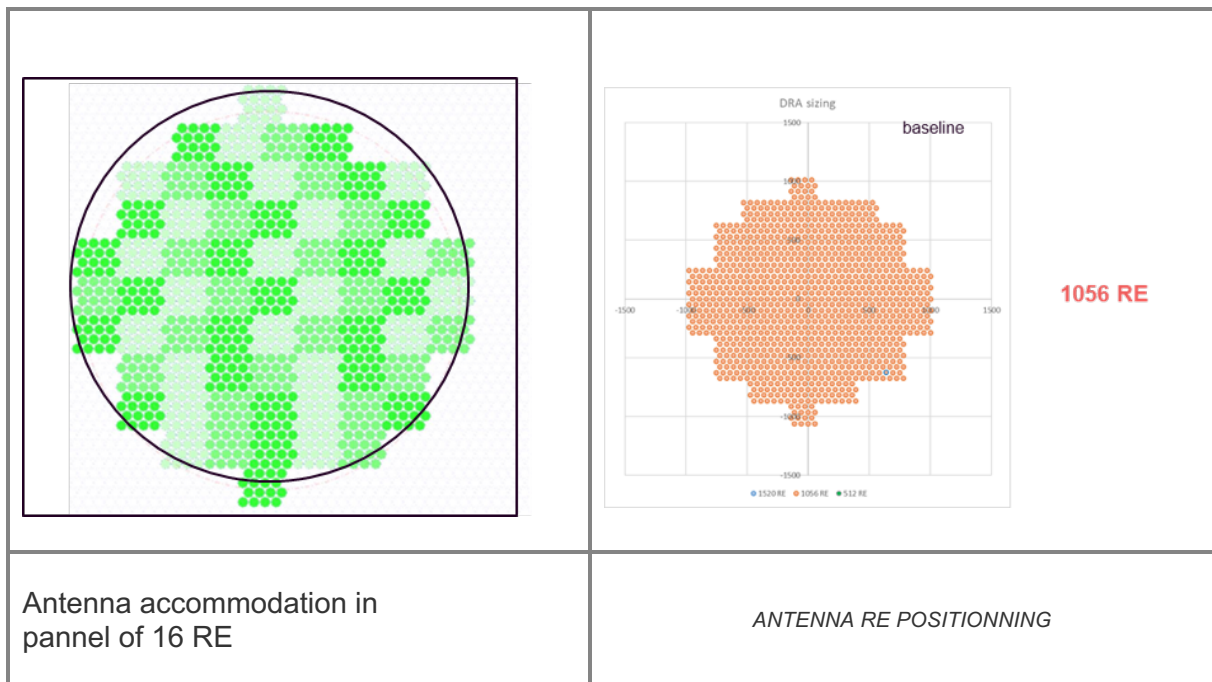
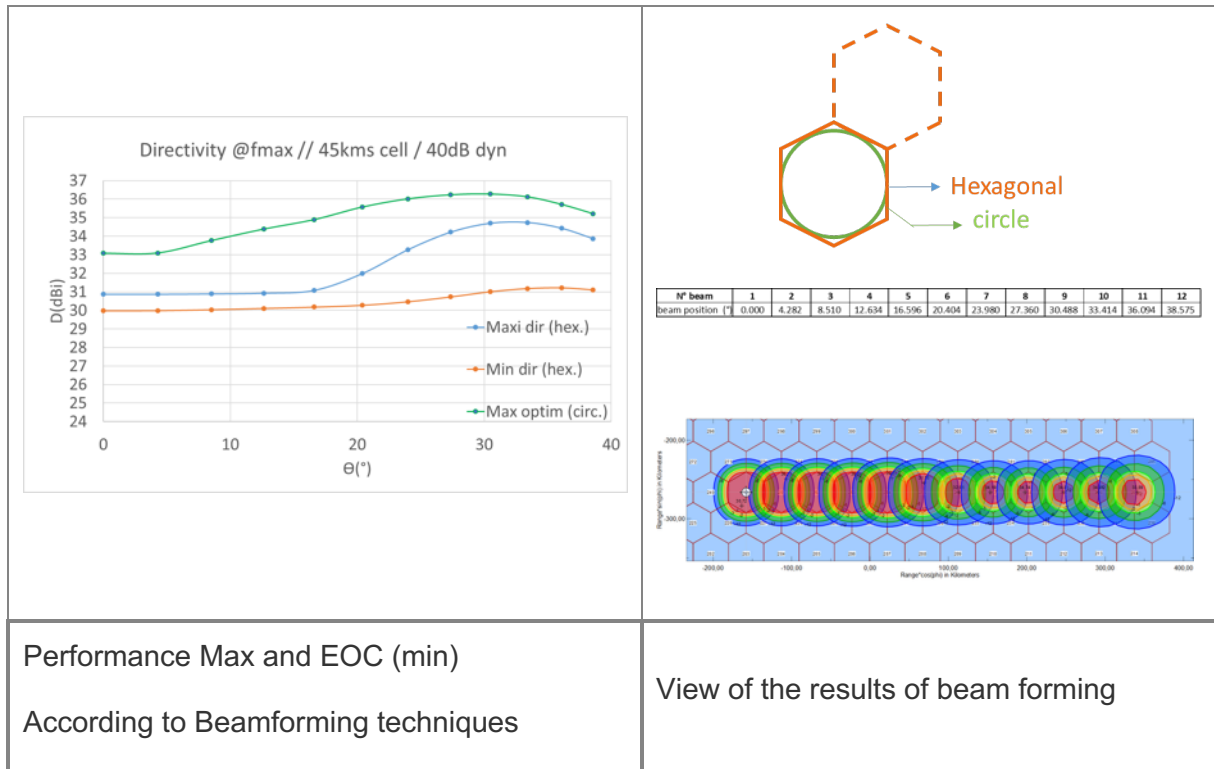


FIGURE 4-40 ANTENNA GEOMETRY

The diagrams are obtained from beam forming over the cells are illustrated by the FIGURE 4-41.

The beamforming could be adjusted according to the performances targets. It have to be noticed that high amplitude variations beamforming could induced additional losses that have to be taken in the dissipation capacity of the satellite.



Performance Max and EOC (min)
According to Beamforming techniques

View of the results of beam forming

FIGURE 4-41 BEAM FORMING TECH. & BEAM SHAPE

The Results for different type of beam forming are presented in 9.4.1.

The layout of the all of the beam for Rx and Tx are presented on FIGURE 4-42 and FIGURE 4-43

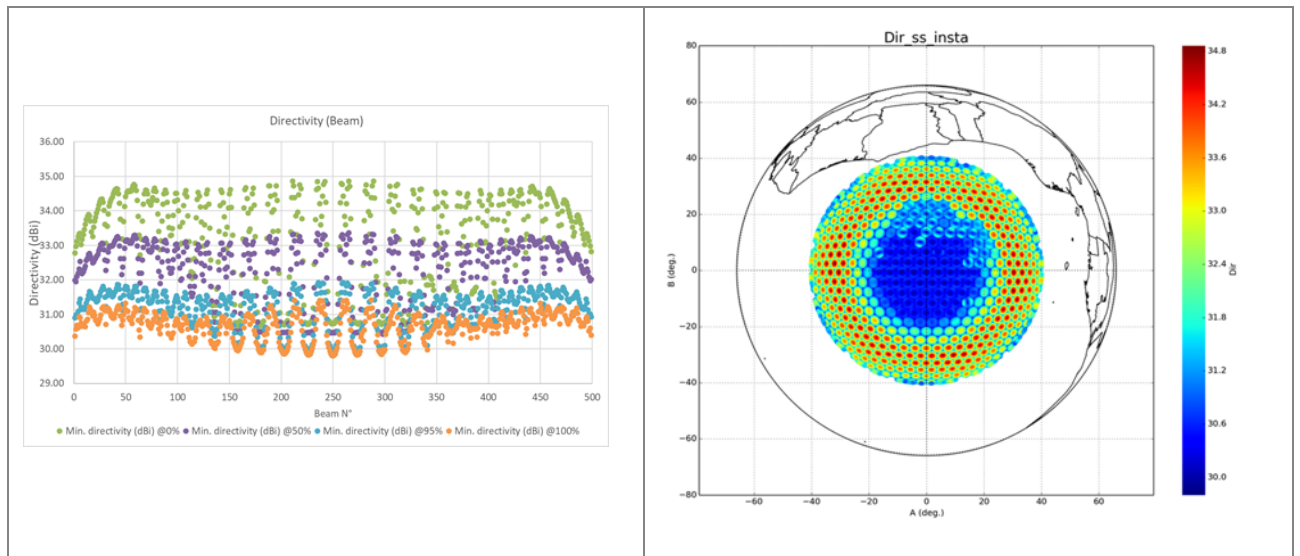


FIGURE 4-42 BEAM PERFORMANCES DIRECTIVITY 0.741 λ (Rx)

The directivity is between 30 dBi to 35 dBi. The minimum is around the nadir where the requirement in gain is lower than at the edges. Consequently, the antenna allows to compensate the FSL with depointing. In the case of Tx beam the performances is illustrated in the FIGURE 4-43.

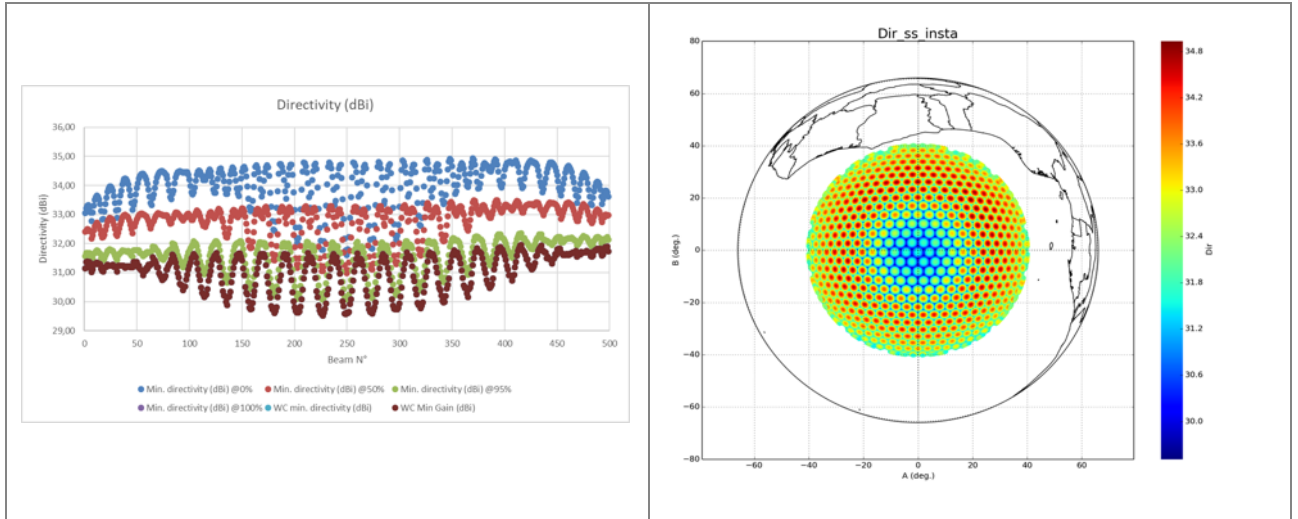


FIGURE 4-43 BEAM PERFORMANCES DIRECTIVITY $0.65 \lambda (Tx)$

4.2.4.5 Grating lobes

Diagrams for 3 extreme pointing directions have been plotted on the map to check that the network lobes are indeed outside the Earth's surface (FIGURE 4-44). The aim is to check that the levels of the secondary lobes of the array lobes remain acceptable. The aim is to ensure that these levels will not interfere with the beams of an adjacent satellite

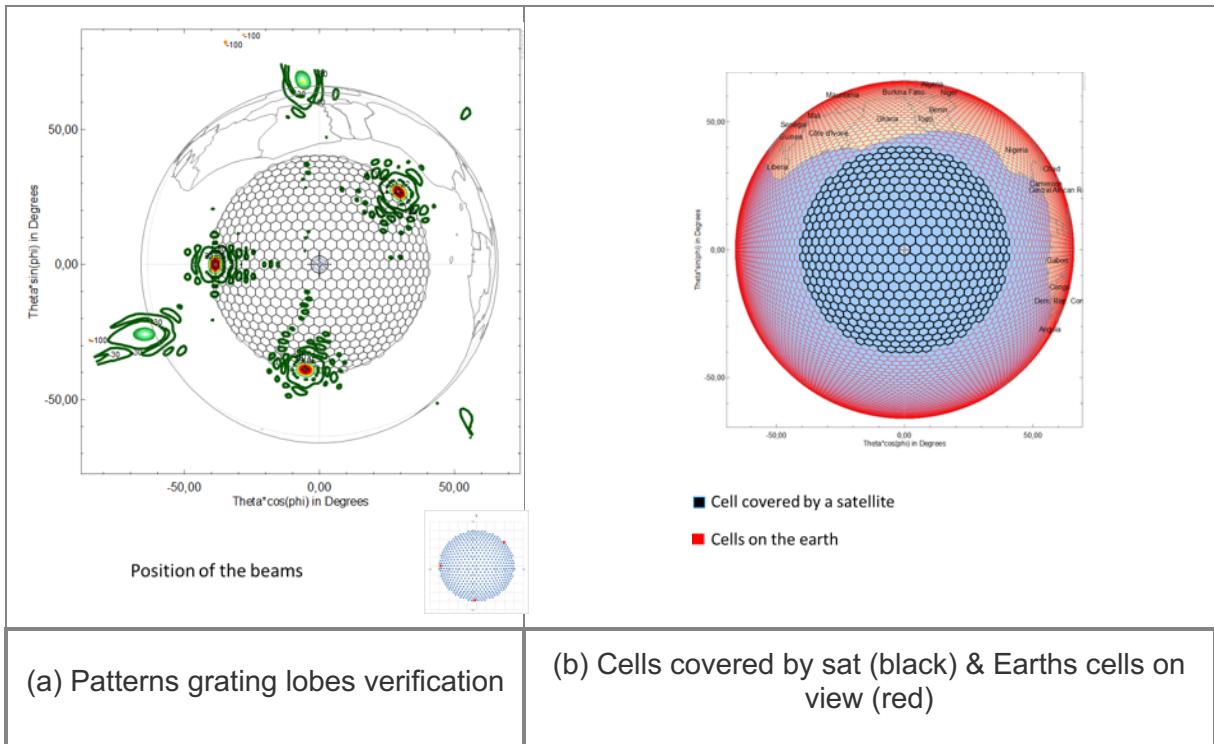


FIGURE 4-44 GRATING LOBES POSITION VERIFICATIONS

The levels of the grating lobes are also attenuated, given the distance between their position and the satellite, which is favorable in terms of link budget. Thus at the edge of the earth the attenuation between a cell at the edge of the satellite coverage ($\alpha=40.3^\circ$) and an earth cell at the edge of the earth ($\alpha=65.7^\circ$) is almost 9.3 dB. The distance varies from 815 km to 2390 km.

4.2.5 Link Budget

4.2.5.1 Objectives

The objectives is to compute the maximum throughput achievable in order to evaluate the link dimensioning (OISL /ISL). In a second step, the evaluation of the average capacity will be given. The parameters and the hypothesis of availability are given in the table below.

Parameter	Unit	Value
Band Name	-	C
Availability	%	99,50
Earth Radius	km	6371
Boltzmann	dBW/K/Hz	-228,6

FIGURE 4-45 CONSTANTS AND HYPOTHESIS

The full estimation of the capacity of the satellite will need an accurate traffic model (distribution of UE and type of terminals) and intensive computation of time in order to converge to a consolidated value. Nevertheless, some case of average throughput will be evaluated to give an idea on expectable throughput.

4.2.5.2 Terminal performances

According to the definition of the terminal type in table of Figure 3-4 could be reduced in 4 cases as listed in the figure below :

→ Derivation of 4 cases :
→ UE type 1 (FDD) : UE : G = -5dBi / NF=7 dB / Power : 26 dBm (center of cell nadir and center of edge cell) (EL45)
→ UE type 2 (FDD) : UE : G = -2dBi / NF=7 dB / Power : 26 dBm (center of cell nadir and center of edge cell) (EL45)
→ UE type 3 (TDD) : UE : G = -5dBi /NF=5.5 dB /power : 26 dBm (center of cell nadir and center of edge cell) (EL45)
→ UE type 4 (TDD) : UE : G = -2dBi /NF =5.5 dB /Power : 26 dBm (center of cell nadir and center of edge cell) (EL45)
UE_1 is the nominal case

FIGURE 4-46 RESUME OF THE TERMINAL PERFORMANCES(UE)

According to the terminal type the gain is between -2 dBi to 5 dBi and the NF between 5.5 to 7 dB and the power at 26 dBm as mentionned in the table. Thus it could be regroup into 4 cases in order to evaluate the performances. Up to now, the TDD mode in NTN is under study, the advantage of this mode is to reduce the filter effort at the front end so the reduce the noise figure (less losses) of 1.5 dB with nevertheless the drawback to have an accurate synchronism protocol. The UE_1 will be the most evaluated and constitute the most stringent requirements.

The full excercise could not be done yet, as the hypotheses of distribution and their number have not yet been established. In our case, the purpose is to evaluate and estimate the maximum throughput achievable to dimension the interlinks without overdimensionning the system.

The hypothesis taken for the satellite are given in the table of FIGURE 4-39. The values for the elementary radiating element and the satellite DRA gain taken for the link budget in the case of maximum achievable performances.

The purpose is not to estimate the worst case but give some value of throughput achievable in an average scenario. Other cases will be dealt with at a later date, by reducing or increasing the values of the characteristics according to the terminal performances. The aim is also to draw up a performance report based on these hypotheses, in order to identify critical points and define areas for improvement for the rest of the study.

4.2.5.3 SATELLITE payload hypothesis (case A nominal Case)

The satellite payload parameters are resume used for the link budget. In each list of parameters only the functioning mode (full of half duplex FDD or TDD) impact on the satellite parameters have been identified and recalled. The table of FIGURE 4-47 gives the satellite parameters for FDD mode and the Table of Figure 4-48 gives the satellite parameters for half duplex or TDD mode. The main difference in the effort in filtering needed in FDD mode. In FDD mode it will necessary to ensure a filtering by an duplexeur with high level of isolation (blocker avoidance). In half duplex FDD and TDD, the filtering could be reduced by a basic need. In the last case if the frequency band Tx and Rx is the same then it could be possible to simplify the satellite front end design (switches and relaxe the filtering section instead of duplexeur). It will also be possible to work only in one circular polarization.

SATELLITE	Parameter	Unit	Value
	Satellite	-	LEO-600
	Altitude	km	600
	Band Name	-	C
	Nb spots total	-	499
	Cell diameter	km	45
TX (downlink)	Downlink Frequency	GHz	3.40
	Antenna Size	m	1.95
	Number of ER	-	1056
directivity Tx	Losses ER	dB	1.5
31.6	Antenna gain (NADIR)	dBi	30.10
33.6	Antenna gain (EI 45°)	dBi	32.10
	EIRP density	dBW/MHz	28.00
	EIRP density attenuation	dB	0.00
	Effective EIRP density	dBW/MHz	28.00
RX (uplink)	Uplink Frequency	GHz	3.90
	Antenna Size	m	1.95
	Number of ER	-	1056
	Losses ER	dB	2
	Antenna Temperature	K	240.00
	Ambiant Temperature	K	290.00
directivity Rx	Equivalent Temperature	K	409.62
30.73	Antenna gain (NADIR)	dBi	28.73
33.84	Antenna gain (45°)	dBi	31.84
offset (au gain)	G/T (NADIR)	dB/K	2.40
26.33	G/T (45°)	dB/K	5.51
SCS PRB	SCS	kHz	30
	Downlink BW	MHz	100
	Nb Downlink PRBs	-	273
	Uplink BW	MHz	100
	Nb Uplink PRBs	-	273
C/I	Downlink (Sat TX)	dB	18
	Uplink (Sat RX)	dB	18

FIGURE 4-47 SATELLITE PARAMETERS FDD CASE (UE_1 & UE_2)

SATELLITE	Parameter	Unit	Value
	Satellite	-	LEO-600
	Altitude	km	600
	Band Name	-	C
	Nb spots total	-	499
	Cell diameter	km	45
	Use of Scan Losses	-	YES
TX (downlink)	Downlink Frequency	GHz	3.40
	Antenna Size	m	1.95
	Number of ER	-	1056
directivity Tx	Losses ER	dB	1
31.6	Antenna gain (NADIR)	dBi	30.60
33.6	Antenna gain (EI 45°)	dBi	32.60
	EIRP density	dBW/MHz	28.00
	EIRP density attenuation	dB	0.00
	Effective EIRP density	dBW/MHz	28.00
RX (uplink)	Uplink Frequency	GHz	3.90
	Antenna Size	m	1.95
	Number of ER	-	1056
	Losses ER	dB	1.5
	Antenna Temperature	K	240.00
	Ambiant Temperature	K	290.00
directivity Rx	Equivalent Temperature	K	409.62
30.73	Antenna gain (NADIR)	dBi	29.23
33.84	Antenna gain (45°)	dBi	32.34
offset (au gain)	G/T (NADIR)	dB/K	2.90
26.33	G/T (45°)	dB/K	6.01
SCS PRB	SCS	kHz	30
	Downlink BW	MHz	100
	Nb Downlink PRBs	-	273
	Uplink BW	MHz	100
	Nb Uplink PRBs	-	273
C/I	Downlink (Sat TX)	dB	18
	Uplink (Sat RX)	dB	18

FIGURE 4-48 SATELLITE PARAMETERS TDD CASE (UE_3 & UE_4)

4.2.5.4 UE hypothesis

The parameters used for the UE are given in the table below :

UE	Parameter	Unit	Value
RX (downlink)	Downlink Frequency	(GHz)	3.40
	Antenna Noise Figure (NF)	(dB)	7.00
	Antenna gain (NADIR)	(dBi)	-5.00
	Antenna gain (45°)	(dBi)	-5.00
	G/T (NADIR)	dB/K	-36.62
	G/T (45°)	dB/K	-36.62
SCS PRB	SCS	kHz	30
	Downlink BW	MHz	100
	Nb Downlink PRBs	-	273
	Uplink BW	MHz	100
	Nb Uplink PRBs	-	273
TX (uplink)	Uplink Frequency	(GHz)	3.90
	Antenna gain (NADIR)	(dBi)	-5.00
	Antenna gain (45°)	(dBi)	-5.00
	Antenna transmit power	dBW/dBm	-4
	Antenna transmit power	W	0.40

FIGURE 4-49 UE HYPOTHESIS (UE_1)

UE	Parameter	Unit	Value
RX (downlink)	Downlink Frequency	(GHz)	3.40
	Antenna Noise Figure (NF)	(dB)	7.00
	Antenna gain (NADIR)	(dBi)	-2.00
	Antenna gain (45°)	(dBi)	-2.00
	G/T (NADIR)	dB/K	-33.62
	G/T (45°)	dB/K	-33.62
SCS PRB	SCS	kHz	30
	Downlink BW	MHz	100
	Nb Downlink PRBs	-	273
	Uplink BW	MHz	100
	Nb Uplink PRBs	-	273
TX (uplink)	Uplink Frequency	(GHz)	3.90
	Antenna Size	(m)	0.05
	Number of ER	-	1
	Antenna gain (NADIR)	(dBi)	-2.00
	Antenna gain (45°)	(dBi)	-2.00
	Antenna transmit power	dBW/dBm	-4
	Antenna transmit power	W	0.40

FIGURE 4-50 UE HYPOTHESIS (UE_2)

The difference between UE_1 and UE_2 are the gain of the terminals.

UE	Parameter	Unit	Value
RX (downlink)	Downlink Frequency	(GHz)	3.40
	Antenna Noise Figure (NF)	(dB)	5.50
	Antenna gain (NADIR)	(dBi)	-5.00
	Antenna gain (45°)	(dBi)	-5.00
	G/T (NADIR)	dB/K	-35.12
	G/T (45°)	dB/K	-35.12
SCS PRB	SCS	kHz	30
	Downlink BW	MHz	100
	Nb Downlink PRBs	-	273
	Uplink BW	MHz	100
	Nb Uplink PRBs	-	273
TX (uplink)	Uplink Frequency	(GHz)	3.90
	Antenna Size	(m)	0.05
	Number of ER	-	1
	Antenna gain (NADIR)	(dBi)	-5.00
	Antenna gain (45°)	(dBi)	-5.00
	Antenna transmit power	dBW/dBm	-4
	Antenna transmit power	W	0.40

FIGURE 4-51 UE HYPOTHESIS (UE_3)

UE	Parameter	Unit	Value
RX (downlink)	Downlink Frequency	(GHz)	3.40
	Antenna Noise Figure (NF)	(dB)	5.50
	Antenna gain (NADIR)	(dBi)	-2.00
	Antenna gain (45°)	(dBi)	-2.00
	G/T (NADIR)	dB/K	-32.12
	G/T (45°)	dB/K	-32.12
SCS PRB	SCS	kHz	30
	Downlink BW	MHz	100
	Nb Downlink PRBs	-	273
	Uplink BW	MHz	100
	Nb Uplink PRBs	-	273
TX (uplink)	Uplink Frequency	(GHz)	3.90
	Antenna Size	(m)	0.05
	Number of ER	-	1
	Antenna gain (NADIR)	(dBi)	-2.00
	Antenna gain (45°)	(dBi)	-2.00
	Antenna transmit power	dBW/dBm	-4
	Antenna transmit power	W	0.40

FIGURE 4-52 UE HYPOTHESIS (UE_4)

The difference between UE_3 and UE_4 are the gain of the terminals.

The evaluation of performances have been done through link budgets presented in Appendices 9.4.1

4.2.5.5 Sensitivity to terminal type (UE_1 to UE_4)

The table resume the sensitivity results presented in 9.4.1.

CASE A	DOWNLINK	Terminal type	Downlink Nominal		Downlink max power 1 beam		Downlink indoor			
			Max nadir	Max edge	Max nadir	Max edge	Max Nadir	attenuation	Max edge	attenuation
UE_1	FDD	CTN_1	31.9	14.2	143.3	143.3	3.6	10 dB	1.4	10 dB
UE_2	FDD	CTN_2 & CTN_3	63.0	19.8	143.3	143.3	7.5	10 dB	2.7	10 dB
UE_3	TDD	CTN_1	41.4	19.8	143.3	143.3	5.2	10 dB	2.0	10 dB
UE_4	TDD	CTN_2 & CTN_3	74.2	31.9	143.3	143.3	10.6	10 dB	3.5	10 dB
CASE A	UPLINK	Terminal type	uplink Nominal		Uplink 1 PRB		Uplink indoor			
			Max nadir	Max edge	Max nadir	Max edge	Max Nadir	attenuation	Max edge	attenuation
UE_1	FDD	CTN_1	0.5	0.4	0.3	0.4	0.08	8	0.08	7
UE_2	FDD	CTN_2 & CTN_3	1.1	0.5	0.5	0.4	0.10	10	0.08	10
UE_3	TDD	CTN_1	1.1	0.4	0.4	0.3	0.08	9	0.08	7
UE_4	TDD	CTN_2 & CTN_3	1.2	0.5	0.4	0.3	0.08	10	0.13	10

FIGURE 4-53 COMPARISON OF THROUGHPUT IN TYPICAL CASE FOR THE 4 UE TYPE IN BANDE C

For these computations, for downlink throughput, EIRP flux density is fixed for each beam. This table gives an overview of the capacity.

But in reality, in a more dynamic mode of use, the power distribution of the beams can be done optimally. It is just necessary that the number of beams and their selection at a given moment be made in such a way that the power bank and the power distribution across the beams ensure maximum efficiency of the HPAs. This will depend on the traffic management and capacity allocation software

4.2.6 System level performance of the proposed C-band (use case of Metropolitan France)

4.2.6.1 Introduction

This chapter is focus on System level performance of the proposed NTN C-band, architecture, and constellation when applied in the use case of Metropolitan France where the non-terrestrial network complements the coverage of the terrestrial network. More precisely, we provide several system metrics evaluated through a simulation environment using the architecture, link budget, and constellation parameters of WP3.3 and WP3.4, respectively. We consider LEO satellites communicating with handheld devices over the service link. The users are consumers which are located outside of the terrestrial coverage and seek connectivity from the non-terrestrial component. This corresponds to Use case UC5 defined in section 3.5 of [23], without the support of light indoor conditions.

4.2.6.2 Region of interest

This simulation focuses on a specific region of the Earth (region of interest - RoI) which is selected to be the land and sea area of Metropolitan France. Since NTN is complementary to the TN coverage, we exclude regions covered by the ground network taken from France's

coverage maps[132] .The resulting region of interest is depicted in Figure 4-54

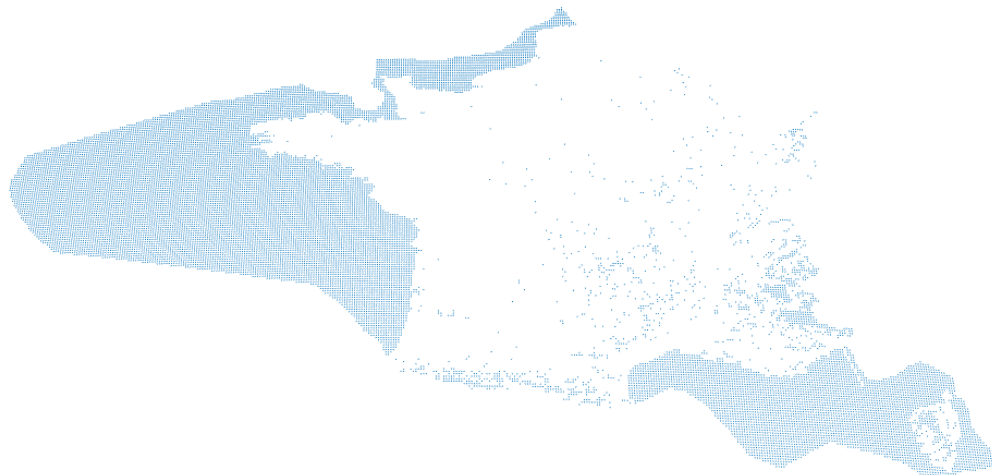


FIGURE 4-54 TERRESTRIAL COVERAGE MAP OF METROPOLITAN FRANCE RETRIEVED FROM [132]

The simulation metrics are taken within the region of interest (RoI) where the non-terrestrial users are. Around the RoI, we add additional NTN cells, but we do not measure metrics there. This is done to make sure that beyond the borders of the RoI there are still interfering satellite beams that create more realistic inter-beam interference conditions.

However, not all the region outside the RoI is served by NTN, meaning that only a percentage of this area should have NTN cells. We expect that sea areas will be 100% served by NTN while land areas are on average 10% served by NTN. Since roughly 2/3 of European territory is land and 1/3 is sea, this results to a $0.67 \cdot 10 + 0.33 \cdot 100 = 40\%$ probability a European area (land and sea) is covered by the non-terrestrial network, and 60% probability it is covered by the terrestrial component. Thus, when creating the region outside the RoI, we randomly create NTN cells with a 40% probability.

Finally, notice that the satellite beams generated outside of the RoI are assigned the average resource utilization (beam load) of the beams serving the RoI.

The resulting system includes: the RoI, the region outside of it, the LEO constellation, the satellite beams, and NTN cells are shown in NTN cell visualisation.

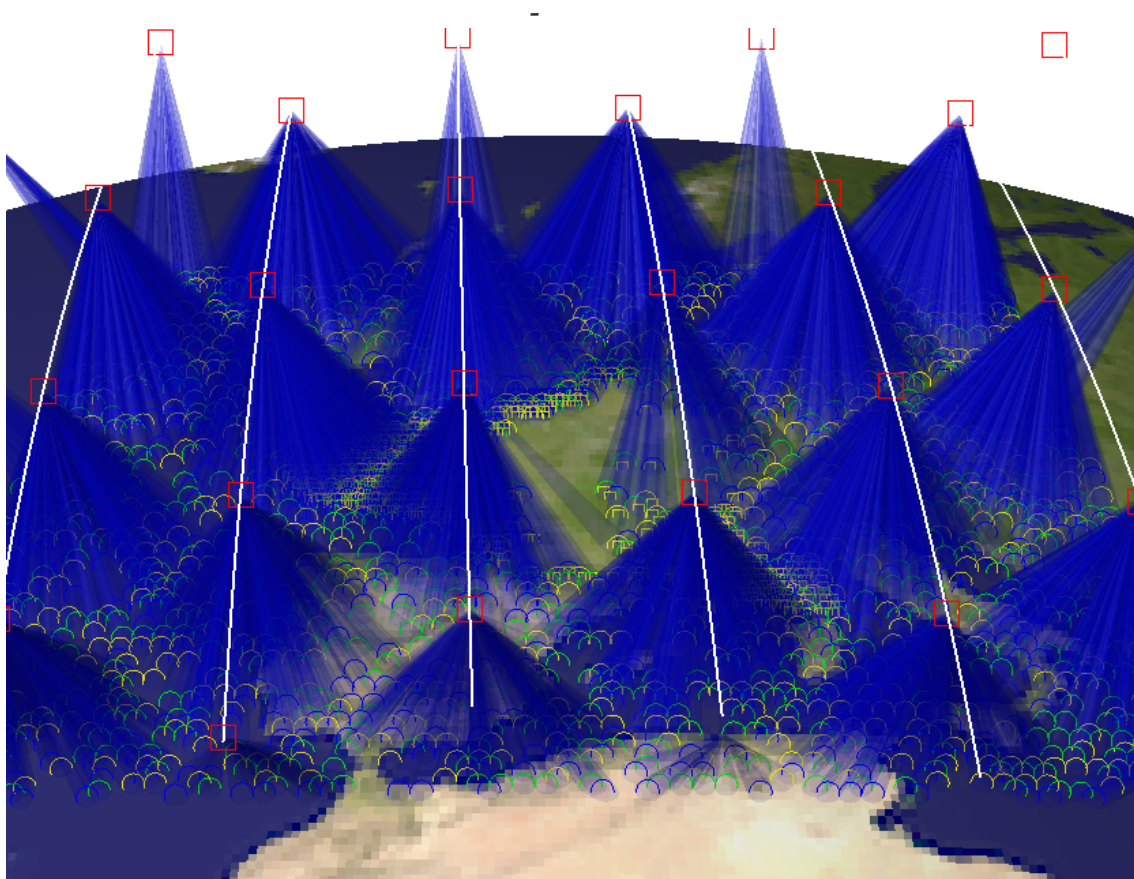


FIGURE 4-55 NTN CELL VISUALISATION A VISUALIZATION OF A SNAPSHOT OF THE CONSTELLATION AND BEAM ASSIGNMENT TO NTN CELLS WITHIN METROPOLITAN FRANCE GIVEN THE PARAMETERS OF TABLE 3TABLE 2 USING $FRF=3$. GREEN, YELLOW AND BLUE CIRCLES INDICATE THE THREE DIFFERENT CELL COLORS. RED SQUARES INDICATE THE LOCATION OF THE LEO SATELLITES, AND WHITE LINES THEIR ORBIT TRACES.

4.2.6.3 Derivation of number of NTN users

To find the number of NTN users and their location, we process the terrestrial coverage maps of Metropolitan France and the population distribution (Figure 4-56) and keep only those users that are located outside the terrestrial coverage. The result is shown in Figure 4-57. We aim to support 99% of NTN population. Finally, the total NTN addressable users are ~560.000 people.

The total Metropolitan France population is 62 million and 560.000 is approximately 0.85% of that. Thus, the calculated number of addressable NTN users agrees with the fact that the terrestrial network provides coverage to ~99% of the total metropolitan France population.

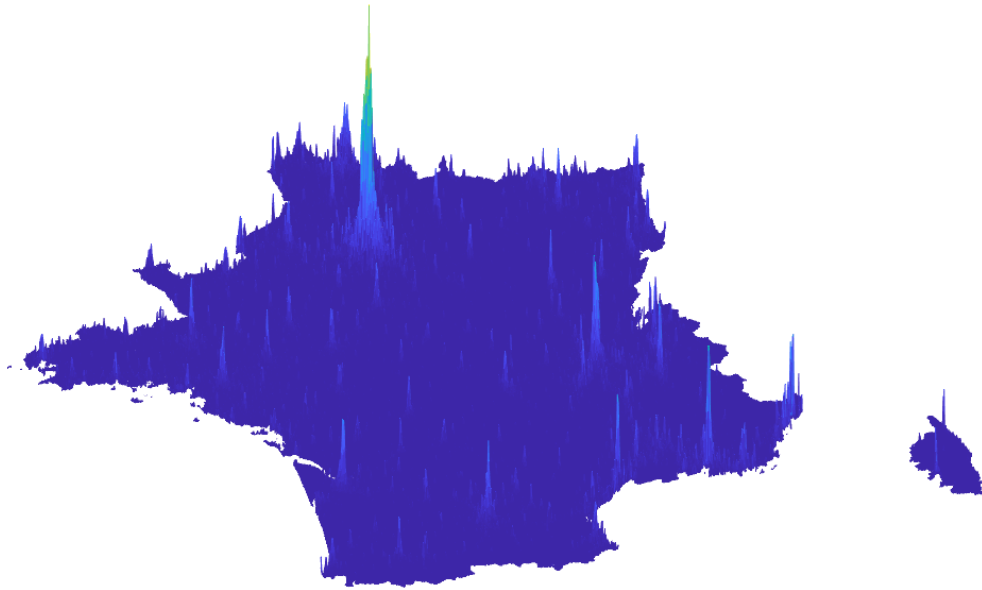


FIGURE 4-56 POPULATION DISTRIBUTION OF METROPOLITAN FRANCE RETRIEVED FROM [133]



FIGURE 4-57 POPULATION DISTRIBUTION OF NTN USERS WITHIN METROPOLITAN FRANCE.

4.2.6.4 User traffic model

The purpose of the user traffic model in the simulation is to provide an instantaneous cell load per NTN cell by accumulating the traffic demand of the connected users of each cell. Each NTN user is assumed to have the same traffic demand. This is then compared to the achievable traffic each cell can deliver and finally calculating a cell traffic satisfaction rate, which is one of the simulation's system metrics.

To derive the per user traffic demand in Mbps, we consider the monthly data consumption of a user (Gbyte/user/moth) utilizing a monthly user traffic profile and convert it to Mbps. The appropriate user traffic profile should consider that NTN users are not expected to use the link

budget limited NTN network to e.g., stream high-definition video. Thus, a less video and more social media-centric user profile is selected, as shown in Figure 4-58.

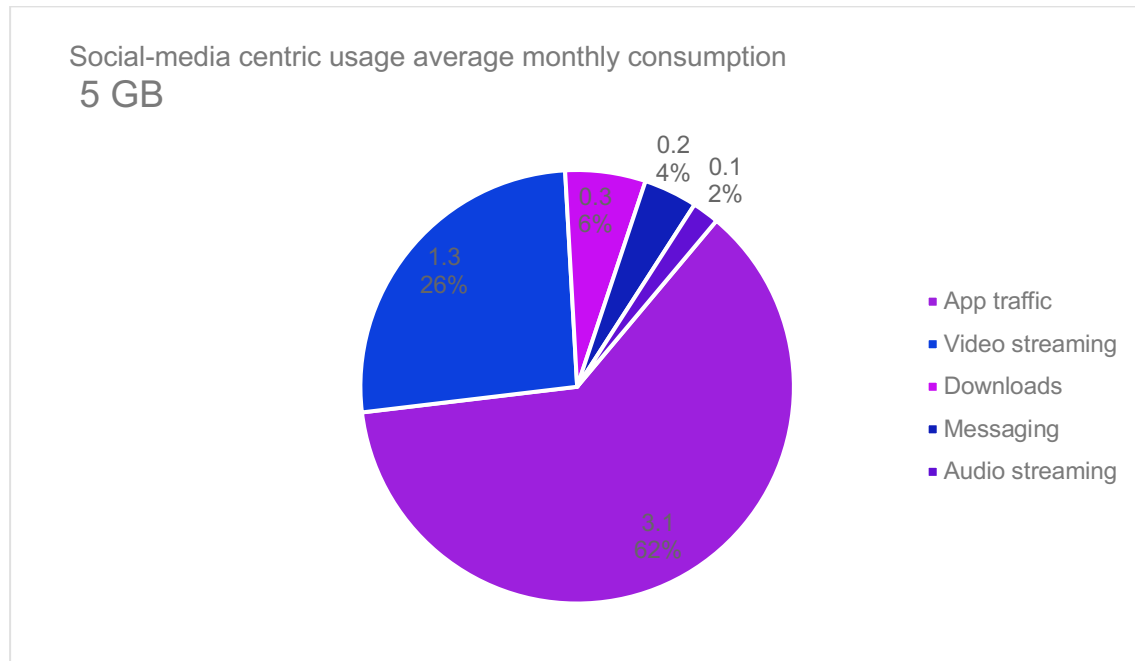


FIGURE 4-58 THE SOCIAL-MEDIA CENTRIC USER TRAFFIC PROFILE (2022).

To convert GB/user/month to Mbps, we assume that the data is consumed within 30 days. However, within a day, the measured demanded data is not evenly distributed, e.g., early morning hours having almost zero data consumption, while the majority of the data volume is demanded in less than half a day span, see Figure 4-59. To approximate the data distribution within the day, we assume a “busy hour” rectangular time window within which we assume that the entirety of the daily data is consumed. Notice that the volume of the measured data curve and the rectangular window data are equal.

Additionally, the data consumption is split between downlink and uplink traffic. After analyzing real-network traffic, we set the busy hour window to 10h, and the downlink uplink traffic split to 90% downlink and 10% uplink, see Figure 4-59.

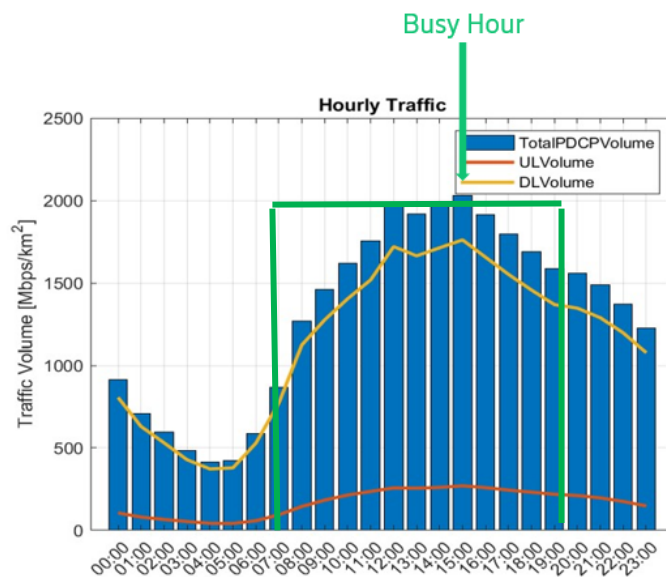


FIGURE 4-59 DATA VOLUME DISTRIBUTION OVER THE DAY AND BUSY HOUR RECTANGULAR APPROXIMATION. CONTRIBUTIONS FROM DOWNLINK AND UPLINK ARE ALSO SHOWN.

Finally, studies have shown that the user consumption increases from year to year with a rate characterized by a Compound annual growth rate (CAGR), see p.17 of [134] . For NTN we select a moderate CAGR increase of 10%, much lower than the 23% estimate of a Western Europe country (France), as shown in Figure 4-60. This is because most of the data increase is due to video streaming services, a service not expected to be the most relevant for NTN. Using the CAGR ratio and setting a number of years to ahead (Yah) from the reference year of the measurement of the traffic (in this case 2022), we can predict the expected data consumption of future years.

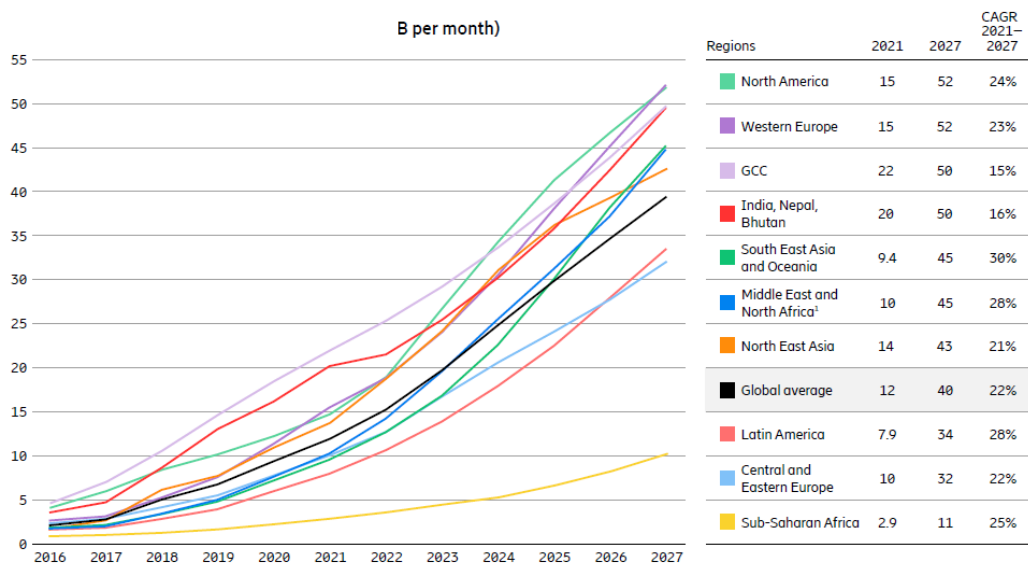


FIGURE 4-60 MOBILE DATA TRAFFIC PER SMARTPHONE (GB PER MONTH) AND ITS EVOLUTION IN TIME (P. 17 OF [134][16]).

Putting all the above together, the per user conversion from GB/month to Mbps for the year 2030 is:

$$X \text{ Mbps} = x \text{ GB/month} \cdot (1 + \text{CAGR})^{\text{Yah}} \cdot \text{GByteToMbit} / \text{DaysOfMonth} / \text{BusyHourWindow} / \text{SecondsPerHour}$$

Where: $x=5\text{GB/month}$, $\text{GByteToMbit} = 1000 \cdot 8 \text{ bits}$, $\text{DaysOfMonth} = 30\text{days}$, $\text{BusyHourWindow} = 10\text{h}$, $\text{SecondsPerHour} = 60 \cdot 60 = 360\text{seconds}$, $\text{CAGR} = 0.1$, $\text{Yah} = 8$ (from 2022 to 2030). Thus:

$$x = 5\text{GB/month} \cdot (1 + 0.1)^8 \cdot 1000 \cdot 8 \text{ bits} / 30 \text{ (days/month)} / 10\text{h} / 360 \text{ (seconds/h)} = 0.08\text{Mbps}$$

Finally, if we consider a 90%-10% split between the downlink and the uplink, we derive the per user average data demand in Mbps for DL and UL:

$$X_{\text{DL}} = 0.072\text{Mbps (or 72kbps)}$$

$$X_{\text{UL}} = 0.008\text{Mbps (or 8kbps)}$$

4.2.6.5 NTN channel and link-level simulations

The NTN system simulations are using link-level block error rate (BLER) to abstract the physical layer. An example of the BLER performance of the 1st HARQ transmission channel model NTN TDL C, LOS, Rural, elevation angle of 80deg (Table 6.7.2-7a of [16]) of different modulation and coding schemes (MCS) from 0 to 20 is shown in Figure 4-61.

The ACK/NACK probability of the transmissions in the simulation are defined by the corresponding BLERs. If a transmission is unsuccessful, then up to three retransmissions will occur, adding a SNR gain that decreases the probability of error affecting, however, the throughput. The SNR gain of re-transmissions considered are: 3dB for the 1st, 2dB for the 2nd, and 1dB for the 3rd.

Using link-level BLER and throughput simulations, we can derive a coefficient of the channel efficiency η to compare with the Shannon upper bound. This coefficient for the NTN TDL C channel was found to be around $\eta = 0.46$ (see Figure 4-62).

Notice, that no Channel State Information (CSI) aging effect is considered in these simulations (outdated MCS selection based on UE CQI reports due to additional propagation delay).

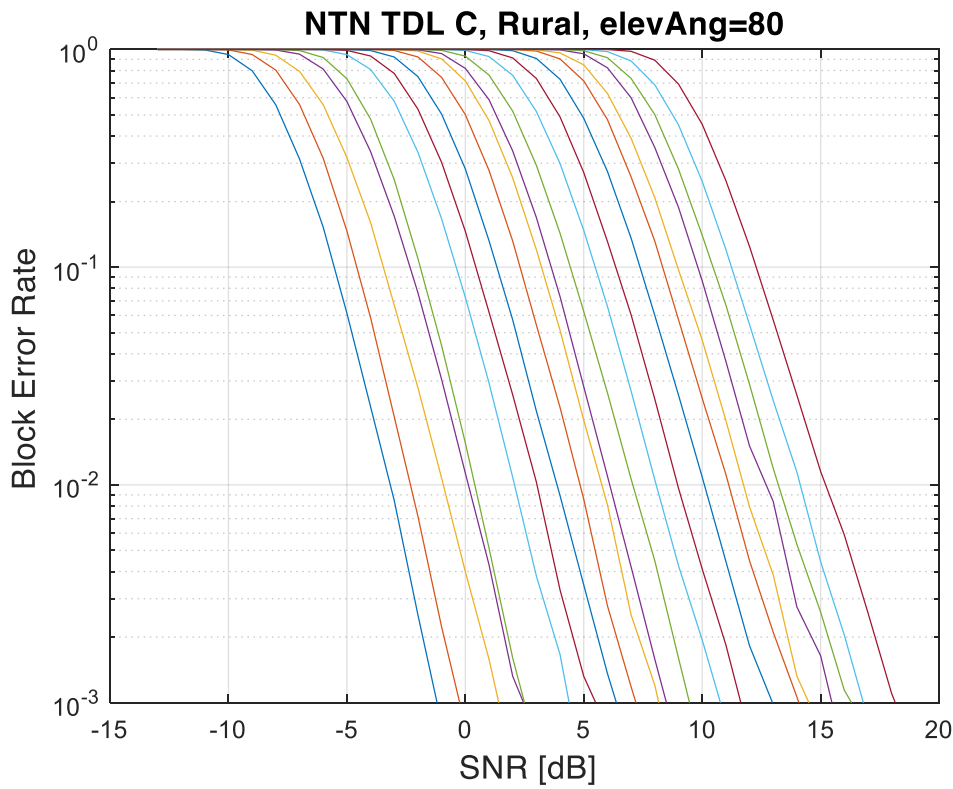


FIGURE 4-61 BLER PERFORMANCE OF THE FIRST HARQ TRANSMISSION OF MCS = {0...20} FOR A NTN TDL C, LOS, RURAL ENVIRONMENT, ELEVATION ANGLE 80° AS SPECIFIED IN TABLE 6.7.2-7A OF [16].

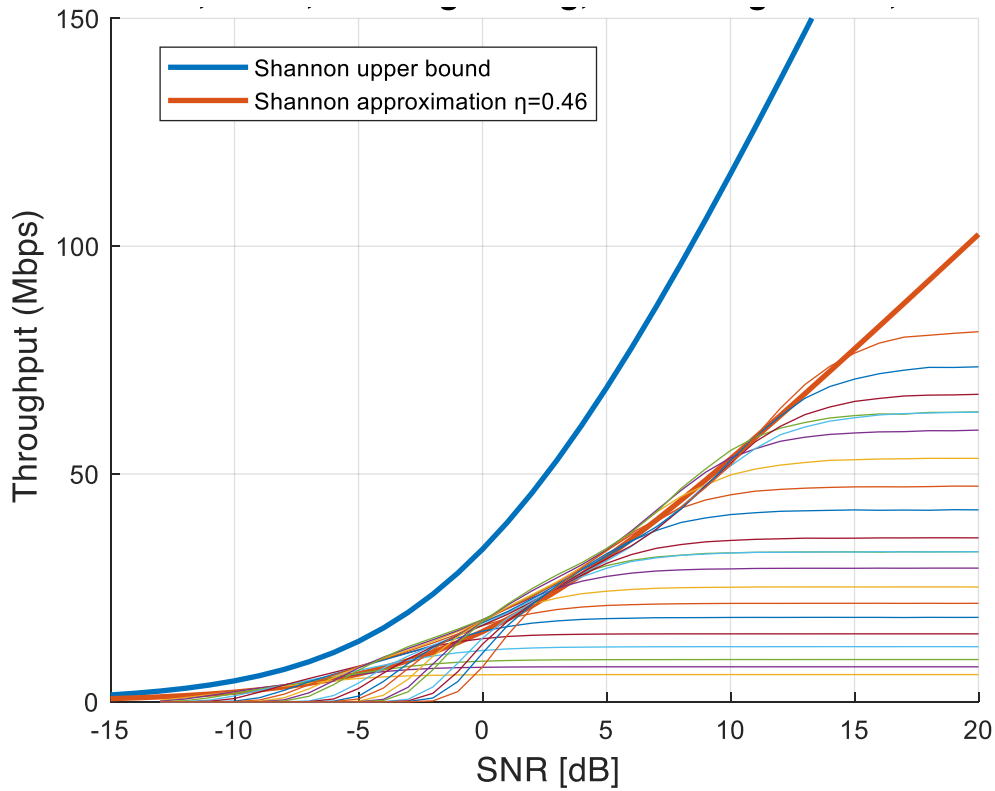


FIGURE 4-62 BLER PERFORMANCE (ADJUSTED FOR A 10% BLER TARGET) OF MCS = {0...20} FOR A NTN TDL C, LOS, RURAL ENVIRONMENT, ELEVATION ANGLE 80°, BW=33.3MHZ (100MHZ WITH FRF=3).

4.2.6.6 Coverage conditions

To evaluate the level of coverage of the proposed NTN system we introduce two coverage conditions. If these conditions are not met, then the UE is not considered to be covered by the NTN.

Coverage conditions:

1. The NTN cell of the UE has been assigned a service beam.

Since beam-hopping is not considered in this simulation, whether an NTN cell has a service beam depends on the combination of the number of NTN cells served by a satellite (i.e., the NTN cell radius and the number of satellites) and the number of simultaneous beams the satellite antenna can generate. All UEs that are camped to NTN cells without an assigned service beam are considered uncovered.

2. The SINR condition of the UE exceeds the lowest $SINR_{min}$ below which the UE will not be able to complete the Random Access (RA) procedure.

To determine $SINR_{min}$ we need to investigate the performance of all random access (RA) channels and find the bottleneck. However, this was studied in Rel-19 work item [NR_NTN_Ph3] in 3GPP (current state-of-the-art) where the coverage limits of different signals were investigated. According to this WI, $SINR_{min}$ is set to -8dB (see FL Summary #2 and #3 Agreements in All UEs that have $SINR < SINR_{min}$ are considered uncovered.

4.2.6.7 User equipment assumptions

Table 1 shows the considered UE characteristics and follows the typical UE characteristics of 4.2.5.2. These parameters are also shown in the overall simulation parameter Table 4.

TABLE 1 PARAMETERS OF SIMULATED "TYPICAL UE" CHARACTERISTICS

UE max output power (dBm)	UE antenna gain [dBi]	Noise figure [dB]
26	-5	7

4.2.6.8 LEO constellation

Table 2 shows the considered LEO constellation and follows the reference constellation CASE A of 4.2.5.3. These parameters are also shown in the overall simulation parameter Table 4.

TABLE 2 PARAMETERS OF SIMULATED LEO CONSTELLATION ([25])

Inclination (deg)	# orbital planes	# satellites per plane	Altitude (km)	RAAN per orbit (deg)	Min. elevation angle (deg)
87.7	27	47	600	6.9	45

A visualization of this constellation is shown in Figure 4-63.

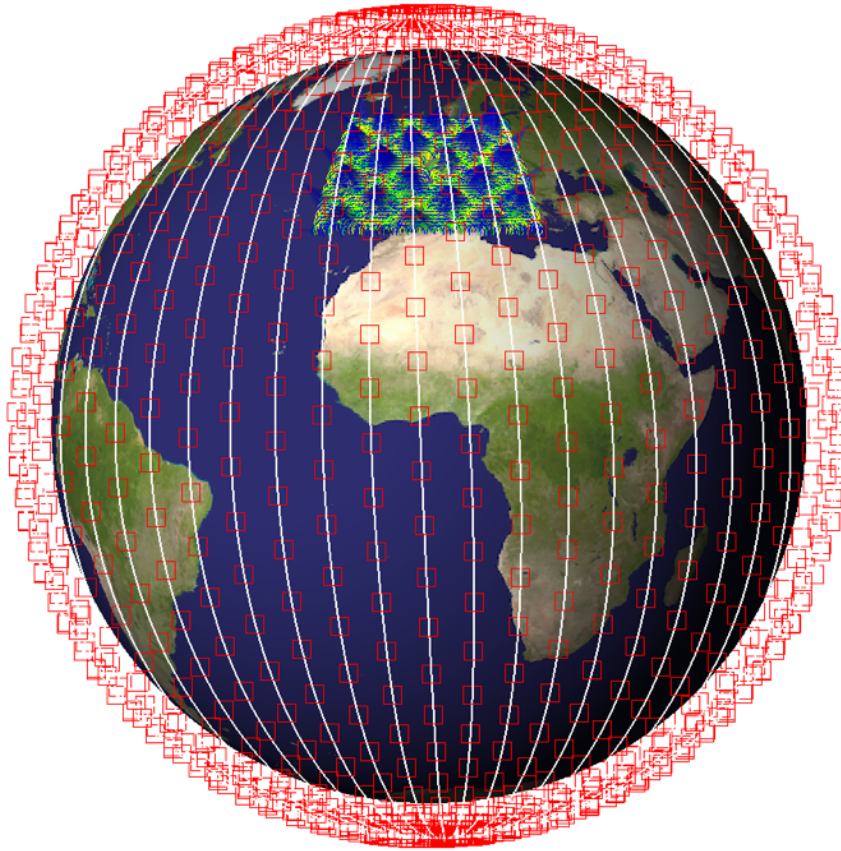


FIGURE 4-63 VISUALIZATION OF THE SIMULATED LEO CONSTELLATION OF TABLE 2.

4.2.6.9 System metrics

Antenna miss-alignment is the angle in degrees between the location of user, the LEO satellite position and the location of the center of the quasi-earth fixed cell. Notice that the boresight of the beam is pointing towards the center of the quasi-earth fixed cell.

Downlink active beams is the number of simultaneous downlink beams per slot of each satellite, subject to power sharing of the total available DL satellite antenna power.

Resource utilization is the load percentage of the beam time and frequency resources (e.g., Physical Resource Blocks – PRB). Notice that this metric also determines the level of interference that each beam will contribute to other cells/beams. This metric is calculated separately for the downlink and the uplink.

Coupling loss (CL) is given by the formula $CL_i = FSPL_i - G_{TX} - G_{RX} - L_{miss}$, where $FSPL_i$ is the free space pathloss, G_{TX} and G_{RX} is the transmitter and receiver gain, respectively, and L_{miss} is the beam misalignment loss.

Signal-to-noise-ratio (SNR) is given by the formula $SNR_i = \frac{p_i}{\sigma_{N_0}^2}$ where p_i is the received power of the i^{th} user (calculated using the corresponding link budget) and $\sigma_{N_0}^2$ is the thermal noise power. The SNR metric is calculated separately for the downlink and the uplink.

Signal-to-interference-ratio (SIR) is given by the formula $SIR_i = \frac{p_i}{\sum_{j \neq i} u_j p_j}$ where p_j and u_j are

the received power and load coefficient of the interfering beam, respectively. Notice that u_j corresponds to a coefficient version of the defined metric resource utilization. For beams to be interfering with each other they are required to be simultaneously active during the same slot and at the same frequency band. The SIR metric is calculated separately for the downlink and the uplink.

Signal-to-interference-plus-noise-ratio (SINR) is given by the formula, $SINR_i = \frac{p_i}{\sigma_{N_0}^2 + \sum_{j \neq i} u_j p_j}$

This metric is calculated separately for the downlink and the uplink.

Elevation angle is the angle in degrees between the horizontal plane of the user and the line of sight to the satellite.

Single user throughput is the throughput in Mbps that a user i would experience if that user was the only user connected to the cell. It is calculated as, $t_i = b_i \cdot \eta \cdot \log_2(1 + SINR_i)$, where $b_i = n_i^{PRB} \cdot b^{PRB}$ is the allocated bandwidth of the user, n_i^{PRB} is the number of physical resource blocks (PRB) allocated to the user, b^{PRB} is the bandwidth of the PRB that depends on the subcarrier spacing (for the C-band $b^{PRB} = 12 \cdot 30 = 360kHz$, η is an adjustment coefficient aiming to introduce the NTN wireless channel effect derived from link level simulations, and $SINR_i$ is the SINR of the user. This metric is calculated separately for the downlink and the uplink.

Cell throughput is the throughput in Mbps of a cell c . It is calculated as $T_c = B_c \cdot \eta \cdot \log_2(1 + SINR_c)$, where $B_c = N^{PRB} \cdot b^{PRB}$ is the cell bandwidth, N^{PRB} is the total number of the PRB of the bandwidth, and $SINR_c$ are SINRs that can be experienced within the cell. This metric is calculated separately for the downlink and the uplink.

Active user throughput is the throughput in Mbps that a user i would experience if that user was sharing the cell resources with a number of users in the cell (see cell active users). It is calculated as $\tau_i = B_c \cdot \eta \cdot r_c \cdot \log_2(1 + SINR_i)$, where $r_c = \frac{v}{a_c}$ is a sharing factor, $v = \frac{B_c}{b_i}$ is the number of users that can be simultaneously scheduled in one slot, and a_c is the number of cell active users. This metric is calculated separately for the downlink and the uplink.

Traffic satisfaction is the ratio (%) of the achieved cell load over the demanded cell load. The achieved cell load is the accumulated active user throughput per cell, $\sum_i \tau_i$. The demanded cell load is the accumulated user traffic per cell. This metric is calculated separately for the downlink and the uplink.

Area coverage is the ratio (%) of the NTN area (i.e., excluding the area covered by the terrestrial network) that NTN can provide coverage according to the coverage criteria of section 4.2.6.6.

Spectral efficiency of a cell measured in bits/second/Hz (b/s/Hz) considering the effect of the NTN channel (via factor η) and using the equation: $\rho_c = \eta \cdot \log_2(1 + SINR_c)$. This metric is calculated separately for the downlink and the uplink.

Cell active users a_c is the number of users per cell c sharing the radio resources during a specific window of time (e.g., a second). This metric is calculated separately for the downlink and the uplink.

TABLE 3 PARAMETER VALUES

Parameter	DL, FRF=1	UL, FRF=1	DL, FRF=3	UL, FRF=3
N^{PRB}	273		90	
n_i^{PRB}	273	6	90	6
ν	1	45.5	1	15.2
η	0.46			

We present the results for two cases, frequency reuse factor 1 (FRF=1), and frequency reuse factor 3 (FRF=3), as depicted in Figure 4-64. Notice that in FRF=1, 100 simultaneous beams can be generated. For FRF=3, 300 simultaneous beams can be generated because each beam carries 1/3 of the power compared to FRF=1.

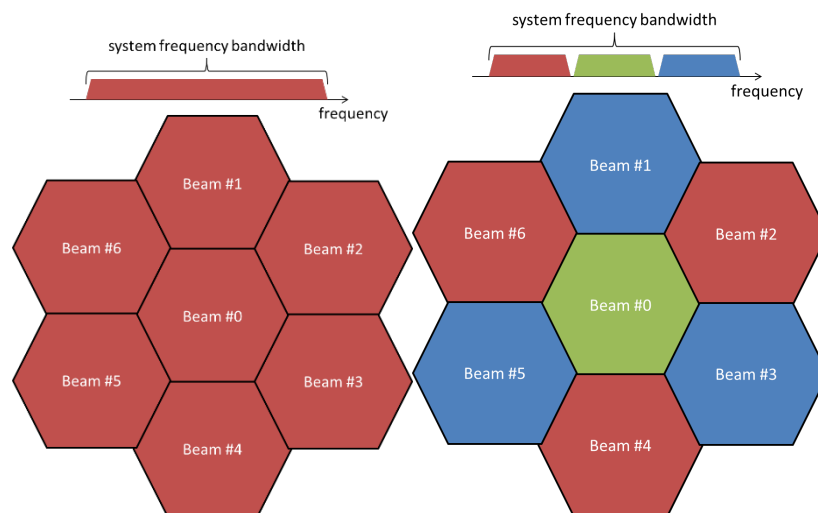


FIGURE 4-64 FREQUENCY REUSE SCHEMES, FRF=1, AND FRF=3, SEE TABLE 6.1.1.1-5 OF 3GPP 38.821[17]

Drop A	6G NTN D3.3 (June 2024)
Drop B	6G NTN D3.9 (June 2025) Revisited link-budget and coverage area Additional performance metrics Support of HARQ re-transmissions

4.2.6.10 Drop A (June 2024)

See section 4.2.6 of [135]

4.2.6.11 Drop B (June 2025)

4.2.6.11.1 Simulation parameters

TABLE 4 SYSTEM LEVEL SIMULATION PARAMETERS

Parameter	Unit	Value	
		1	3
Frequency reuse factor (FRF)		1	3
NR numerology (μ)		1	
DL Bandwidth	(MHz)	100	100/3
UL Bandwidth	(MHz)	100	100/3
DL maximum user PRB	#PRB	273	90
UL maximum user PRB	#PRB	6	
Carrier frequency Tx sat	(GHz)	3.4	
Carrier frequency Rx sat	(GHz)	3.9	
UE max output power (max TRP)	(dBm)	26	
UE antenna gain (typical)	(dBi)	-5	
UE noise figure (NF)	(dB)	7	
Payload total power level	(dBm)	63	
Payload antenna gain (Nadir)	(dBi)	Tx: 34.4 Rx: 35.5	
Satellite antenna figure of merit (G/T) (Nadir)	(dB/K)	6.5	
Satellite beam pattern		According to 6.4.1 of [16]	
Satellite antenna 3dB beamwidth (θ_{3dB}) (notice $\theta_{3dB} = \text{HPBW}/2$)	(deg)	3	
Number of planes		27	
Number of satellites per plane		47	
RAAN per orbit	(deg)	6.9	
Orbit altitude	(km)	600	
Orbit inclination	(deg)	87.7	
NTN cell diameter in 3D cartesian system	(km)	45	
Maximum active beams per satellite during a slot		100	300
Minimum elevation angle	(deg)	45	
User traffic (see section Error! Reference source not found.)	(kbps/user)	DL: 72 and UL: 8	
Number of addressable users (see 4.2.6.3)	#	~560.000	

Atmospheric loss	(dB)	0
Body loss	(dB)	3dB
Shadow fading loss	(dB)	0
Polarization mismatch loss	(dB)	3dB
Channel model (see section Error! Reference source not found.)		NTN TDL C, LOS
HARQ re-transmission SNR gain (see section Error! Reference source not found.)	(dB)	1st: 3dB, 2nd:2dB, 3rd:1dB
SINR coverage limit (see section 4.2.6.6)	(dB)	-8

All the computations results are given in Appendix 9.4.2.

4.2.6.12 Summary

Table 5 summarizes the performance metric results of the simulation activity categorized between DL, UL, FRF=1, FRF=3.

TABLE 5 PERFORMANCE SUMMARY

Metric	DL, FRF=1	UL, FRF=1	DL, FRF=3	UL, FRF=3
Guaranteed single user throughput [Mbps]	3.78	0.10	3.95	0.27
Median single user throughput [Mbps]	4.62	0.12	5.24	0.36
Maximum single user throughput [Mbps]	5.82	0.17	7.12	0.48
Guaranteed cell throughput [Mbps]	0.40	0.48	3.95	4.11
Median cell throughput [Mbps]	4.51	5.55	5.24	5.49
Maximum cell throughput [Mbps]	7.06	9.01	7.12	7.31
Guaranteed active user throughput [Mbps]	0.012	0.003	0.06	0.04
Median active user throughput [Mbps]	0.21	0.06	0.14	0.08

Maximum active user throughput [Mbps]	0.87	0.16	0.50	0.26
Guaranteed spectral efficiency [b/s/Hz]	0.12	0.18	0.15	0.16
Median spectral efficiency [b/s/Hz]	0.14	0.22	0.20	0.21
Maximum spectral efficiency [b/s/Hz]	0.18	0.27	0.26	0.26
Coverage [%]	25	25	100	100
Note: Guaranteed values relate to the 5% CDF point, median values relate to the 50% CDF point, and maximum values relate to the 95% CDF point.				

4.2.7 Observations

By observing simulation results of section 4.2.6.11 and the corresponding summary Table 5 we can draw some high-level conclusions about the expected performance of the proposed NTN system.

1. **Interference.** From the low SINR and coverage metrics of FRF=1, it is obvious that full frequency reuse is not a feasible option. This is due to high inter-beam interference caused by adjacent cells due to the relatively small NTN cell size and the increased beam load (due to the high traffic demand). Methods such as e.g., frequency reuse, beam-hopping, or others are required to reduce inter-beam interference. For example, we observe that the DL SIR is improved by more than 5dB going from FRF=1 to FRF=3.
2. **Spectral efficiency.** This system is of quite low spectral efficiency, as shown in the spectral efficiency curves, reaching up to a maximum of 0.3b/s/Hz. This is a combination of the poor link budget resulting from relatively high orbit altitude (600km) and high frequency (average 3.6GHz) of the C-band. For the same altitude, these C-band frequencies add a 5dB free space pathloss when compared to the S-band (2GHz).
3. **Coverage.** Given the coverage results, we observe that full frequency reuse results in very low coverage % due to poor SINR performance that prevents users from attaching for the network. With frequency reuse factor 3, coverage is improved to 100%, assuming the UEs can attach down to a minimum SINR of -8dB.
4. **User throughput (maximum).** Focusing on frequency reuse 3, we observe that the maximum user throughput (95%ile of the CDF) is ~7Mbps for the downlink and ~0.5Mbps for the uplink. This performance is well below the UC5 requirements of 20Mbps and 2Mbps of Table 9 of [24], respectively.
5. **Traffic satisfaction.** Focusing on frequency reuse factor 3, we observe that the average downlink traffic satisfaction is ~10% and the uplink is ~50%. This performance imbalance is due to the fact the spectral efficiency of the DL and UL are generally balanced; however, the downlink traffic demand is much higher than the uplink. To achieve higher traffic satisfaction rates, improvements to the spectral

efficiency are necessary and potentially having more assigned bandwidth from the UL to the DL.

In general, the low spectral efficiency performance negatively affects most of the system metrics, failing to deliver the targeted user throughput and delivers a low traffic satisfaction rate.

In conclusion, the above results indicate the selected satellite and constellation parameters lead to limited performances when considering the C band hand-held scenario. Requirements for 6G NTN as identified in [24] are not met.

Assuming that the principle of seamless integration of satellite networks with terrestrial ones, would remain, in particular without impacting the specification of UEs, it is the view of Ericsson that satellite system vendors should take the necessary steps to address these performances issues.

Some of these steps, which are not exclusive to each other, may consist in:

- Increasing the satellite platform power capabilities,
- Increasing the power amplification efficiency
- Increasing the satellite antenna performances, both in the transmit and receive direction, to improve the antenna gain, as well as antenna isolation to reduce impact of internal interferences
- Lowering the satellite constellation altitude, and increasing the number of satellites, to reduce the total path loss
- Improving the industrial efficiency in manufacturing and delivering satellite in orbit to ensure adequate cost of infrastructure and pace of delivery vs revenue expectations

4.2.8 Satellite C-band performances (case A)

4.2.8.1 Constellation superposition factor

The constellation is a quasi-polar type constellation (see [25]), that means that the superposition of satellite footprints with increasing latitude will allow to decrease the number of cells to cover and enhance the capacity furnished. Other type of constellation could be taken but do not allow a full earth coverage and will necessitate to have double constellations [78]. The worst case will be the equator case. Thus the estimation of this superposition factor [see doc of task 3.4 [25] have been computed and applied in our case to evaluate this increase in capacity taking into account the handover constraints. And then at each latitude the number of cell that a satellite shall cover and deduce the value of the total throughput that the constellation shall handheld.

SUPERPOSITION FACTOR and throughput

The constellation include 1269 service satellites. Each satellite is able to serve instantaneously X beams (for instance X=25 to 100 active beams) over the coverage of 499 cells (see Doc 3.4 for details [25])

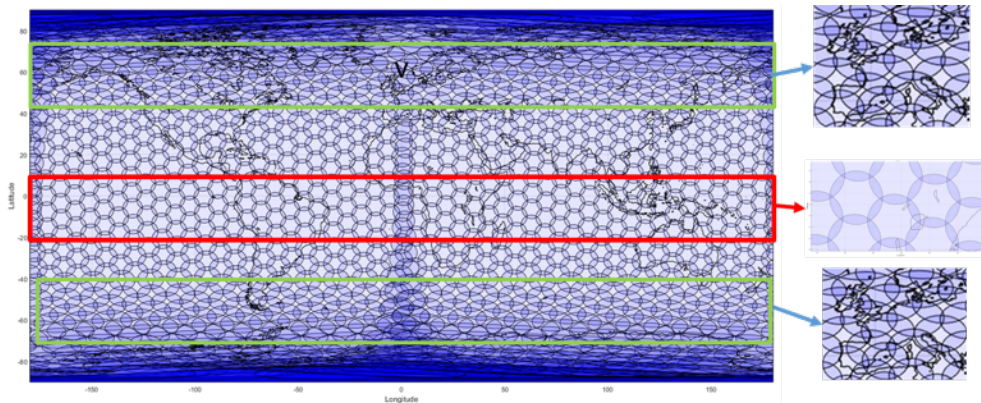


FIGURE 4-65 VIEW OF THE COVERAGE OVERLAP WITH ELVATION ANGLE [25]

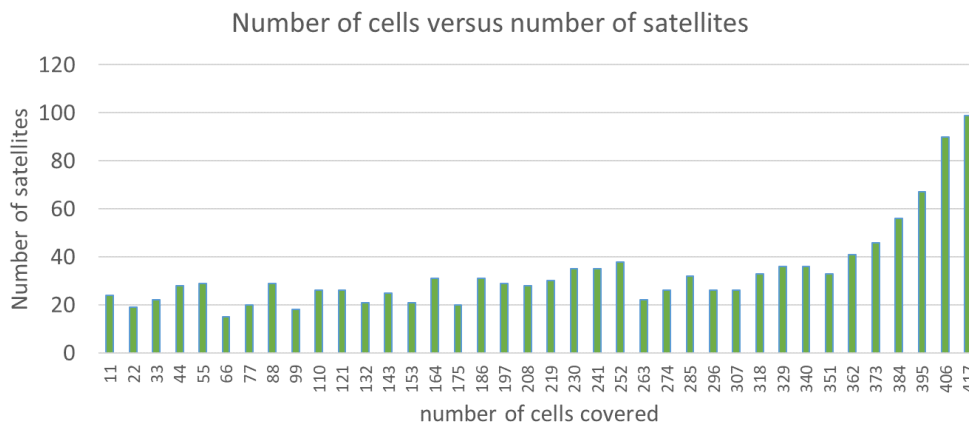


FIGURE 4-66 NUMBER OF SATELLITES AND ASSOCIATED CELLS TO COVER [25]

4.2.8.2 Satellite capacity evaluation C-BAND

The simulation of the maximum capacity that a satellite could ensure on his coverage have been estimated in the following curves. It proceed in optimizing the capacity by selecting the case where the max throughput have been reached for a given number of active beams.

The Figure 4-67 show the results for 100 actives beams. The ring distribution of the optimum cells is due to the gain compensation on the antenna design (see) which increase with depointing angle.

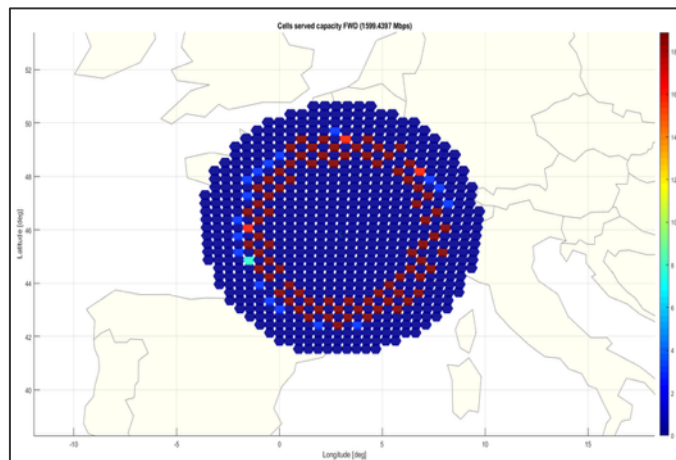


FIGURE 4-67 SELECTED CELLS IN (BROWN)

The optimization have been done with the constraint to have EIRP flux density constant on the earth with the aditionnal constraint of power max of 2000 W.

Thus, for a given power of 2000 W, the downlink throughput have been calculated and shown in Figure 4-68 versus the number of actives beams. As expected the average EIRP flux decrease with the increase of number of active beams (see Figure 4-69)

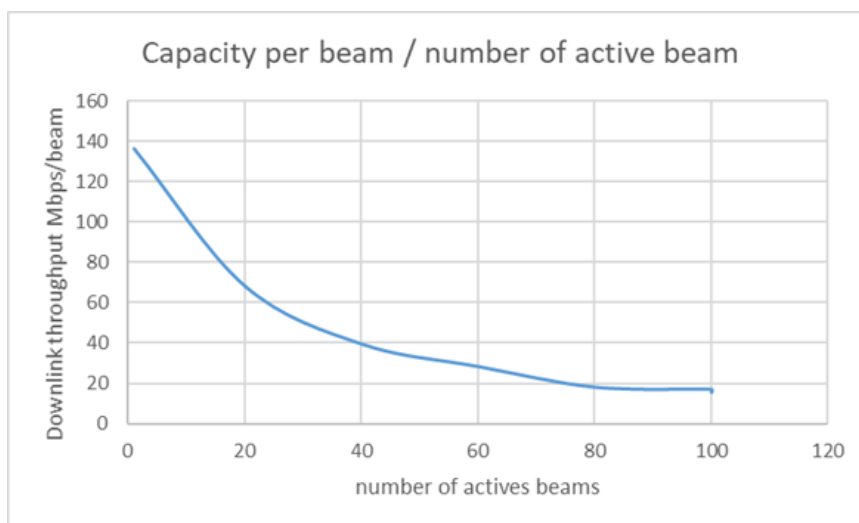


FIGURE 4-68 CAPACITY PER BEAM VERS NUMBER OF ACTIVE BEAMS

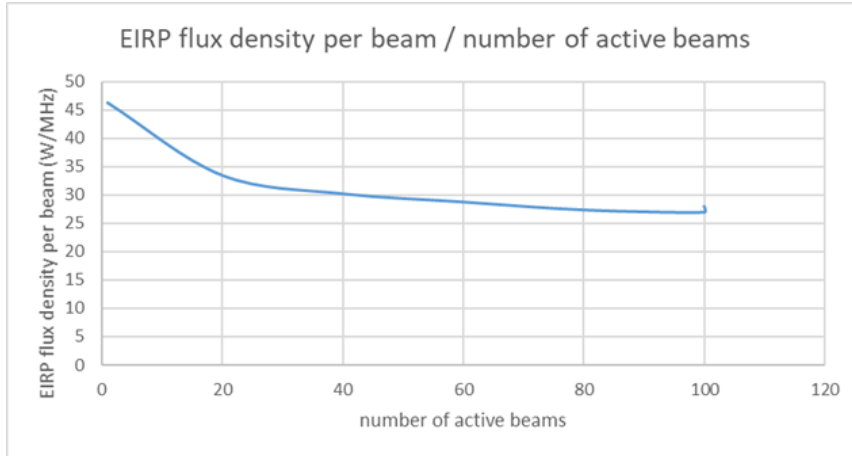


FIGURE 4-69 EIRP FLUX DENSITY VERSUS NUMBER OF ACTIVE BEAMS

Thus the total capacity of a satellite is given in Figure 4-70.

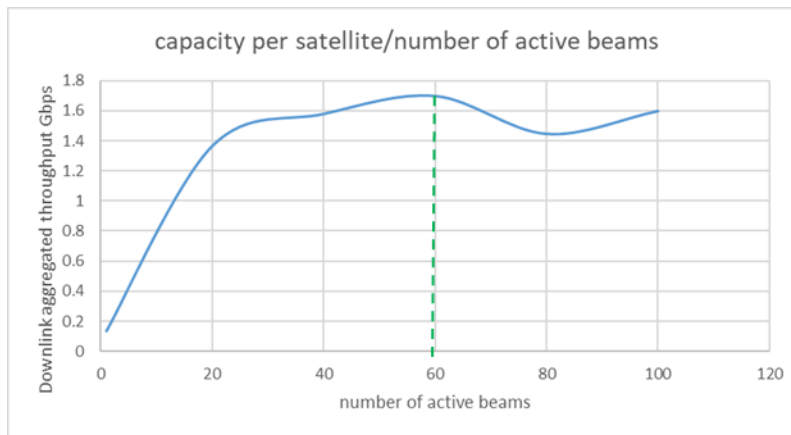


FIGURE 4-70 DOWNLINK THROUGHPUT TOTAL CAPACITY OF A SATELLITE VERS NUMBER OF ACTIVE BEAMS

The maximum is reached for 60 active beams and reached 1.7 Gbps.

Up to now the throughput is computed for the optimum case, in the case where the selection is random as in the real case is illustrated in the Figure 4-71.

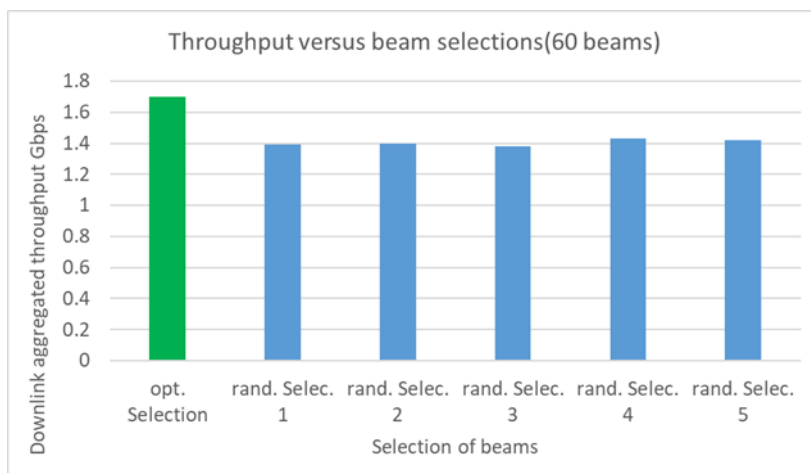


FIGURE 4-71 VARIATION OF THE THROUGHPUT WITH RANDOM SELECTION OF 60 BEAMS

The throughput varies between 1.4 Gbps to 1.67 Gbps for 60 active beams and the average throughput is 23 Mbps per beam.

For the uplink, the throughput is proportional to the number of active beams as illustrated by the Figure 4-72.

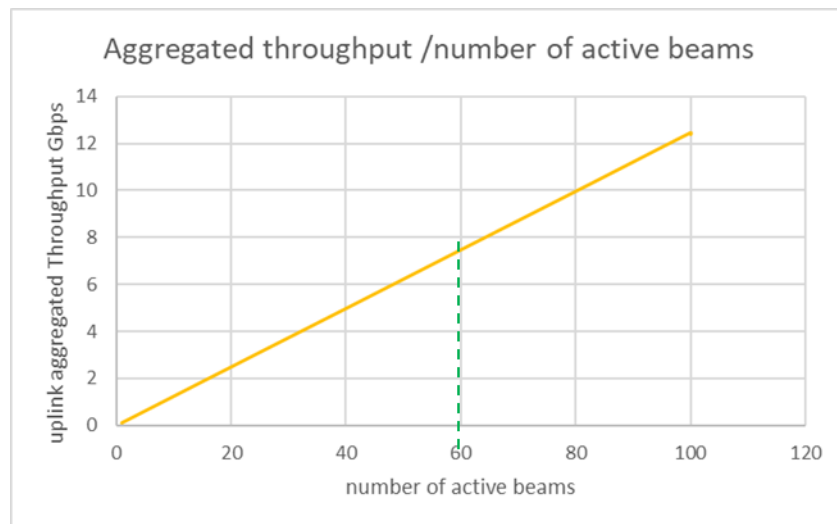


FIGURE 4-72 UPLINK THROUGHPUT VERSUS NUMBE OF ACTIVE BEAMS

- Uplink throughput proportional to number of active beams.
- The max throughput is 120 Mbps per beam with 1 PRB per user.
- The limitation of the uplink throughput is more on the capacity of processing data of the payload instead of power of the Front-ends (HPA)

The throughput will vary according to the beam distribution over the coverage and in average Throughput per beam is 95 Mbps. For the maximum of beams that could reach a maximum of throughput the total uplink throughput is 7.2 Gbps.

4.3 INVESTIGATION ON IMPROVEMENT IN C-BAND CONSTELLATIONS

4.3.1 Introduction

The results in the previous chapter shows an decrease at low elevation angle (Rf performance). The solution described and obtain shows a weakness of the solutions as mentioned in and could be problematic in wors conditions (masking factors much more important; In that context, some improvement have been investigated. In fact, there axis of improvements are known and respond to several parameters in reaching the best compromise. Nevertheless, a deeper analysis have been performed by reviewing some critical parameters in order to complete the initial trade-off. The trade-off to be complete when discussing on constellation not only concerns the payload complexity but also the final launches effort (task 3.4). Nevertheless, the complexity is one of the cost driver. The trade-off allowed to defined

an altitude of 600 km to be a best compromise, (number of satellite , FSL ..).if we consider that the number of satellite is not a cost driver, it will be possible to envisage a constellation in VLEO, This point is investigated. The improvement of the satellite (and consequently the overall. To improve the performance of a satellite is to LEO → limitation the complexity of the payload :

- For uplink, increasing number of element is the (the surface of the antenna) will complicated the payload routing as well as power consumption
- For downlink , increasing the power will complicated the dissipation capacity, and will require some devices to extract and convey to radiated the dissipation towards space. This drawback could be partially with a high efficient HPA and associated architecture. Some axis of improvement are under investigation (Doherty, Envelope tracking) and could be implemented if enable at term. Nevertheless these improvement will no revolutionize the solutions, even if it could offer some noticeable improvement.
- The surface of the payload have an impact of the fairing and on impact the optimization of the number of launchers
- These two hypothesis are based on heritage, but if we consider an other axis for instance If we relaxes this parameter (the increasing number of element do not necessary induced a great impact on the cost) some others axis could be explored.
- It remains the surface /volume of the spacecraft which
- Thus it is possible to increase the number of RE without significantly increase the surface and power so that the cost of launch will not be impact. It means that to keep the surface constant it is necessary to reduce each size of the elements, it goes in the righ way as the scan losses could be reduced when the antenna depointing. This could be an great interest , by the way the performances of the payload will be more attractive. With this hypothesis, some investigations have been performed for different number of RE.

4.3.2 VLEO constellation at 350 km (case B)

4.3.2.1 Introduction

Most of the large constellation in design are in low altitude to take profit of limited FSL, but as mentioned such constellation are possible only if a high capacity of launchers are available at term. Nevertheless, changing to extreme constellation pose to review entirely the cost driver in the overall sense. A constellation design as it involves several parameters necessitates to go in each one more deeply in order to conclude or to give some possible orientations.

4.3.2.2 Resizing the satellite parameters

For dimensioning the VLEO constellation an altitude of 350 km have been taken for the exercise. The objective is to limit the FSL, so the distance between the antenna and edge of the coverage. The maximum distance between antenna and the edge for the LEO is almost the distance we had for a nadir beam with the LEO constellation. Moreover, to ensure an reasonable view angle with have to decrease the minimum elevation angle (35°). The impact is the grating lobes appearance in visible surface of the earth when depointing with the antenna . the size of the RE have reduced

Altitude	terminal min elevation	Antenna scan angle	isoflux compensation	max distance	cell size	number of cells
km	(°)	(°)	dB	km	km	
600	45	40.26	2.66	815	45	499
350	35	50.94	4.74	581	45	367

FIGURE 4-73 COVERAGE PARAMETERS LEO AND VLEO

In the case of the VLEO the RE have been resized in order to avoid any grating lobes and the the number of the RE have been increased in order to compensate the surface reduction if maintaining the initial number of RE.

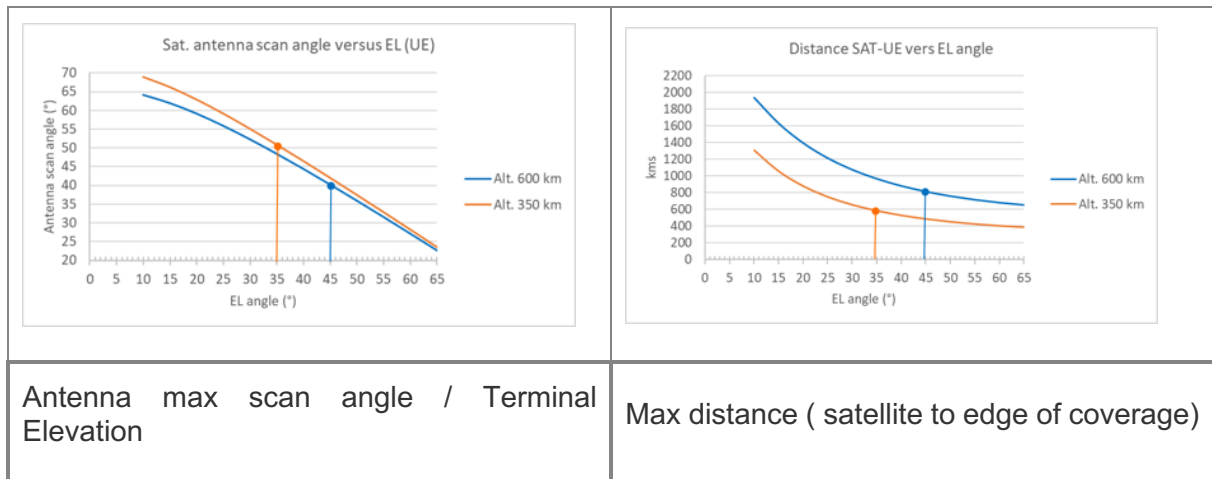


FIGURE 4-74 IMPACT OF ALTITUDE CHANGE IN ANGLE VIEW

The objectif is to decrease the distance in order to gain and also to limit the number of satelltes. For low altitude the Elevation min at 35° instead of 45° have been choose in that purpose.

The C-band VLEO constellation has been defined as follow :

- Altitude 350 km /inclination 87.8°
- Coverage per satellite EL min : 35°
- cell size

The impact in the coverage have been illustrated in the following Figure 4-75. At altitude 350 km, the view angle is large to cover a high number of cells. The number of cells have been reduced to fulfill the best compromise between limiting the grating lobes (reduction of the RE size) and the number of elements of the antenna to ensure a sufficient large antenna.

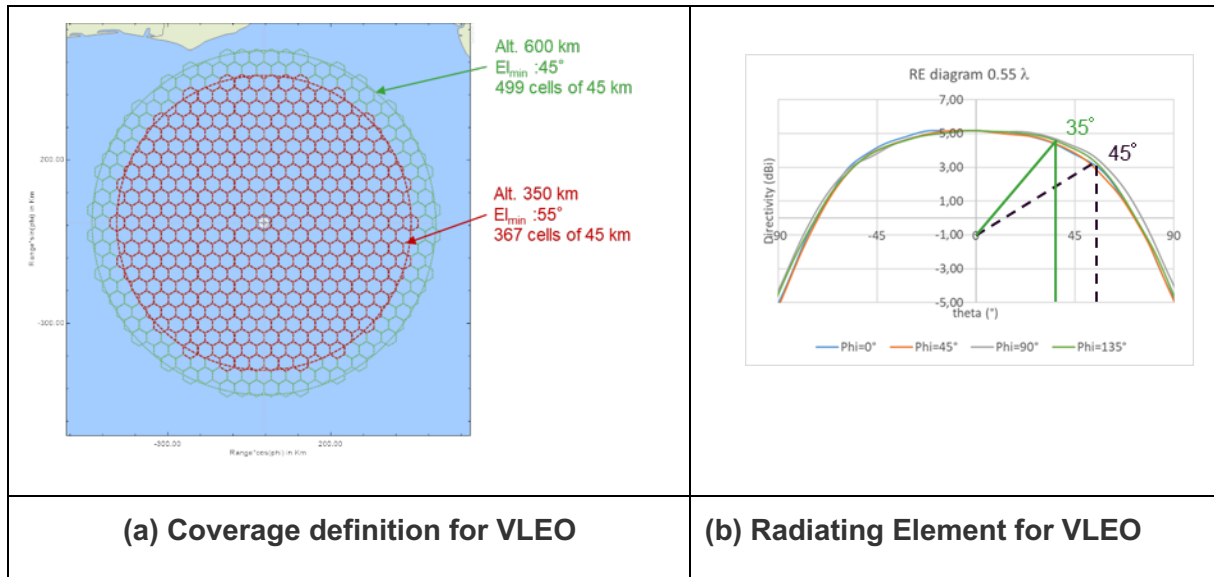


FIGURE 4-75 COVERAGE AND RE-ADJUSTMENT FOR VLEO

RE ELEMENT Sizing	Frequency	λ	lattice	lattice
	GHz	mm	λ	mm
Tx (sat) Rx(UE)	3.4	88.24	0.65	57.08
Rx (sat) Tx(UE)	3.9	76.92	0.742	57.08

RE ELEMENT Sizing	Frequency	λ	lattice	lattice
	GHz	mm	λ	mm
Tx (sat) Rx(UE)	3.4	88.24	0.54	47.69
Rx (sat) Tx(UE)	3.9	76.92	0.62	47.69

FIGURE 4-76 RE SIZE REDUCTION FOR VLEO

The number of element have consequently be increased from 1056 to 1536 RE, the size of the antenna is almost identical to LEO case (diameter of 2 m).

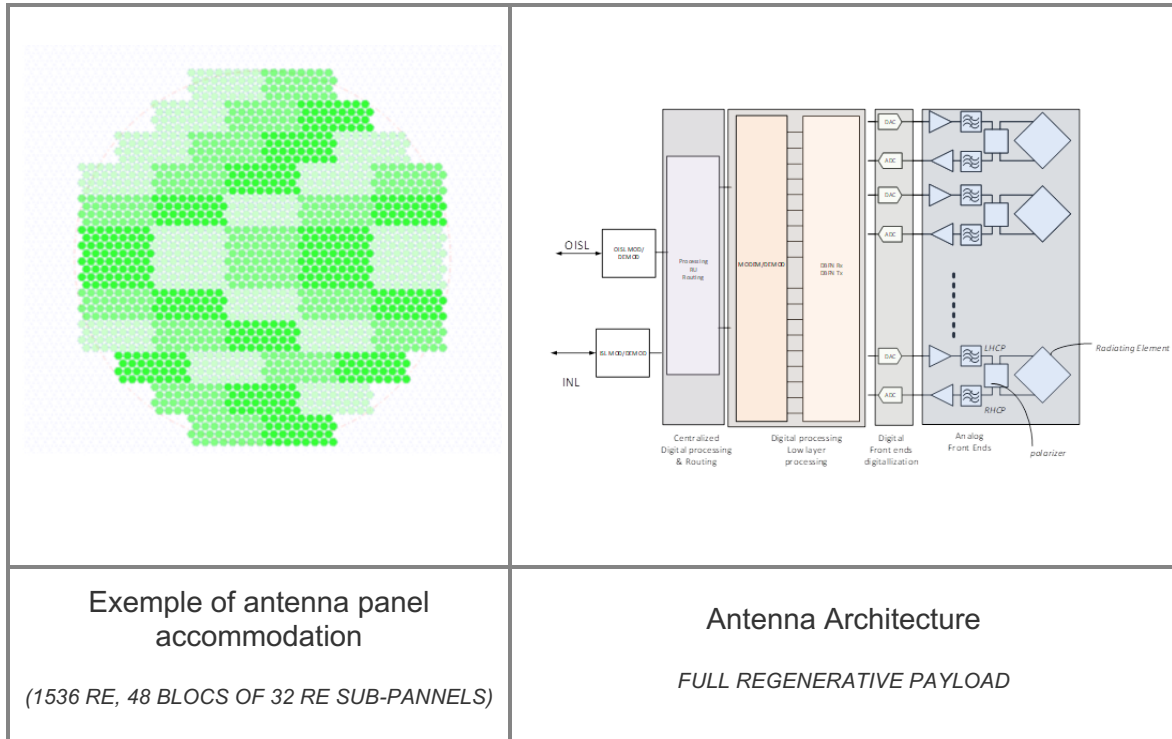


FIGURE 4-77 ANTENNA FOOTPRINT & ARCHITECTURE

4.3.3 Antenna Peformances

The numerology remains the same as for the LEO 600 km constellation and is recalled in the table below :

C	ID	Used Frequency		Channel Bandwidth		PRB						PRACH
		Uplink Sat Rx / UE Tx	Downlink Sat Tx / UE Rx	Uplink Sat Rx / UE Tx	Downlink Sat Tx / UE Rx	Uplink Sat Rx / UE Tx	Downlink Sat Tx / UE Rx	Number of carriers	SCS bandwidth	PRB bandwidth	Number of PRB	PRACH bandwidth
		GHz	GHz	MHz	MHz	kHz	kHz	-	kHz	kHz	-	kHz
	C2	3,9	3,4	100	100	360	360	12	30	360	273	3600

FIGURE 4-78 C-BAND NUMEROLOGY

4.3.3.1 Rx & Tx performances

The different case of beam forming have been performed and reported in Annexe

-phase only → maximization at one point : allow low losses and simplification of beamforming. But not well matched to the cell

-Amplitude-phase 6 dB and 12 dB of dynamique : allow to shape the beam and optimize the performances.

The compomize for a general use is to take the Beamforming with 12 dB dynamique. All the trade-off is presented in **Appendix**

4.3.3.2 Satellite capacity evaluation C BAND (VLEO) CASE B

As for the initial case (CASE A). The simulation of the maximum capacity that a satellite could ensure on his coverage have been estimated in the following curves. It proceed in optimizing the capacity by selecting the configuration where the max throughput have been reached for a given number of active beams.

For a given power of 2000 W of RF power, the downlink throughput have been calculated and shown in Figure 4-68 versus the number of actives beams. As expected the EIRP flux decrease with the increase of number of active beams (see)

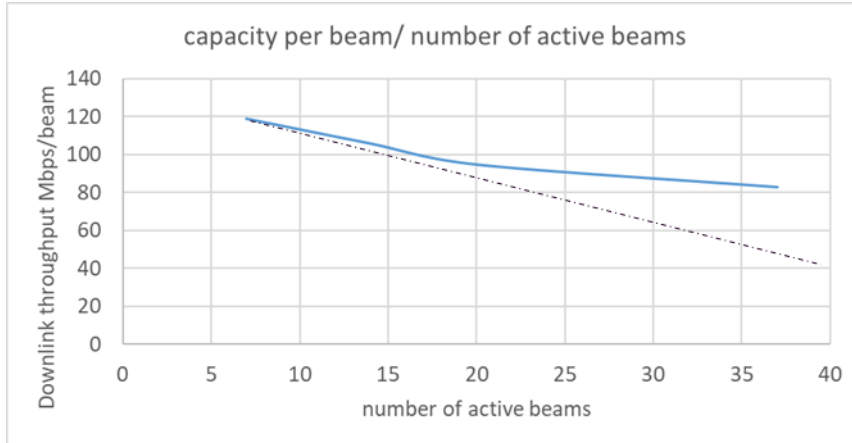


FIGURE 4-79 CAPACITY PER BEAM VERS NUMBER OF ACTIVE BEAMS

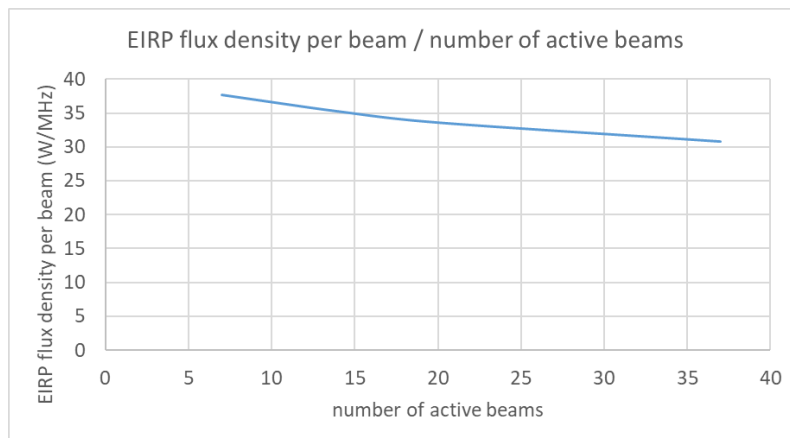


FIGURE 4-80 EIRP FLUX DENSITY VERSUS NUMBER OF ACTIVE BEAMS

Thus the total capacity of a satellite si given in Figure 4-70.

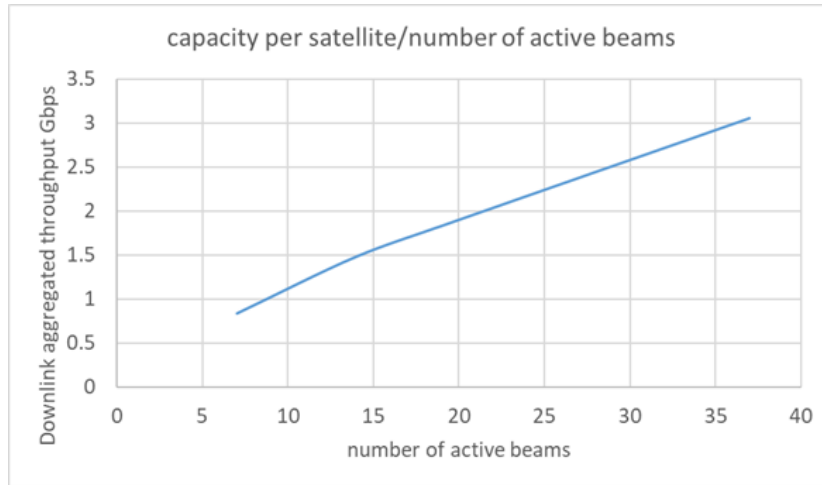


FIGURE 4-81 DOWNLINK THROUGHPUT TOTAL CAPACITY OF A SATELLITE VERS NUMBER OF ACTIVE BEAMS

The maximum is reached for 60 actives beams and reached 3 Gbps.

Up to know the throughput is computed for the optimum case, in the case where the selection is random as in the real case is illustrated in the Figure 4-71.

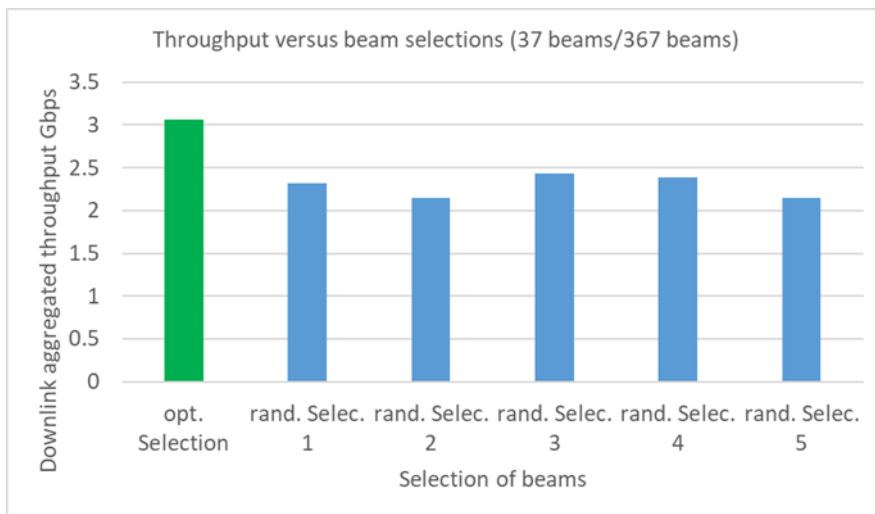


FIGURE 4-82 VARIATION OF THE THROUGHPUT WITH RANDOM SELECTION OF 60 BEAMS

The throughput varies between 2.1 Gbps to 3. Gbps for 37 active beams and the average throughput is 62 Mbps per beam (3 times the initial CASE A LEO constellation)

For the uplink, the throughput is proportional of the number of active beams as illustrated by the Figure 4-72.

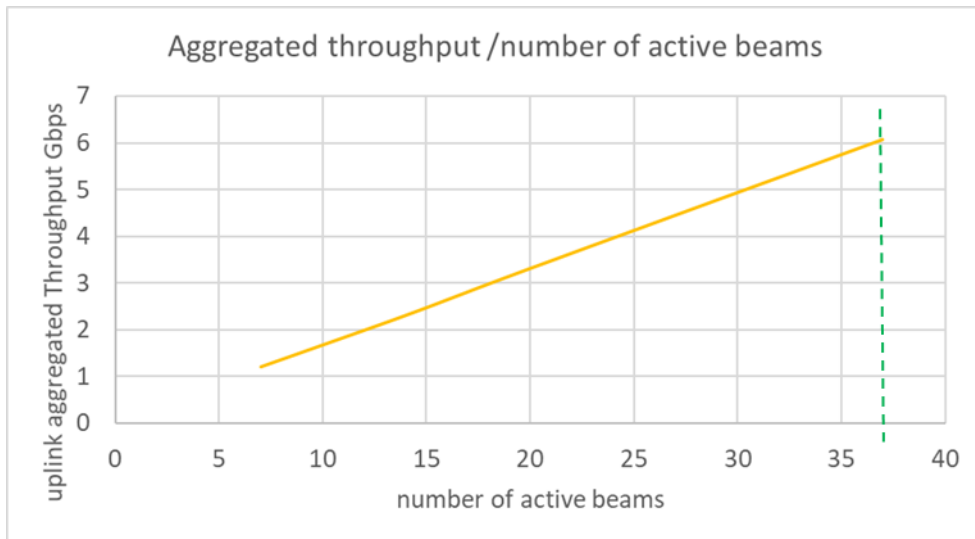


FIGURE 4-83 UPLINK THROUGHPUT VERSUS NUMBE OF ACTIVE BEAMS

- Uplink throughput proportional to number of active beams.
- The max throughput is 164 Mbps per beam with 1 PRB per user.
- The limitation of the uplink throughput is more on the capacity of processing data of the payload instead of power of the Front-ends (HPA)

The throughput will vary according to the beam distribution over the coverage and in average Throughput per beam is 101 Mbps. For the maximum of beams that could reach a maximum of throughput the total uplink throughput is 6. Gbps with an average of 3.7 Gbps.

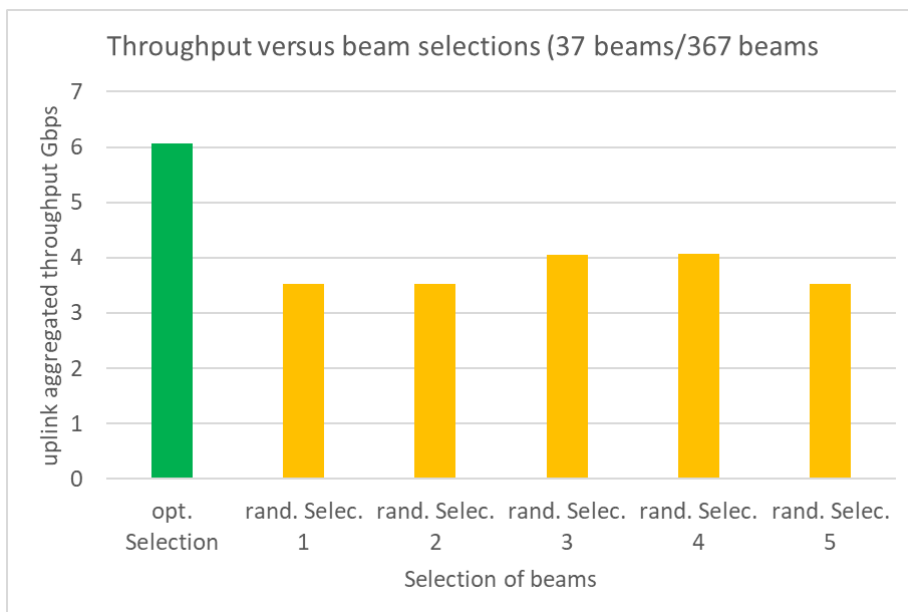


FIGURE 4-84 UPLINK THROUGHPUT FOR RANDOM SET OF BEAMS

4.3.4 LEO Satellite C-Band Enhanced performances (Case C)

4.3.4.1 Introduction

The Reference solution in band C (CASE A) present to have limited performances in link budget in uplink at the edge as observed in low spectral efficiency which could be problematic in worst case conditions (masking + edge of coverage). The solution presented in VLEO allow to improve the uplink performance by reducing the FSL (free space losses). Although at some point the solution may be interesting in terms of reduced latency, the major drawback of the VLEO solution is to require a significant number of satellites.

Two other axis of improvement of the performances have been investigated with the main objective to increase the uplink performances. The only way to increase this performances is to increase the G/T of the satellite and more precisely the G the gain and reduce the losses.

To increase the G, therefore the directivity of the antenna, a natural way is to increase the surface area of the antenna. But the beam size will naturally be small so that it is not adapted to the chosen cell size and adopting a small size poses the problem of having a lot of cells to cover the same coverage, which generates capacity management as well as bottlenecks on processing capabilities.

Thus, studies have been conducted on the increase in surface area, choice of ER as well as cell size and are presented in the appendix summarized in the next chapter.

4.3.4.2 Axis of investigation

- ➔ In appendix 8.4.3.1 First sensitivity analysis is to resize the RE to limit the scan losses (not to optimize the size to avoid grating lobes) → these relaxation induce an increase in number of RE : the sensitivity analysis have been done for 1504, 2048, 3008, 4080 RE. The solution 2048 RE with new sizing of the RE (0.62 in Rx (0.55 in Tx) allow a isoflux behavior (natural increase in directivity with depointing angle) see appendix 9.4.4
- ➔ The reduction of cell size 45 km to 21 km and increase the number of elements (1056 to 1520 RE) do not show interesting results, even if the global performances are improvement, no isoflux compensation which is the most important point in uplink. Moreover, the complexity induced (in term of number of cell 499 to 2275) do not justify to adopt this way (reducing cell size) see appendix 9.4.4.2

According to these analysis the best solutions in term of performances is the antenna with be the DRA containing 2058 RE and a appropriate lattice of 0.62λ in Rx. The performances for this configuration have also been calculated to consolidate this solution (see appendix 9.4.4.1).

4.3.4.3 Satellite performances evaluation

In the same manner than case A & Case B the performance of the satellite have been evaluated to .The result of the simulation of the maximum capacity are given in the following curves. To recall that the optimization process is to find the maximum of throughput for a given number of active beam.

The Figure 4-67 show the results for 60 actives beams. The ring distribution of the optimum cells is due to the gain compensation on the antenna design (see) which increase with depointing angle.

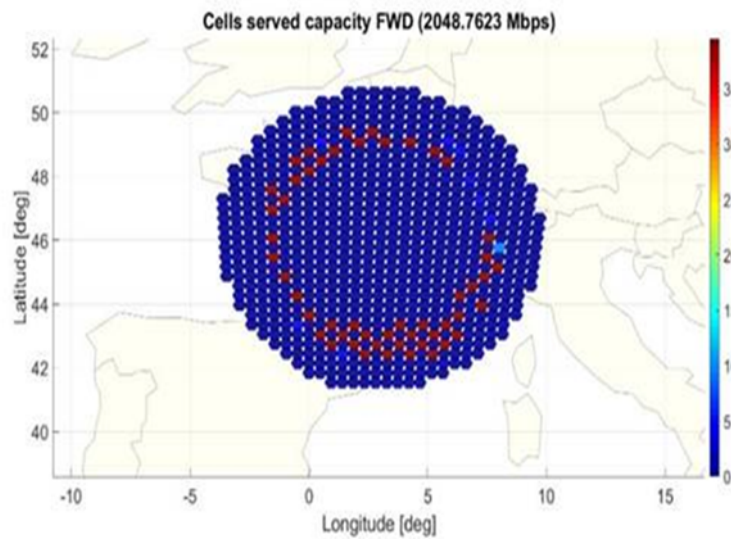


FIGURE 4-85 60 ACTIVE BEAMS ISSUED FROM OPTIMIZATION

The power applied on the array is 2325 W, the surface of the antenna is increased of 10%. The performances maximum reached is 2 Gbps in downlink and 9.7 in uplink.

4.4 SYNTHESIS OF THE SOLUTIONS A,B,C

4.4.1 Synthesis of the 3 solutions

4.4.1.1 Introduction

In this chapter, the performance results of the 3 types of satellites considered are synthesized. The results will make it possible to evaluate the relevance of one in relation to the other with the other cost indicators that are the implementation of the constellation, mass and volume of each satellite up to the number of launches. Moreover, they will allow to define which one would correspond to the needs when these are more precisely defined. They are supplemented in annexes with other more capacitive configurations. These data constitute a basis for future reflection to guide future choices.

4.4.1.2 RF performances

The table Figure 4-86 synthesises the performances of the 3 solutions in the previous chapters.

C-BAND	altitude	nb RE	LINK	nb active beams	max throughput per beam	average per beam	Total max achievable	Total average	% coverage
	km				Mbps	Mbps	Gbps	Gbps	
CASE A	600	1056	uplink	60	124.8	93	7.5	5.6	12.0
	600	1056	downlink	60	28.3	23	1.7	1.4	12.0
CASE B	350	1536	uplink	37	164.1	101	6.1	3.7	10.1
	350	1536	downlink	37	82.7	62	3.1	2.3	10.1
CASE C	600	2048	uplink	60	161.7	121	9.7	7.3	12.0
	600	2048	downlink	60	34.2	28	2.0	1.7	12.0

FIGURE 4-86 SYNTHESIS OF THE PERFORMANCE OF THE 3 SOLUTIONS (AT MAX THROUGHPUT)

The case A is the reference solution. The solution Case B is a VLEO solution, compared to Case A it offers better performances in uplink with an improvement in spectral efficiency that could ensure a more reliable link in worst condition. The solution C is a LEO solution and remains an alternative, the performances in Rx and Tx are better than in case A.

These evaluations have to be completed by estimating the performance of the overall parameters (payloads & constellation and system level).

The comparison between the 3 solutions (CASE A, B and C) for the nominal UE type (UE_1) is given in the table below.

	DOWNLINK			Downlink	Nominal	Downlink	max power 1 beam	Downlink		indoor	
	Identification	Mode	Terminal type	Max nadir	Max edge	Max nadir	Max edge	Max Nadir	attenuation	Max edge	attenuation
CASE A	UE_1	FDD	CTN_1	31.9	14.2	143.3	143.3	3.6	10 dB	1.4	10 dB
CASE B	UE_1	FDD	CTN_1	86.63	31.9	143.3	143.3	15.27	10 dB	3.3	10 dB
CASE C	UE_1	FDD	CTN_1	50.85	19.81	143.3	143.3	5.81	10 dB	2.18	10 dB

	UPLINK			uplink	Nominal	uplink	1 PRB	uplink		indoor	
	Identification	Mode	Terminal type	Max nadir	Max edge	Max nadir	Max edge	Max Nadir	attenuation	Max edge	attenuation
CASE A	UE_1	FDD	CTN_1	0.5	0.4	0.3	0.4	0.1	8 dB	0.08	7 dB
CASE B	UE_1	FDD	CTN_1	1.9	0.9	0.6	0.4	0.2	10 dB	0.078	10 dB
CASE C	UE_1	FDD	CTN_1	0.6	0.5	0.4	0.4	0.1	8 dB	0.078	9 dB

FIGURE 4-87 COMPARISON BETWEEN CASE, A , B AND C FOR UE_1

According to the table of Figure 4-87, the CASE B and CASE C allow to improve the performance of the throughput uplink and downlink. The significant improvement is obtained with VLEO 350 km constellation (CASE B).

All these solutions will be estimated in term of performances and cost effort in Task 3.4 (document 3.10 [25] and also Task 3.1 document 3.7 [19]).

4.4.1.3 Payload Mass/ Volume/consumption & dissipation

For the 3 CASE (A,B & C) the 3 architectures (1,2 and 2') have been evaluated in term of mass, Volume, power consumption and dissipation.

The 3 architectures are described in Figure 4-131 where the contains of each payload according to the architecture is listed.

The payload budget of each case are liste below on the tables of Figure 4-88,Figure 4-89 and Figure 4-90.

LEO SAT 1056 RE 600 Kms					
CASE A	architecture 1	architecture 2		architecture 2'	
	sat (user)	sat (feeder)	sat (user)	sat (feeder)	sat (user)
number of satellites	1269	336	1269	336	1269
Mass Kg	320	223	253	193	248
Power consumption (W)	9704	1980	9124	2086	9018
Power dissipation (W)	8206	1946	7696	2037	7606
diameter or Lxl (mm)	2800	1400x800	2300	1200x1200	2050
hight (mm)	800	700	400	700	300

FIGURE 4-88 PAYLOAD BUDGETS CASE A

VLEO SAT 1536 RE 350 Km					
CASE B	architecture 1	architecture 2		architecture 2'	
	sat (user)	sat (feeder)	sat (user)	sat (feeder)	sat (user)
number of satellites	1760	448	1760	448	1760
Mass Kg	328	223	260	193	255
Power consumption (W)	10905	1980	10324	2086	10219
Power dissipation (W)	9406	1946	8897	2037	8806
diameter or Lxl (mm)	2850	1400x800	2350	1200*1200	2100
hight (mm)	800	700	400	700	300

FIGURE 4-89 PAYLOAD BUDGET CASE B

LEO SAT 2048 RE 600 Km					
CASE C	architecture 1	architecture 2		architecture 2'	
	sat (user)	sat (feeder)	sat (user)	sat (feeder)	sat (user)
Number of satellites	1269	336	1269	336	1269
Mass Kg	369.61	223	302	193	297
Power consumption (W)	13030	1980	12450	2086	12344
Power dissipation (W)	11322	1946	10813	2037	10722
diameter or Lxl (mm)	2950	1400x800	2450	1200*1200	2375
hight (mm)	800	700	400	700	350

FIGURE 4-90 PAYLOAD BUDGET CASE C

These budget will be used in document [25] of Task 3.4 to evaluate the budgets of each satellite and also the relative effort in cost of each one.

4.4.2 Performances and target objectives defined in [24]

The objectives defined in [24] in term of peak data rate of 20 Mbps in downlink could be reached by almost all the solutions and in term of total capacities (densities of UE) ensured by the concept of scalability where the number of satellites could be increased to fulfill the demand(see in § 5). The target of 2 Mbps defined in [24] for uplink is more problematic, the maximum of throughput is 1.9 Mbps with VLEO constellation and at the best conditions. If this

target is an priority in objective, the payload shall be improved significantly. Differents analysis have been performed and presented in the previous chapter and also in appendix 9. The table in Figure 4-91.

LEO 600 Km			λ	DIRECTIVITY Rx			cell size km	nb cell	diameter m
				nb RE	nadir	edge			
					dB	dB			
reference	CASE A	(1)	0.741	1056	30.7	33.8	45	499	1.95
		(2)	0.62	1504	30.7	34.7	45	499	1.95
advanced	CASE C	(3)	0.62	2048	30.9	35.6	45	499	2.3
		(4)	0.62	3008	32.7	35.9	45	499	2.75
		(5)	0.62	4080	33.4	35.4	45	499	3.2
		(6)	0.741	1056	37.7	34.9	21	2275	1.95
		(7)	0.741	1520	39.0	36.9	21	2275	2.3

FIGURE 4-91 SYNTHESIS OF INVESTIGATIONS (SEE APPENDIX 9.4.4)

To achieve the 2 Mbps uplink target, the natural approach is to increase antenna size for a given cell diameter (45 km), as illustrated in entries (3), (4), and (5) in Table of Figure 4-91. Entry (3) corresponds to the Case C solution, while (4) and (5) improve directivity at nadir but remain insufficient at the cell edges, which are critical. In this configuration, beams do not align properly with the cells. Enlarging the antenna without reducing cell size runs counter to the natural design tendency.

A other solution will be to reduce the size of the cells as in (6) and (7). The increase of the size allow to reach interesting directivities (7) notably. The throughput in uplink could reach 4 Mbps at nadir and almost 0.8 Mbps at edge of the coverage (see §9.4.4.2 Figure 9-64).The effect of isoflux compensation is not observed. This could be envisaged by taking a large array of 2048 RE for instance and do the beam forming with a high level of amplitude dynamique of by selecting one part of the array see M_AX directivity versus depointing angle (Figure 4-92).

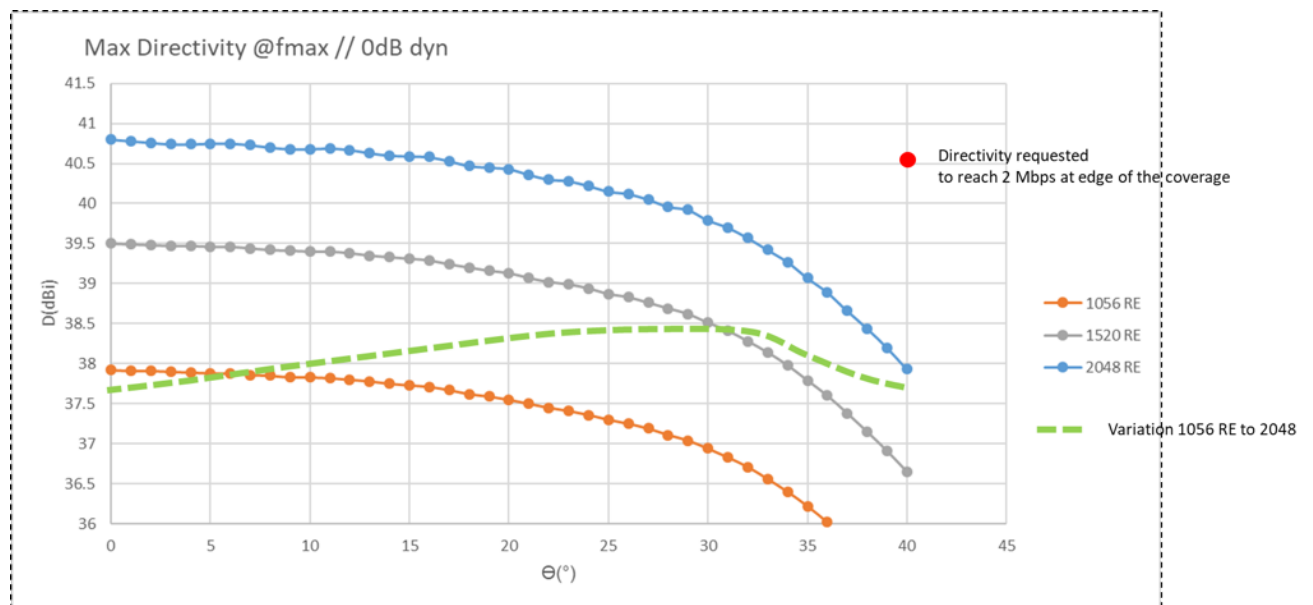


FIGURE 4-92 MAX DIRECTIVITY VERSUS DEPOINTING ANGLE

A directivity of 40.5 dBi is needed to reach the target of 2 Mbps in uplink see Figure 4-92. And in appendix Figure 9-65 and Figure 9-66.

An optimization have to be done to adjust the size of the cell in relation with the antenna size. Thus, the throughput in uplink could be reached compared to previous cases (1) and (3) with an increase of the size of the DRA and cell less than 45 km. The throughput in downlink is conditioned by the power that it is possible to embark.

Increase in size and reducing the cell size induce several complexity to manage. The number of cell will increase so that the Tx performance over the coverage will be not efficient (the power embarked in each satellite is limited, and will need densification of the constellation. Moreover the stability requirement at the satellite level and the accuracy in term of positioning and refreshing beam will be more stringent. In Rx the number of RE combined with the increase of number of cell will induce a significant request in term of processing capacity. Moreover the interlink and feeder links shall be resized in consequence.

Thus, identifying the best compromise from this analysis remains not complete (several additional parameters have to be taken into account: cost of technological components and evolution of the market, accessibility on the market...etc), although certain tendencies can be observed.

The VLEO solution (Case B) appears attractive for mitigating free-space losses, and the objectives in downlink (20 Mbps) and uplink (2 Mbps) can be achieved with slight adjustments. However, it requires a substantial increase in the number of satellites, along with the constraints inherent to very low-altitude operations (such as frequent beam refreshing and stability issues), even though latency is improved.

Résumé :

In any case the target could be reached in downlink by considering a EIRP flux on earth surface constant everywhere and reduce the number of active beams and densify the constellation to fulfill the requirement in total aggregated throughput over a coverage.

In Rx, it is more problematic as mentioned above, and needs an increase of antenna surface or reduce the cell coverage (with the drawback mentioned above) and to compensate the poor performances of terminal Tx front-end.

Thus, this chapter has examined several parameters to support reflection on the most suitable solution. However, the selection of payloads and the satellite sizing must still be assessed in terms of deployment and operational costs (including satellite manufacturing, launches, gateways, etc.), which are addressed in Task 3.4 and Task 3.1

4.4.3 Conclusion

The 3 payload solutions have been proposed: 1 resulting from a trade-off based on a simplification of satellites and a minimization of the number of satellites for a very low cost (but low capacitance), a constellation (case B) in VLEO more capacitive but with more satellites

at the constellation level, a third which is an improved version of the first one with enhanced performances with a more complexity in term of payload and cost.

These results have made it possible to define parameters that affect the complexity and cost of satellites and will ultimately allow for a more careful choice in relation to consolidated objectives.

4.5 LEO CONSTELLATION PAYLOAD Q/V

The LEO constellation is composed of several satellites ensuring the full coverage of the earth

4.5.1 Q/V frequency band

For the Q/V band, the ITU is studying a potential regulatory framework for ESIMs (Earth Stations In Motion) in this frequency range for both GSO and NGSO systems. Such framework, if approved by WRC-27, could enable NTN deployment in Q/V bands see document [20].

4.5.2 Mission description

4.5.2.1 Coverage

The Mission for the Q/V band satellites LEO nodes is identical as for C-band and recalled hereafter :

- the coverage ensure by the satellite payload is a coverage composed of cells, defined by a Elmin at UE level.
- The cells are fixed-type earth cells. The earth surface is supposed to be of cells.

In the Q/V case, the main difficulties as for the C-band LEO constellation is also to define a right combination between size of cell / size of antenna with the same axis with the same characteristics :

- Optimize the RTT (latency)
- Number of satellites impact on cost /size power consumption/dissipation
- Full coverage : the right & optimum combinaison of coverage per sat & number of cells per coverage.
- Flexibility in capacity enhancement by satellite by densifying the number of satellite
- Sustainability : global efficiency of the payload in the system

As mentioned previously in chapter 2.1.3, the major difficulties in Q/V band is to take into account technological maturity at the 6G NTN deployment, i.e. beyond 2030. It is necessary to anticipate the technological advances in the components that could be used to design of this future constellation. The difficulties are not only linked on the components design at this frequency range but also in term of thermal management device. Given the frequency, the lattice are very small, which complicates the components integration and dissipation capacity. The definition of the payload and more particularly the antenna shall take into account these constraints.

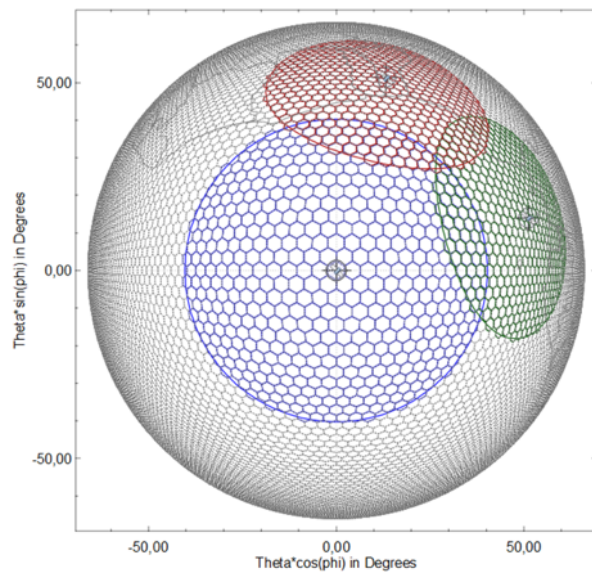


FIGURE 4-93 EARTH COVERAGE

The mission coverage in Q/V band will be identical to the C-band (see FIGURE 4-93), the main driver in the selection of the coverage is to have constellation in C-band and Q/V band in the same Altitude 600 Km. The latency constraints and the satellite velocity will be identical and do not depend on the frequency range. These two last parameters are the main drivers, latency request for ensure a quality of service and the velocity to ensure the handover management and synchronization constraints (visibility of two satellites during the handover). The constellation size will also be the same. The choice is also driven by the coordination between the two constellations in a judicious way. It will be proposed in chapter §2.2 an organization of the nodes that could allows to reduce the overall NTN architecture. Nevertheless, this choice is not fixed at the present time and could evolve according to the trade-off and over consideration and feedback from analysis.

The size of the cells :

The size of the ground cells is also linked to the satellite's ability to manage stability. Q/V satellites will be smaller than C-band satellites. Maintaining satellites with ground accuracies of the order of ± 5 km is quite problematic. Even if it is not a blocking point, it will require additional correction and measurement resources that are far from simple to implement. What's more, to ensure compatibility in the definition of cells between bands and to have the same cell identification, the choice was made to use the same cell types as those used in C band.

4.5.3 Payload description

The FIGURE 4-94 gives an overview of the functions that the Q/V payload shall ensure in the two case of constellation (architecture 1 & architecture 2)

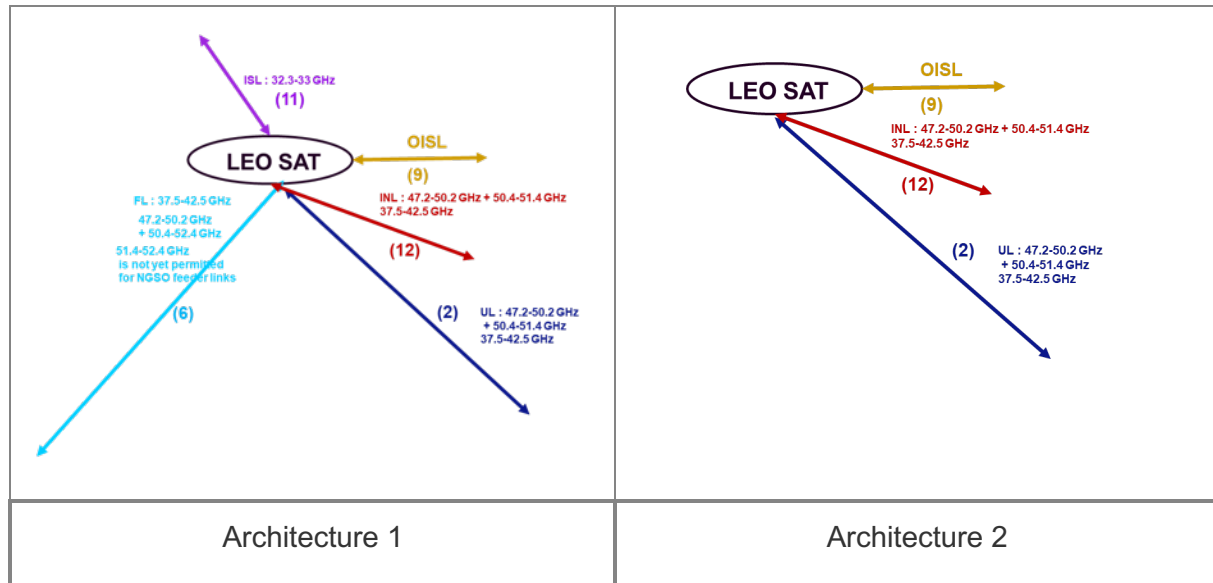


FIGURE 4-94 PAYLOAD Q/V-BAND FONCTIONNALITIES

As for the C-Band the difference between the architecture 1 & 2 remains on the absence of 2 links on the LEO SAT of architecture 2. The aim of architecture 2, as in the case of C-band, is also to reduce satellite complexity and concentrate available energy on the user link.

List of payload functionalities:

- (2) User link Q/V band
- (6) Feeder link in Q/V band
- (12) INL :Interlink between the LEO satellite and an Aerial nodes in Q/V band
- (9) OISL link to the other identical satellite LEO (architecture 1) or with a Feeder LEO satellite in architecture 2.
- (11) ISL to GEO satellite in Ka band.

4.5.4 User link (Q/V-Band)

4.5.4.1 Frequency band & numerology

The frequency band in Q/V Band foreseen is subject to proposition in the document 2.5 and is recalled in the table below:

Q-V	ID	Frequency Range				Used Frequency		Channel Bandwidth		PRB						PRACH
		Uplink		Downlink		Uplink	Downlink	Uplink	Downlink	Uplink	Downlink	Number of carriers	SCS bandwidth	PRB bandwidth	Number of PRB	PRACH bandwidth
		Sat Rx / UE Tx	Sat Tx / UE Rx	Sat Rx / UE Rx	Sat Tx / UE Tx	Sat Rx / UE Tx	Sat Tx / UE Rx	Sat Rx / UE Tx	Sat Tx / UE Rx	Sat Rx / UE Tx	Sat Tx / UE Rx	-	kHz	kHz	-	kHz
Q-V2		47,2	50,4	37,5	40,5	50	40	400	400	1440	1440	12	120	1440	264	14400

FIGURE 4-95 NUMEROLOGY FR2 USED FOR Q/V-BAND

The choice of the numerology refers to document also to [25].

A bandwidth of 400 MHz for Rx and Tx are considered. The frequency band have not yet defined and will be adjusted when it will be defined [16].

The problematic in Q/V band is the frequency separation between the Tx and Rx frequency bands 40 GHz and 50 GHz which constrain to separate the two function into 2 payloads.

4.5.4.2 Orientation

In Q/V band, a technological orientation shall be done. In the near future, an antenna that would function in the both bands Rx and Tx in Q/V band is not feasible. Moreover, the lattice will be small : indeed the wavelengths are of the order of 6 mm and 7.5 mm, i.e. given the grating lobes constraints, the lattice will be of order of 4 to 5.5 mm, which complicates the routing of the radiating element to the polarizer, filters and amplifiers. Moreover the connections will also be complicated in the sense that the coupling effect between Rx and Tx shall be avoided. Consequently, there is no major interest in developing an Rx/Tx antenna for satellites, where the priority is to create several beams and optimize the power per beam. However, it is possible to imagine a ground terminal that could eventually provide both bands. However, mesh interleaving has been a subject of study for several years, and while solutions are currently being studied for Ka-band, for Q/V-band, solutions of this type could be envisaged for severe integration constraints (aircraft, drones, vehicles). In the following, we'll assume that antennas are separate, whether for satellite or ground terminal antennas.

Several options are possible, but the solution chosen for cost reasons is to limit the number of beams per antenna and increase the number of antennas, which will ensure a sufficient number of beams. The advantage of this is that the energy is concentrated on a few beams only per antenna, thus ensuring sufficient throughput and better dissipation. The antenna footprint will also be reduced, thanks to the lattice so that the accommodation of several antenna is not constraining.

A complexity analysis shows that, in the long term, it will be possible to have active antennas with an ABFN (analog) solution, using either AsGa or SiGe amplifiers. The latter technology will enable high integration, and therefore optimum mass and minimize the footprint; however, a trade-off will have to be made between these two technologies.

4.5.4.3 State-of art : technological bottleneck

RF front-end building-blocks are key enablers within the satellite based telecommunication systems in so far as they provide the fundamental functionalities to properly manage the modulated signal between the antenna (RF/mmW domain) and the core digital processor (analogue/base-band domain). On one hand, the contribution of the requested up and down frequency conversion blocks with complementary low amplification and filtering functions is critical towards the overall electrical budget performance (gain, noise, linearity, power efficiency) of the space-borne system. On the other hand, the capability to electronically drive the amplitude and phase of the RF signal within the active antenna subsystem represents a fundamental option in the quest for improved flexibility (beam forming concept).

In this context, the implementation of such wide portfolio of RF functionalities, with their associated smart biasing circuitry and digital command interfaces, represents a huge challenge considering the mandatory compliance of the hardware solution with the antenna lattice. Being directly correlated with the RF operating frequency, this mechanical integration constraint becomes even more critical considering the management of Q/V bands which allow highly capacitive communication flux.

To that end, an exhaustive investigation must be conducted on the IC (Integrated Circuit) technology offer dealing both with the requested electrical performance and integration capability, in the frame of a targeted harsh space environment (to be defined through the accurate description of a mission profile). Beside these technical considerations, the selected technology hardware solution shall also deal with economical and industrial criteria in compliance with the peculiar characteristics of the space market (reliable supply chain, efficient production flow, competitive target price, ...)

The table here below provides an overview of the available RF technology options to be considered with a very preliminary assessment of their respective strengths and weaknesses, which needs to be further investigated towards the targeted Q/V band application.

Criterion	GaN HEMT	GaAs pHEMT	Si CMOS-Bulk	Si CMOS-SOI	SiGe BiCMOS
<i>Technology node</i>	<i>Middle range</i>	<i>Middle range</i>	<i>Advanced</i>	<i>Advanced</i>	<i>Middle range</i>
Gain / Noise (RF)	😊	😊	😞	😞	😊
Power / Linearity (RF)	😊	😊	😞	😞	😊
Overdrive hardening (RF)	😊	😊	😞	😞	😊
A/Φ setting (RF)	😊	😊	😊	😊	😊
Freq. conversion (RF)	😊	😊	😊	😊	😊
Freq. filtering (RF)	😊	😊	😞	😞	😞
Power density (RF)	😊	😊	😞	😞	😊
Power consumption (DC)	😞	😊	😊	😊	😊
Smart command (DAC)	😞	😞	😊	😊	😊
Smart biasing (PVT)	😞	😞	😊	😊	😊
Digital interface	😞	😞	😊	😊	😊





Radiation hardening					
Multi-functions handling					
Integration capability					
Smart packaging (Tj)					
Antenna in package					
NR cost					
Manufacturing yield					
R cost					

TABLE 6 : OVERVIEW OF INTEGRATED CIRCUIT TECHNOLOGY PORTFOLIO AND PRELIMINARY TRADE-OFF TRENDS FOR Q/V BAND APPLICATIONS

The **GaN HEMT technology**, operating in the higher range of voltage supply, addresses state-of-the-art performance in terms of RF power density up to the targeted Q/V-band considering lower technology nodes down to 100nm, thus widely covers the potential requirements of flexible power [100] and robust low noise [101] amplifiers at the cost of high power consumption and associated thermal management challenge. The excellent linearity property of the technology is also demonstrated through the synthesis of amplitude / phase setting functionality [102] at the cost of limited integration capability which may also be confirmed towards the implementation of high frequency band conversion blocks [103].

Q/V band circuits implementation on a **GaAs pHEMT technology** is far more conventional insofar as it intrinsically offers the state-of-the-art gain performance at the highest operating frequency range. A clever selection of the technology node may provide mid-range RF power handling capability [104] at the cost of significant chip size. On the other hand, such technology excels in the low noise and high gain range amplifying domain [105]. The publication reference [106] illustrates the limitation of the technology towards the dream goal to integrate multi-functional and/or multi-RF paths on a single chip. Tentative of monolithic on-chip integration, as depicted in reference [107] applied to a receiver front-end use-case, mostly leads to large die size, poor manufacturing yield and challenging encapsulation phase.

Considering the intrinsic limitation of **Si CMOS-Bulk technology** with respect to RF gain performance in the Q/V-bands and higher, the selection of advanced nodes (< 65nm typ.), to address basic amplifying functionalities for instance, becomes mandatory. As a consequence, the allowed voltage supply range is affected thus impacting the power handling capability of the targeted building-blocks as depicted in references [108] and [109] for instance. Still the proposed very compact implementation solutions remain attractive for low performance demanding applications and allow to efficiently implement multi-functions circuitry on a single chip (System on Chip) [110] and extend the ambition of integration to the management of multiple amplitude phase control nodes with appropriate digital interface [111].

Similar comments can be applied to the **Si CMOS-SOI technology**. Additionally, this solution proposes some performance improvements in terms of RF switching and intrinsic robustness towards radiation stress among others. An example of power (resp. low noise) amplifier application in Q-band (resp. V-band) is depicted in reference [112] (resp. [113]). Following publications [114] and [115] illustrate the technology capability toward highly challenging multi-paths integration requirement in V-band.

At last, the **SiGe BiCMOS technology** appears to offer the best trade-off between electrical performance, layout integration and production cost criteria. The key contribution provided by the embedded bipolar transistor component enables to reach the targeted Q/V-band performance with a standard technology node (typ. from 65 to 130nm). As an example, [116] and [117] show the reachable power and noise performance of an amplifier building block in the Q and V bands respectively. The extremely ambitious functionality perimeter (Tx/Rx frequency conversion + amplitude/phase setting) covered by the single chip of [118] perfectly illustrates the tremendous integration and performance capability of this technology which as a reminder is also pretty costly effective.

An example of application of these technology is presented for a SATCOM application in ka band [119], the design are scalable ie the increase of the number of elements of the antenna do not impact the architecture of the antenna.

4.5.4.4 Trade-off on the antenna size /cell size beamforming techniques

The first trade-off is to compute the maximum directivity for several size of antenna with a coverage of EI min of 45° in other word with a radiating element of 0.741λ at higher frequency.

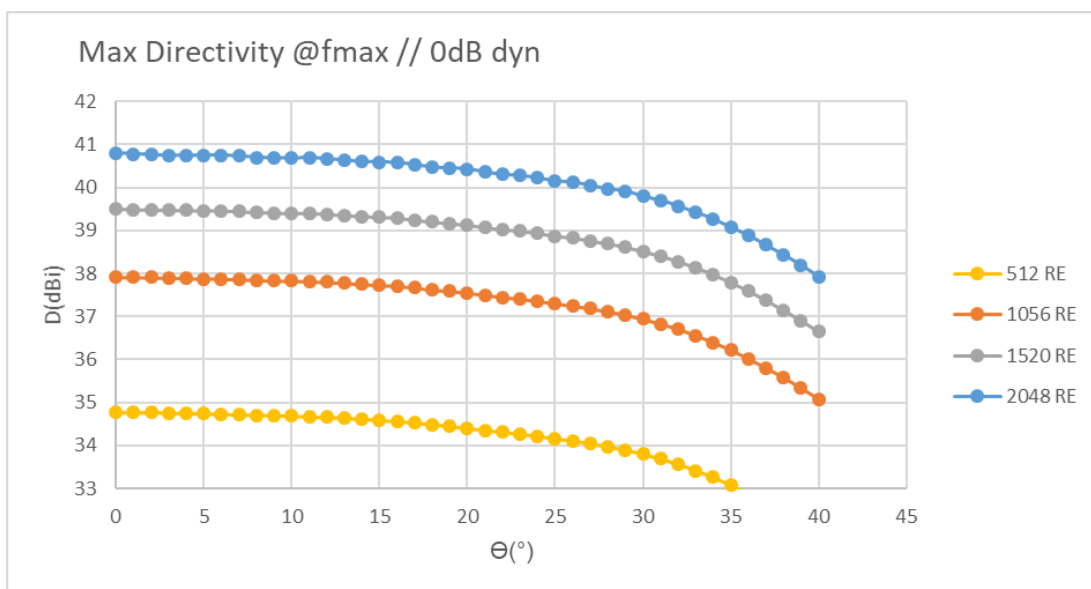


FIGURE 4-96 MAX DIRECTIVITY ANTENNA TRADE-OFF

Maximum directivities naturally increase with the number of Elements. So does also the complexity of the architecture, especially the number of nodes required to create the ABFN. At present, it's hard to say whether the technology will eventually allow us to build architectures with more than 1000 elements in Q/V band able to generate 4 or 8 beams at a reasonable cost.

Increasing the number of elements beyond 1000 poses a problem: the antenna is naturally directive, and it is necessary to choose an antenna with an aperture that matches the cell's beam width at almost 3dB. It will be necessary to use high attenuation to cover beams from nadir to the edge.

Nevertheless, the case of an antenna having 512 RE up to 1024 RE will be investigated. The upper limit of 1024 RE is an objective to be consolidated and could be the target at term.

The trade-off to perform is an antenna having 1024 RE or 512 RE.

For Tx antennas :

In the 1024 RE / 4 beams case:

Over and above the complexity of the architecture, having 1056 element enables us to have low-power amplifiers (less constraining dissipation). However, the dimensions will be larger.

In the case of 512 RE / 4 beams or 8 beams :

Lower complexity, higher power amplifiers to compensate for low directivity. Smaller size. Lower cost.

The priority on the last solutions is given. It will allow to estimate à low cost solution and moreover a most reachable solution at term.

For Rx antennas : the lattice size are even more constraining, and the integration of the elements is more complex to achieve. Although dissipation is much less of a constraint in Rx, given this complexity, analyses are needed to determine the feasibility of antennas beyond 1000 elements. To facilitate the Rx and Tx balance, we prefer to choose a 512 RE antenna on the cells and multiply the antennas to increase the number of active beams in the same way as for Tx.

The solution is to limit the complexity of the antenna Rx and Tx to 4 beams and 512 RE, to reduce drastically the non-recurrent cost. Multiplying the number of antenna will allow to reduce the recurrent cost. This orientation is consolidated by the fact that the thermal and mechanical management will be facilitated by limiting power at each antenna level which relaxes the thermal dissipation device which could have an important mass impact.

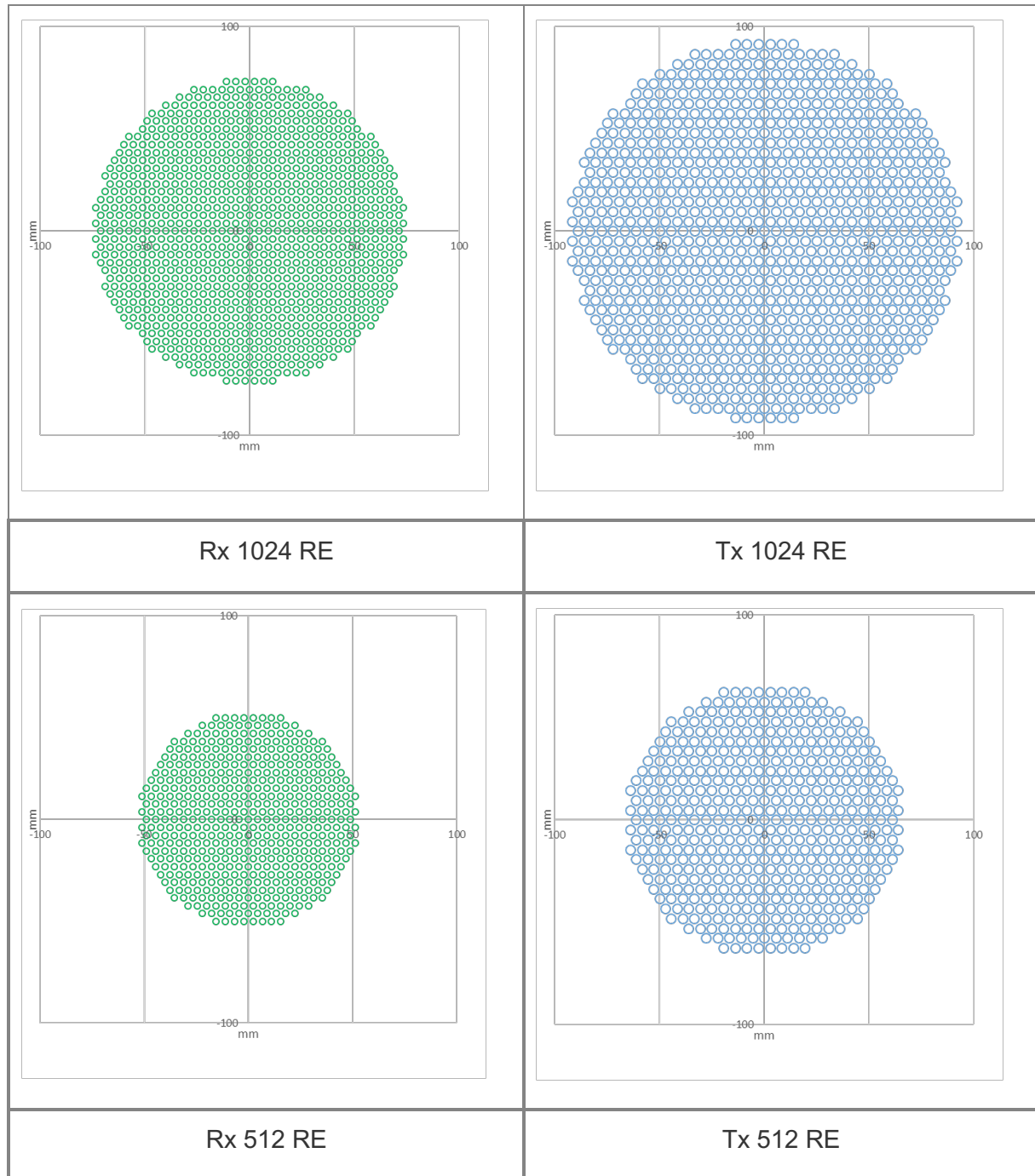
The validation and the tests of each antenna module will be facilitated and will also contribute to reduce the overall cost of the constellation.

4.5.5 Solution Q/V band Analysis

The following solutions are envisaged : antenna array of 512 to 1024 radiating elements.

A 512 radiating elements antenna capable of generating 4 to 8 beams is the baseline. The 1024 RE case remains an option that could be considered if maturity in the developpement have been observed.

The Tx antenna shall be able to handle power dissipation and consequently low losses. The technology based on radiating aperture technology (waveguide) is preferable. It will include a polarization and a matching section or if this is not the case, then directly in patch antenna technology on PCB substrate with limitation of the interconnection section.



The organization of antennas is not clearly defined as in the case of C-band, where a possible layout is proposed based on digital building blocks. In the case of Q-band and V-band, all options are possible. It will depend on the basic element, the BFIC 4x4 or 8x8 that with the elementary brick from which the whole architecture can be envisaged for building the ABFN and consequently the accommodation of the filtering section and amplifier section. These constraints will impose a change in the aperture organization of the final antenna around a circular shape. The circular shape will allow to have reduced side lobes levels.

In our case, simulations are based on circular aperture in a hexagonal lattice.

The Q/V band payload will be based on separate Rx and Tx antenna.

4.5.5.1 Payload architecture

The payload architectures are presented in the FIGURE 4-98 to FIGURE 4-101.

The architectures Rx and Tx are composed of a analog front end stage followed by a beam forming section. 7 antenna are connected to 7 ABFN. Each one is able to generate 4 or 8 beams. After digitalization, all the beam accesses are processed (beam management and demodulation/modulation section). The routing section will allow to dispatch the data towards the different nodes thru the appropriate link (ISL, OISL, INL or Feeders). The architecture 1 and 2 differs only in the presence or not of the 2 links ISL and Feeder.

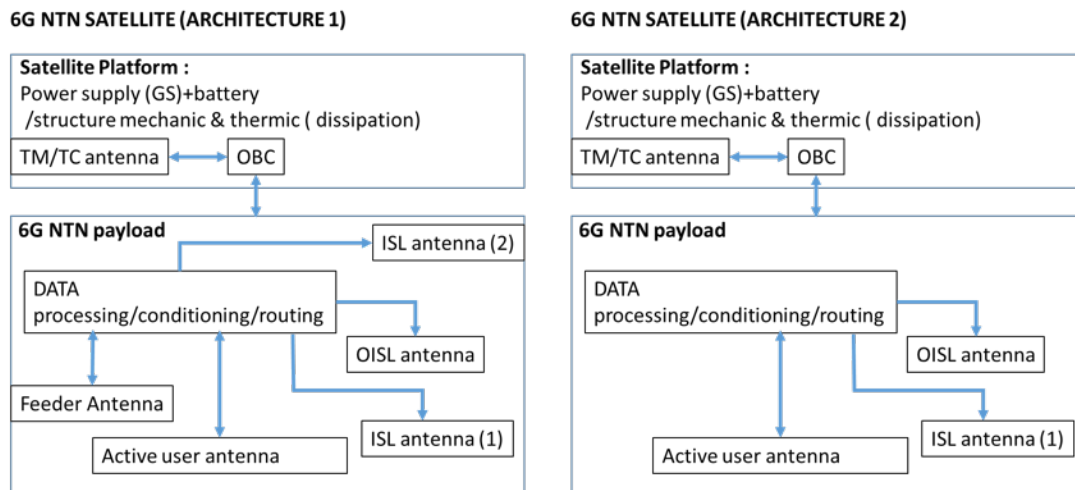


FIGURE 4-97 FUNCTIONAL DESCRIPTION SATELLITE /PAYLOADS

The functional description of the payload and its interface description with the payload are illustrated in the FIGURE 4-97. The schematics of the payload has been detailed in the FIGURE 4-98.

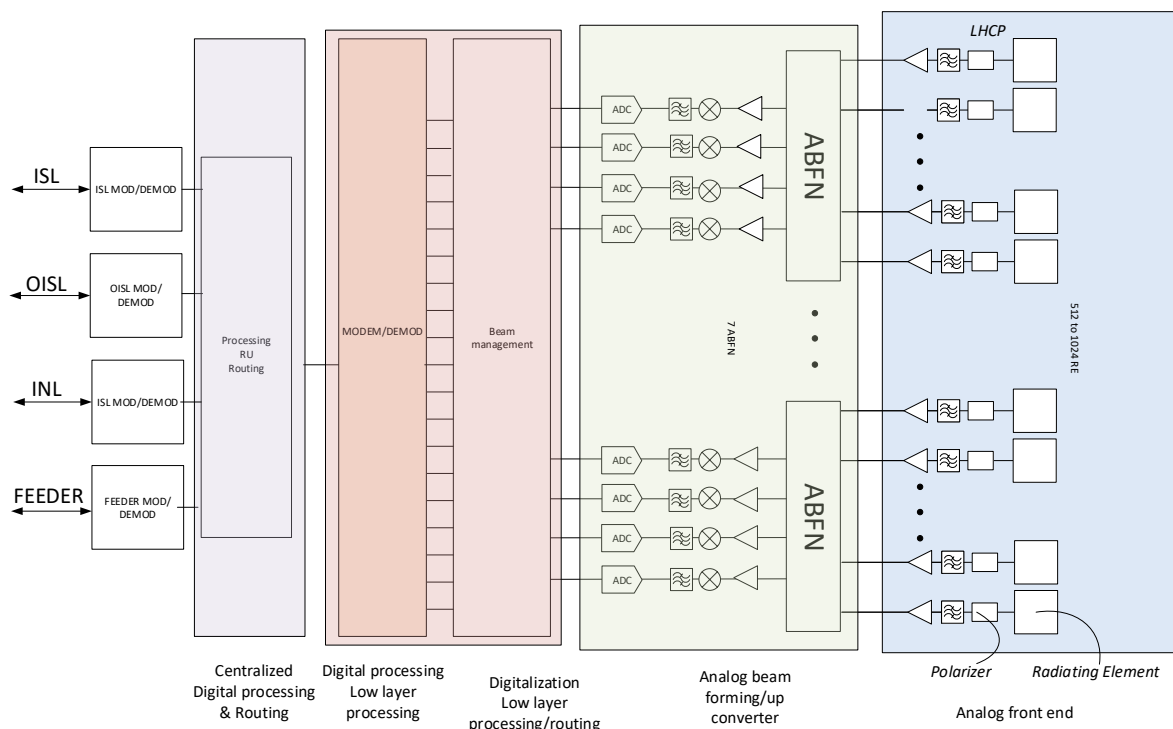


FIGURE 4-98 ARCHITECTURE 1 :V BAND RX ANTENNA SYSTEM

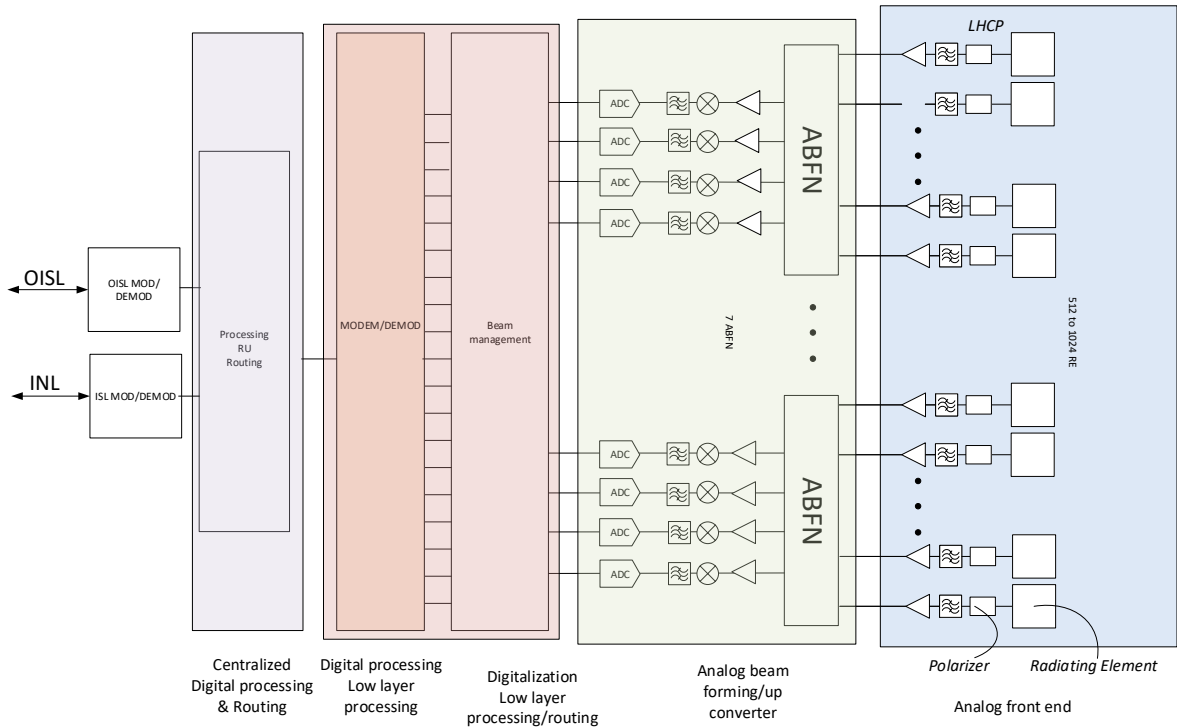


FIGURE 4-99 ARCHITECTURE 2 : V BAND RX ANTENNA SYSTEM

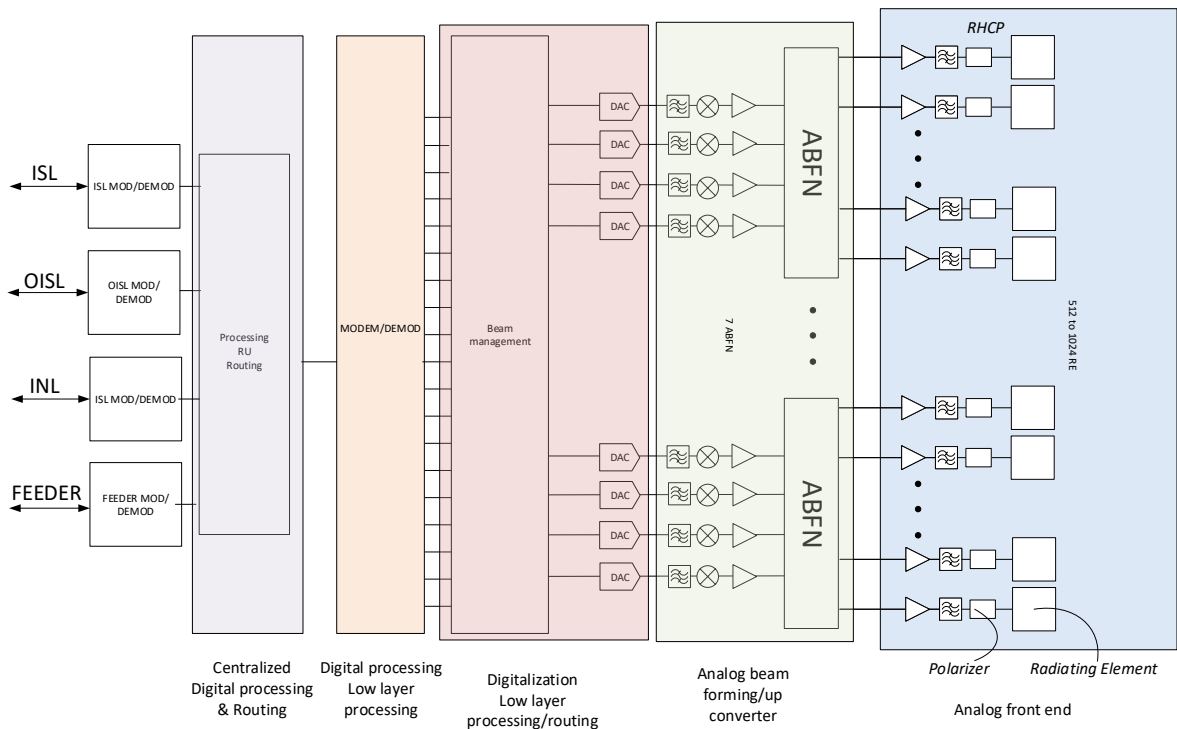


FIGURE 4-100 ARCHITECTURE 1 : Q BAND TX ANTENNA SYSTEM

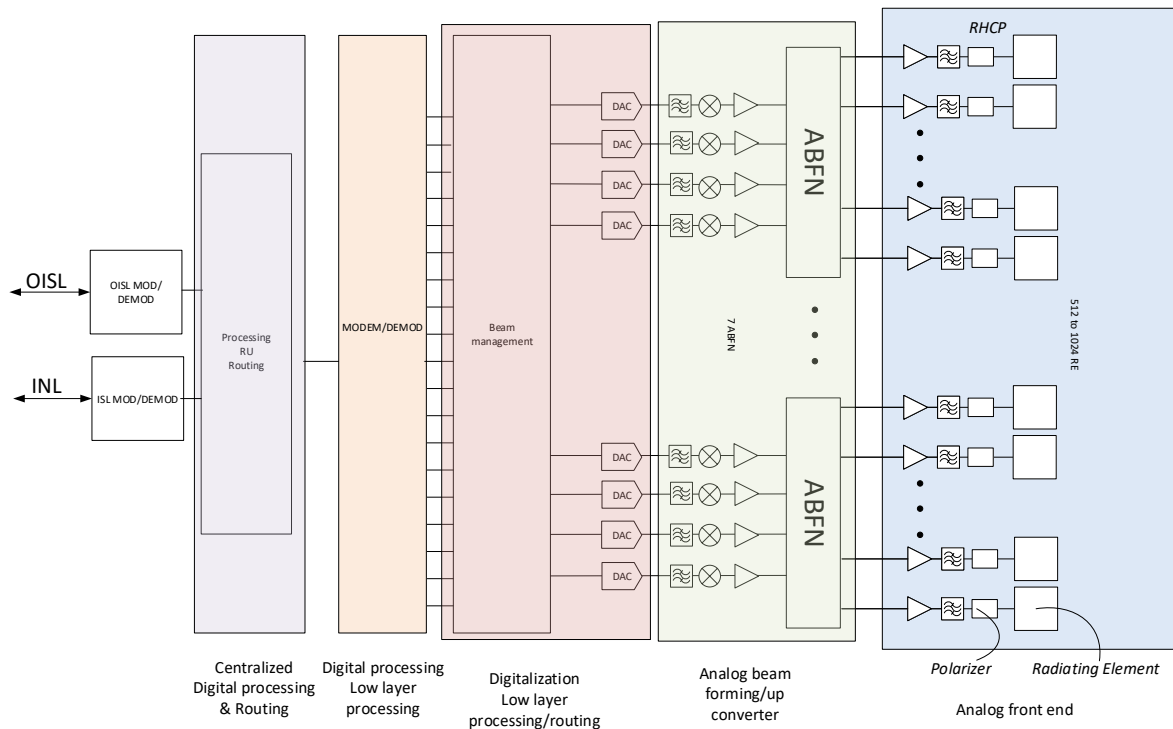


FIGURE 4-101 ARCHITECTURE 2: Q BAND TX ANTENNA SYSTEM

4.5.5.2 Alternative solution (fully digital)

The architecture proposed in the previous chapter is based on several antennas using an analog beamformer. Each ABDF is limited in the number of beams in order to reduce complexity and ensure sufficient power per beam. Given the technological constraints related to the cell size, it is not feasible to consider high power per ABFN, as this would complicate thermal control. The total number of beams is obtained by combining several antennas in a panel and performing digitization at the beam access level, with selection ensured by a switch matrix.

Following the same philosophy, in [131] a similar type of architecture is proposed, but with a digital beamformer. Each antenna generates a limited number of beams. The antennas are smaller and contain a limited number elements (256), which requires coverage with larger cells and results in degraded performances. Increase the number will have a consequence in term of power consumption. Nevertheless, the advantage of full digitization lies in its greater flexibility. However, since the number of channels to be digitized is very large and the bandwidth is wide, this solution risks being highly energy-consuming. Moreover, the feasibility of such a system depends on the availability of suitable technology in the future, and its maturity remains to be confirmed.

4.5.5.3 Radiating element model

The radiating model is a 0.741λ elements as for the C-band. The lattice is hexagonal as shown in the FIGURE 4-102.

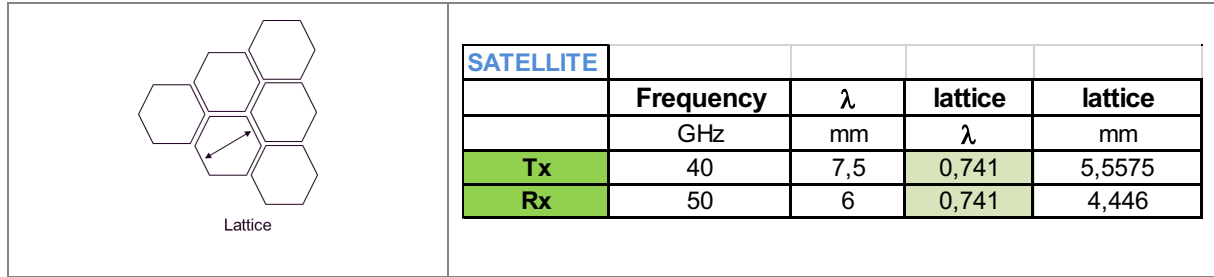


FIGURE 4-102 ANTENNA LATTICE

As mentioned previously, in the case of Q/V band the lattice is extremely small which complicate the thermal management and the integration of the components. An ABFN of 512 elements with 4 or 8 beams is a challenge in terms of technological development. Nevertheless, the progress in SiGe and PCB design will allow to reach enough maturity to envisage such network at short time for 4 or 8 beams.

The estimation of the gain is given in the table FIGURE 4-103. The losses budget have been taken to 2 dB. This budget shall be consolidated with more attention in the design of the element and in the choice of the technology.

SAT		EL 90°	EL°45°
		dBi	dBi
	Tx (Sat)	5,31	3,81
	Rx (Sat)	5,31	3,81

FIGURE 4-103 SATELLITE ANTENNA RADIATING ELEMENT GAIN

The radiating element model is given in the figure FIGURE 4-104. In Tx and In Rx the same lattice have been taken as the two functions are separated in two separate antenna and associated payload.

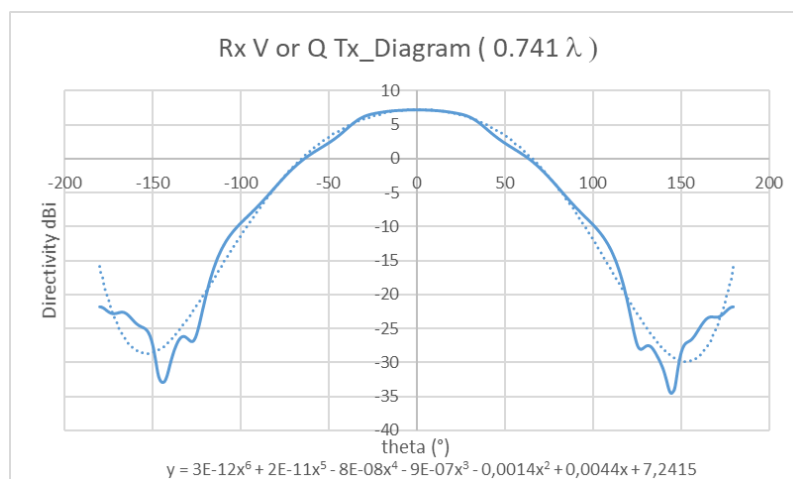


FIGURE 4-104 RADIATING ELEMENT DIAGRAMS FOR Q/V BAND (DIRECTIVITY)

The radiating element behavior especially at off axis will depend slightly on the technology used, it will also depend on the coupling effect between the elements which is generally enhanced for low lattice (close to 0.5 λ). In our case the lattice is constant in Q band and in V band, the antenna are separated and the choice of 0.741 λ will avoid this.

4.5.5.4 Antenna definition

The antenna panel is composed of 7 antenna of each function Rx and Tx as illustrated in the FIGURE 4-105. The two panel will be accommodated on the earth panel of the satellite. The separation between the Rx panel and the Tx panel will allow to limit the filtering effort in order to reduce the interference level. The antennas have been grouped together (Rx and Tx) and positioned to reduce the distance between the beam accesses of each antenna, in accordance with the functional architectural schematics shown in the FIGURE 4-98 à FIGURE 4-101.

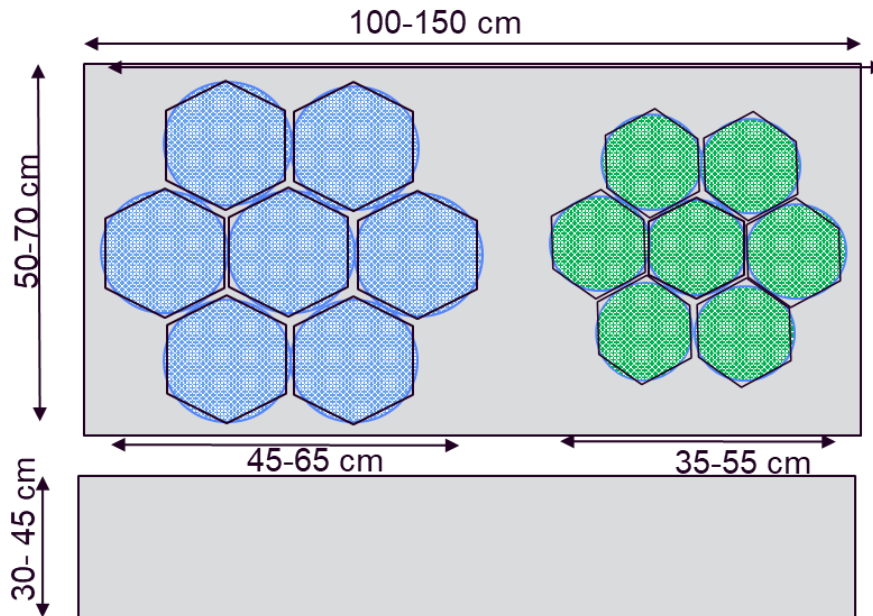


FIGURE 4-105 ANTENNA PANNEL

The beams that can be generated by each antenna are illustrated in figure . Each antenna can only generate 4 or 8 active beams among the 499 ground cells. As there are 7 Rx antennas and 7 Tx antennas, this makes a total of 28 or 56 active beams per satellite.

The performance of the antenna of 512 elements in depointing is given in FIGURE 4-107 and FIGURE 4-106 for a dynamic of beam forming of 12 dB . The directivity is >29 dBi, with a increase around 30° (scan angle from the antenna). The roll-off is between 3.5 dB at nadir to 2 dB at the edge.

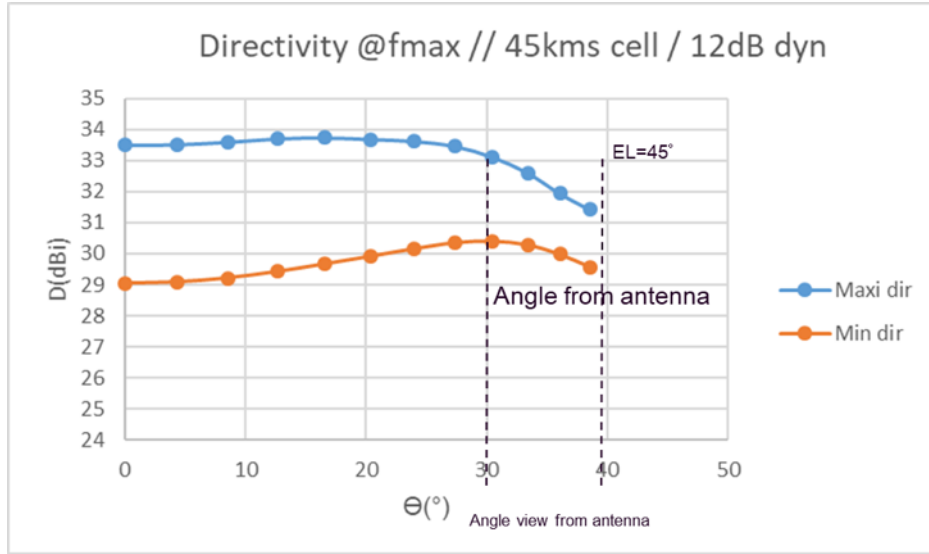


FIGURE 4-106 ANTENNA PERFORMANCES 512 RE IN DEPOINTING (DYN.=12 DB)

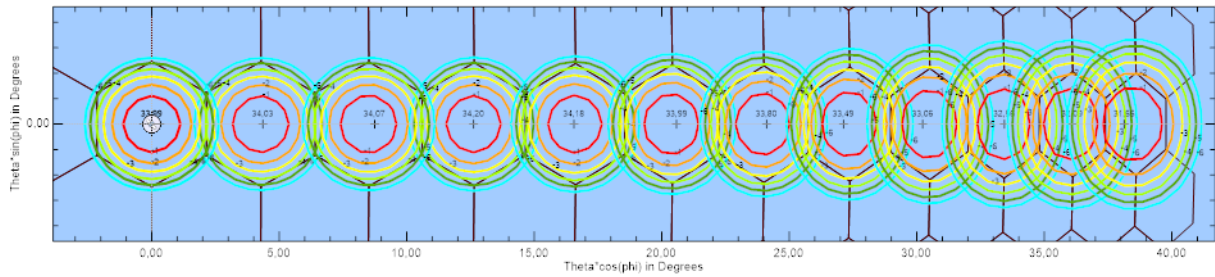


FIGURE 4-107 ANTENNA PERFORMANCES 512 RE IN DEPOINTING (DYN.=12 DB)

Similarly, performance for the same antenna but with beamforming dynamics limited to 6 dB is shown in FIGURE 4-108 and FIGURE 4-109 The roll-off is between 5 dB at nadir to 2 dB at the edge.

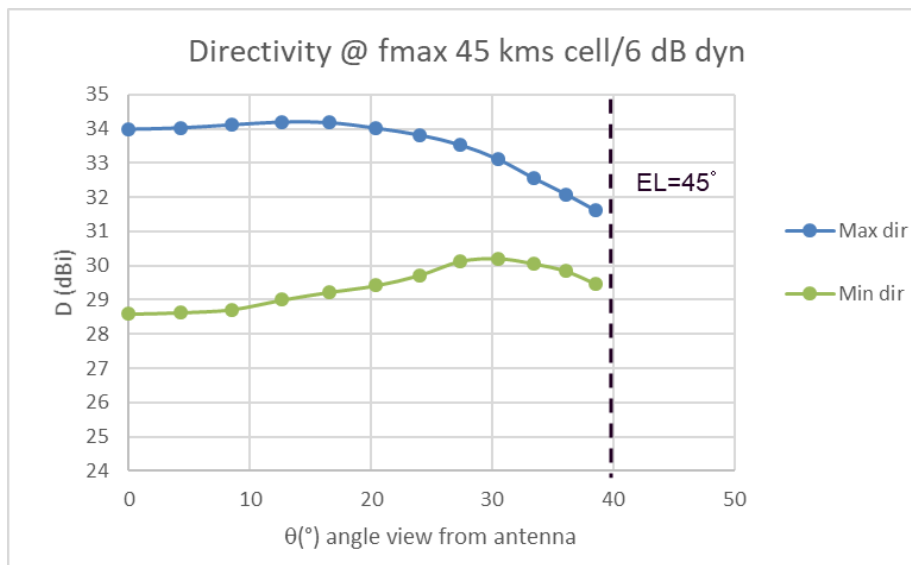


FIGURE 4-108 ANTENNA PERFORMANCES 512 RE IN DEPOINTING (DYN.=6 DB)

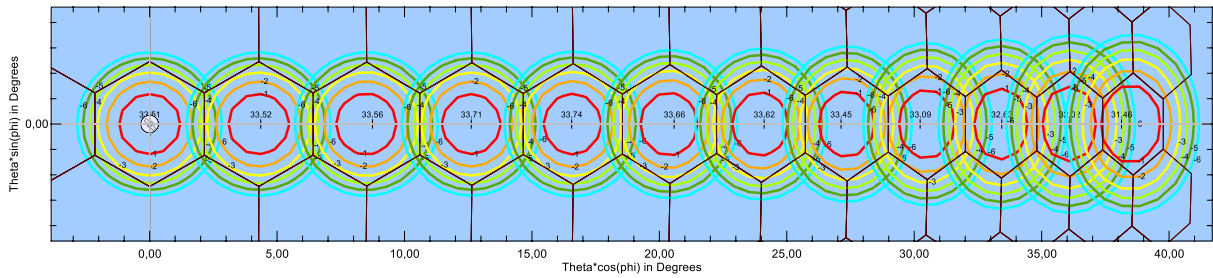


FIGURE 4-109 BEAM PERFORMANCES IN DEPOINTING 6DB

Performance at nadir is not optimal in terms of roll-off, but what is very dimensioning is at the edge due to higher FSL. It could be possible to use a high level of dynamic in beam forming to increase nadir performance. But in this case the antenna would not be optimal, as the number of beams per antenna in Q (4 to 8 beams) is limited, unlike in the case of C-band where it is high (100 beams), the efficiency of the amplifiers would be affected, and it would be difficult to maintain each amplifier at its nominal operating point, as the power aggregated at its access would not be constant. Consequently, it is preferred to limit in Tx the dynamic to 6dB and relax the dynamic up to 12 dB in Rx. The beams layout for Tx and Rx is shown in FIGURE 4-110./

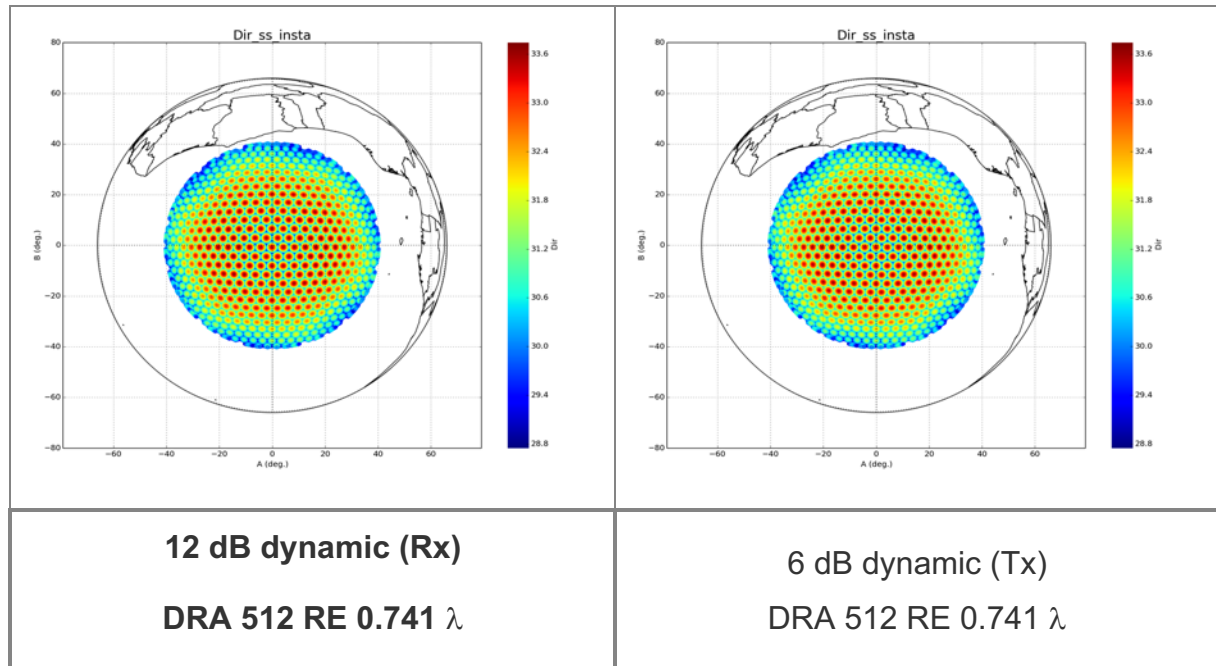


FIGURE 4-110 512 RE 12 DB AMPLITUDE & 6 DB AMPLITUDE

The performances and the tables of values are given in Appendix 9.5.1.

The nominal case is to have a flat panel which is easy to implement on the satellite platform.

The flat panel is composed of 7 identical antenna panels that have the same performances over the cells. Each antenna covers the same area : a coverage of EL min of 45° (red in

FIGURE 4-112- (a).The power capacity is fixed by antenna, that means that the power have to be shared by the number of 1 to 4 beams or 1 to 8 beams (depending on the ABFN).

Nevertheless a slight facetized panel could be used to optimized the performances. Each antenna could be oriented toward a slight angle of 10° for instance.

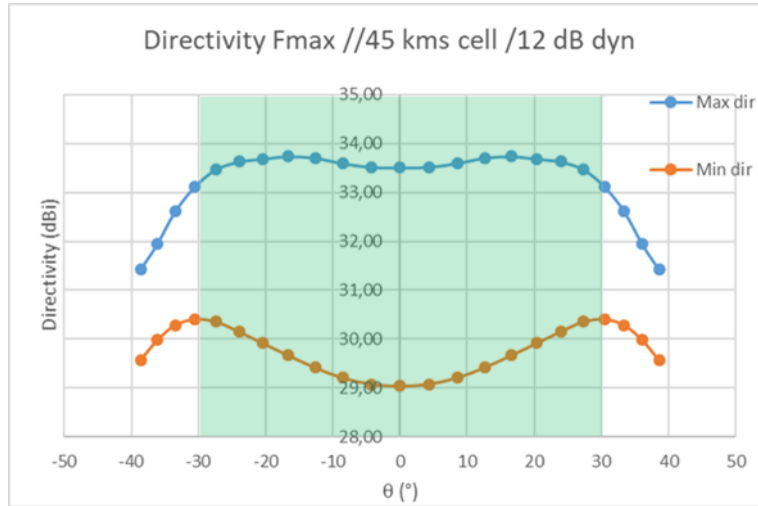


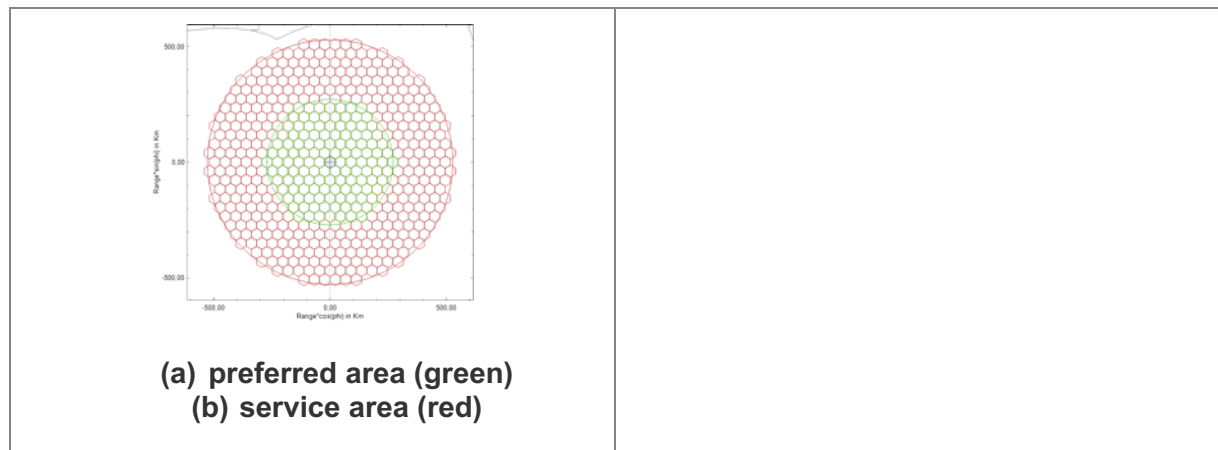
FIGURE 4-111 PERFORMANCE OF ANTENNA WITH SLIGH ANGLE

This optimization phasis to enhance the performance shall be evaluated with the restriction that it will induce in term of beam management. This feature could be taken as an axis of future improvements.

The coverage as defined could be optimized :

- a depointing angle could be applied allowing to defined an priority area for each antenna (green in FIGURE 4-112).
And an exchange area where all the antenna could form a beam

A right management of the beam will allow to let enough flexibility to manage all the critical cases. This will allow also to reduce the number of satellites of the constellation or reduce the number of element of each antenna by increasing the size of each element according to the reduction of the scan angle limited to the common area.



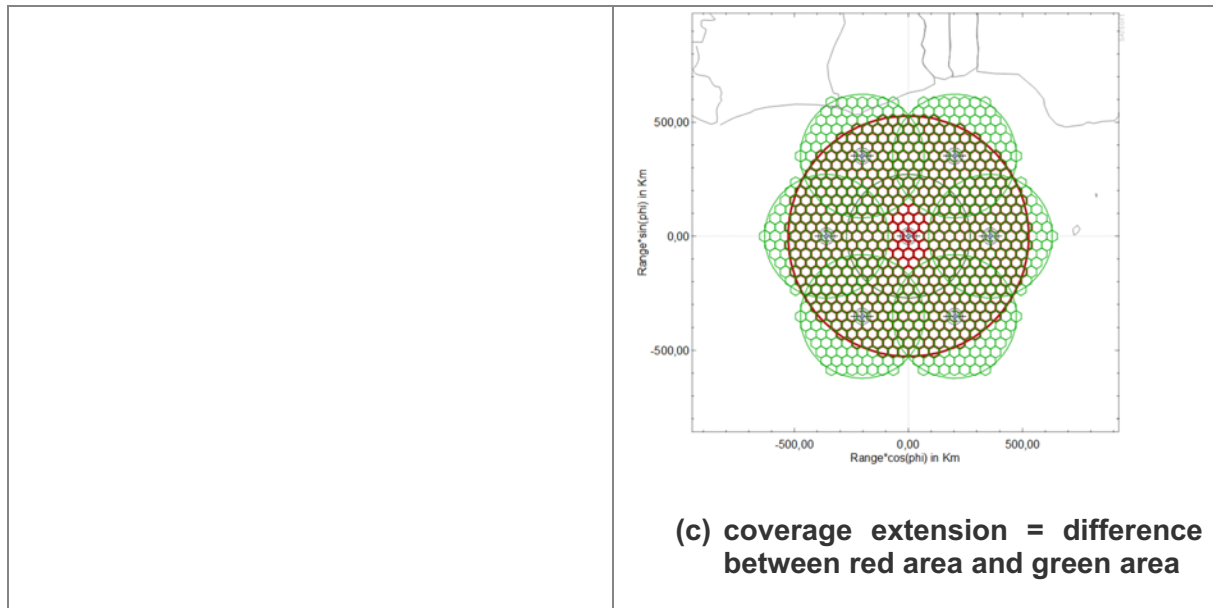


FIGURE 4-112 OPTIMISATION OF COVERAGE OF EACH ANTENNA

The Beam hopping process shall be used to cover all the cells and the capacity of each antenna to generate a number of beams instantaneously is limited to 4 to 8. The satellite is designed to have 7 antennas which means that it could generate instantaneously between 28 to 56 beams.

Several constraints have to be taken into account when at each slot of the Beam hopping frame the beams are activated :

- C/I constraints (if a deterministic frequency reuse scheme is not used)
- Number of beams by sub area.

This solution could allow to optimize the performance of the constellation and reduce the overall cost by decreasing the number of satellite. The evaluation of such configuration could be envisaged in a second step. A compromise between full flexibility and restrained flexibility have to be evaluated with a typical scenario.

4.5.5.5 Grating lobes

The grating lobes constraint are similar as for C-band, and it has been checked that it will avoid the grating lobes on the visible earth as the coverage is defined by an EL_{min} of 45° and a RE size of 0.741λ . This conditions will avoid grating lobes in the visible earth.

In the difference of the solution for C-band the number of elements is limited, The side lobes positions depending only of the spacing (lattice) will be at the same positions. It can be observed some slight change in the level of the grating lobes and also on the secondary lobes with the dynamic of amplitude used for the beam forming.

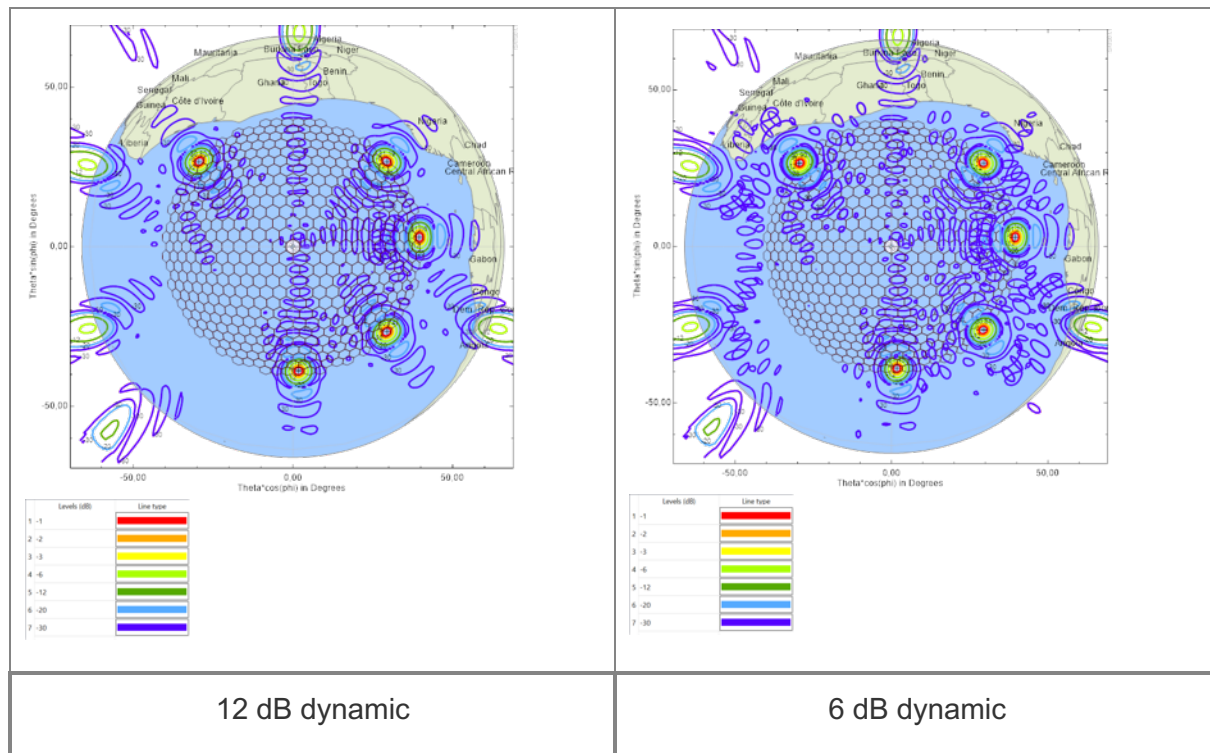


FIGURE 4-113 GRATING LOBES

The level of side lobes is an important factor to mastering in order to reduce the aggregated C/I which could limit the reuse of the frequency band in some cells (adjacents cells) and will impose a criterium to select the beams in the beam hopping frame.

4.5.6 Link Budget

4.5.6.1 Objectives

As for C-band, the objectives is to compute the maximum throughput achievable (best conditions) in order to evaluate the link dimensioning (OISL /ISL). In a second step, the evaluation of the average capacity will be given.

Parameter	Unit	Value	Comment
Band Name	-	Q-V	
Availability	%	99,50	
Earth Radius	km	6371	Value from [RD2] section 6.3
Boltzmann	dBW/K/Hz	-228,6	

FIGURE 4-114 CONSTANTS AND HYPOTHESIS

The estimation of the constellation performances will also need a representative traffic model, which is not yet established. Only a traffic model and hypothesis of loads could repond to the question if the system will repond to the expected request. In our case, the future market is not yet defined and will need an intensive analysis of propection. As the uncertainties remains, the payload and the overall system shall be scalable to repond to the future request. In that perspective, the orientation in design is based on basic brick that could be adjusted according to the demand. The term of scalability is already included in the reflexion early in the design.

4.5.6.2 Antenna performances

The satellite and Terminal are DRA type antenna where the elementary element of the hexagonal is defined in the table below :

SATELLITE				
	Frequency	λ	lattice	lattice
	GHz	mm	λ	mm
Tx	40	7.5	0.741	5.5575
Rx	50	6	0.741	4.446

FIGURE 4-115 ELEMENTARY ELEMENT PERFORMANCES SATELLITE

TERMINAL				
	freq(GHz)	lambda	lattice	lattice
		mm	lambda	mm
Rx	40	7.5	0.65	4.875
Tx	50	6	0.65	3.9

FIGURE 4-116 ELEMENTARY ELEMENT PERFORMANCES TERMINAL

In each case TERMINAL and SATELLITE, the antenna Rx and Tx are supposed to be separated.

The two basis elements are first considered identical for this first analysis. With the the study on terminal in WP3.4 the terminal performances will be updated. The pattern of ythe radiating element is depicted in FIGURE 4-117

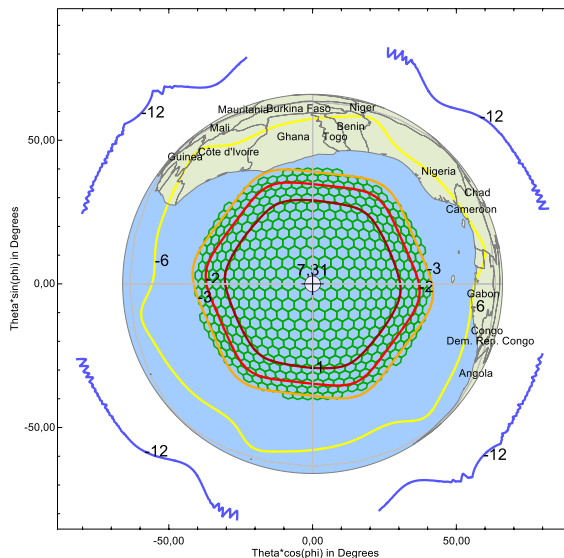


FIGURE 4-117- RADIATING ELEMENT MODEL 0.741 λ

The radiating model could have some variation more particularly at off-axis. It depends on several factor : aperture, coupling effects for instance. A theoretical model could not be sufficient to evaluate the real performances. Moreover according to the technology used the

losses will be more less important. In Q/V band the preferred technology is in waveguide aperture, the patch on substract could have high losses at this frequency. Thus, the error budget shall take into account this discrepancy. In the present case a provision of 1.4 dB and 2 dB have been taken into account in the performances estimations.

The lattice for the terminal and the satellite antenna is fixed to 0.741λ .

The performances of the terminal is subject to work on the document of task 3.4 The performances will be updated according to the results.

Terminal	Antenna	FREQ GHz	Size (ϕ) m	nb element	directivity			Gain	
					nadir	El 45°	losses	nadir	El 45°
					dB	dB	dB	dB	dB
	QRx	40	0.12	512	33.3	31.8	1.5	31.8	30.3
	VTx	50	0.09	512	33.3	31.8	2.0	31.3	29.8

FIGURE 4-118 TERMINAL ANTENNA PERFORMANCES

The power will be subject to sensitivity analysis. The power handling capacity will dimension the satellite platform.

4.5.6.3 Satellite hypothesis : resume

The table of FIGURE 4-119 give the resume of all the parameters for the satellite payload definition used for the link budget.

SATELLITE	Parameter	Unit	Value
	Satellite	-	LEO-600
	Altitude	km	600
	Band Name	-	Q-V
	Nb spots total	-	499
	Nb active spots during 1ms timeslot	-	4
	Cell size	km	45
TX (downlink)	Downlink Frequency	GHz	40.00
	Antenna Size	m	0.13
	Number of ER	-	512
	Losses ER	dB	1.4
	Antenna gain (NADIR)	dBi	32.59
	Antenna gain (Ei 45°)	dBi	30.20
	EIRP density	dBW/MHz	18.20
	EIRP density attenuation	dB	0.00
	Effective EIRP density	dBW/MHz	18.20
RX (uplink)	Uplink Frequency	GHz	50.00
	Antenna Size	m	0.1
	Number of ER	-	512
	Losses ER	dB	2
	Antenna Temperature	K	240.00
offset to D	Ambiant Temperature	K	290.00
29.9	Antenna gain (NADIR)	dBi	31.50
	Antenna gain (45°)	dBi	29.40
	G/T (NADIR)	dB/K	3.60
	G/T (45°)	dB/K	1.50
SCS PRB	SCS	kHz	120
	Downlink BW	MHz	400
	Nb Downlink PRBs	-	264
	Uplink BW	MHz	400
	Nb Uplink PRBs	-	264

FIGURE 4-119 SATELLITE HYPOTHESIS

4.5.6.4 UE hypothesis : summary

The table of FIGURE 4-120 and FIGURE 4-119 give the summary of all the parameters for the terminal definition used for the link budget.

UE	Parameter	Unit	Value
	Band Name	-	Q-V
RX (downlink)	Downlink Frequency	GHz	40.00
	Antenna Size	m	0.12
	Number of ER	-	512.00
	Directivity ER (NADIR)	dBi	6.17
	Directivity ER (EI 45°)	dBi	4.66
	Losses ER	dB	1.50
	Antenna Noise Figure (NF)	dB	4.00
	Antenna Temperature	K	140.00
	Ambiant Temperature	K	290.00
	Antenna gain (NADIR)	dBi	31.76
offset to D	Antenna gain (45°)	dBi	30.26
29.45	G/T (NADIR)	dB/K	3.81
	G/T (45°)	dB/K	2.31
SCS PRB	SCS	kHz	120.00
	Downlink BW	MHz	400.00
	Nb Downlink PRBs	-	264.00
	Uplink BW	MHz	400.00
	Nb Uplink PRBs	-	264.00
TX (uplink)	Uplink Frequency	GHz	50.00
	Antenna Size	m	0.09
	Number of ER	-	512.00
	Directivity ER (NADIR)	dBi	6.17
	Directivity ER (EI 45°)	dBi	4.66
	Losses ER	dB	2.00
	Antenna gain (NADIR)	dBi	31.26
	Antenna gain (45°)	dBi	29.76
	Antenna transmit power	dBW	4.00
	Antenna transmit power	W	2.51

FIGURE 4-120 UE HYPOTHESIS

For the terminal, a power of 2.5 W is considered on the budget and will be subject to sensitivity analysis.

The link budgets are given in Appendices **Error! Reference source not found.** and **Error! Reference source not found.**

4.5.7 Satellite Q/V band performances

The same methodology has been used for the estimation of the for constellation capacity estimation. The superposition factor for the Q/V band constellation remains the same as for C-band constellation (see FIGURE 4-66) as the coverage is identical.

As for the C-band. The simulation of the maximum capacity that a satellite could ensure on his coverage have been estimated in the following curves. It proceed in optimizing the capacity by selecting the configuration where the max throughput have been reached for a given number of active beams. In Q/V band, the payload is constituted of a panel of 7 DRA in Tx Q-band and 7 DRA in Rx V-band. Each DRA antenna is able to generate 4 beams which result in 28 actives beams per Tx panel antenna and 28 actives beams in Rx panel antenna.

4.5.7.1 Downlink performances Tx Q-band

For a given power of 53 W of RF power per DRA antenna in Tx, the downlink throughput have been calculated. For instance the results of optimization shows the set of beams obtained in the case of selection of 28 beams over 499 cells. Most of beams are near the centers of the coverage as expected. The optimizer manage to distribute beams with the RF power available with the constraint of 1 to 4 beams per DRA on the same coverage ensured by the 7 DRA.

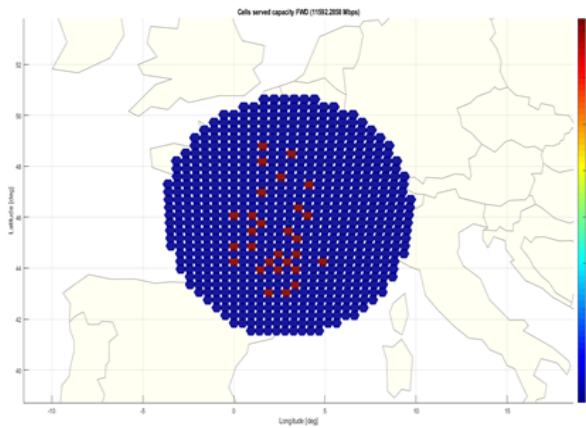


FIGURE 4-121 OPTIMUM DISTRIBUTION OF 28 BEAMS (PER DRA)

The Figure 4-122Figure 4-122 presents the results issued from optimization of maximum downlink throughput obtained versus the number of active beams (minimum of 7 with 1 per DRA to 28 with 4 per DRA). It could be noticed that the curve is not flat, the maximum is obtained for 1 beam per DRA.

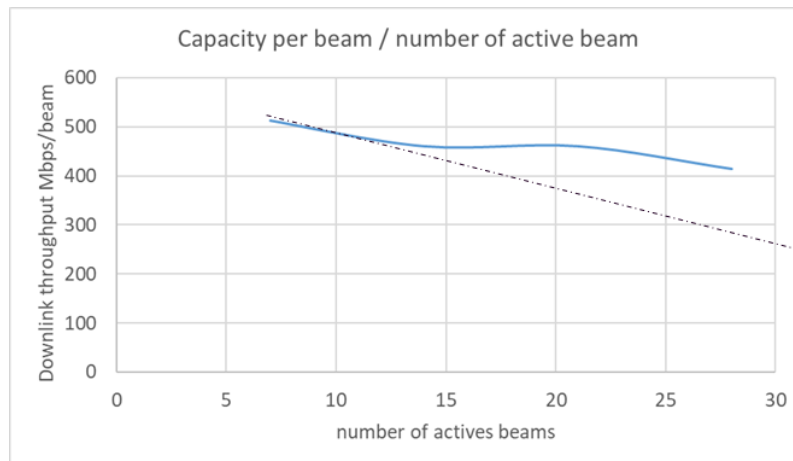


FIGURE 4-122 CAPACITY PER BEAM VERS NUMBER OF ACTIVE BEAMS

The EIRP flux density and the EIRP per beam versus the number of active beams are given in the Figure 4-123 and Figure 4-124.

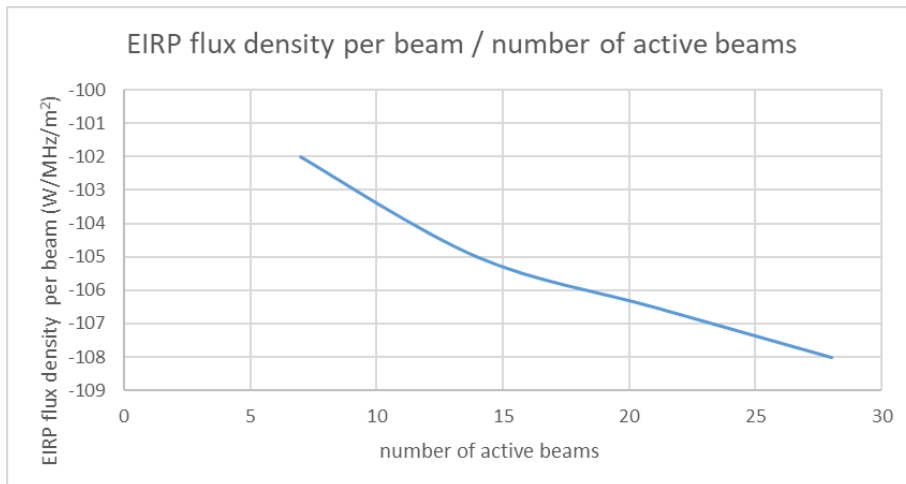


FIGURE 4-123 EIRP FLUX DENSITY VERSUS NUMBER OF ACTIVE BEAMS

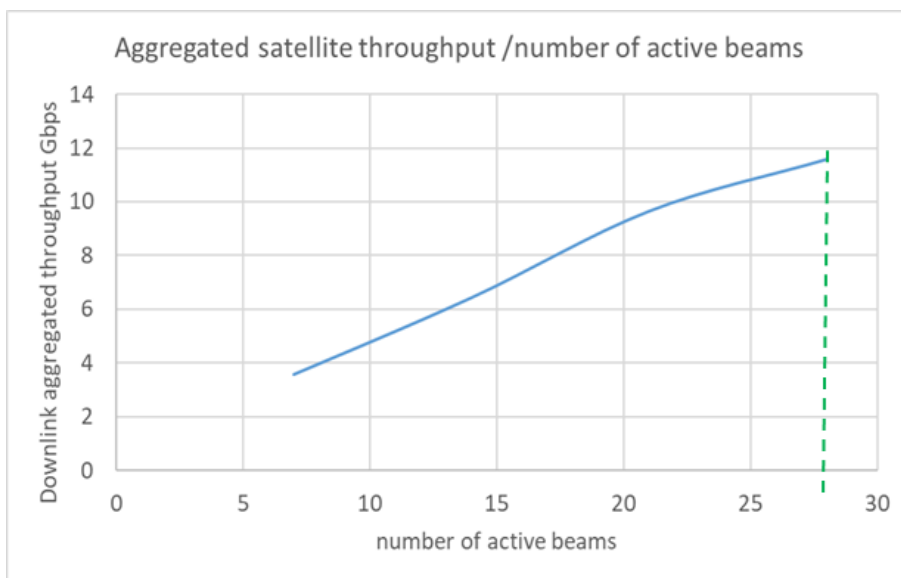


FIGURE 4-124 EIRP DENSITY VERSUS NUMBER OF ACTIVE BEAMS

Thus the total aggregated capacity of a satellite is given in Figure 4-125 Figure 4-70.

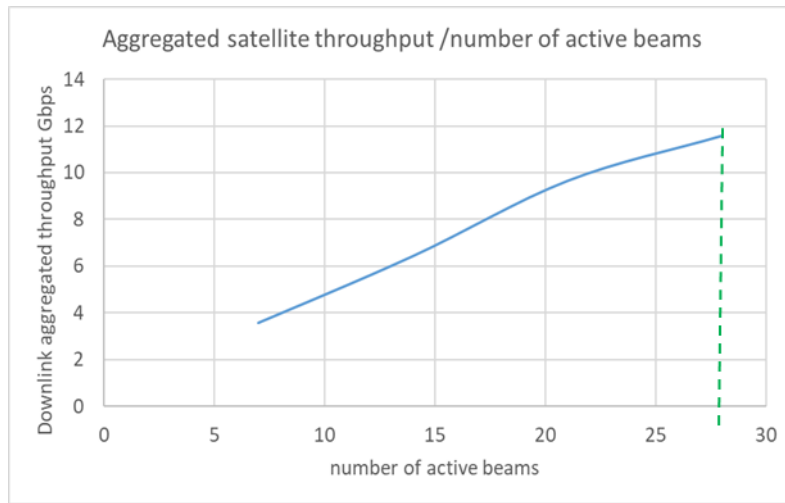


FIGURE 4-125 DOWNLINK THROUGHPUT TOTAL CAPACITY OF A SATELLITE VERS NUMBER OF ACTIVE BEAMS

The maximum is reached for 28 actives beams and reached almost 11.6 Gbps.

Up to know the throughput is computed for the optimum case, in the case where the selection is random as in the real case, the computation have been done and presented on the figure below :

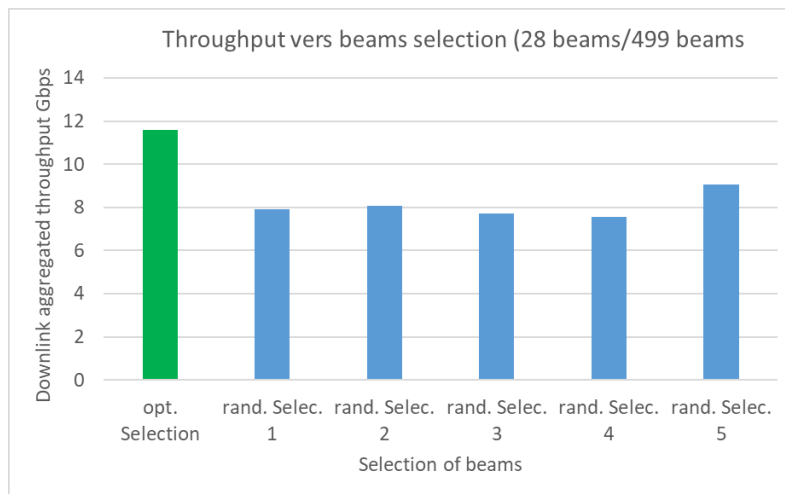


FIGURE 4-126 VARIATION OF THE THROUGHPUT WITH RANDOM SELECTION OF 28 BEAMS

The throughput varies between 11.6 Gbps to 7.5 Gbps for 28 active beams and the average 550 Mbps per beam.

4.5.7.2 Uplink Performances Rx V-band

For the uplink, the throughput is proportional of the number of active beams as illustrated by the Figure 4-127.

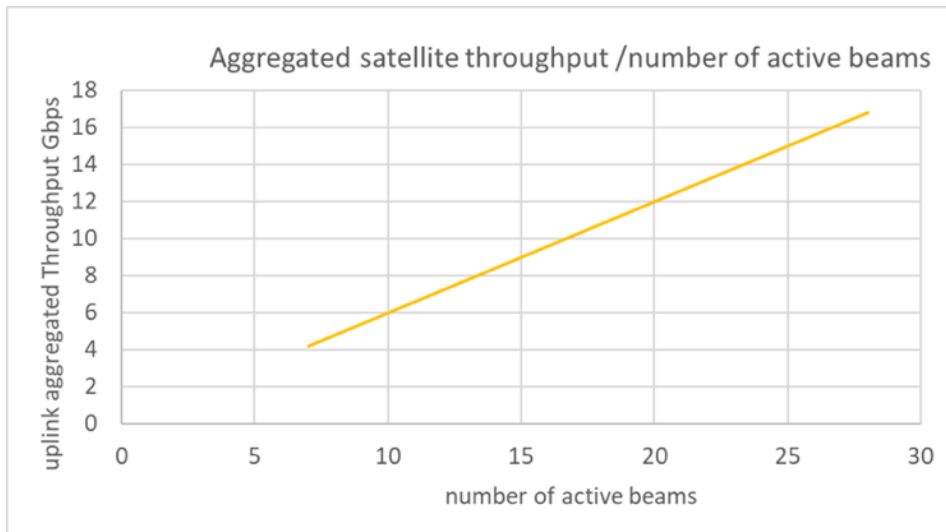


FIGURE 4-127 UPLINK THROUGHPUT VERSUS NUMBE OF ACTIVE BEAMS

- Uplink throughput proportional to number of active beams.
- The max throughput is 600 Mbps per beam with 1 PRB per user.
- The limitation of the uplink throughput is more on the capacity of processing data of the payload so the power consumption of the digital part of the paylod.

The throughput will vary according to the beam distribution over the coverage and in average Throughput per beam is 550 Mbps instead of 600 Mbps. For the maximum of beams that could reach a maximum of throughput the total uplink throughput 16.8 Gbps with an average of 15.4 Gbps.

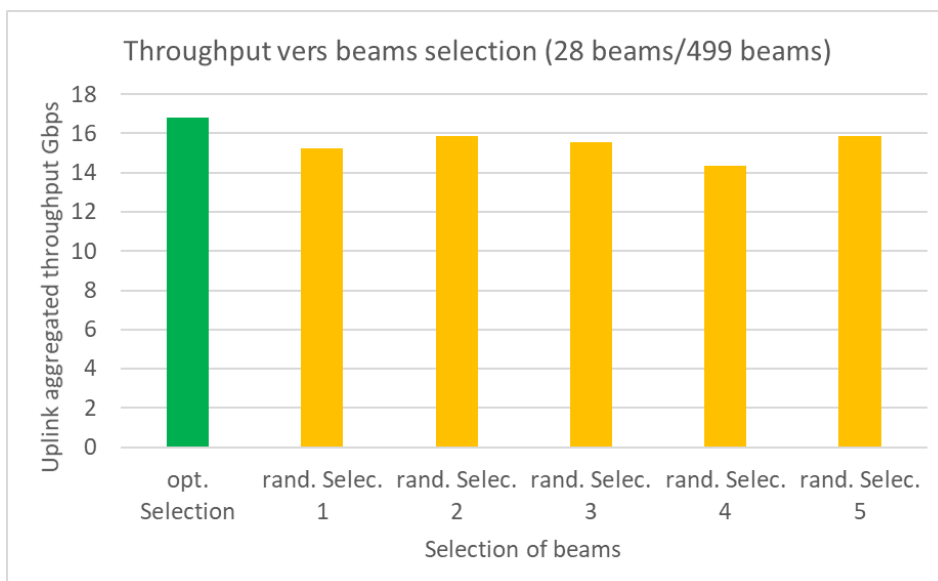


FIGURE 4-128 UPLINK THROUGHPUT FOR RANDOM SET OF BEAMS

4.6 LEO CONSTELLATION SATELLITE DESIGN

The FIGURE 4-129 give an “artistic” view of the two type of satellite (Feeder and User), the tables of The FIGURE 4-130 the C-band satellites description and the table of FIGURE 4-132 (3 architectures have been investigated (1,2 and 2’) and the Q/V band satellites 2 architectures have been investigated (1 & 2) . The architecture 2’ have been added only for C-band, the architecture 2’ is just an alternative where all other RF link than the user link are on the Feeder satellite. In C-band due to constraints off accommodation of the User antenna which occupy a large foot print on the platform.

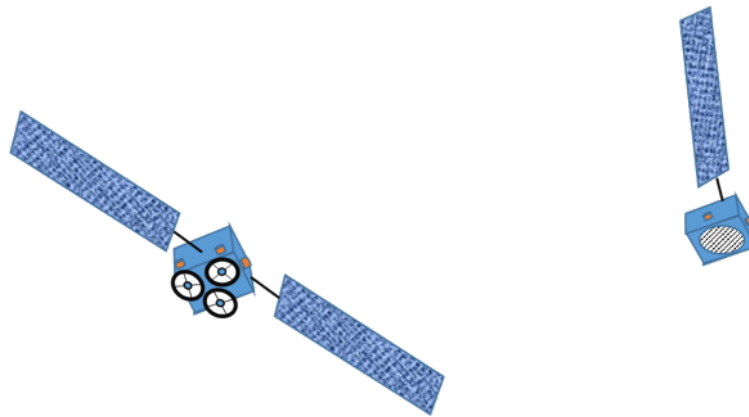


FIGURE 4-129 FEEDER SATELLITE & USERS SATELLITE (ARCH. 2)

In architecture 2 and 2’, the feeder are on the earth deck of the feeder satellite and the user antenna on the earth deck of the User satellite. The FIGURE 4-130 gives the Satellites description for C-Band mission according to the architecture 1,2 or 2’.

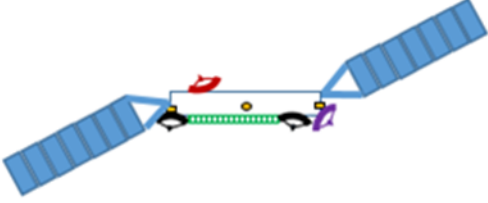
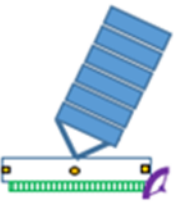



ARCHITECTURE 1	Service Satellite		Contents
Notes : Only one type of satellites	 <p>(1)</p>		(1) : OISL (4) C-BAND DRA (1) Q/V band feeder (2) Q/V band INL (1) Ka band ISL (1)
ARCHITECTURE 2	Service Satellite	Feeder satellite	
Notes : 2 types of satellites 1 composing two constellations	 <p>(1)</p>	 <p>(2)</p>	(1) : OISL (2) C-BAND DRA (1) Q/V band INL (1) (2) : OISL (8) Q/V band Feeder (2) Ka Band ISL (1)
ARCHITECTURE 2'	Service Satellite	Feeder satellite	
Notes : 2 types of satellites 1 composing two constellations	 <p>(1)</p>	 <p>(2)</p>	(1) : OISL (2) C-BAND DRA (1) (2) : OISL (8) Q/V band Feeder (2) Q/V band INL (1) Ka Band ISL (1)

FIGURE 4-131 SATELLITE DESCRIPTION C-BAND CASE A B & C

TheFIGURE 4-132, the satellites description for Q/V-Band mission according to the architecture 1,2.

For the Q/V band constellation only two architectures have been selected.

ARCHITECTURE 1	ARCHITECTURE 2	
User Satellite LEO Q/V-band	User Satellite LEO Q/V-Band	Feeder Satellite LEO Q/V-Band

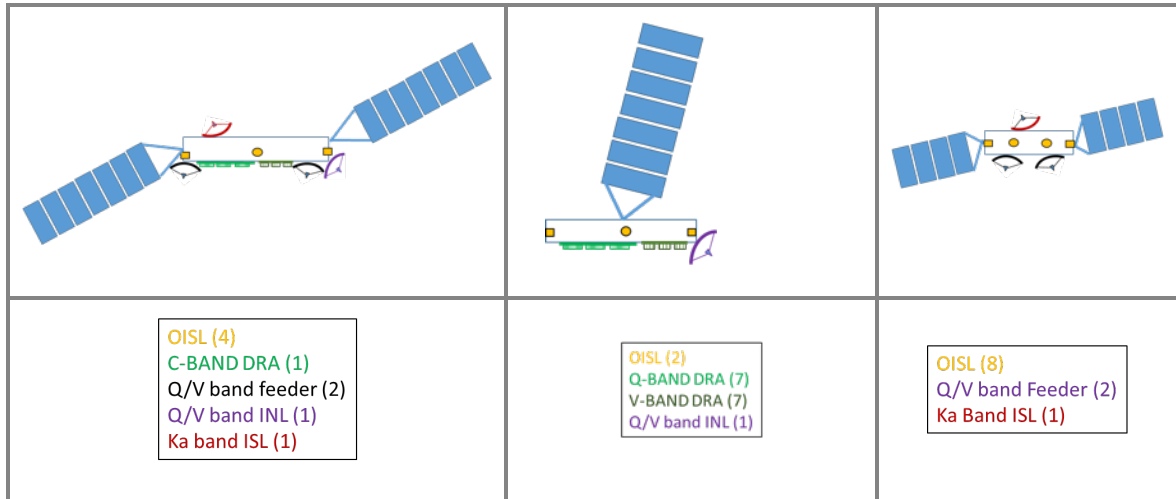


FIGURE 4-132 SATELLITE DESCRIPTION Q/V-BAND

These architecture will be estimated in term of advantages/drawback in term of satellite complexity in Task 3.4 and on its impact at system level in Task 3.1.

4.7 UAV PAYLOAD (HAPS) (FLEXIBLE)



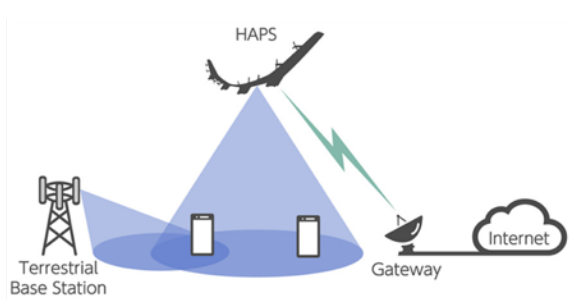

4.7.1 HAPS and Drones as a Station

4.7.1.1 Context

In this chapter we focus on the Aerials used as a base station not as an UE. The objective of the The Aerials type have different options several manufacturer works on this subject. [120]-[122]. There is a multiple possibility to envisage. HAPS and Aerials are subject to several studies in the literature and even some project are quite advanced. In this chapter we focus our interest on the HAPS or Drone as a “Base station “ providing an extension or an enhancement of the coverage locally or to face a temporarily failure for instance. In ITU HAPS used as Base Stations are named HIBS. This is a flexible nodes and it could also intervene in the “scalability concept” of the 6G NTN.

4.7.1.2 State of art

As mentioned previously the aerials could be diversives : ballon based (or flying base (close to a plane) The exemple of investigations is given in the figure below :

 	 
<p>Example project Thales Alenia Space [120]</p>	<p>Example : Aerial coverage (Softbank) [121]</p>

The two types illustrated above do not have the same constraints and have different operating modes, which has an impact on the missions for which they are intended.

There is also other types of Aerials. In this preliminary document we focus on HAPS types platform to investigate this flexible node, and we will look at what could be the mission that we can affect to such platform.

4.7.2 Mission descriptions

4.7.2.1 Requirements

The mission of a HAPS or Drone, is to cover a region with the same functionality then a base station- thus the main requirements will be :

- Ensure an additional coverage to the deterministic coverage in order to:
- enhance locally the capacities (adding a HAPS to fulfill a gap or infrastructure failure, natural disasters ...etc.)
- to fulfill new request and support market evolution
- to face a failure
- to allow a fast deployment (diseases) ...etc...
- The missions shall be consistent with the other all coverage (NTN and TN)
- the node shall be integrated to the 6 G NTN at any place on the earth.

- the HAPS evolve at a altitude of 18 to 25 kms

The HAPS have a real advantage : fast deployment and extremely low latency with the other advantage which to be relatively flexible could be removed if not needed and could also be updated.

4.7.2.2 State of Art on antenna solutions

The haps evolve at an altitude of maximum of 25 kms. In the literature several solutions are proposed with an associated antenna. For instance the solution with an antenna with 7 facets have been proposed

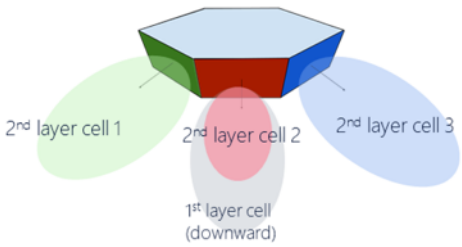
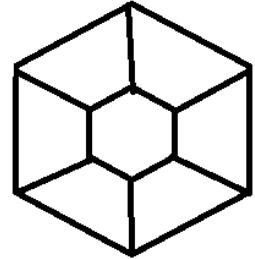
<p>FIGURE 6 Example of HIBS antenna design (for 7 cells deployment)</p> 	
<p>Altitude 20-50 km : payload composed of 7 pannels</p>	<p>Face view of the panel :</p> <p>Central panel DRA of 2x2 elements</p> <p>Side panel : DRA of 4x2 elements</p> <p>Gain of 8 dBi per elements</p>

FIGURE 4-133 EXEMPLE OF ANTENNA SOLUTIONS PROPOSED

The solution in [49] decribed in the figure FIGURE 4-133 could be used for ensuring a

- - HAPS 7 facet antenna covering each one cell
- Gain Tx : 14 and 17 dBi
- Gain Rx 14 and 17 dBi

An other solution is to use a cylindral antenna which will allow to cover low elevation angle and ensuring large coverage area.

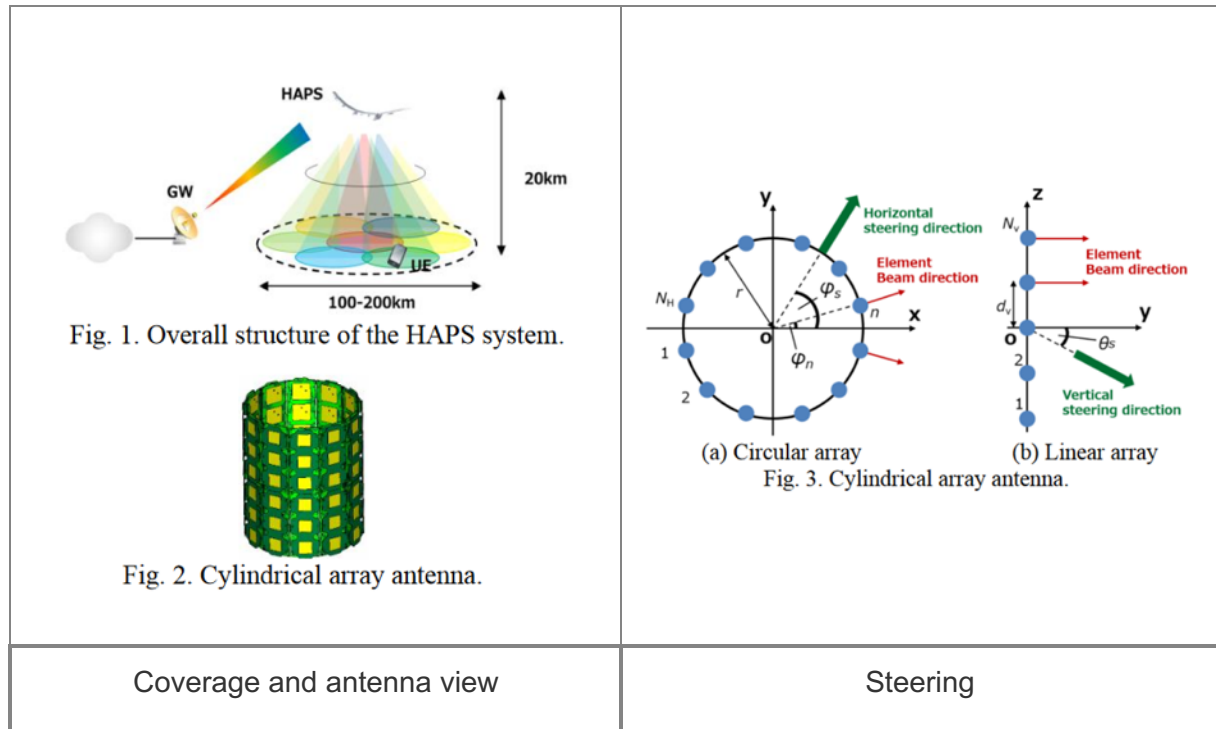


FIGURE 4-134 EXEMPLE OF ANTENNA SOLUTIONS PROPOSED IN [122]

These two solutions could be used for ensuring a service area. But present some drawbacks. They are based on fixed beam for the first and the second sectorial beams with beamsteering in horizontal plane. In the case of fixed earth beam, the first solution will be difficult to maintain the maximum gain over the cell with the movement of the platform; The second solution present the advantage to be adjustable over the cell, but the cell shape shall be in petals form. For the nadir beam an additional antenna shall be integrated at the top face.

4.7.2.3 Coverage selection

Up to now the constellation in LEO have been based on cell coverage of 45 km in LEO C-band and Q/V band. All the earth surface is meshed with this type of hexagonal cells.

The FIGURE 4-135 gives the parameters that define the HAPS coverage.

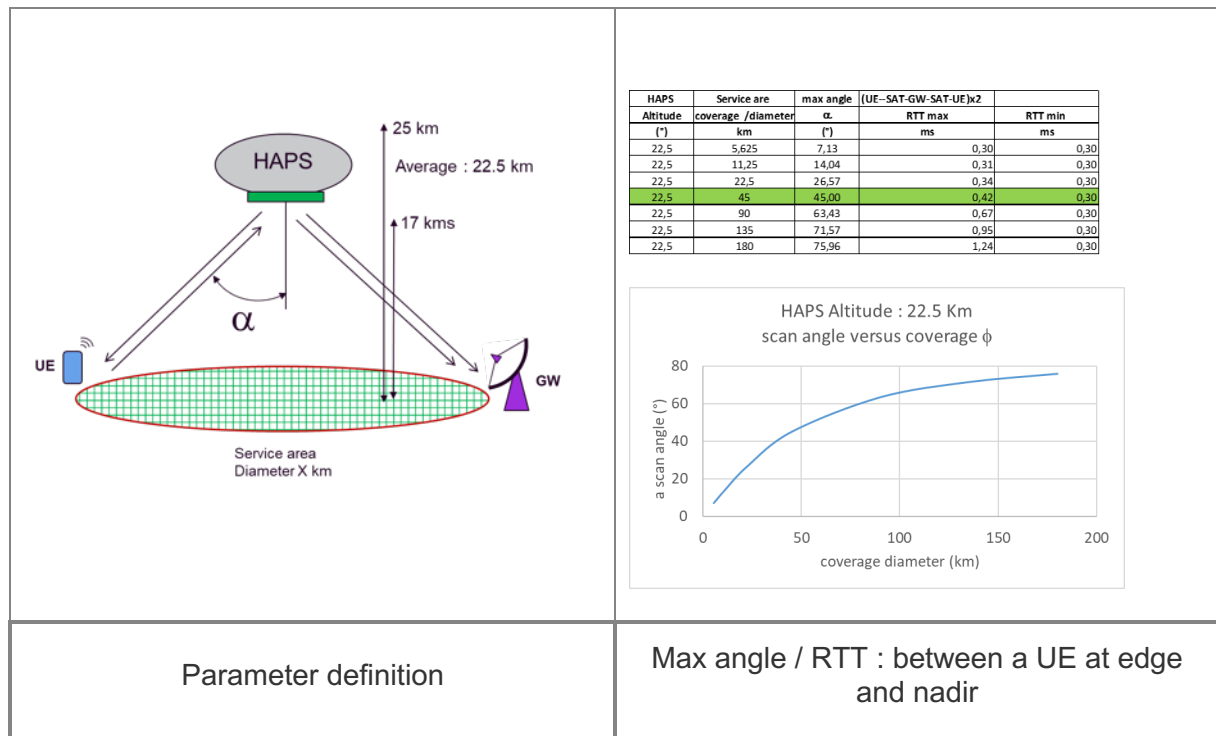


FIGURE 4-135 HAPS CHARACTERISTICS & PARAMETERS

The size of the coverage will determine the efficiency of the antenna and consequently the payload efficiency. From the curve of FIGURE 4-135, we can note that if the coverage exceed 50 km, the antenna shall be not efficient if it remains a plat plannel (DRA) oriented towards earth. As noticed in the previous solutions, to cover large area some solutions have been investigated, facetized antenna, cylindrical antenna and even in some same case some cosequant antenna. These last solutions are more complex to implement and to manage in terms of beam size over the cell. Although it allows to cover a large area, it is not compatible with constant sized cell.

The HAPS missions shall also be compatible in terms of integration to the overral system. Although several possibilities could be envisaged, even completely different coverage type, for convenience the first study in the scope of this system definition is to first chose a coverage almost compatible with the up to now cell definition. The orientation taken is to have a cell of max diameter of 45 km. This cell will be the same cell defined previously in LEO constellation. This limitation will allow to have a flat antenna (max scan angle 53° to 42° with haps altitude see FIGURE 4-137) which do not necessitate conformal or 3 dimensionnal type antenna. It will be possible to have a Basic DRA type antenna mounted on the earth deck of the HAPS platform.

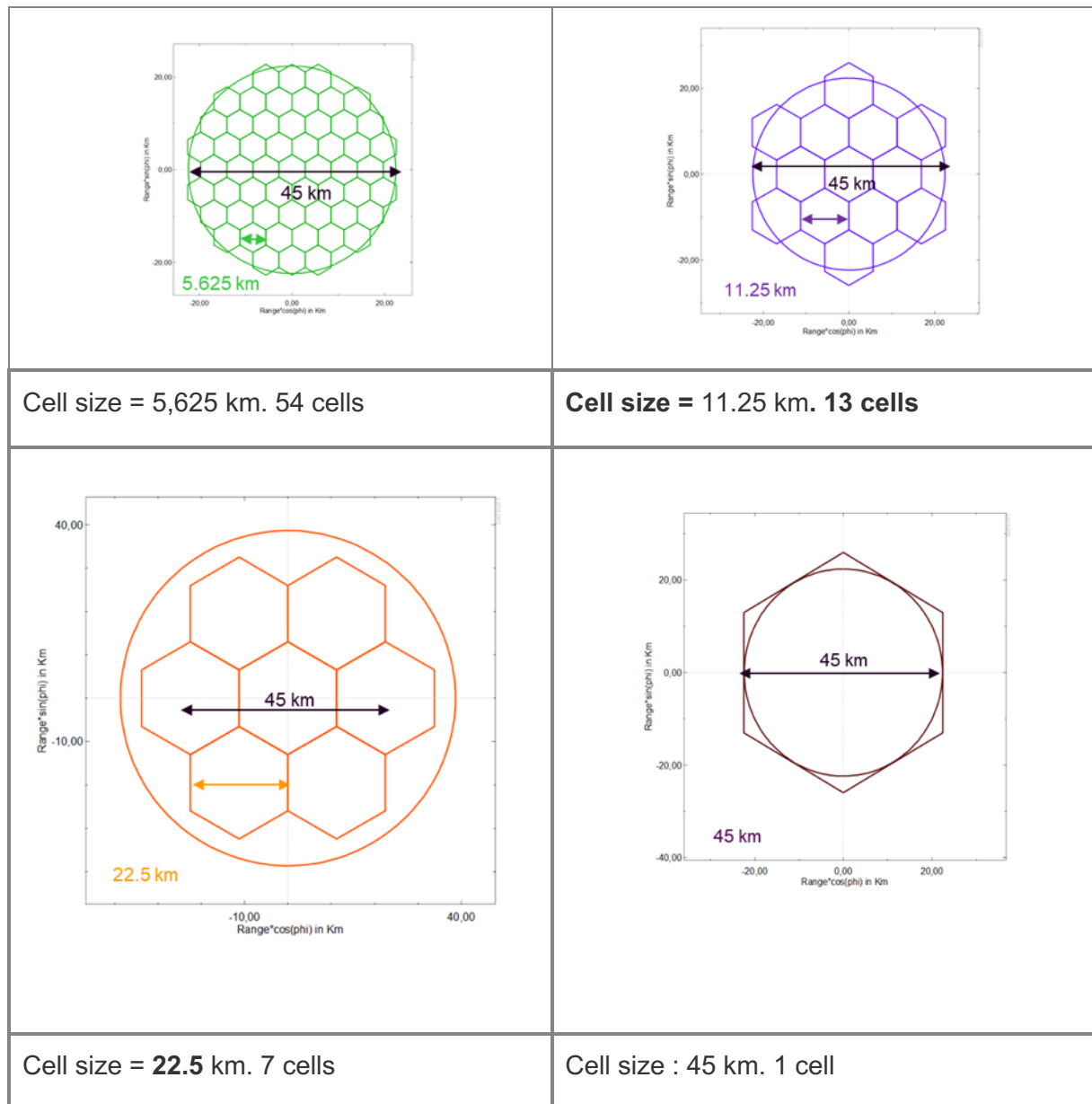


FIGURE 4-136 CELLS DEFINITIONS

The coverage and sub coverage (defined by sub-cells) are all superposed on the same area.

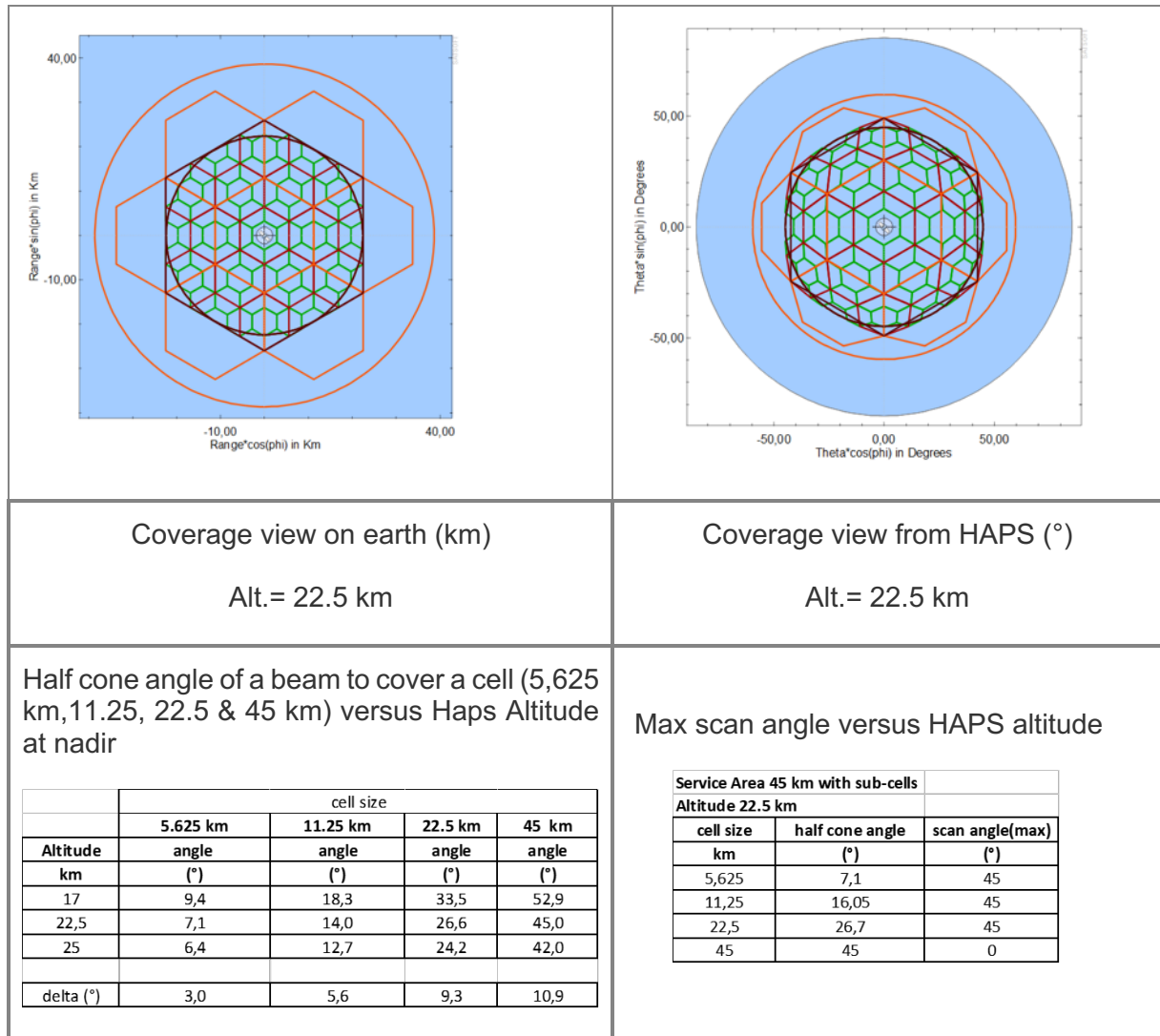


FIGURE 4-137 COVERAGE IMPACT VERSUS HAPS ALTITUDE AND CELLS SIZE

The tables in FIGURE 4-137 gives the variation of the view angle versus the altitude variation of the Haps. The beam forming shall be active and a refreshment operational; The HAPS stability is controlled but according to the atmosphere conditions could evolve. The need is a active antenna able to adapt over the fixed cells the beam performances.

The Table in FIGURE 4-137 gives also the maximum scan angle for cover all the cells. The maximum scan angle is 45°.

The figure show also the beam size according to subdivision of the coverage. The solution could be to generate multiples beams inside the coverage (a cell of 45 km identical to a cell of LEO satellite) so that the system 6G-NTN will be fully compatible between the nodes coverage. Moreover this compatibility could also be matched with the TN coverage. Firstly in order to facilitate the management of interferences between base station and HAPS which could function in the same frequency band as expected.

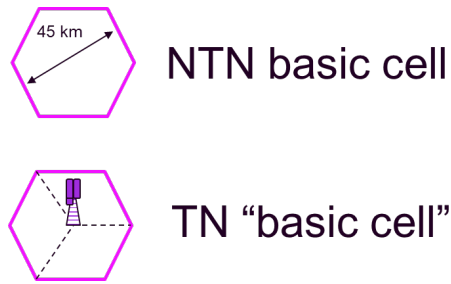


FIGURE 4-138 NTN CELL AND TN SECTOR COVERAGE COMPATIBILITY

4.7.3 Payload functionalities

The FIGURE 4-139 gives a view of all the link that the node (Haps_sta or Drone_sta) shall ensure.

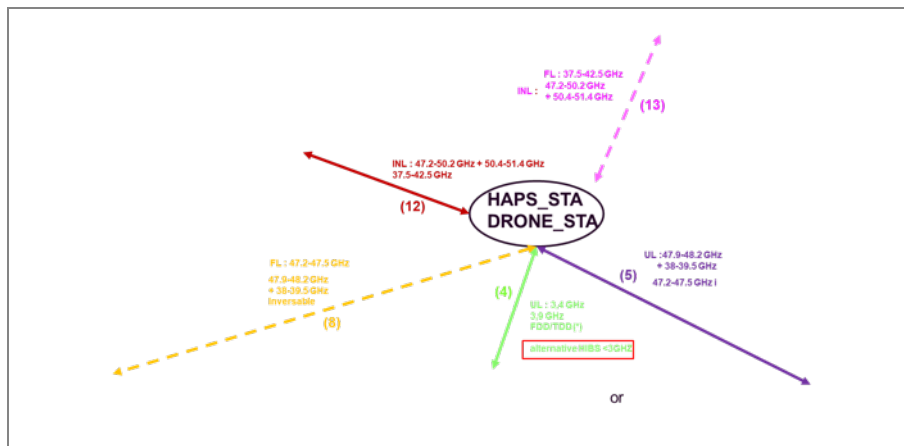


FIGURE 4-139 GEO CONSTELLATION AND THE LINK (USER, INTERNODES, FEEDER)

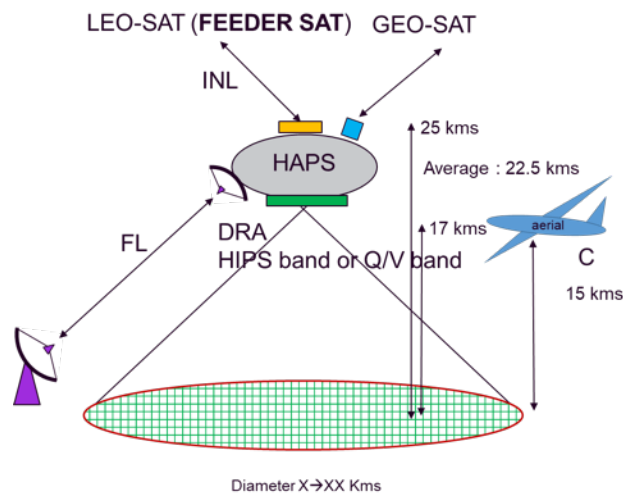


FIGURE 4-140 LINK DESCRIPTION FROM A HAPS

List of links :

(4) users links in S band (HIPS)

(5) user link in Q/V band

Remark : the HAPS not necessarily ensure the two missions and could be two types of drones

(8) Link to a gateway on earth → this link is not a priority by itself, because this limits the range of HAPS to being close to a gateway.

(12) Feeder link to a LEO satellite could be a LEO user satellite in case of architecture 1 or to a Feeder satellite in the case of architecture 2.

4.7.4 User Links S band (HIBS)

4.7.4.1 Frequency band & numerology

The frequency band in S Band foreseen is subject to proposition in the document 2.5 and is recalled in the table below (HIBS band):

ID	Frequency Range				Used Frequency				Channel Bandwidth				PRB				PRACH bandwidth
	Uplink Sat Rx / UE Tx		Downlink Sat Tx / UE Rx		Uplink Sat Rx / UE Tx		Downlink Sat Tx / UE Rx		Uplink Sat Rx / UE Tx		Downlink Sat Tx / UE Rx		Number of carriers	SCS bandwidth	PRB bandwidth	Number of PRB	
	Fmin (GHz)	Fmax(GHz)	Fmin (GHz)	Fmax(GHz)	GHz	Sat Tx / UE Rx	GHz	Sat Tx / UE Rx	MHz	Sat Rx / UE Tx	MHz	Sat Tx / UE Rx					
S	S2	1.98	2.015	2.16	2.2	2	2	20	20	180	180	12	15	180	106	1800	

FIGURE 4-141 NUMEROLOGY FR1 USED FOR Q/V-BAND

The choice of the numerology refers to document [16].

The HAPS acts as a base station; It is necessary when operating to verify the interference between HAPS coverage and the base station.

A bandwidth of 20 MHz for Rx and Tx are considered. The frequency band have not yet defined and will be adjusted when it will be defined (doc 2.5 [20]). Other HIBS band are possible. In this first analysis of solution one of the S band is taken.

rem :	The frequency band <1 GHz are removed		
	3GPP band	Uplink	Downlink
		MHz	MHz
	n1	1920-1980	2110-2170
	n2/n25	1850-1915	1930-1995
	n3	1710-1785	1805-1880
	n7	2500-2570	2620-2690

FIGURE 4-142 ALTERNATIVE FREQUENCY BAND

4.7.4.2 Orientation

The HAPS users link is in the HIBS bands at lower frequency (FR1) S band. The technology at this frequency is well mastered and the constraint of operation remain close to the terrestrial constraints (no stringent space environment). The design of such payload could be based on COTS technology.

In the choice of the cells and coverage, the mission dedicated to the HAPS (as defined) is to limit the coverage over a common cell (from LEO) with some subdivisions inside the master cell. This is a proposition up to now in order to allow the complementary and also the consistency of the missions between Earth/LEO/HAPS coverages.

The design of the antenna will be less complex than for satellite, EL min limited to 45° could be achieved with optimum losses in scan and in FSL. As the HAPS is moving, it is necessary to have a active antenna capable to adjust in real time the beams shaping. The natural orientation will be to have a DRA type antenna with a DBFN. The constraint of interference with the Base station shall also be taken into account especially the interference as (at grazing angle). As the Rx and Tx frequency is close, the DRA will be in Rx/Tx and in circular polarization.

4.7.4.3 Trade-off on the antenna size /cell size beamforming techniques

The first trade-off has been performed in order to define a geometry for the antenna. The maximum directivity for several size of antenna with a coverage of EI min of 45° but the avoidance angle shall not generate grating lobes towards will orient to take a RE of 0.55λ .

The number of elements will be limited to the size of the beam we would like to generate between 19 RE to 37 RE with a 9 dB dynamic.

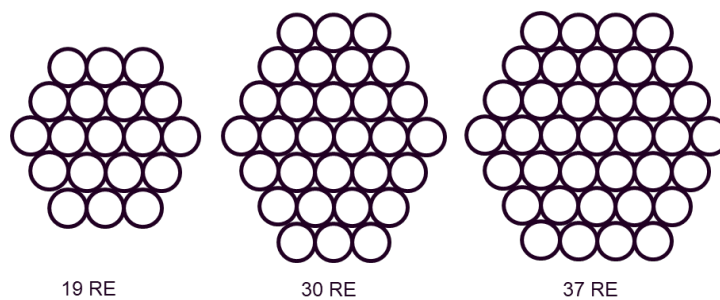


FIGURE 4-143 DRA SIZING

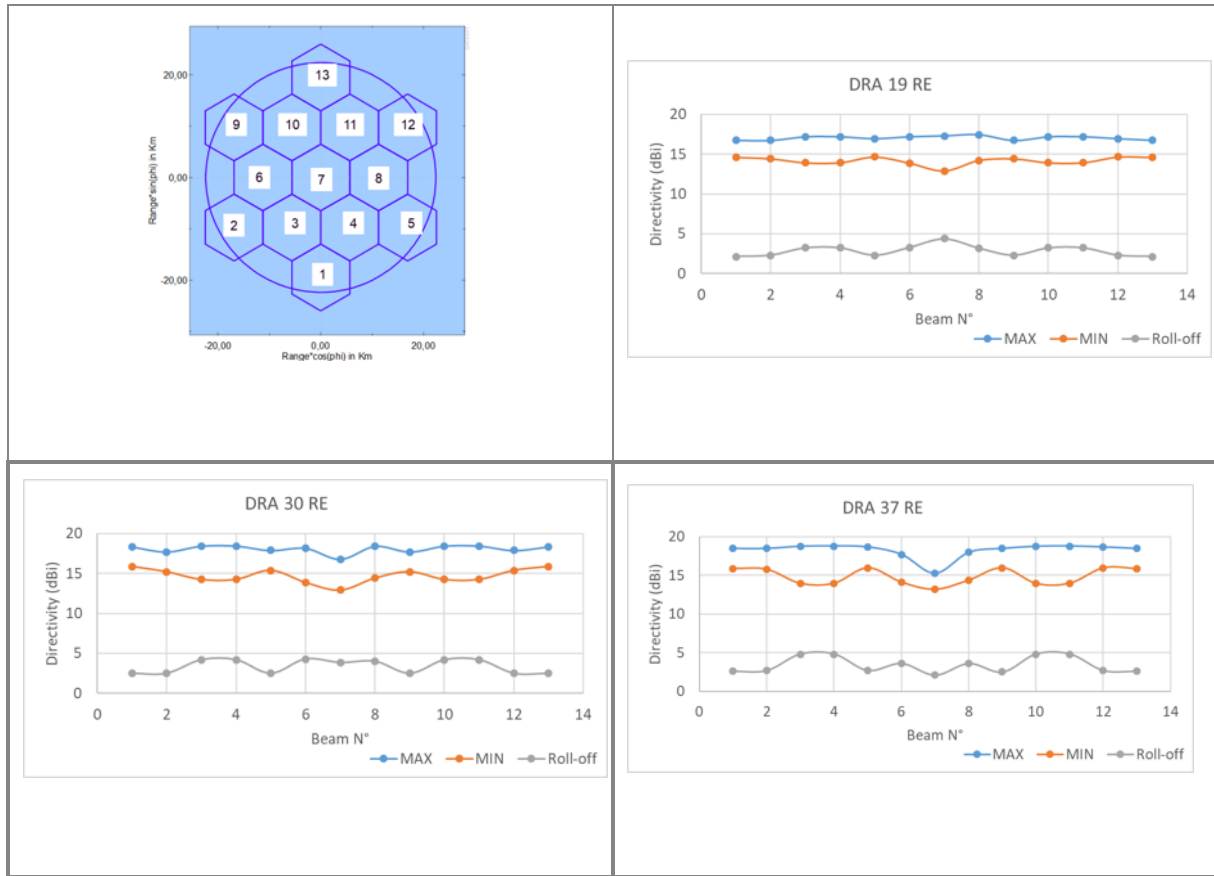


FIGURE 4-144 MAX/MIN DIRECTIVITY ANTENNA TRADE-OFF

The case of cells of 11.25 km have been taken as a basic value to evaluate the performances of the antenna in term of beam forming. In the beam forming a dynamic of 9dB have been applied. In general the minimum directivity will increase with the number of RE. But in some case the antenna could be too directive for the cell coverage. The dynamic, here in our case could be not sufficient for adapt the beam to the cell as shown in the FIGURE 4-144.

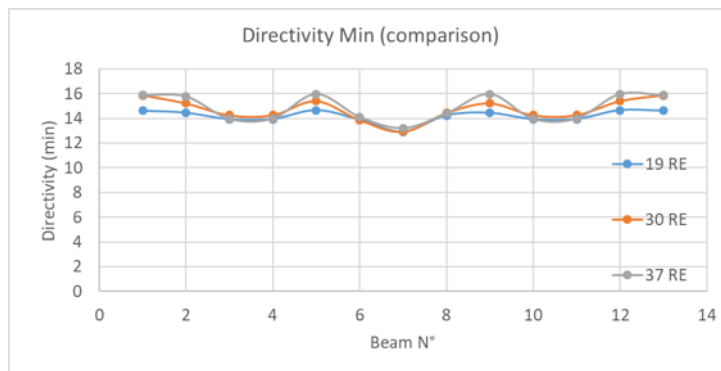


FIGURE 4-145 DIRECTIVITY MIN COMPARISON

The 30 RE DRA could be a compromise solution for cover all the cells from the smallest one

(5.625 km) to the largest one (45 km). If needed, the dynamic will be adjusted.

4.7.5 Solution S band Analysis

The following solutions 30 RE :

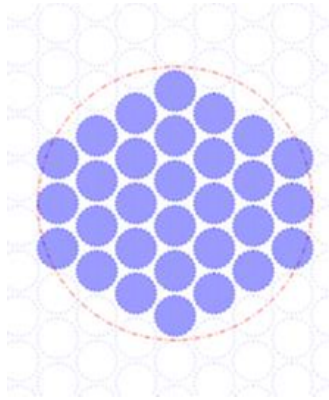


FIGURE 4-146 ANTENNA ARRAY GEOMETRY

The antenna have 30 RE in an hexagonal lattice. The spacing will be 0.55λ in order to avoid any grating lobes disturbance. It will realized in PCD or in patch on air (cup dipole ..etc) The diversity on the technology exist and are already used in space environment.

The antenna will be Rx/Tx , in circular polarization Rx :RHCP and Tx in LHCP.

The HAPS environment remains in atmospheric conditions even if the capacity of the dissipation is reduced, it is possible by means of appropriate dissipation (extractor device) to maintain a constant temperature.

4.7.5.1 Payload architecture

The payload architectures are presented in the FIGURE 4-148.

The architectures Rx and Tx are composed of an analog front end stage followed by a beam forming section. 7 antenna are connected to 7 ABFN. Each one is able to generate 4 or 8 beams. After digitalization, all the beam access are processed (beam management and demodulation/modulation section). The routing section will allow to dispatch the data towards the differents nodes thru the appropriate link (ISL, OISL, INL or Feeders). The architecture 1 and 2 differs only in the presence or not of the 2 links ISL and Feeder.

6G NTN HAPS (ARCHITECTURE)

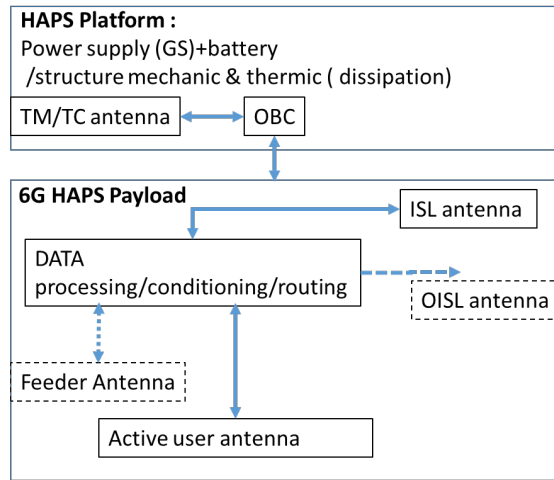


FIGURE 4-147 FUNCTIONAL DESCRIPTION HAPS/PAYLOAD

The beamforming will be based on a DBFN.

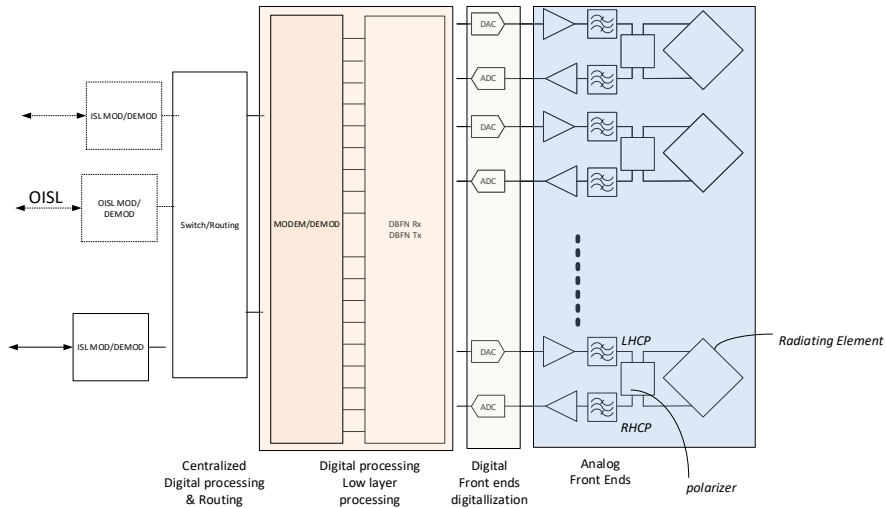


FIGURE 4-148 HAPS PAYLOAD ARCHITECTURE S BAND

4.7.5.2 Radiating element model

The radiating model is a 0.55λ elements. The lattice is hexagonal as shown in the FIGURE 4-102.

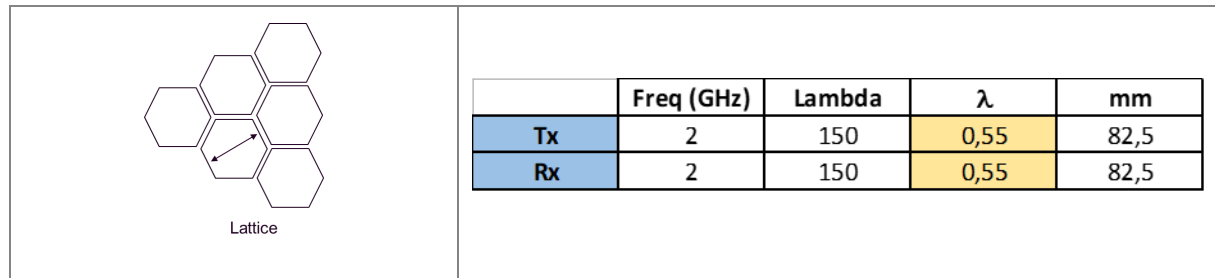


FIGURE 4-149 ANTENNA LATTICE

The radiating element model is given in the figure FIGURE 4-104. In Tx and In Rx the same lattice have been taken as the two functions are separated in two separate antenna and associated payload.

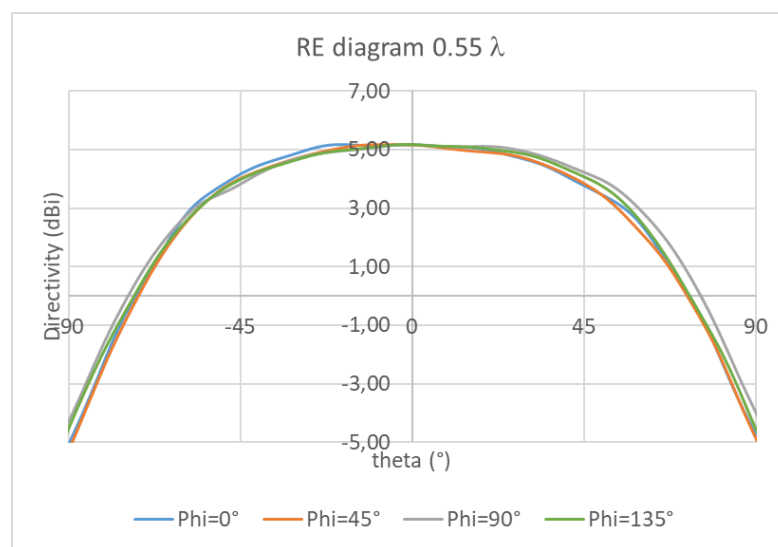


FIGURE 4-150 RADIATING ELEMENT DIAGRAMS FOR S BAND (DIRECTIVITY)

The radiating element size is 0.55λ . Close to 0.5λ , the coupling effect is normally more pronounced and impact off-axis directivity. In our case, the slope decrease will be less pronounced. The model used is based on an PCB based radiating element, which is certainly one of the technology that will be used for this antenna.

4.7.5.3 Antenna performances

The antenna panel is composed of 30 RE which work Rx and Tx . This antenna size have been selected to cover all type of beam inside the 45 km cells. The FIGURE 4-151, show the definition of the cells. Moreover the choice of the RE size to 0.55λ lets margin to cover some cells outside the nominal region of 45 cell.

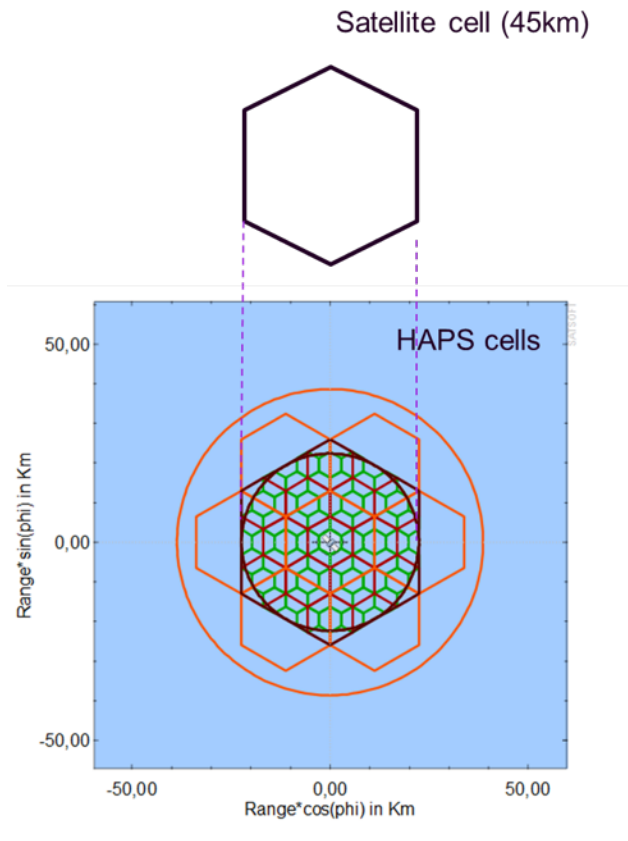


FIGURE 4-151 CORRESPONDENCE BETWEEN CELL DEFINITIONS (SATELLITE & HAPS) AND NESTINGS

The beams view for the different cell size are given in the following FIGURE 4-152 fo 5.615 kms cell, FIGURE 4-153 for the 11.25 km cell, FIGURE 4-154

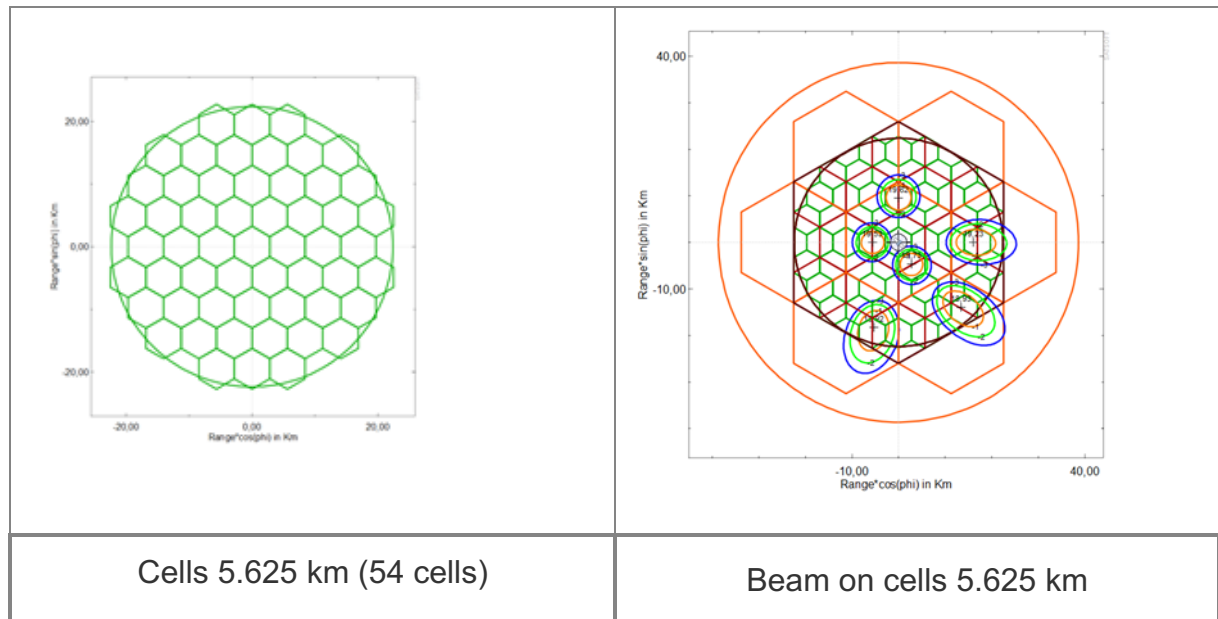


FIGURE 4-152 BEAM ON COVERAGE COMPOSED OF CELLS OF 5.625 KM

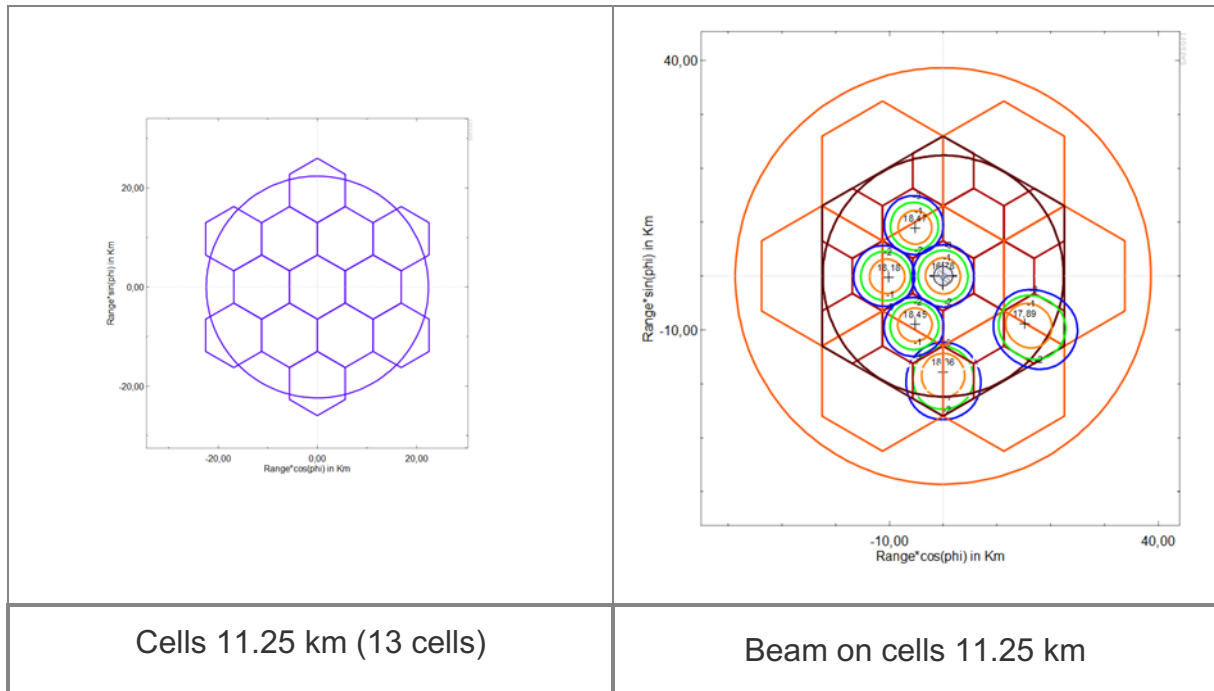


FIGURE 4-153 BEAM ON COVERAGE COMPOSED OF CELLS OF 11.25 KM

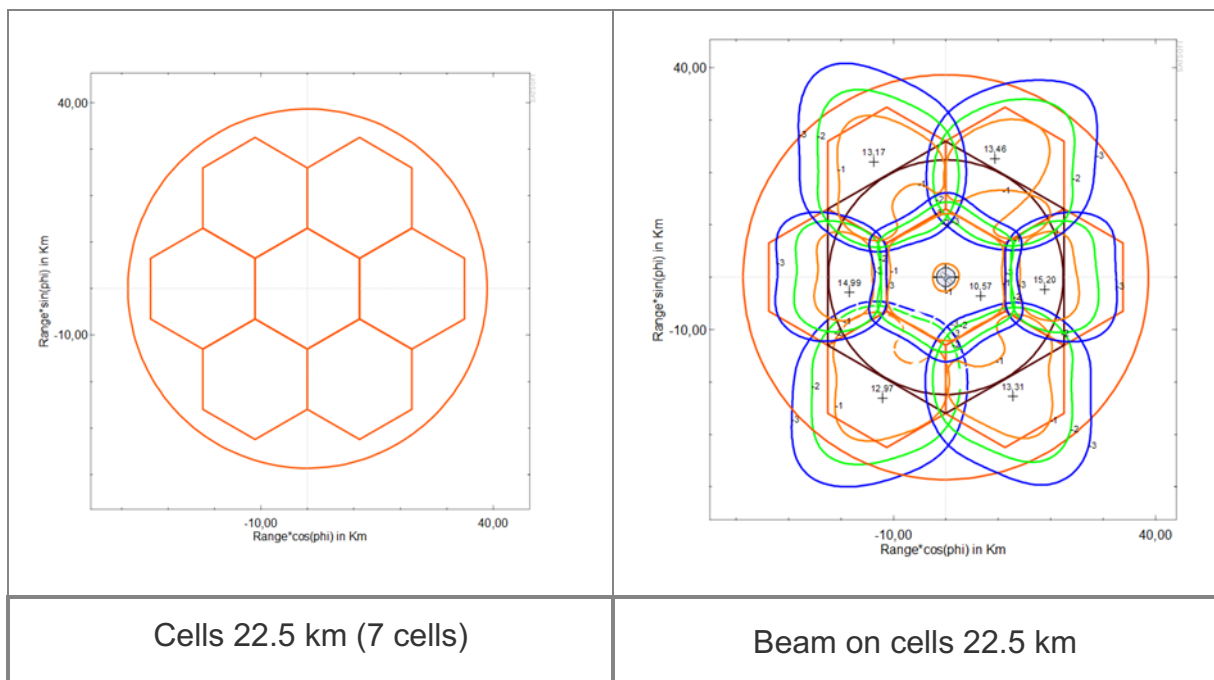


FIGURE 4-154 BEAM ON COVERAGE COMPOSED OF CELLS OF 22.5 KM

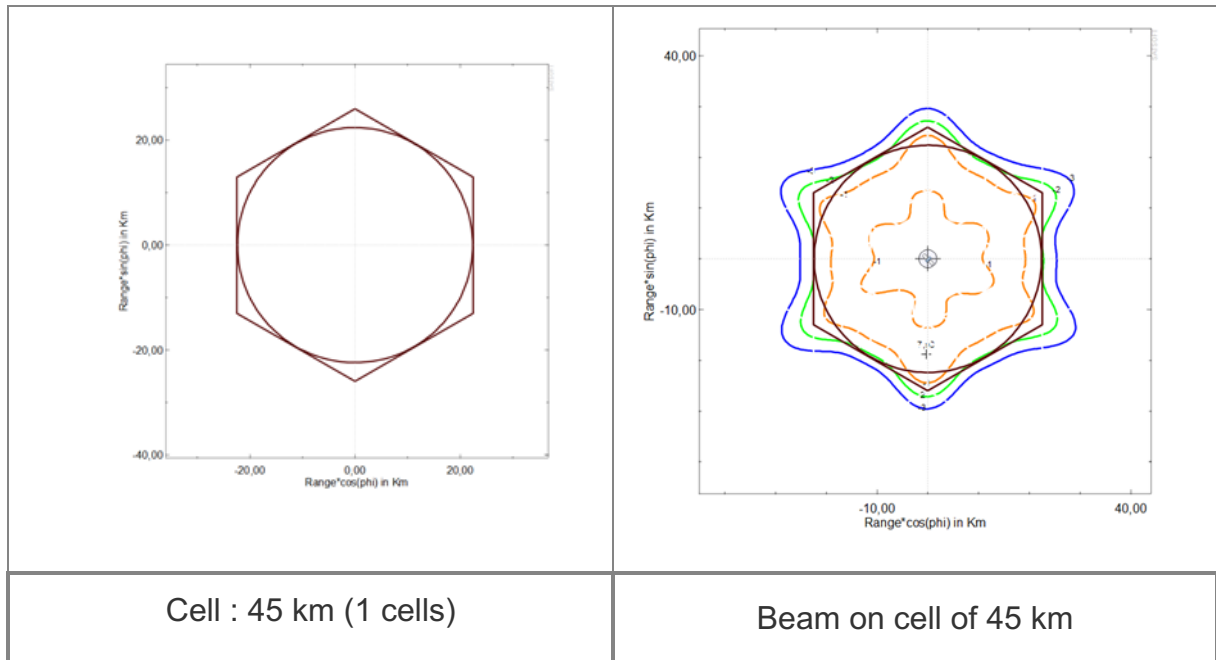


FIGURE 4-155 BEAM ON COVERAGE COMPOSED OF A CELL OF 45 KM

The performance of the antenna among the cells are summarized in the FIGURE 4-156.

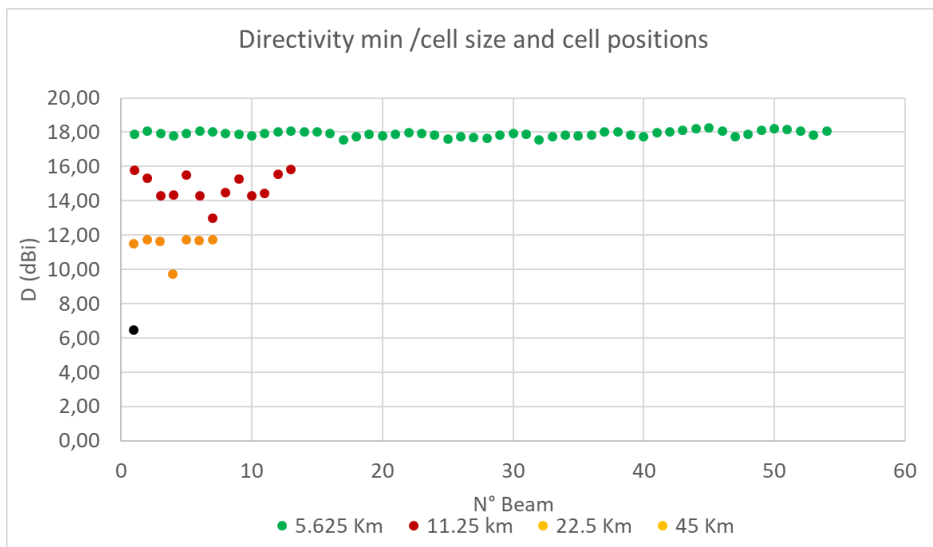


FIGURE 4-156 ANTENNA PERFORMANCES 30 RE

According to the needs in performances the beamforming could be adjusted to numbers of cells (and size) to cover. To realize a well matched beam to cell, it is necessary to have a high dynamic in amplitude. The min directivity will vary between 6 dBi to 18 dBi according to the cell size.

4.7.5.4 Grating lobes and side lobes

The frequencies for HAPS is in the HIBS frequency bands. Thus the limit to protect the UE from TN : are defined in [130] and recalled hereafter :

- Frequency band : 700-800-900 MHz : -114 dBW/m²/MHz
- Frequency band : 2 GHz (1.7-2.2 GHz) : -111 dBW/m²/MHz
- Frequency band around : 2.6 GHz : -109 dBW/m²/MHz

As we are concerned by the frequency band 2 GHz , we defined an exclusion area around the Haps coverage.

The FIGURE 4-157 give the PFD to confirm.

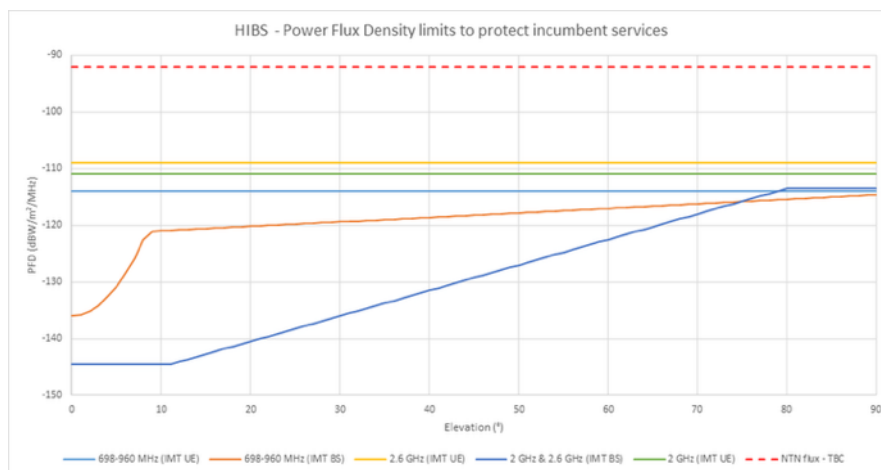


FIGURE 4-157 FLUX DENSITY LIMITS TO PROTECT MOBILE (IMT) SERVICES

The side lobes levels of the beam and the grating lobes shall be evaluated to respect this level of leakage emission toward an UE.

In our case the side lobes max level shall be less than -3 dBi as illustrated in the table of FIGURE 4-158 with a power of 20 W per beam.

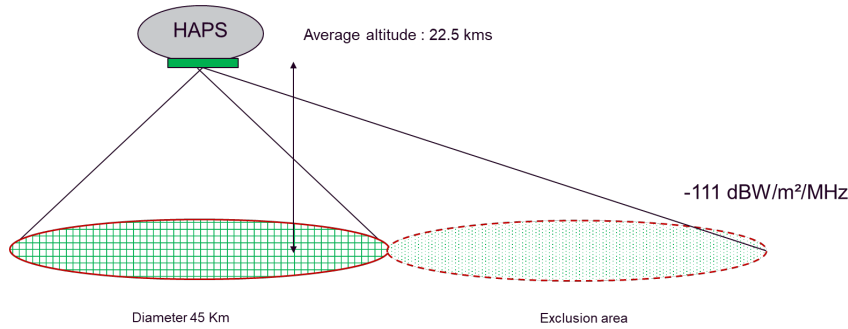


FIGURE 4-158 PFD LIMITS

4.7.6 Link Budget

4.7.6.1 Objectives

The objectives is to estimate the maximum throughput achievable with a mission on a HAPS with the hypothesis taken in the present case.

Parameter	Unit	Value
Band Name	-	S
Availability	%	99,50
Earth Radius	km	6371
Boltzmann	dBW/K/Hz	-228,6

FIGURE 4-159 CONSTANTS AND HYPOTHESIS

4.7.6.2 Antenna performances

The FIGURE 4-160 gives the hypothesis taken for elementary radiating element of the DRA mounted on a HAPS establish the preliminary link budget analysis.

	HAPS				Directivity	Directivity	Gain	Gain
	Frequency	λ	lattice	lattice	(NADIR)	(EI 45°)	(NADIR)	(EI 45°)
	GHz	mm	lambda	mm	dBi	dBi	dBi	dBi
Tx	2	150	0,55	82,5	4,72	3,67	2,72	1,67
Rx	2	150	0,55	82,5	4,72	3,67	1,67	1,67

FIGURE 4-160 ELEMENTARY ELEMENT PERFORMANCES HAPS

The Table below gives the UE terminal performances, it is supposed to be a single radiating elements. This terminal is a hemispheric coverage terminal, I will be used to estimated the best performance that could be reached with a S band terminal. In order to handle the other cases an attenuation factor up to -6 dB will be applied.

	Frequency	λ	lattice	lattice	Directivity	Directivity	Gain	Gain
	GHz	mm	lambda	mm	(NADIR)	(EI 45°)	(NADIR)	(EI 45°)
					dBi	dBi	dBi	dBi
Tx	2	150	0,55	82,5	4,72	3,67	2,72	1,67
Rx	2	150	0,55	82,5	4,72	3,67	1,67	1,67

FIGURE 4-161 ELEMENTARY ELEMENT PERFORMANCES TERMINAL (BEST CASE)

The value for the Terminal is taken as the best case, this hypothesis shall be reviewed with the different type of terminal as mentioned in the chapter 3.1.3.

The lattice for the satellite antenna is fixed to 0.55λ . The terminal is supposed to be also connectable to a base station (HIBS band) and the directivity shall be almost hemispheric. The Terminal performance in S band (HIBS) is not listed in the table. Integrated in a standard handheld it will have the following performances :Gain =-3 dBi NF=9 dB and power = 23 dBm. In our case we will consider G= 1 element gain (hemispheric), NF=9dB and power =23 dBm.

It is considered as a best case of terminal. In the link budget it will be used to estimate the peak performances. It could be the basis of an antenna on the top of a vehicle for instance. The real link budget and the estimation of the average throughput is not on the scope of this work. Nevertheless, an attenuation will be taken from this value to evaluate the worst case of link budget.

The power will be subject to sensitivity analysis. The power handling capacity will dimension the HAPS platform.

4.7.6.3 HAPS hypothesis : resume

The table of FIGURE 4-119 give the resume of all the parameters for the HAPS payload definition used for the link budget.

HAPS	Parameter	Unit	Value
	Satellite	-	HAPS
	Altitude	km	22,5
	Band Name	-	S
	Nb Sats	-	1
	Nb spots total	-	54
	Nb active spots during 1ms timeslot	-	1
	Cell diameter	km	45
TX (downlink)	Downlink Frequency	GHz	2,00
	Antenna Size	m	1
	Number of ER	-	30
	Directivity ER (NADIR)	dBi	4,72
	Directivity ER (EI 45°)	dBi	3,67
	Directivity ER (EI 30°)	dBi	1,71
	Losses ER	dB	2
	Antenna gain (NADIR)	dBi	17,49
	Antenna gain (EI 45°)	dBi	16,44
	Antenna gain (EI 30°)	dBi	14,48
	EIRP density	dBW/MHz	15,00
	EIRP density attenuation	dB	0,00
	Effective EIRP density	dBW/MHz	15,00
RX (uplink)	Uplink Frequency	GHz	2,00
	Antenna Size	m	0
	Number of ER	-	30
	Directivity ER (NADIR)	dBi	4,72
	Directivity ER (EI 45°)		3,67
	Directivity ER (EI 30°)		1,71
	Losses ER	dB	2
	Antenna Noise Figure (NF)	dB	4,20
	Antenna Temperature	K	290,00
	Ambiant Temperature	K	290,00
	Equivalent Temperature	K	762,78
	Antenna gain (NADIR)	dBi	17,49
	Antenna gain (45°)	dBi	16,44
	Antenna gain (30°)	dBi	14,48
	G/T (NADIR) Target	dB/K	-11,13
	G/T (NADIR)	dB/K	-11,34
	G/T (45°)	dB/K	-12,38
	G/T(30°)	dB/K	-14,35
SCS PRB	SCS	kHz	15
	Downlink BW	MHz	20
	Nb Downlink PRBs	-	106
	Uplink BW	MHz	20
	Nb Uplink PRBs	-	106
c/I	Downlink (Sat TX)	dB	14
	Uplink (SatRX)	dB	14

FIGURE 4-162 HAPS HYPOTHESIS

4.7.6.4 UE hypothesis : summary

The table of give the summary of all the parameters for the terminal definition used for the link budget.

UE	Parameter	Unit	Value
	Band Name	-	S
RX (downlink)	Downlink Frequency	(GHz)	2,00
	Antenna Size	(m)	0,0825
	Number of ER	-	1
	Directivity ER (NADIR)	(dBi)	4,72
	Directivity ER (EI 45°)	(dBi)	3,67
	Directivity ER (EI 30°)	(dBi)	1,71
	Losses ER	(dB)	2
	Antenna Noise Figure (NF)	(dB)	9,00
	Antenna gain (NADIR)	(dBi)	2,72
	Antenna gain (45°)	(dBi)	1,67
	Antenna gain (30°)	(dBi)	-0,29
	G/T (NADIR)	dB/K	-30,91
	G/T (45°)	dB/K	-31,96
	G/T(30°)	dB/K	-33,92
	Polarisation mismatch loss	dB	3,00
SCS PRB	SCS	kHz	15
	Downlink BW	MHz	20
	Nb Downlink PRBs	-	106
	Uplink BW	MHz	20
	Nb Uplink PRBs	-	106
TX (uplink)	Uplink Frequency	(GHz)	2,00
	Antenna Size	(m)	0,0975
	Number of ER	-	1
	Directivity ER (NADIR)	(dBi)	4,72
	Directivity ER (EI 45°)	(dBi)	3,67
	Directivity ER (EI 30°)	(dBi)	1,71
	Losses ER	(dB)	2
	Antenna gain (NADIR)	(dBi)	2,72
	Antenna gain (45°)	(dBi)	1,67
	Antenna gain (30°)	(dBi)	-0,29
	Antenna transmit power	dBW	-7
	Antenna transmit power	W	0,20
	Polarisation mismatch loss	dB	3,00

FIGURE 4-163 UE HYPOTHESIS

The parameters for the UE is for a terminal in the best conditions. Sensitivity analysis shall be performed to estimate the average performance achieved with an UE.

4.7.6.5 Uplink

The exemple of link budget has been given for the uplink in the table of FIGURE 9-81.

✓ PRACH Link Budget		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	S	S
	PRB bandwidth	kHz	180,00	180,00
	Number Max of PRBs	-	106	106
	Number of used PRBs	-	106	106
	Occupied Channel Bandwidth	MHz	19,08	19,08
	Total Channel Bandwidth	MHz	19,08	19,08
	Uplink Frequency	GHz	2,00	2,00
	Nb spots	-	1	1
UE - TX	Elevation angle to satellite	°	45,00	90,00
	Skant Range	km	31,76	22,50
	Antenna view angle	°	44,80	0,00
	Polarisation mismatch loss	dB	3,00	3,00
	Antenna Transmit Power	dBW	-7,00	-7,00
	Cable loss	dB	0,00	0,00
	Transmit Gain	dBi	1,67	2,72
	EIRP	dBW	-5,33	-4,28
	EIRP per PRB	dBW	-25,59	-24,54
SATELLITE - RX	Satellite altitude	km	22,50	22,50
	Satellite figure of merit (G/T)	dB/K	-12,38	-11,34
LOSSES	Free space propagation	dB	128,51	125,51
RESULTS CONFIGURATIONS	Number of PRB per UE	-	106	106
	Efficiency value sources	-	TAS simulations Sky Tower	
	Block Error Rate Target	-	0,1	0,1
RESULTS	Obtained C/N	dB	5,85	9,66
	Nearest C/N	dB	5,62	9,01
	Residual Margins	dB	0,2269	0,6548
	Spectral Efficiency	bits/s/Hz	1,3585	1,9874
	PRB Rate	kb/s	244,525	357,729
	UE Rate	Mbit/s	25,920	37,919
	Max cell rate (1 UE by cell) transmitting on all PRB	Mbits/s	25,920	37,919
	Total sat capacity	Mbits/s	25,92	37,92
	Total BW	MHz	20	20
	Nb Sats	-	1,00	1,00
	Constellation capacity	Tb/s	0,00	0,00

FIGURE 4-164 UPLINK BUDGET

The uplink performances evaluations in different contexts is given in the table

UE	Parameter	Unit	Value
	Band Name	-	S
RX (downlink)	Downlink Frequency	(GHz)	2,00
	Antenna Size	(m)	0,0825
	Number of ER	-	1
	Directivity ER (NADIR)	(dBi)	4,72
	Directivity ER (Ei 45°)	(dBi)	3,67
	Directivity ER (Ei 30°)	(dBi)	1,71
	Losses ER	(dB)	2
	Antenna Noise Figure (NF)	(dB)	9,00
	Antenna gain (NADIR)	(dBi)	2,72
	Antenna gain (45°)	(dBi)	1,67
	Antenna gain (30°)	(dBi)	-0,29
	G/T (NADIR)	dB/K	-30,91
	G/T (45°)	dB/K	-31,96
	G/T(30°)	dB/K	-33,92
	Polarisation mismatch loss	dB	3,00
SCS PRB	SCS	kHz	15
	Downlink BW	MHz	20
	Nb Downlink PRBs	-	106
	Uplink BW	MHz	20
	Nb Uplink PRBs	-	106
TX (uplink)	Uplink Frequency	(GHz)	2,00
	Antenna Size	(m)	0,0975
	Number of ER	-	1
	Directivity ER (NADIR)	(dBi)	4,72
	Directivity ER (Ei 45°)	(dBi)	3,67
	Directivity ER (Ei 30°)	(dBi)	1,71
	Losses ER	(dB)	2
	Antenna gain (NADIR)	(dBi)	2,72
	Antenna gain (45°)	(dBi)	1,67
	Antenna gain (30°)	(dBi)	-0,29
	Antenna transmit power	dBW	-7
	Antenna transmit power	W	0,20
	Polarisation mismatch loss	dB	3,00

FIGURE 4-165 PERFORMANCES EVALUATION IN DIFFERENT CONFIGURATIONS.

4.7.6.6 Downlink

		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	S	S
	PRB bandwidth	khz	180,00	180,00
	Number Max of PRBs	-	106	106
	Number of used PRBs	-	106	106
	Occupied Channel Bandwidth	MHz	19,08	19,08
	Total Channel Bandwidth	MHz	19,08	19,08
	Downlink Frequency	GHz	2,00	2,00
	Nb active spots during 1ms timeslot	-	1	1
	Nb spots total	-	54	54
SATELLITE - TX	EIRP density	dBW/MHz	15,00	15,00
	EIRP	dBW	27,81	27,81
	EIRP per PRB	dBW	7,55	7,55
	Satellite altitude	km	22,50	22,50
UE - RX	Elevation angle to satellite (seen from UE)	°	45,00	90,00
	Slant Range	km	31,76	22,50
	Antenna view angle	°	44,80	0,00
	Equivalent Temperature	K	2303,55	2303,55
	Receive Antenna Gain	dBi	1,67	2,72
	Figure of Merit: G/T	dB/K	-31,96	-30,91
	Polarisation mismatch loss	dB	3,00	3,00
	Effective G/T under satellite coverage	dB/K	-34,96	-33,91
LOSSES	Free space propagation	dB	128,51	125,51
RESULTS CONFIGURATIONS	Number of used PRBs	-	106	106
RESULTS	Obtained C/N	dB	13,05	13,60
	Required C/N	dB	10,85	13,36
	Residual Margins	dB	2,20	0,24
	Spectral Efficiency	bits/s/Hz	1,6461	1,8578
	Rate per PRB	kb/s	296,30	334,40
	UE Rate	Mbits/s	31,41	35,45

FIGURE 4-166 DOWNLINK LINK BUDGET

4.7.7 User Links Q/V band

The case of User link from HAPS in Q/V band will be addressed in the next phase of the study. The solution foreseen in that case could be a DRA as for the satellite user link. The solution is less obvious in this case: if we adopt the S-band solution with the same mesh, the antenna would only have around 30 elements for the cell sizes targeted (5.625 km, 11.25 km, 22.5 km, 45 km). The antenna will be physically small, making the insertion of power amplifiers more constraining, and the dissipation to be managed more critical. This means that a single antenna will not be able to generate enough EIRP for several beams. In this case, a panel of smaller antennas will have to be used, as in the case of the Q/V user antenna.

4.8 FEEDER LINK LEO GATEWAY

4.8.1 Introduction

In this part, only for Feeder link in LEO (link (6) defined in **Error! Reference source not found.** and FIGURE 4-94 are presented. In GEO case link are defined are essentially in Ka band, even if in the last recent years the frequency this link evolve to Q/V band. In GEO the need is just fixed oriented beam, at least steerable beam to point toward a Gateways, but no need for a high speed pointing system.

The satellite feeder antenna is based on reflector type antenna. It could be based on a double reflector type antenna as Gregorian or cassegranian topology based on simple optics

(paraboloid). This will allow high gain with low losses. The system shall be mechanically steerable also in GEO in order to be able to change the Gateways. but the constraint are relaxed compared to LEO satellite where the antenna shall be able to point toward a gateway constantly and ensure the handover when it keep out of the coverage region. For LEO mission the needs are completely different and the strong request is to be steerable when moving on the orbital plane. The next chapters are dedicated to LEO feeder links.

4.8.2 Trade-off and solution orientation

Several solutions based on reflector system are been investigated in the literature and also operational in the constellation in service and foreseen in the next fews years. These kind of antenna are largely used for feeder link in LEO and GEO and solutions exist. In the 6G NTN, the number of feeder links by satellite is not yet fixed and are in discussions.

Active antenna could also be used for the capacity to steer beam electronically. Its efficiency remains low compared to an optical system for the same functionality and it is not justified. It could be a solution if several beams is necessary up to 4 for instance.

In certain case, one or two beams from the users antenna (active antenna) could be used as a feeder backup. This eventually therefore will depend on the capacity throughput to handle. These links capacity through the users antenna remains low compared to the throughput to convey. A dedicated active antenna in Q/V band could be used on the Feeder satellite for instance.

Another solution for generating a single beam is to take a purely passive antenna array with a passive combiner and place it on a mechanically adjustable platform. This type of solution can be interesting if the footprint on the platform is very restrictive, to the detriment of efficiency. Solutions are still being studied, and the idea is to leave this possibility open. In our case, the best solutions are based on a dual-reflector system [123-126].

Among the solutions, the two main promising solutions are the solution based on a newton optics and one based Cassegrainian optics. They are based on steerable antenna compact or deployable in order to reduce the volume in the satellite fairing.

For the first one the feed is fix only the reflector (plane reflector associated with a paraboloid reflector) are moving as illustrated in the figure FIGURE 4-167.

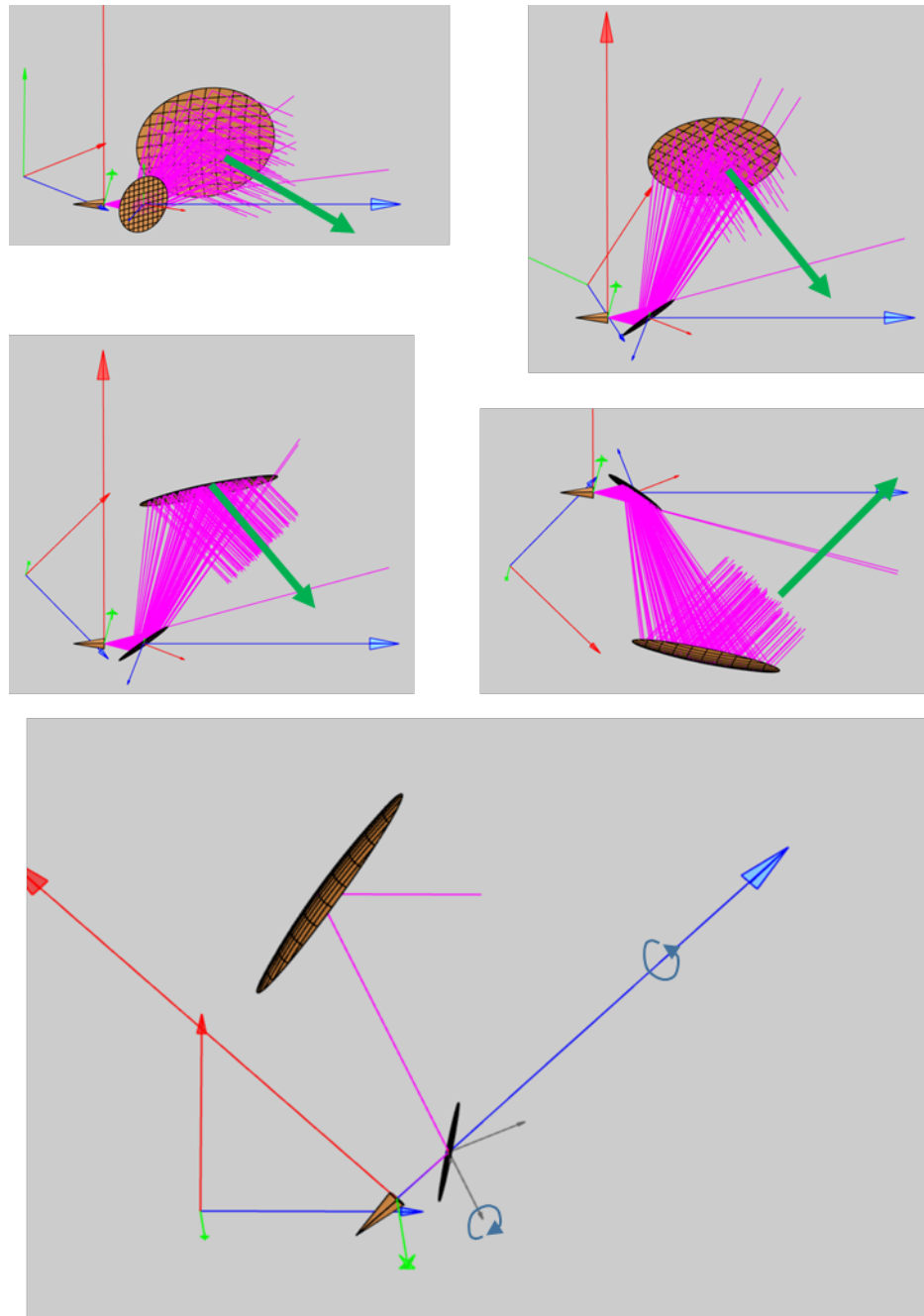


FIGURE 4-167 NEWTON BASED STEERABLE ANTENNA

The advantage with this configuration is avoid mechanical RF movement of the RF feed, only the reflector move to point toward a gateway.

The drawbacks is that this kind of optics occupy a large volume when pointing. This system could be stowed and deployed so that the footprint in the launcher will be reduced.

Nevertheless, the environment must be clear enough not to obstruct other antennas. This configuration is less compact than a cassegrain configuration. This antenna will pose constraints with other antennas, and in the case of architecture 2 (for the user satellite) it is very problematic.

The second solution based on cassegrainian configuration optics as illustrated in the FIGURE 4-168.

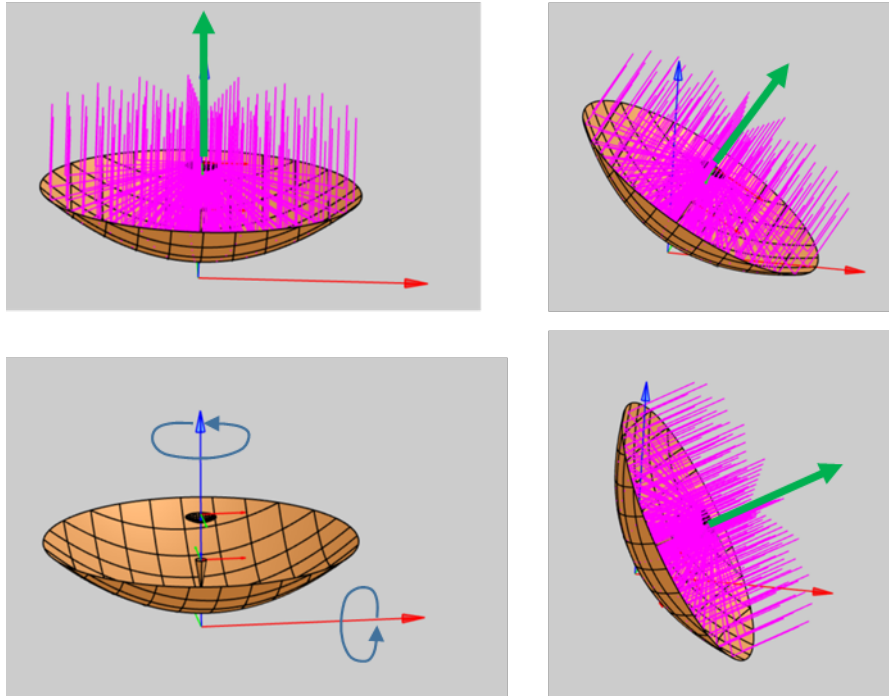


FIGURE 4-168 CASSEGRANIAN BASED STEERABLE ANTENNA

The cassegrain configuration is interesting, as it is very compact and the volume around which it moves is less problematic. Combined with a mechanical system and RF rotary joints, it is the one best suited to our mission. With a few mechanical adjustments, it allows a high pointing angle, while maintaining a focused beam. However, there are additional losses associated with the rotating RF joint. In the present study, this is the preferred solution for estimating feeder link performance.

4.8.3 Frequency band

The frequency band for the feeder link is defined in the table in the FIGURE 4-169.

	Fmin	Fmax	Bandwidth
	GHz	GHz	GHz
Rx2 (*)	47,2	52,2	5
Rx1	47,2	50,2	3
Tx1	37,5	42	4,5

FIGURE 4-169 FREQUENCY BAND FOR THE FEEDER LINK

(*) The frequency band 51.4-52.4 GHz is not permitted for NGSO links, only the Band 47.2-50.2 GHz (3 GHz) bandwidth is authorized, and 50.4-51.4 GHz.

The full frequency band could be used 4.5 GHz in Tx and 3 GHz in uplink. The interference between other link shall be ensured (GEO to Gateway) by orbital arc protection (shut down / attenuation and handover with a second feeder). (see [75]-[77]).

4.8.4 Feeder Links of the NTN mission

The feeder link is used in the user satellite (architecture 1) or in the feeder satellite (architecture 2) (see FIGURE 3-1).

The objective is to be in view of a gateway. Up to now, the number and position of the gateways is not determined. In the case of architecture 2 (see The FIGURE 4-130 & FIGURE 4-132), the feeders are installed on the Feeder satellite wich ensure the feeder link of several users satellite. Each user satellite cover an ELmin of 45° as defined in (see FIGURE 4-170) . In order to ensure a view to a gateway, his coverage shall exceed each user Satellite service area. As each feeder satellite ensure 4 satellites his coverage will be at least a coverage of EL min of 15° (see FIGURE 4-170). Moreover , to garanted a visibility to a gateway, a coverage of EL min of 10° - have been taken to evaluate the link budget performances.

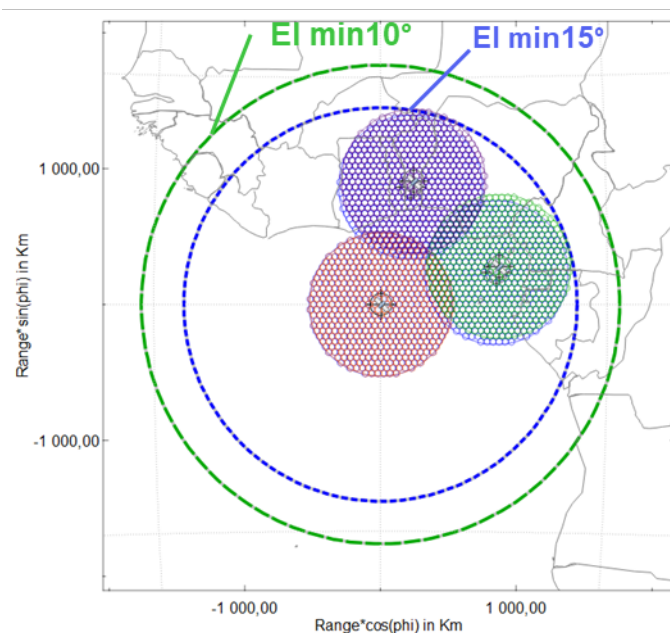


FIGURE 4-170 COVERAGE AREA OF A FEEDER SATELLITE

In this figure, the protection of the geostationary arc is not shown, but will have to be considered in the future more detailed analyses.

4.8.4.1 Gateways in Q/V

For the Gateways it is based on performances of existing base stations [127]-[129] in study and design, the performances taken are typical order to evaluate the link budget performances and could be adjusted with deeper analysis in the next document update.

GATEWAY		earth	Diameter 9.3 m	
TX			GAIN	67,9 dBi
	50	GHz	EIRP	87,0 dBW
RX			GAIN	68,4 dBi
	40	GHz	G/T	40,7 dB.K ⁻¹

FIGURE 4-171 GATEWAY PERFORMANCES

This performances has been issued from existing Gateways used from MEO to LEO constellations.

4.8.4.2 Feeder in Q/V

The maximum size in antenna aperture have been taken for the evaluation of the feeder link. The size will be adjusted according to the satellite platform.

FEEDER		satellite	diameter 700 mm	
TX			GAIN	43,9 dBi
	40	GHz	EIRP	52,7 dBW
RX			GAIN	46,2 dBi
	50	GHz	G/T	12,7 dB.K ⁻¹

FIGURE 4-172 FEEDER HYPOTHESIS

The size and aperture could be optimized from a diameter between 300 mm to 1200 mm; The maximum aperture envisaged is a 1200 m aperture, it could be possible to envisage more larger aperture but that will require complex mechanical arrangements which induce bulky system. It will require to foresee higher cost technology carbon fiber (instead of aluminum) and deployable mechanism in order to store the antenna.

Moreover each platform shall have at least two antenna in order to ensure a handover and geostationary arc protection [75]-[77] or to ensure redundancy or to handle with the throughput by feeders. Thus, the optimization of the number of gateways will also depend on the capacity of the traffic to manage. The feeders participate in the balance evaluation between the capacity of the satellite (throughput target) and the power available on each platform;

4.8.5 Feeder Solution (architecture)

The front end architecture is illustrated on the FIGURE 4-173. The antenna work in the two polarization RHCP & LHCP. The front is composed of two amplified access per function (Rx or Tx).

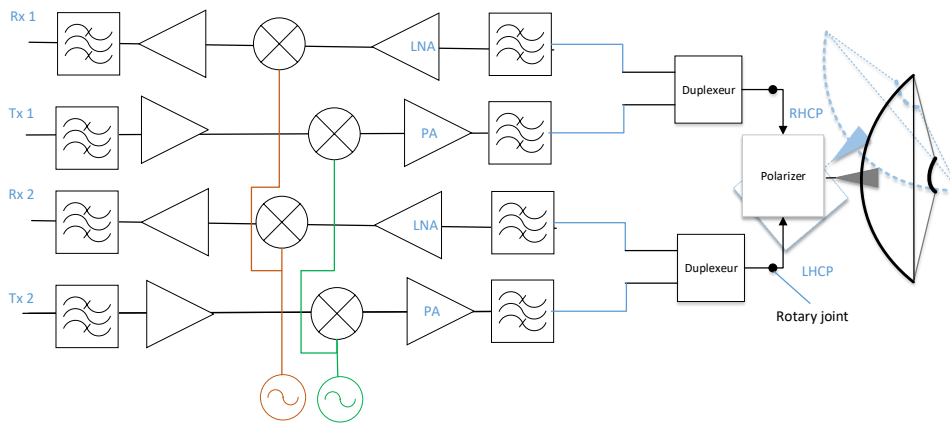


FIGURE 4-173 FRONT END ARCHITECTURE FEEDER

The throughput could be multiplied by 2 by using the two polarizations.

4.8.6 Link Budget

4.8.6.1 Satellite Feeder synthesis

The characteristics of the Feeder are summarized in the table below :

FEEDER	Parameter	Unit	Value
	Band Name	-	Q-V
	Downlink Frequency	GHz	40,00
	Uplink Frequency	GHz	50,00
Constellation	Selection for Feeder Link	-	Upper constellation
	Reference - Number of satellite	-	1380
	Reference - Altitude	km	600
	Reference - Elevation Min	°	10
	Upper - Altitude	km	600
	Upper - Elevation Min	°	10
	Selected - Number of satellite	-	196
	Selected - Altitude	km	600
	Selected - Elevation Min	°	10
Satellite	Satellite Antenna Gain Tx	dBi	43,90
	Satellite EIRP	dBW	52,70
	Satellite Antenna Gain Rx	dBi	46,20
	Satellite G/T	dB/K	12,70
Gateway	Gateway Antenna Gain Tx	dBi	67,90
	Gateway EIRP	dBW	87,00
	Gateway Antenna Gain Rx	dBi	68,40
	Gateway G/T	dB/K	40,70
C/I	Downlink (Sat TX)	dB	18
	Uplink (SatRX)	dB	18

FIGURE 4-174 RESUME OF FEEDER HYPOTHESIS

4.8.6.2 Uplink

The Uplink link budget are given in the table of the FIGURE 4-175

UPLINK		Unit	Uplink GW --> SAT	Uplink GW --> SAT (NADIR)
GLOBAL	Band Name	-	Q-V	Q-V
	Uplink Frequency	GHz	50,00	50,00
	Useful Bandwidth	MHz	3000,00	3000,00
GATEWAY - TX	Elevation angle to satellite	°	10,00	90,00
	Slant Range	km	1931,64	600,00
	Antenna view angle	°	64,16	0,00
	Polarisation mismatch loss	dB	0,00	0,00
	EIRP	dBW	87,00	87,00
SATELLITE - RX	Satellite altitude	km	600,00	600,00
	Figure of merit (G/T)	dB/K	12,70	12,70
LOSSES	Free space propagation	dB	192,15	181,99
	Propagation losses computation	-	Computation [RD1] & [RD2]	
	UE location	-	Toulouse	
	Weather condition	-	Clear Sky	
	Atmospheric loss	dB	9,81	2,07
	Shadowing margins	dB	0,00	0,00
RESULTS	Obtained C/N	dB	17,81	18,00
	Spectral Efficiency	bits/s/Hz	2,7140	2,7140
	UE Rate	Mbit/s	8142,120	8142,120

FIGURE 4-175 LINK BUDGET UPLINK

Per antenna the throughput max in uplink is almost 1,6 Gbits/s.

4.8.6.3 Downlink

The downlink link budget is given in the table of FIGURE 4-176.

Downlink		Unit	Downlink SAT --> GW	Downlink SAT --> GW (NADIR)
GLOBAL	Band Name	-	Q-V	Q-V
	Downlink Frequency	GHz	40,00	40,00
	Useful Bandwidth	MHz	5000,00	5000,00
SATELLITE - TX	EIRP	dBW	52,70	52,70
	Satellite altitude	km	600,00	600,00
GATEWAY - RX	Elevation angle to satellite (seen from UE)	°	10,00	90,00
	Slant Range	km	1931,64	600,00
	Antenna view angle	°	64,16	0,00
	Figure of Merit: G/T	dB/K	40,70	40,70
	Polarisation mismatch loss	dB	0,00	0,00
	Effective G/T	dB/K	40,70	40,70
	Free space propagation	dB	190,21	180,05
Propagation losses computation	-	Computation [RD1] & [RD2]		
UE location	-	Toulouse		
Weather condition	-	Clear Sky		
Atmospheric loss	dB	8,36	0,63	
RESULTS	Obtained C/N	dB	17,42	17,99
	Spectral Efficiency	bits/s/Hz	1,3901	1,3901
	UE Rate	Mbits/s	6950,73	6950,73

FIGURE 4-176 LINK BUDGET DOWNLINK

Per antenna the throughput max in uplink is almost 1,4 Gbits/s.

4.9 INL : LEO FEEDER SAT TO HAPS

4.9.1 Introduction

In this part, we focus our interest on the INL (inter node link) between a LEO satellite and a HAPS. This link will allow in priority to feed the HAPS, in the baseline a link between the HAPS station and a earth Gateway is not foreseen as a priority.

We suppose that the Feeder SAT have a diameter of 700 mm (maximum) same as used for the LEO sat feeder link to Gateway (From User Satellite or from Feeder Satellite to Gateways) and HAPS antenna.

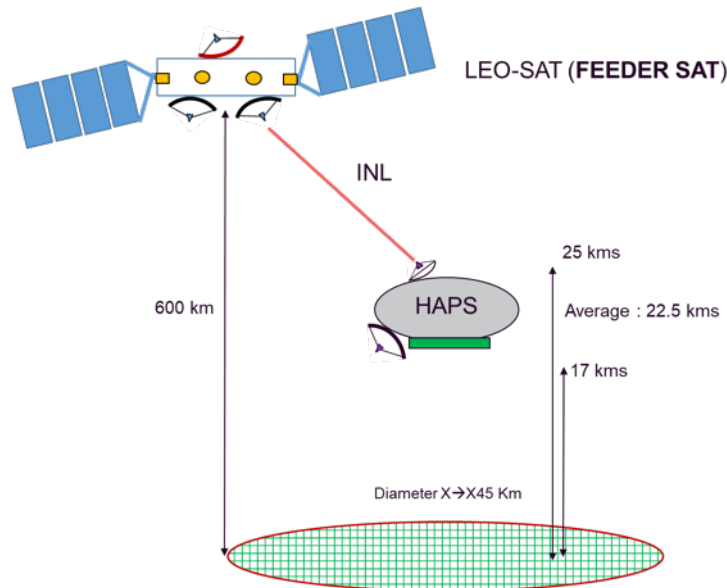


FIGURE 4-177 INTERNODE LINK

The accommodation of an antenna on the top of the HAPS is not yet confirmed, and could be replaced by an electronically steerable active antenna (1 beam or 2 beam) if some constraints appear in the accommodation of a reflector type antenna. Moreover a UE type terminal in Q/V band could also be used if the throughput is sufficient to feed the HAPS.

4.9.2 Solution orientation

The dimension and performance of the feeder HAPS and Feeder Satellite is defined below :

Antenna HAPS diameter 300 mm			
TX		GAIN	38.3 dBi
	50 GHz	EIRP	46.8 dBW
RX		GAIN	37.1 dBi
	40 GHz	G/T	10.3 dB/K
FEEDER satellite Diameter 700 mm			
TX		GAIN	43.9 dBi
	40 GHz	EIRP	52.7 dBW
RX		GAIN	46.2 dBi
	50 GHz	G/T	12.7 dB/K

FIGURE 4-178 PERFORMANCES HAPS ANTENNA AND FEEDER SATELLITE

The table in the FIGURE 4-179 gives the frequency band that could be used for this INL link.

Frequency Band		Fmin	Fmax	Bandwidth
Satellite	HAPS	GHz	GHz	GHz
Rx1	Tx1	47,2	50,2	3
Rx2	Tx2	50,4	51,4	1
Tx1	Rx1	37,5	42,5	5

FIGURE 4-179 FREQUENCY BAND

This table gives the maximum bandwidth available. A reduced bandwidth could be taken, for instance 1GHz if it will be sufficient to handle the throughput to the HAPS.

SATELLITE	Parameter	Unit	Value
FEEDER	Band Name	-	Q-V
	Downlink Frequency	GHz	40,00
	Uplink Frequency	GHz	50,00
Constellation	Selection for Feeder Link	-	Upper constellation
	Reference - Number of satellite	-	1269
	Reference - Altitude	km	600
	Reference - Elevation Min	°	10
	Upper - Number of satellite	-	336
	Upper - Altitude /Haps altitude	km	580
	Upper - Elevation Min	°	10
	Selected - Number of satellite	-	336
Satellite	Satellite Antenna Gain Tx	dBi	43,90
	Satellite EIRP	dBW	52,70
	Satellite Antenna Gain Rx	dBi	46,20
	Satellite G/T	dB/K	12,70
HAPS	Gateway Antenna Gain Tx	dBi	38,30
	Gateway EIRP	dBW	46,80
	Gateway Antenna Gain Rx	dBi	37,10
	Gateway G/T	dB/K	10,30
C/I	Downlink (Sat TX)	dB	14
	Uplink (SatRX)	dB	14

FIGURE 4-180 SATELLITE ANTENNA FEEDER SYNTHESIS

HAPS	Parameter	Unit	Value
FEEDER	Band Name	-	Q-V
	Gain attenuation (UE)	dB	0
	Use of Scan Losses	-	YES
RX (downlink)	Downlink Frequency	GHz	40,00
	Antenna Size	m	0,1
	Number of ER	-	379
	Directivity ER (NADIR)	dBi	6,17
	Directivity ER (EI 45°)	dBi	5,12
	Directivity ER (EI 30°)	dBi	3,16
	Losses ER	dB	1,5
	Antenna Noise Figure (NF)	dB	4,00
	Antenna Temperature	K	240,00
	Ambiant Temperature	K	290,00
	Equivalent Temperature	K	678,45
	Antenna gain (NADIR)	dBi	30,45
	Antenna gain (45°)	dBi	29,41
	Antenna gain (30°)	dBi	27,44
	G/T (NADIR)	dB/K	2,14
	G/T (45°)	dB/K	1,09
	G/T(30°)	dB/K	-0,87
Polarisation mismatch loss	dB	0,00	
Overhead	-	0,18	
SCS PRB	SCS	kHz	480
	Downlink BW	MHz	800
	Nb Downlink PRBs	-	132
	Uplink BW	MHz	800
	Nb Uplink PRBs	-	132
TX (uplink)	Uplink Frequency	GHz	50,00
	Antenna Size	m	0,08
	Number of ER	-	379
	Directivity ER (NADIR)	dBi	6,17
	Directivity ER (EI 45°)	dBi	5,12
	Directivity ER (EI 30°)	dBi	3,16
	Losses ER	dB	3,5
	Antenna gain (NADIR)	dBi	28,45
	Antenna gain (45°)	dBi	27,41
	Antenna gain (30°)	dBi	25,44
	Antenna transmit power	dBW	3
	Antenna transmit power	W	2,00
Polarisation mismatch loss	dB	0,00	
Overhead	-	0,10	

FIGURE 4-181 HAPS ANTENNA

4.9.3 Link Budget

The budget have been establish for a bandwidth of 1 GHz for a first estimation.

4.9.3.1 Uplink budget

The table on FIGURE 4-182 give the link budget establish for this INL link.

		Unit	Uplink HAPS --> SAT	Uplink HAPS --> SAT (NADIR)
GLOBAL	Band Name	-	Q-V	Q-V
	Uplink Frequency	GHz	50,00	50,00
	Useful Bandwidth	MHz	1000,00	1000,00
HAPS - TX	Elevation angle to satellite	°	10,00	90,00
	Slant Range	km	1885,46	580,00
	Antenna view angle	°	64,51	0,00
	Polarisation mismatch loss	dB	0,00	0,00
	EIRP	dBW	46,80	46,80
SATELLITE - RX	Satellite altitude	km	580,00	580,00
	Figure of merit (G/T)	dB/K	12,70	12,70
LOSSES	Free space propagation	dB	191,94	181,70
	Atmospheric loss	dB	9,81	2,07
	Shadowing margins	dB	0,00	0,00
RESULTS	Obtained C/N	dB	-3,72	11,15
	Spectral Efficiency	bits/s/Hz	0,2759	2,3133
	UE Rate	Mbit/s	275,940	2313,270

FIGURE 4-182 UPLINK LINK BUDGET

4.9.3.2 Downlink link budget

The table on FIGURE 4-183 give the downlink budget establish for this INL link.

		Unit	Downlink SAT --> GW	Downlink SAT --> GW (NADIR)
GLOBAL	Band Name	-	Q-V	Q-V
	Downlink Frequency	GHz	40,00	40,00
	Useful Bandwidth	MHz	1000,00	1000,00
SATELLITE - TX	EIRP	dBW	52,70	52,70
	Satellite altitude	km	580,00	580,00
HAPS - RX	Elevation angle to satellite (seen from UE)	°	10,00	90,00
	Slant Range	km	1885,46	580,00
	Antenna view angle	°	64,51	0,00
	Figure of Merit: G/T	dB/K	10,30	10,30
	Polarisation mismatch loss	dB	0,00	0,00
	Effective G/T	dB/K	10,30	10,30
LOSSES	Free space propagation	dB	190,00	179,76
	Atmospheric loss	dB	8,36	0,63
	Shadowing margins	dB	0,00	0,00
	Body loss	dB	0,00	0,00
RESULTS	Obtained C/N	dB	2,89	13,24
	Spectral Efficiency	bits/s/Hz	0,8424	1,5696
	UE Rate	Mbits/s	842,39	1569,56

FIGURE 4-183 DOWNLINK BUDGET

4.10 ISL RF LEO TO GEO

4.10.1 Introduction

The link between a LEO satellite and a GEO satellite will be based on a steerable cassegranian type antenna. Most of the solutions are based on this type of antenna. In addition to layout and

weight constraints, this link requires sufficient power to establish the link (>35400 km up to 41200 km). All RF solutions for this type of mission are based on a cassegrain antenna mounted on a mechanical pointing system. Most of the Interlink are actually based on RF ISL, generally used for data transfert.

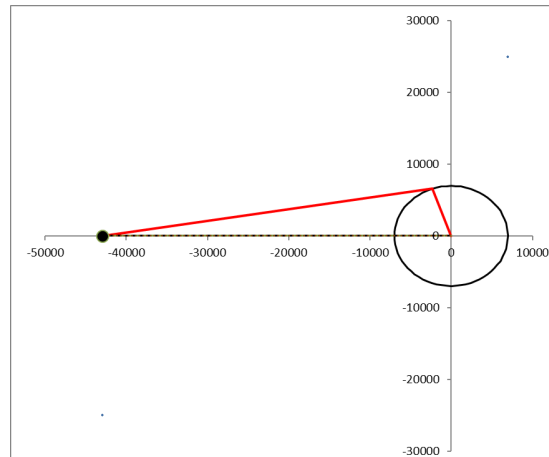


FIGURE 4-184 DISTANCE BETWEEN A LEO SAT AND GEO SATELLITE

All LEO Feeder satellites must be connectable to a GEO satellite in visibility (limited to an EL min of 10°). The GEO satellite are always visible to a LEO satellite at least 3 GEO satellite cover the entire earth. The handover between one LEO satellite and GEO satellites is not planned in the initial dimensioning. It will need additional antenna on the LEO satellite. The hypothesis is that this link LEO to GEO is not a priority, only one link or few link could be ensured between a GEO satellite and LEO satellites. During the handover phase, it is supposed that the data will be buffered.

4.10.2 Solution orientation

The best compact and sufficiently efficient solution is based on a steerable cassegrain-type antenna. As shown in FIGURE 4 123. This solution offers the advantage of being sufficiently mature, and studies on this subject to improve performance (materials and amplifier power in the Ka bands are making major progress). Possible apertures range from 300 mm to 1.2 m. We'll limit ourselves to the smallest aperture to estimate the data rate we can achieve. This link has not been clearly defined, and is essentially used as a back-up (resilience in the system). From a technical point of view, there are no major obstacles to increasing the capacity of this link, and solutions exist to lighten the load (carbon fiber technology, de-stacking system). Eventually, we'll have to dimension the link according to the constraints of the platforms and the effort involved.

4.10.3 Frequency band selection

The frequency band availables and possible for this link are presented on the table of FIGURE 4-185.

	BANDS			ITU FREQUENCY BAND FOR ISL
	Fmi	Fmax	bandwidth	
	GHz	GHz	GHz	
F1	22,55	23,55	1	used by Iridium (23.18-23,38) and GSO data Relay systems with LEO identification for terrestrial 5G
	24,45	24,75	0,3	
	25,25	27,5	2,25	
F2	32,3	33	0,7	identification for terrestrial 5G
	59,3	66	6,7	
	66	71	5	
	122,25	123	0,75	
	130	134	4	
	167	174,8	7,8	

FIGURE 4-185 FREQUENCY FOR ISL RF (DATA ITU)

Numerous frequencies band are possible to be envisaged. The trade-off is to use the low frequency as possible for a question of cost and technological maturity. The two frequency band identified are in Ka band : F1=22,55-23,55 GHz or F2 =32,3-33 GHz. It is also possible to use the two frequency bands. The upper frequency bands could also be possible with high capacity (large bandwidth available) but it will need to develop intensive technological development in power amplifier and in LNA; The avantage will be that antenna will be smaller than in Ka band. This possibility will be let for the second upgrade of this link. There is no justification to high throughput capacity request for this link.

4.10.4 Antenna Architecture trade-off

Several architectures could be possible for this link. Exemple of architecture working in 2 band for maximum throughput see FIGURE 4-186.

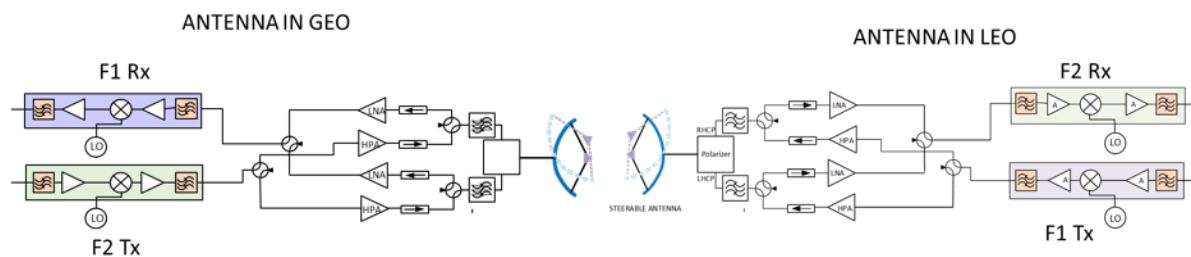


FIGURE 4-186 EXEMPLE OF ARCHITECTURE (BI-POLARIZATION FULL FLEXIBLE/FULL DUPLEX) TWO POLARIZATIONS

The architecture 1 will allows a full flexibility in the selection of polarization. It works in the two frequency bands. A choice shall be done between the LEO and GEO ISL in term of front ends. In GEO receive function in F1 and transmit function in F2 and in LEO the inverse is adopted. In this architecture the two polarizations could be used selectable by the switch to establish the link.

EXEMPLE OF LINKS						
case 1	Uplink	LEO-->GEO		F1Tx	F1Rx	RHCP
	downlink	GEO-->LEO		F2Rx	F2Tx	LHCP
case 2	Uplink	LEO-->GEO		F2Rx	F2Tx	RHCP
	downlink	GEO-->LEO		F1Tx	F1Rx	LHCP

FIGURE 4-187 EXEMPLE OF LINKS

This could also be fully flexible if additional RF chain and allow to work in the two band in Rx and Tx, have been implemented but it will complexifie the payload and will need to develop component for the two bands in Rx and Tx.

To limit the complexity it is preferred to select only one frequency band and work in one polarization and use polarization discrimination as illustrated in the FIGURE 4-188.

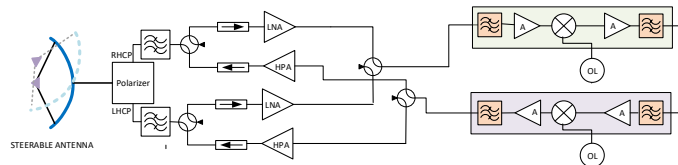


FIGURE 4-188 EXEMPLE OF ARCHITECTURE ONE POLARIZATION /ONE FREQUENCY/ POLARIZATION DISCRIMINATION (F1 OR F2)

EXEMPLE OF LINKS						
case 1	Uplink	LEO-->GEO		FTx	FRx	RHCP
	downlink	GEO-->LEO		FRx	FTx	LHCP

FIGURE 4-189 EXEMPLE OF LINK (F=F1 OR F2)

The FIGURE 4-190 gives the gain variation according to aperture of the antenna

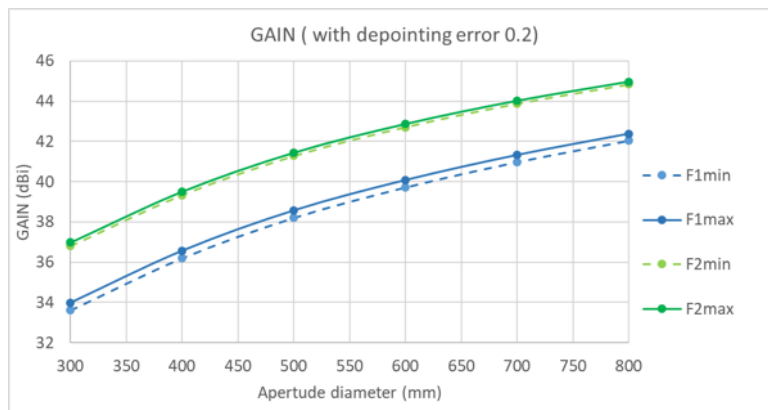


FIGURE 4-190 Example of achievable Gain versus aperture

The table in FIGURE 4-191 give the characteristics of the antenna for two apertures 300 mm and 700 mm). These apertures correspond to the maximum aperture that could be achievable in a raisonnabe cost.

300 mm		ANTENNA		
			F1	F2
	Diameter	mm	300,00	300,00
	Frequency	GHz	23,1	32,7
	GAIN	dBi	33,8	36,7
	EIRP	dBW	50,8	49,8
	G/T	dB.K ⁻¹	8,5	10,7

700 mm		ANTENNA		
			F1	F2
	Diameter	mm	700	700
	Frequency	GHz	23,1	32,7
	GAIN	dBi	41,2	43,8
	EIRP	dBW	57,2	59,8
	G/T	dB.K ⁻¹	17,7	15,9

FIGURE 4-191 EXEMPLE ANTENNA PERFORMANCE FOR TWO APERTURES

Simplification in one frequency on working in one polarization by switching the appropriate link.

4.10.5 Link Budget

The bandwidth have been taken to 700 MHz full bandwidth available and the size of the antenna have been reduced to an aperture of 300 mm. The amplifier power is taken to 20 W.

Tx20 Rx20			Tx 30 Rx 30		
BW available	1	GHz	0,7	GHz	
Carrier BW	700,000	MHz	700,000	MHz	
gain	41,15		43,80		
Frequency	23,05	GHz	32,67	GHz	
Power SSPA	20	W	20,00	W	
Power SSPA	13,01029996	dBW	13,01	dBW	
EIRP Tx20	54,2	dBW	EIRP Tx30	56,8	dBW
Power Control Back off	0,00	dB	Power Control Back off	0,00	dB
C/Im up	15,0	dB	C/Im up	15,0	dB
Distance between sat	40000,0	km	Distance between sat	40000,0	km
Free space loss	-211,7	dB	Free space loss	-214,8	dB
Rain/Atmos attenuation	0,0	dB	Rain/At attenuation	0,0	dB
pointing loss	0,00	dB	pointing loss	0,00	dB
link margin	0,50	dB	link margin	0,50	dB
G/T	15,9	dB/K	G/T	17,7	dB/K
C/No up	86,9	dBHz	C/No up	88,4	dBHz
C/I uplink	27	dB	C/I uplink	27	dB
C/N uplink	-1,3	dB	C/N uplink	0,1	dB
C/(N+I) uplink	-1,92	dB	C/(N+I) uplink	-0,50	dB
DVB-S2X rate	397,46	Mb/s	DVB-S2X rate	459,51	Mb/s
Spectral Efficiency S2X	0,57	bits/s/Hz	Spectral Efficiency S2X	0,66	bits/s/Hz
Required C/N @ Rate	-2,03	dB	Required C/N @ Rate	-1,24	dB
Residual margins	0,11	dB	Residual margins	0,74	dB

Link budget Frequency F1 Antenna ($\phi=700\text{mm}$)	Link budget Frequency F2 Antenna ($\phi=700\text{mm}$)
---	--

FIGURE 4-192 EXEMPLE OF THROUGHPUT ACHIEVABLE

The throughput could be increase by adjusting the size of the aperture and the power of the amplifier. An analysis on the need for this link shall be evaluated in order to reajuste these parameters. RF ISL offers the solution to be accessible at a reasonable cost. If the need is important >1Gbps the solution to use an OISL is more appropriate in term of mass and volume

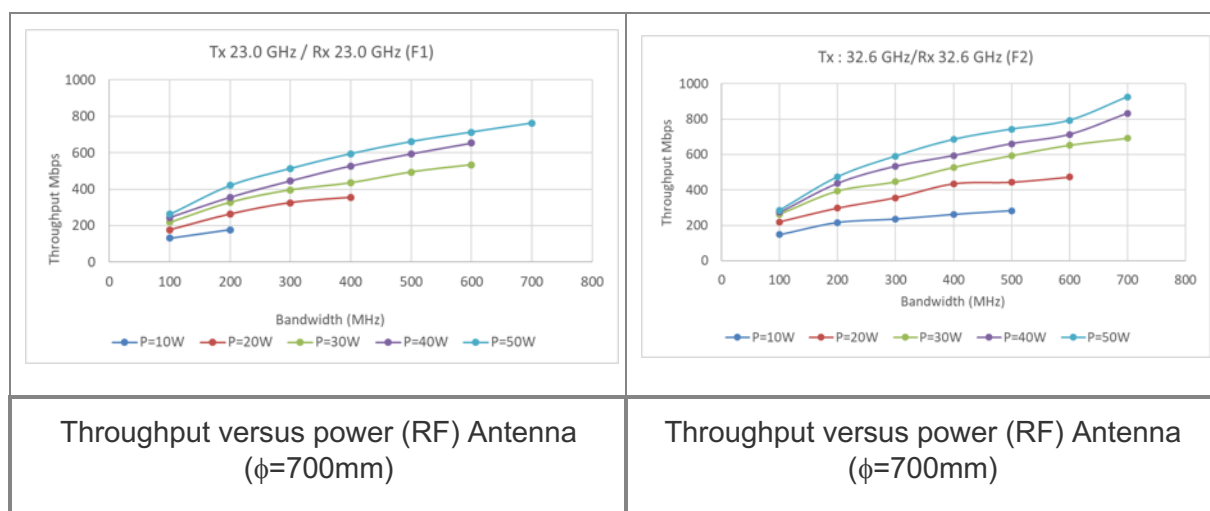


FIGURE 4-193

The antenna size will be determine according to the throughput objective. To this distance a minimum power and Gain shall be ensured to reach the target. In F1, the bandwidth could go up 1 GHz and in F2 to 700 MHz. The results are the worst case of distance of 40 000 km.

5 SCALABILITY

5.1 SCALABILITY OF PAYLOAD DESIGN

The architecture of the antenna and associated payload are scalable in design, it means in that sense that the an increase in capacity do not impact the concept of architecture of the overall payload.

- In C-band , the beamforming is digital and is distributed (not hierarchic) the increase in number of elements do not change the concept by itself. The antenna size could be adjusted by block of 16 elements as shown in FIGURE 4-36 & FIGURE 4-40 Antenna geometry.
- In Q/V the beam forming is Analogic , the scaling of the antenna will be complex and induce several change in the design. But by concept the payload is composed of several antenna (7 in Tx and 7 in Rx) as shown in FIGURE 4-98 & FIGURE 4-105, so the payload could be scalable by adding additional antennas and the concept of architecture will not change.

5.2 SCALABILITY AT PAYLOAD LEVEL

Each payload and the constellation definitions are based on the concept of scalability. It means that each of element shall be “thicked “ with a capability of adjustment with a low effort to the market evolution. It means that everything shall be design in such a way that the resources are optimized in terms of cost; it means that the system will be “optimally designed”, not overdimensionned in other word “just tailored”; This aspect is a really complex point as the need is not exactly defined with uncertainties and open questions related to evolutions of the market demand and services.

Consequently, uncertainties persist regarding the precise guidelines to be adopted. Two options have been explored : payload for architecture 1 and payload for architecture 2 (see FIGURE 3-1).

Option 1 : defined by the system architecture 1, the objective intends to minimize the number of nodes (for instance the number of satellites of each of the constellation) but, in that case, the payload will be more complex, and the performance per satellite will be lower.

Option 2: defined by the system architecture 2 , the objective is to simplify the payload of each satellite by separating and regroup the function on 2 types of satellites. The advantage to do this, is to simplify the design of the satellites and improve their efficiency.The drawback remains to have a double constellation in that case, so to envisage two payload designs.

The approach taken in the second option involves developing a system based on a simple basic unit, which could then become more complex to manage when they are associated (linked) in large numbers. However, achieving this complexity may be feasible through AI-assisted management, a possibility currently under investigation. While such powerful tools remain largely unexplored, they may have an impact on the way the system design and payloads will evolve in the future. Additionally, the system aims to transfer energy-intensive computing capabilities to space, thereby reducing ground-based energy costs in alignment with sustainable development goals. The primary orientation is to maximize power consumption in space (storage and computation capacity) while rationalizing the system by

centralizing functions (as seen in architecture 2). Leveraging Optical Inter-Satellite Links (OISL) for data transfer between nodes remains a significant advantage in terms of space link budget efficiency

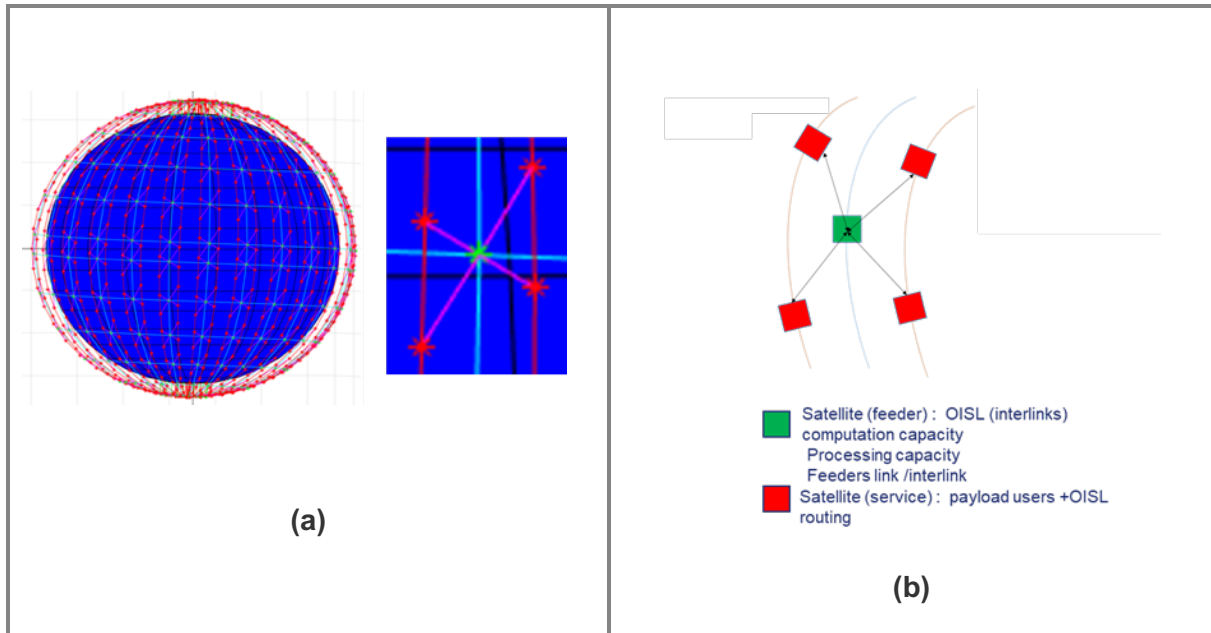
The constellation C- and Q/V band: in architecture 2, it lies on two types of constellations one for user link and one for processing capacity and routing. Each of the payloads have been optimized to reduce the complexity and consequently the cost of the final system.

The scalability at system level, in the case of architecture 2 are presented in the following chapter. The case of architecture 1, the enhancement of the capacity could be done in a classical way, by increasing the number of satellite (add planes)

5.3 CONNECTIVITY ASPECT AND FUNCTIONAL SPLIT IMPLEMENTATION

The functional split implementation is discussed and described in document D.3.7 [19]. Different options are analysed. The functions distributions between the feeder satellite and service satellites are discussed and the distribution of software functions are presented in document D.3.7 [19]. The links OISL (interlinks and intra plane links) and feeder ISL RF link are evaluated. For allow an scalability, the OISL dimensioning shall be dimensioned properly according to the throughput to convey between the links. The two main scalability are :

- to insert a additional feeder satellite between existing feeder satellites through the OISL links and to connect new service satellite to this feeder satellite.
- to connect a service satellite with a existing service satellite through the OISL Links.



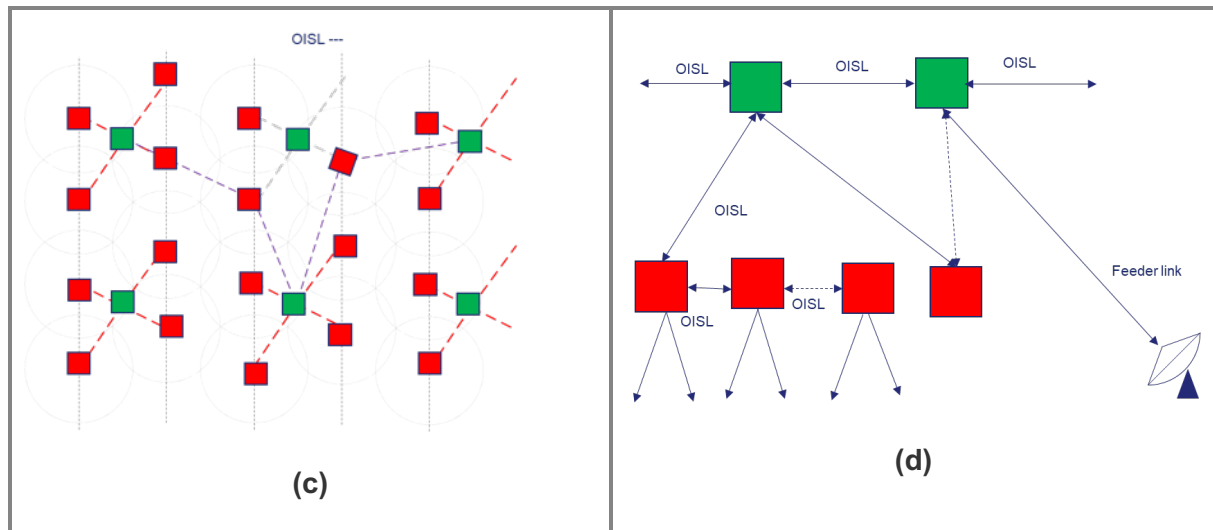


FIGURE 5-1 DESCRIPTION OF THE LINKS

Figure 5-1 (a) shows the constellation (see also document [25]) and Figure 5-1 (b) shows the satellite descriptions. The Figure 5-1 (c) and (d) the different possible links between the satellites . These links will allow to insert a new satellite and will allow to increase the capacity progressively. The scalability is illustrated for architecture 2 in the Figure 5-2 for two fonctionnal splits (see document 3.7 [19] for more details).

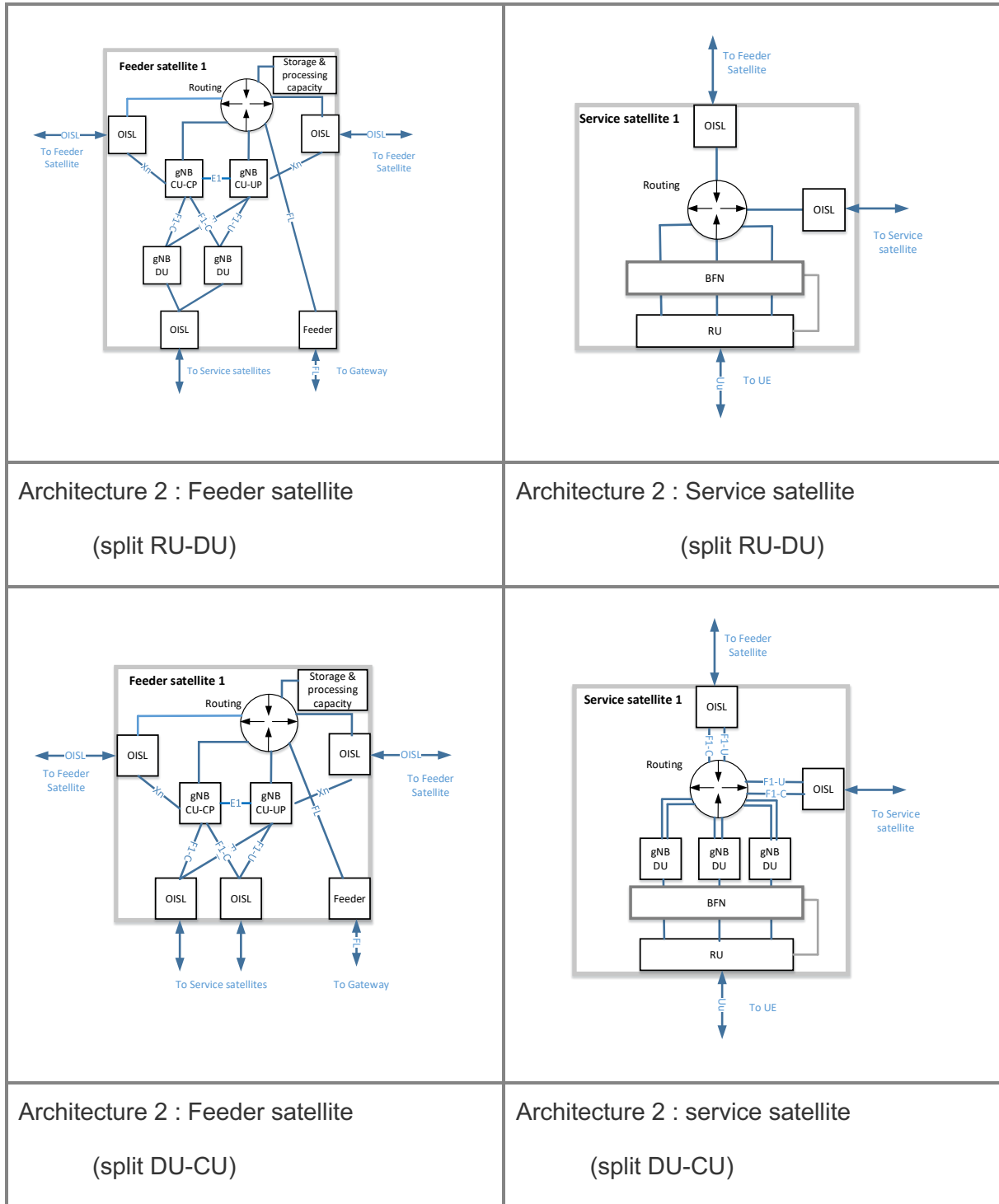


FIGURE 5-2 ARCHITECTURE : SPLIT OPTION RU-DU AND CU-DU

5.4 SCALABILITY: INCREMENTAL NUMBER OF PAYLOADS

The Figure 5-3Figure 1-1Error! Reference source not found., illustrates the scalability of enhancing the capacity on satellite coverage in the case of architecture 2. As mentioned in document [25] Task 3.4, in the case of architecture 2, the user (service) satellites are linked with the feeder satellite. All the links are done with OISL in document [19].

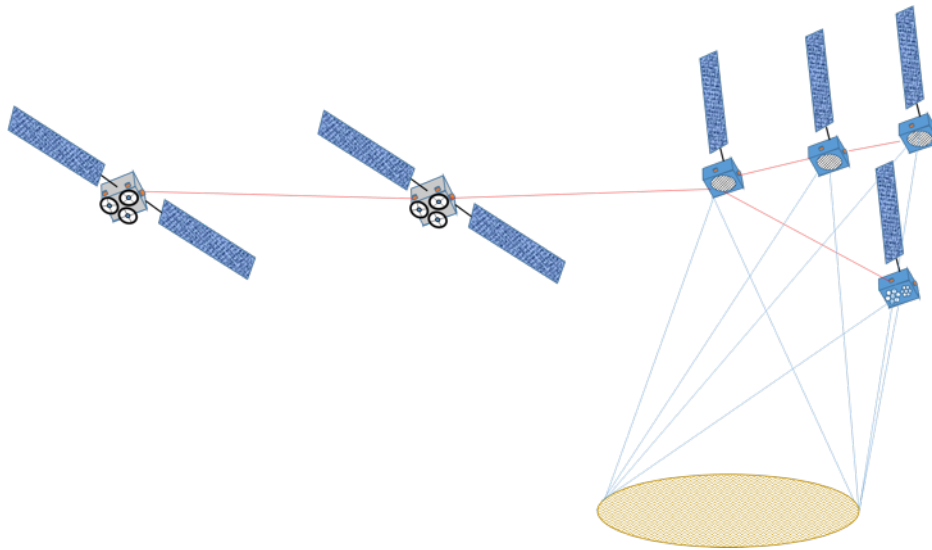


FIGURE 5-3 EXEMPLE OF SCALABILITY OF THE PAYLOADS

To increase the capacity on a coverage, it will be possible to add an additional user satellite which serve the save coverage by connecting it to the first user satellite **Error! Reference source not found.**. In that case, it is necessary to have over-dimensionned the OISL link between user satellite and feeder satellite and also over-dimensionned the feeder satellite processing capacity to allow this connectivity. The scenario could be :

-A constellation is defined for a certain capacity (as seen in the previous chapters) and defined interlink capacity.

-First the deployment of the Feeder satellite : 336 satellites will be launched and the constellation of 1269 users satellites. Progressively the connection between the first satellite and the users satellites will be established, the nominal capacity will be reached .

When this capacity becomes insufficient the following process will be applied :

Example of constellation (C or Q/V) incremental deployment scenario:

To increase the capacity: users satellites will be added, and will enhance the global capacity of the satellite system : additional planes of satellites and densification of feeders satellite.

When the feeder satellite capacity reaches the maximum value, additional feeder satellites will be added (additional planes of satellites) with a re-optimized routing of the users satellite traffic will be performed.

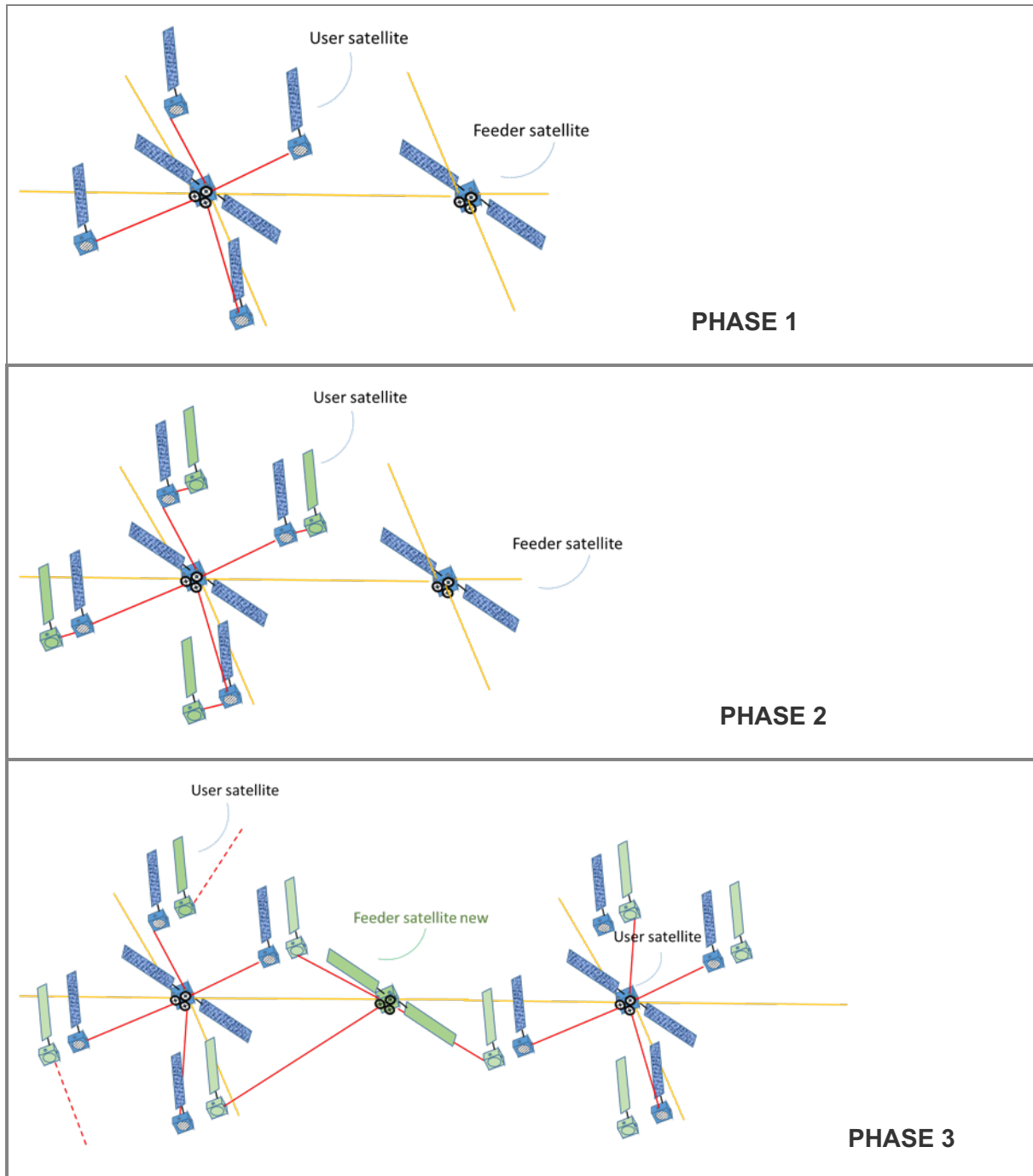


FIGURE 5-4 INCREASE IN CAPACITY

The scalability is as follow :

- PHASE 1: deployment of the initial Constellations feeder and users : for a given throughput
- PHASE 2 : Add users satellites progressively on the existing structure : up to the interlink capacity
- PHASE 3 : Deployment of additional new Feeder satellites (new generation, high capacity). Connection establish between these Feeder satellite and the users satellite. The first generation feeder satellites will be progressively suppressed. The users satellite will be progressive upgraded and repeat PHASE 2

5.5 PAYLOADS SCALABILITY OVER COVERAGE

5.5.1 Coverage of each payload

Coverage and cells have been defined on the one hand to be compatible with payload and link budget feasibility, and on the other hand to ensure compatibility between the payloads associated with the nodes. The basic cell is the one with the size of 45 km. All other cells are defined as either a multiplication or a division of this basic cell size. For GEO, the cell definition can be a multiple of the basic cell ranging from 900 km to 225 km, for LEO the cell size is 45 km (issued from trade-off see FIGURE 4-33), and for HAPS from 45 km to 11.25 km, 5,625 km (see FIGURE 4-151). The choice is not set in stone, but it does meet a need for compatibility of coverage and adjustment of performance (scalability) over time and intra-system interference management.

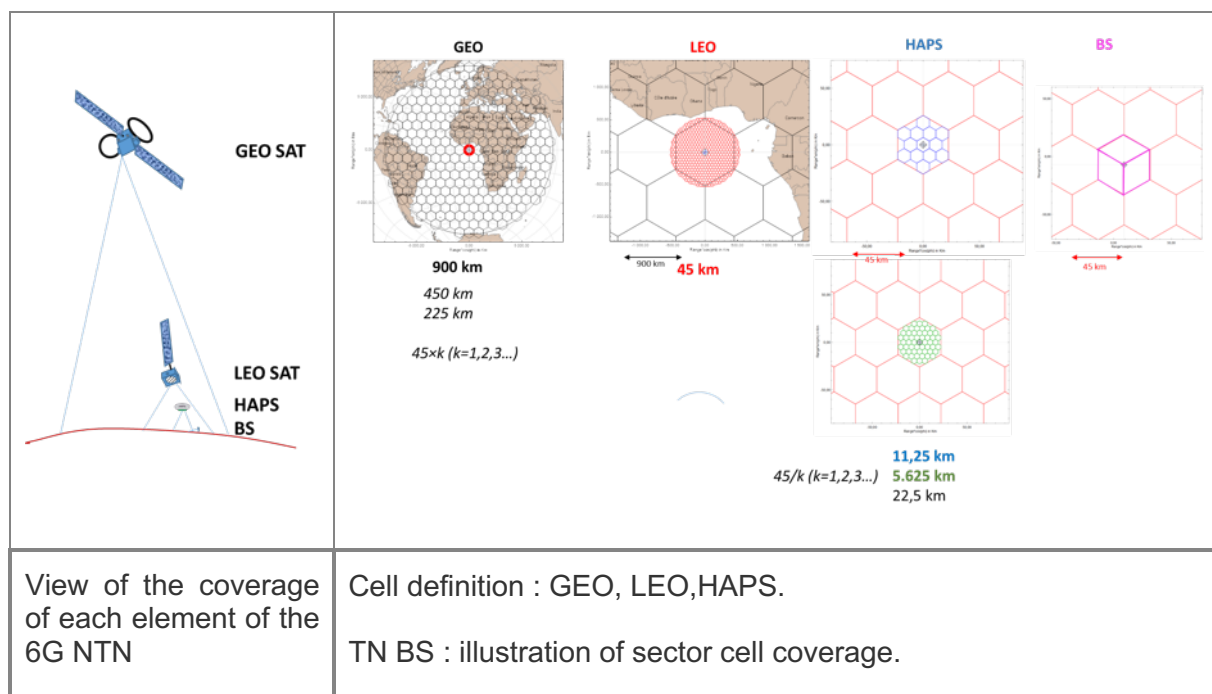


FIGURE 5-5 COMPATIBILITY OF COVERAGE AND CELL SIZE

The FIGURE 5-6 Illustrates the coverage over a region what could be ensured by GEO, LEO SAT and HAPS, and BS (TN base station).

-The deployment of TN progress will progress according to the area to cover . The tendency is to evolve to intensify the capacity where the demand increase.

- the blank region is ensured by the LEO SAT coverage

An increase of demand could rapidly be ensured by few deployment of HAPS locally to enhance the capacity, so that the LEO SAT could ensure a better coverage in the other areas.

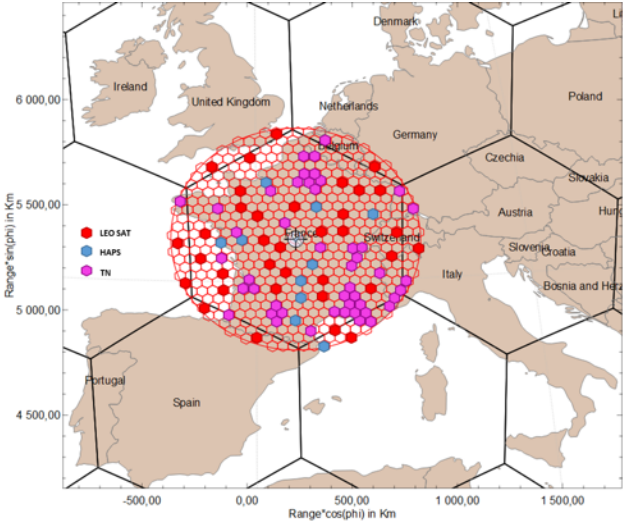


FIGURE 5-6 ILLUSTRATION OF SHAPING COVERAGE OVER A ZONE

6 NAVIGATION CAPABILITIES OF THE PAYLOADS

6.1 INTRODUCTION

Up to now, the payloads have been evaluated in term of performance as a telecommunication system which is the main feature. The objective of this chapter is to investigate the possibilities offered by the system 6G NTN to offer an accurate positioning. The case of coarse positioning by one satellite for system entry is dealt in document TASK 5.2 in this part we focus our interest on an accurate positioning.

6.2 ENLARGED BEAM

An accurate positioning system need at least 4 satellites [136]. In our case, according to curve (see documentation TASK 3.4) and recalled hereafter Figure 6-1, the superposition factor will increased with latitude.

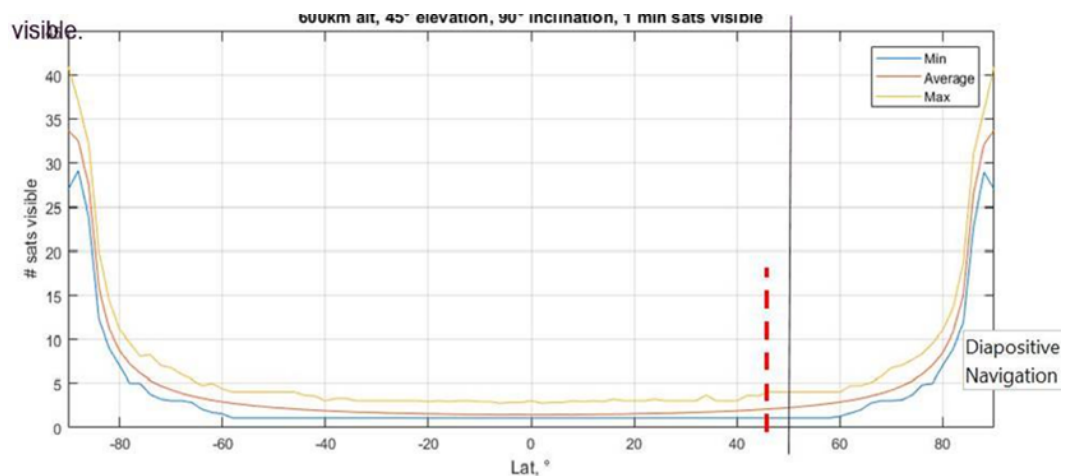


FIGURE 6-1 SUPERPOSITION OF THE SATELLITES (COVERAGE EL MIN 45°, 10 S HANDOVER) (--- DASHED-LINE :POSITION OF FRANCE METROPOLITAN COVERAGE)

The Figure 6-1 gives the superposition factor for a coverage of 45° EL of each satellite (with handover 10s for edge cells). This factor minimum evolves from 1 to 26 for a coverale of EL 45° coverage. Thus, the objective is to generate a wide beam from each satellite in the way that it increase the superposition factor Figure 6-2 .

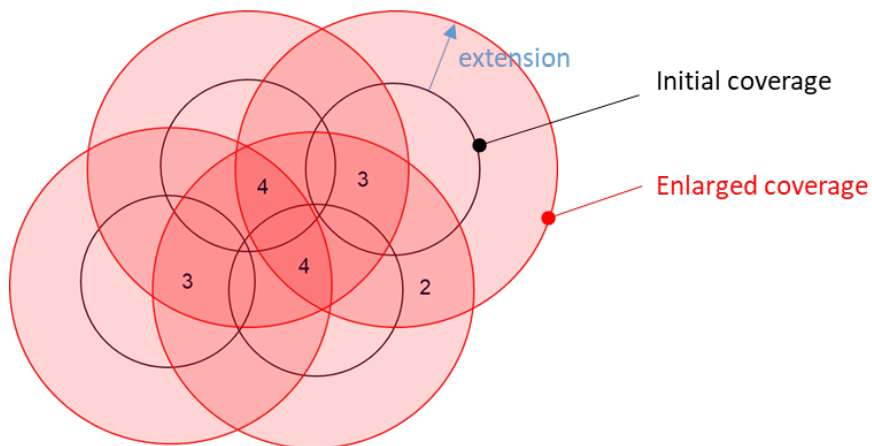


FIGURE 6-2 EXTENSION OF EACH SATELLITE COVERAGE

The most critical region is at latitude 0° as shown in Figure 6-1. Exemple of extension with the case C of constellation C-band. The LEO constellation (Case C see § 4.3.4) is the most powerfull and is taken for the exercise. The Figure 6-3 illustrates the superposition : from an enlarged beam generated by a satellite Figure 6-3 (a) to 2 and 7 satellites superposition (b) and (c).

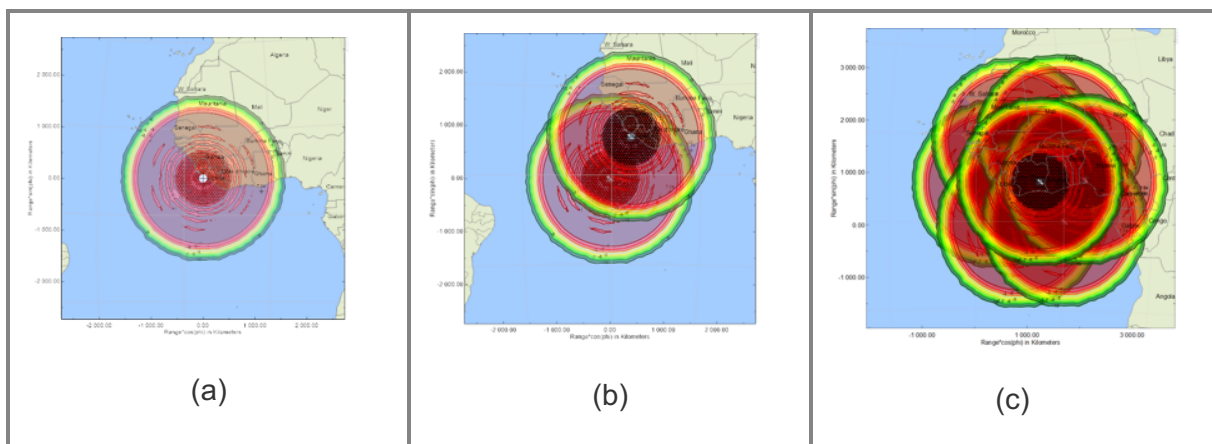


FIGURE 6-3 COVERAGE EXTENSION (C-BAND CASE C)

Each satellite is able to cover the adjacent satellite. The beam obtained is wide and the minimum of satellite in visibility is 7 (due to the almost hexagonal lattice chosen). In that case the gain of each beam is low and the distance between the satellite and the edge point varie from 600 km to 1400 km. The power needed to ensure a correct link budget will be consequent and will impact the power available for the main telecommunication system.

To compensate this drawback and generate a efficient beam the EL min is reduced to 26.1 °, the maximum distance between a satellite and user become 1180 km and the beamforming is adjusted to generate a flux compensation as illustrated by the Figure 6-4. The beam presents a ring where the depointing angle increases.

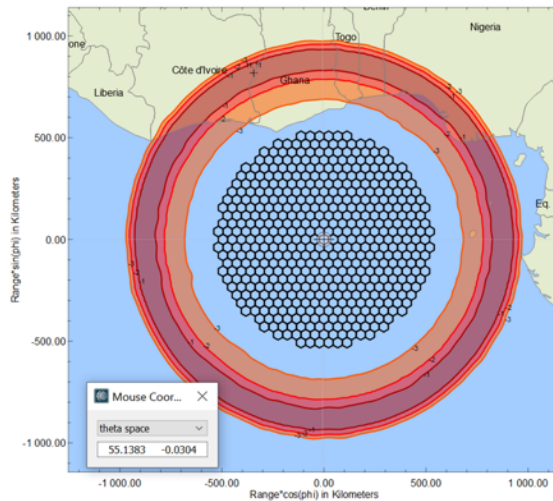
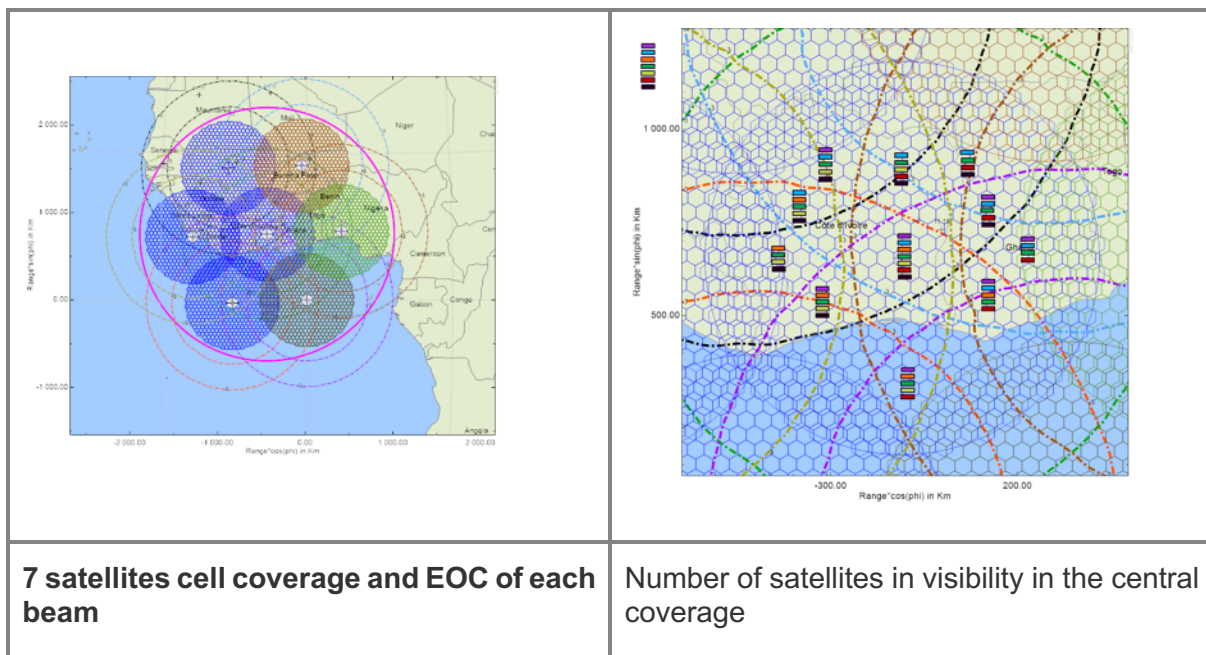


FIGURE 6-4 WIDE BEAM 26.1° ELMIN (55.1° DEPOINTING ANGLE FROM SATELLITE)

The Figure 6-5 illustrates the superposition of the EOC of each beam of the 7 adjacent satellites and the number of overlapping covers ranging from 4 to 7 satellites.



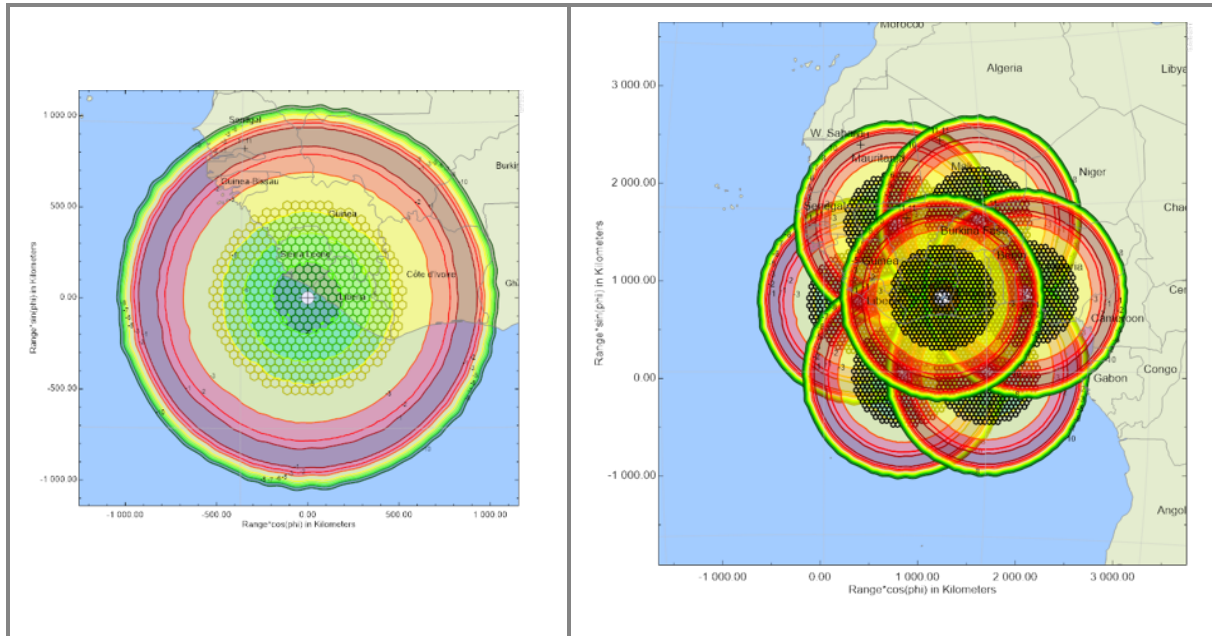


FIGURE 6-5 SUPERPOSITION OF WIDE BEAM GENERATED BY THE ANTENNA COVERAGE 26.1°

In Figure 6-6 is plotted the region over the earth map with the number of satellites in visibility.

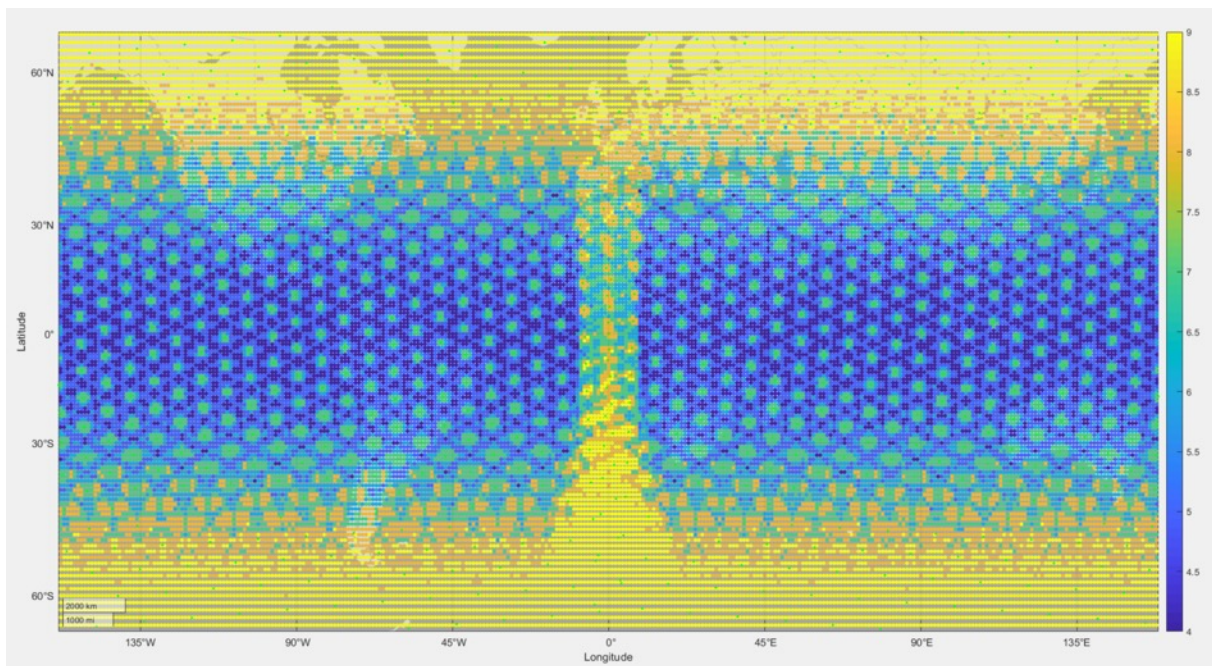


FIGURE 6-6 NUMBER OF SATELLITE THAT SUPERPOSE ITS COVERAGE OVERS LONG/LAT

EL min (°)	% earth surface covered by at least 4 satellites %
25.1	100.00
25.2	100.00
25.3	99.99
25.4	99.99
25.5	99.98
25.6	99.97
25.7	99.95
25.8	99.92
25.9	99.88
26	99.84
26.1	99.79

FIGURE 6-7 % OF SURFACE COVERED BY AT LEAST 4 SATELLITES

The results in table (Figure 6-7 show that in 99.79% of cases of a point on earth surface, an overlay of at least 4 satellites. A precise positioning can be envisaged. Nevertheless, the accuracy will depend on multiple factors that it is necessary to analyze and will be the subject of task 5.1.

6.3 CONCLUSION

In this chapter is discussed the possibility of generating beams for navigation. Solutions are proposed in the case of a LEO C-band constellation. It is about integrating an autonomous positioning solution by a payload functionality.

It is also possible to use other characteristics of the 6G NTN such as the contribution of the other nodes (Feeder Satellite in LEO) or to add some elements (MEO constellation) to enhance precision. These elements will be discussed in task 5.1.

7 CONCLUSION /PERSPECTIVE /NEXT STEP

First, from the global architectures elaborated [doc 3.5 of Task 3.1 [19]], constellations definition from Task 3.4 [25] and the terminal investigation in Task 3.2[26]. This work focus on the nodes payloads associated to this system definition. A trade-off have been performed in order to defined the axis of investigations for the future payloads associated with the 6G NTN .

More precisely for payload for users links:

- C-band constellations (LEO & VLEO)
- Q/V band constellation (LEO)
- HAPS (S)

All these payloads are in link with the overall nodes GEO to earth base stations. The parameters of base stations and GEO are proposed based on heritage.

A section was also devoted to building the network, i.e. the performance of the links between them, and defining appropriate solutions INL, ISL and Feeder links.

At each element (nodes) is associated the dimensioning and a preliminary architecture have been proposed. As the payload performance depend on the antenna performances, at each payload solution have been associated a preliminary antenna solution. It also include for users link a deeper analysis on beam forming techniques and coverage propositions and missions definitions in order to evaluate the link performances. Several trade-off and results have been given in appendix for adjust and also to pursue the investigations. The solutions are not unique, according to orientation, a choice could be done on the basis on hypothesis.

The solutions are proposed within view on the enabling technologies at term. All solutions are based on the state of the art and the technologies that will be available in the future for the deployment of the NTN 6G system. Nevertheless, studies will have to be carried out, and the developments identified in this context are also taken into account.

As mentioned, this document in conjunction with Task 3.4 (constellation definition), Task 3.1 (system definition) as well as Task 3.2 (Terminals) give the keys to estimate the effort to consider to have a successful 6G NTN system. Several interactions and convergence have been establishes as the performance of a system is also the performance of each nodes and their links capacities.

The most crucial points have been identified, preliminary assessments established. It was noted the important points that will contribute to reflexion and progress towards the 6G NTN system. The points that seem essential to progress and that will limit and slow down, in other words the bottlenecks and even block progress are: The technological development should be consolidated. Critical components have been identified. All need to progress in efficiency. Notably for ease the thermal dissipation management (additional cost in mass) by optimizing the efficiency (gain in mass : GS surface and dissipative surface).

Progress notably in the mass impact will improve significantly the cost of the overall system. Moreover, the concept of scalability have been proposed through illustrations over a principle of increasing capacity by incremental deployment.

Evaluating system performance is a complex and significant task. It requires defining the system, testing it against probable scenarios, and iterating to refine solutions. In the absence of an accurate traffic model, fundamental questions arise about the basis on which the system definition should rely. The approach adopted in this study acknowledges this reality: how can solutions be proposed for a need that is not precisely defined? Only estimates based on assumptions, within the context of market evolution and projections of TN usage, can be considered. To address these limitations, scalability becomes essential. Scalability is intrinsic to the 6G NTN concept, aiming to design a system capable of adapting to future developments while ensuring sustainability and cost control. Consequently, the NTN network design has been guided by hardware simplification to reduce overall costs, while enabling densification to meet future demands if required. A solution built solely on current assumptions risks leading to a rigid or oversized system, potentially resulting in inefficiency.

The solutions proposed in this context rely on interlinks between the nodes of the 6G NTN system. The definition of these interlinks has been addressed in this document (RF ISL) and in Task 3.1 for OISL. Given the uncertainties surrounding future demand—particularly with the rise of AI and its wide range of applications—significant resources will undoubtedly be required in the coming years. Although this trend is clearly established, the challenge remains to quantify its evolution with confidence.

In this work, original solutions were proposed to meet future needs and provide guidance on how to tackle the challenges ahead. All of these need to be confirmed in the next stage, by taking the NTN 6G system vision a step further.

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- [137] R1-2409226,3GPP TSG RAN WG1 #118bis

9 APPENDICES



9.1 FRONT-ENDS DEFINITION

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Topic: HORIZON-JU-SNS-2022-STREAM-B-01-03
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FRONT END DEFINITION									
Designation	FREQUENCY BAND	DESIGNATION	class	Band designation	Frequency band	Antenna type	Polarization	Characteristics	
UE (handeld)	C_BAND	C_NTN_1	NTN	NTN C	see doc 2.5 and §	wide coverage	linear	typ. NF=7 Gain : -5dBi, Tx=26 dBm	(1)
UE pro (handeld)		C_NTN_2	NTN	NTN C	see doc 2.5 and §	wide coverage	linear	typ. NF=7 Gain : -2dBi, Tx=26 dBm	(2)
UE mounted		C_NTN_3	NTN	NTN C	see doc 2.5 and §	wide coverage	linear	typ. NF=7 Gain : -2 dBi, Tx =26 dBm	(3)
UE terminal	Q/V BAND	QV_NTN_1	NTN	NTN Q/V	see doc 2.5 and §	directive /steerable	Circular	NF=5 GAIN 28 dBi Tx=34 dBm	(4)
UE terminal enhanced /UE_STA		QV_NTN_2	NTN	NTN Q/V	see doc 2.5 and §	directive /steerable	Circular	NF=4 Gain 32 dBi Tx=37 dBm	(5)
UE (handeld)	Terrestrial sub6 band	C_TN_1	TN	TN_C	terrestrial 3,6 GHz	wide coverage	linear	typ. NF=7 Gain : -5dBi, Tx=26 dBm	(6)
		HIBS_TN_1	TN	TN <3GHz	terrestrial cellular bands identified for HIBS (<3 GHz)	wide coverage	linear	typ. NF=9 Gain : -3dBi, Tx=23 dBm	(7)
UE (handeld)		Cell_TN_1	TN	TN cellular	terrestrial cellular bands for general use	wide coverage	linear	typ. NF=9 Gain : -3dBi, Tx=23 dBm	(8)
		Aerial_TN_1	NTN	TN_Aerial	terrestrial cellular bands permitted for Aerial use (< 3 GHz)	wide coverage	linear	typ. NF=9 Gain : -3dBi, Tx=23 dBm	(9)
		remark :	HIBS_TN	any terrestrial frequency band identified for HIBS below 3 GHz					
				TN frequency band					
				NTN frequency band					

- (1) classical integrated front end on handeld
- (2) professional handeld (The front end losses and LNA NF and Power is enhanced)
- (3) C band for vehicule, light drone , train and maritime backup (Polar Circular ? Visibility increased top of the vehicu
- (4) directive antenna with limited power and higher NF (TBC)
- (5) directive antenna withenhanced power and lower NF (TBC)
- (6) see (1)
- (7) note: BS is on board a HAPS, HIBS_Tn could any terrestrial frequency band identified below 3 GHz
- (8) note: BS is on ground
- (9) note: BS is on ground and UE is on-board un unmanned or manned aircraft

TERMINALS (Front ends on each equipement) ⁽¹⁰⁾					
Designation Terminal	integrated on :	Front ends			
UE handeld	handeld (mobile)	C_NTN_1	Cell_TN_1	HIBS_TN_1	
UE handeld professionnall	handeld (mobile pro)	C_NTN_2	Cell_TN_1	HIBS_TN_1	
UE terminal enhanced	Automobile	C_NTN_3	QV_NTN_1	Cell_TN_1	HIBS_TN_1
UE handeld	drone light	C_NTN_1 or C_NTN_2	QV_NTN_1	HIBS_TN_1	Aerial_TN_1
UE terminal enhanced/UE mounted	drone heavy	QV_NTN_2	C_NTN_3	HIBS_TN_1	(11)
UE_STA	haps_sta+drone_sta	QV_NTN_2	or QV_NTN_1	+ users antenna in C or HIBS band	
UE terminal enhanced	plane	QV_NTN_2	or QV_NTN_1		
UE mounted	maritime	C_NTN_3	QV_NTN_2	Cell_TN_1	HIBS_TN_1
UE_terminal enhanced	train	QV_NTN_2	C_NTN_3	Cell_TN_1	HIBS_TN_1
UE_terminal enhanced	bus	QV_NTN_2	C_NTN_3	Cell_TN_1	HIBS_TN_1
				TN frequency band	
				NTN frequency band	

(10)	each terminals could have several front-ends
(11)	rem HIBS (HIBS_TN) is a backup of C_NTN_3

FIGURE 9-1 TABLE RESUME OF THE FRONT-ENDS DEFINITION

Comments:

- (1) Classical integrated front-end on handheld
- (2) Professional handheld (the front end losses improvement , better LNA NF and power enhanced)
- (3) C-band front-end for vehicule, light drone, train and maritime backup terminal. Polar circular and hemispheric (except light drone)
- (4) Directive antenna (steerable) with limited power and high NF (TBC)
- (5) Directive antenna (steerable) with power enhanced and low NF (TBC)
- (6) C-band terrestrial band terminal only applicable for TN
- (7) HAPS acts as a Base Station functioning in HIBS band
- (8) Base station(BS) on earth. TN frequency band.
- (9) Base station (BS) on the ground and UE is on-board an unmanned of manned aircraft
- (10) Each terminal could have several front-ends as mentioned on the table
- (11) HIBS (HIBS_TN) is a backup of C_NTN_3

9.2 GENERAL TRADE-OFF

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9.3 NUMEROLOGY

The *transmission bandwidth configuration* N_{RB} for each *BS channel bandwidth* and subcarrier spacing is specified in table 5.3.2.-1 for FR1 and table 5.3.2-2 for FR2.

Table 5.3.2-1: Transmission bandwidth configuration N_{RB} for FR1

SCS (kHz)	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz	35 MHz	40 MHz	45 MHz	50 MHz	60 MHz	70 MHz	80 MHz	90 MHz	100 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}
15	25	52	79	106	133	160	188	216	242	270	N/A	N/A	N/A	N/A	N/A
30	11	24	38	51	65	78	92	106	119	133	162	189	217	245	273
60	N/A	11	18	24	31	38	44	51	58	65	79	93	107	121	135

Table 5.3.2-2: Transmission bandwidth configuration N_{RB} for FR2-1

SCS (kHz)	50 MHz	100 MHz	200 MHz	400 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}
60	66	132	264	N/A
120	32	66	132	264

Table 5.3.2-3: Transmission bandwidth configuration N_{RB} for FR2-2

SCS (kHz)	100 MHz	400 MHz	800 MHz	1600 MHz	2000 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}
120	66	264	N/A	N/A	N/A
480	N/A	66	124	248	N/A
960	N/A	33	62	124	148

NOTE: All Tx and Rx requirements are defined based on *transmission bandwidth configuration* specified in table 5.3.2-1 for FR1 and table 5.3.2-2 and table 5.3.2-3 for FR2.

FIGURE 9-3 EXTRACT NUMEROLOGY 3GPP TR 38.811 V15.4.0 [16]

9.4 C-BAND PAYLOAD

The downlink budget is given in the following tables table for the 3 cases :

CASE A : constellation C-BAND LEO 600 Km , 1056 RE (reference constellation)

CASE B : constellation C-BAND VLEO 350 Km, 1536 RE (alternative constellation)

CASE C : constellation C-Band LEO 600 km, 2048 RE (enhanced constellation)

9.4.1 CASE A – C band LEO

9.4.1.1 REFERENCE solution 1056 RE

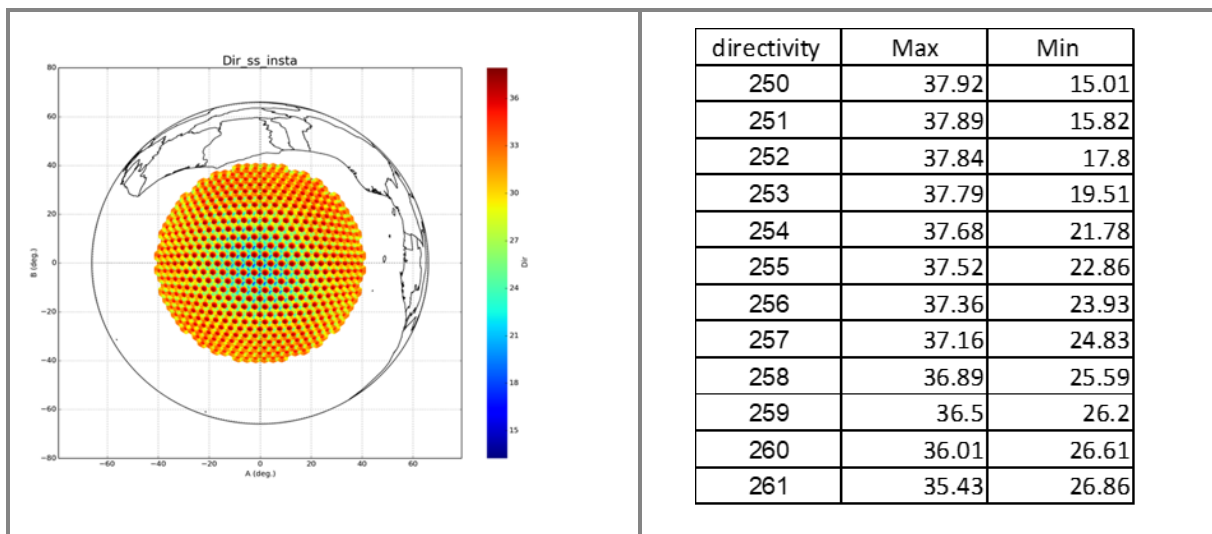
a) Dimensioning size of the antenna

The main guidelines

- DRA type antenna : array of 1056 of Radiated elements
- -0.742λ (at high frequency band) to limit grating over the earth surface when depointing up to $EL_{min}=45^\circ$
- cell size of 45 km over hexagonal lattice
- minimizing the number of RE / beam sizing
- Rx/Tx antenna
- circular polarisation RHCP/LHCP
- monopolarization in Rx and Tx

9.4.1.2 Rx performances

a) Best performances



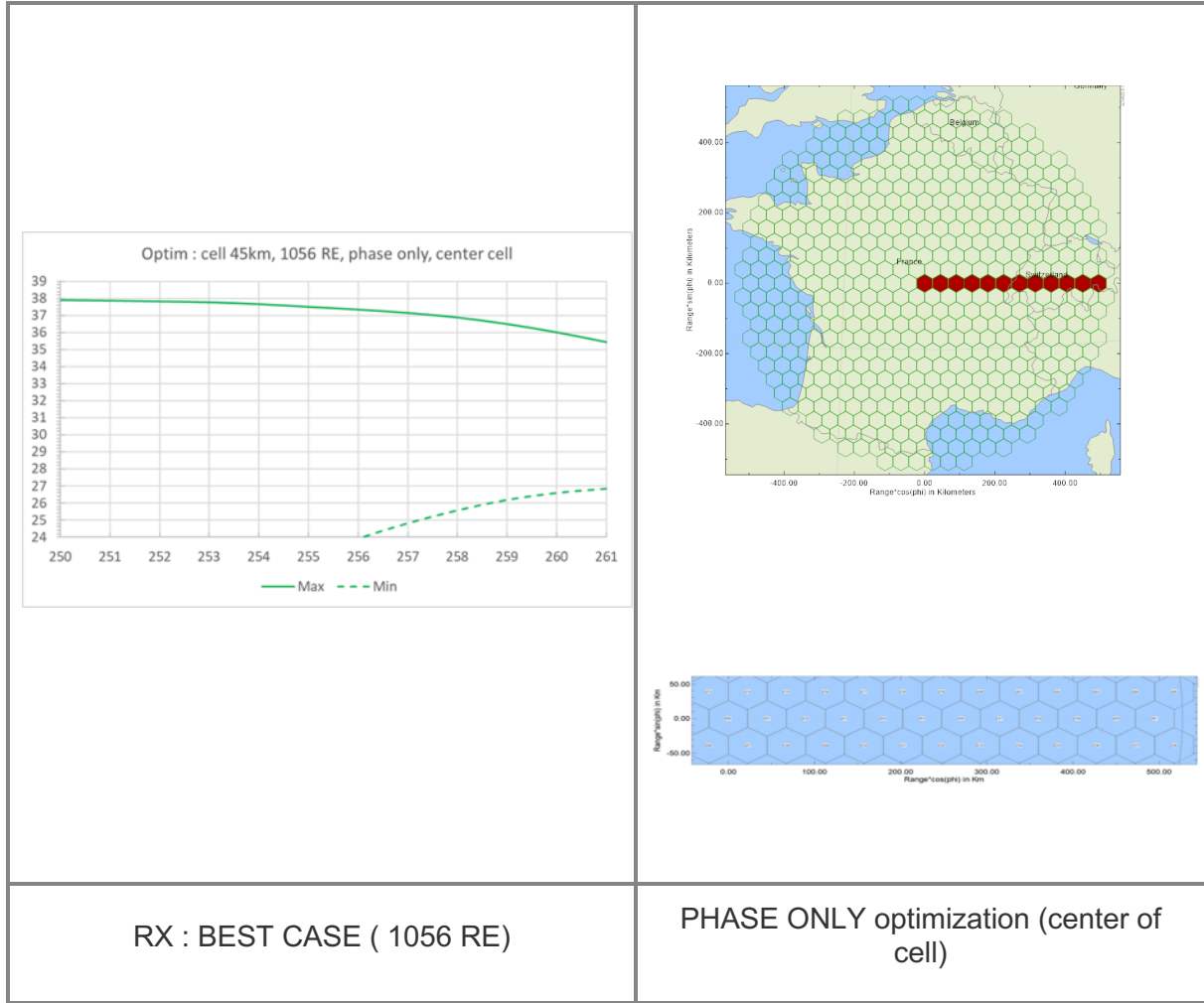
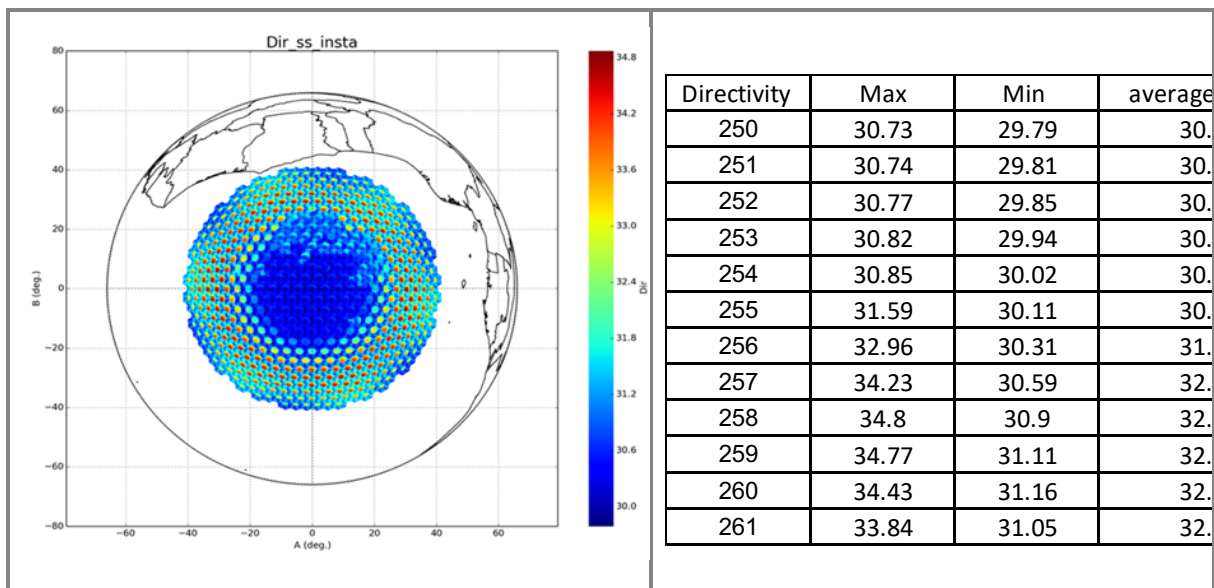


FIGURE 9-4 RX BEST PERFORMANCE CASE (PHASE ONLY)

b) Typical performances



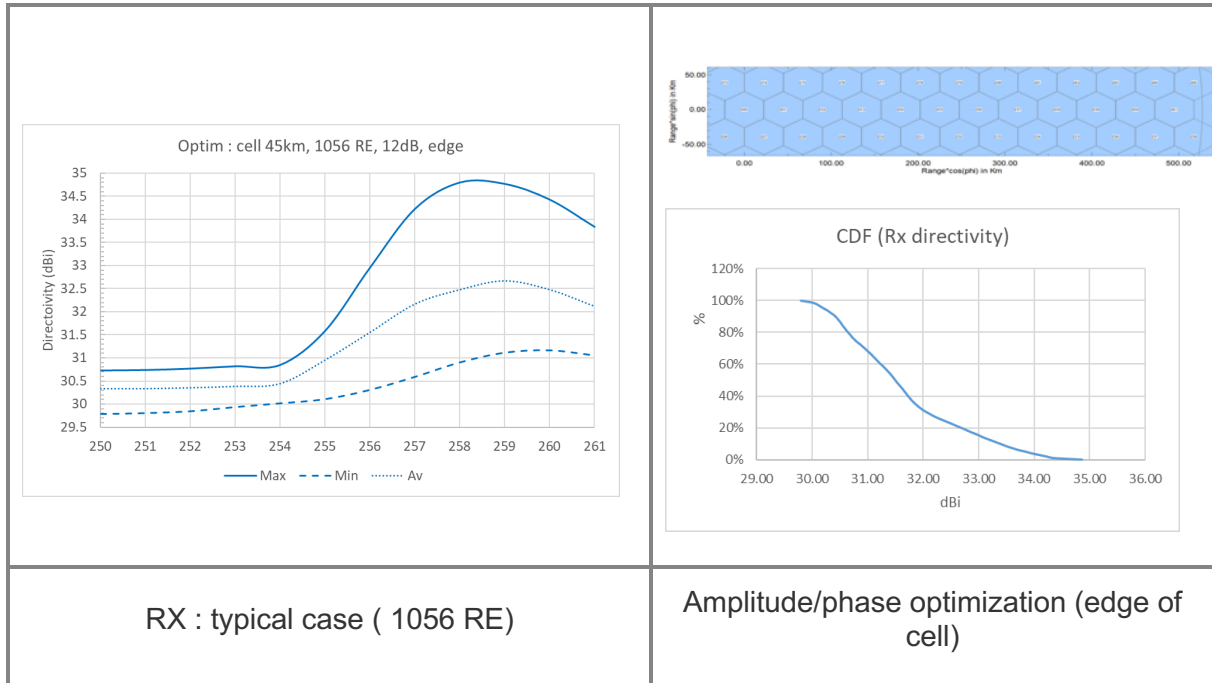


FIGURE 9-5 RX TYPICAL CASE (12 DB AMPLITUDE/PHASE)

c) Comparison between Best performances and typical case

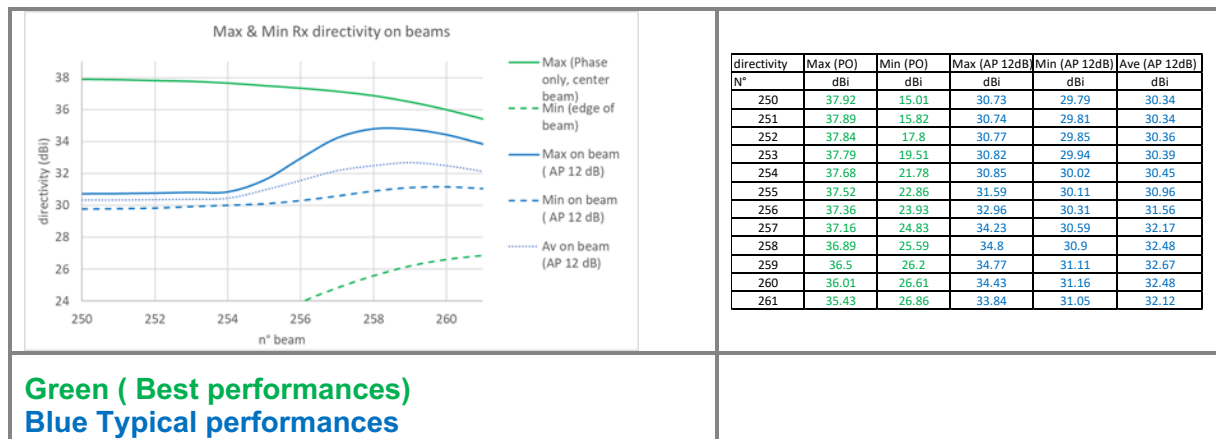


FIGURE 9-6 COMPARISON RX : BEST PERFORMANCE (PHASE ONLY) & TYPICAL CASE (AMPLITUDE/PHASE 12 DB)

9.4.1.3 Tx performances

a) Best performances Phase only (center of cell and edge of cell)

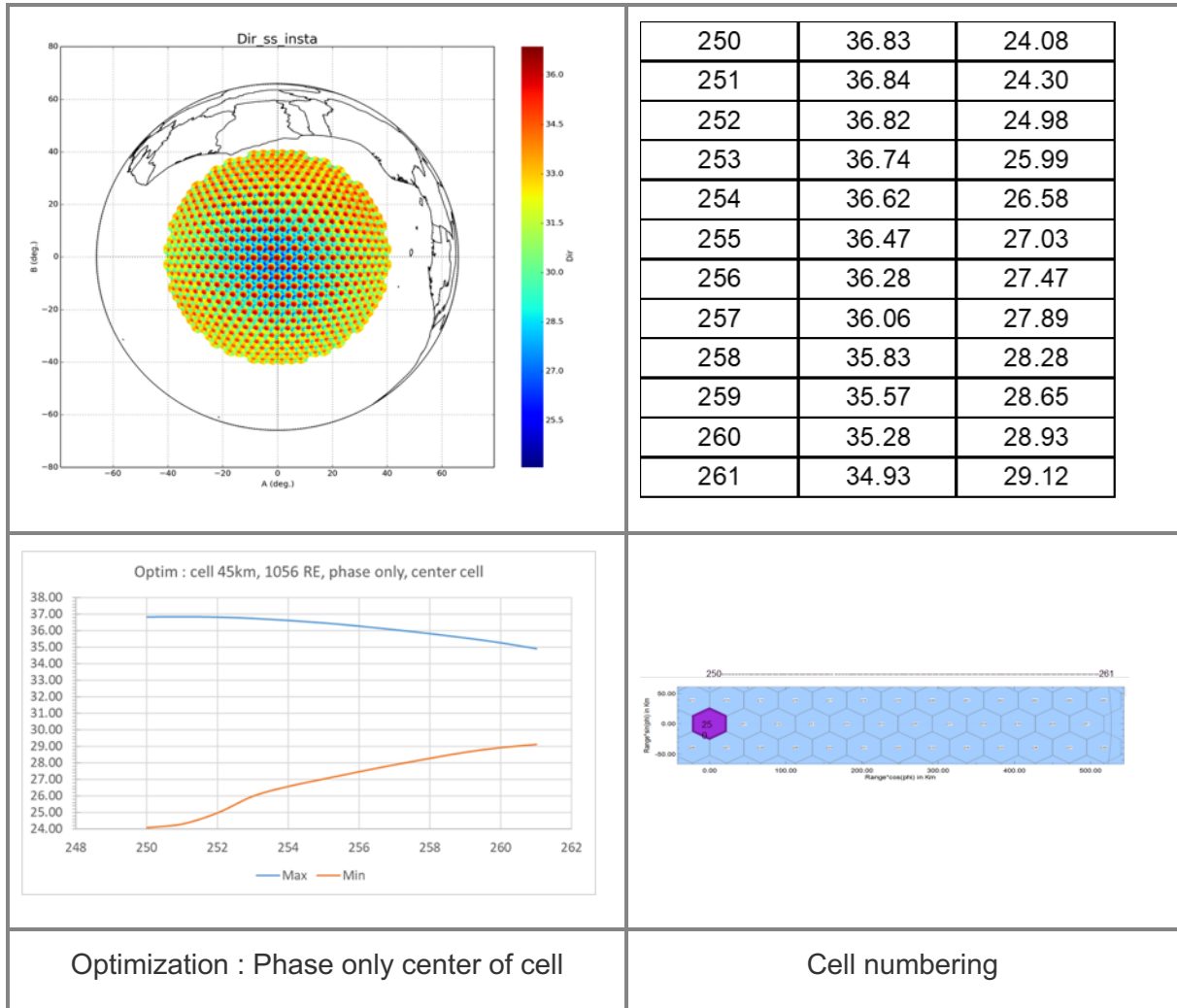
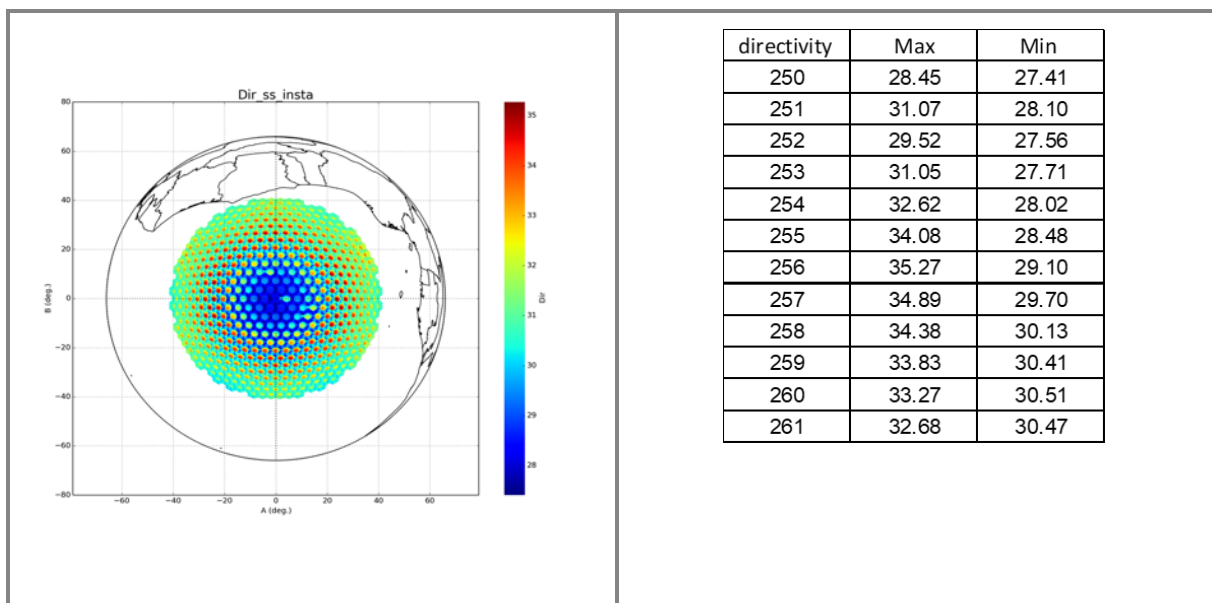


FIGURE 9-7 TX BEST CASE (PHASE ONLY CENTER OF CELL)



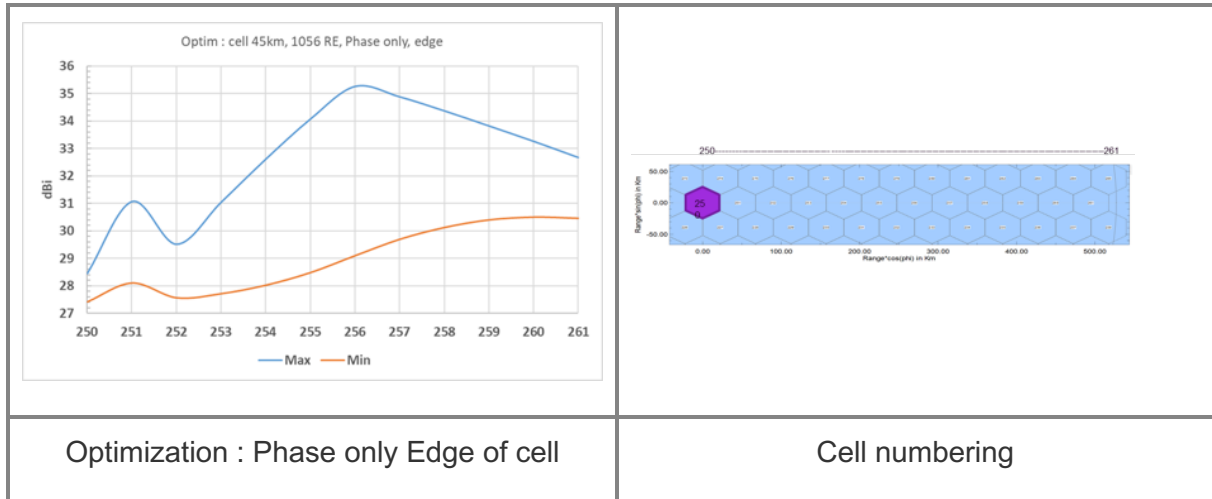
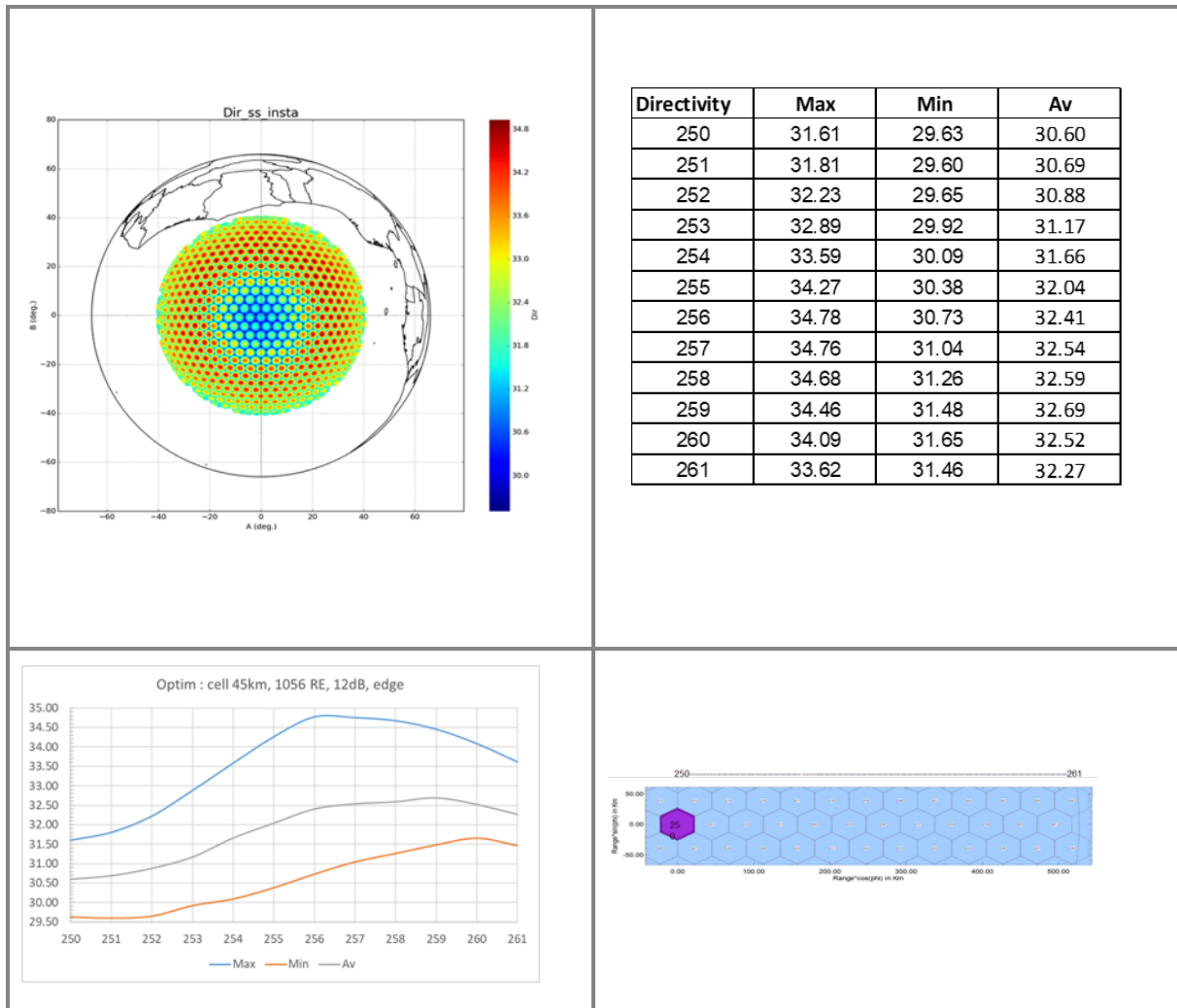


FIGURE 9-8 TX BEST CASE (PHASE ONLY EDGE OF CELL)

b) Typical case Tx (Amplitude/phase beamforming 12 dB)



Optimization : Amplitude/phase 12 dB	Cell numbering
--------------------------------------	----------------

FIGURE 9-9 TX TYPICAL CASE (12 AMPLITUDE/PHASE EDGE OF CELL)

c) Comparison between the 3 cases

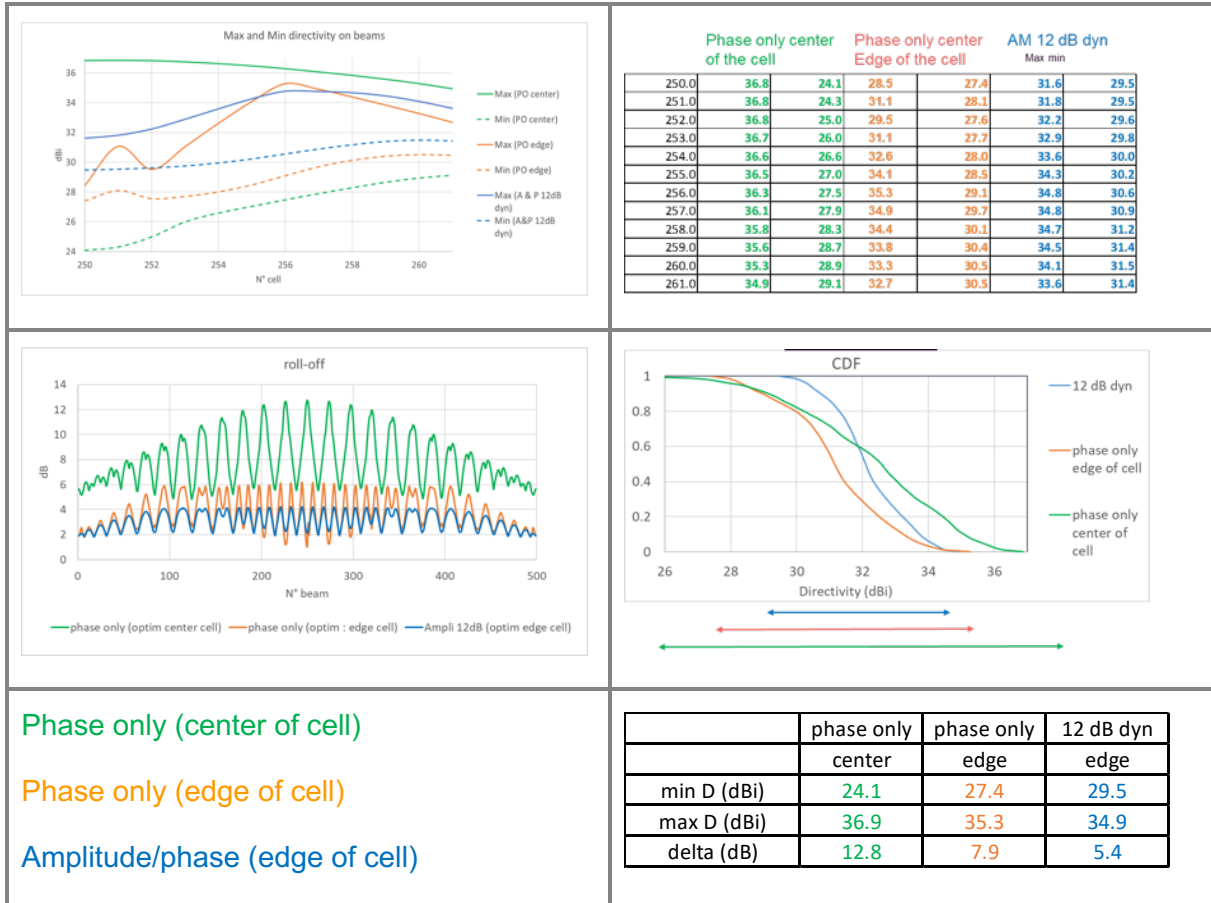


FIGURE 9-10 COMPARISON BETWEEN THE 3 BEAMFORMING TECHNIQUES

9.4.1.4 Power Hypothesis Case A

CASE A	1056	
densité PIRE	dBW/MHz	28
nb beam total		499
nb de beam actif		50
bande de fréquence	MHz	100
PIRE /beam	dBW	48
PIRE Total	dBW	65
nb elements		1056
Puissance Total RF		1991
efficacité SSPA	%	35
Puissance Totale	W	5687
dissipation	W	3697

FIGURE 9-11 POWER HYPOTHESIS (CASE A) FRONT-END TX

9.4.1.5 Downlink Maximization of the throughput Case A C-Band (sensitivity to UE type UE_1 to UE_4)

Hypothesis 1 UE at the center of the cell at nadir and at edge (EL=45°), and the link budget are given for the 4 UE case (UE_1, UE_2, UE-3 & UE_4) at boresight and at edge EL 45°.

EIRP hypothesis of 28 dBW/MHz per beam, 100 beams.

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	196	273
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	28.00	28.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-5.00	-5.00
	Figure of Merit: G/T	dB/K	-36.62	-36.62
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-39.62	-39.62
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	0.00	0.00
	Body loss	dB	0.00	0.00
	Scan loss	dB	0.00	0.00
	Additional loss	dB	0.00	0.00
GLOBAL LOSSES	Calibration mismatch loss	dB	0.00	0.00
	System margin	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	196	273
RESULTS	Obtained C/N	dB	-4.45	-1.75
	Spectral Efficiency	bits/s/Hz	0.2016	0.3242
	UE Rate	Mbits/s	14.22	31.86

FIGURE 9-12 DOWNLINK BUDGET CASE A NOMINAL CASE (UE_1)

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	273	273
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	28.00	28.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-2.00	-2.00
	Figure of Merit: G/T	dB/K	-33.62	-33.62
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-36.62	-36.62
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	0.00	0.00
	Body loss	dB	0.00	0.00
	Scan loss	dB	0.00	0.00
	Additional loss	dB	0.00	0.00
GLOBAL LOSSES	Calibration mismatch loss	dB	0.00	0.00
	System margin	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	273	273
RESULTS	Obtained C/N	dB	-2.90	1.20
	Spectral Efficiency	bits/s/Hz	0.2637	0.6366
	UE Rate	Mbits/s	25.91	62.56

FIGURE 9-13 DOWNLINK BUDGET CASE A NOMINAL CASE (UE_2)

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	273	273
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	28.00	28.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-5.00	-5.00
	Figure of Merit: G/T	dB/K	-35.12	-35.12
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-38.12	-38.12
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	0.00	0.00
	Body loss	dB	0.00	0.00
	Scan loss	dB	0.00	0.00
	Additional loss	dB	0.00	0.00
GLOBAL LOSSES	Calibration mismatch loss	dB	0.00	0.00
	System margin	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	273	273
RESULTS	Obtained C/N	dB	-4.39	-0.27
	Spectral Efficiency	bits/s/Hz	0.2016	0.4216
	UE Rate	Mbits/s	19.81	41.43

FIGURE 9-14 DOWNLINK BUDGET CASE A NOMINAL CASE (UE_3)

DOWNLINK		Unit	Average Case (E145°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	273	273
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	28.00	28.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-2.00	-2.00
	Figure of Merit: G/T	dB/K	-32.12	-32.12
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-35.12	-35.12
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	0.00	0.00
	Body loss	dB	0.00	0.00
	Scan loss	dB	0.00	0.00
	Additional loss	dB	0.00	0.00
GLOBAL LOSSES	Calibration mismatch loss	dB	0.00	0.00
	System margin	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	273	273
RESULTS	Obtained C/N	dB	-1.42	2.67
	Spectral Efficiency	bits/s/Hz	0.3242	0.7542
	UE Rate	Mbits/s	31.86	74.12

FIGURE 9-15 DOWNLINK BUDGET CASE A NOMINAL CASE (UE_4)

9.4.1.6 Downlink throughput Case A C-Band (All power (48 dBW/MHz) in one beam, one UE (UE_1 to UE_4)

DOWNLINK		Unit	Average Case (E145°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	273	273
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	48.00	48.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-5.00	-5.00
	Figure of Merit: G/T	dB/K	-36.62	-36.62
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-39.62	-39.62
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	0.00	0.00
	Body loss	dB	0.00	0.00
	Scan loss	dB	0.00	0.00
	Additional loss	dB	0.00	0.00
GLOBAL LOSSES	Calibration mismatch loss	dB	0.00	0.00
	System margin	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	273	273
RESULTS	Obtained C/N	dB	12.64	15.13
	Spectral Efficiency	bits/s/Hz	1.4580	1.4580
	UE Rate	Mbits/s	143.29	143.29

FIGURE 9-16 DOWNLINK BUDGET CASE A BEST CASE (UE_1)

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	273	273
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	48.00	48.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-2.00	-2.00
	Figure of Merit: G/T	dB/K	-33.62	-33.62
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-36.62	-36.62
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	273	273
RESULTS	Obtained C/N	dB	14.53	16.33
	Spectral Efficiency	bits/s/Hz	1.4580	1.4580
	UE Rate	Mbits/s	143.29	143.29

FIGURE 9-17 DOWNLINK BUDGET CASE A BEST CASE (UE_2)

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	273	273
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	48.00	48.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-2.00	-2.00
	Figure of Merit: G/T	dB/K	-33.62	-33.62
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-36.62	-36.62
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	273	273
RESULTS	Obtained C/N	dB	14.53	16.33
	Spectral Efficiency	bits/s/Hz	1.4580	1.4580
	UE Rate	Mbits/s	143.29	143.29

FIGURE 9-18 DOWNLINK BUDGET CASE A BEST CASE (UE_3)

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	273	273
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	48.00	48.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-2.00	-2.00
	Figure of Merit: G/T	dB/K	-32.12	-32.12
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-35.12	-35.12
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	273	273
RESULTS	Obtained C/N	dB	15.29	16.76
	Spectral Efficiency	bits/s/Hz	1.4580	1.4580
	UE Rate	Mbits/s	143.29	143.29

FIGURE 9-19 DOWNLINK BUDGET CASE A BEST CASE (UE_1)

9.4.1.7 Downlink throughput Case A C-Band (nominal power in one beam, 10 dB attenuation (indoor), UE_1 to UE_4)

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	12	50
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	28.00	28.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-5.00	-5.00
	Figure of Merit: G/T	dB/K	-36.62	-36.62
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-39.62	-39.62
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	10.00	10.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	12	50
RESULTS	Obtained C/N	dB	-2.34	-4.36
	Spectral Efficiency	bits/s/Hz	0.3242	0.2016
	UE Rate	Mbits/s	1.40	3.63

FIGURE 9-20 DOWNLINK BUDGET (UE_1) WORST CASE INDOOR 10 DB ATTENUATION

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	28	64
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	28.00	28.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-2.00	-2.00
	Figure of Merit: G/T	dB/K	-33.62	-33.62
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-36.62	-36.62
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	10.00	10.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	28	64
RESULTS	Obtained C/N	dB	-3.01	-2.45
	Spectral Efficiency	bits/s/Hz	0.2637	0.3242
	UE Rate	Mbits/s	2.66	7.47

FIGURE DOWNLINK BUDGET (UE_2) WORST CASE INDOOR 10 DB ATTENUATION

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	21	55
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	28.00	28.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-5.00	-5.00
	Figure of Merit: G/T	dB/K	-35.12	-35.12
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-38.12	-38.12
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	10.00	10.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	21	55
RESULTS	Obtained C/N	dB	-3.26	-3.28
	Spectral Efficiency	bits/s/Hz	0.2637	0.2637
	UE Rate	Mbits/s	1.99	5.22

FIGURE 9-21 DOWNLINK BUDGET (UE_3) WORST CASE INDOOR 10 DB ATTENUATION

DOWNLINK		Unit	Average Case (E145°)	Best Case (NADR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	30	91
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	ERP density	dBW/MHz	28.00	28.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-2.00	-2.00
	Figure of Merit: G/T	dB/K	-32.12	-32.12
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-35.12	-35.12
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	10.00	10.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	30	91
RESULTS	Obtained CN	dB	-1.82	-2.47
	Spectral Efficiency	bits/s/Hz	0.3242	0.3242
	UE Rate	Mbits/s	3.50	10.62

FIGURE 9-22 DOWNLINK BUDGET (UE_4) WORST CASE INDOOR 10 DB ATTENUATION

9.4.1.8 Rx hypothesis case A

The hypothesis taken for the link budget are summarized in the table below :

FDD mod : Losses L: 2 dB LNA NF : 2 dB Tant=240 K G/T = G-26.33 dB G/T= D-L-26.33 dB G/T=D-28.33 dB	D dBi	G/T dB.K ⁻¹	TDD mod : Losses L: 1.5 dB LNA NF : 2 dB Tant=240 K G/T = G-26.33 dB G/T= D-L-26.33 dB G/T= D-27.83 dB
	37	8.67	
	36	7.67	
	35	6.67	
	34	5.67	
	33	4.67	
	32	3.67	
	31	2.67	
	30	1.67	
	29	0.67	
	28	-0.33	
	27	-1.33	
	26	-2.33	

FIGURE 9-23 RX FRONT END HYPOTHESIS CASE A

9.4.1.9 Uplink budget Best case

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	4	7
	Occupied Channel Bandwidth	MHz	1.44	2.52
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	5.51	2.40
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	4	7
RESULTS	Obtained C/N	dB	-3.54	-4.91
	Spectral Efficiency	bits/s/Hz	0.2821	0.2156
	UE Rate	Mbit/s	0.406	0.543

FIGURE 9-24 UPLINK BUDGET BEST CASE (UE_1)

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	7	11
	Occupied Channel Bandwidth	MHz	2.52	3.96
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	5.51	2.40
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	7	11
RESULTS	Obtained C/N	dB	-2.98	-3.88
	Spectral Efficiency	bits/s/Hz	0.3468	0.2821
	UE Rate	Mbit/s	0.874	1.117

FIGURE 9-25 9-26 UPLINK BUDGET BEST CASE (UE_2)

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (E1 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	7	11
	Occupied Channel Bandwidth	MHz	2.52	3.96
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	5.51	2.40
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	7	11
RESULTS	Obtained C/N	dB	-2.98	-3.88
	Spectral Efficiency	bits/s/Hz	0.3468	0.2821
	UE Rate	Mbit/s	0.874	1.117

FIGURE 9-27 UPLINK BUDGET BEST CASE (UE_3)

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (E1 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	9	10
	Occupied Channel Bandwidth	MHz	3.24	3.6
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	6.01	2.90
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	9	10
RESULTS	Obtained C/N	dB	-3.56	-2.97
	Spectral Efficiency	bits/s/Hz	0.2821	0.3468
	UE Rate	Mbit/s	0.914	1.249

FIGURE 9-28 UPLINK BUDGET BEST CASE (UE_4)

9.4.1.10 Uplink budget for 1 PRB

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (E145°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	1	1
	Occupied Channel Bandwidth	MHz	0.36	0.36
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	5.51	2.40
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	0.00	0.00
INTERMEDIATE RESULTS	C/No per PRB	dBHz	58.1	59.1
	C/No for all PRB	dBHz	58.1	59.1
	C/N	dB	2.5	3.6
	C/Io	dBHz	73.56	73.56
	C/I	dB	18.00	18.00
	C/(No+Io) per PRB	dBHz	57.95	58.97
	C/(No+Io) for all PRB	dBHz	57.95	58.97
	Overall C/(No+Io) (including Glob	dBHz	57.95	58.97
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	Obtained C/N	dB	2.39	3.41
	Spectral Efficiency	bits/s/Hz	0.9451	1.0817
	UE Rate	Mbit/s	0.340	0.389

FIGURE 9-29 UPLINK BUDGET FOR 1 PRB CASE UE_1 (TO SIMPLIFY)

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (E145°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	1	1
	Occupied Channel Bandwidth	MHz	0.36	0.36
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	5.51	2.40
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	Obtained C/N	dB	5.27	6.26
	Spectral Efficiency	bits/s/Hz	1.2201	1.3585
	UE Rate	Mbit/s	0.439	0.489

FIGURE 9-30 UPLINK BUDGET FOR 1 PRB CASE UE_2

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	1	1
	Occupied Channel Bandwidth	MHz	0.36	0.36
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	6.01	2.90
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	Obtained C/N	dB	2.87	3.89
	Spectral Efficiency	bits/s/Hz	0.9451	1.0817
	UE Rate	Mbit/s	0.340	0.389

FIGURE 9-31 UPLINK BUDGET FOR 1 PRB CASE UE_3

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	1	1
	Occupied Channel Bandwidth	MHz	0.36	0.36
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	6.01	2.90
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	Obtained C/N	dB	5.74	6.73
	Spectral Efficiency	bits/s/Hz	1.2201	1.3585
	UE Rate	Mbit/s	0.439	0.489

FIGURE 9-32 UPLINK BUDGET FOR 1 PRB CASE UE_4

9.4.1.11 Uplink budget worst case

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	1	1
	Occupied Channel Bandwidth	MHz	0.36	0.36
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	5.51	2.40
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	7.00	8.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	Obtained C/N	dB	-4.51	-4.46
	Spectral Efficiency	bits/s/Hz	0.2156	0.2156
	UE Rate	Mbit/s	0.078	0.078

FIGURE 9-33 UPLINK BUDGET WORST CASE (UE_1) 7 DB MAX ATTENUATION

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	1	1
	Occupied Channel Bandwidth	MHz	0.36	0.36
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	5.51	2.40
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	10.00	10.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	Obtained C/N	dB	-4.51	-3.47
	Spectral Efficiency	bits/s/Hz	0.2156	0.2821
	UE Rate	Mbit/s	0.078	0.102

FIGURE 9-34 UPLINK BUDGET WORST CASE (UE_2) 10 DB MAX ATTENUATION

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	1	1
	Occupied Channel Bandwidth	MHz	0.36	0.36
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	6.01	2.90
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	7.00	9.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	Obtained C/N	dB	-4.02	-4.96
	Spectral Efficiency	bits/s/Hz	0.2156	0.2156
	UE Rate	Mbit/s	0.078	0.078

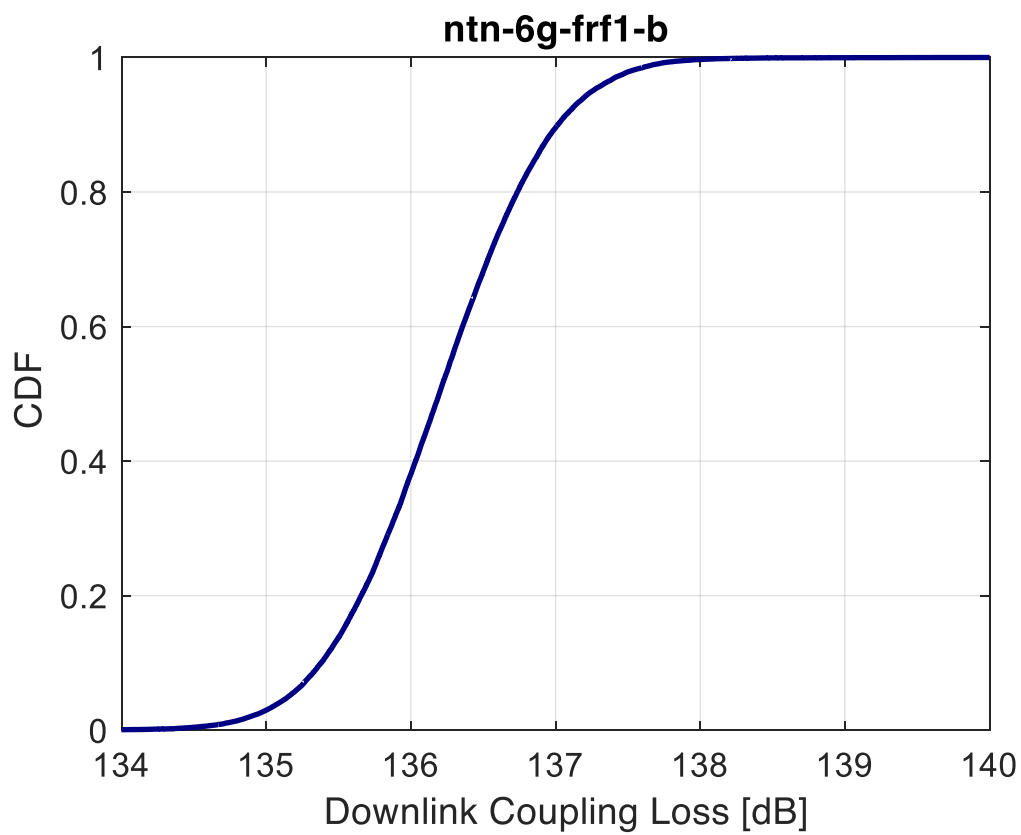
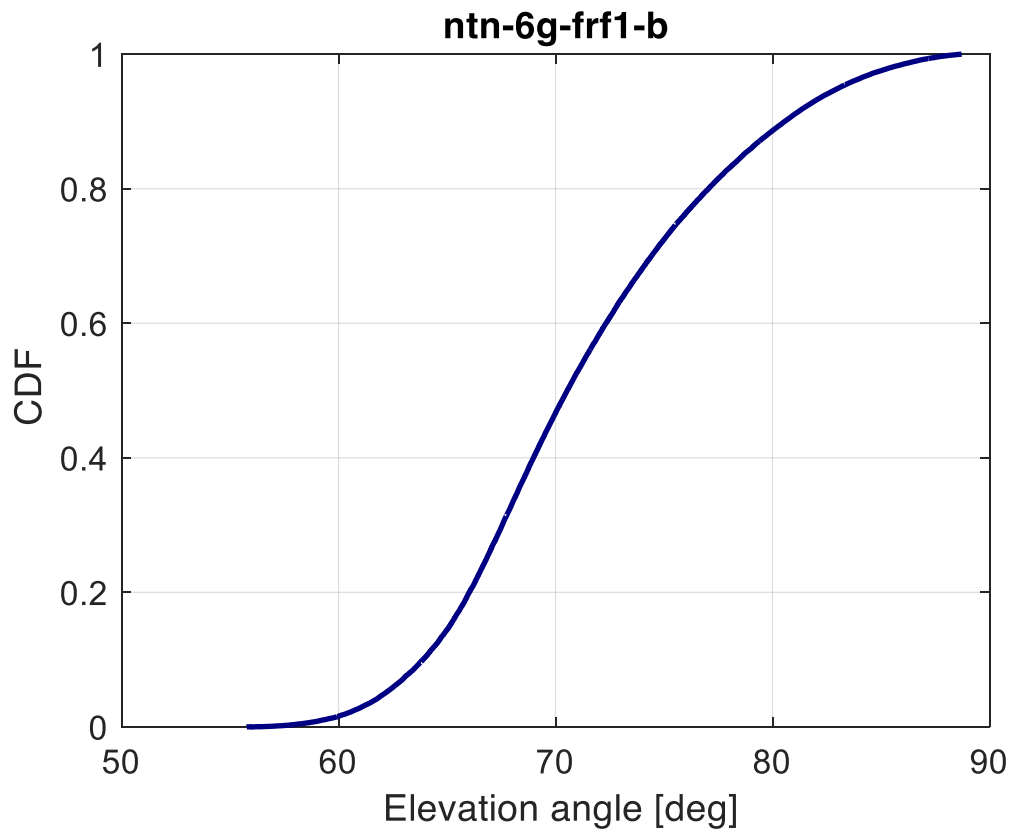
FIGURE 9-35 UPLINK BUDGET WORST CASE (UE_3) 7 DB AND 9 DB MAX ATTENUATION

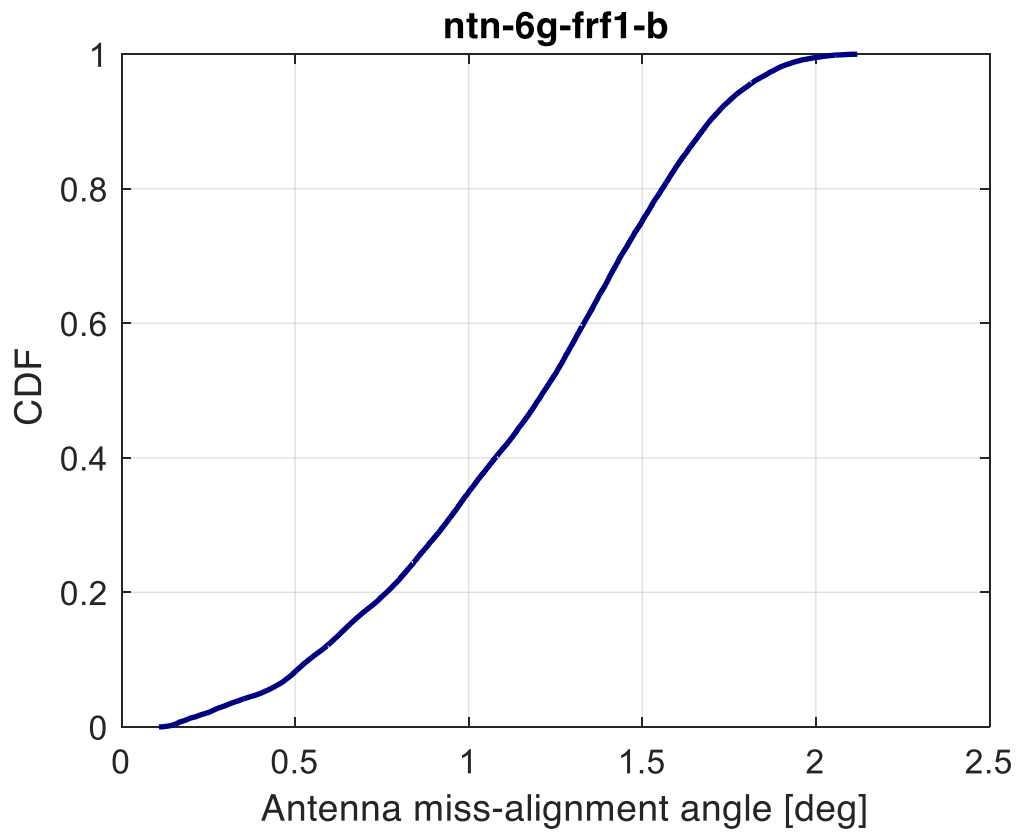
<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	1	1
	Occupied Channel Bandwidth	MHz	0.36	0.36
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	6.01	2.90
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	10.00	10.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	Obtained C/N	dB	-4.02	-2.97
	Spectral Efficiency	bits/s/Hz	0.2156	0.3468
	UE Rate	Mbit/s	0.078	0.125

FIGURE 9-36 UPLINK BUDGET WORST CASE (UE_4) 10 DB MAX ATTENUATION

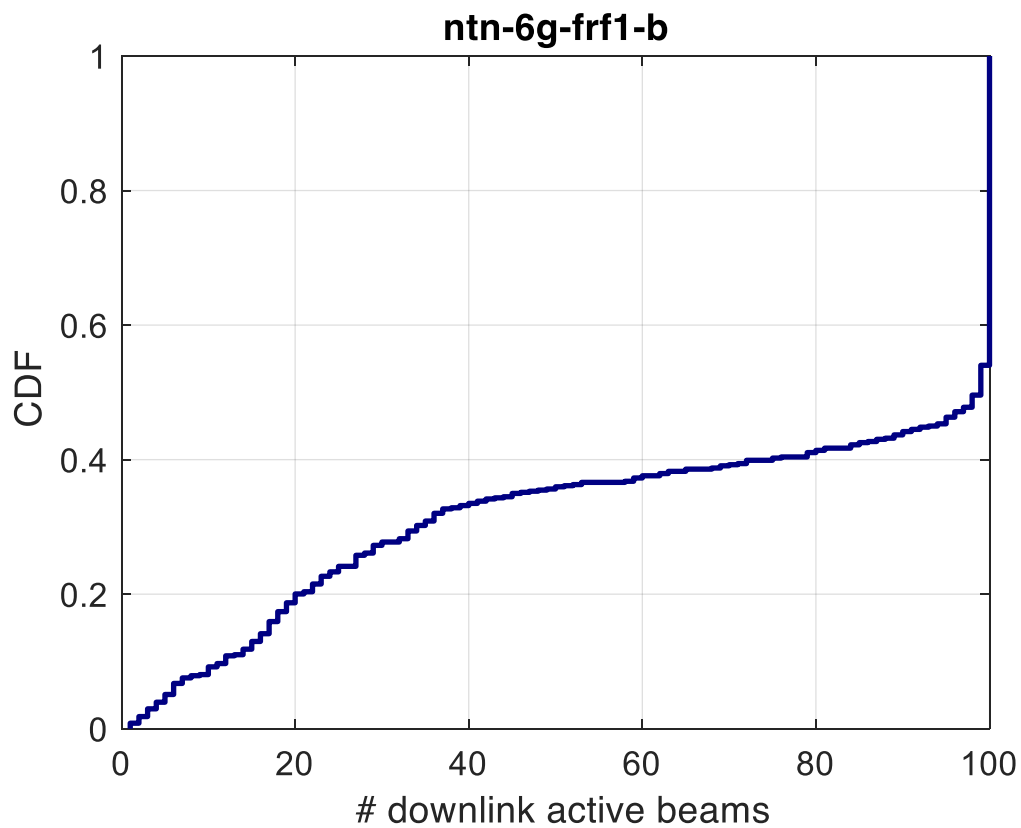
9.4.2 Metropolitan France

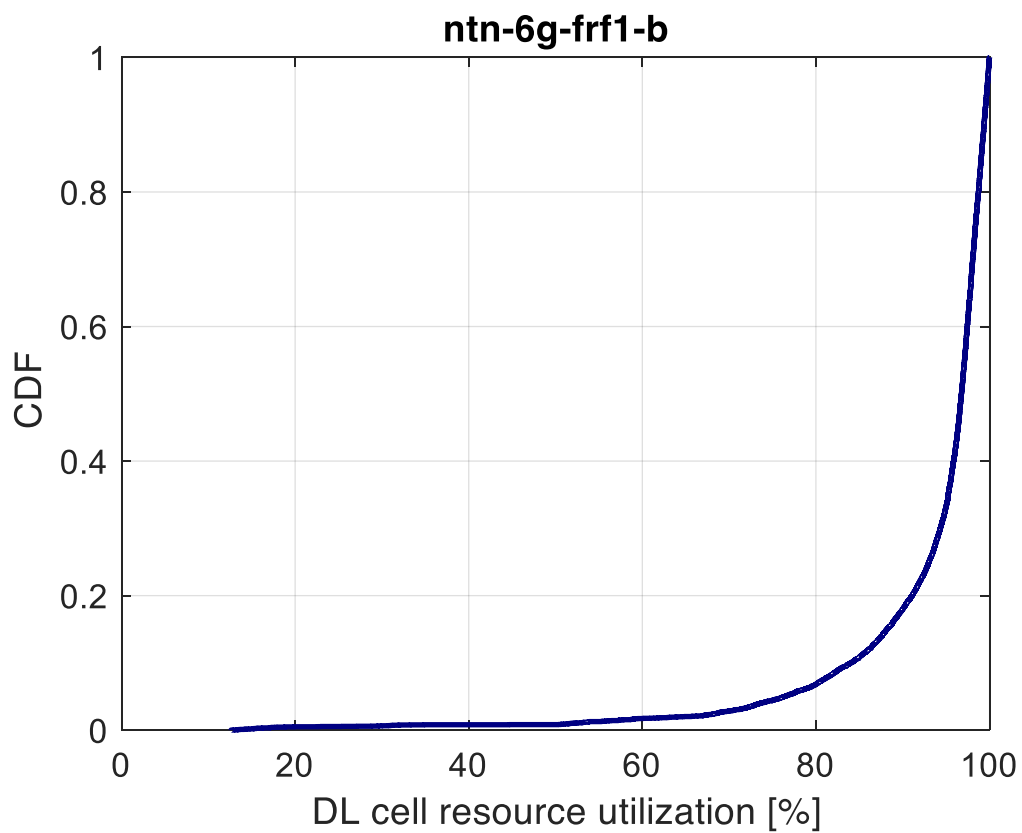
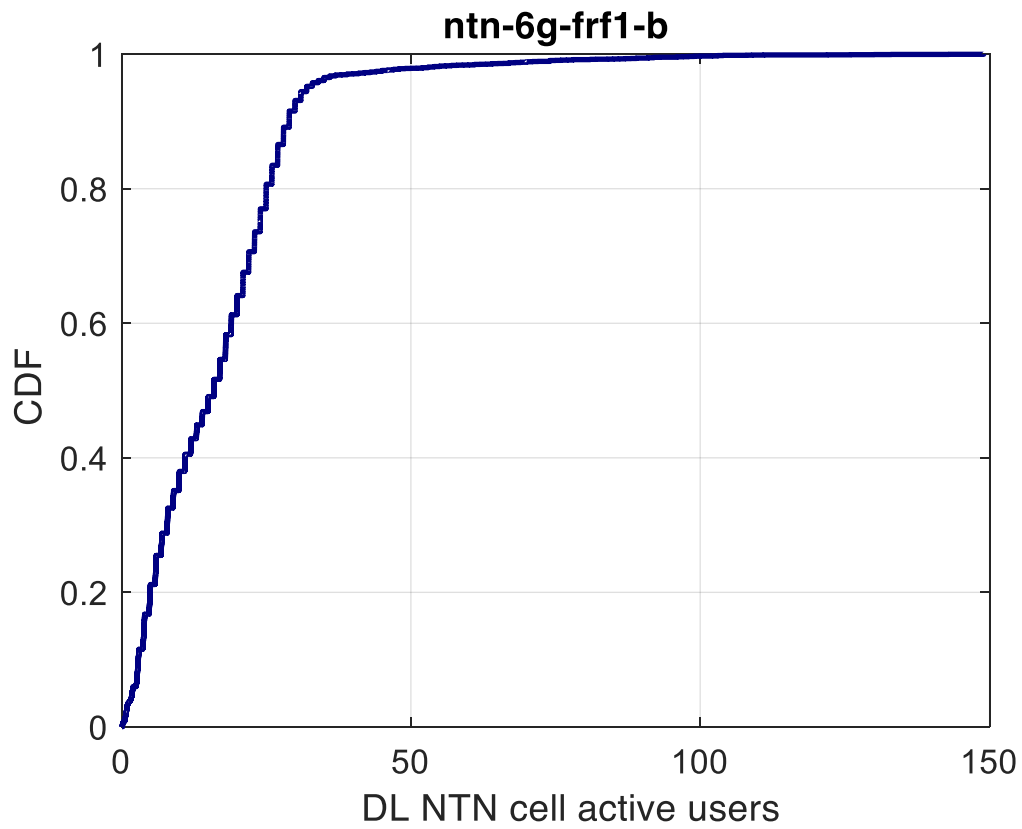
9.4.2.1 Results for FRF=1

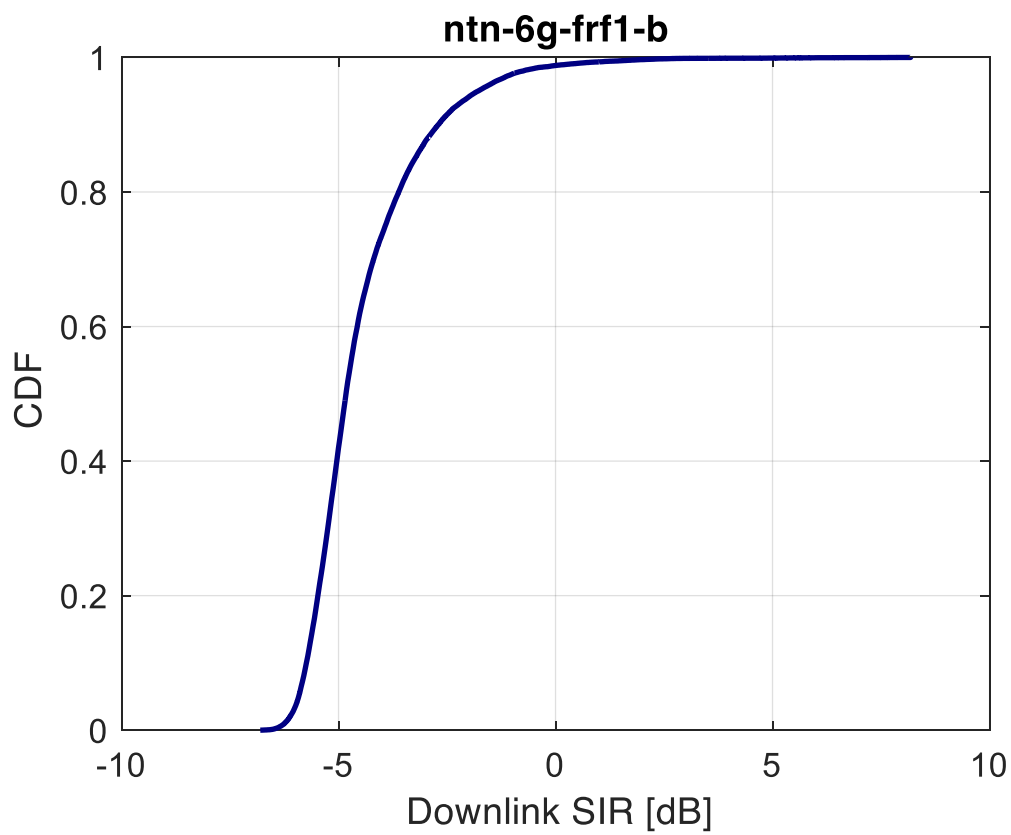
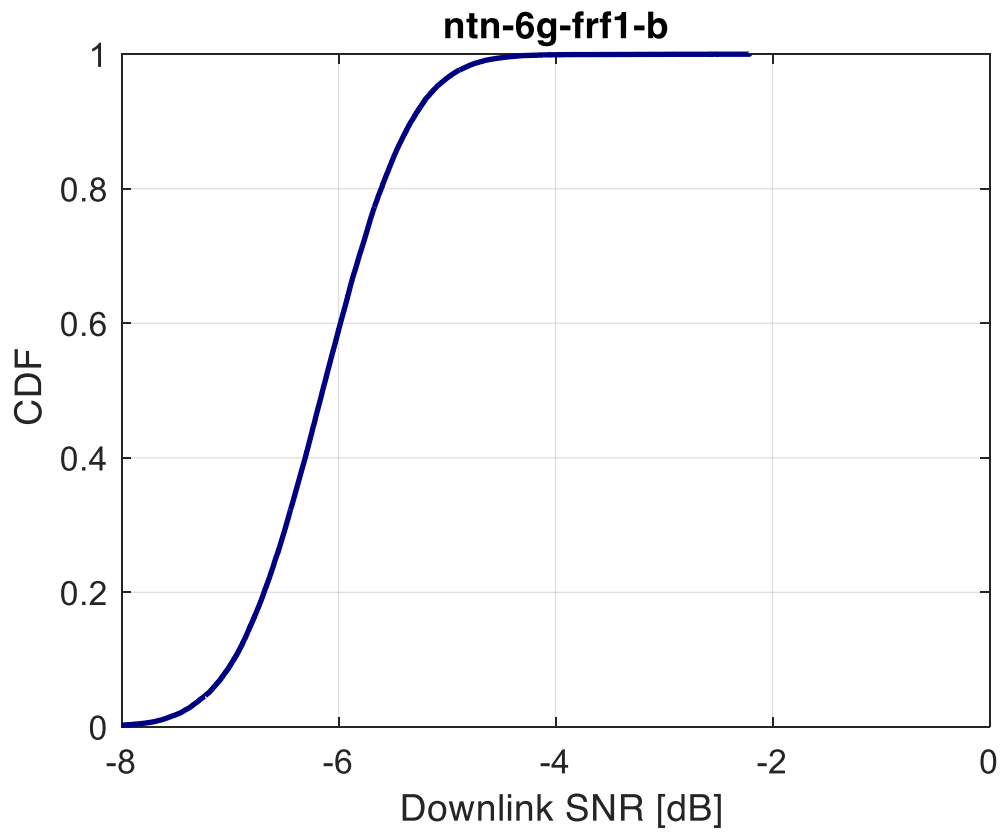


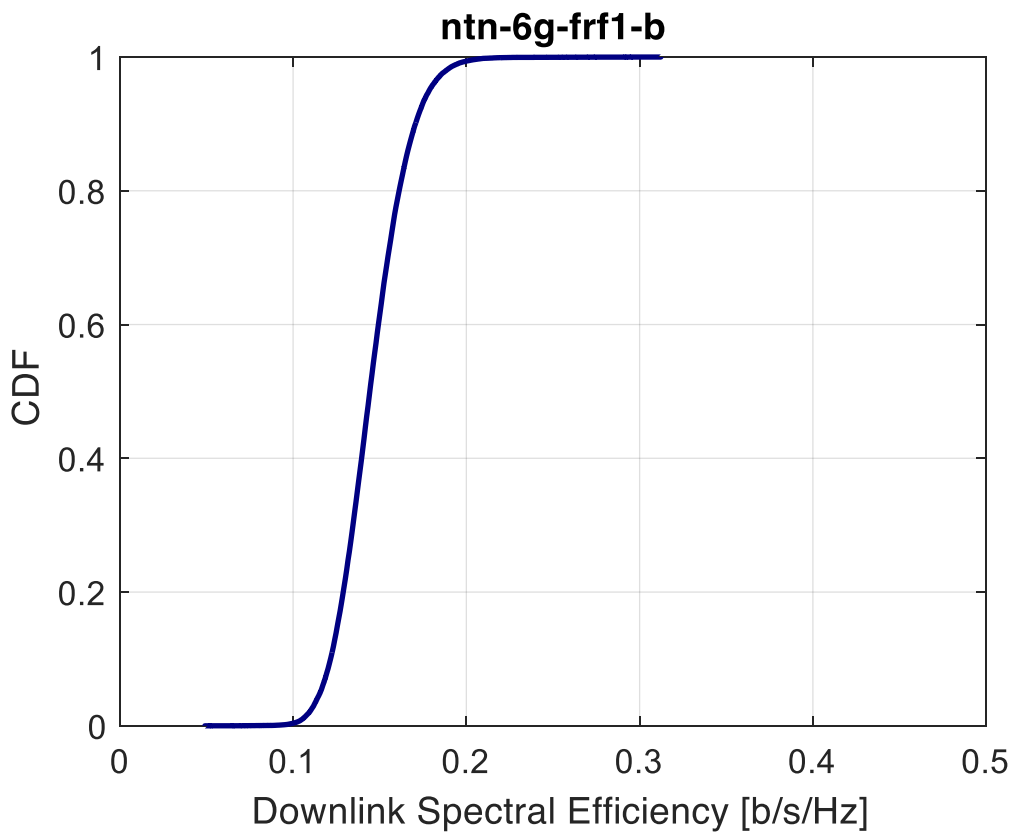
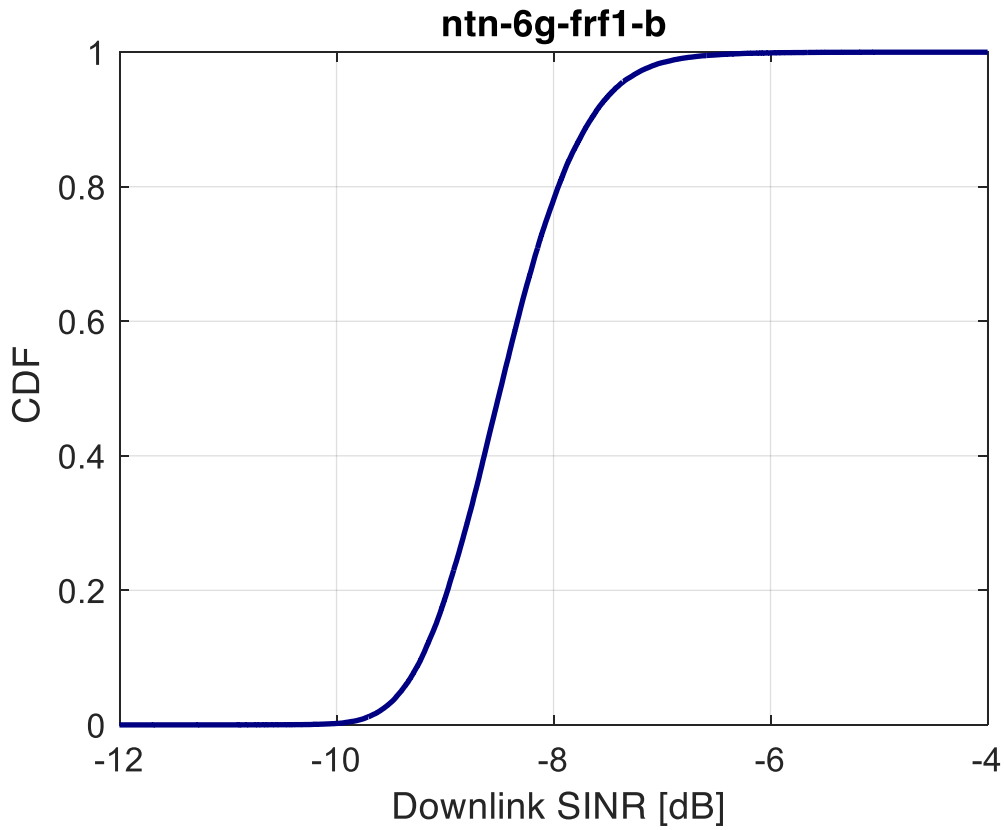


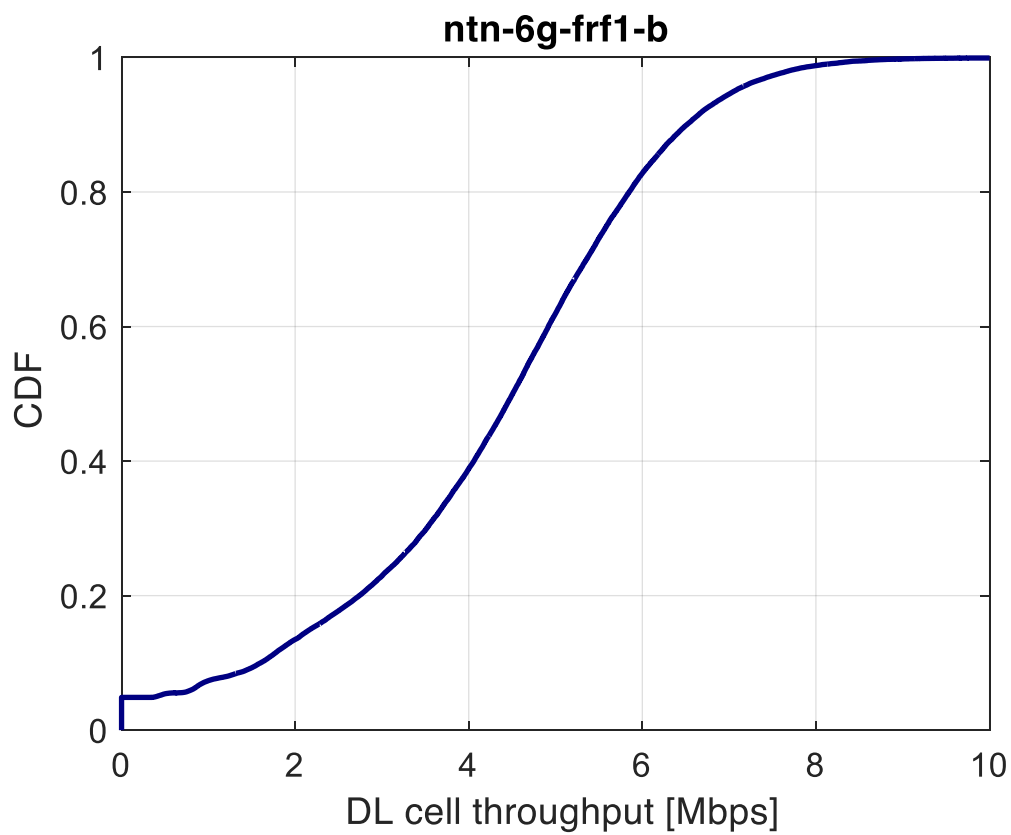
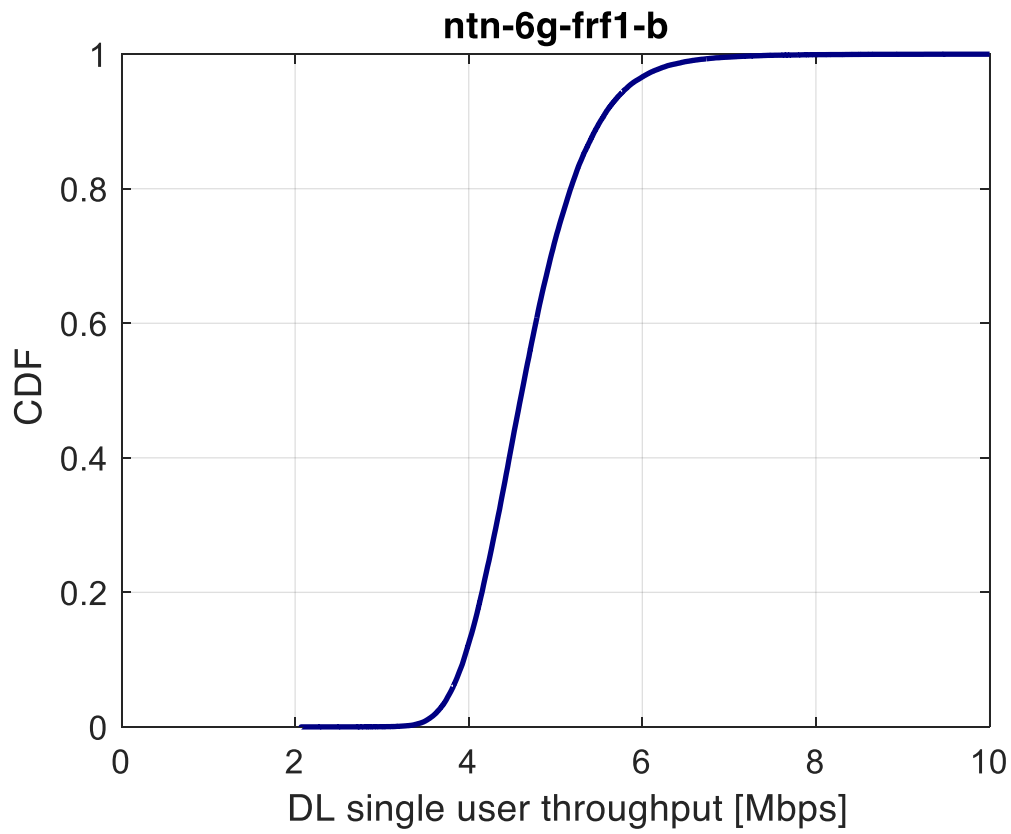
9.4.2.1.1 Downlink

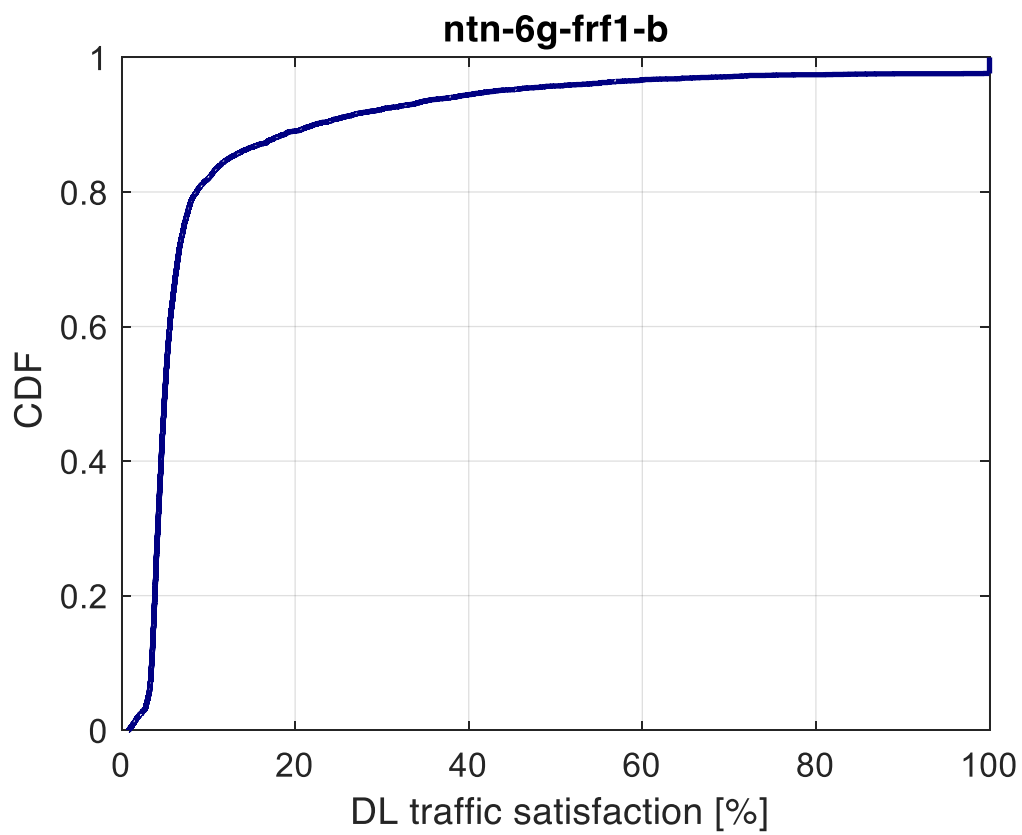
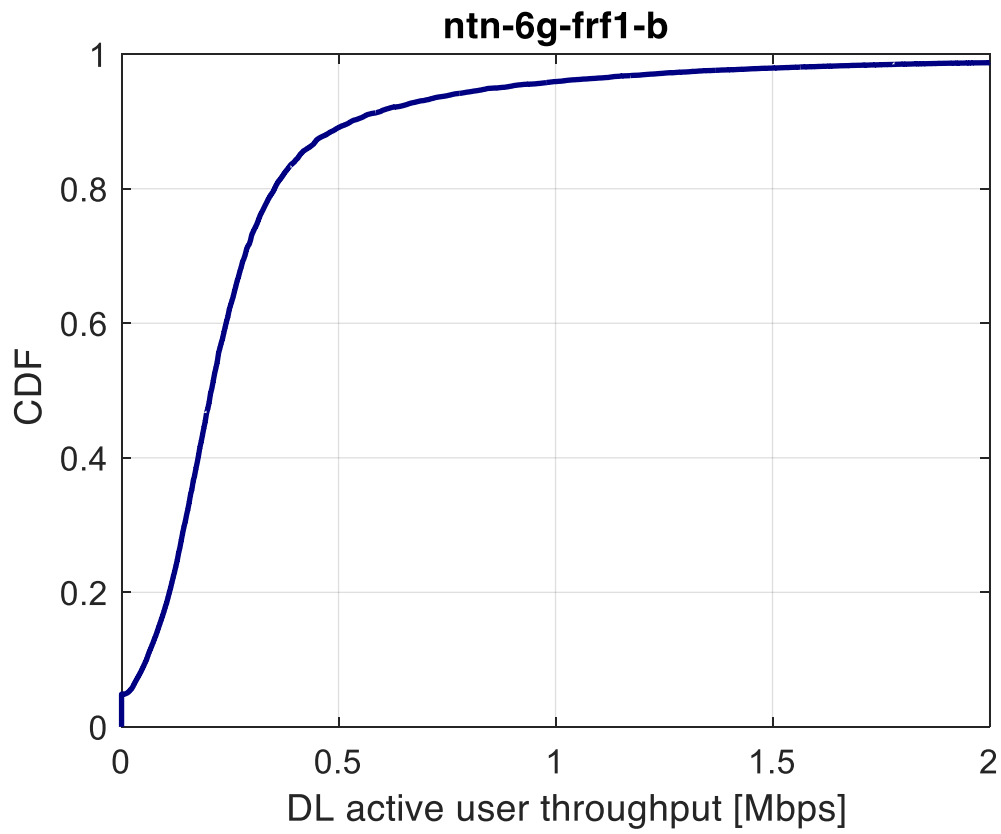


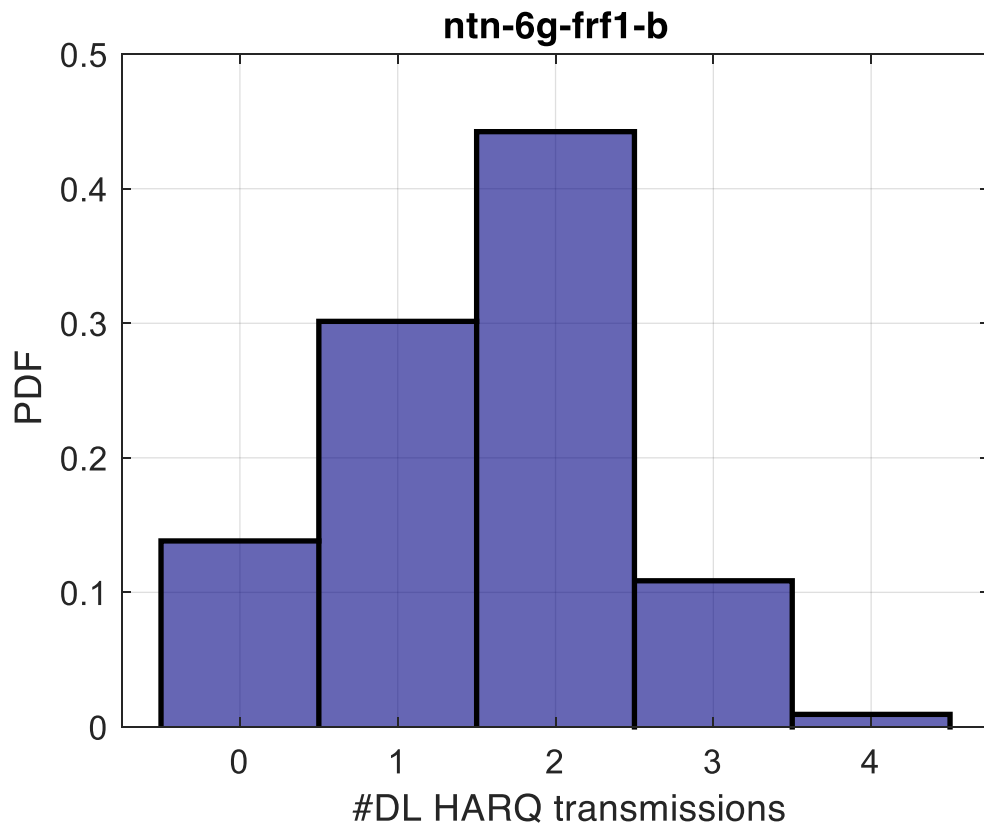




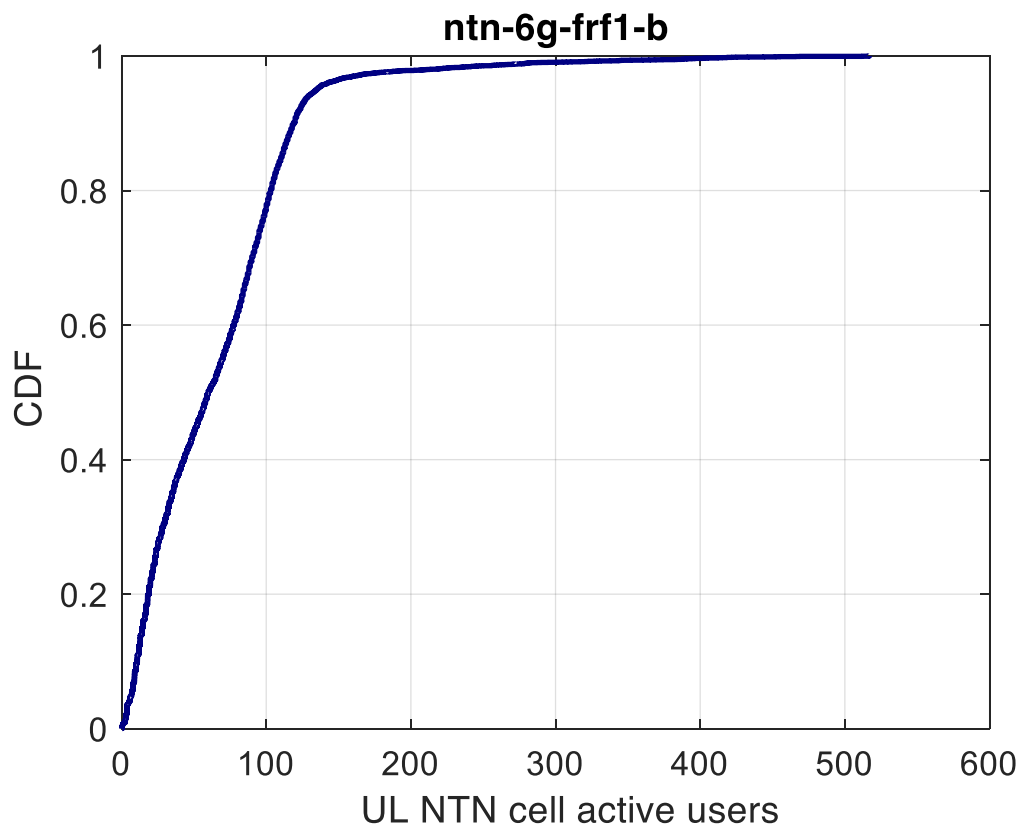


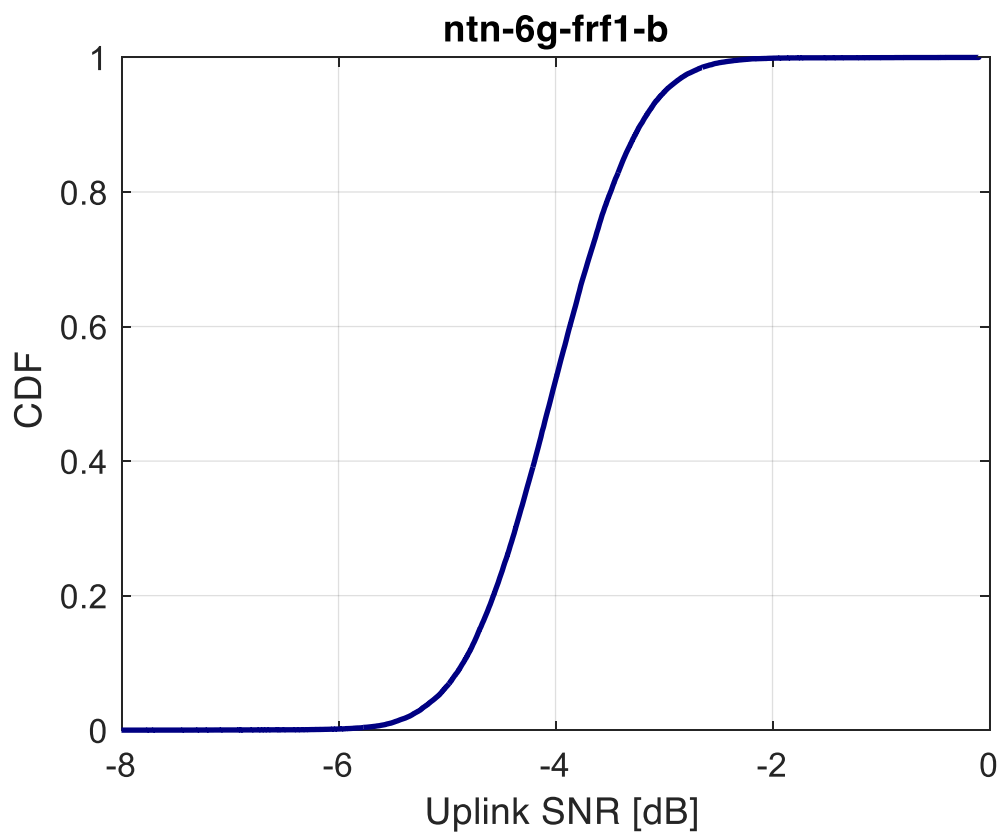
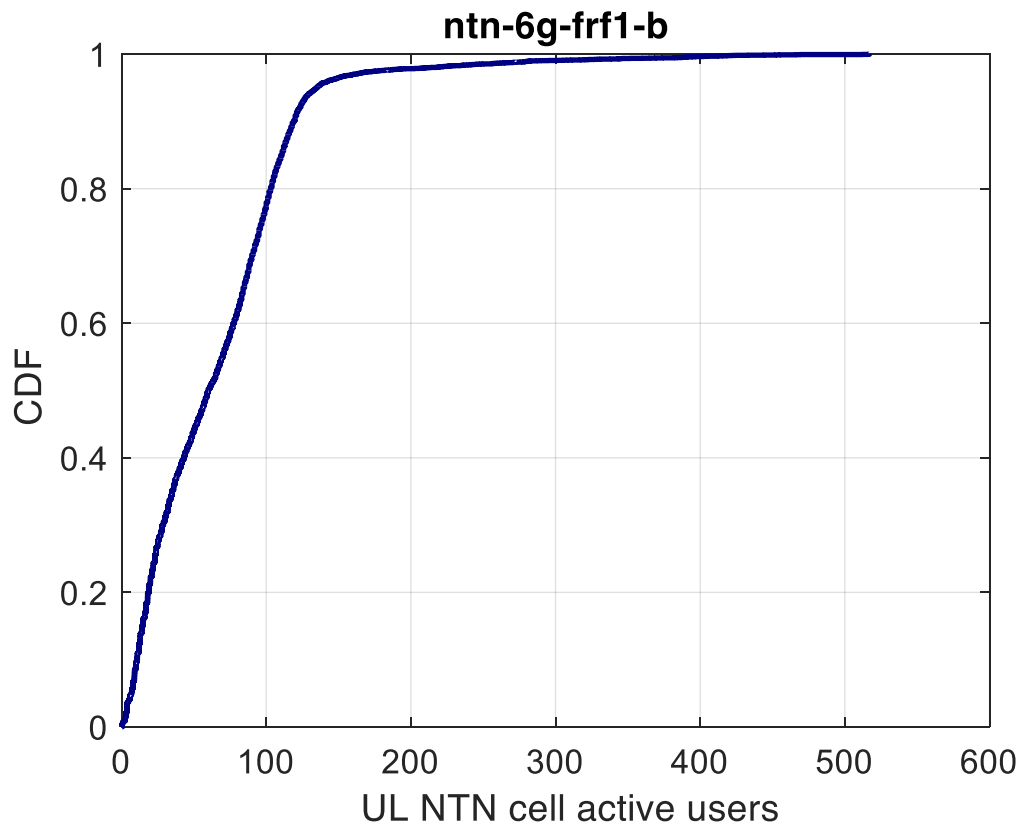


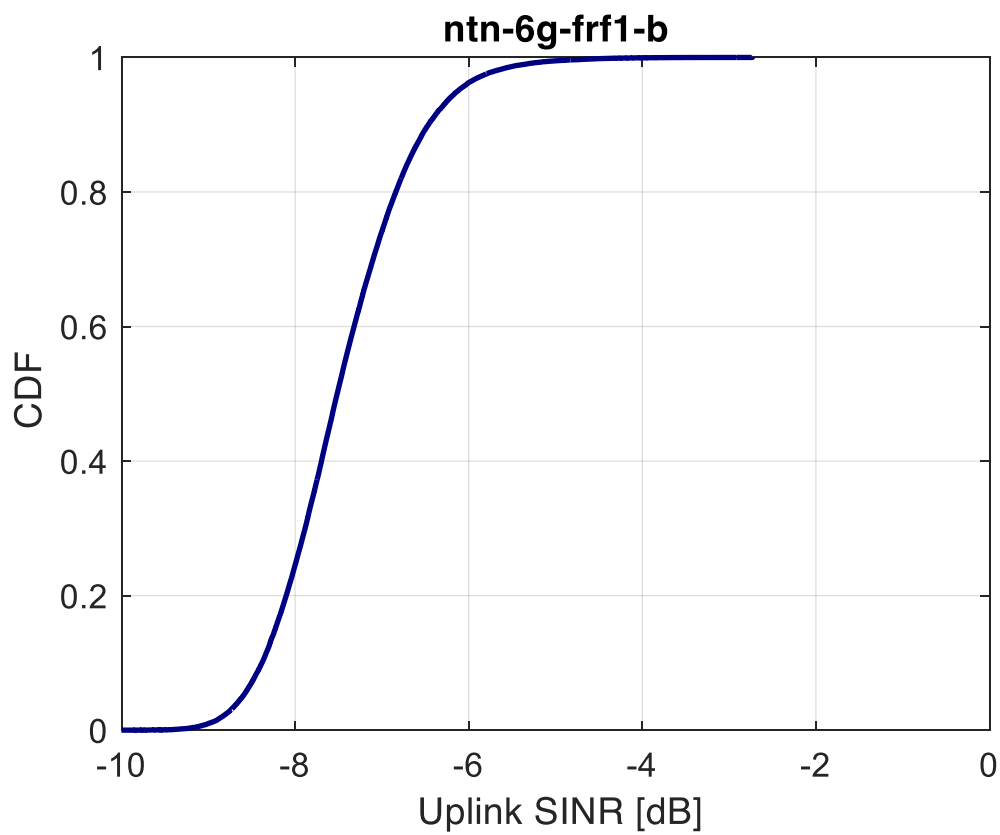
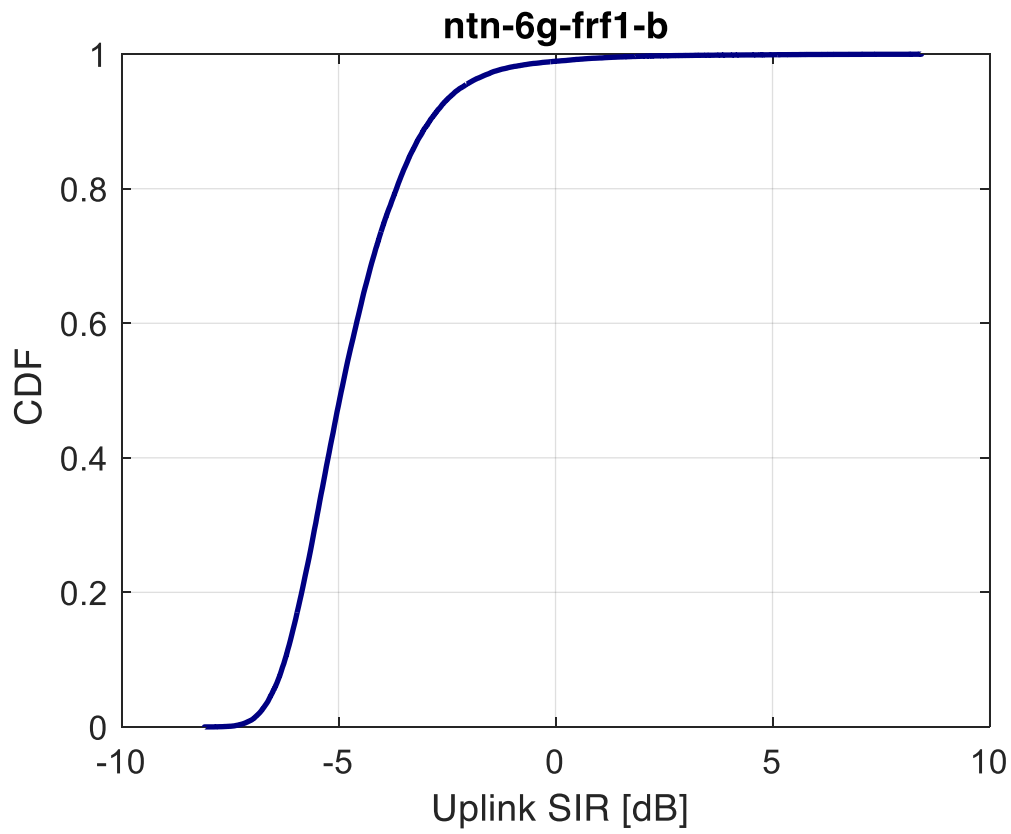


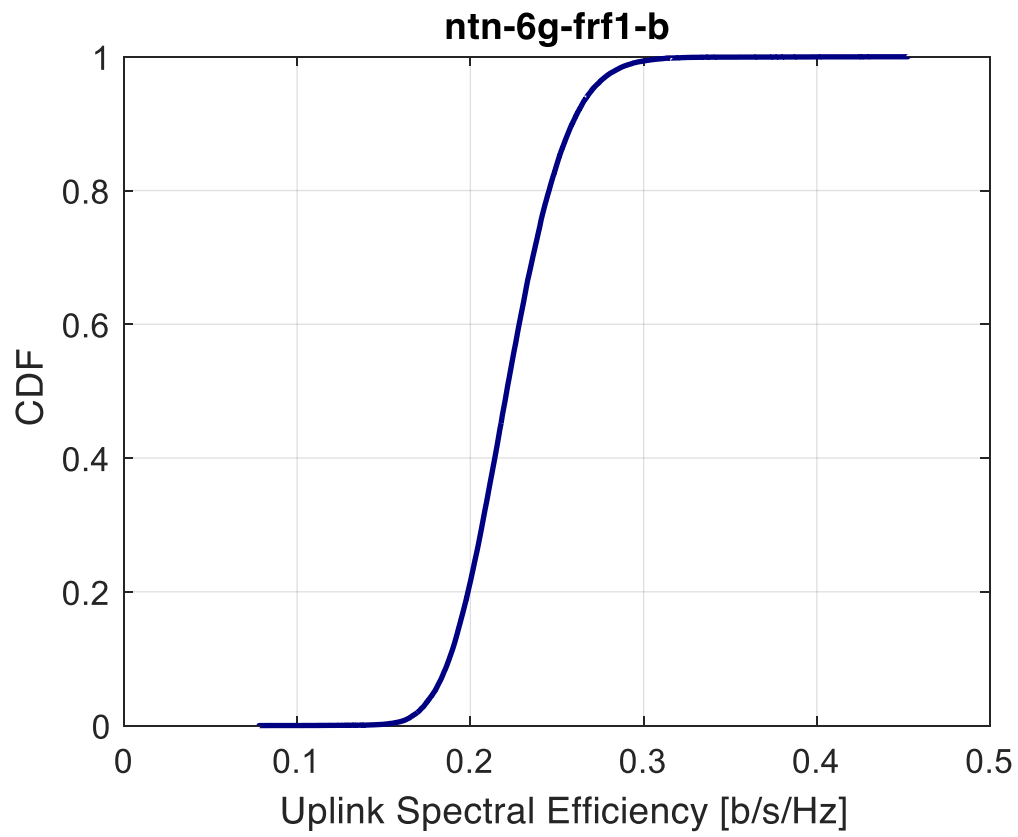


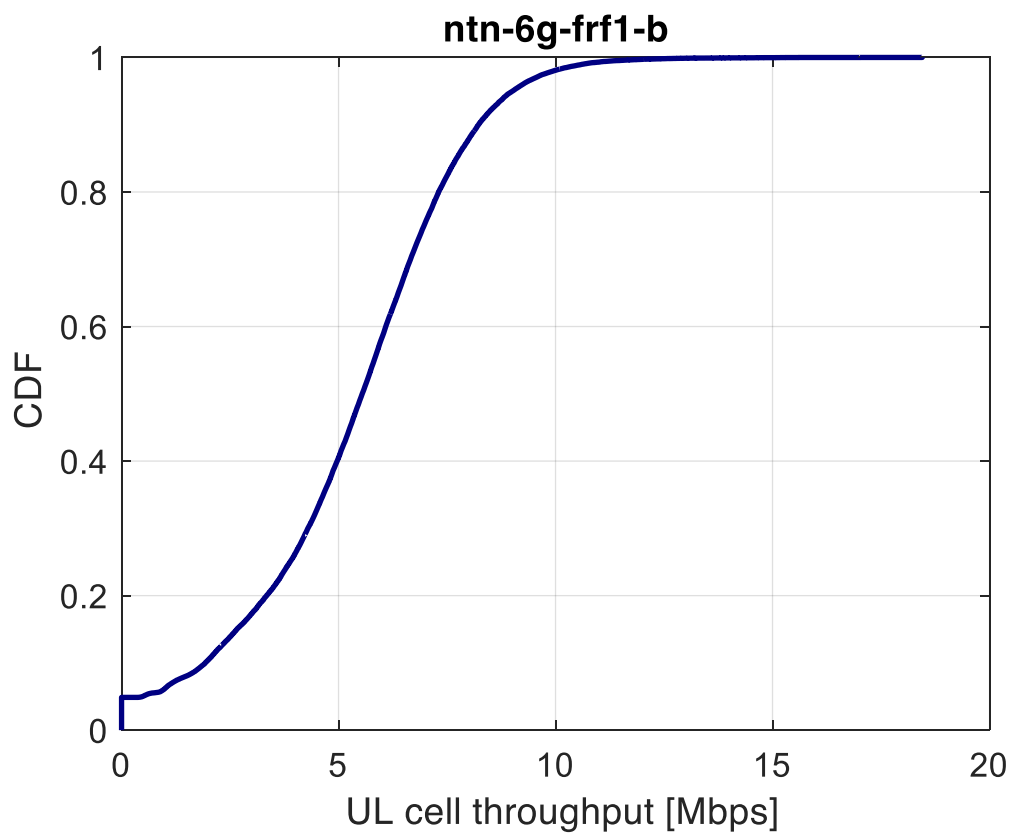
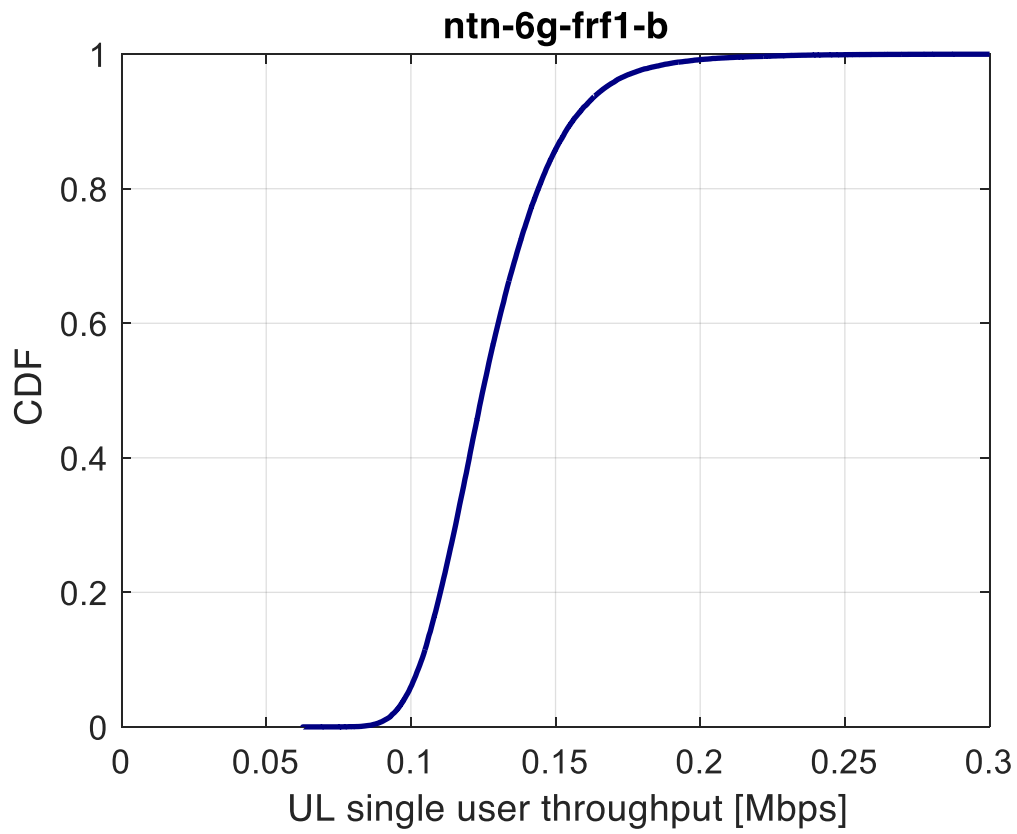
9.4.2.1.2 Uplink

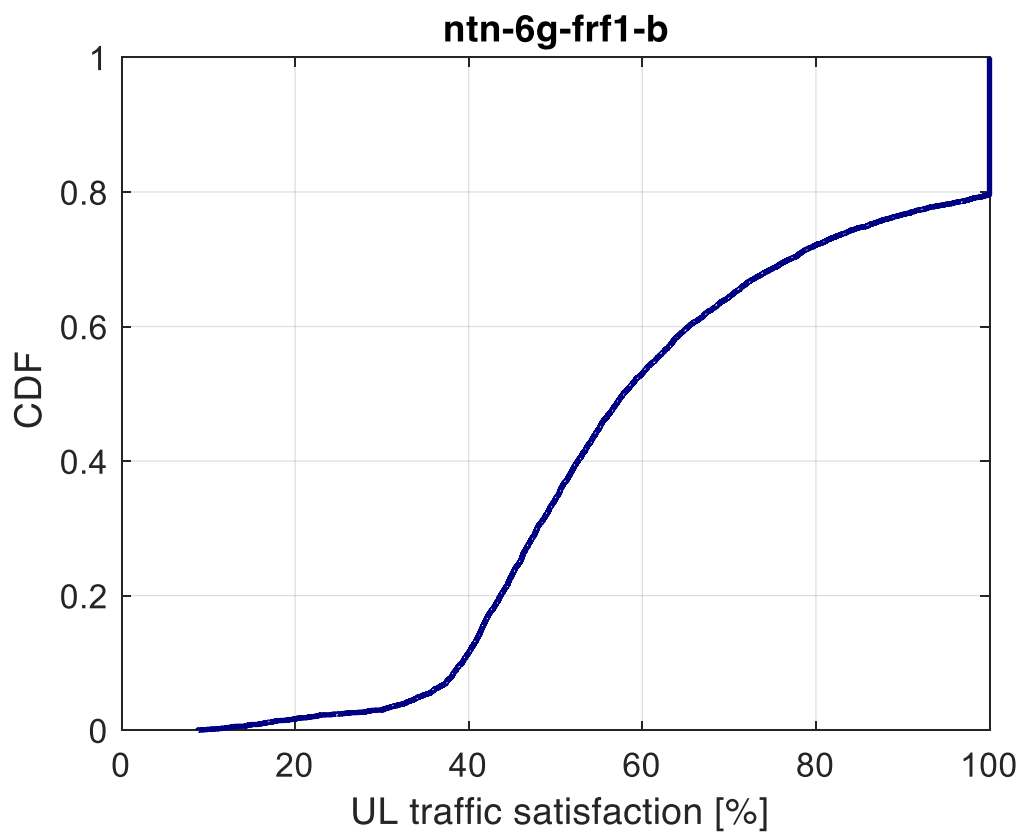
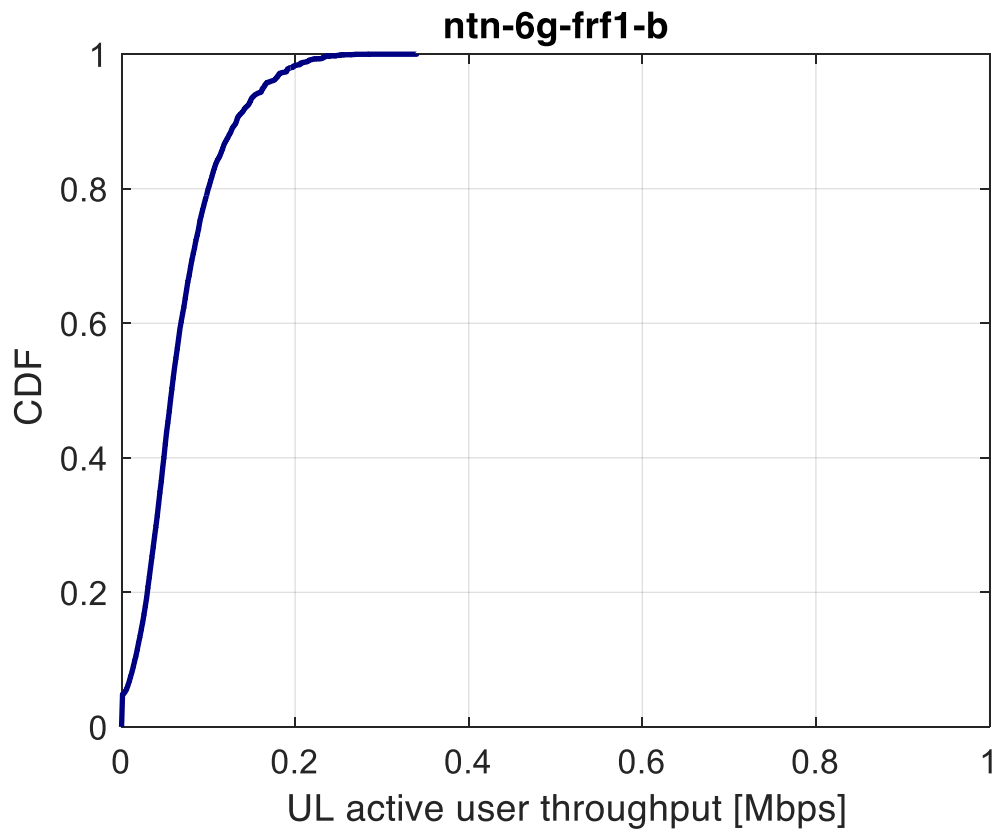


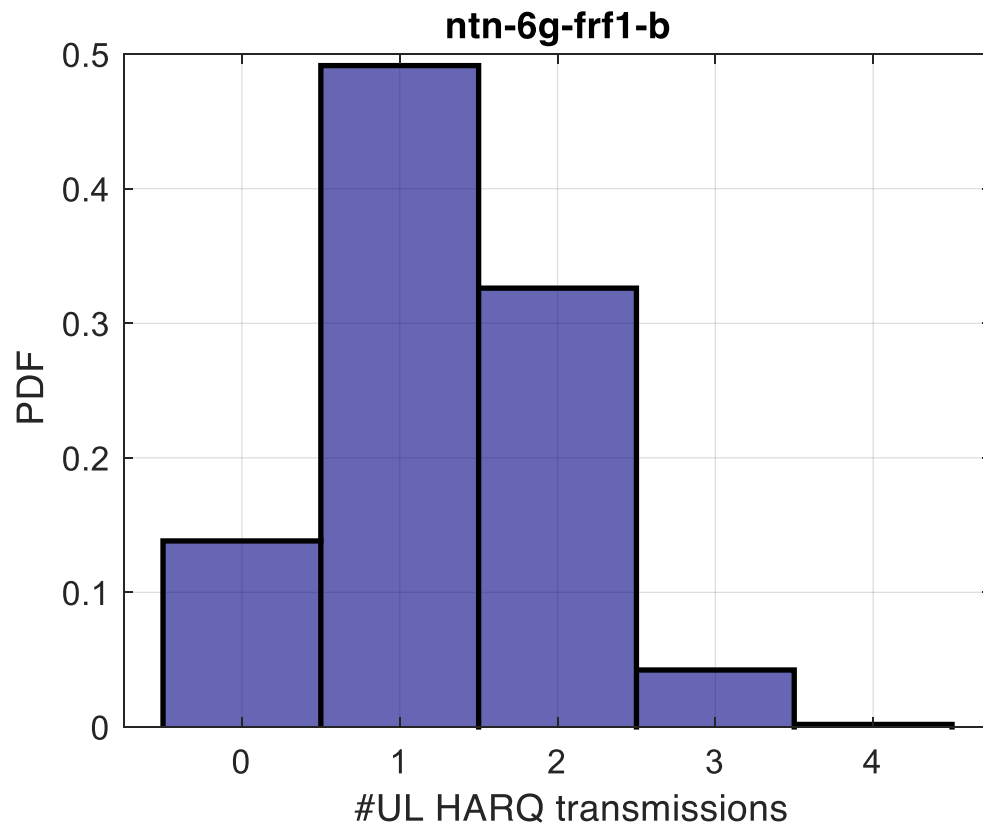




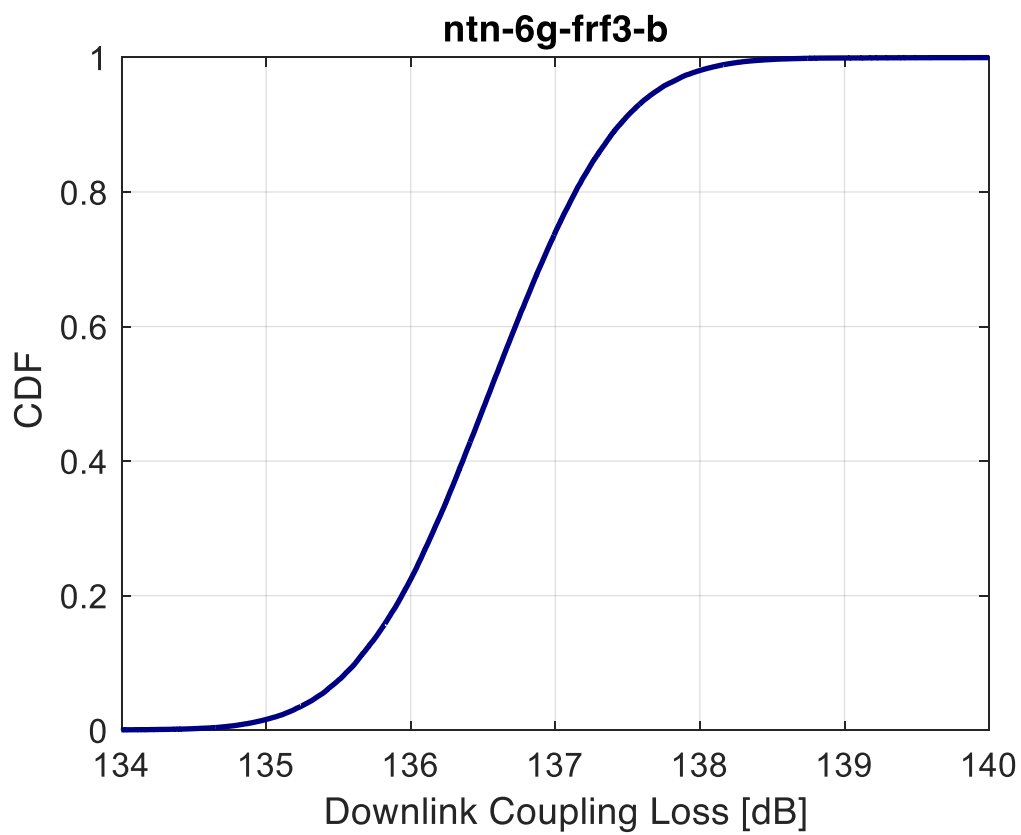
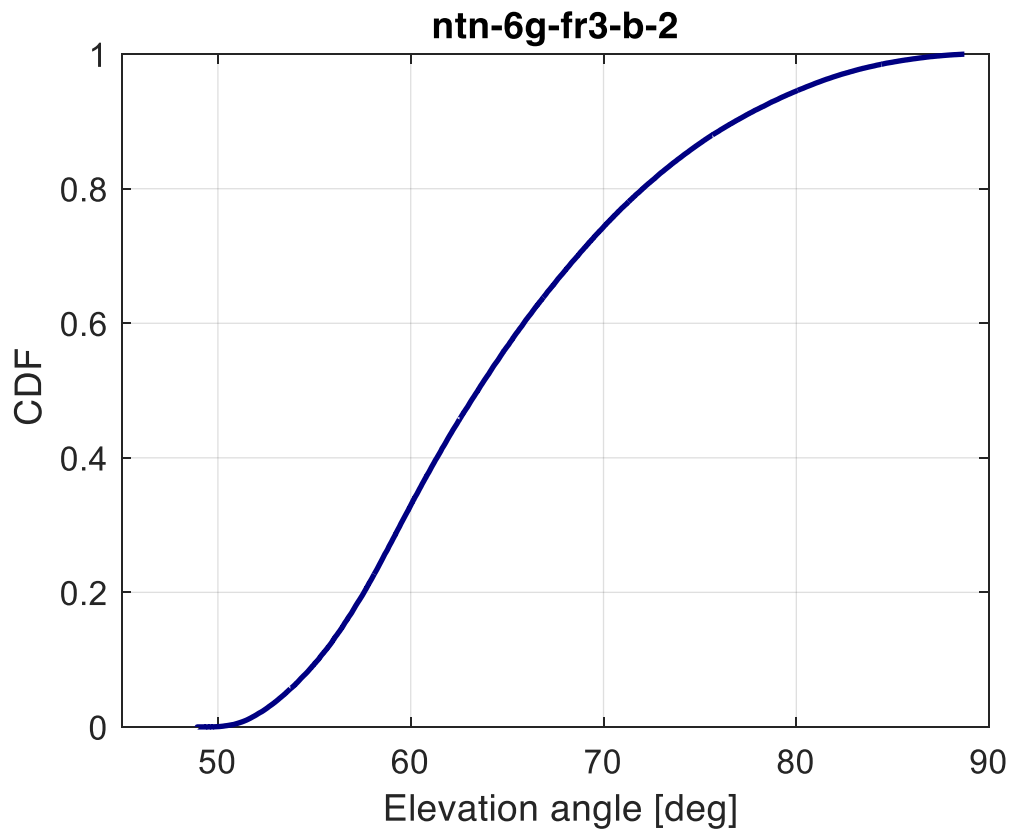


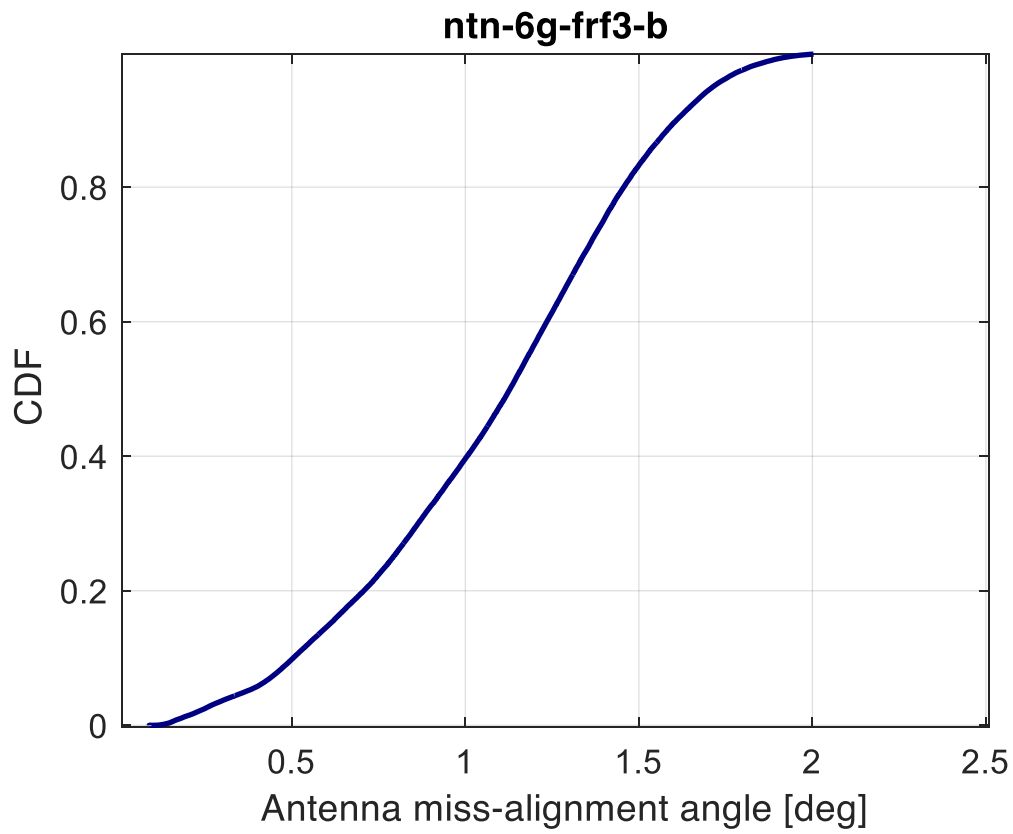




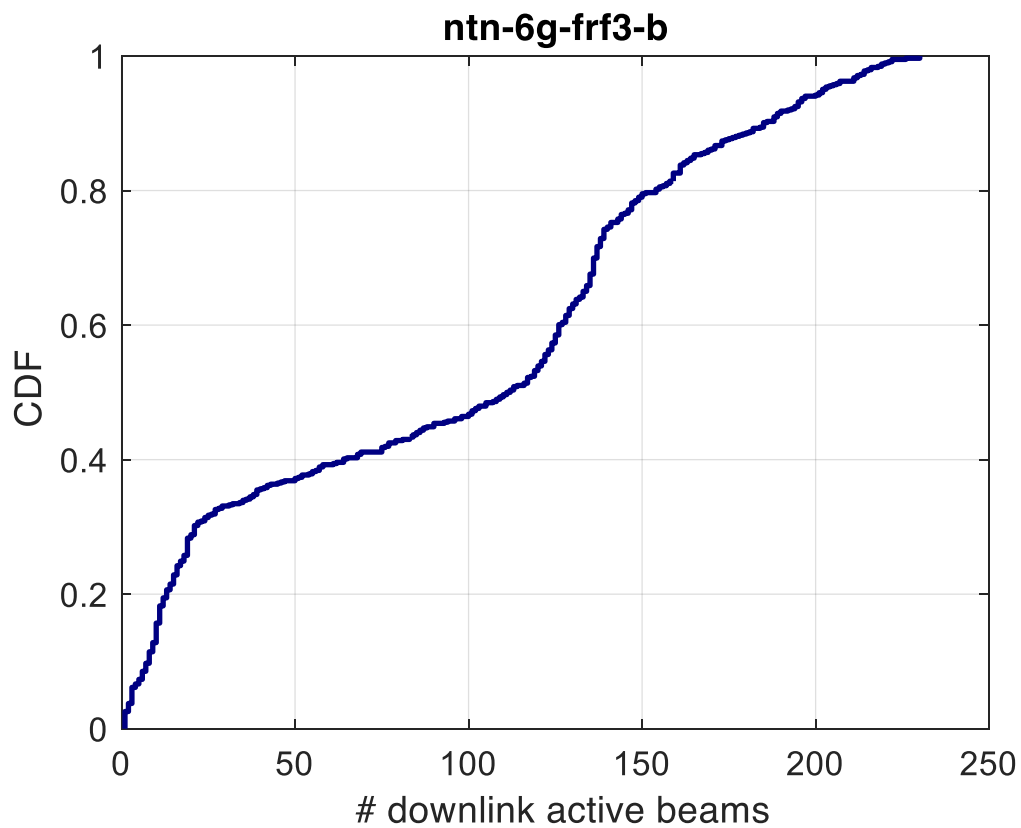


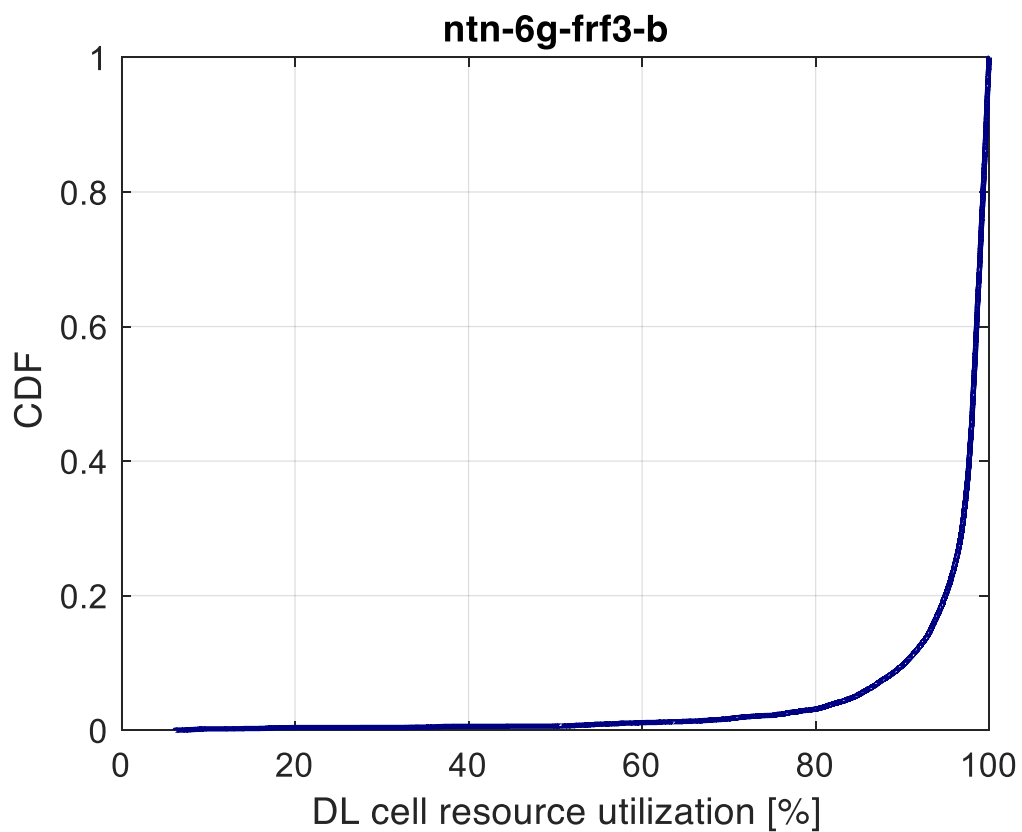
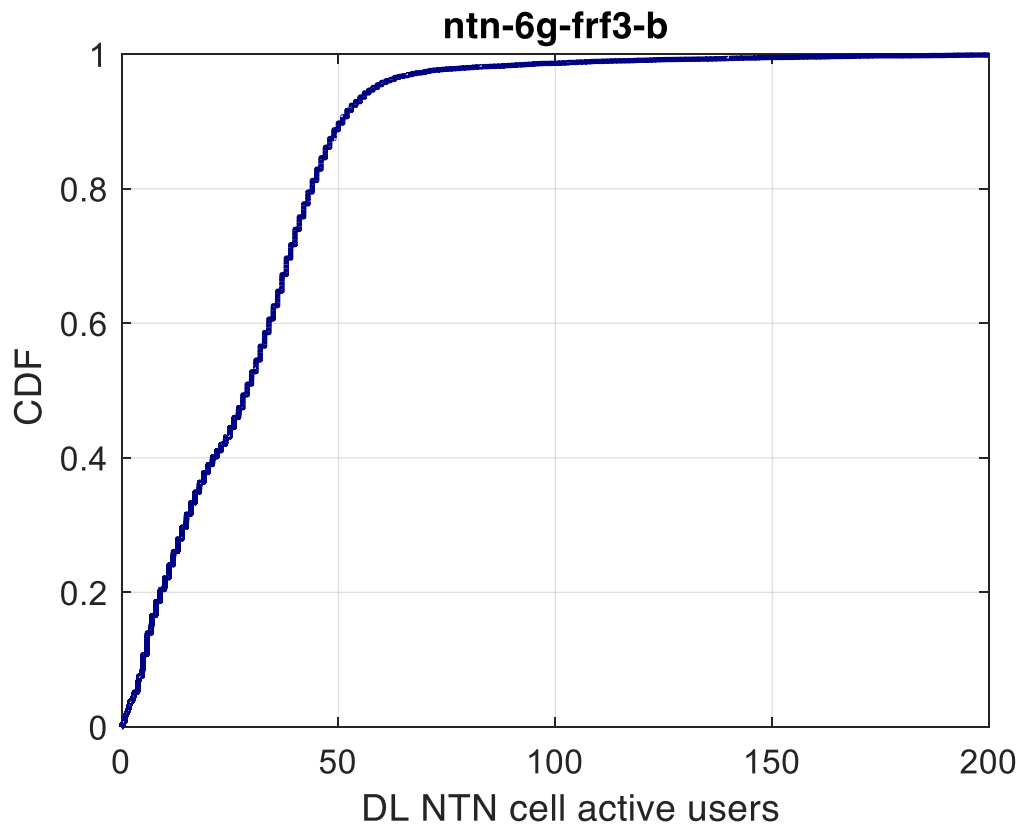
9.4.2.2 Results for FRF=3

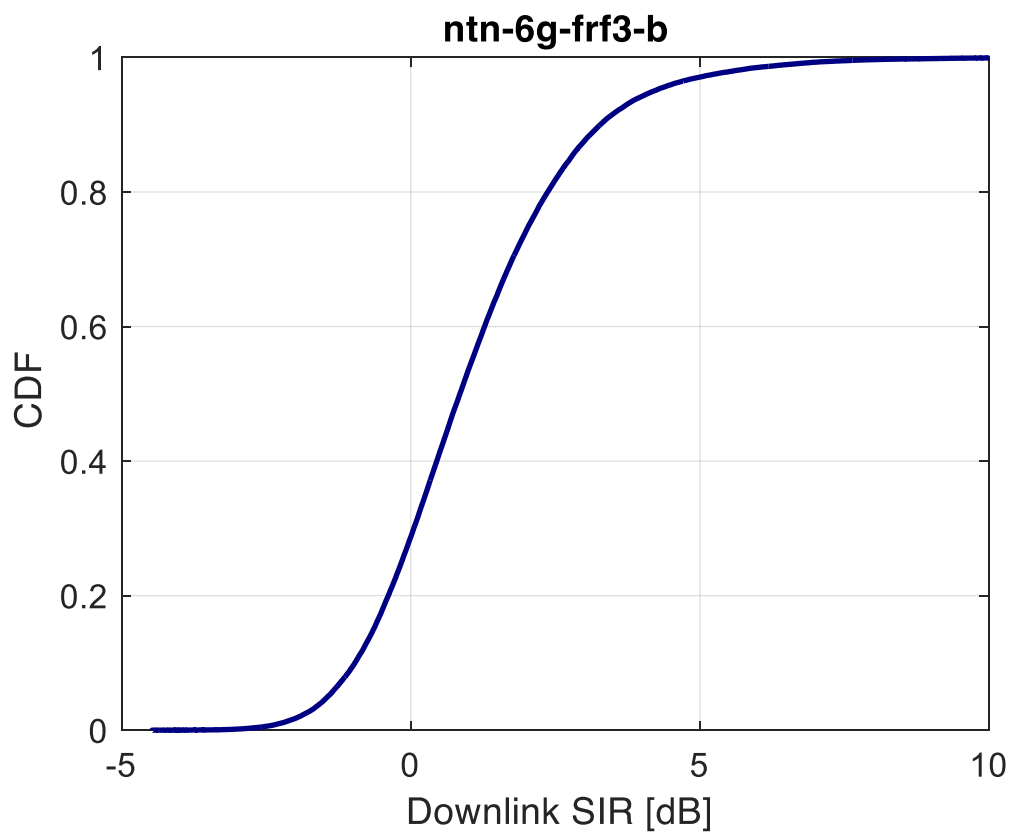
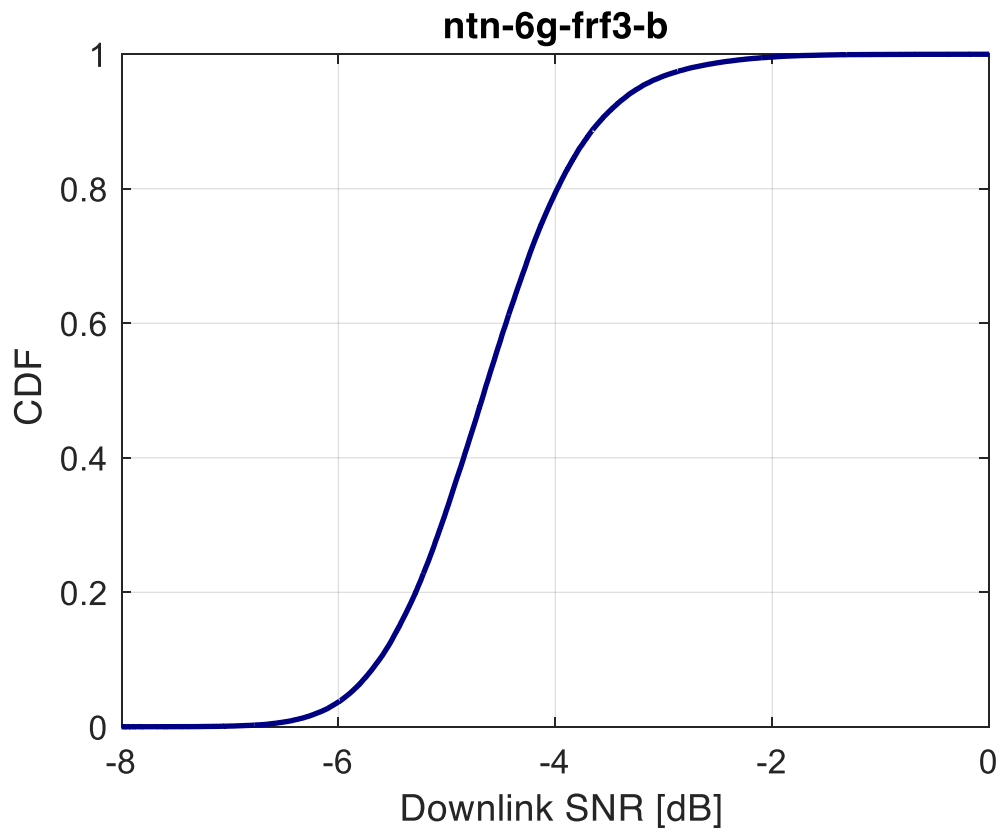


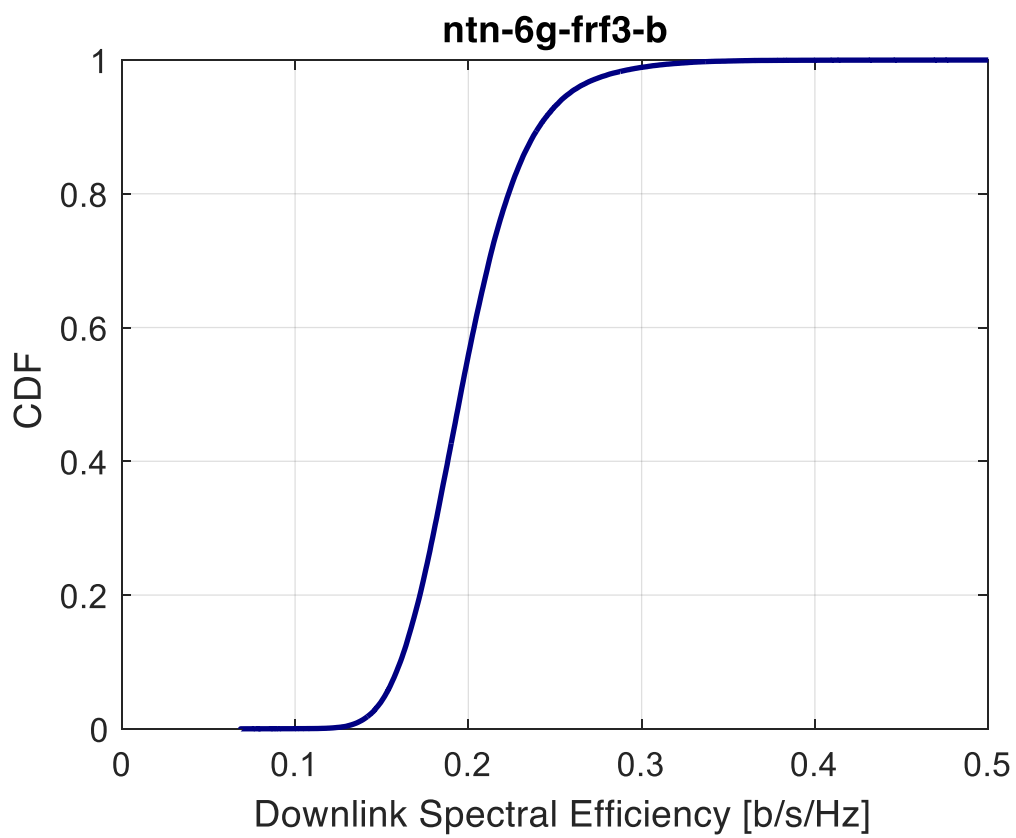
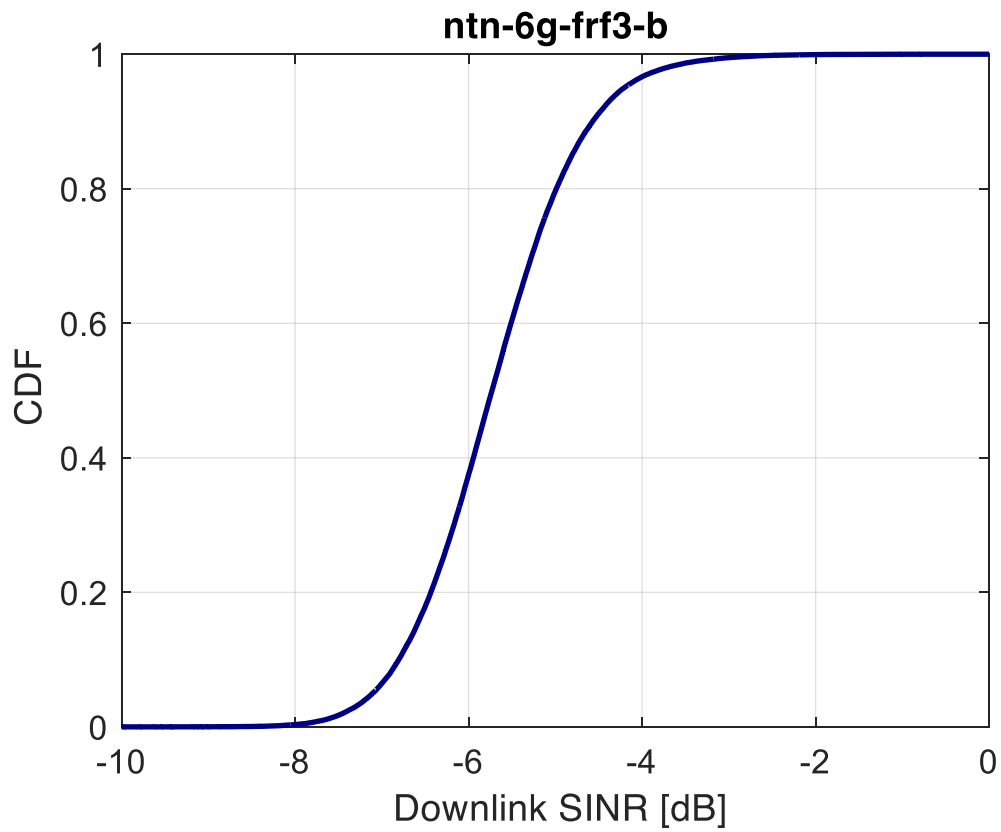


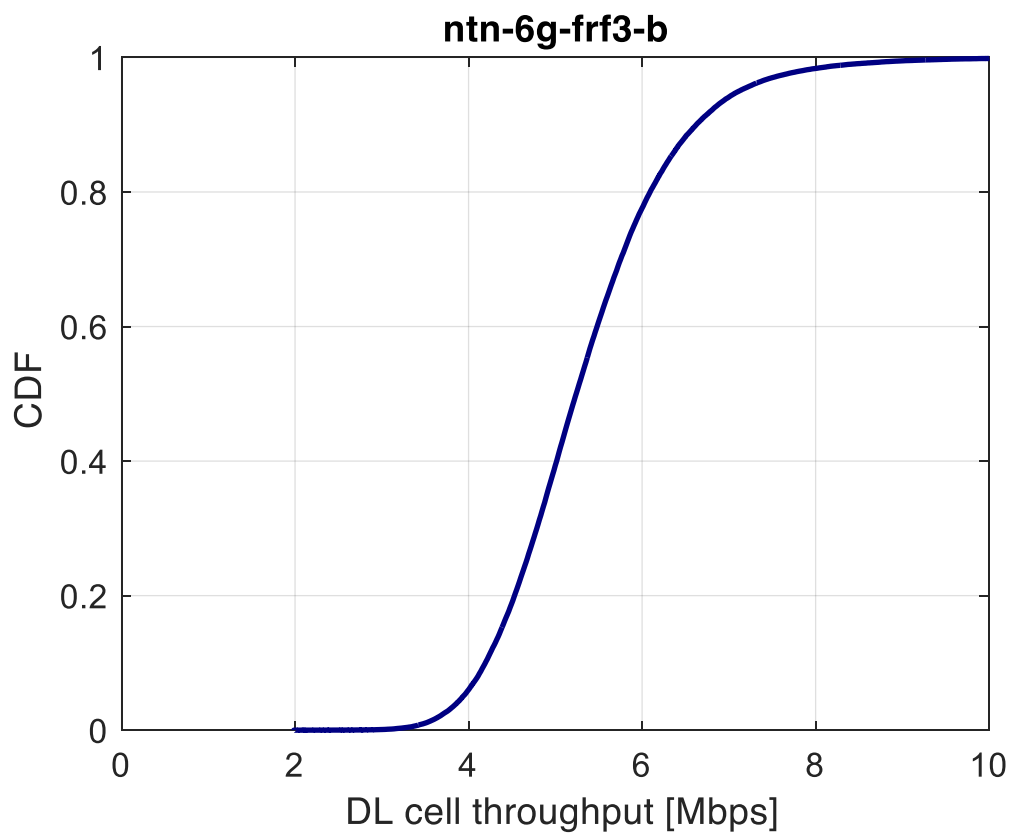
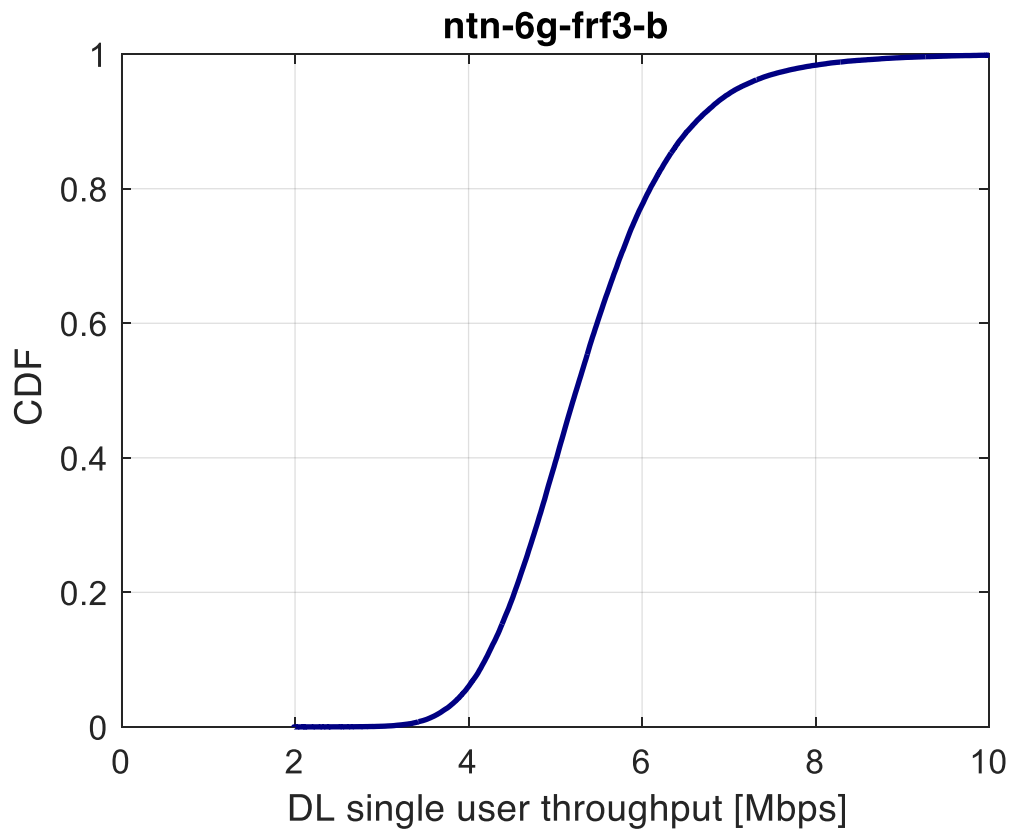
9.4.2.2.1 Downlink

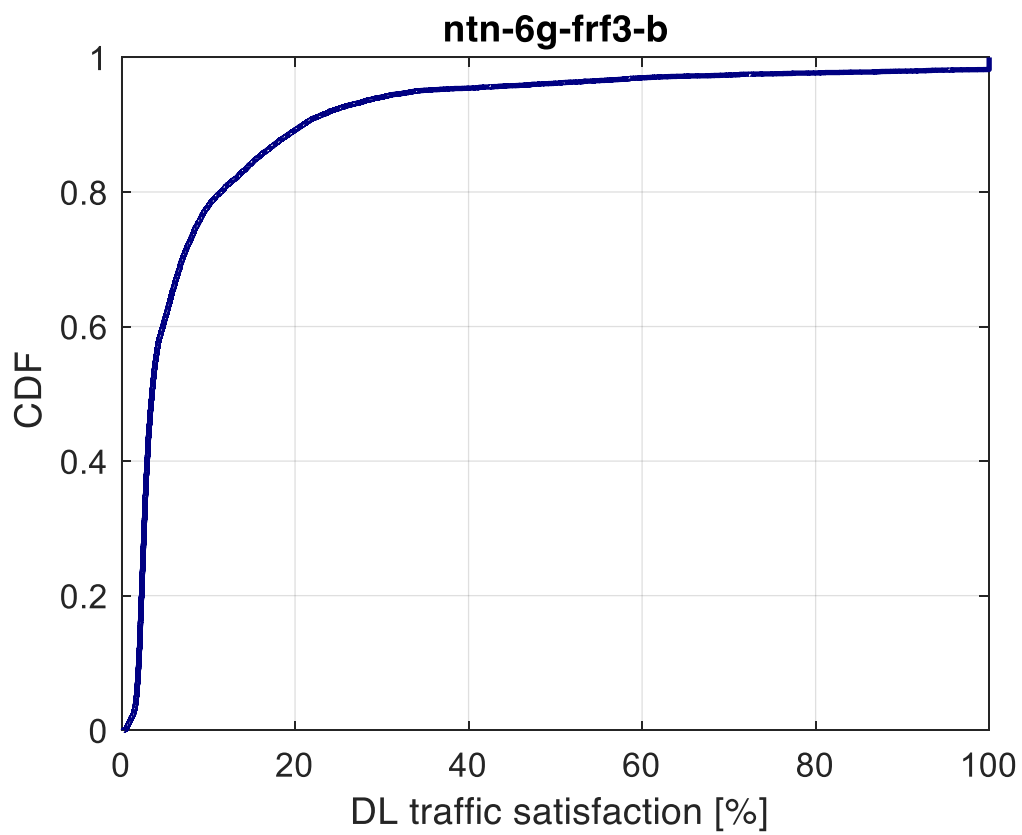
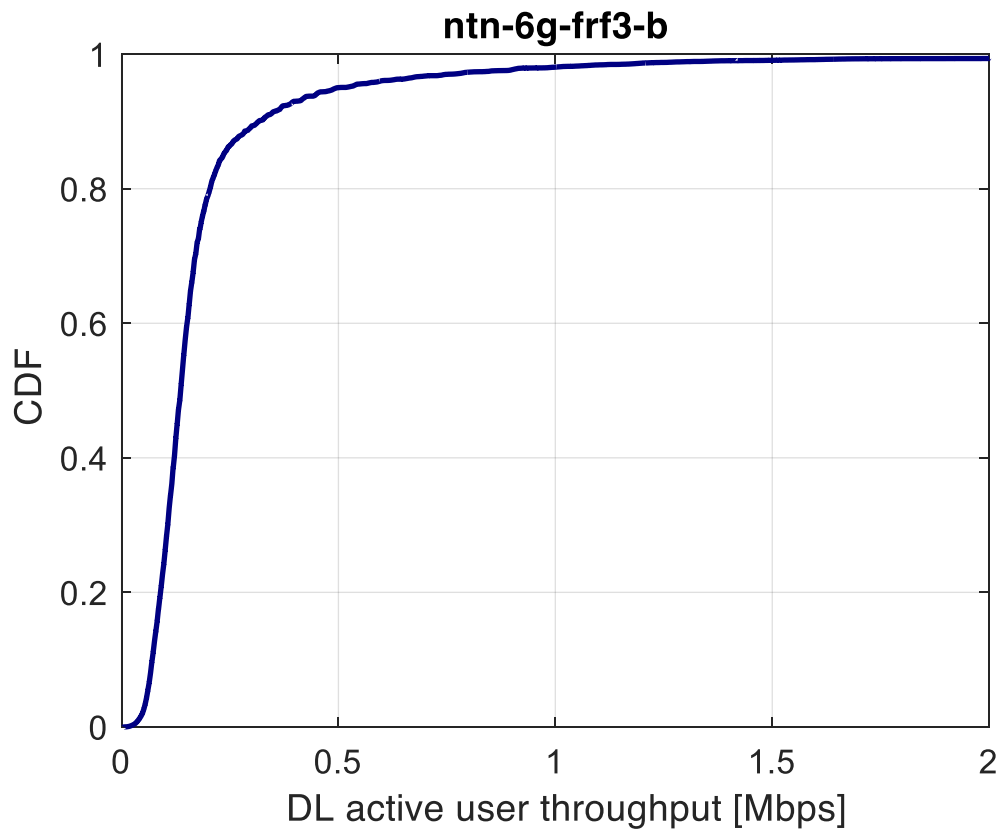


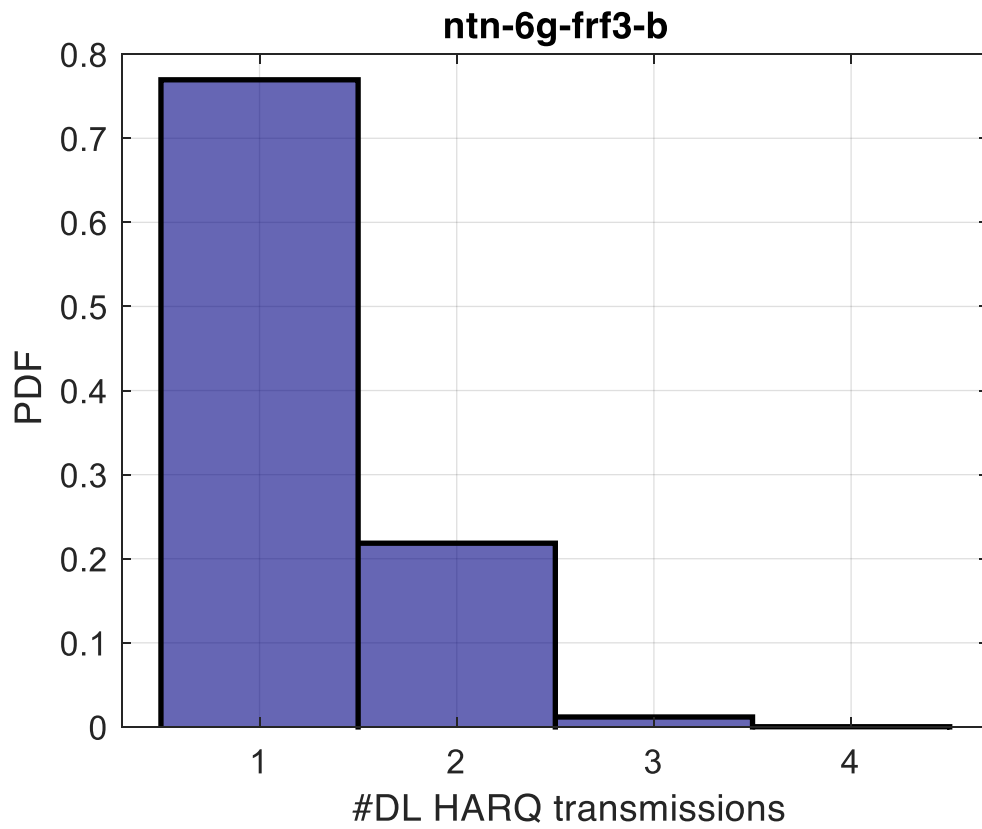




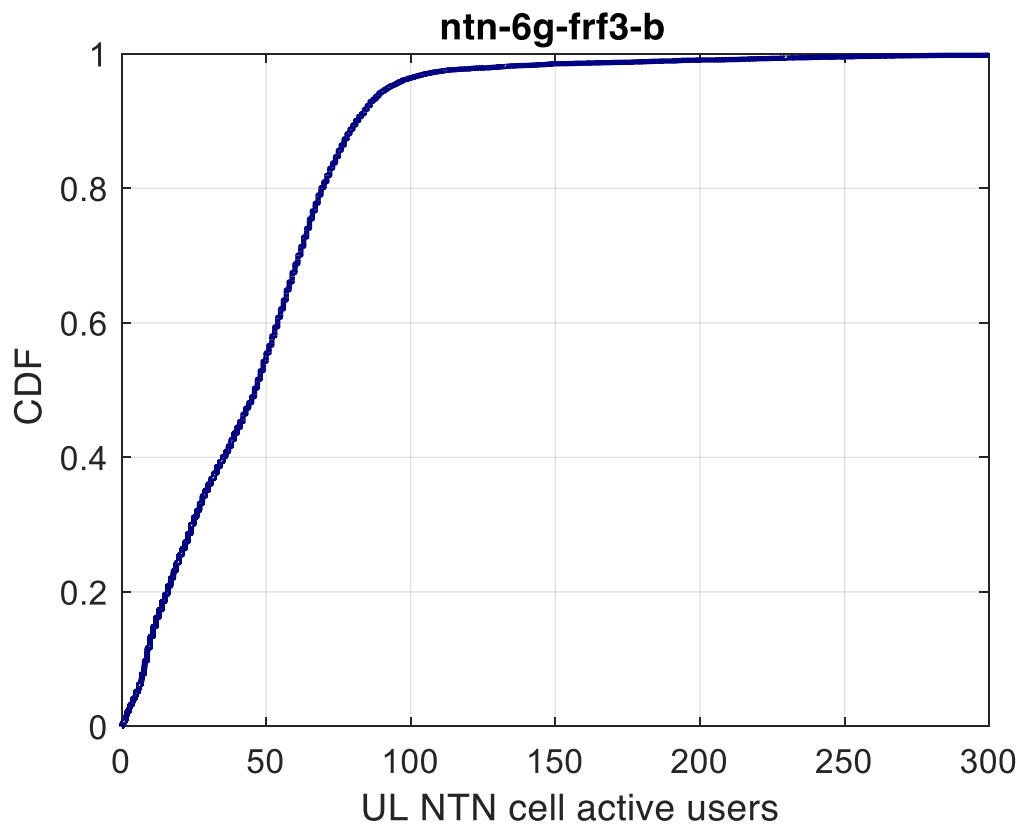


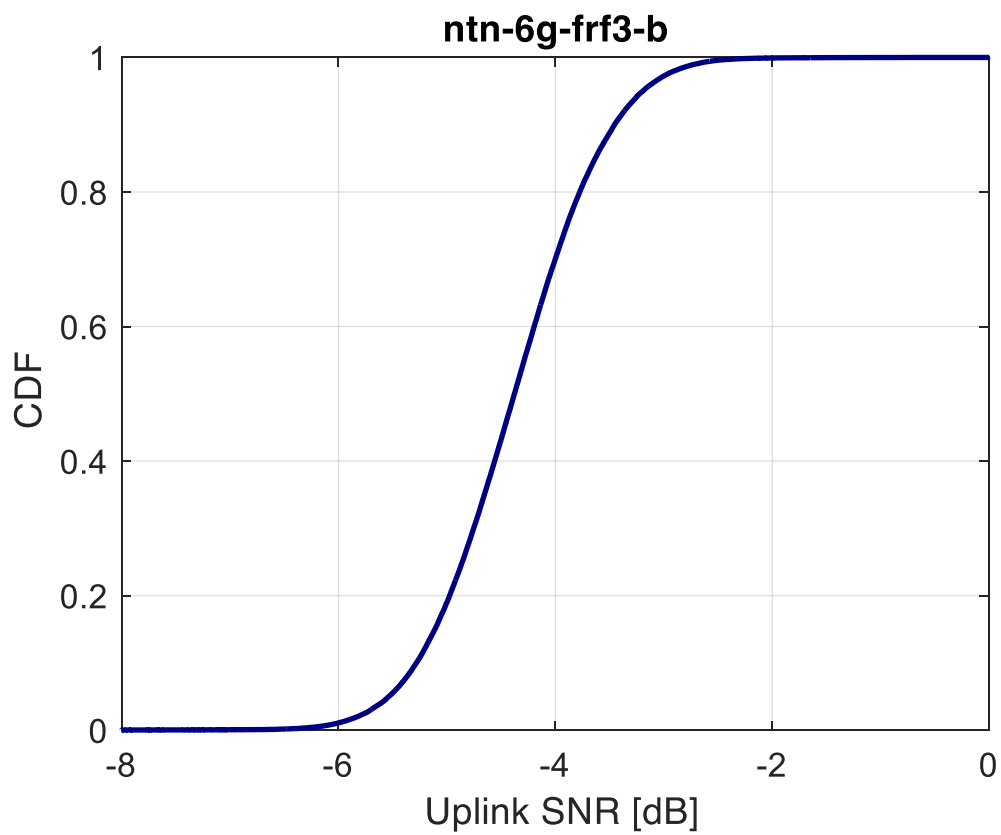
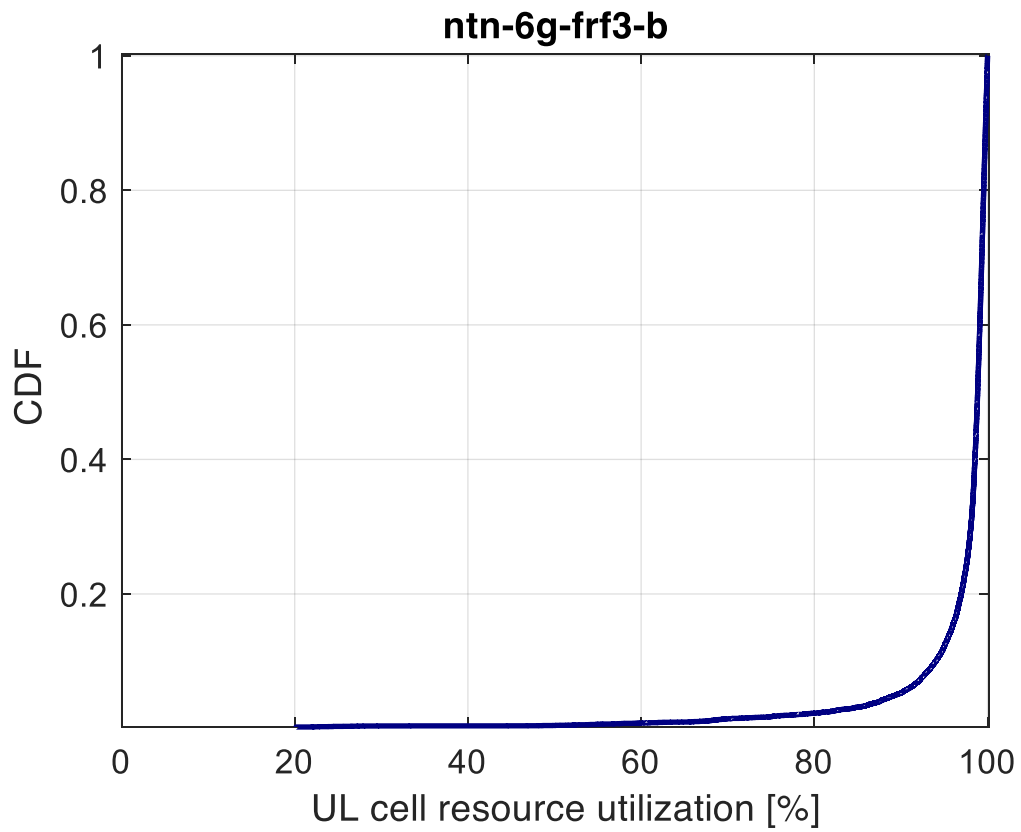


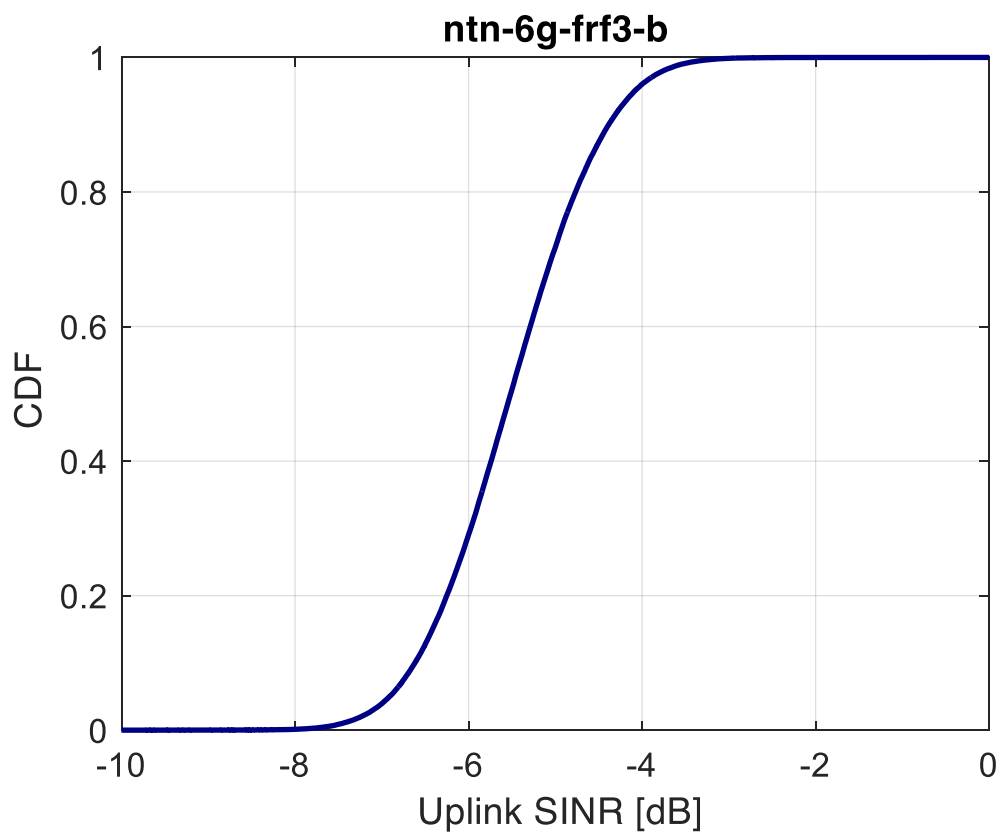
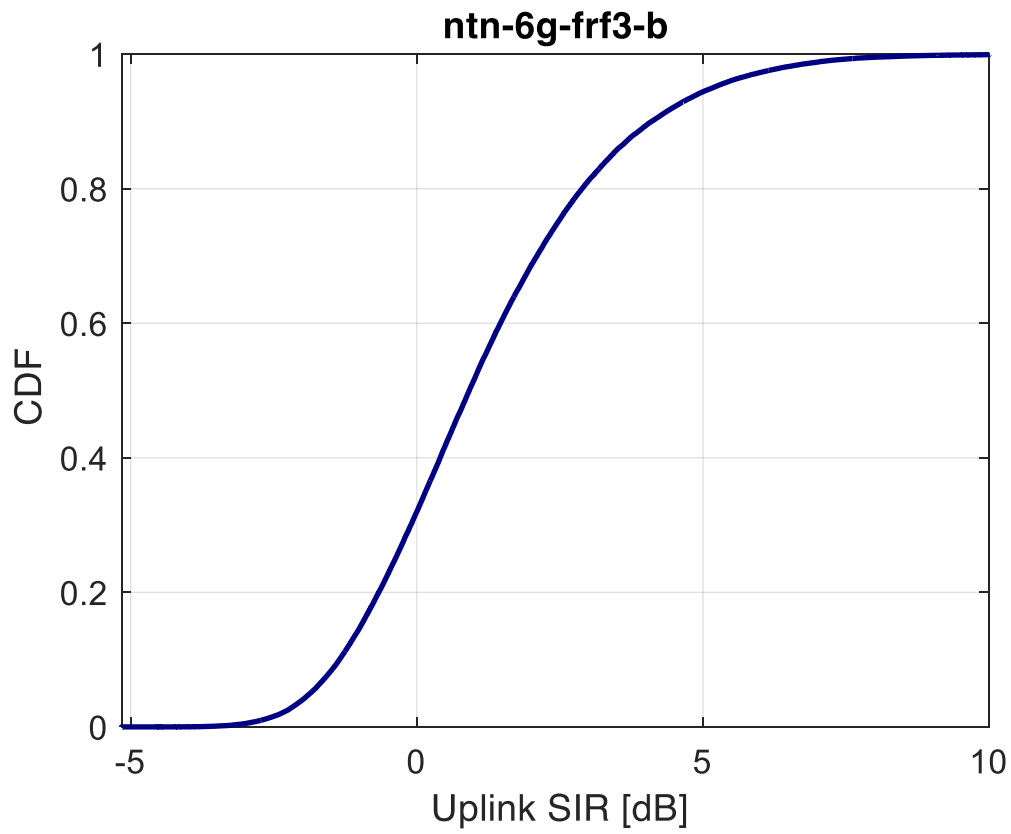


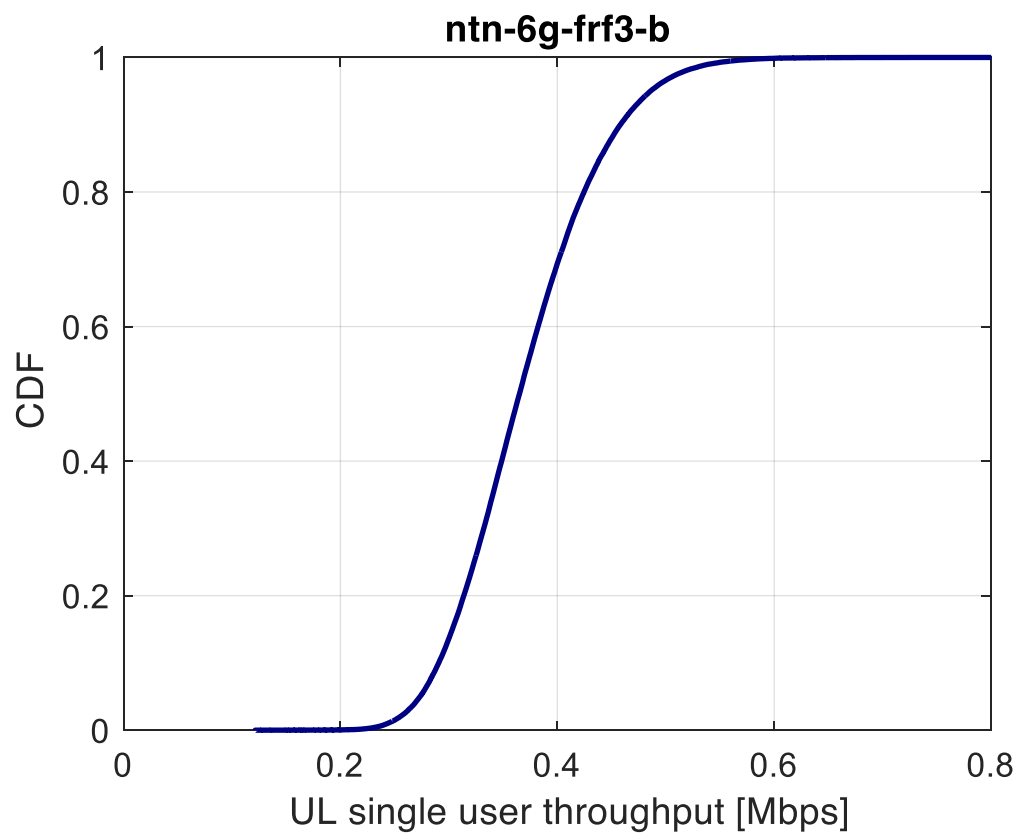
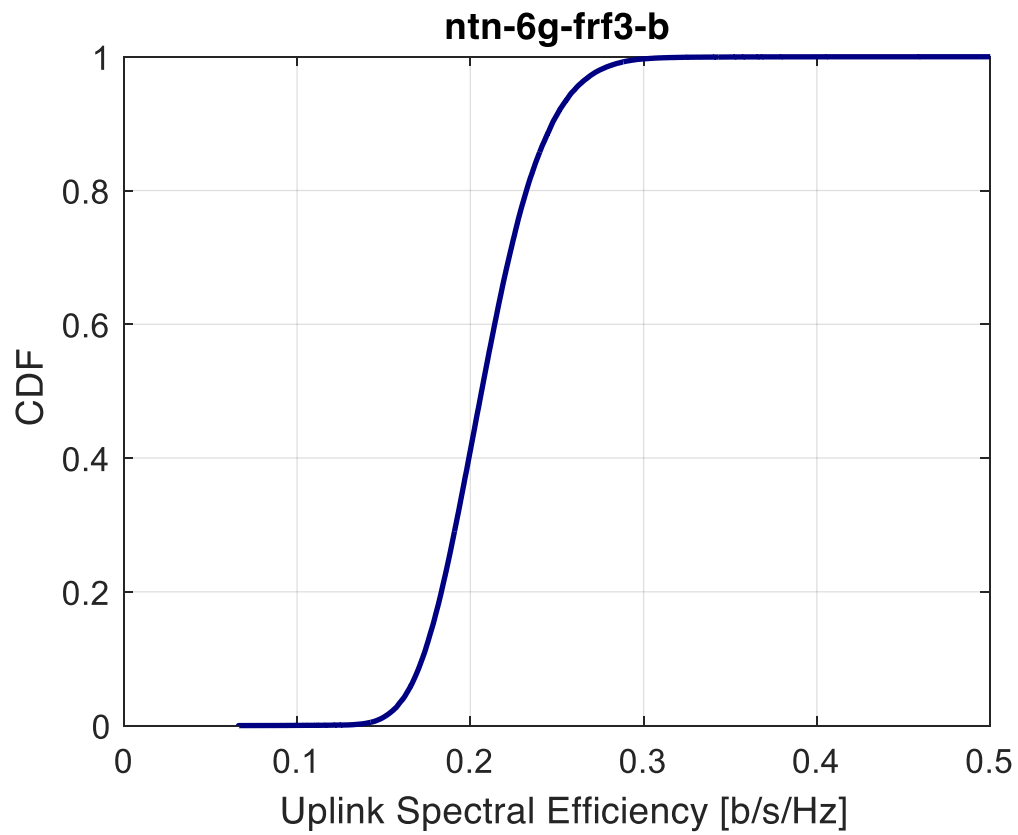


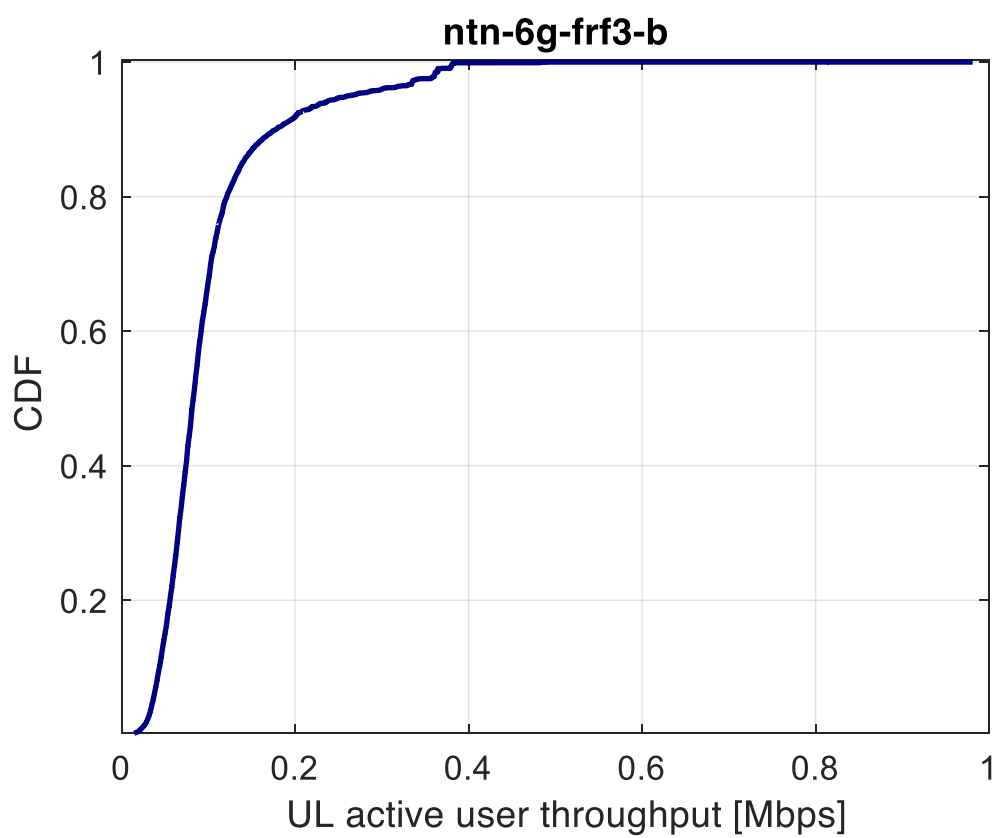
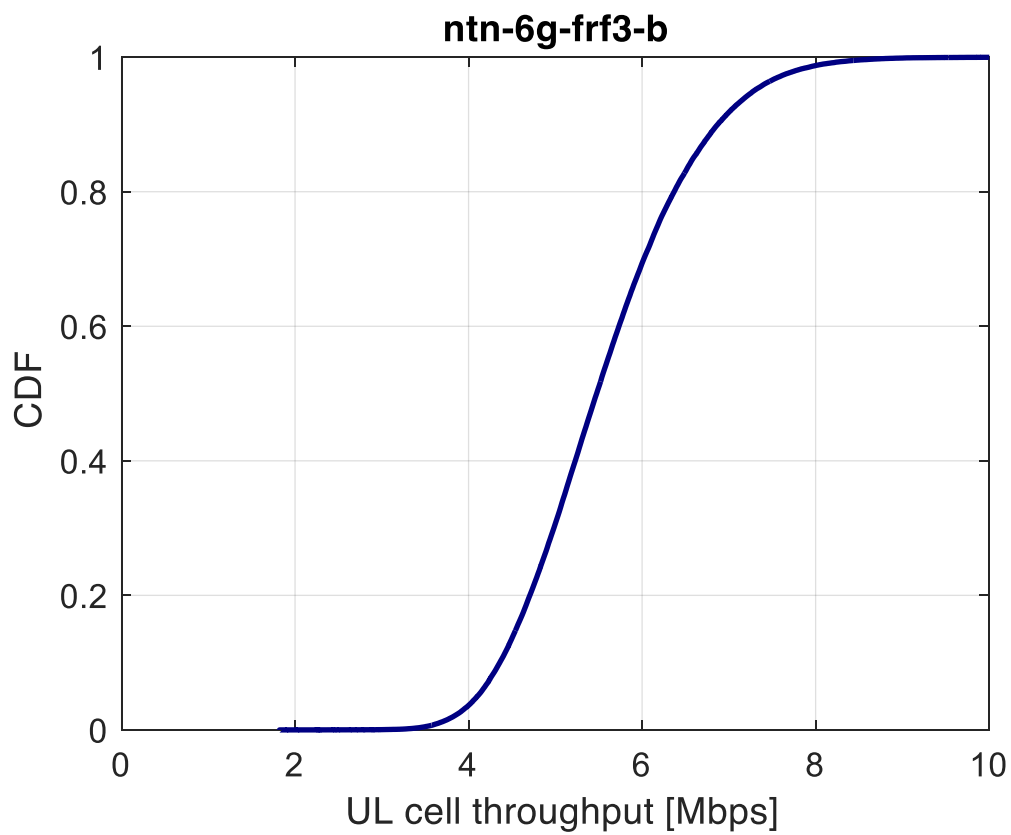
9.4.2.2.2 Uplink

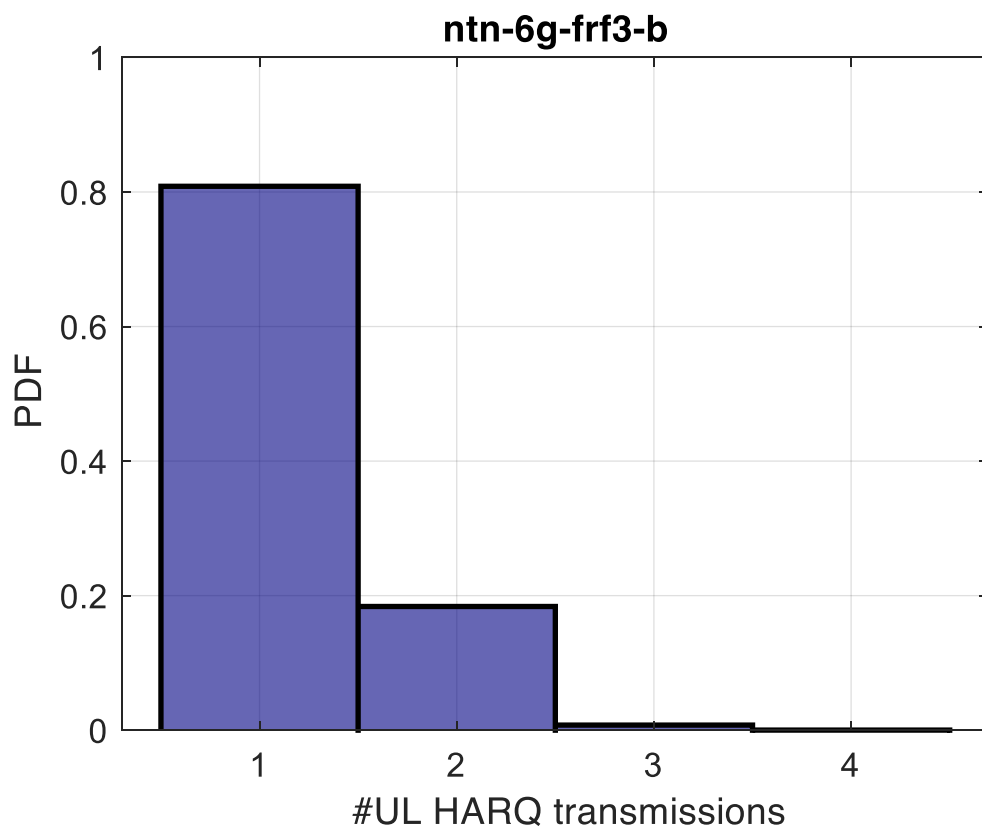
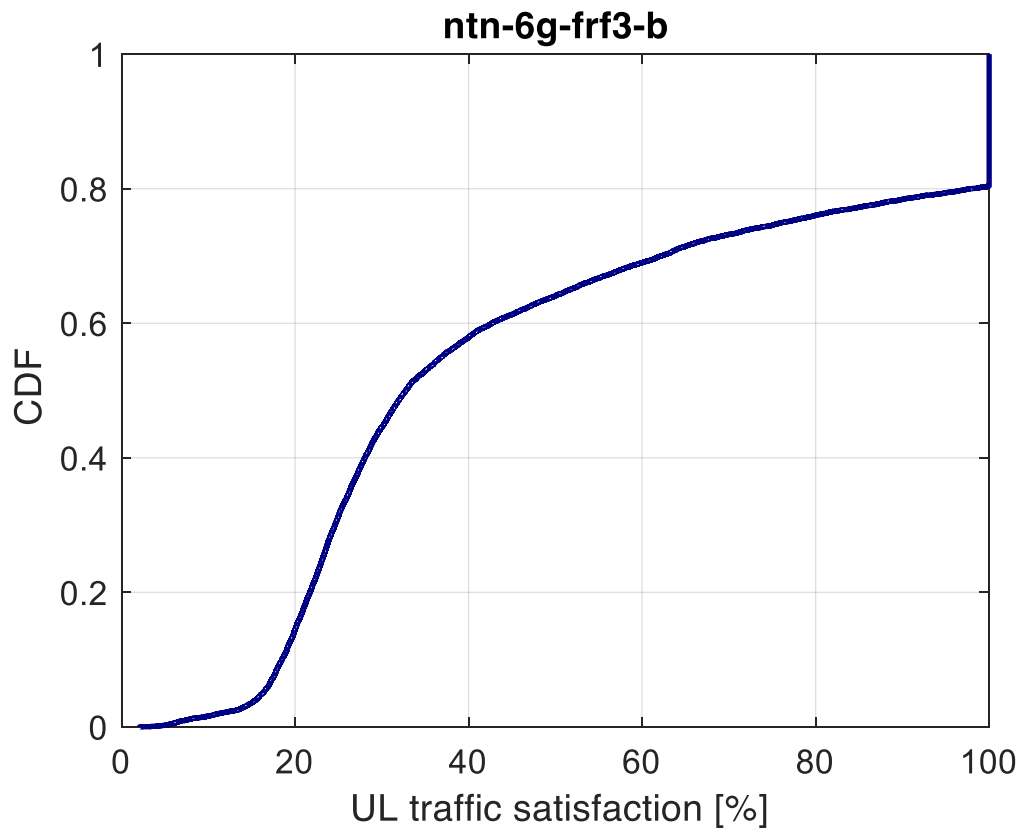






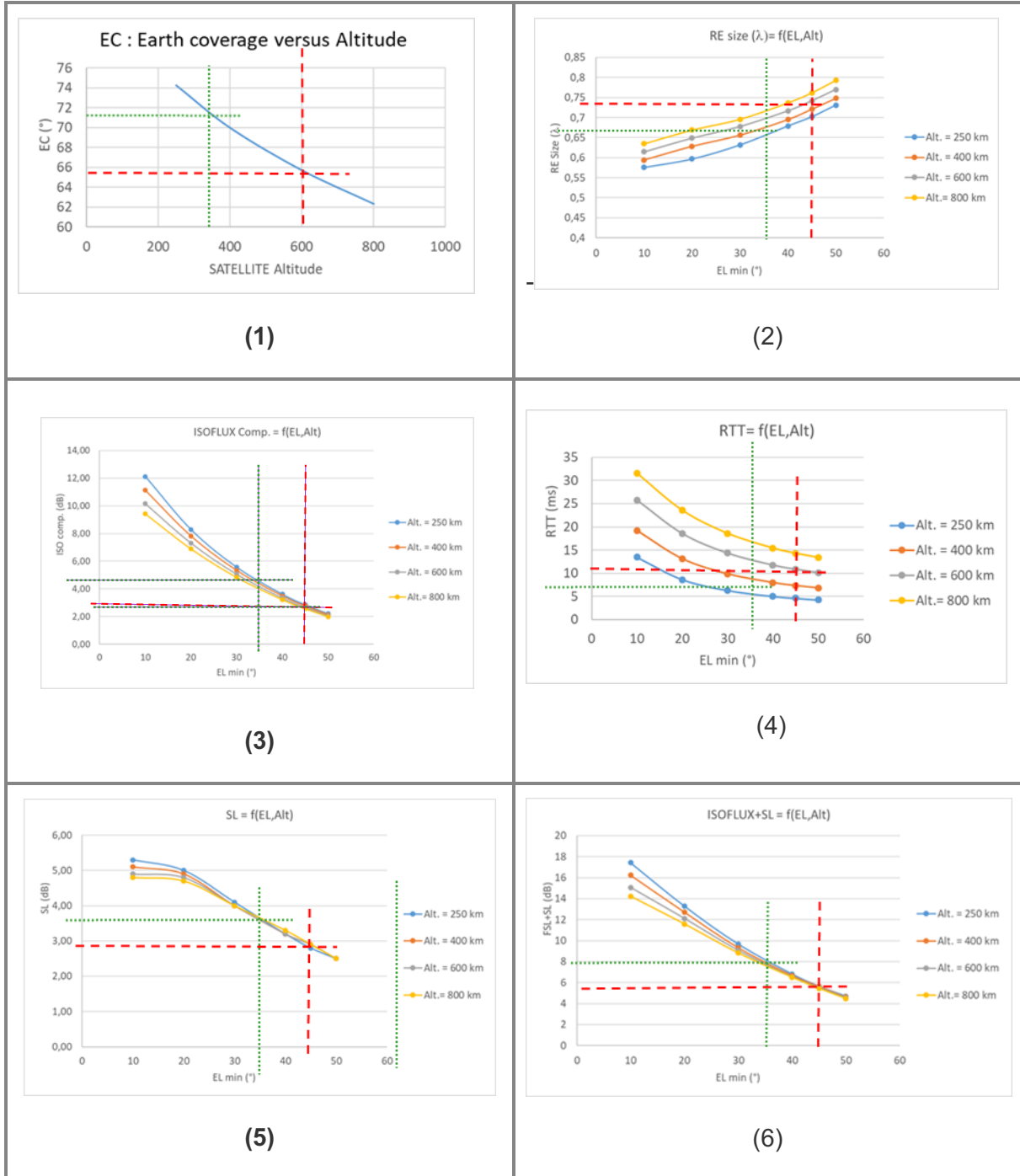


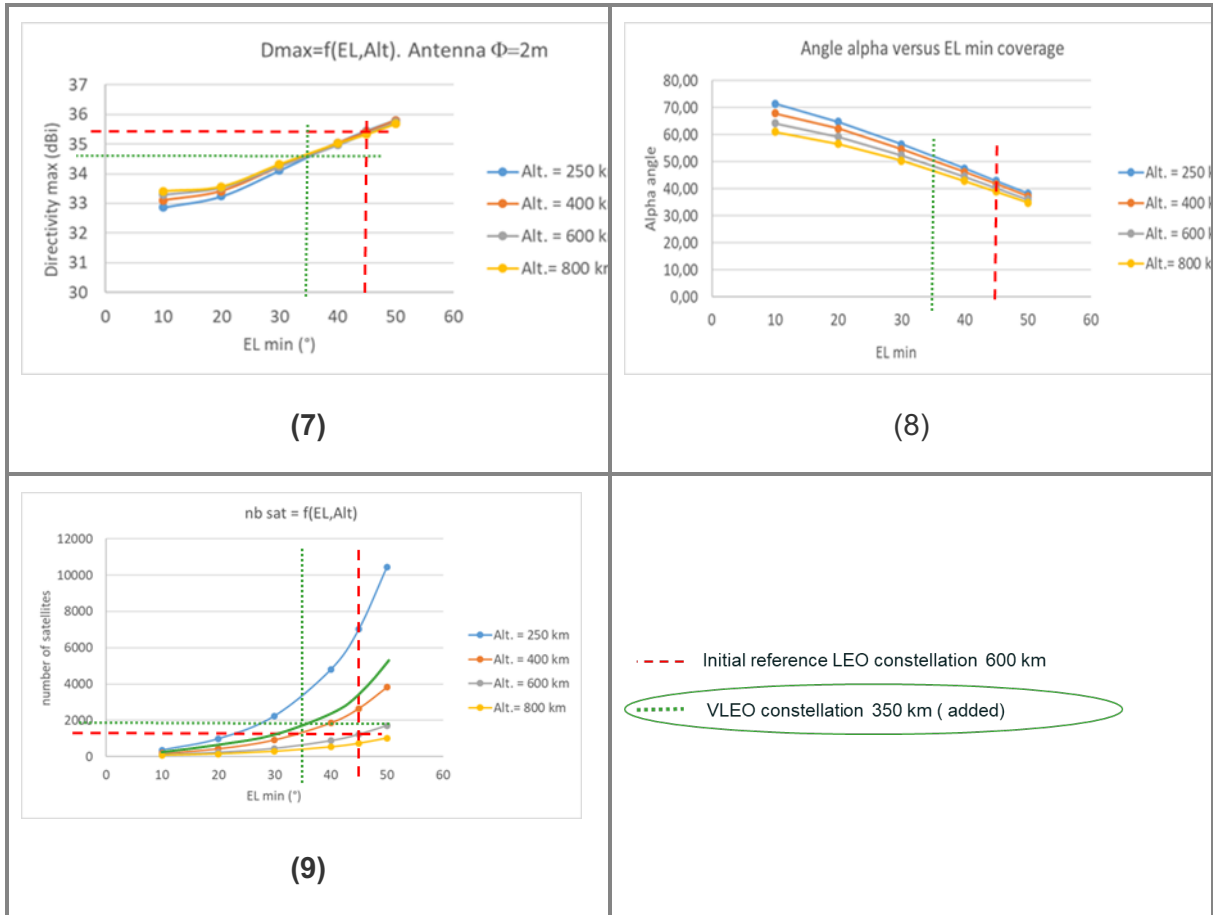




9.4.3 CASE B – C band VLEO

9.4.3.1 Review of trade-off parameters : an other optimum for a given VLEO





- Reduced the size (SC↓)
- Increase the number of RE (D ↑)
- ↔ Increase the surface (D↑)

9.4.3.2 Element of trade-off

a) Hypothesis case C

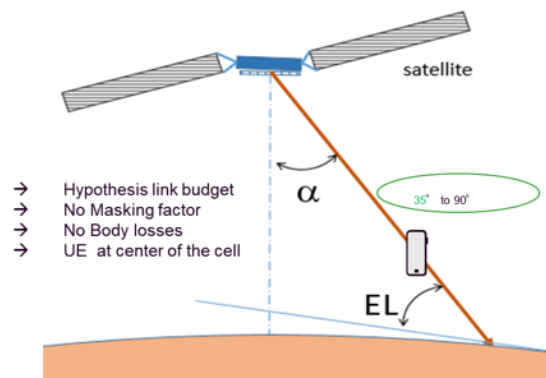


FIGURE 9-37 HYPOTHESIS

b) Beamforming results (Tx beams results)

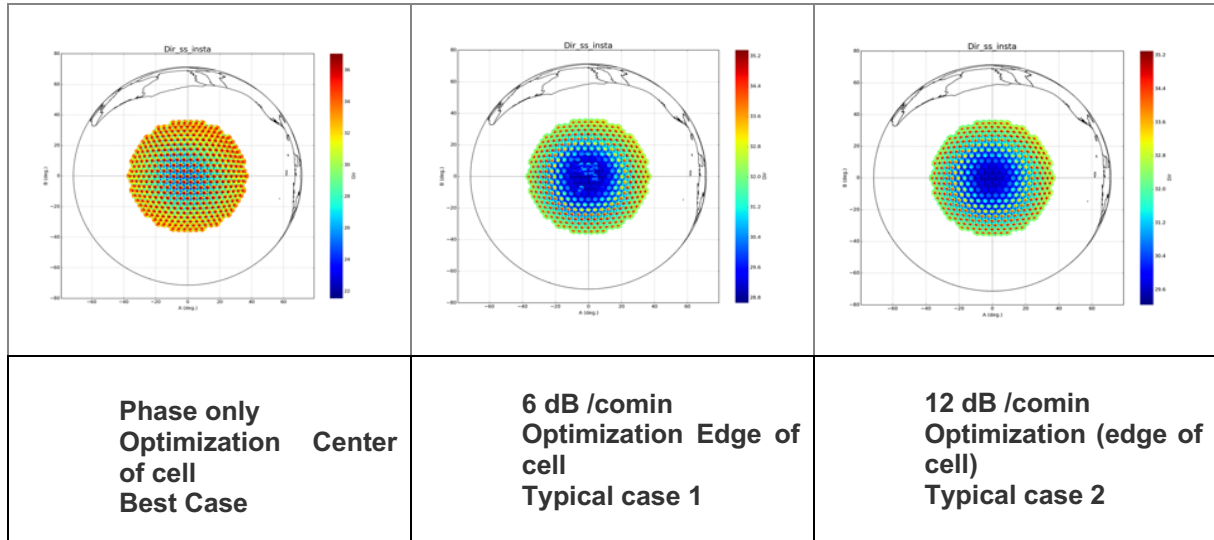
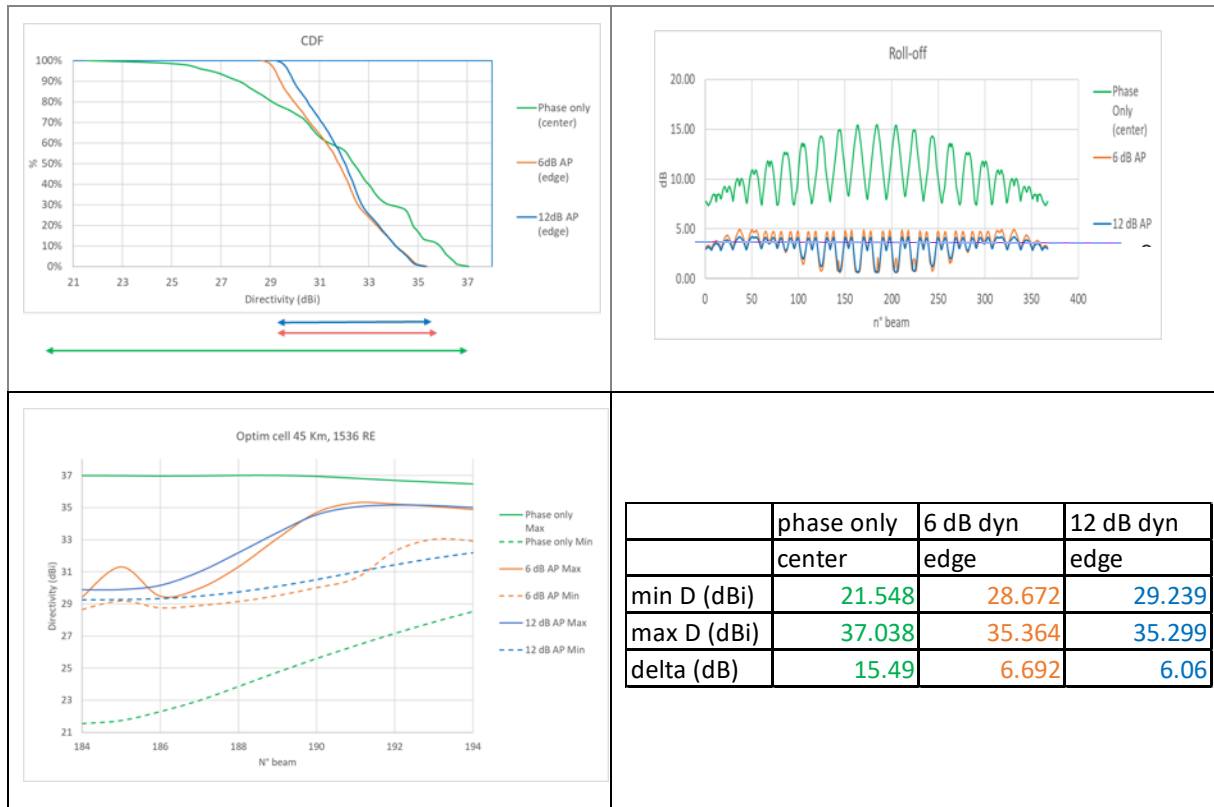


FIGURE 9-38 TX BEAMS FOOTPRINT (DIFFERENT BEAM FORMING)

3 types of beamforming is presented in Figure 9-39. All of these Beamforming could be used for ensuring the best performances in particular request. The nominal will be the Typical case 2 which allow to optimise the performances less roll-off and isoflux compensation (Figure 9-39).



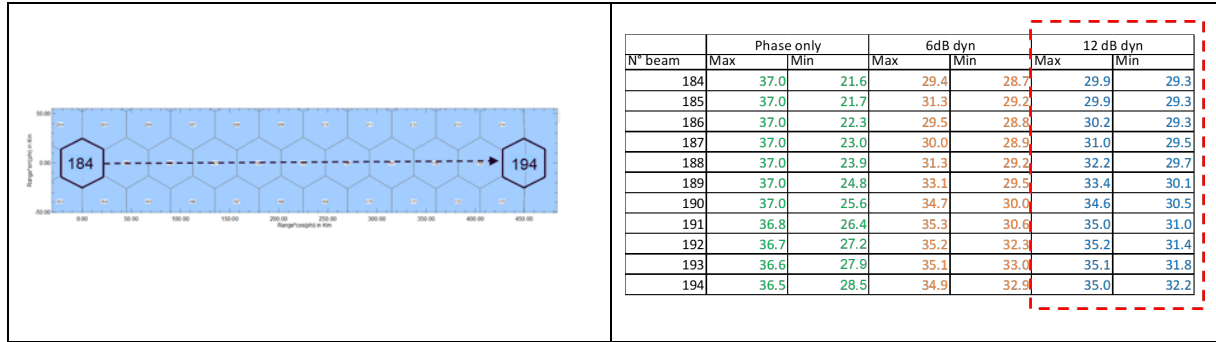


FIGURE 9-39 BEAM FORMING TX BEAMS RESUME

According to the behavior of the performances in directivity of the antenna with Beamforming 12dB is better designed to compensate the FSL than the case A.

c) Beamforming results (Rx beams results)

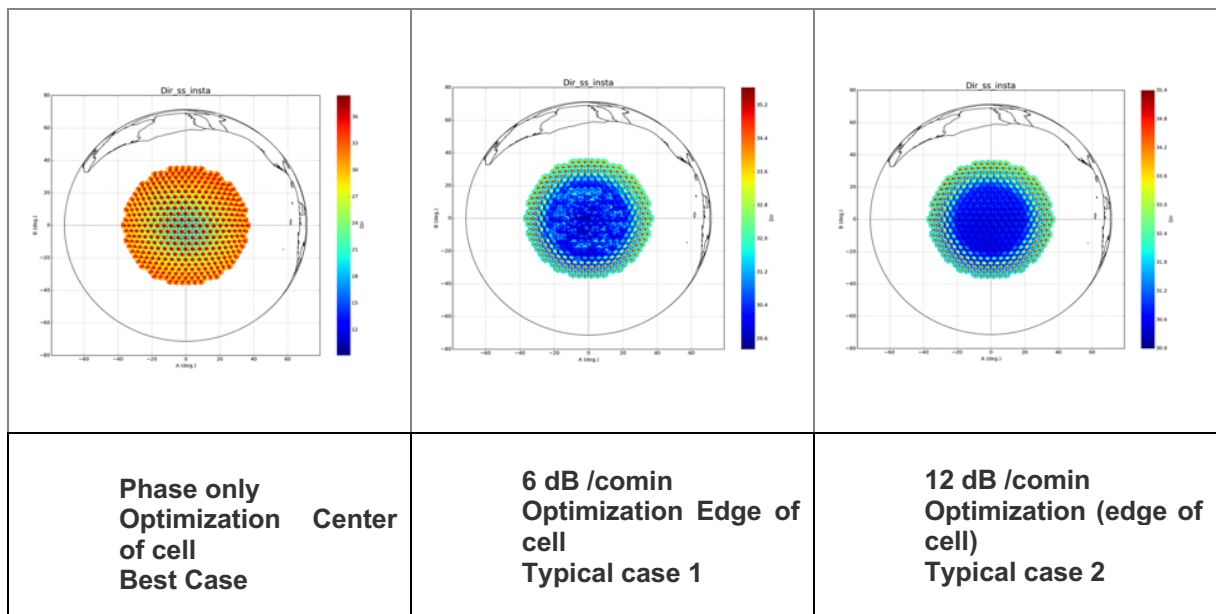


FIGURE 9-40 RX BEAMS FOOTPRINT (DIFFERENT BEAM FORMING)

. As for Tx beams, 3 types of beamforming have been investigated for Rx beams and is presented in All of these Beamforming could be used for ensuring the best performances in particular request. The nominal will be the Typical case 2 which allow to optimise the performancesless roll-off and isoflux compensation (see Figure 9-41

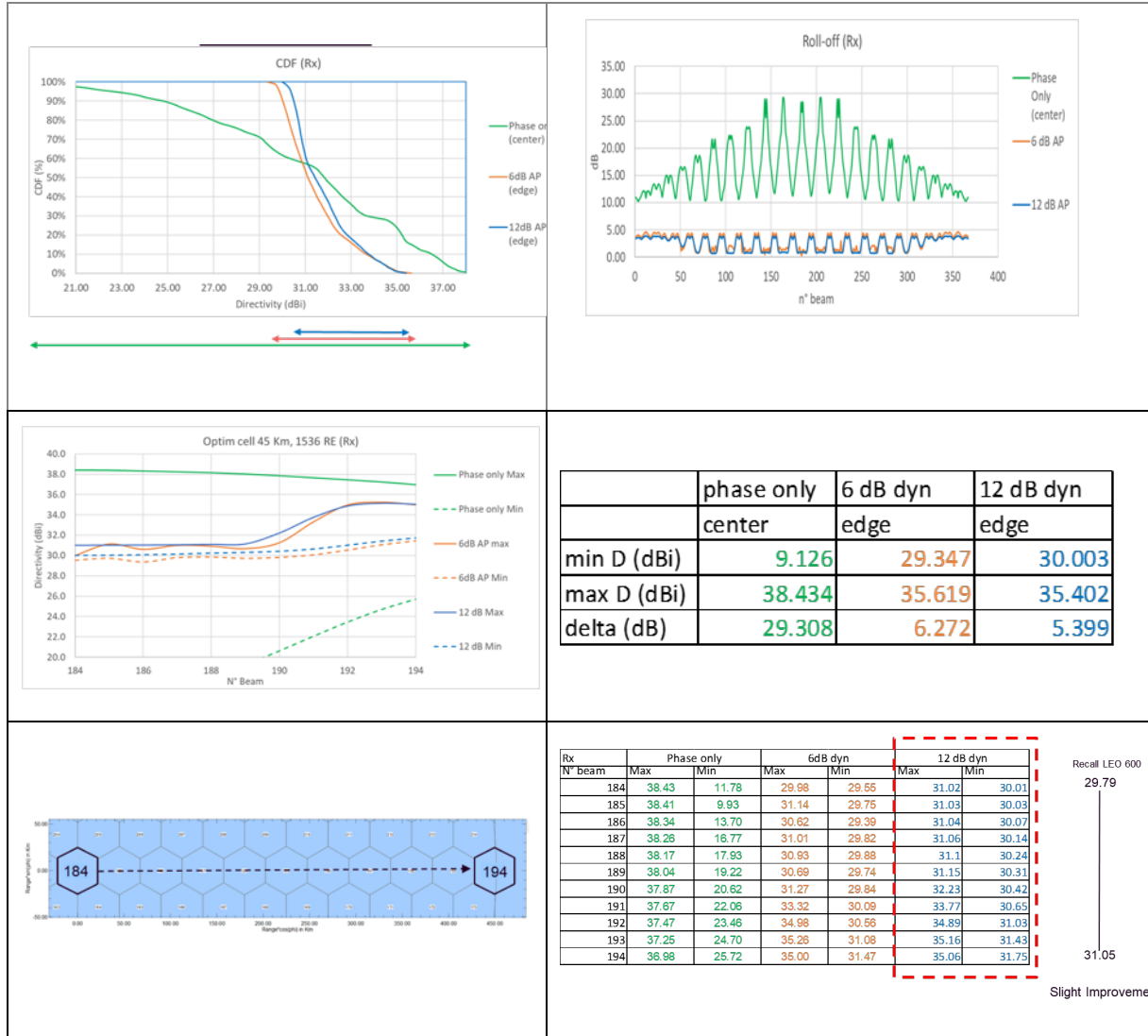


FIGURE 9-41 BEAM FORMING RX BEAMS RESUME

9.4.3.3 Power hypothesis (case B)

CASE B	1536	RE
densité PIRE	dBW/MHz	29.7
nb beam total		367
nb de beam actif		37
bande de fréquence	MHz	100
PIRE /beam	dBW	49.7
PIRE Total	dBW	65.4
nb elem		1536
Puissance Total RF		2024
Puissance Totale	W	5783
dissipation	W	3759

FIGURE 9-42 POWER HYPOTHESIS CASE B

Losses in Tx front end is taken 1.5 dB for FDD mode (as used in the table of . Figure 9-44)
For TDD it will be reduced to 1dB.

9.4.3.4 Downlink throughput C-Band (Nominal case, UE_1) (case B)

DOWNLINK		Unit	Average Case (E1 35°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	273	273
	Downlink Frequency	GHz	3.40	3.40
	Nb active spots during 1ms timeslot	-	37	37
	Nb spots total	-	367	367
SATELLITE - TX	EIRP density	dBW/MHz	29.70	29.70
	Satellite altitude	km	350.00	350.00
UE - RX	Elevation angle to satellite (seen from UE)	°	35.00	90.00
	Slant Range	km	580.81	350.00
	Antenna view angle	°	50.94	0.00
	Receive Antenna Gain	dBi	-5.00	-5.00
	Figure of Merit: G/T	dB/K	-36.62	-36.62
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-39.62	-39.62
LOSSES	Free space propagation	dB	158.36	153.96
	Atmospheric loss	dB	2.45	0.04
RESULTS CONFIGURATIONS	Number of used PRBs	-	273	273
RESULTS	Obtained C/N	dB	-2.18	4.48
	UE Rate	Mbits/s	31.86	86.83

FIGURE 9-43 DOWNLINK BUDGET NOMINAL CASE (UE_1)

9.4.3.5 Downlink throughput C-band Best case (case B)

DOWNLINK		Unit	Average Case (E1 35')	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	273	273
	Downlink Frequency	GHz	3.40	3.40
	Nb active spots during 1ms timeslot	-	74	74
	Nb spots total	-	367	367
SATELLITE - TX	EIRP density	dBW/MHz	48.39	48.39
	Satellite altitude	km	350.00	350.00
UE - RX	Elevation angle to satellite (seen from UE)	°	35.00	90.00
	Slant Range	km	580.81	350.00
	Antenna view angle	°	50.94	0.00
	Receive Antenna Gain	dBi	-5.00	-5.00
	Figure of Merit: G/T	dB/K	-36.62	-36.62
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-39.62	-39.62
LOSSES	Free space propagation	dB	158.36	153.96
	Atmospheric loss	dB	2.45	0.04
RESULTS CONFIGURATIONS	Number of used PRBs	-	273	273
RESULTS	Obtained C/N	dB	14.21	16.89
	UE Rate	Mbits/s	143.29	143.29

FIGURE 9-44 DOWNLINK BUDGET BEST CASE (UE_1)

9.4.3.6 Downlink throughput C-band worst case (case B)

DOWNLINK		Unit	Average Case (E1 35')	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	46	82
	Downlink Frequency	GHz	3.40	3.40
	Nb active spots during 1ms timeslot	-	74	74
	Nb spots total	-	367	367
SATELLITE - TX	EIRP density	dBW/MHz	29.70	29.70
	Satellite altitude	km	350.00	350.00
UE - RX	Elevation angle to satellite (seen from UE)	°	35.00	90.00
	Slant Range	km	580.81	350.00
	Antenna view angle	°	50.94	0.00
	Receive Antenna Gain	dBi	-5.00	-5.00
	Figure of Merit: G/T	dB/K	-36.62	-36.62
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-39.62	-39.62
LOSSES	Free space propagation	dB	158.36	153.96
	Propagation losses computation	-	Computation [RD1] & [RD2]	
	UE location	-	Toulouse	
	Weather condition	-	Clear Sky	
	Atmospheric loss	dB	2.45	0.04
	Shadowing margins	dB	10.00	10.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	46	82
RESULTS	Obtained C/N	dB	-4.43	-0.17
	UE Rate	Mbits/s	3.34	15.27

FIGURE 9-45 DOWNLINK BUDGET WORST CASE (UE_1)

9.4.3.7 Rx hypothesis (case B)

The hypothesis taken for the link budget are summarized in the table below :

FDD mod : Losses L: 2 dB LNA NF : 2 dB Tant=240 K G/T = G-26.33 dB G/T= D-L-26.33 dB G/T=D-28.33 dB	D dBi	G/T dB.K ⁻¹	TDD mod : Losses L: 1.5 dB LNA NF : 2 dB Tant=240 K G/T = G-26.33 dB G/T= D-L-26.33 dB G/T= D-27.83 dB
	37	8.67	
	36	7.67	
	35	6.67	
	34	5.67	
	33	4.67	
	32	3.67	
	31	2.67	
	30	1.67	
	29	0.67	
	28	-0.33	
27	-1.33		
26	-2.33		

FIGURE 9-46 RX FRONT END HYPOTHESIS CASE A

9.4.3.8 Uplink budget best case (case B)

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 35°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	9	15
	Occupied Channel Bandwidth	MHz	3.24	5.4
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	74	74
UE - TX	Elevation angle to satellite	°	35.00	90.00
	Slant Range	km	580.81	350.00
	Antenna view angle	°	50.94	0.00
SATELLITE - RX	Satellite altitude	km	350.00	350.00
	Satellite figure of merit (G/T)	dB/K	6.73	2.69
LOSSES	Free space propagation	dB	159.55	155.15
	Propagation losses computation	-	Computation [RD1] & [RD2]	
	UE location	-	Toulouse	
	Weather condition	-	Clear Sky	
	Atmospheric loss	dB	2.45	0.04
RESULTS CONFIGURATIONS	Number of PRB per UE	-	9	15
RESULTS	Obtained C/N	dB	-3.81	-3.26
	UE Rate	Mbit/s	0.914	1.873

FIGURE 9-47 UPLINK BUDGET BEST CASE (UE_1)

9.4.3.9 Uplink budget 1 PRB case B

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 35°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	1	1
	Occupied Channel Bandwidth	MHz	0.36	0.36
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	37	37
UE - TX	Elevation angle to satellite	°	35.00	90.00
	Slant Range	km	580.81	350.00
	Antenna view angle	°	50.94	0.00
SATELLITE - RX	Satellite altitude	km	350.00	350.00
	Satellite figure of merit (G/T)	dB/K	6.73	2.69
LOSSES	Free space propagation	dB	159.55	155.15
	Propagation losses computation	-	Computation [RD1] & [RD2]	
	UE location	-	Toulouse	
	Weather condition	-	Clear Sky	
	Atmospheric loss	dB	2.45	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	Obtained C/N	dB	5.51	8.07
	UE Rate	Mbit/s	0.439	0.561

FIGURE 9-48 UPLINK BUDGET FOR ONE PRB (UE_1)

9.4.3.10 Uplink budget worst case case B



PRACH Link Budget		Unit	Average Case (EI 35°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	1	1
	Occupied Channel Bandwidth	MHz	0.36	0.36
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	74	74
UE - TX	Elevation angle to satellite	°	35.00	90.00
	Slant Range	km	580.81	350.00
	Antenna view angle	°	50.94	0.00
SATELLITE - RX	Satellite altitude	km	350.00	350.00
	Satellite figure of merit (G/T)	dB/K	6.73	2.69
LOSSES	Free space propagation	dB	159.55	155.15
	Propagation losses computation	-	Computation [RD1] & [RD2]	
	UE location	-	Toulouse	
	Weather condition	-	Clear Sky	
	Atmospheric loss	dB	2.45	0.04
	Shadowing margins	dB	10.00	10.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	Obtained C/N	dB	-4.26	-1.51
	UE Rate	Mbit/s	0.078	0.162

Figure 9-49 uplink budget for worst case (UE_1) 10 dB attenuation

9.4.4 CASE C C-BAND

9.4.4.1 Improvement of the initial solution

Objective increase the number of elements. Hypothesis that the cost is not driven by the number of elements.

Resizing the elements as for the VLEO constellation but with the objective to reduce the scanlosses by taking a small size of RE.

RE ELEMENT	Frequency	λ	lattice	lattice
Sizing	GHz	mm	λ	mm
Tx (sat) Rx(UE)	3.4	88.24	0.65	57.08
Rx (sat) Tx(UE)	3.9	76.92	0.742	57.08

→

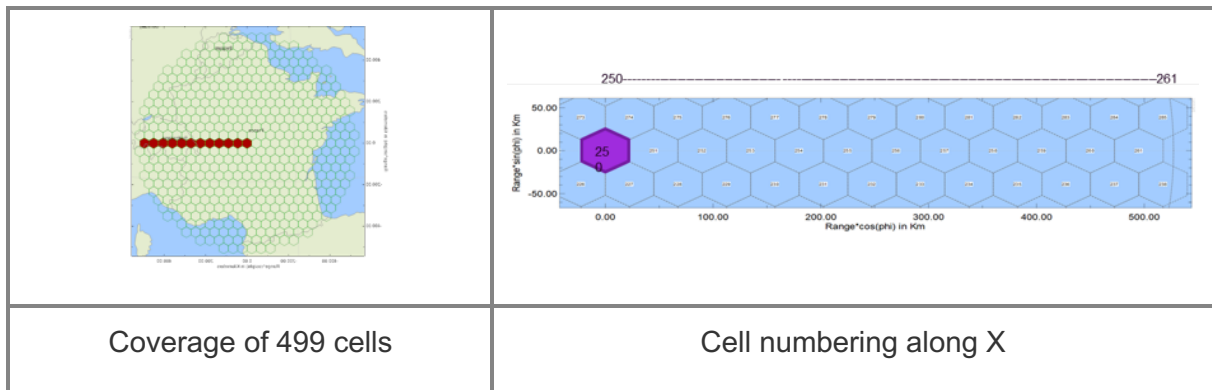
RE ELEMENT	Frequency	λ	lattice	lattice
Sizing	GHz	mm	λ	mm
Tx (sat) Rx(UE)	3.4	88.24	0.54	47.69
Rx (sat) Tx(UE)	3.9	76.92	0.62	47.69

FIGURE 9-50 RESIZING FOR RE

The resizing of the radiating element to a minimum 0.55λ in Tx and 0.62 in Rx wich represents a size of almost 47.69 mm. The table in the Figure 9-51 show the 4 cases tested for the trade-off.

lambda	nb RE	diameter	
λ		mm	
0.742	1056	1948	(0)
lambda	nb RE	diameter	
0.62	1056	1627	
0.62	1504	1942	(1)
0.62	2048	2266	(2)
0.62	3008	2747	(3)
0.62	4080	3199	(4)

FIGURE 9-51 SIZING TRADE-OFF TESTS



The performances have been calculated for Rx function

- a) Case (1) 1504 RE
 - i. Rx function

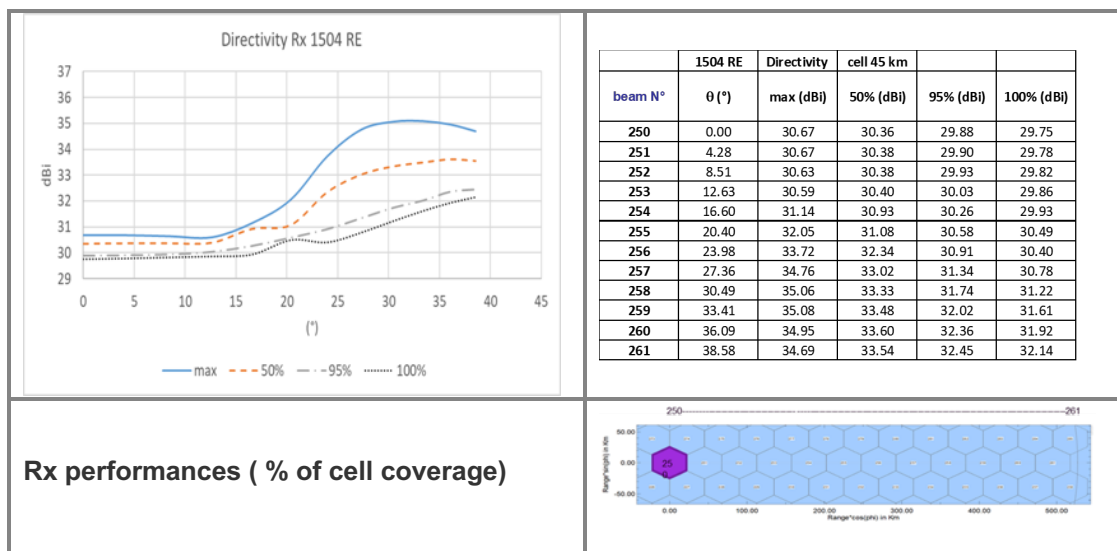


FIGURE 9-52 ANTENNA OF 1504 RE

- b) Case (2) 2048 RE
 - i. Rx function

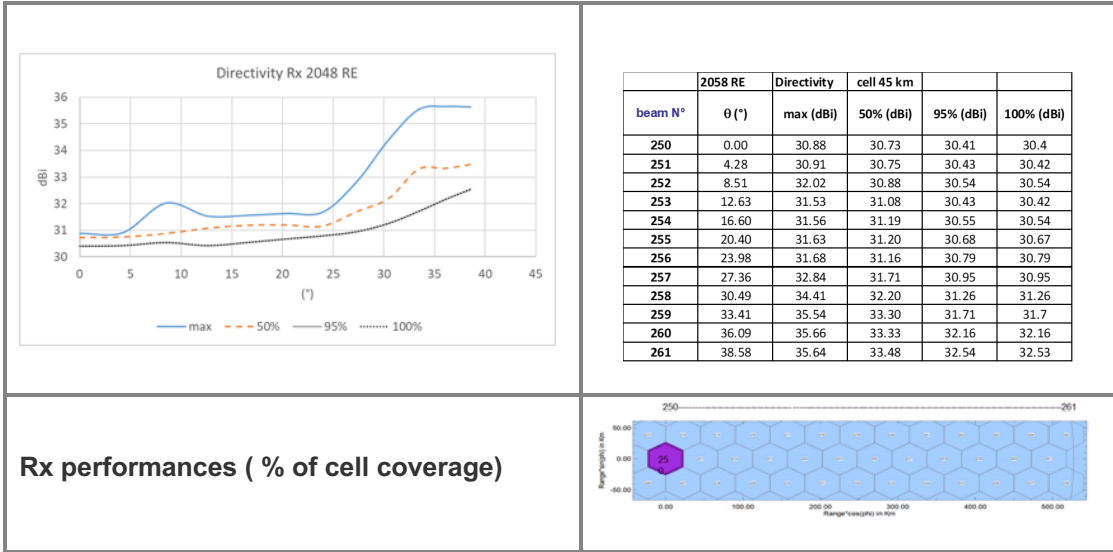


FIGURE 9-53 ANTENNA OF 2048 RE

i. Tx function

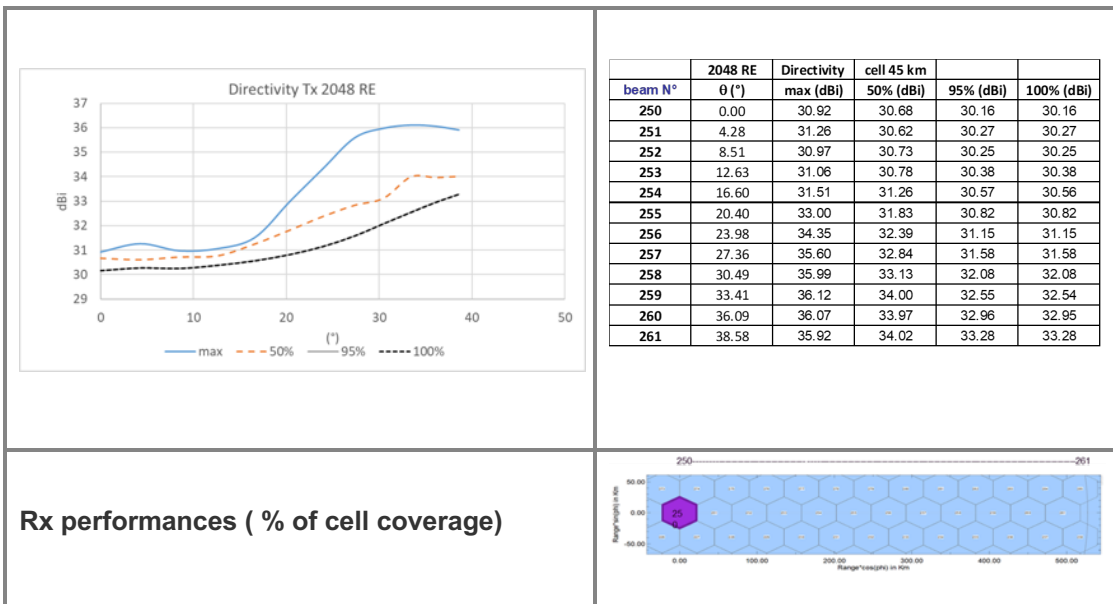


FIGURE 9-54 ANTENNA OF 2048 RE

c) Case (3) 3008 RE

i. Rx function

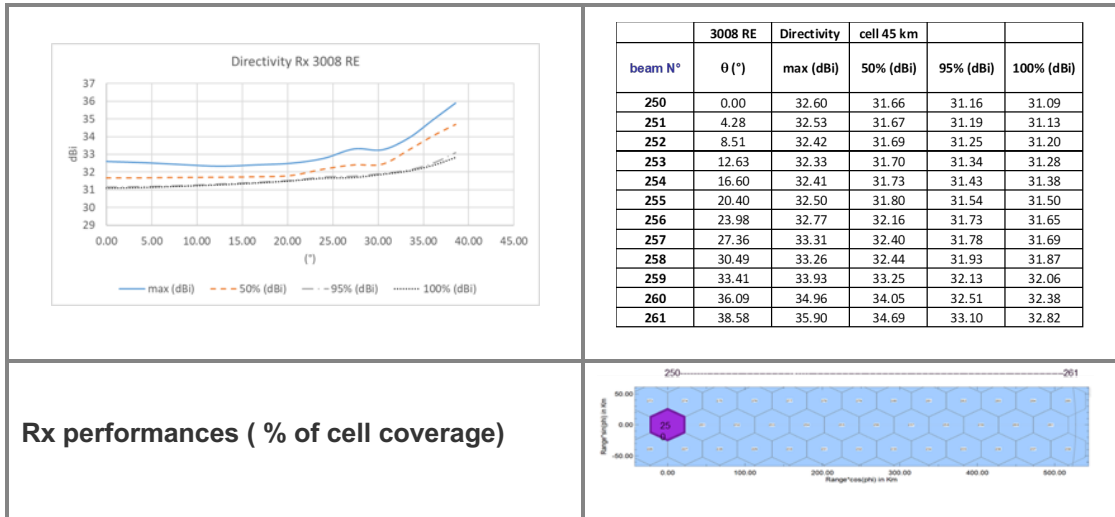


FIGURE 9-55 ANTENNA OF 3008 RE

d) Case (1) 4080 RE

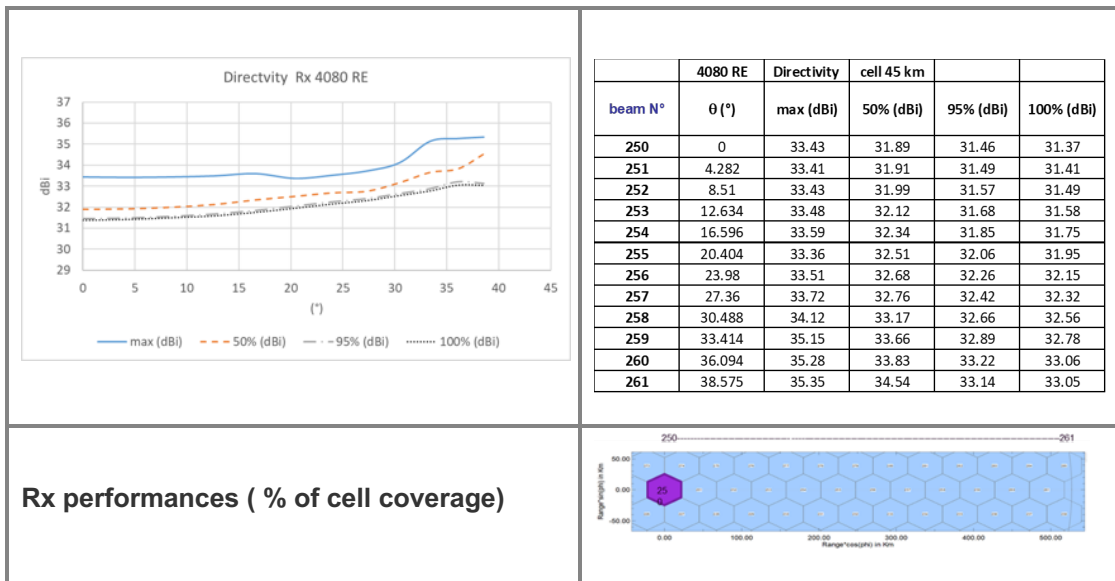


FIGURE 9-56 ANTENNA OF 4080 RE

9.4.4.2 Investigation on cell size

The purpose of the study is to improve the performance in Rx by reducing the cell size initially define. Although the number of cell will increase for a given coverage it could allow to enhance the performance in uplink which is the most weak more precisely at the edge. As the beam become small it is necessary to increase the size of the antenna.

In this chapter, we focus study on 1056 ER /1520 RE/ Beamforming techniques/ cell size 45/21 kms

The initial reference solution DRA of 1056 RE and 45 km cell on a coverage of $E_{l_{min}}$ of 45° is compared with the DRA of 1520 RE and 22 km cell on a coverage of $E_{l_{min}}$ of 45° . The new antenna view is presented in comparison of the previous footprint.

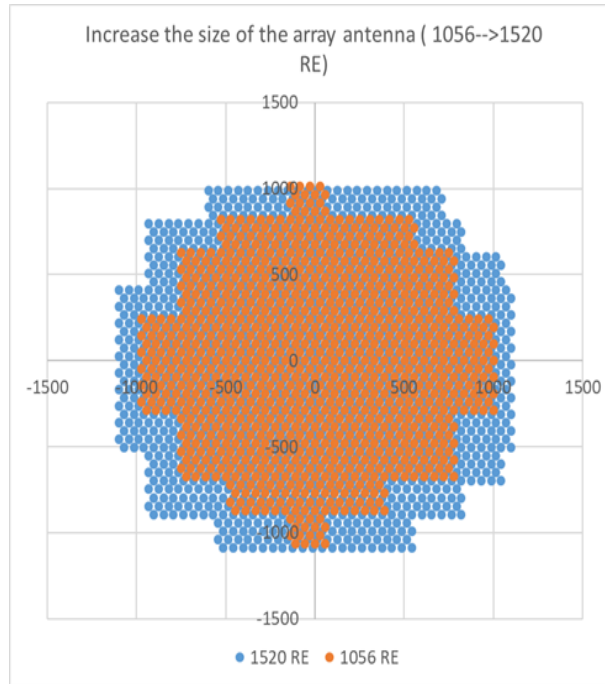


FIGURE 9-57 ANTENNA SIZE INCREASE 1056 TO 1520 RE

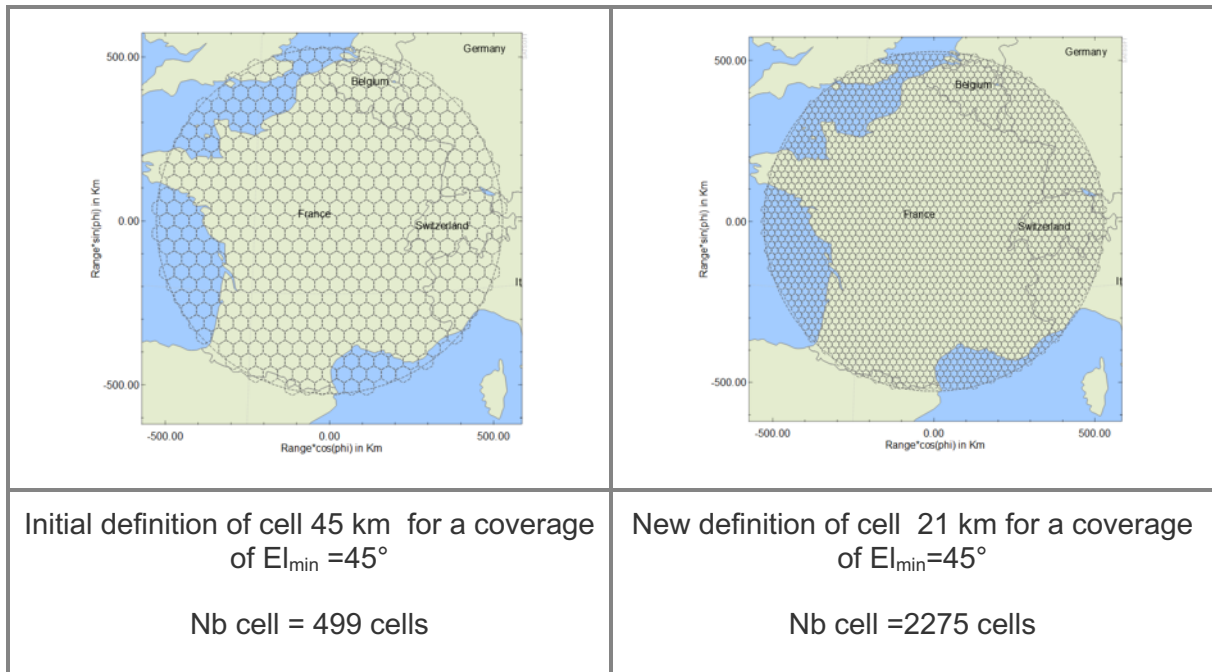


FIGURE 9-58 NEW CELL DISCRETIZATION

a) Comparison of the two DRA performances on 45 Km cells

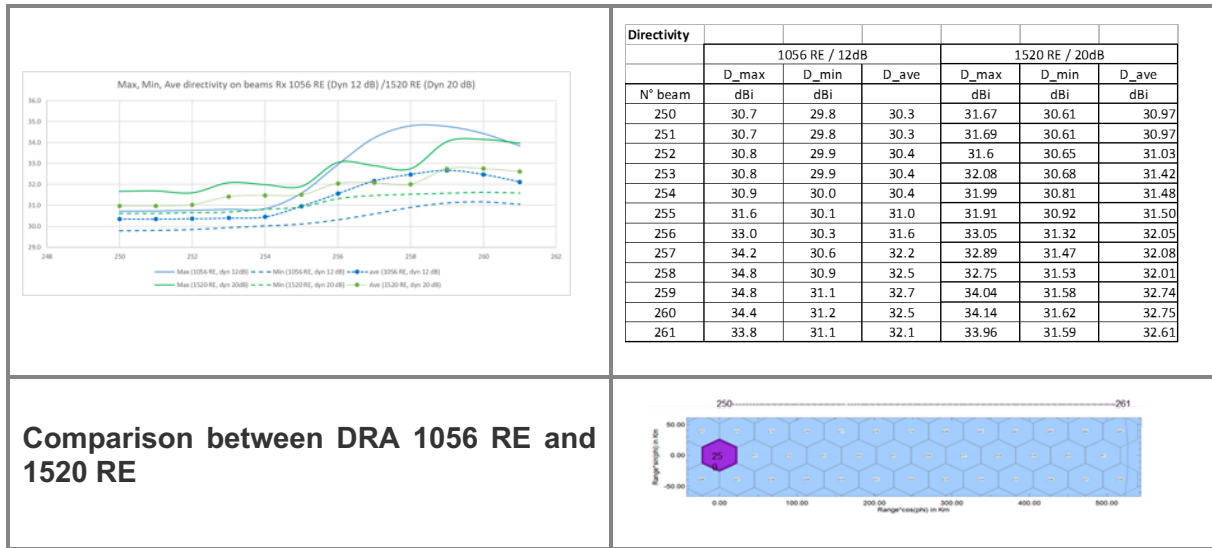


FIGURE 9-59 COMPARISON DRA 1056 RE AND 1520 RE ON CELL OF 45 KM (EL_{MIN}=45°)

- roll-off reduction
- slight increase in directivity
- Increase the number make the antenna more directive → need to increase the Beamforming dynamic
- No significant advantage

b) Comparison of the DRA 1056 performances on 21 Km cells in comparison of 45 km

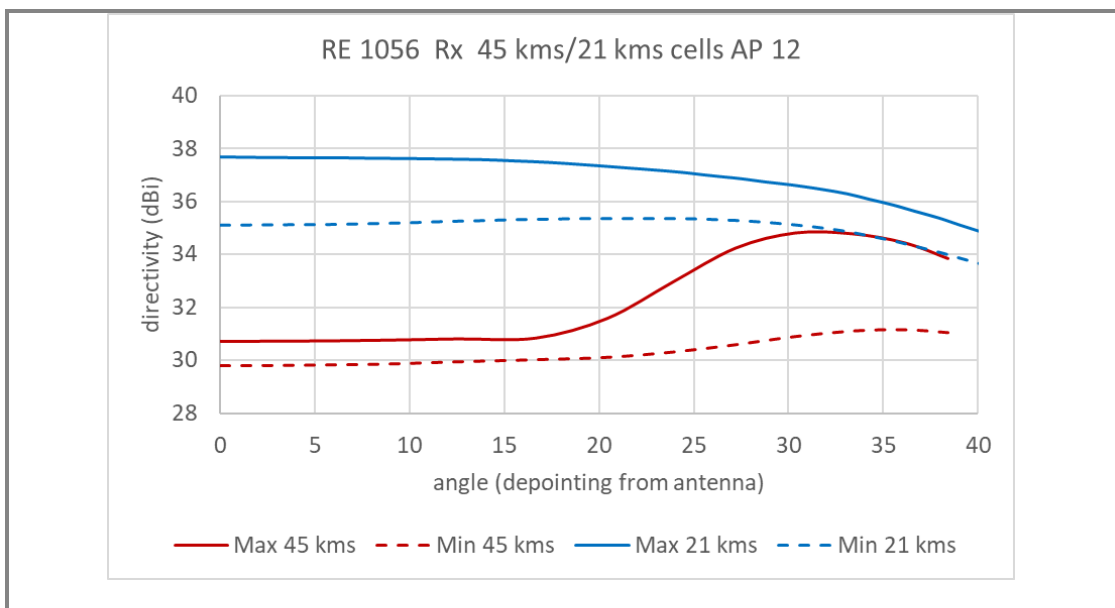


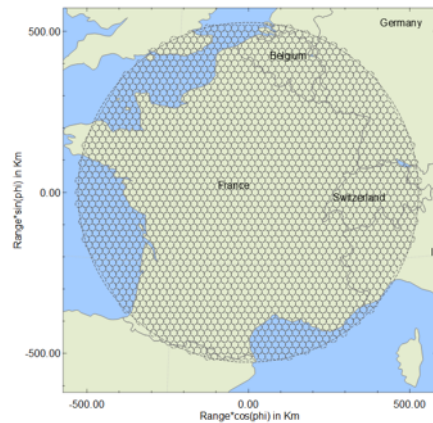
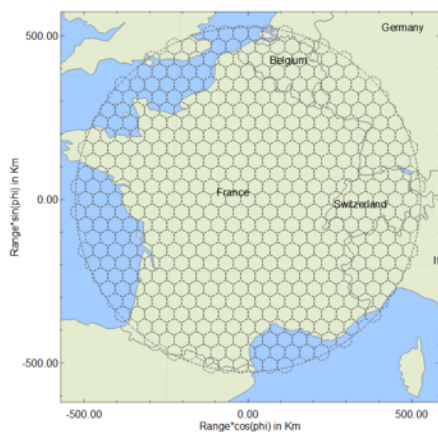
FIGURE 9-60 DRA 1056 RE : COMPARISON BETWEEN PERFORMANCES RX ON 45 KM AND 21 KM CELLS

The results show that :

- ➔ global better performances but the gain is low at EL : isoflux behavior not recovered (increase of directivity with depointing)
- ➔ should Impact on beam management : refreshing and beam hopping and stability ensuring.
- ➔ Solution will need huge processing capacity du to the number of beam to manage
- ➔ The impact in Tx in term of % simultaneously coverage will be limited even if 499 to 2275 : the power on the payload is limited by its dissipation capacity and will need heavy thermal dissipation device and dissipation surface to evacuate the heat towards cold space.
- ➔ In resume : this solution could be envisaged with some constraints listed above.

Directivity	Max	Min	average
250	30.73	29.79	30.34
251	30.74	29.81	30.34
252	30.77	29.85	30.36
253	30.82	29.94	30.39
254	30.85	30.02	30.45
255	31.59	30.11	30.96
256	32.96	30.31	31.56
257	34.23	30.59	32.17
258	34.8	30.9	32.48
259	34.77	31.11	32.67
260	34.43	31.16	32.48
261	33.84	31.05	32.12

Directivity	Max	Min
1138	37.69	35.12
1139	37.67	35.13
1140	37.66	35.14
1141	37.66	35.15
1142	37.64	35.18
1143	37.63	35.21
1144	37.61	35.26
1145	37.59	35.29
1146	37.54	35.33
1147	37.48	35.35
1148	37.4	35.37
1149	37.31	35.37
1150	37.21	35.37
1151	37.11	35.37
1152	36.99	35.34
1153	36.87	35.29
1154	36.75	35.23
1155	36.63	35.14
1156	36.47	35.02
1157	36.3	34.88
1158	36.09	34.71
1159	35.88	34.53
1160	35.65	34.33
1161	35.39	34.1
1162	35.13	33.88
1163	34.88	33.66



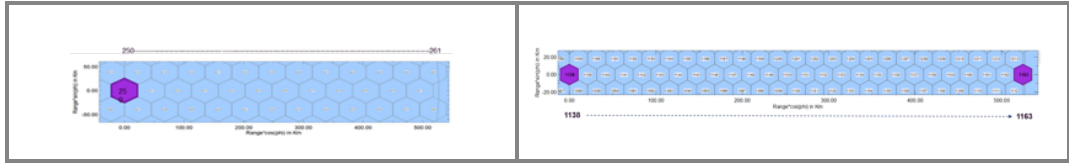


FIGURE 9-61 DRA 1056 RE : COMPARISON BETWEEN PERFORMANCES ON 45 KM AND 21 KM CELLS

c) Comparison of the DRA 1056 performances and DRA 1520 on 21 Km cells

The interest is focussed only on Rx where the directivity impact directly the G/T. For the Tx beams, the management of power could be flexible (compensate FSL & scan losses) with power distribution adjustment between beams.

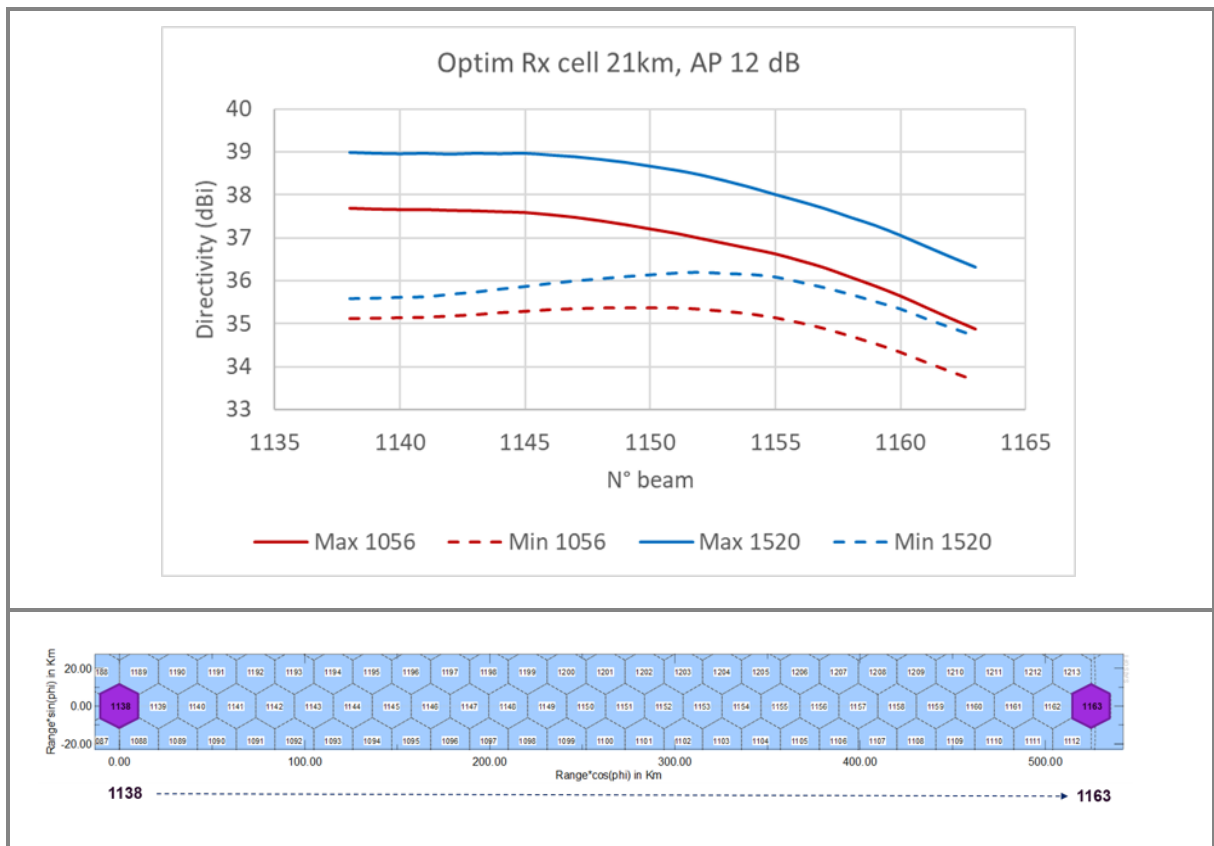


FIGURE 9-62 COMPARISON BETWEEN RX DRA 1056 & 1520 ON CELLS OF 21 KM

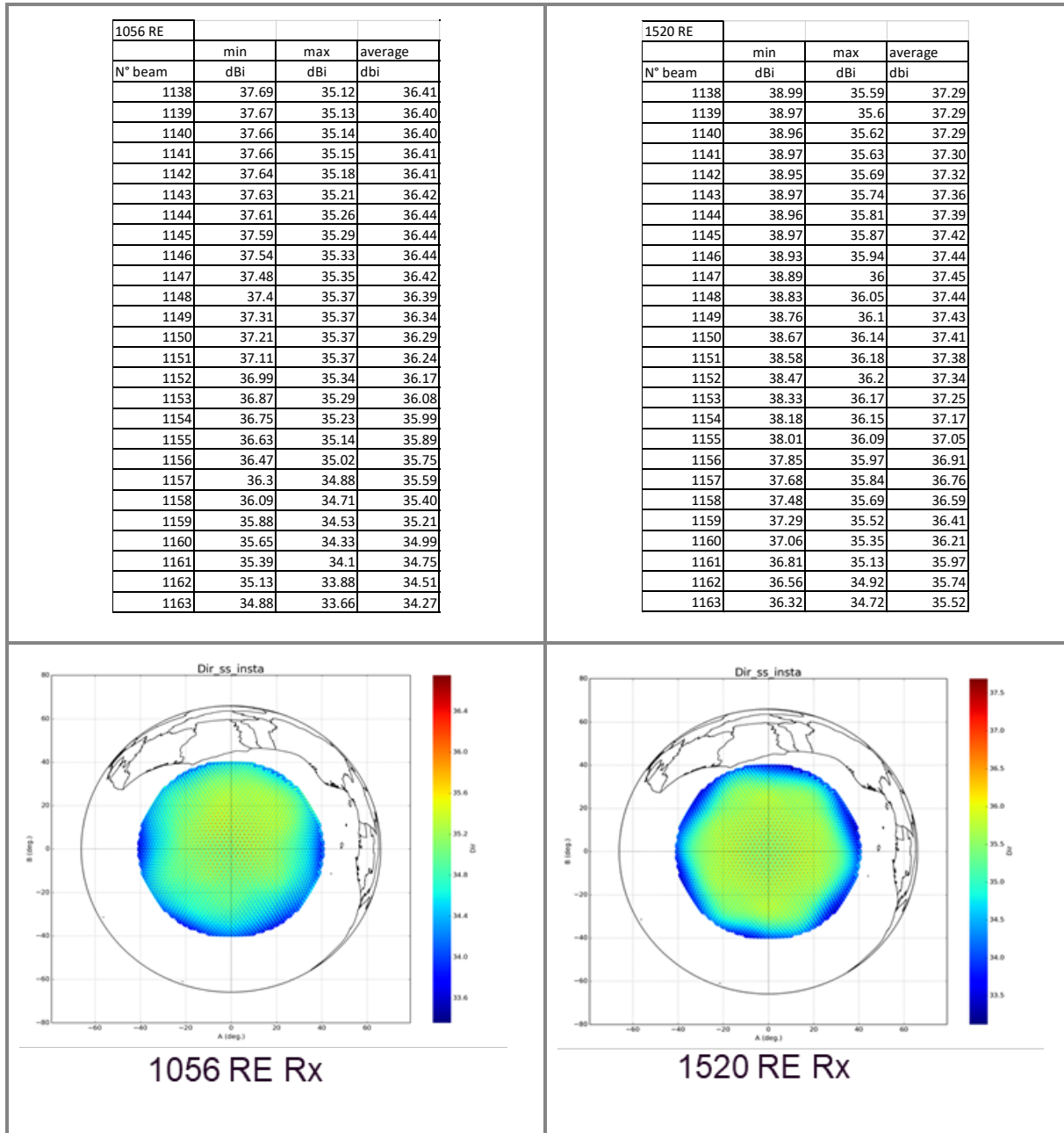


FIGURE 9-63 COMPARISON BETWEEN RX DRA 1056 & 1520 ON CELLS OF 21 KM

d) Conclusion : the investigation on increase tye Rx performances could be achieved by reducing cell and increasing the size of the antenna. But the behavior of the directivity with depointing angle would not allow a compensation of the FSL and of the scanlosses which is not optimum in Rx. The gain at the edge will nevertheless allow an increase of 1 or 2 dB at the edge but in

a) Performance in uplink of solution 1520 RE on 21 kms cell

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	8	32
	Occupied Channel Bandwidth	MHz	2.88	11.52
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	8.57	10.67
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	8	32
RESULTS	Obtained C/N	dB	-3.49	-3.25
	Spectral Efficiency	bits/s/Hz	0.2821	0.3468
	UE Rate	Mbit/s	0.812	3.996

FIGURE 9-64 UPLINK PERFORMANCE OF DRA 1520 RE ON (MAX ACHIEVABLE THROUGHPUT)

According to results in Figure 9-64, the Uplink Minimum directivity to ensure is 2 Mbps in uplink : it could be reached at boresight but not at the edge.

directivity Rx	Equivalent Temperature	K	409.62
36	Antenna gain (NADIR)	dBi	34.00
40.6	Antenna gain (45°)	dBi	38.60
offset (au gain)	G/T (NADIR)	dB/K	7.67
26.33	G/T (45°)	dB/K	12.27
SCS PRB	SCS	kHz	30
	Downlink BW	MHz	100
	Nb Downlink PRBs	-	273
	Uplink BW	MHz	100
	Nb Uplink PRBs	-	273
C/I	Downlink (Sat TX)	dB	18
	Uplink (Sat RX)	dB	18

FIGURE 9-65 SATELLITE RX FRONT END HYPOTHESIS IN DIRECTIVITY TO REACH 2 MBPS IN UPLINK

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	26	26
	Occupied Channel Bandwidth	MHz	9.36	9.36
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	12.27	8.37
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	26	26
RESULTS	Obtained C/N	dB	-4.90	-4.64
	Spectral Efficiency	bits/s/Hz	0.2156	0.2156
	UE Rate	Mbit/s	2.018	2.018

FIGURE 9-66 UPLINK LINK BUDGET 2 MBPS

9.4.4.3 Reference Case C

9.4.4.4 Power Hypothesis Case C

CASE C	2048	RE
densité PIRE	dBW/MHz	30
nb beam total		499
nb de beam actif		50
bande de fréquence	MHz	100
PIRE /beam	dBW	50
PIRE Total	dBW	67.0
nb elem		2048
Puissance Total RF		2285
Puissance Totale	W	6530
dissipation	W	4244

FIGURE 9-67 POWER TX CASE C

9.4.4.5 CASE C Nominal case

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	273	273
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	30.00	30.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-5.00	-5.00
	Figure of Merit: G/T	dB/K	-36.62	-36.62
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-39.62	-39.62
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	0.00	0.00
GLOBAL LOSSES	Calibration mismatch loss	dB	0.00	0.00
	System margin	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	273	273
RESULTS	Obtained C/N	dB	-3.90	0.22
	Spectral Efficiency	bits/s/Hz	0.2016	0.5174
	UE Rate	Mbits/s	19.81	50.85

FIGURE 9-68 DOWNLINK BUDGET NOMINAL CASE (UE_1)

9.4.4.6 CASE C Best Case

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	273	273
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	50.00	50.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-5.00	-5.00
	Figure of Merit: G/T	dB/K	-36.62	-36.62
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-39.62	-39.62
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	273	273
RESULTS	Obtained C/N	dB	13.96	15.99
	UE Rate	Mbits/s	143.29	143.29

FIGURE 9-69 DOWNLINK BUDGET BEST CASE (UE_1)

9.4.4.7 CASE C Worst Case

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	khz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	23	80
	Downlink Frequency	GHz	3.40	3.40
SATELLITE - TX	EIRP density	dBW/MHz	30.00	30.00
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	-5.00	-5.00
	Figure of Merit: G/T	dB/K	-36.62	-36.62
	Polarisation mismatch loss	dB	3.00	3.00
	Effective G/T under satellite coverage	dB/K	-39.62	-39.62
LOSSES	Free space propagation	dB	161.30	158.64
	Atmospheric loss	dB	1.54	0.04
	Shadowing margins	dB	10.00	10.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	23	80
RESULTS	Obtained C/N	dB	-3.16	-4.40
	UE Rate	Mbits/s	2.18	5.81

FIGURE 9-70 DOWNLINK BUDGET WORST CASE (UE_1)

9.4.4.8 Rx hypothesis case C

9.4.4.9 Uplink budget best case C

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	8	7
	Occupied Channel Bandwidth	MHz	2.88	2.52
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.60	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	7.31	2.61
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
RESULTS CONFIGURATIONS	Number of PRB per UE	-	8	7
RESULTS	Obtained C/N	dB	-4.74	-4.70
	UE Rate	Mbit/s	0.621	0.543

FIGURE 9-71 UPLINK BUDGET BEST CASE (UE_1)

9.4.4.10 Uplink budget for one PRB case C

<input type="checkbox"/> PRACH Link Budget		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	1	1
	Occupied Channel Bandwidth	MHz	0.36	0.36
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.60	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	7.31	2.61
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	Obtained C/N	dB	4.13	3.61
	Spectral Efficiency	bits/s/Hz	1.0817	1.0817
	UE Rate	Mbit/s	0.389	0.389

FIGURE 9-72 UPLINK BUDGET FOR ONE PRB (UE_1)

9.4.4.11 Uplink budget worst case C

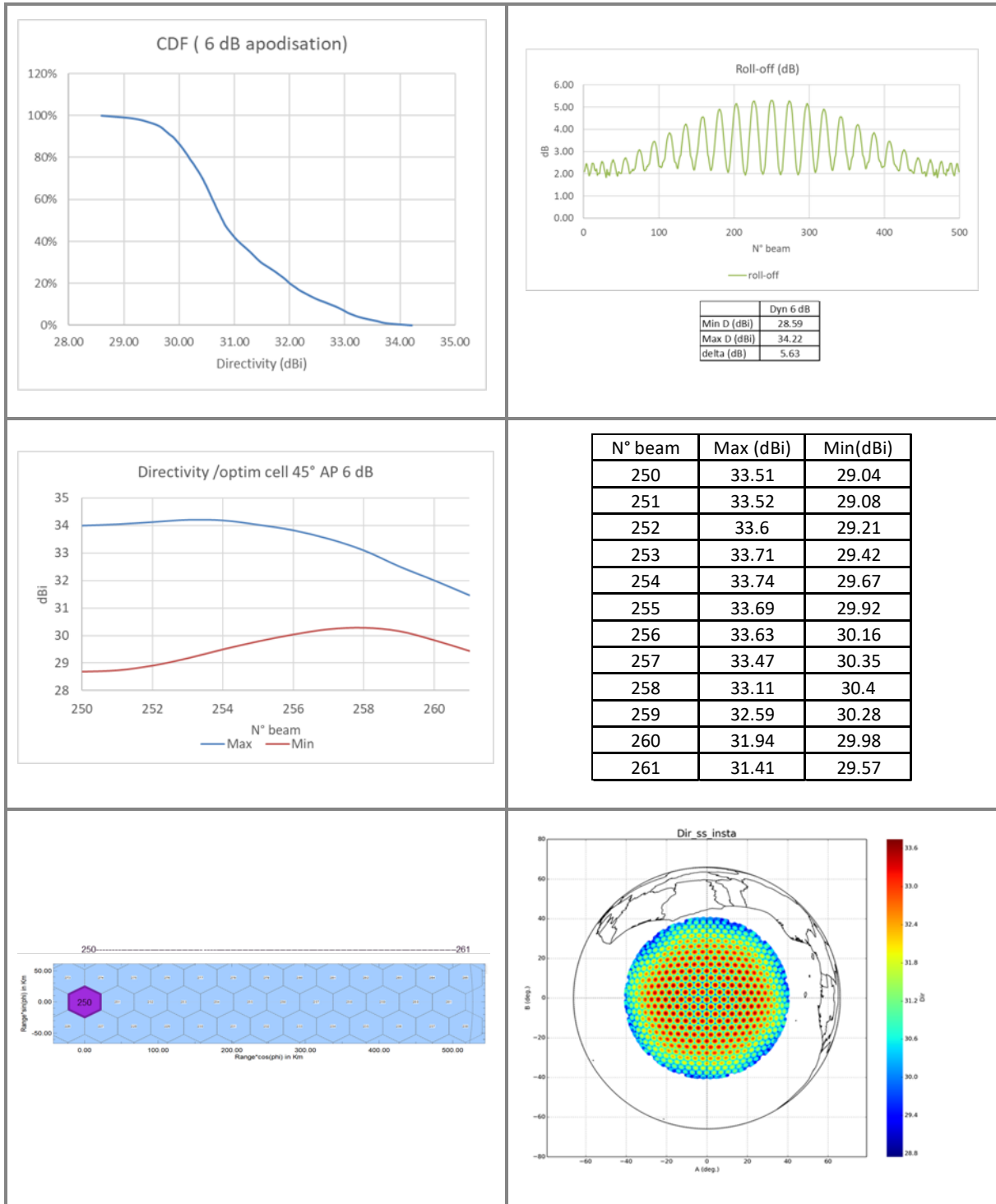
PRACH Link Budget		Unit	Average Case (E1 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	C	C
	PRB bandwidth	kHz	360.00	360.00
	Number Max of PRBs	-	273	273
	Number of used PRBs	-	1	1
	Occupied Channel Bandwidth	MHz	0.36	0.36
	Total Channel Bandwidth	MHz	98.28	98.28
	Uplink Frequency	GHz	3.90	3.90
	Nb spots	-	X	X
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	3.00	3.00
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	7.31	2.61
LOSSES	Free space propagation	dB	162.49	159.83
	Atmospheric loss	dB	1.55	0.04
	Shadowing margins	dB	9.00	8.00
INTERMEDIATE RESULTS	C/No per PRB	dBHz	50.9	51.3
	C/No for all PRB	dBHz	50.9	51.3
	C/N	dB	-4.7	-4.2
	C/Io	dBHz	73.56	73.56
	C/I	dB	18.00	18.00
	C/(No+Io) per PRB	dBHz	50.85	51.31
	C/(No+Io) for all PRB	dBHz	50.85	51.31
	Overall C/(No+Io) (including Glob	dBHz	50.85	51.31
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	Obtained C/N	dB	-4.71	-4.25
	UE Rate	Mbit/s	0.078	0.078

FIGURE 9-73 UPLINK BUDGET WORST CASE (UE_1) 8 AND 9 DB ATTENUATION

9.5 Q/V BAND PAYLOAD

9.5.1 Antenna performances

9.5.1.1 Tx antenna



<p>Tx antenna</p> <p>Beamforming technique :</p> <ul style="list-style-type: none"> - 6 dB amplitude/phase <p>Optimisation goal :</p> <ul style="list-style-type: none"> -Maximization performances edge of cell 	<p>499 cells, coverage Elmin= 45°</p>
---	---------------------------------------

FIGURE 9-74 PERFORMANCES DIRECTIVITY BEAM TX

9.5.1.2 Rx antenna

	<table border="1" style="margin-top: 10px;"> <tr><td>Max D (dBi)</td><td>33.74</td></tr> <tr><td>Min D (dBi)</td><td>28.71</td></tr> <tr><td>delta (dB)</td><td>5.02</td></tr> </table>	Max D (dBi)	33.74	Min D (dBi)	28.71	delta (dB)	5.02																																	
Max D (dBi)	33.74																																							
Min D (dBi)	28.71																																							
delta (dB)	5.02																																							
	<table border="1"> <thead> <tr> <th>N° beam</th> <th>Max (dBi)</th> <th>Min(dBi)</th> </tr> </thead> <tbody> <tr><td>250</td><td>33.51</td><td>29.04</td></tr> <tr><td>251</td><td>33.52</td><td>29.08</td></tr> <tr><td>252</td><td>33.6</td><td>29.21</td></tr> <tr><td>253</td><td>33.71</td><td>29.42</td></tr> <tr><td>254</td><td>33.74</td><td>29.67</td></tr> <tr><td>255</td><td>33.69</td><td>29.92</td></tr> <tr><td>256</td><td>33.63</td><td>30.16</td></tr> <tr><td>257</td><td>33.47</td><td>30.35</td></tr> <tr><td>258</td><td>33.11</td><td>30.4</td></tr> <tr><td>259</td><td>32.59</td><td>30.28</td></tr> <tr><td>260</td><td>31.94</td><td>29.98</td></tr> <tr><td>261</td><td>31.41</td><td>29.57</td></tr> </tbody> </table>	N° beam	Max (dBi)	Min(dBi)	250	33.51	29.04	251	33.52	29.08	252	33.6	29.21	253	33.71	29.42	254	33.74	29.67	255	33.69	29.92	256	33.63	30.16	257	33.47	30.35	258	33.11	30.4	259	32.59	30.28	260	31.94	29.98	261	31.41	29.57
N° beam	Max (dBi)	Min(dBi)																																						
250	33.51	29.04																																						
251	33.52	29.08																																						
252	33.6	29.21																																						
253	33.71	29.42																																						
254	33.74	29.67																																						
255	33.69	29.92																																						
256	33.63	30.16																																						
257	33.47	30.35																																						
258	33.11	30.4																																						
259	32.59	30.28																																						
260	31.94	29.98																																						
261	31.41	29.57																																						
<p>Rx antenna</p>	<p>499 cells, coverage Elmin= 45°</p>																																							

<p>Beamforming technique :</p> <p>- 12 dB amplitude/phase</p> <p>Optimisation goal :</p> <p>-Maximization performances edge of cell</p>	
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FIGURE 9-75 PERFORMANCES DIRECTIVITY BEAM RX

9.5.2 Downlink Q/V band link budget

9.5.2.1 Power hypothesis

Max power of 53 W RF power per beam 4 active beams

DRA 512 ELEMENTS 4 beam		
nb elements		512
EIRP density	dBW/MHz	18.2
nb beam total		499
nb de beam actif		4
frequency band	MHz	400
PIRE /beam	dBW	44.2
PIRE Total	dBW	50.2
GAIN		33.0
nb elem		512
Total power	dBW	17.2
power per /ELEM	DBW	-9.85
averaging		1
P elem RF	W	0.104
RF total power		52.99
SSPA efficiency	%	20
Power consumption	W	294.41
Disssipated power	W	241.42

FIGURE 9-76 POWER HYPHESIS (53 W PER DRA)

The power could be adjusted for a given number of beam and its distribution.

The hypothesis taken for the link budget is given in the table of Figure 9-77.

9.5.2.2 Downlink link budget Nominal case

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	Q-V	Q-V
	PRB bandwidth	khz	1440.00	1440.00
	Number Max of PRBs	-	264	264
	Number of used PRBs	-	264	264
	Occupied Channel Bandwidth	MHz	380.16	380.16
	Total Channel Bandwidth	MHz	380.16	380.16
	Downlink Frequency	GHz	40.00	40.00
	Nb active spots during 1ms timeslot	-	4	4
Nb spots total	-	499	499	
SATELLITE - TX	EIRP density	dBW/MHz	18.20	18.20
	EIRP	dBW	44.00	44.00
	EIRP per PRB	dBW	19.78	19.78
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	30.26	31.76
	Figure of Merit: G/T	dB/K	2.31	3.81
	Polarisation mismatch loss	dB	0.00	0.00
	Effective G/T under satellite coverage	dB/K	2.31	3.81
LOSSES	Free space propagation	dB	182.71	180.05
	Propagation losses computation	-	Computation [RD1] & [RD2]	
	UE location	-	Toulouse	
	Weather condition	-	Clear Sky	
	Atmospheric loss	dB	2.26	0.63
Shadowing margins	dB	0.00	0.00	
GLOBAL LOSSES	Calibration mismatch loss	dB	0.00	0.00
	System margin	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	264	264
RESULTS	Obtained C/N	dB	3.71	8.49
	Spectral Efficiency	bits/s/Hz	0.8424	1.3901
	UE Rate	Mbits/s	320.24	528.48

FIGURE 9-77 DOWNLINK BUDGET **NOMINAL CASE** (4 BEAMS CENTER BEAM)

DOWNLINK		Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	Q-V	Q-V
	PRB bandwidth	khz	1440.00	1440.00
	Number Max of PRBs	-	264	264
	Number of used PRBs	-	264	264
	Occupied Channel Bandwidth	MHz	380.16	380.16
	Total Channel Bandwidth	MHz	380.16	380.16
	Downlink Frequency	GHz	40.00	40.00
	Nb active spots during 1ms timeslot	-	4	4
	Nb spots total	-	499	499
SATELLITE - TX	EIRP density	dBW/MHz	24.22	24.22
	EIRP	dBW	50.02	50.02
	EIRP per PRB	dBW	25.80	25.80
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	30.26	31.76
	Figure of Merit: G/T	dB/K	2.31	3.81
	Polarisation mismatch loss	dB	0.00	0.00
	Effective G/T under satellite coverage	dB/K	2.31	3.81
LOSSES	Free space propagation	dB	182.71	180.05
	Propagation losses computation	-	Computation (RD1) & (RD2)	
	UE location	-	Toulouse	
	Weather condition	-	Clear Sky	
	Atmospheric loss	dB	2.26	0.63
	Shadowing margins	dB	0.00	0.00
GLOBAL LOSSES	Calibration mismatch loss	dB	0.00	0.00
	System margin	dB	0.00	0.00
RESULTS CONFIGURATION S	Number of used PRBs	-	264	264
RESULTS	Obtained C/N	dB	8.65	11.85
	Spectral Efficiency	bits/s/Hz	1.3901	1.5696
	UE Rate	Mbit/s	528.48	596.68

FIGURE 9-78 DOWNLINK LINK BUDGET **BEST CASE** ALL POWER IN ONE BEAM

DOWNLINK		Unit	Average Case (Ei 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	Q-V	Q-V
	PRB bandwidth	kHz	1440.00	1440.00
	Number Max of PRBs	-	264	264
	Number of used PRBs	-	150	264
	Occupied Channel Bandwidth	MHz	216	380.16
	Total Channel Bandwidth	MHz	380.16	380.16
	Downlink Frequency	GHz	40.00	40.00
	Nb active spots during 1ms timeslot	-	4	4
	Nb spots total	-	499	499
SATELLITE - TX	EIRP density	dBW/MHz	18.20	18.20
	EIRP	dBW	44.00	44.00
	EIRP per PRB	dBW	22.24	19.78
	Satellite altitude	km	600	600
UE - RX	Elevation angle to satellite (seen from UE)	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Receive Antenna Gain	dBi	30.26	31.76
	Figure of Merit: G/T	dB/K	2.31	3.81
	Polarisation mismatch loss	dB	0.00	0.00
	Effective G/T under satellite coverage	dB/K	2.31	3.81
LOSSES	Free space propagation	dB	182.71	180.05
	Propagation losses computation	-	Computation [RD1] & [RD2]	
	UE location	-	Toulouse	
	Weather condition	-	Clear Sky	
	Atmospheric loss	dB	2.26	0.63
	Shadowing margins	dB	10.00	10.00
GLOBAL LOSSES	Calibration mismatch loss	dB	0.00	0.00
	System margin	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of used PRBs	-	150	264
RESULTS	Obtained C/N	dB	-3.49	-0.24
	Spectral Efficiency	bits/s/Hz	0.2514	0.4933
	UE Rate	Mbits/s	54.30	187.54

FIGURE 9-79 DOWNLINK LINK BUDGET WORST CASE 10 DB ATTENUATION

9.5.3 Uplink A/V band link budget

9.5.3.1 RX front end hypothesis

SATELLITE		
FDD Mod		
Front-end Rx		
Losses	L =	2 dB
LNA	NF =	3.5 dB
Tant	Tant =	240 K
G/T	=G+L-29.9	dB/K
G/T	=D-29.9	dB/K

FIGURE 9-80 SATELLITE RX FRONT END HYPOTHESIS

9.5.3.2 Uplink budget (Q band)

The exemple of link budget has been given for the uplink in the table of FIGURE 9-81.

<input type="checkbox"/> PRACH Link Budget	UPLINK	Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	Q-V	Q-V
	PRB bandwidth	kHz	1440.00	1440.00
	Number Max of PRBs	-	264	264
	Number of used PRBs	-	1	1
	Occupied Channel Bandwidth	MHz	1.44	1.44
	Total Channel Bandwidth	MHz	380.16	380.16
	Uplink Frequency	GHz	50.00	50.00
	Nb spots	-	4	4
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	0.00	0.00
	Antenna Transmit Power	dBW	4.00	4.00
	Transmit Gain	dBi	29.76	31.26
	EIRP	dBW	33.76	35.26
	EIRP per PRB	dBW	33.76	35.26
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	1.50	3.60
LOSSES	Free space propagation	dB	184.65	181.99
	Propagation losses computation	-	Computation [RD1] & [RD2]	
	UE location	-	Toulouse	
	Weather condition	-	Clear Sky	
	Atmospheric loss	dB	3.71	2.07
	Shadowing margins	dB	0.00	0.00
	Body loss	dB	0.00	0.00
	Scan loss	dB	0.00	0.00
	Additional loss	dB	0.00	0.00
GLOBAL LOSSES	Calibration mismatch loss	dB	0.00	0.00
	System margin	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	Obtained C/N	dB	10.95	13.34
	Spectral Efficiency	bits/s/Hz	2.3133	2.7140
	UE Rate	Mbit/s	3.331	3.908

FIGURE 9-81 UPLINK BUDGET NOMINAL CASE (1 PRB)

<input type="checkbox"/> PRACH Link Budget		UPLINK	Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	Q-V	Q-V	Q-V
	PRB bandwidth	kHz	1440.00	1440.00	1440.00
	Number Max of PRBs	-	264	264	264
	Number of used PRBs	-	54	64	64
	Occupied Channel Bandwidth	MHz	77.76	92.16	92.16
	Total Channel Bandwidth	MHz	380.16	380.16	380.16
	Uplink Frequency	GHz	50.00	50.00	50.00
	Nb spots	-	4	4	4
UE - TX	Elevation angle to satellite	°	45.00	90.00	90.00
	Slant Range	km	814.80	600.00	600.00
	Antenna view angle	°	40.26	0.00	0.00
	Polarisation mismatch loss	dB	0.00	0.00	0.00
	Antenna Transmit Power	dBW	4.00	4.00	4.00
	Transmit Gain	dBi	29.76	31.26	31.26
	EIRP	dBW	33.76	35.26	35.26
	EIRP per PRB	dBW	16.43	17.20	17.20
SATELLITE - RX	Satellite altitude	km	600	600	600
	Satellite figure of merit (G/T)	dB/K	1.50	3.60	3.60
LOSSES	Free space propagation	dB	184.65	181.99	181.99
	Propagation losses computation	-	Computation [RD1] & [RD2]		
	UE location	-	Toulouse		
	Weather condition	-	Clear Sky		
	Atmospheric loss	dB	3.71	2.07	2.07
	Shadowing margins	dB	0.00	0.00	0.00
	Body loss	dB	0.00	0.00	0.00
	Scan loss	dB	0.00	0.00	0.00
	Additional loss	dB	0.00	0.00	0.00
GLOBAL LOSSES	Calibration mismatch loss	dB	0.00	0.00	0.00
	System margin	dB	0.00	0.00	0.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	54	64	64
RESULTS	Obtained C/N	dB	-3.49	3.36	3.36
	Spectral Efficiency	bits/s/Hz	0.3393	1.0582	1.0582
	UE Rate	Mbit/s	26.384	97.526	97.526

FIGURE 9-82 UPLINK BUDGET BEST CASE (MAXIMISATION OF UPLINK)

<input type="checkbox"/> PRACH Link Budget	UPLINK	Unit	Average Case (EI 45°)	Best Case (NADIR)
GLOBAL	Band Name	-	Q-V	Q-V
	PRB bandwidth	kHz	1440.00	1440.00
	Number Max of PRBs	-	264	264
	Number of used PRBs	-	8	50
	Occupied Channel Bandwidth	MHz	11.52	72
	Total Channel Bandwidth	MHz	380.16	380.16
	Uplink Frequency	GHz	50.00	50.00
	Nb spots	-	4	4
UE - TX	Elevation angle to satellite	°	45.00	90.00
	Slant Range	km	814.80	600.00
	Antenna view angle	°	40.26	0.00
	Polarisation mismatch loss	dB	0.00	0.00
	Antenna Transmit Power	dBW	4.00	4.00
	Transmit Gain	dBi	29.76	31.26
	EIRP	dBW	33.76	35.26
	EIRP per PRB	dBW	24.72	18.27
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	dB/K	1.50	3.60
LOSSES	Free space propagation	dB	184.65	181.99
	Propagation losses computation	-	Computation [RD1] & [RD2]	
	UE location	-	Toulouse	
	Weather condition	-	Clear Sky	
	Atmospheric loss	dB	3.71	2.07
	Shadowing margins	dB	10.00	10.00
	Body loss	dB	0.00	0.00
	Scan loss	dB	0.00	0.00
	Additional loss	dB	0.00	0.00
GLOBAL LOSSES	Calibration mismatch loss	dB	0.00	0.00
	System margin	dB	0.00	0.00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	8	50
RESULTS	Obtained C/N	dB	-5.17	-5.22
	Spectral Efficiency	bits/s/Hz	0.2110	0.2110
	UE Rate	Mbit/s	2.430	15.189

FIGURE 9-83 UPLINK BUDGET WORST CASE (10 DB ATTENUATION)