6GNTN

D3.3 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.
Keywords	HAPS, GEO, LEO, VLEO, constellations, software defined payloads.

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DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

DATA: Data sets, microdata, etc.

DMP: Data management plan

ETHICS: Deliverables related to ethics issues.

SECURITY: Deliverables related to security issues

OTHER: Software, technical diagram, algorithms, models, etc.

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, and HAPS.

In this initial version of the document, the hardware solutions for the payload are outlined with the objective of providing global coverage. This definition considers the multi-layered 3D architecture, which is still under study. The payload design is an iterative process encompassing all tasks in Work Package (WP) 3, involving various parameters from constellation definition to terminal characterization. The design of payload solutions is proposed based on the trade-offs on LEO constellations and HAPS.

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 preliminary performance evaluations.

These solutions are mainly:

- Satellite payloads for LEO constellations in C band and Q/V bands.
- HAPS: 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 preliminary 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 (LEO constellations, HAPS, RF interlinks) 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.

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ABBREVIATIONS

3GPP	3rd Generation Partnership Project
AFSR	Array fed shaped reflector Antenna
AI	Artificial Intelligence
ASIC	Application-specific integrated circuit
BH	Beam Hopping
BS	Base station
BVLoS	Beyond Visual Line of Sight
BW	Bandwidth
C2	Command and Control
C2CSP	C2 Link communication service provider
CMOS	Complementary metal-oxide semiconductor
CoW	Cell on Wheels
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

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GSO	Geostationary orbit
HAPs	High Altitude Platform (station)
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
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
PPDR	Public Protection and Disaster Relief

PTT	Push-To-Talk
QoE	Quality of Experience
QoS	Quality of Service*
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
SON	Self-organizing networks
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:

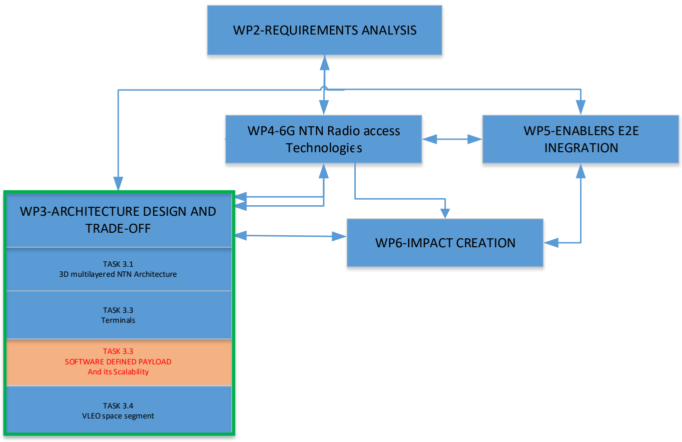

FIGURE 1-1: 6G-NTN PERT CHART – FOCUS ON TASK 3.3

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).

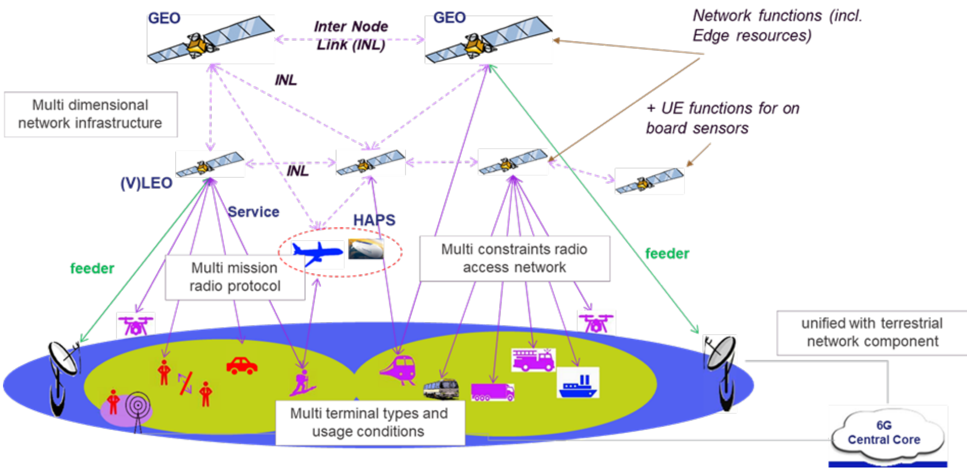

FIGURE 1-2 6G-NTN 3D NETWORK CONCEPT. [1]

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 organized on five main chapters, plus this introduction, that synthetize the work carried out during the first part of this research activity.

Chapter 2 defines the context of the activity, discusses the state of art, clarifies the challenges, and gives the methodology applied during this study. Specifically, the two system architectures proposed in task 3.1 are revisited and supplemented by the definitions that pertain to the aspects covered in this document. This Chapter provides also system-level definitions, addresses the functionalities of each node type, i.e., GEO, LEO C, LEO Q/V, and HAPS, and presents the methodology and the philosophy applied in this study.

Chapter 3 focuses on defining the system, considering inputs such as terminals and gateways characteristics and identifies the payloads to be developed (with scalability in mind).

Chapter 4 describes the payloads associated with each node of the architecture and delves into the internode link definitions. This chapter addresses also the dimensioning aspect of the main challenging payloads for deterministic nodes—specifically, satellites for LEO constellations in the C-band and Q/V band—and provides performance analysis through link budgets. Also, it explores the new concept of flexible nodes, including an investigation into a possible HAPS design and proposes a possible dimensioning. Additionally, the ISL and INL link dimensioning is performed, offering solutions in terms of payload requirements.

Chapter 5 discusses the concept of scalability based on the previously defined parameters.

Chapter 6, provides the conclusions outlining the next steps and detailing the points to be addressed and consolidated in the second 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:

<u>Starlink direct to device [29]</u>: 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.

<u>Space mobile AST[30]</u>: 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.

<u>Lynk Global [31]:</u> 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.

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. 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.

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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 possibility ....etc)

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 THE APPLIED METHODOLOGY

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

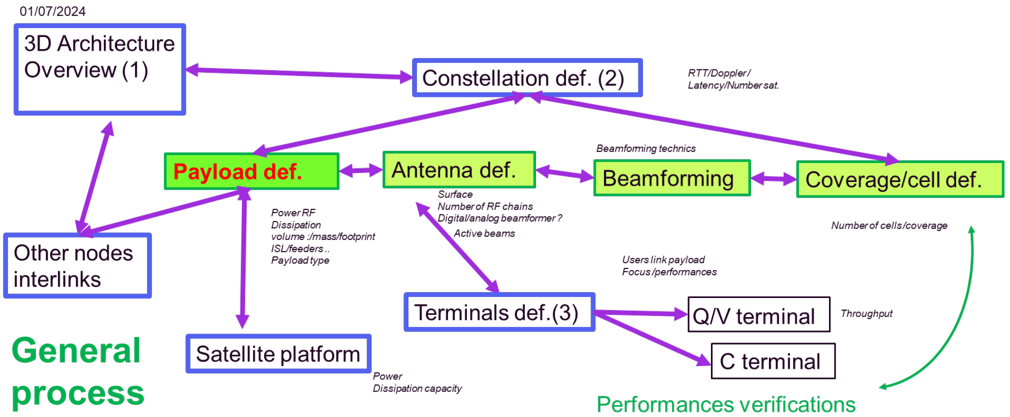


FIGURE 2-1 ILLUSTRATION OF THE METHODOLOGY (APPLICABLE TO LEO CONSTELLATION

(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 THE 6G NTN SYSTEM

3.1 DESCRIPTION OF THE 6G NTN SYSTEM

3.1.1 Definition of the system

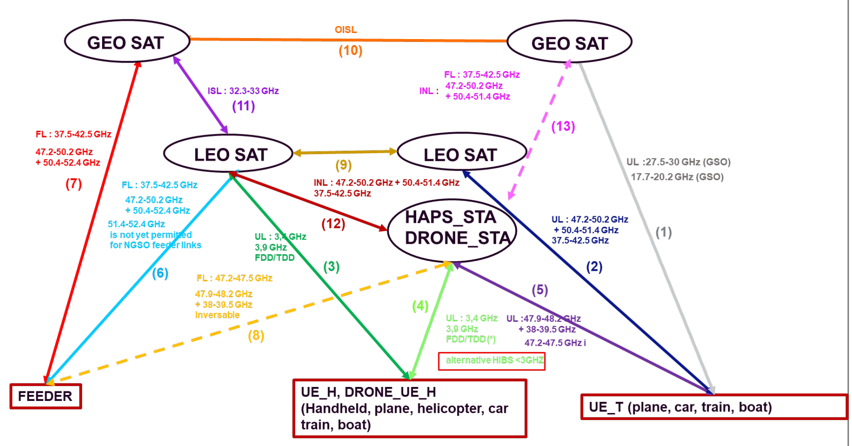
The definition of the 6G NTN system is based on investigations already envisaged and initiated in preliminary studies [2]-[15]. This gives us an overall vision of the objectives in broad outline as recalled in numerous articles [32]-[35]. To build this system, it is also necessary to associate elements 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 foreseen system and 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.



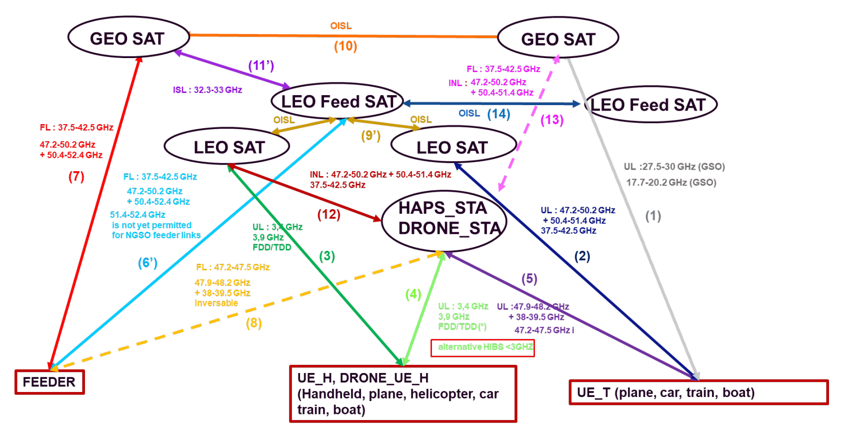
FL : feeder link
ISL :inter satellite link
OISL : optical inter satellite link
UL : user link
INL : internode link

_T : directive terminal type
_H : handheld type
(omni/wide angle)

(*) risk of non availability of C band
For HAPS

1 GEO constellation
2 LEO constellations :
1 constellation LEO in C band
1 constellation LEO in QV band

Architecture system N°1	Architecture system N°1



FL : feeder link
ISL :inter satellite link
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_T : directive terminal type
_H : handheld type
(omni/wide angle)

(*) risk of non availability of C band
For HAPS

1 GEO constellation
4 LEO constellations :
1 constellation LEO in C band
1 constellation LEO in QV band
1 constellation LEO feeder in C band
1 constellation LEO feeder in Q/V band

Architecture system N°2	Architecture system N°2

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.

<u>Difference between architecture 1 & 2:</u>

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.

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 SAT for access, and LEO Link for network functions.

a. Ground-node links:

i. GEO node

Same as in architecture 1

ii. LEO Link node

Same as in architecture 1 for LEO node

iii. HAPS/Drone node

Same as is architecture 1

b. Inter-node links:

iv. GEO-GEO alternatives to OISL

Same as in architecture 1

v. GEO-LEO Link, LEO Link-LEO Link and LEO Link-LEO SAT

Same as in architecture 1 for GEO-LEO and LEO-LEO alternatives to OISL

vi. GEO/LEO SAT-HAPS

Same as in architecture 1

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 front-ends definition are given in FIGURE 3-2, the different type of terminals could integrate several front-ends. The first table gives the lists of front-ends and his identification. The front-ends are designated as:

(Frequency band)_(Type)_(N°) with :

- Frequency band: C, Q/V, HIBS, cell (frequency <6GHz)
- Type: NTN or TN
- N°: 1,2,3: is the different type of terminal performances.

HAPS are High Altitude Platform System, i.e., radio stations located on a platform flying at about 20 km altitude. HIBS are defined as “HAPS as IMT Base Stations”, IMT being the ITU name for mobile networks.

The terminal could be more or less complex and could integrate several front-ends in addition of the others front ends for the connection to the TN as mentioned in the table of FIGURE 3-2.

The terminals are defined in the table below:

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 professionnal	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		

FIGURE 3-2 TABLE RESUME OF THE TERMINALS DEFINITION

In this document, this identifcation of the different type of terminals (FIGURE 3-2) and the performances targets given in FIGURE 8-1 (ANNEXES) will serve as the basis for estimating the performance of the constellation dedicated to serving user equipment (UE) with this type of terminals.

1. Note that the terminals defined with “ _STA” designate a HAPS that act as a base station.

The terminals definition and more particularly the C_Band and Q/V band terminals study is carried out in document task 3.2 [26].

Remarks:

It is straitforward to establish all the links with the different terminals and handheld, and an average case will be taken to establish the preliminary link budget. For instance in C-band:

UE radiating element: a 0.67 λ radiating element spacing (max-min)

Linear Polarization: -3 dB depolarization losses

NF=9dB

Power: 23 dBm

According to table on terminal it will depend of the terminal:

For the Handled (consumer and professional): 0 to -3 dBi (best case and worst case)

The diagram is supposed to be half hemispheric, And sensitivity analysis will be performed to estimate according to the terminal type the throughput reached.

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 4.6.4.1.

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 the 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.

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 multibeams 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).

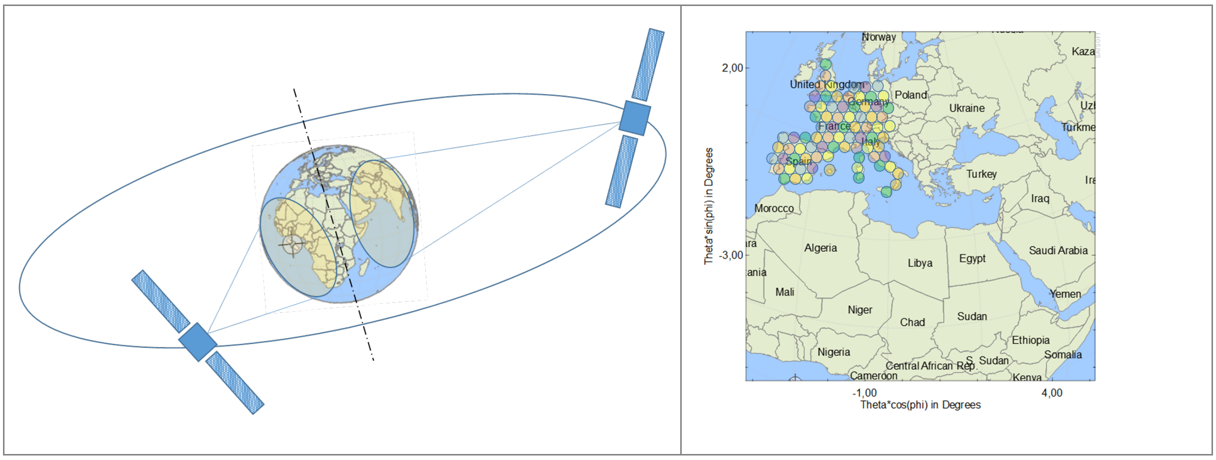


FIGURE 4-1 LEO COVERAGE USER LINK (MULTISPOTS)

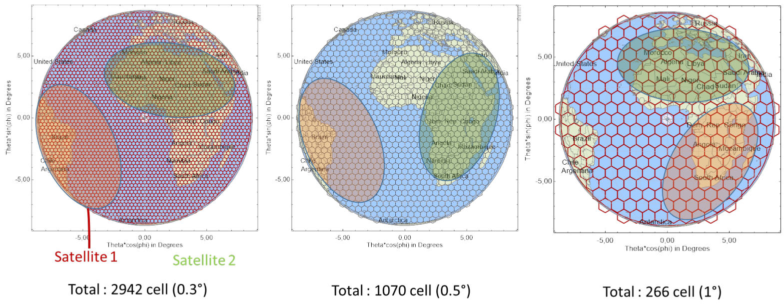


FIGURE 4-2 AREA OF COVERAGE OF A GEO SATELLITE

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.

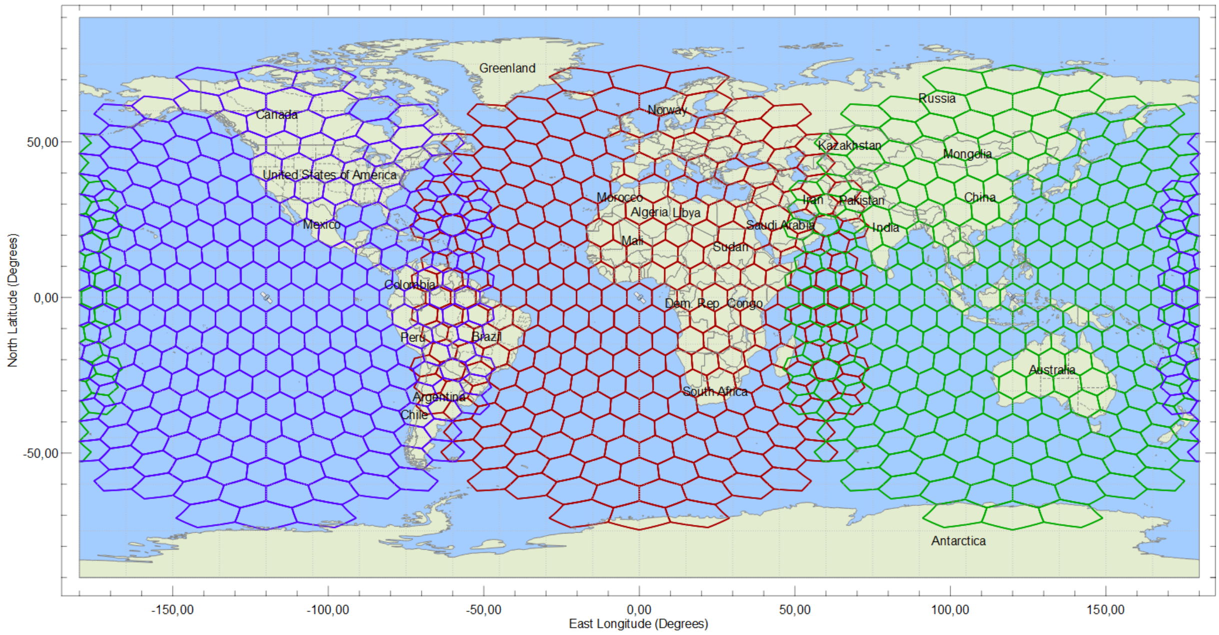


FIGURE 4-3 EXAMPLE: EARTH COVERAGE WITH 3 SATELLITES,
SAT1 (BLUE), SAT2 (RED), AND SAT3 (GREEN), WITH CELLS OF 900 KM

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 estasblished.

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 alrey 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.

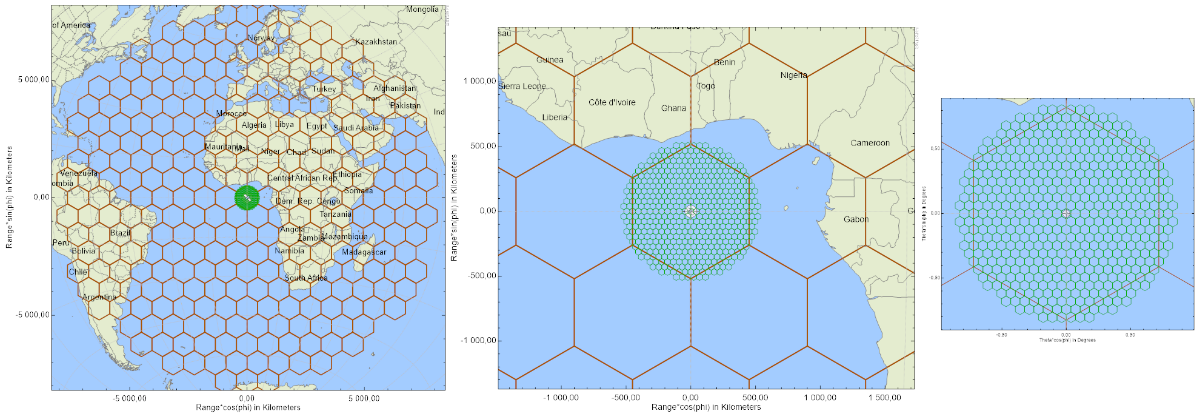


FIGURE 4-4 EXEMPLE COVERAGE COMPATIBILITY
GEO COVERAGE WITH CELL = 900 KM, NB=284 (RED) AND
LEO COVERAGE WITH CELL=45KM, NB=499, (GREEN)

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 ugradated 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.

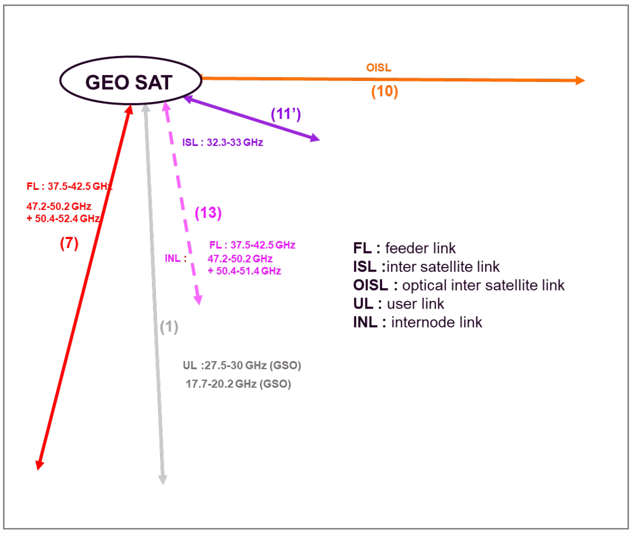


FIGURE 4-5 GEO CONSTELLATION AND THE LINKS

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 multisport 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 cassegrenian 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

4.2.1 Mission objectives

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 rasonable 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]).

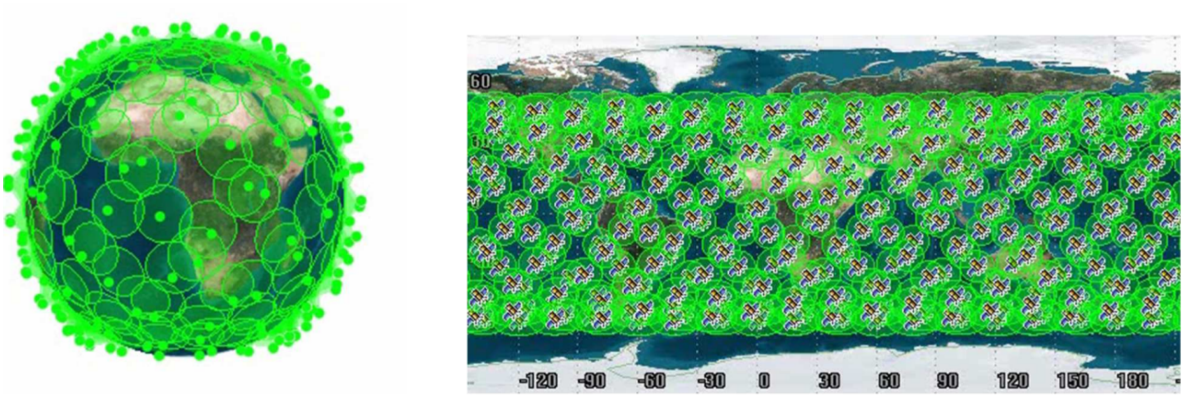


FIGURE 4-6 EXEMPLE CONSTELLATION

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:

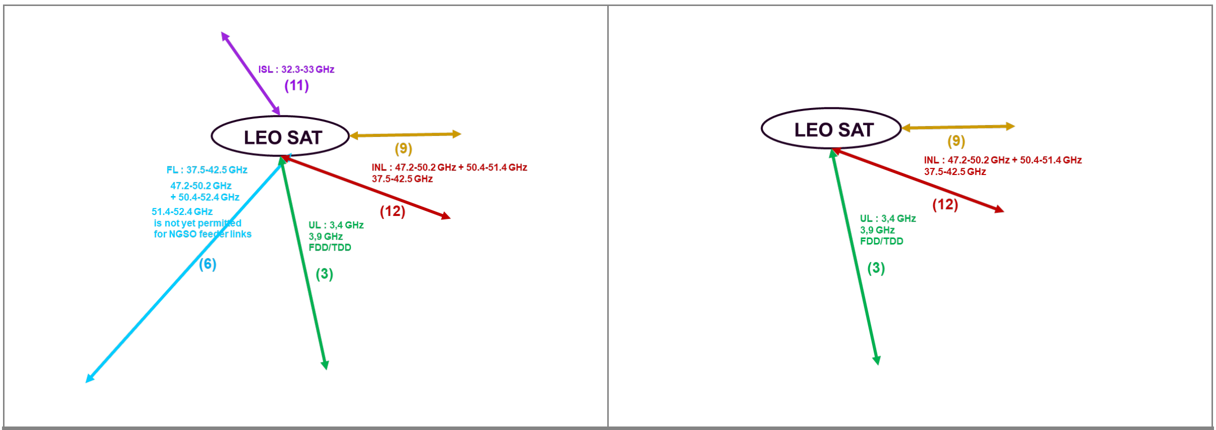
- Optimize the RTT (Round Trip Time): impact on altitude / coverage ELmin (minimum elevation)
- Number of satellites: impact on cost /size/ power consumption/dissipation
- Full coverage: impact on coverage size per sat / number of cells: constellation size/power
- Flexibility in capacity enhancement 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:
  - Define an elevation (EL) per coverage and define antenna size/cell definition
  - Evaluate each satellite capacity and then dimension the required link capacity and then envisage a first level of power consumption and dissipation capacity.
  - 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 show the links that the satellite should ensure in the two case of the 2 proposed architectures .



Architecture 1	Architecture 2

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.

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 redunded 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**
	User Satellite	User Satellite
User antenna C band	1	1
ISL to GEO	1	0
ISL to HAPS	1	1
OISL	4	2
Feeder	2	0

FIGURE 4-8 NUMBER OF ANTENNA ACCORDING TO THE ARCHITECTURE

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:

		Used Frequency		Channel Bandwidth		PRB						PRACH
	ID	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	Nummber 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 NUMEROLOLGY 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.

<u>Coverage definition:</u>

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.

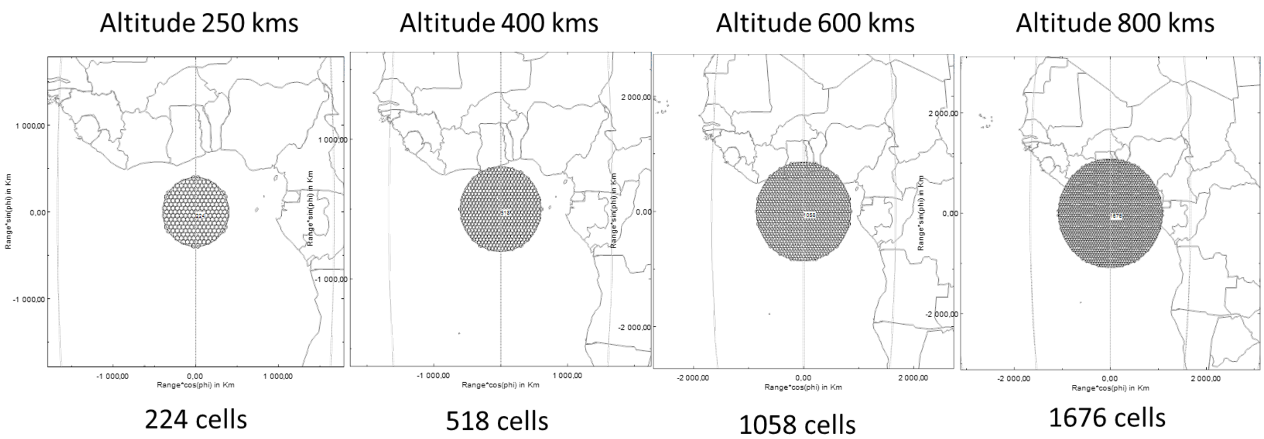


FIGURE 4-10 EXEMPLE OF COVERAGE FOR DIFFERENT ALTITUDE WITH ELMIN OF 30°, CELL SIZE OF 50 KM

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

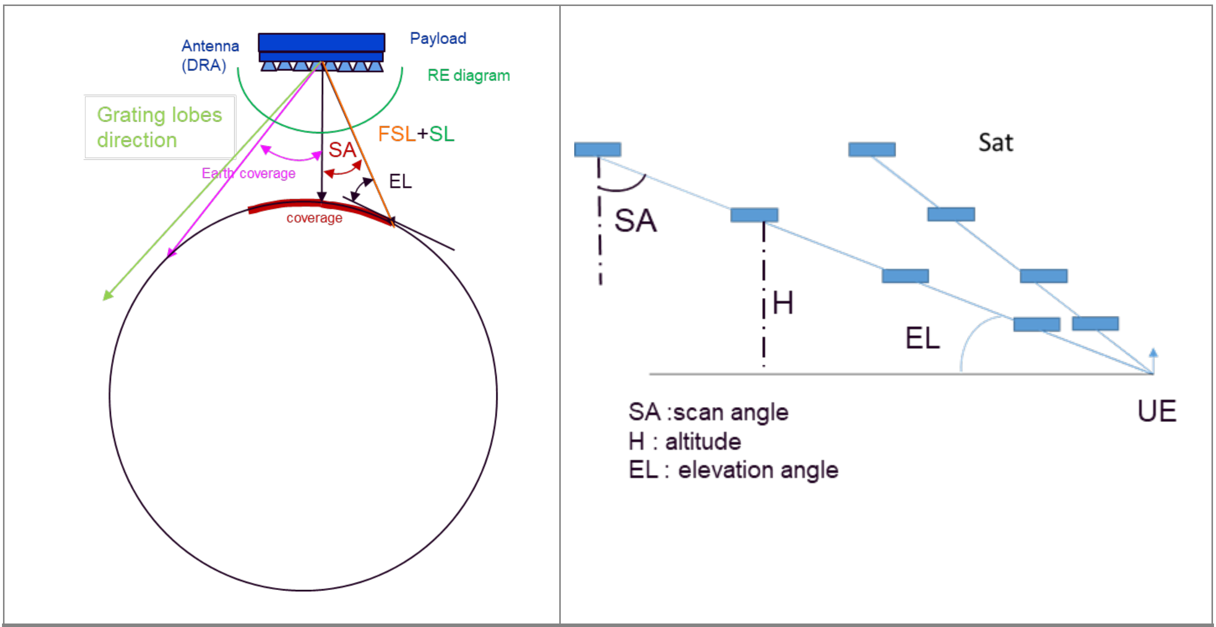
The main advantage of the DBFN is the ability to generate beam theoretically without any limit. In practice, the constraint on the processing capacity will nevertheless limit this number. The ABFN complexity limit the number of beam and do not offer a full flexibility as with the DBFN.

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 8-2)

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.



Parameters for LEO constellation Dimensioning

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.

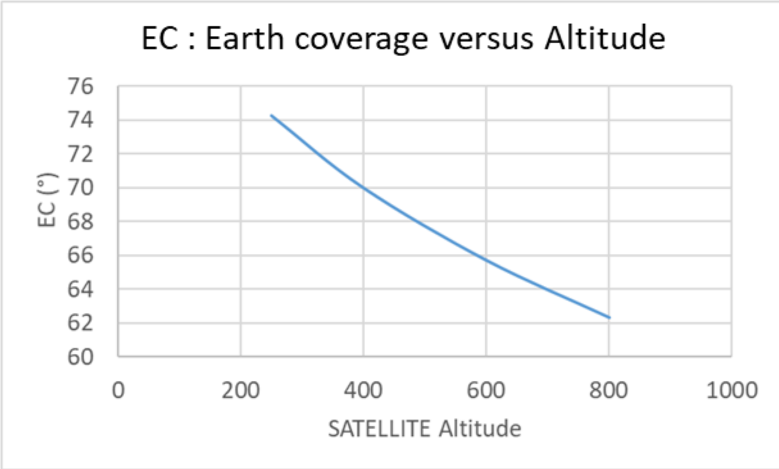


FIGURE 4-12 EARTH COVERAGE ANGLE VERSUS SATELLITE ALTITUDE

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.

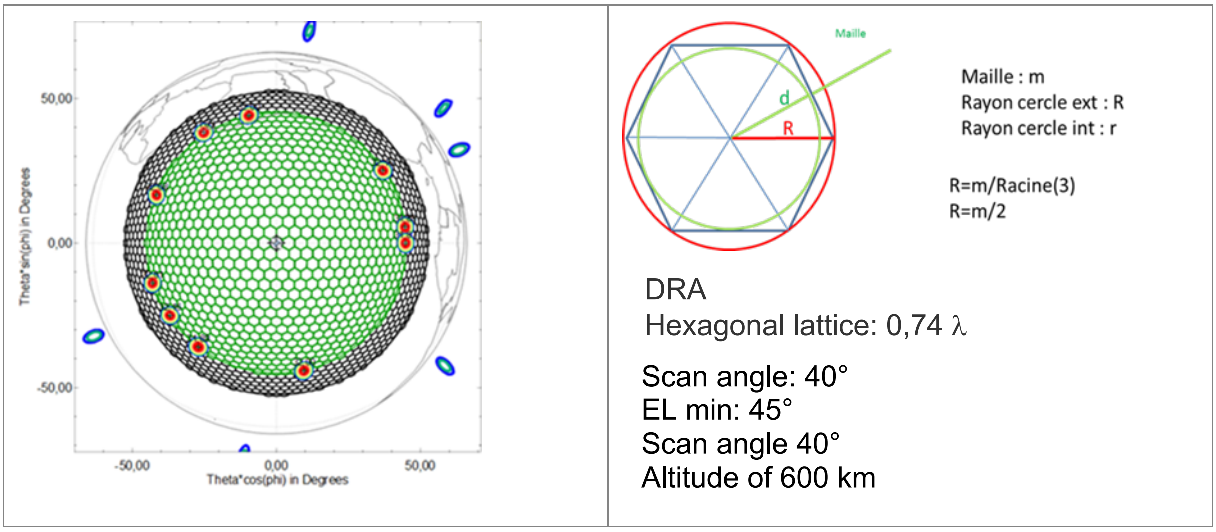


FIGURE 4-13 ILLUSTRATION OF SCAN ANGLE DUE TO GRATING LOBES

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 be not favorable in the diagonal direction.

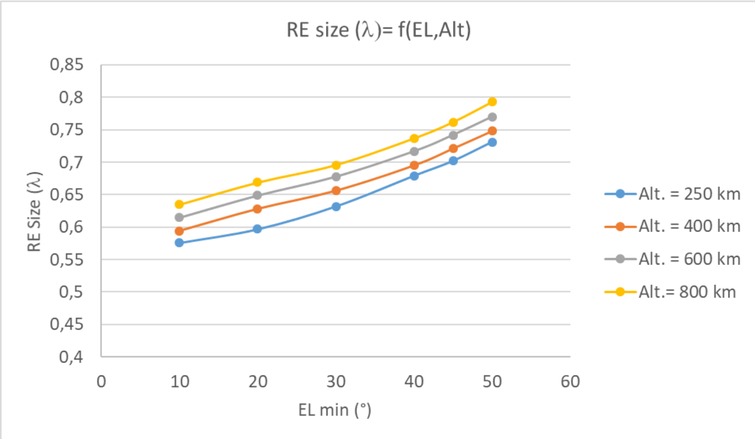


FIGURE 4-14 RE SIZE VERSUS ELMIN AND ALTITUDE TO AVOID GRATING LOBES

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.

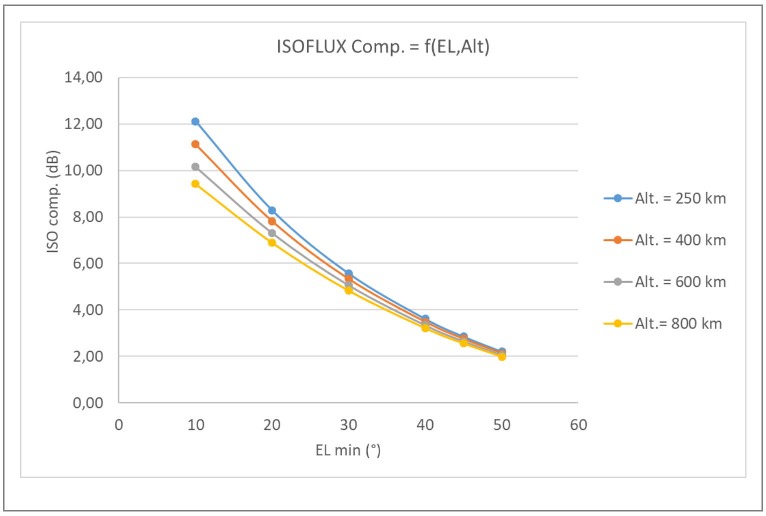


FIGURE 4-15 FREESPACE LOSSES (DELTA NADIR-EDGE)

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).

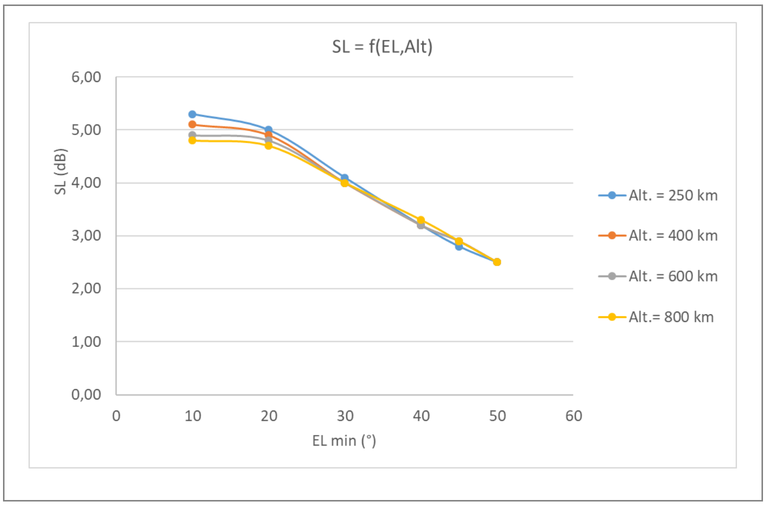


FIGURE 4-16 SCAN LOSSES (DELTA NADIR-EDGE)

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

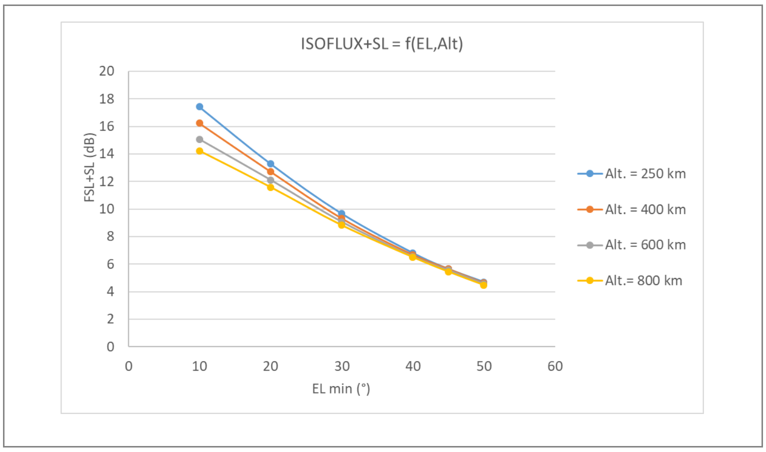


FIGURE 4-17 TOTAL FSL+SC

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.

<u>Performances in directivity for two antenna apertures:</u> 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.

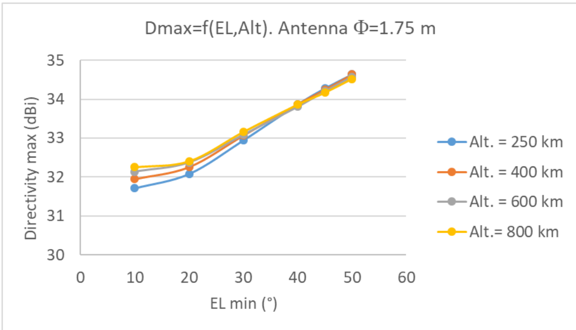
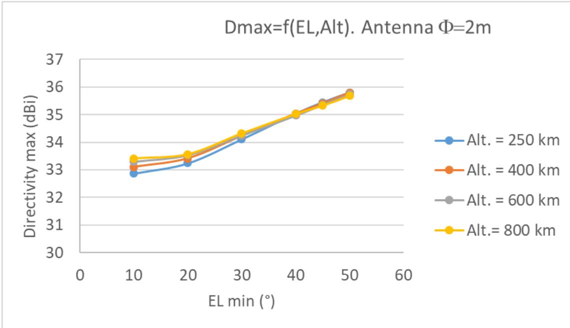
<table>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>ANTENNA DIAMETER 1.75 m</td>
<td>ANTENNA DIAMETER 2. m</td>
</tr>
</table>

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.

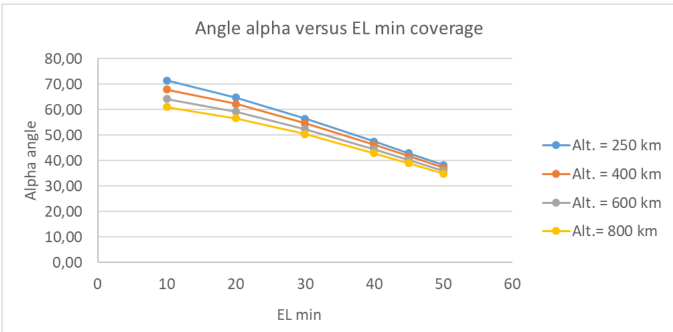
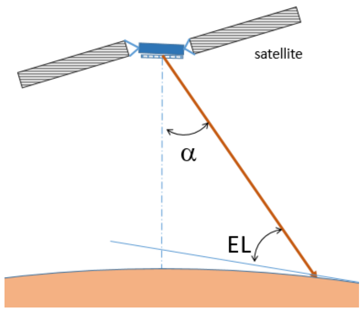
<table>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Scan angle (α) versus Altitude and minimum Elevation angle (EL_{min})</td>
<td>Angle definition</td>
</tr>
</table>

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.

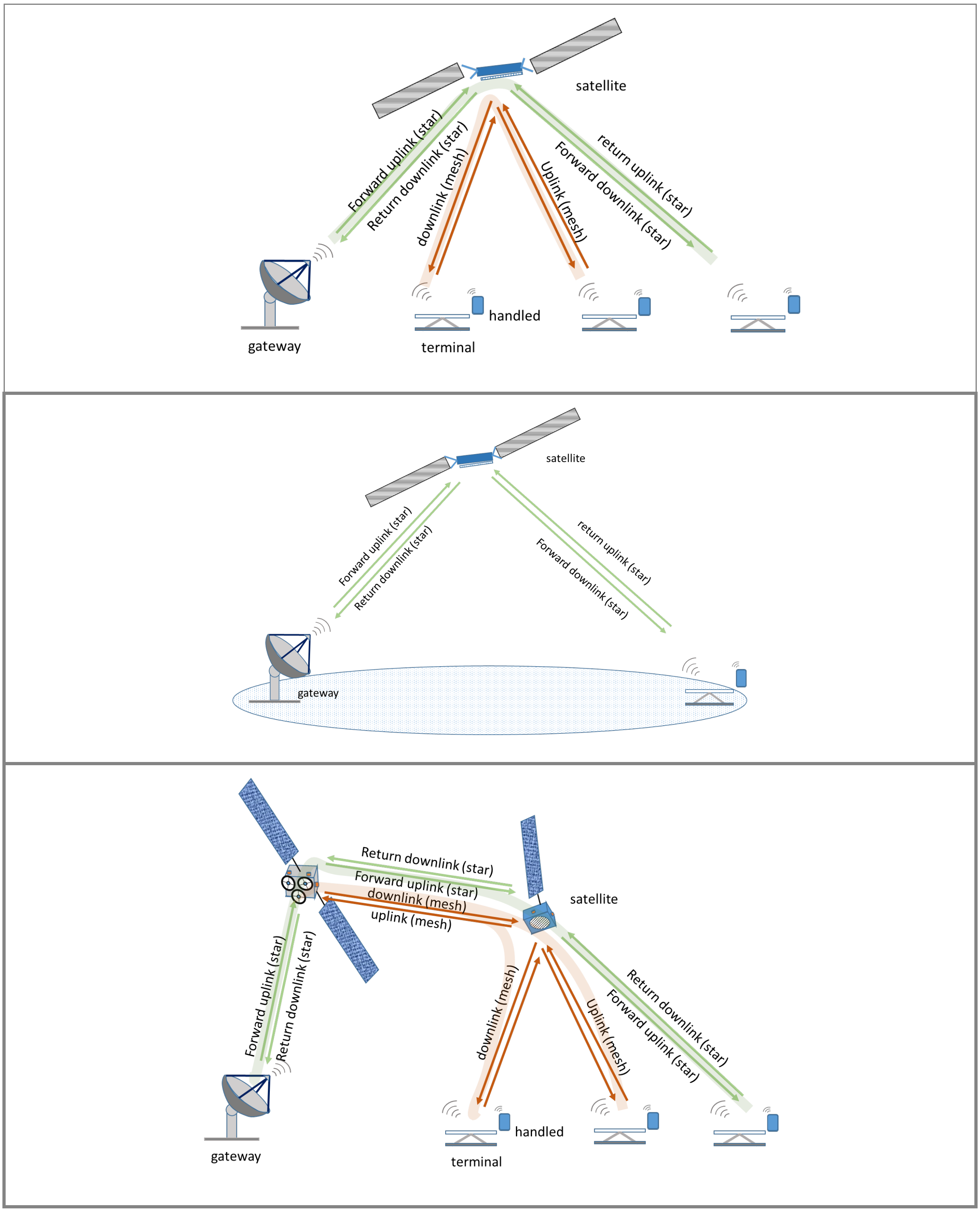


FIGURE 4-20 COMMUNICATION TYPE DEFINITION

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

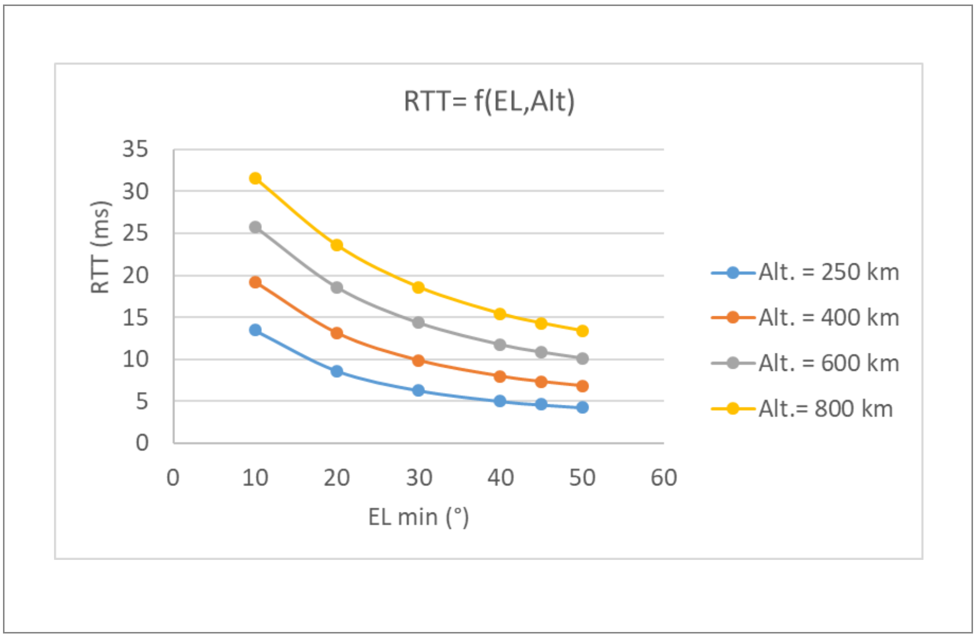


FIGURE 4-21 RTT VERSUS EL_{MIN} AND SATELLITE ALTITUDE

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}.

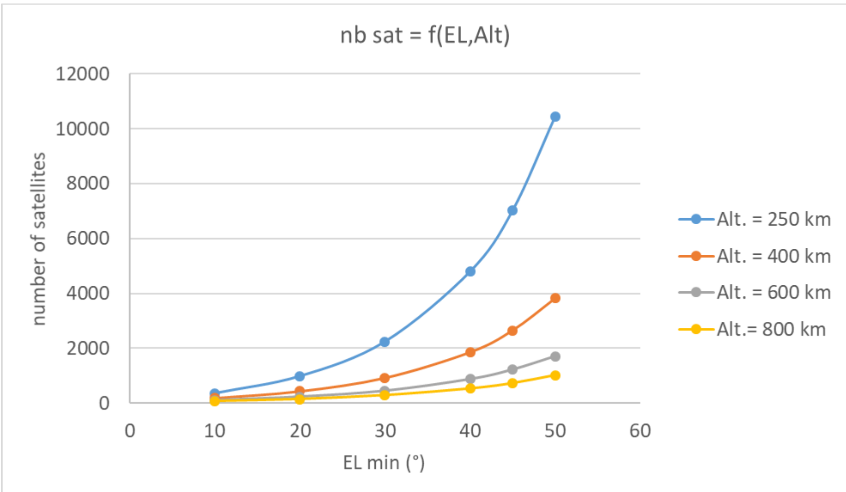


FIGURE 4-22 NUMBER OF SATELLITE NEEDED VERSUS ALTITUDE AND ELMIN

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

2 satellites in visibility during at least 10s

Number of satellites (ELmin 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

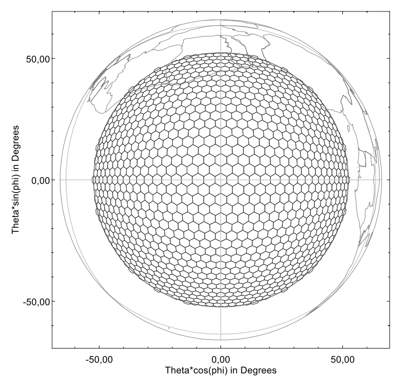
2 satellites in visibility (always)

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.

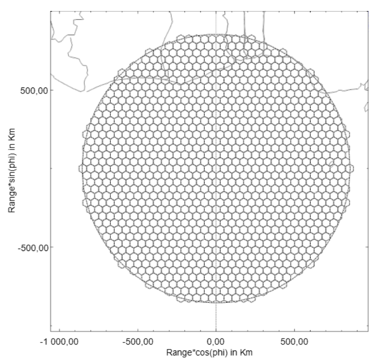
Trade-off issues on number of cell for a given Altitude 600 km and El_{min} =45°

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

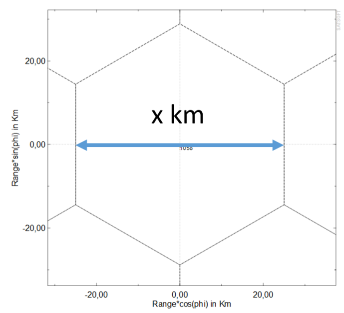


Coverage Angular view

ELmin 10° to 50°



Coverage earth in km



Cell definition

X=22,5 km,45km,67,5 km,90 km,112,5 km

FIGURE 4-24 COVERAGE DEFINITION FOR TRADE-OFF

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

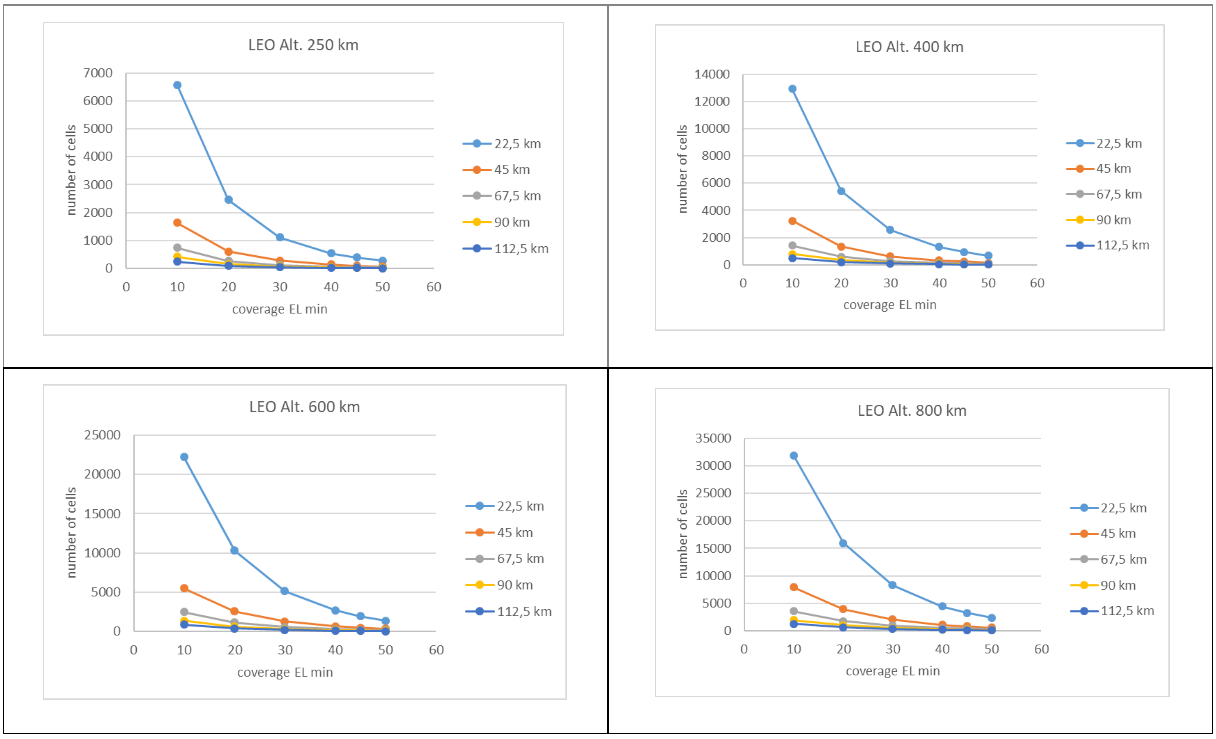


FIGURE 4-25 NUMBER OF CELL VERSUS CELL SIZE/AND COVERAGE EL_{MIN}

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 0.741 λ
- 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)

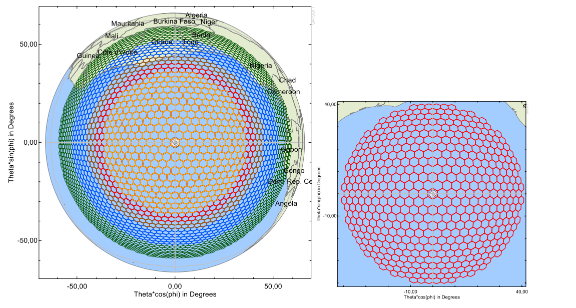
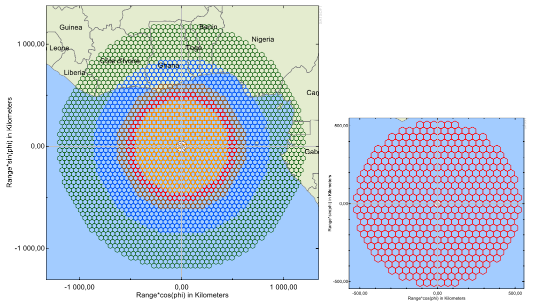
	
Coverage at 600 km Altitude Angular view of the cells from the satellite	Coverage at 600 km Altitude Cells view on earth surface

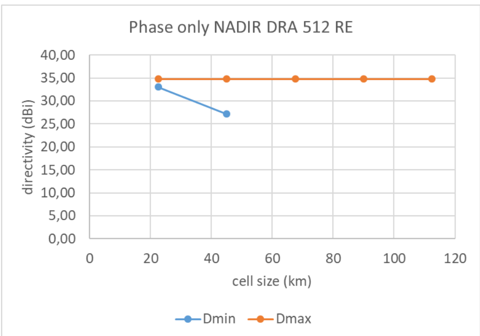
FIGURE 4-26 VIEW OF THE CELLS

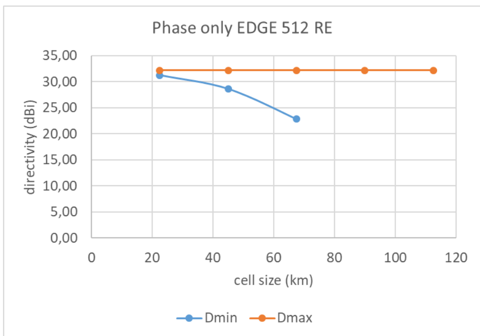
4.2.3.4 Trade off on the antenna size /cell size beamforming techniques:

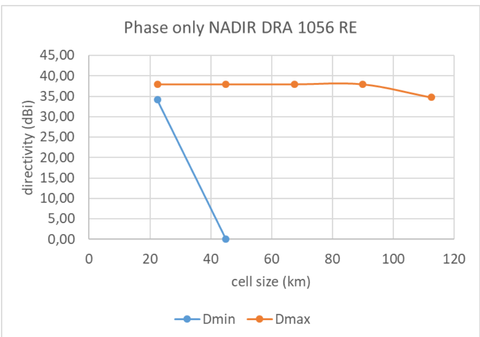
The altitude, coverage have been selected, now it is necessary to define the cells size and the antenna size based on the number of RE that compose the antenna and the power of each satellite.

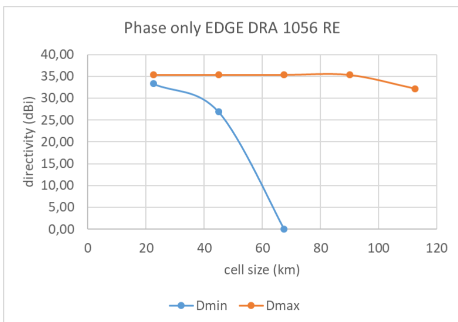
To do that, a trade-off have been performed on cell size in conjunction with antenna size and beamforming techniques.

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









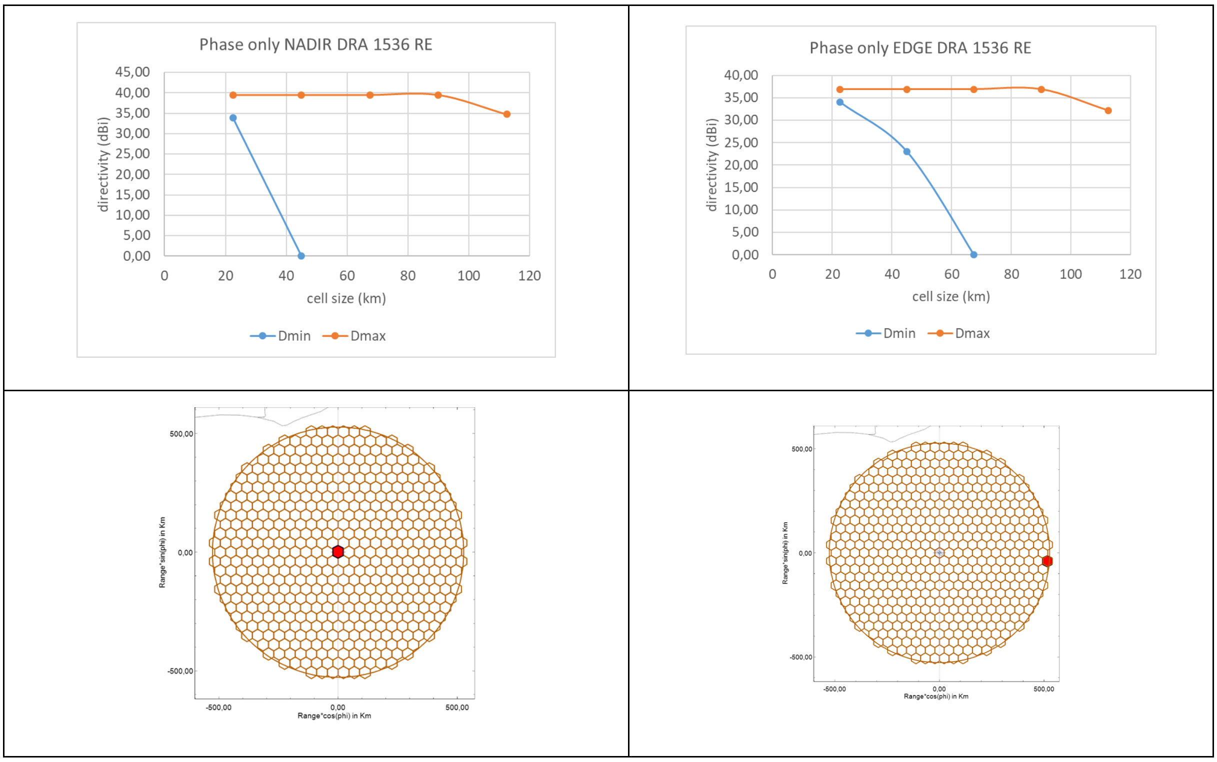


FIGURE 4-27 BEAM POINTING BY PHASE PLANE ONLY RE 512, 1056 & 1536 RE

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 ELmin 45° (see FIGURE 4-28). 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.

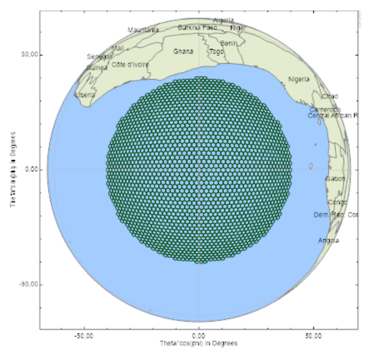
	Satellite Altitude 600 km Coverage El_{min} =45° Cell of 22,5 km 1984 cells

FIGURE 4-28 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.

<u>ANTENNA 512 RE:</u>

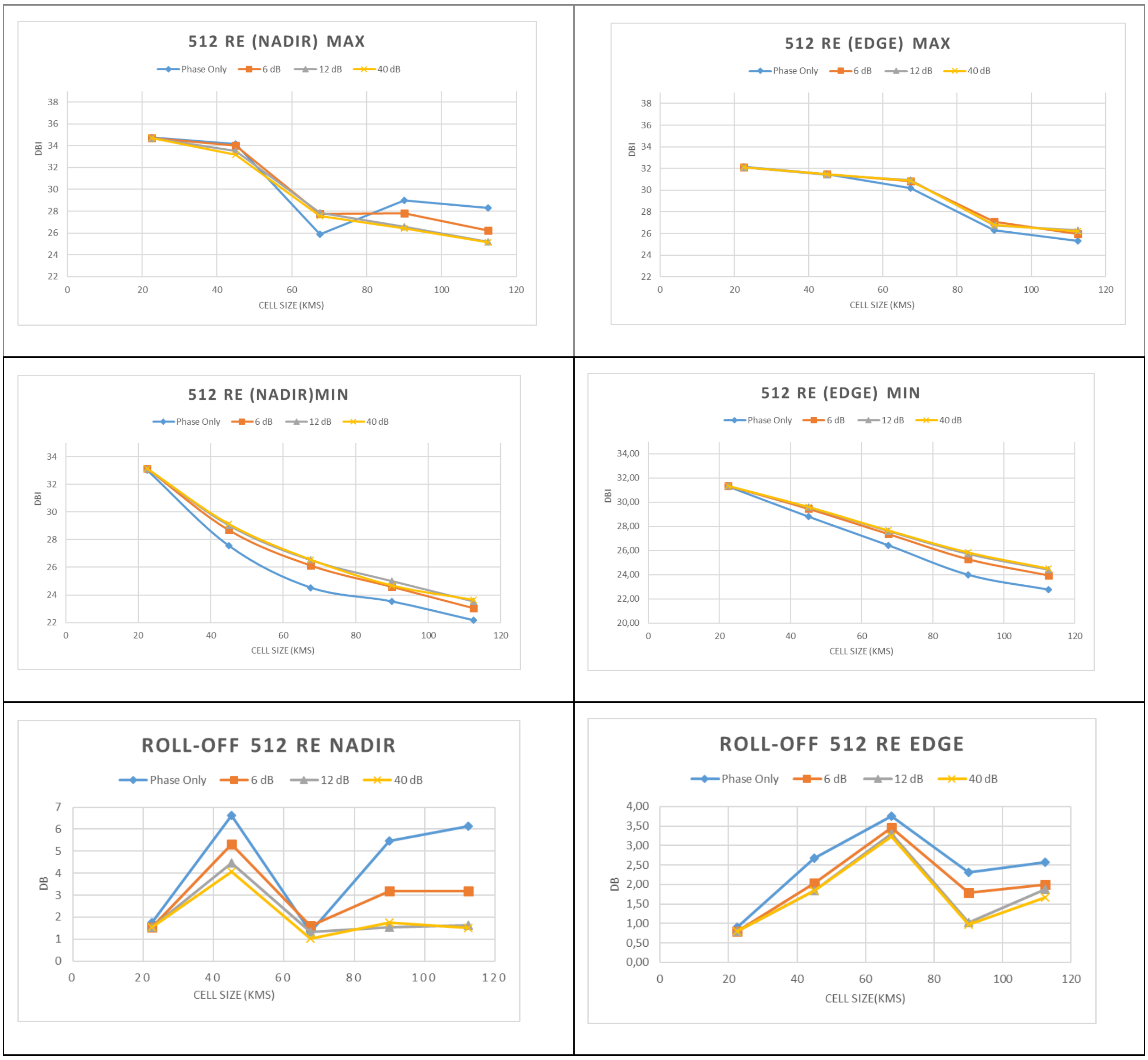


FIGURE 4-29 ANTENNE 512 RE 0.741λ : directivity min and max over cell at nadir and edge

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 4-30 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:

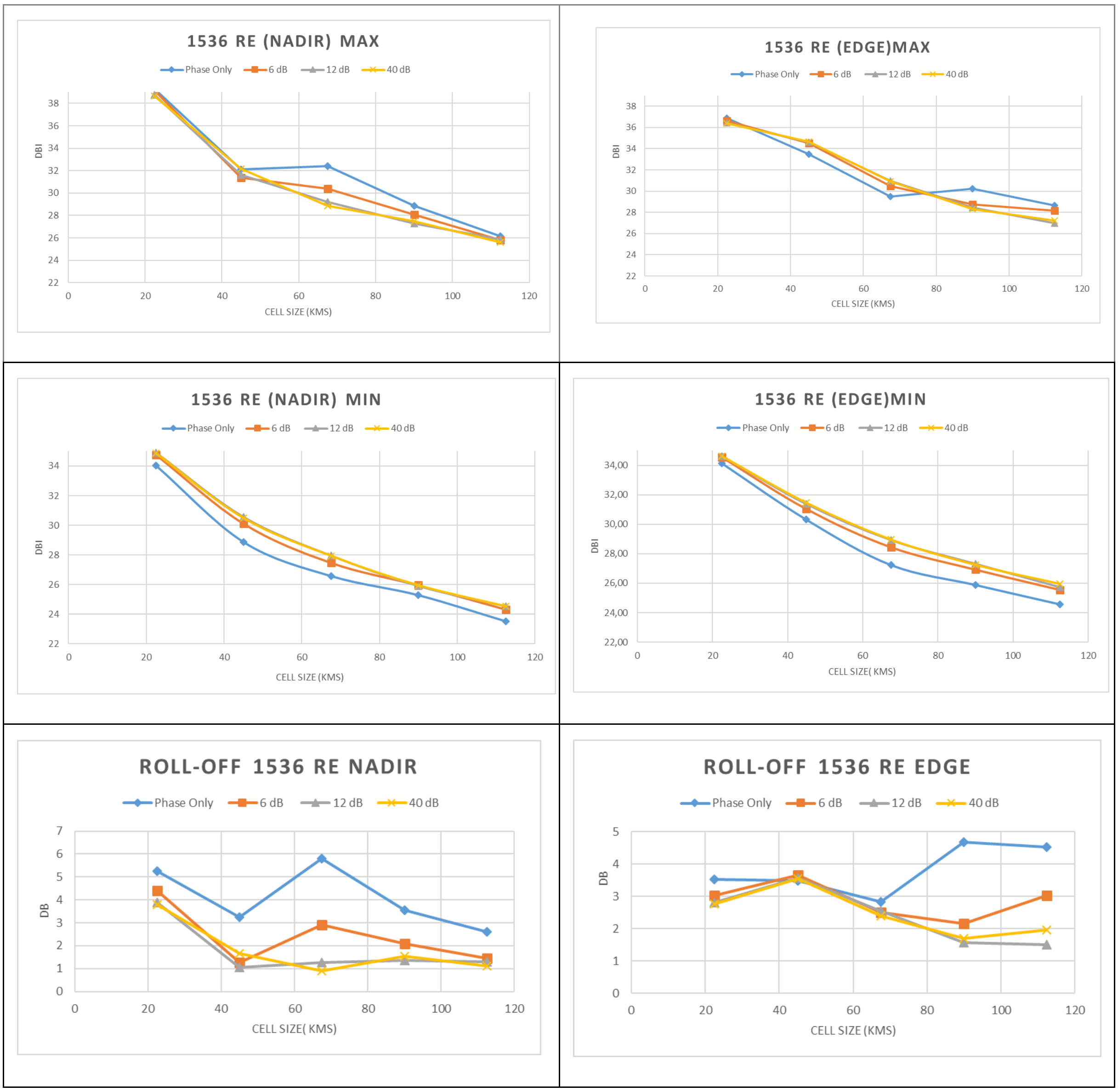


FIGURE 4-31 ANTENNE 1536 RE 0.741λ : directivity min and max over cell at nadir and edge

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.

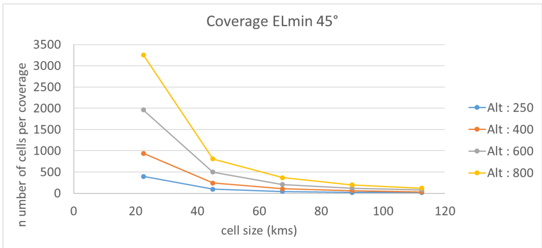
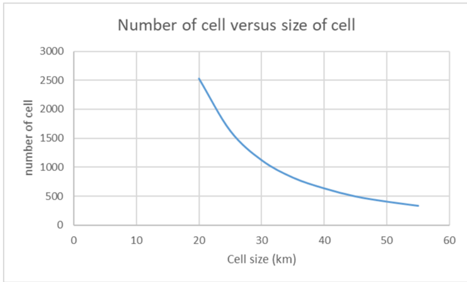
	
Number of cell at 45° E_{lmin} for different satellite altitude	Altitude of 600 kms, 499 cells of 45 kms

FIGURE 4-32 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 El_{min}

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

Satellite altitude: 600 km

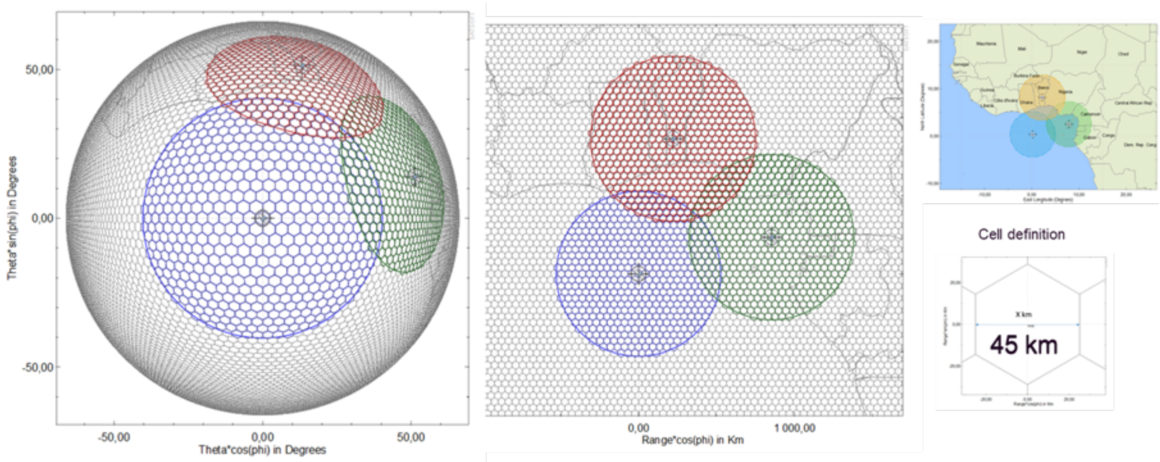


FIGURE 4-33 COVERAGE OF LEO-C BAND

- The RE size 0.741 λ

➲ 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].

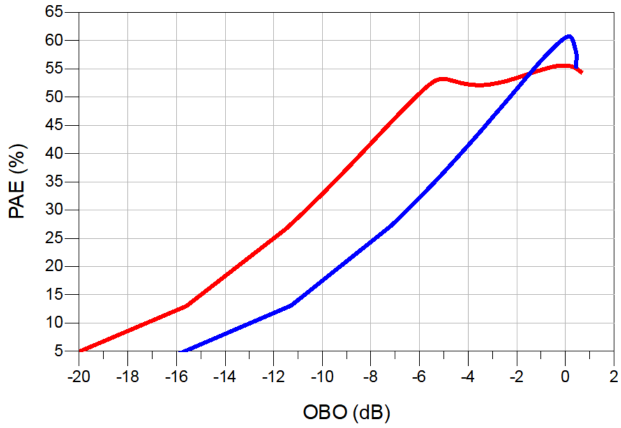


FIGURE 4-34 PAE VS OBO SHAPES COMPARISON BETWEEN CLASS-AB (BLUE) AND DOHERTY (RED) HPA DESIGNS (TAS-F DESIGN, C-BAND, GAN)

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-chiped 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.

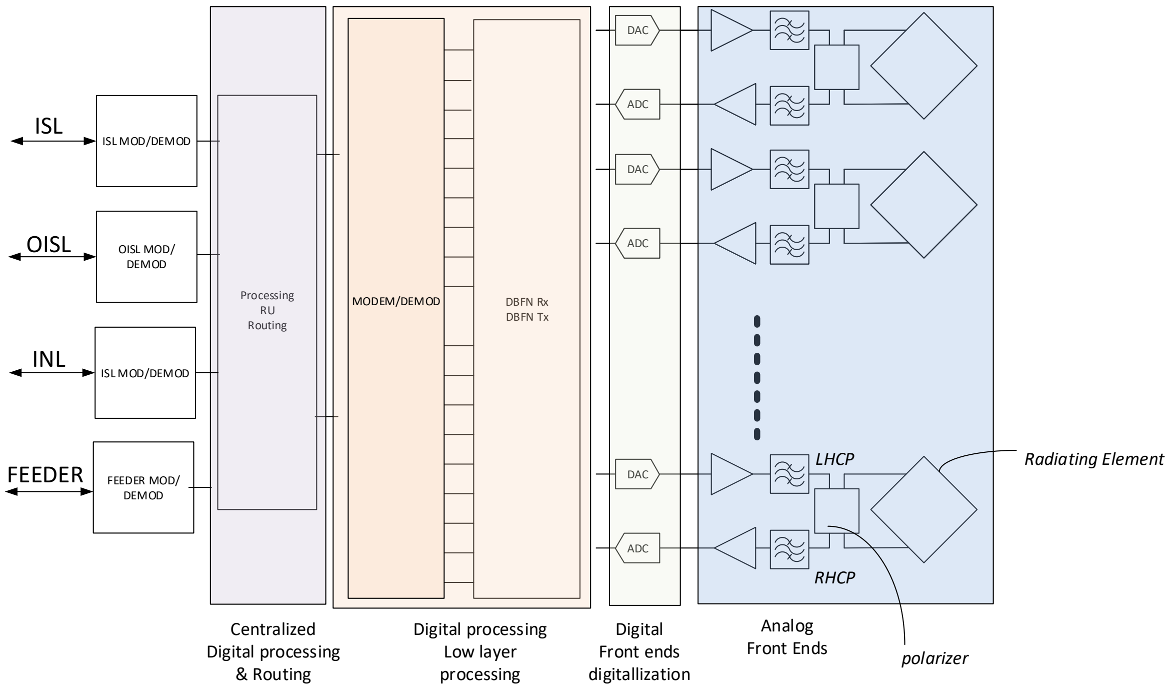


FIGURE 4-35 PAYLOAD ARCHITECTURE 1 (SERVICE SATELLITE)

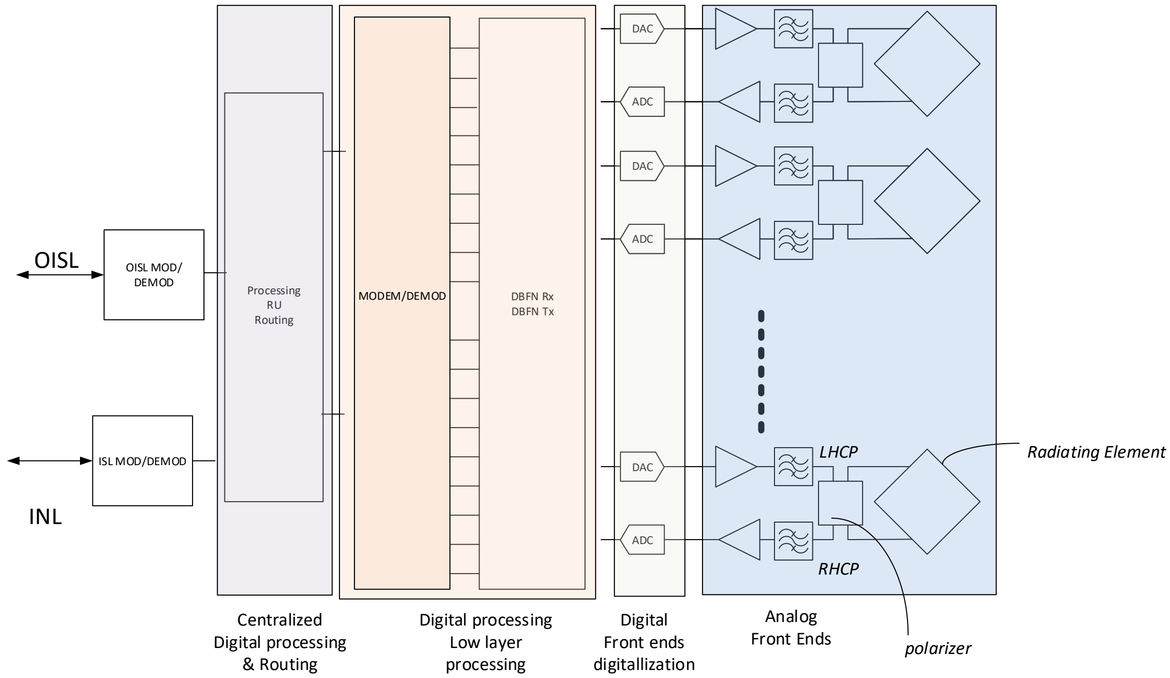


FIGURE 4-36 PAYLAOD ARCHITECTURE 2 (SERVICE SATELLITE)

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 4-35 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 4-36, 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.

4.2.4.3 Radiating Elements

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

<u>The polarization is RHCP or LHCP 1 polarization for Rx and 1 polarization for Tx</u>

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 prefered 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 theoritical 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 0.741 λ radiating element is presented in the FIGURE 4-37.

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.

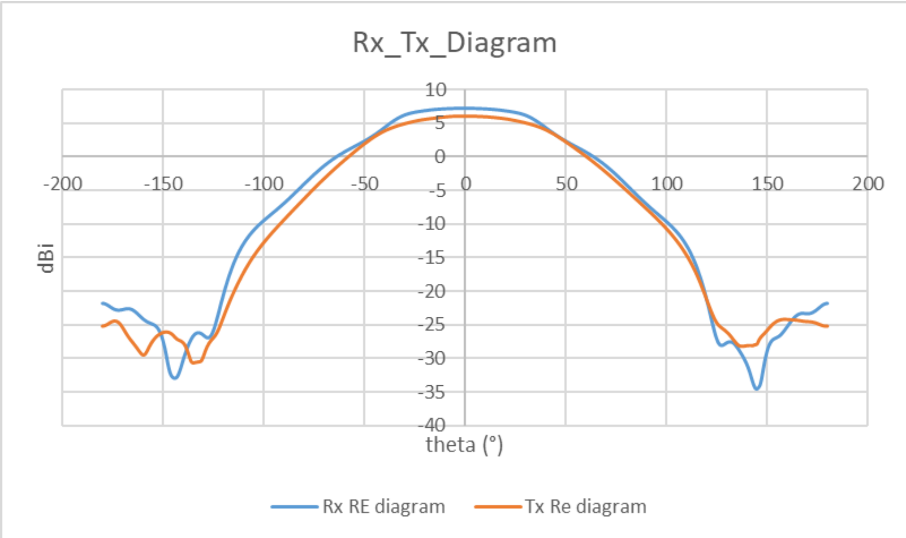


FIGURE 4-37 RADIATING ELEMENT DIAGRAM 0.741 λ

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	pertes 2dB	Gain	directivity	pertes 2dB	Gain
				diametre			nb ELEMENTS		dBi	dB	dBi	dBi	dB	dBi
radiating element		3,4	C Tx	0,055575	m		1		5,89	2	3,89	4,39	2	2,39
		3,9	C Rx	0,055575	m		1		7,09	2	5,09	5,58	2	3,58
			Nfsat	9	dB									

satellite									NADIR MAX			EDGE MAX EL 45°		
									directivity	pertes 2dB	Gain	directivity	pertes 2dB	Gain
				diametre			nb ELEMENTS		dBi	dB	dBi	dBi	dB	dBi
antenne	SATELLITE	3,4	C Tx	1,95	m		1056		36,13	2	34,13	34,63	2	32,63
		3,9	C Rx	1,95	m		1056		37,32	2	35,32	35,82	2	33,82

FIGURE 4-38 ANTENNA DEFINIITON

The antenna comprises 1056 elements arranged to form a flat panel (see FIGURE 4-39). 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.

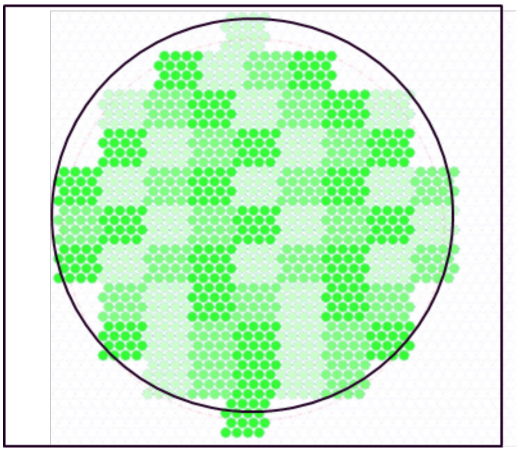
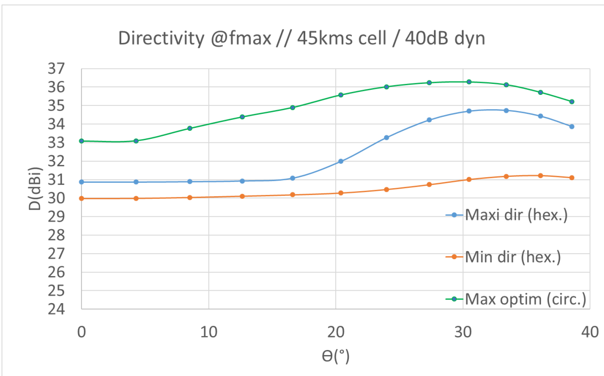
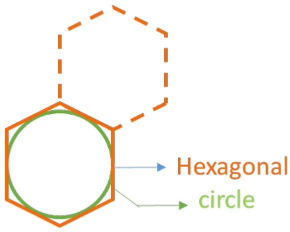


FIGURE 4-39 ANTENNA GEOMETRY

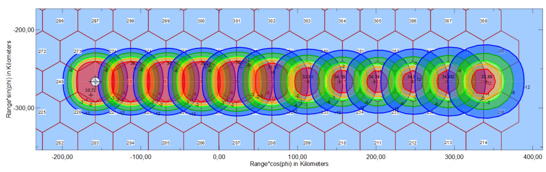
The diagrams are obtained from beam forming over the cells are illustrated by the FIGURE 4-40.

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.





N° beam	1	2	3	4	5	6	7	8	9	10	11	12
beam position (°)	0.000	4.282	8.510	12.634	16.596	20.404	23.980	27.360	30.488	33.414	36.094	38.575



Performance Max and EOC (min)

According to Beamforming techniques

View of the results of beam forming

FIGURE 4-40 BEAM FORMING TECH. & BEAM SHAPE

The layout of the all of the beam for Rx and Tx are presented on FIGURE 4-41 and FIGURE 4-42

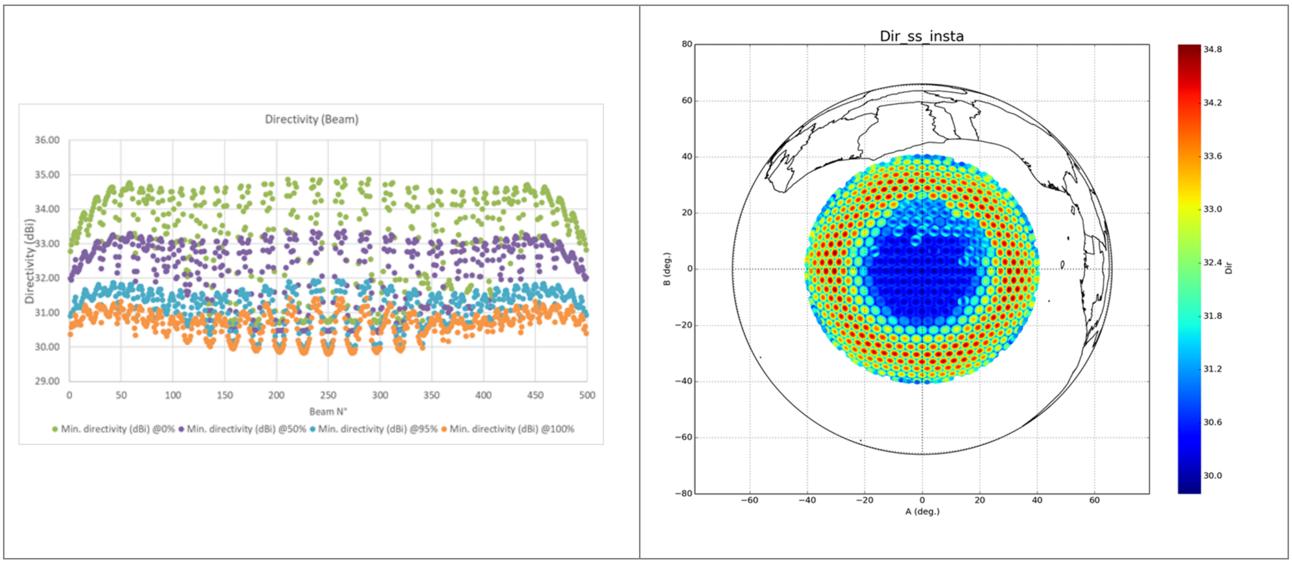


FIGURE 4-41 BEAM PERFORMANCES DIRECTIVITY 0.741 λ

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. Consequenltly, the antenna allows to compensate the FSL with depointing. In the case of Tx beam the performances is illustrated in the FIGURE 4-42.

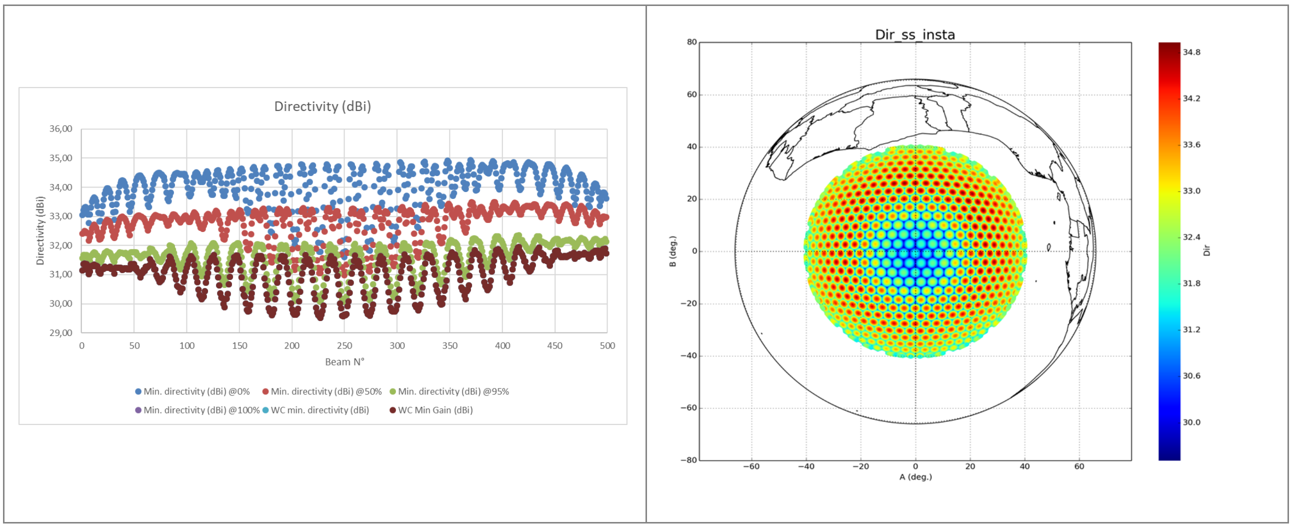
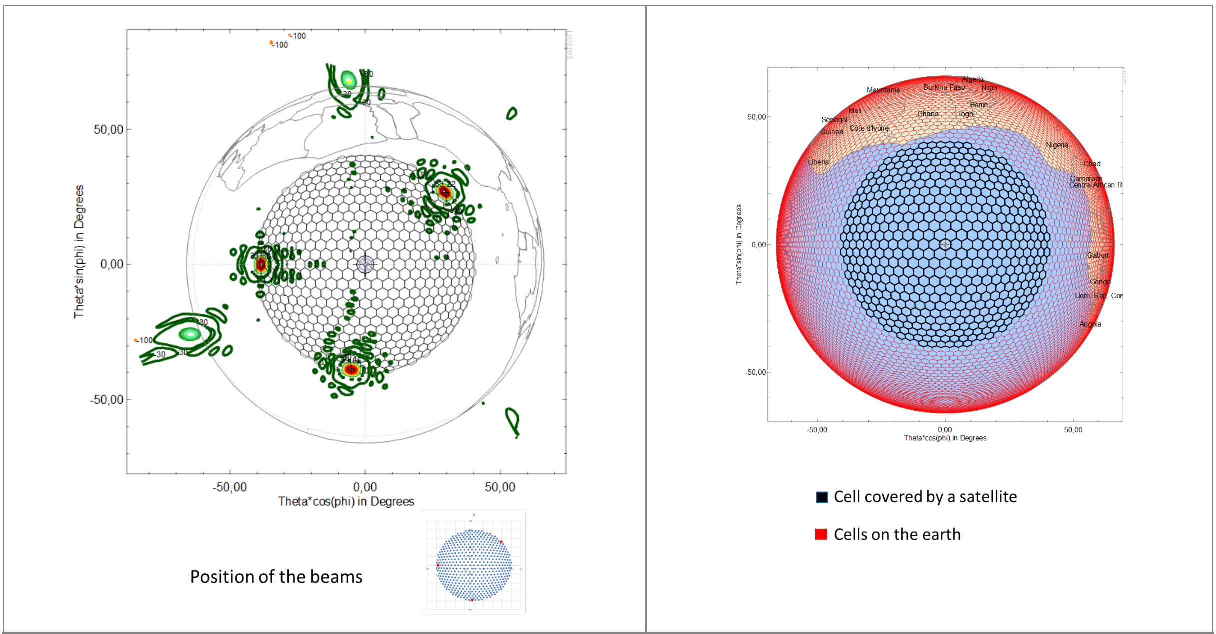


FIGURE 4-42 BEAM PERFORMANCES DIRECTIVITY 0.65 λ

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 4-43). 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



(a) Patterns grating lobes verification	(b) Cells covered by sat (black) & Earths cells on view (red)

FIGURE 4-43 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 (α=40.3°) and an earth cell at the edge of the earth (α=65,7°) 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 4-44 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 Antenna performances

The table below give the hypothesis taken for the UE:

UE									NADIR MAX			EDGE MAX EL 45°		
									directivity	pertes 2dB	Gain	directivity	pertes 2dB	Gain
				diametre			nb ELEMENTS		dBi	dB	dBi	dBi	dB	dBi
antenna	earth UE	3,4	C Rx	0,04615385	m		1		4,28	2	2,28	2,78	2	0,78
		3,9	C Tx	0,04615385	m		1		5,47	2	3,47	3,97	2	1,97
			Nfsat	9	dB									

FIGURE 4-45 ELEMENTARY RADIATING ELEMENT PERFORMANCES (UE)

According to the terminal type the gain is between 0 to -3 dBi, the NF between 7 and 9 dB and the power between 23 to 26 dBm. These are all cases to be dealt with and have an impact on the throughput. The values have to be adjusted according to the user to determine the achieved throughput. In the present case, to illustrate the balance, an average case defined by the gain in the table above, with a power of 23 dBm and a NF of 9 dB.

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 throughtput achievable to dimension the interlinks without overdimensionning the system.

The hypothesis taken for the satellite are given in the table of FIGURE 4-38. 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

The satellite payload parameters used for the link budget are summarized in the next figure.

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 ER (NADIR)	dBi	5,89
	Directivity ER (El 45°)	dBi	4,39
	Losses ER	dB	2
	Antenna gain (NADIR)	dBi	34,13
	Antenna gain (El 45°)	dBi	32,63
	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
	Directivity ER (NADIR)	dBi	7,09
	Directivity ER (El 45°)		5,58
	Losses ER	dB	2
	Antenna Temperature	K	290,00
	Ambiant Temperature	K	290,00
	Equivalent Temperature	K	762,78
	Antenna gain (NADIR)	dBi	35,32
	Antenna gain (45°)	dBi	33,82
	G/T (NADIR) Target	**dB/K**	**6,50**
	G/T (NADIR)	**dB/K**	**6,50**
	G/T (45°)	dB/K	4,99
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	12
	Uplink (Sat RX)	dB	12

FIGURE 4-46 SATELLITE PARAMETERS

4.2.5.4 UE hypothesis

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

UE	Parameter	Unit	Value
	Band Name	-	C
RX (downlink)	Downlink Frequency	(GHz)	3,40
	Antenna Size	(m)	0,05
	Number of ER	-	1
	Directivity ER (NADIR)	(dBi)	4,28
	Directivity ER (El 45°)	(dBi)	2,78
	Losses ER	(dB)	2
	Antenna Noise Figure (NF)	(dB)	9,00
	Antenna Temperature	(K)	290,00
	Ambiant Temperature	(K)	290,00
	Equivalent Temperature	(K)	2303,55
	Antenna gain (NADIR)	(dBi)	2,28
	Antenna gain (45°)	(dBi)	0,78
	Antenna gain (30°)	(dBi)	-0,73
	G/T (NADIR)	dB/K	-31,34
	G/T (45°)	dB/K	-32,85
	G/T(30°)	dB/K	-34,35
	Polarisation mismatch loss	dB	3,00
	Overhead	-	0,14
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
	Directivity ER (NADIR)	(dBi)	5,47
	Directivity ER (El 45°)	(dBi)	3,97
	Losses ER	(dB)	2
	Antenna gain (NADIR)	(dBi)	3,47
	Antenna gain (45°)	(dBi)	1,97
	Antenna transmit power	dBW	-7
	Antenna transmit power	W	0,20
	Polarisation mismatch loss	dB	3,00
	Overhead	-	0,08

FIGURE 4-47 UE HYPOTHESIS (BEST CASE)

The evaluation of performances have been done through link budgets presented in Appendices 8.4 and 8.5.

In the case of average throughput in downlink, the sensitity analysis have been performed with the different terminal for the scenario (2) and (3) described in Appendices 8.4:

	NF	gain	power	nadir	edge Elmin45°
Terminal	dB	dBi	dBm	Mbps (2)	Mbps (3)
Average case	9	hemispheric	23	74,10	31,86
C_NTN_1	9	-3	23	31,86	12,33
C_NTN_2	7	-3	23	50,85	19,80
C_NTN_3	7	0	26	74,10	41,43

FIGURE 4-48 SENSITITY OF THROUGHPUT WITH TERMINAL TYPE

We can see that throughput can be doubled depending on the type of terminal: between the least efficient and the best, throughput is doubled or even quadrupled at the lowest elevation.

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

In this section we provide several system metrics evaluated through a simulation environment. This simulation focuses on a specific region of the Earth which is selected to be the land and sea region of Metropolitan France. This use case is UC5 defined in section 3.5 of D2.2. More specifically, 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.

To find the number of NTN users and their location, we process the population distribution (Figure 4-49) and the terrestrial coverage maps (Figure 4-50) of Metropolitan France and keep only those users that are located outside the terrestrial coverage. The result is shown in Figure 4-51. Notice that the number of total NTN users shown in Figure 4-51 is 550,000 which is the 0.85% of the Metropolitan France population.

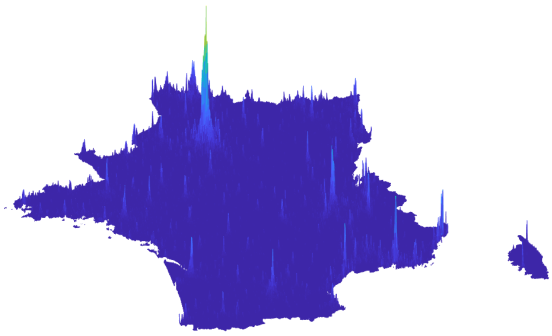


FIGURE 4-49 POPULATION DISTRIBUTION OF METROPOLITAN FRANCE RETRIVED FROM HTTPS://DATA.HUMDATA.ORG/DATASET/WORLDPOP-POPULATION-DENSITY-FOR-FRANCE

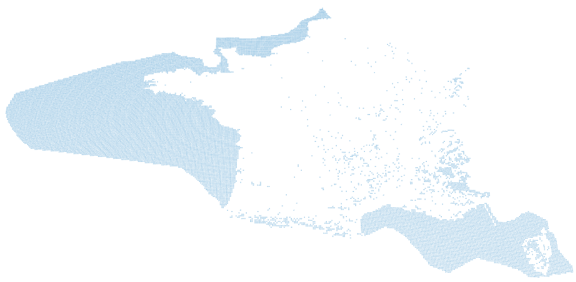


FIGURE 4-50 TERRESTRIAL COVERAGE MAP OF METROPOLITAN FRANCE RETRIEVED FROM HTTPS://FILES.DATA.GOUV.FR/ARCEP_DONNEES/MOBILE/COUVERTURES_THEORIQUES/

FIGURE 4-51 POPULATION DISTRIBUTION OF NTN USERS WITHIN METROPOLITAN FRANCE

Table 1 shows the system level simulation parameters regarding the RAN and antenna configuration, the link budget, the user traffic, and the constellation configuration.

TABLE 1 SYSTEM LEVEL SIMULATION PARAMETERS

Parameter	Unit	Value
NR numerology (μ)		1
DL Bandwidth	(MHz)	100 for FR=1 and 100/3 for FR=3
UL Bandwidth	(MHz)	100 for FR=1 and 100/3 for FR=3
Frequency reuse factor		FR=1 and FR=3
Carrier frequency Tx sat	(GHz)	3.4
Carrier frequency Rx sat	(GHz)	3.9
UE max output power (max TRP)	(dBm)	23
UE antenna gain	(dBi)	-3
UE noise figure (NF)	(dB)	9
Payload total power level (Note 1)	(dBm)	63
Payload antenna gain	(dBi)	Tx: 34.4 Rx 35.5 (dBi (Nadir)
Satellite antenna figure of merit (G/T)	(dB/K)	6.5
Satellite beam pattern		According to 6.4.1 of 3GPP TR 38.811
Satellite antenna 3dB beamwidth (θ_{3dB}) (notice θ_{3dB} = HPBW/2)	(deg)	3
Number of plane		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 for FR=1 and 300 for FR=3
Minimum elevation angle (Note 3)	(deg)	45
User traffic	(kbps/user)	DL: 72 kbps and UL: 8 kbps
Atmospheric loss	(dB)	Formula [RD2] 6.6-8

Body loss	(dB)	3dB
Shadow fading loss	(dB)	According to 6.4.1 of 3GPP TR 38.811
Polarization mismatch loss	(dB)	3dB

We present the results for two cases, frequency reuse 1 (FR=1), and frequency reuse 3 (FR=3), as depicted in Figure 4-52. Notice that in FR=1, 100 simulateous beams can be generated. For FR=3, 300 simultaneous beams can be generated because each beam carries 1/3 of the power compared to FR=1.

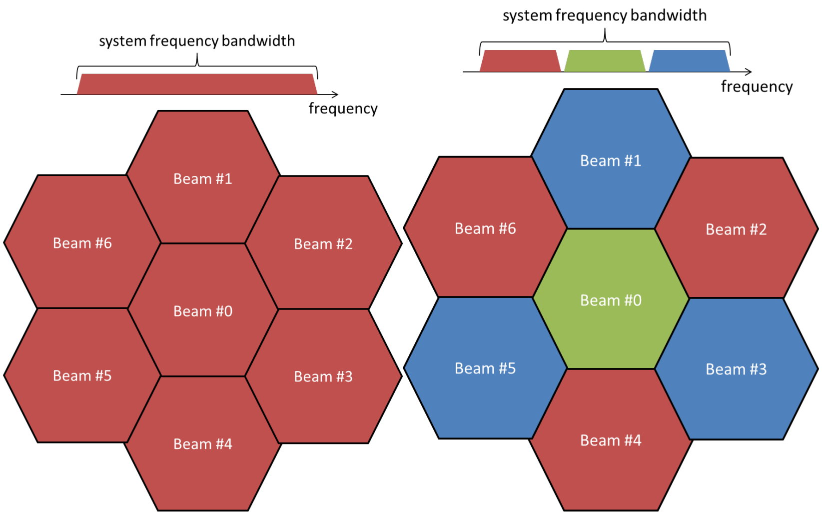


FIGURE 4-52 FREQUENCY REUSE SCHEMES, FR=1, AND FR=3, SEE TABLE 6.1.1.1-5 OF 3GPP 38.821

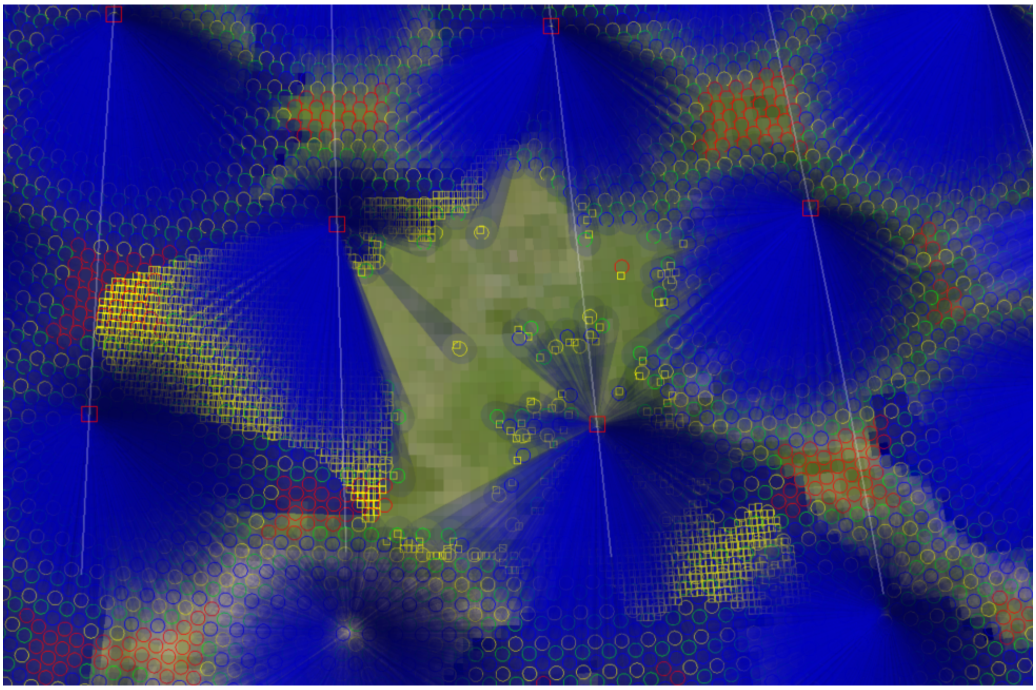


FIGURE 4-53 VISUALISATION OF A SNAPSHOT (FRANCE)

In FIGURE 4-53 a visualization of a snapshot of the constellation and beam assignment to ntn cells within metropolitan france have been done. This assignment correspond to the parameters of Table 1 using FR=3. green, yellow and blue Circles indicate the three different cell color, and red cells are uncovered cells. Red squares indicate the location of the leo satellites.

4.2.6.1 System metrics

Antenna miss-alignment is the angle 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 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 $FSPL$ 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 and $\sigma_{N_0}^2$is the thermal noise power. This metric is calculated separately for the downlink and the uplink.

Signal-to-interference-ratio (SIR) is given by the formula $SIR_i = \frac{p_i}{\sum_{\substack{j \\ j\neq i}} u_j \cdot p_j}$ 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 simultanously active during the same slot and at the same frequency band. This metric is calculated separately for the downlink and the uplink.

Signal-to-interference-plus-noise-ratio (SINR) is given by the formula , $SINR_i = \frac{p_i}{\sigma_{N_0}^2 + \sum_{\substack{j \\ j\neq i}} u_j \cdot p_j}$ This metric is calculated separately for the downlink and the uplink.

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

All these parameters have been evaluated for the two cases of frequency reuse scheme FR=1 and FR=3.

The results are given in the next chaper 4.2.6.2 for the FR1=1 and in chapter 4.2.6.3 (FR=3)

4.2.6.2 Results for FR=1

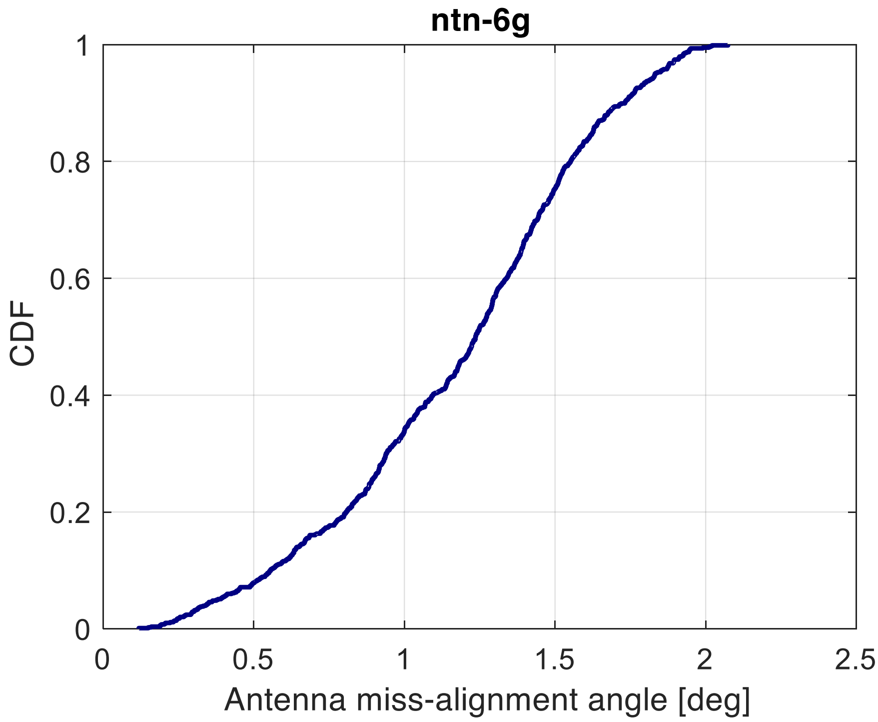


FIGURE 4-54 CDF ANTENNA MISS-ALIGNMENT (DEG)

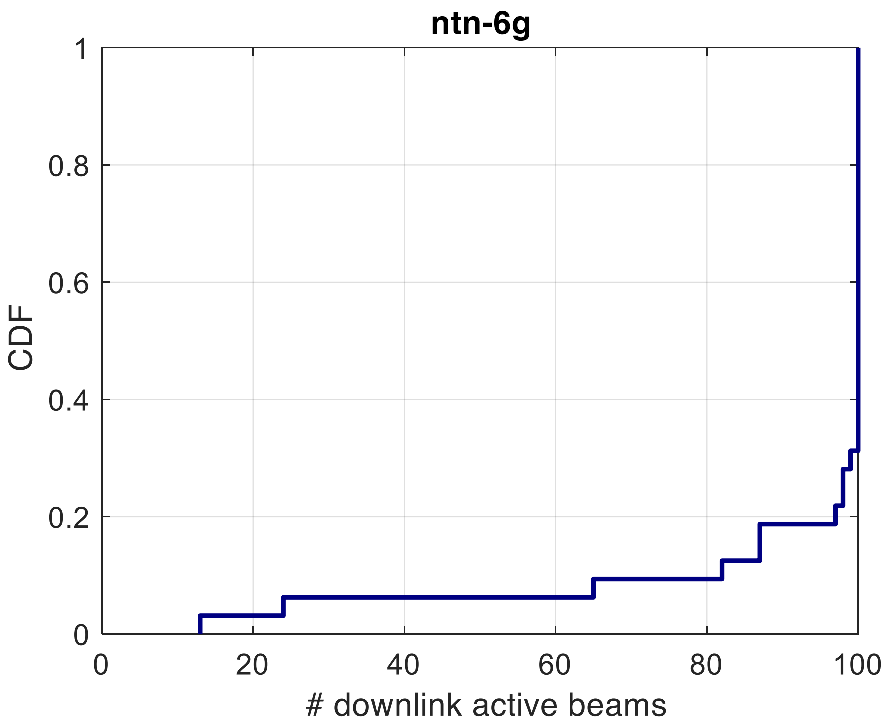


FIGURE 4-55 DOWNLINK ACTIVE BEAMS

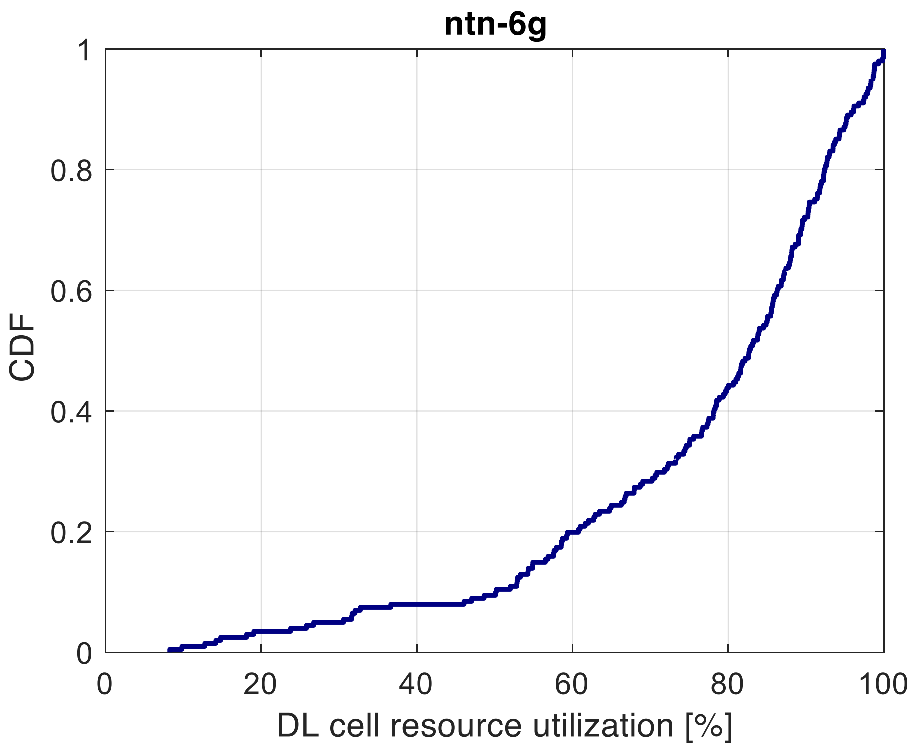


FIGURE 4-56 DL CELL RESOURCE UTILISATION (%)

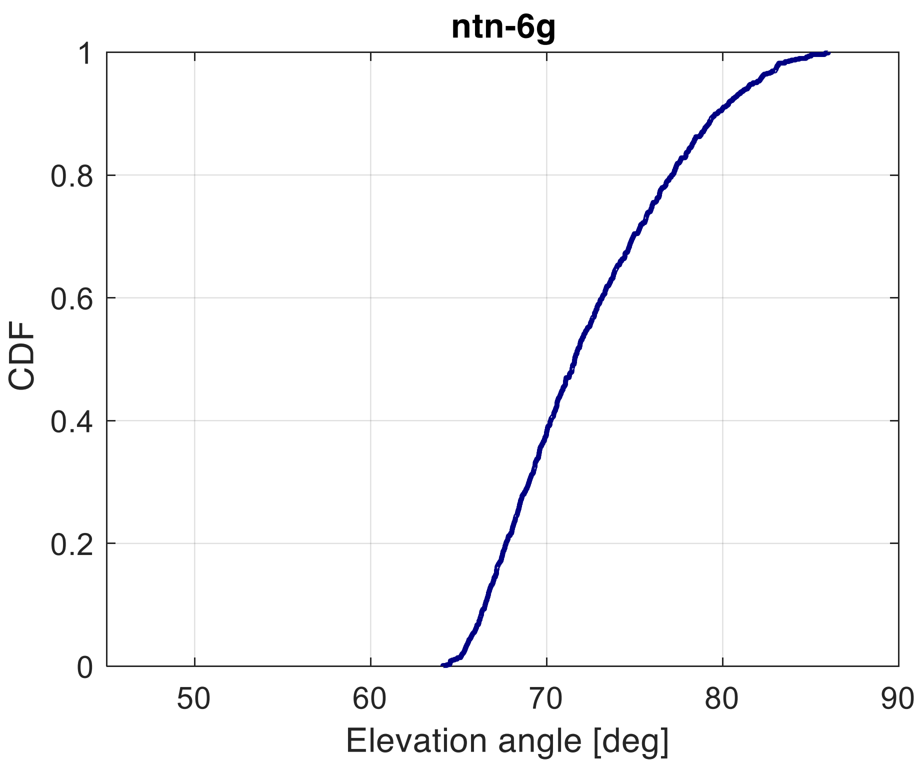


FIGURE 4-57 ELEVATION ANGLE (DEG)

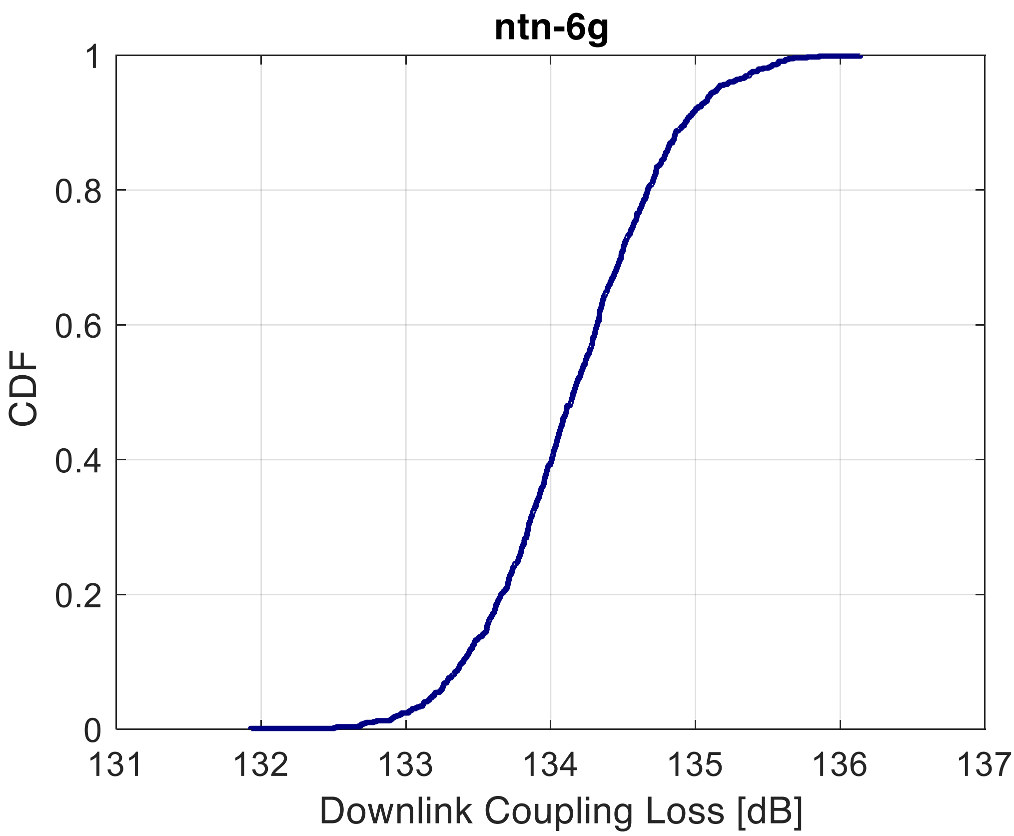


FIGURE 4-58 DOWNLINK COUPLING LOSS (DB)

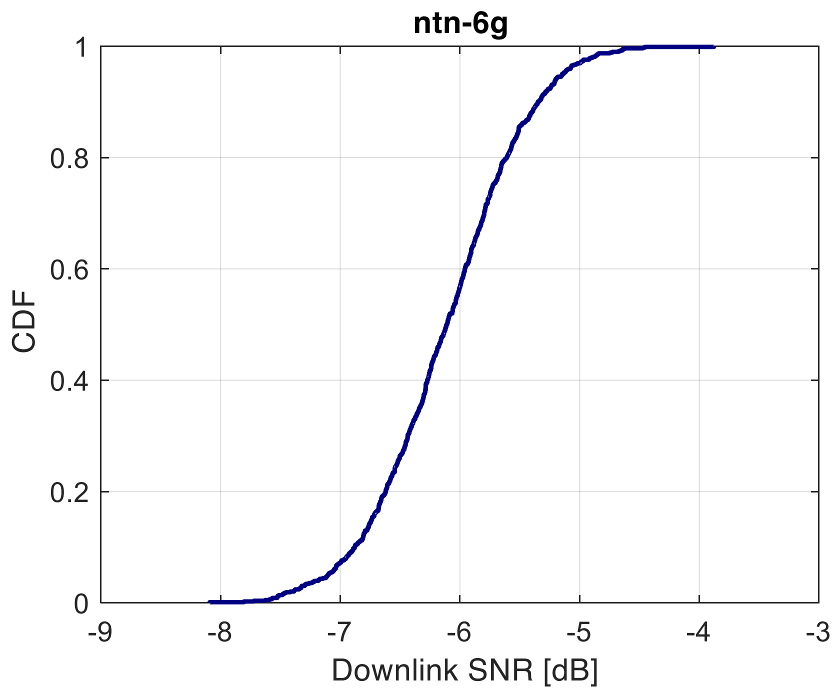


FIGURE 4-59 DOWNLINK SNR (DB)

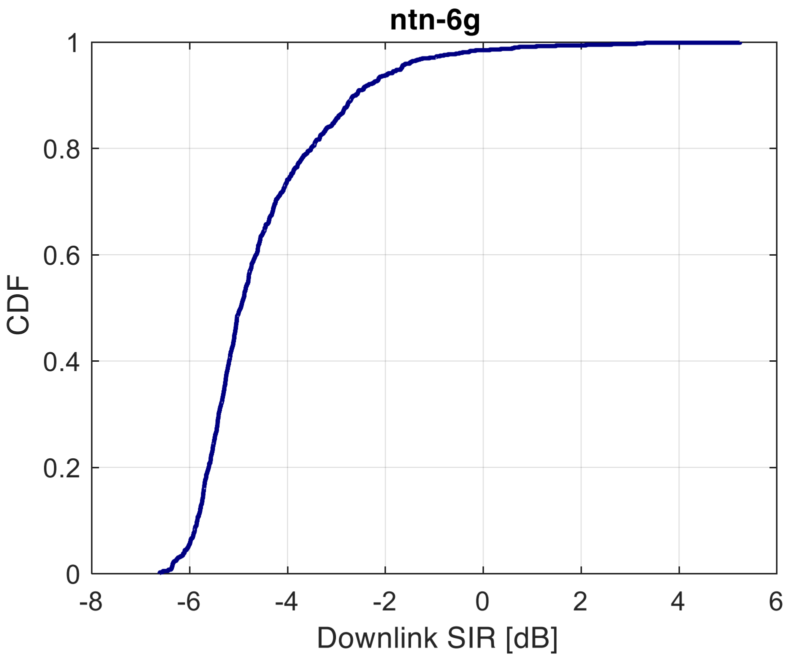


FIGURE 4-60 DOWNLINK SIR (DB)

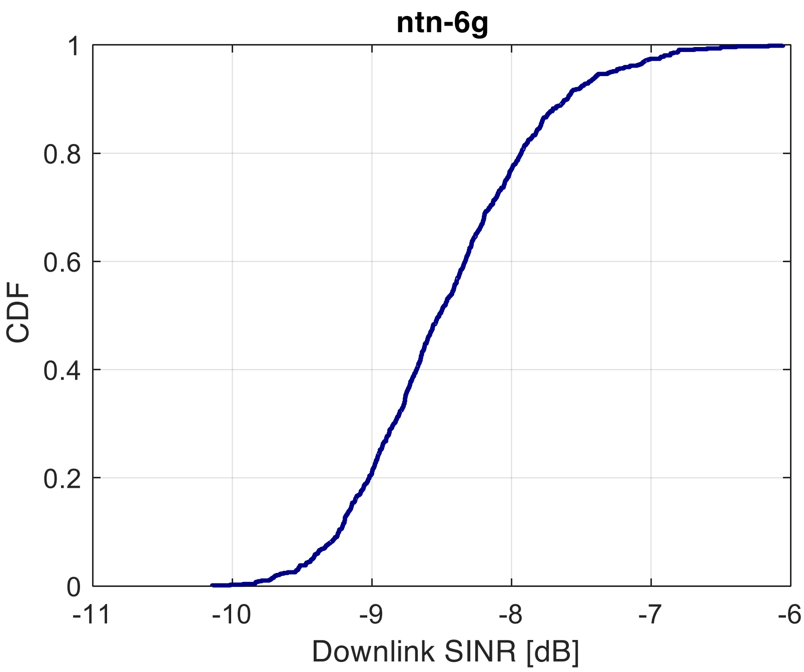


FIGURE 4-61 DOWNLINK SINR (DB)

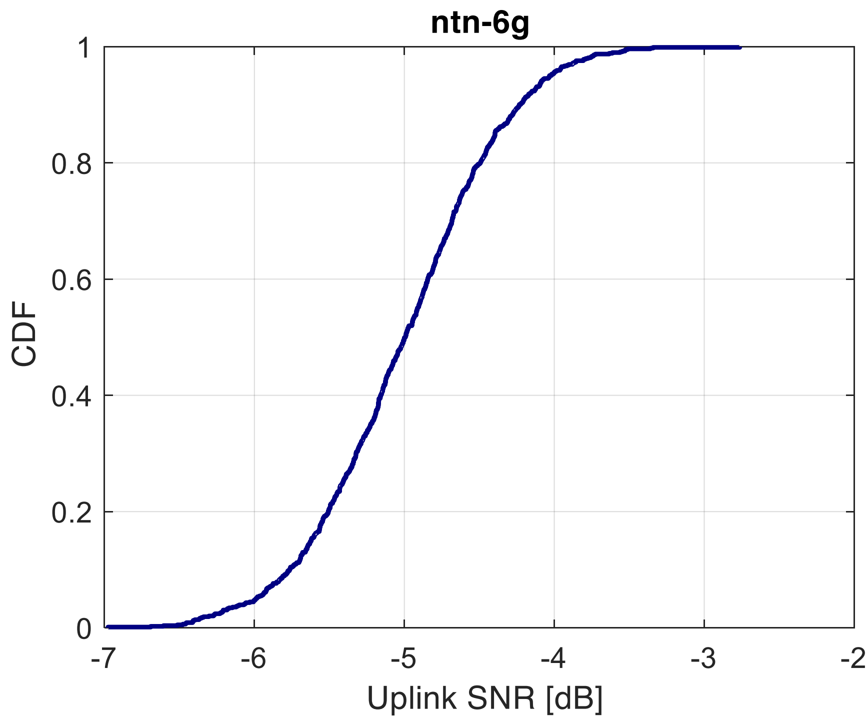


FIGURE 4-62 UPLINK SNR (DB)

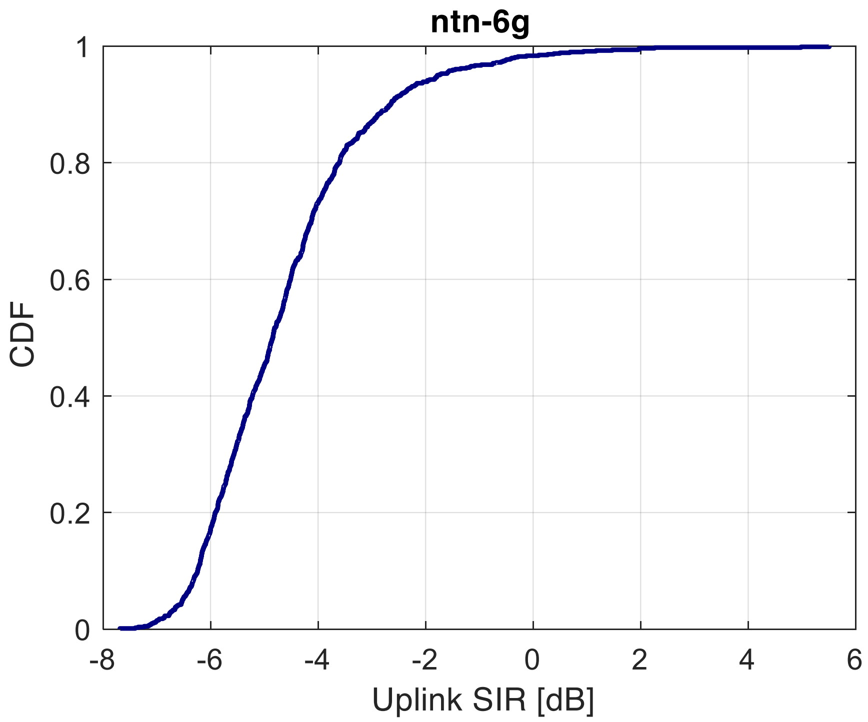


FIGURE 4-63 UPLINK SIR (DB)

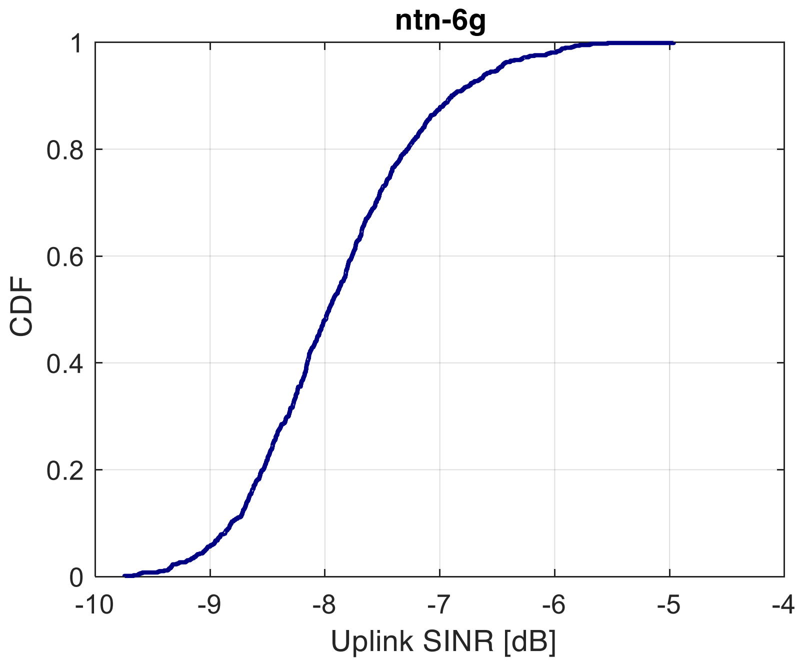


FIGURE 4-64 UPLINK SINR (DB)

4.2.6.3 Results for FR=3

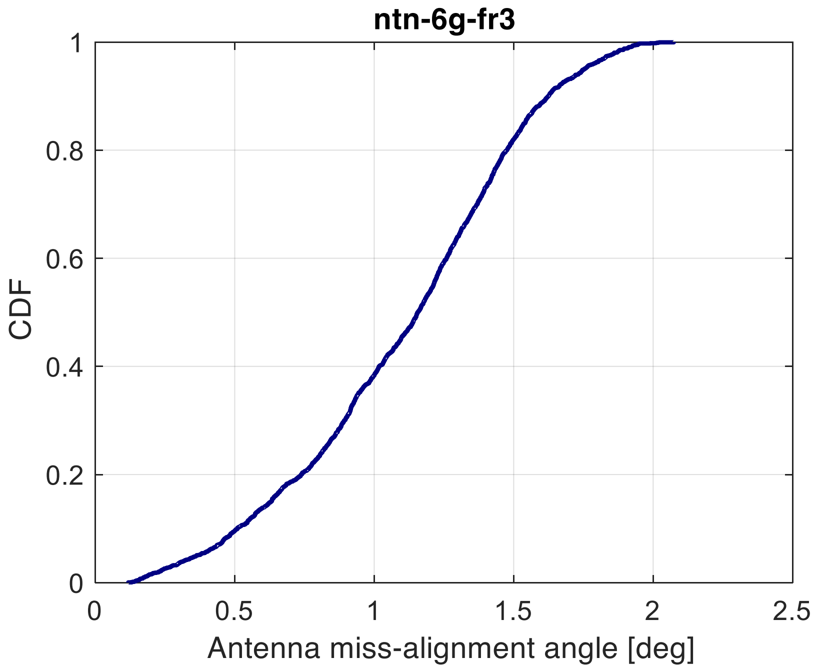


FIGURE 4-65 ANTENNA MISS-ALIGNMENT ANGLE(DEG)

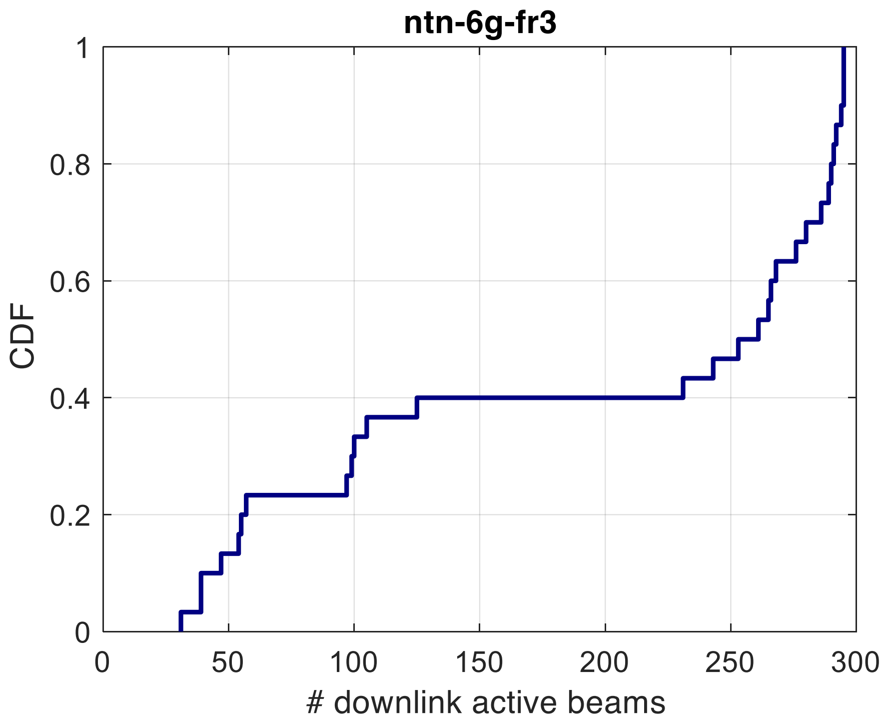


FIGURE 4-66 DOWNLINK ACTIVE BEAMS

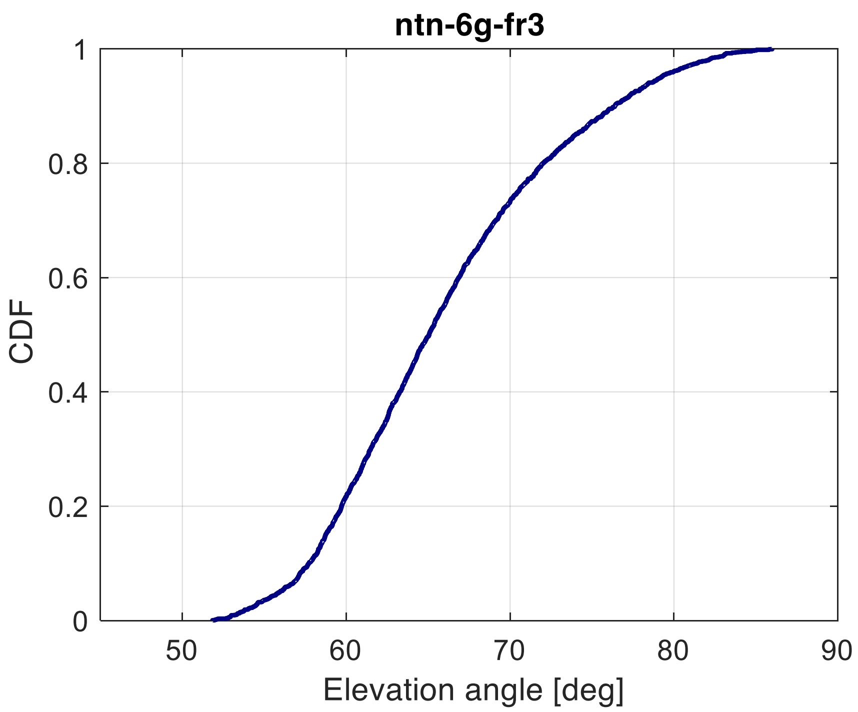


FIGURE 4-67 ELEVATION ANGLE (DEG)

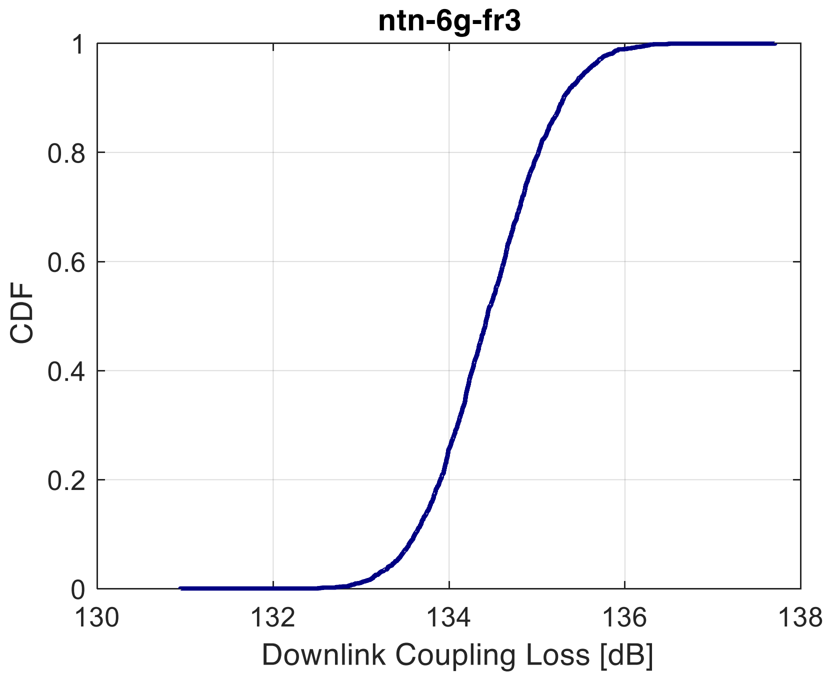


FIGURE 4-68 DOWNLINK COUPLING FACTOR (DB)

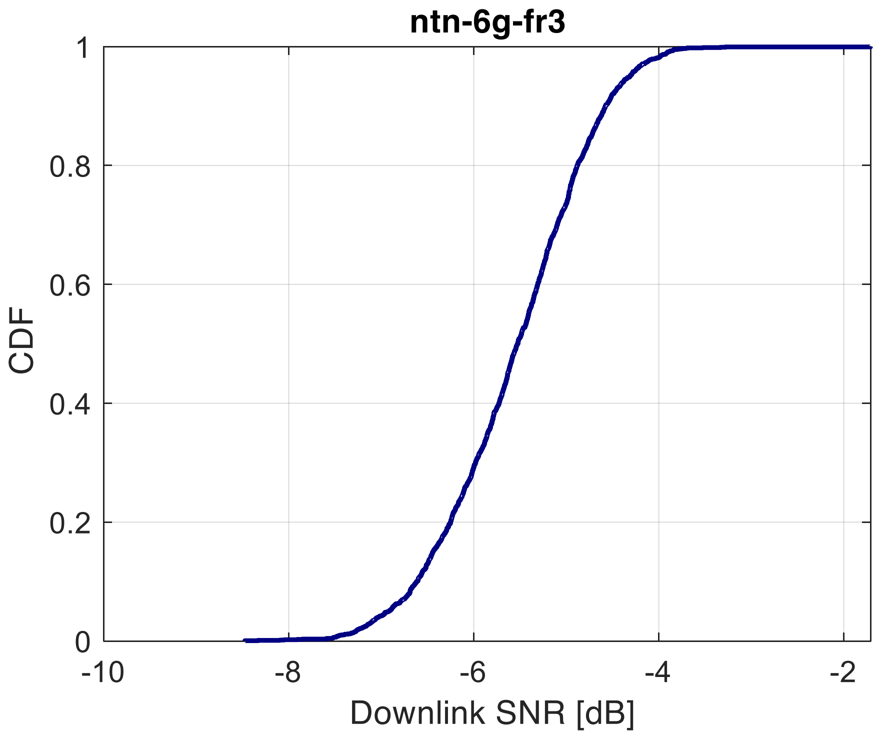


FIGURE 4-69 DOWNLINK SNR (DB)

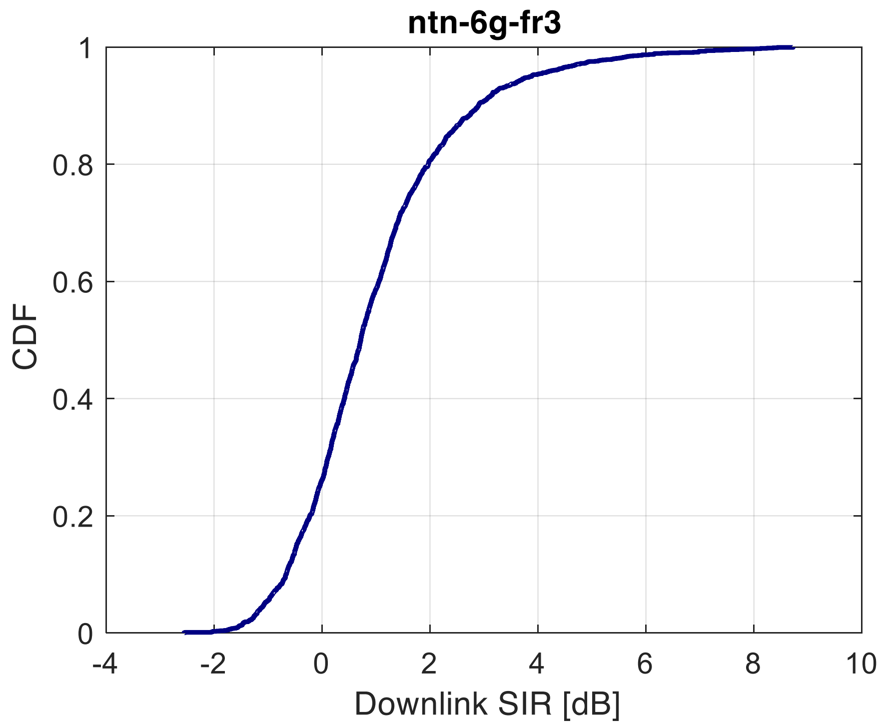


FIGURE 4-70 DOWNLINK SIR (DB)

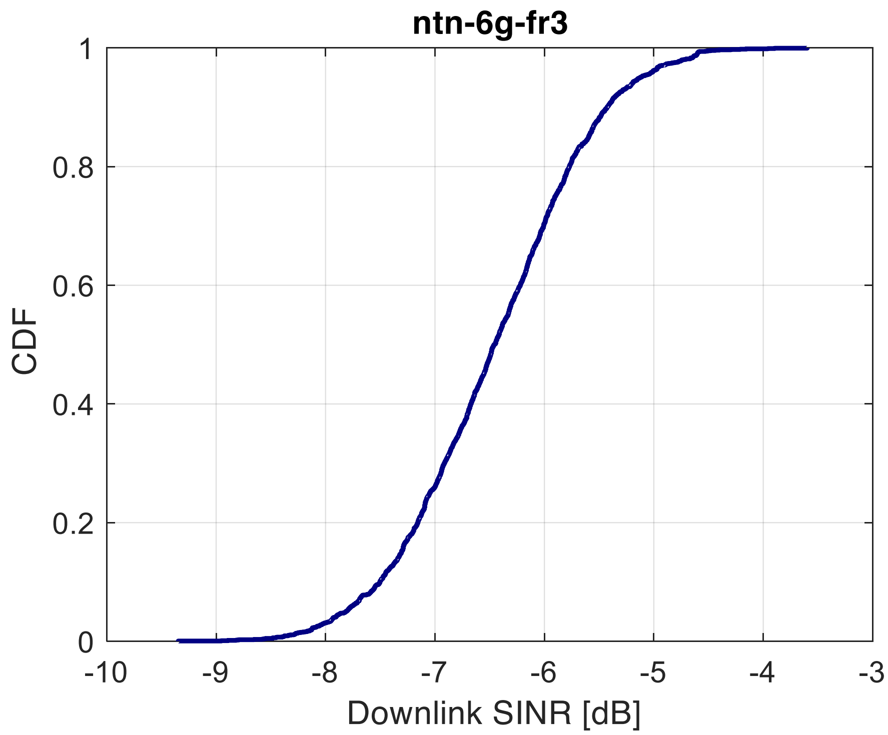


FIGURE 4-71 DOWNLINK SINR (DB)

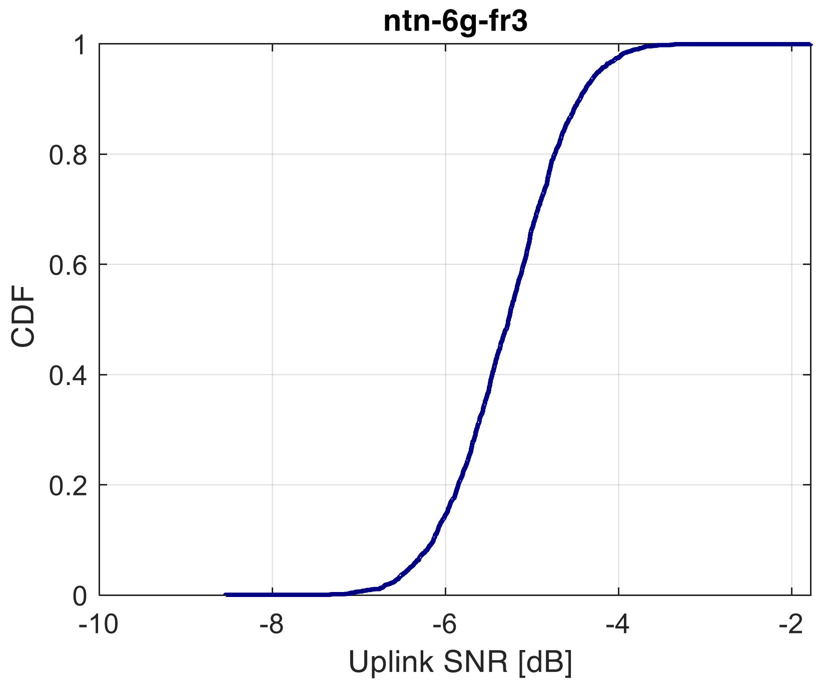


FIGURE 4-72 UPLINK SNR (DB)

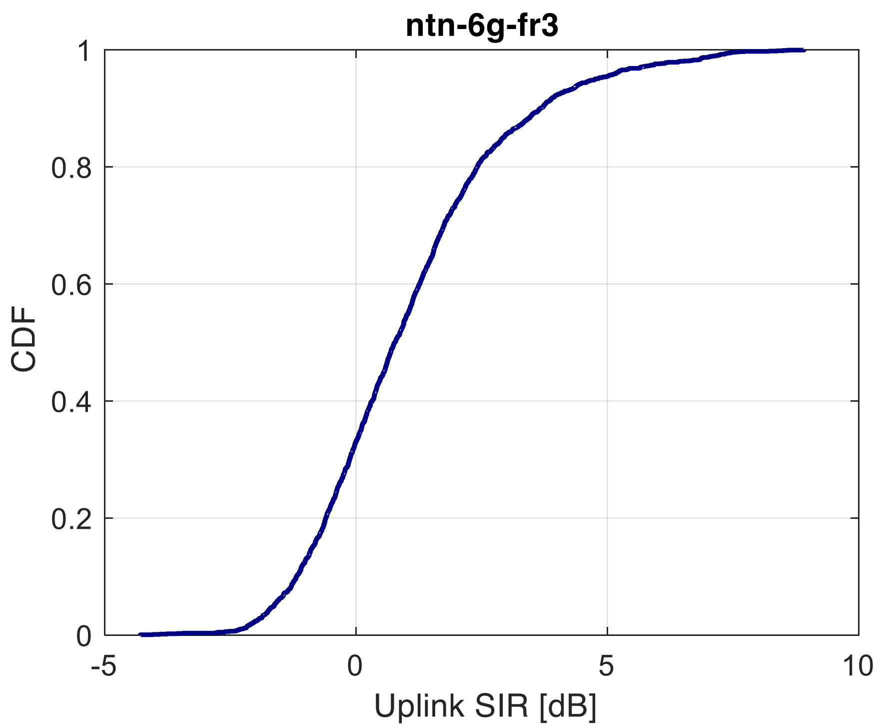


FIGURE 4-73 UPLINK SIR (DB)

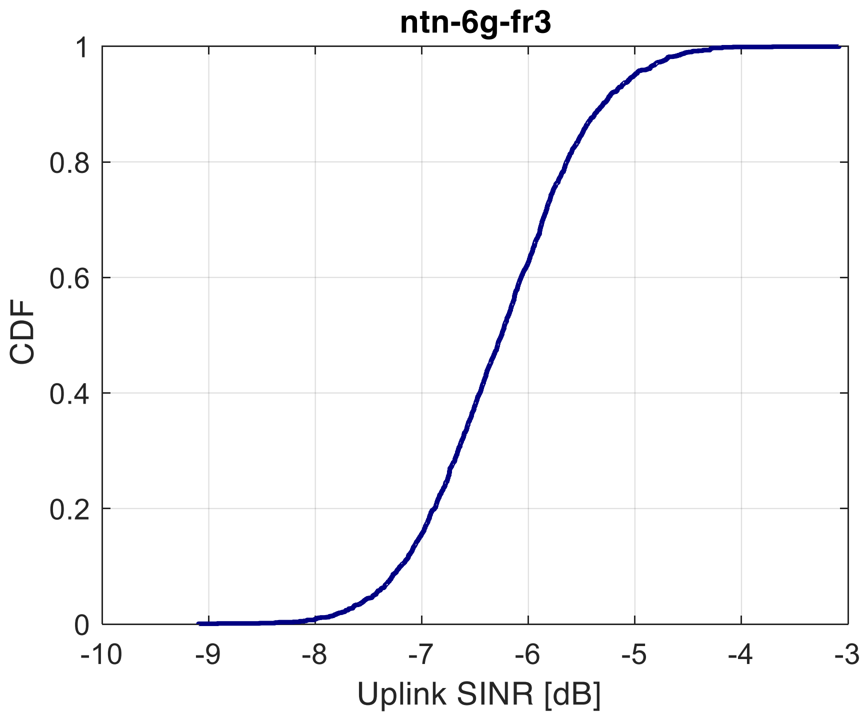


FIGURE 4-74 UPLINK SINR (DB)

4.2.7 Constellation C performances and number of gateways estimations.

4.2.7.1 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])

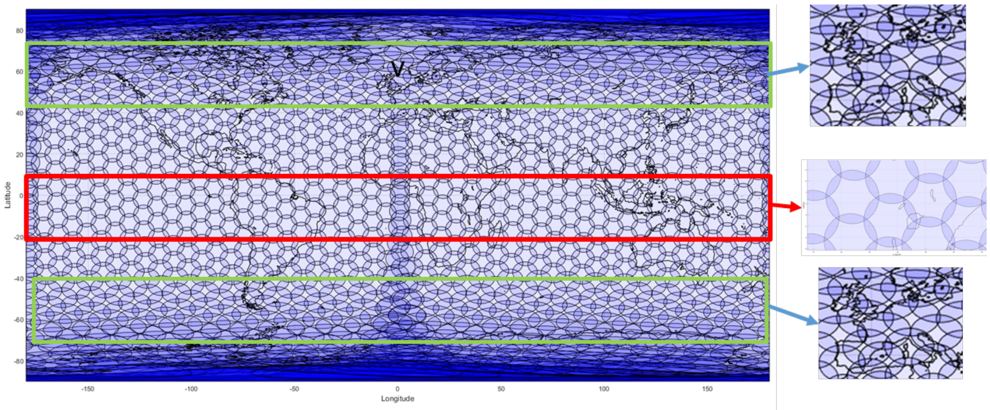


FIGURE 4-75 VIEW OF THE COVERAGE OVERLAP WITH ELVATION ANGLE [25]

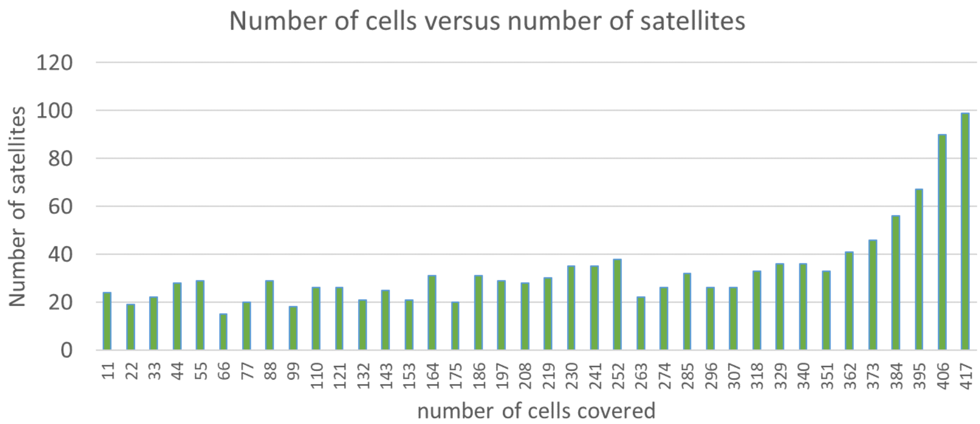


FIGURE 4-76 NUMBER OF SATELLITES AND ASSOCIATED CELLS TO COVER [25]

4.2.7.2 Constellation capacity evaluation C BAND

Case 1:

25, 50 and 100 active beams 28 dBW/MHz per beam

According to the FIGURE 4-76, the throughput of the constellation have been evaluated.

Up to the number of cells to serve corresponding to the number of actives beams, all of the beams are covered, otherwise a reduction factor due to Beam hopping have been applied.

SATELLITE				
nb active beams		100	50	25
Tx Throughput total cells	Gbps	4,45	2,225	1,1125
Tx throughput per cell	Gbps	0,0445	0,0445	0,0445
Rx Throughput total cells	Gbps	13,6	6,8	3,4
Rx throughput per cell	Gbps	0,136	0,136	0,136

FIGURE 4-77 THROUGHPUT PER SATELLITE FOR 25, 50 AND 100 ACTIVE BEAMS

The constellation capacity (maximum) is evaluated taking into account the superposition factor and is presented in the table FIGURE 4-78.

activity factor 100%	Aggregated throughput		nb of feeder	
nb active beams	Tx	Rx	Tx	Rx
28 dBW/MHz per beam	Gbps	Gbps		
nb active beams : 25	1394	4261	81	212
nb active beams : 50	2734	8355	159	416
nb active beams : 100	5232	15989	305	795

activity factor 30%	Aggregated throughput		nb of feeder	
nb active beams	Tx	Rx	Tx	Rx
28 dBW/MHz per beam	Gbps	Gbps		
nb active beams : 25	418	1278	27	71
nb active beams : 50	820	2506	53	139
nb active beams : 100	1569	4797	102	265

Max throughput activity factor 100%	Max throughput activity factor 30%

FIGURE 4-78 TOTAL THROUGHPUT

In these computation it has been considered that when the number of cells to serve is lower than the number of active cells then the available excess power is not used for enhance the capacity. The 3 cases 25, 50 and 100 case of active beams with the same EIRP density per beam, the power consumption consequently decrease with the number of active beam.

The constellation performances is given for the best case (best conditions) users placed at the center of the cells.

These figures give us an idea of the constellation's capacity. Full simulation calculations would be required to estimate the actual constellation capacity with exact cell configuration and statistical performance analysis.

4.3 LEO CONSTELLATION PAYLOAD Q/V

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

4.3.1 Mission description

4.3.1.1 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.

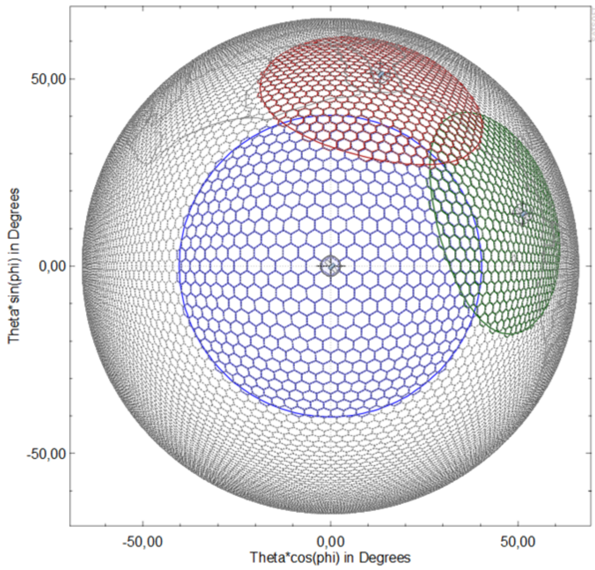


FIGURE 4-79 EARTH COVERAGE

The mission coverage in Q/V band will be identical to the C-band (see FIGURE 4-79), 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 +- 5km 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.

4.3.2 Payload description

The FIGURE 4-80 gives an obverwiew of the functions that the Q/V payload shall ensure in the two case of constellation (architecture 1 & architecture 2)

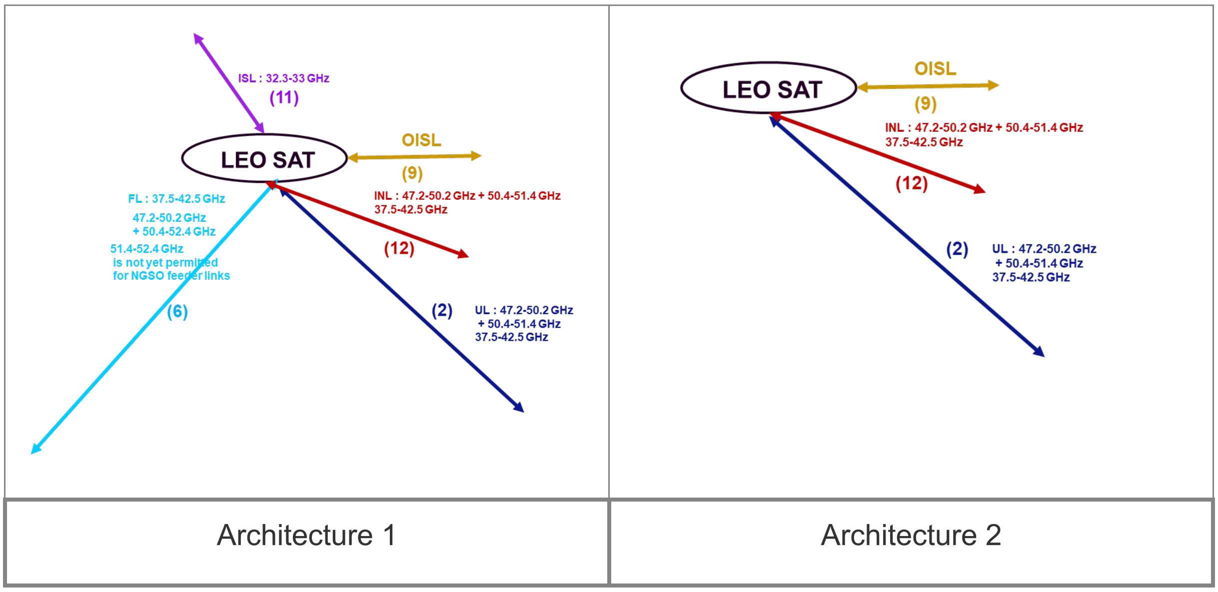


FIGURE 4-80 PAYLOAD Q/V-BAND FONCTIONNALITIES

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.

4.3.3 User link (Q/V-Band)

4.3.3.1 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:

		Frequency Range				Used Frequency		Channel Bandwidth		PRB						PRACH
	ID	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	Uplink Sat Rx / UE Tx	Downlink Sat Tx / UE Rx	Number of carriers	SCS bandwidth	PRB bandwidth	Number of PRB	PRACH bandwidth
		Fmin (GHz)	Fmax(GHz)	Fmin (GHz)	Fmax(GHz)	GHz	GHz	MHz	MHz	kHz	kHz	-	kHz	kHz	-	kHz
Q-V	Q_V2	47,2	50,4	37,5	40,5	50	40	400	400	1440	1440	12	120	1440	264	14400

FIGURE 4-81 NUMEROLOLY FR1 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 problem 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.

4.3.3.2 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 dissipationt. 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.

4.3.3.3 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**
Technology node	***Middle range***	***Middle range***	***Advanced***	***Advanced***	***Middle range***
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	☹	☹	😊	😊	😊

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

TABLE 2: 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].

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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.

4.3.3.4 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 El min of 45° in other word with a radiating element of 0.741 λ at higher frequency.

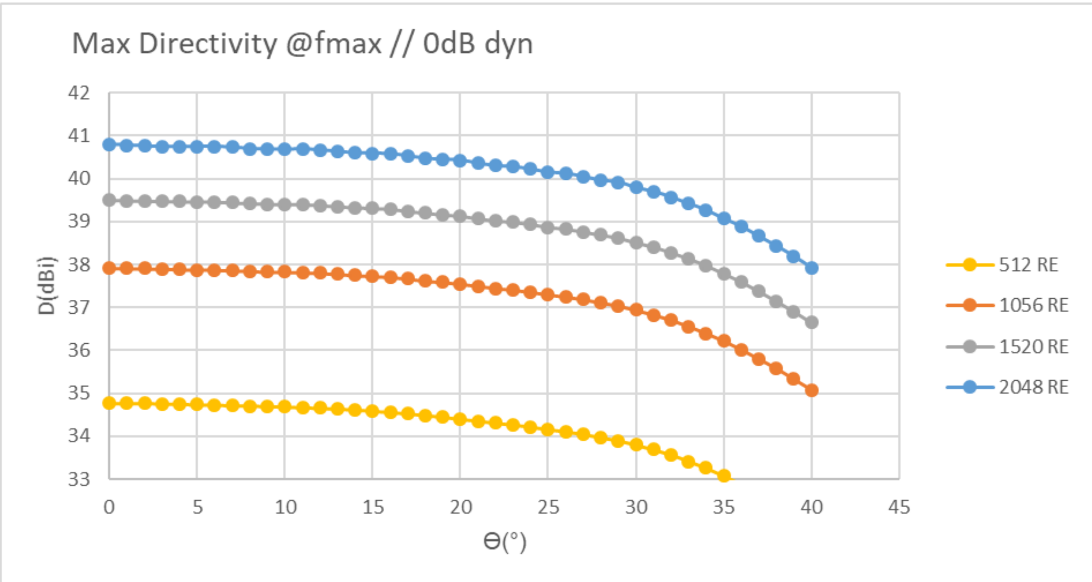


FIGURE 4-82 MAX DIRECTIVITY ANTENNA TRADE-OFF

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 reacheable 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-reccurent 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.

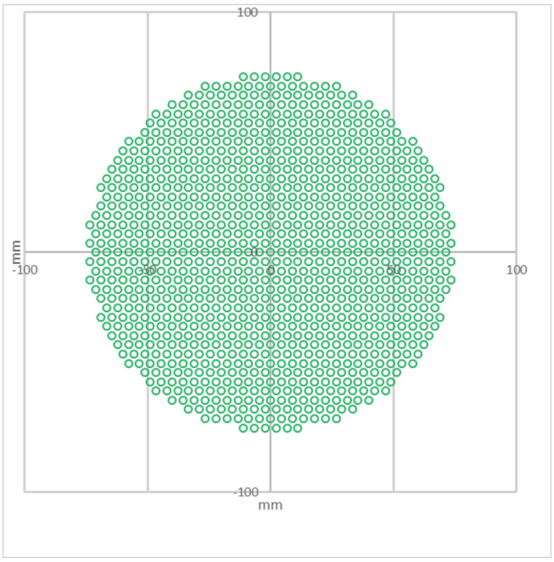
The validation and the tests of each antenna module will be facilitated and will also contribute to reduce the overall cost of the constellation.

4.3.4 Solution Q/V band Analysis

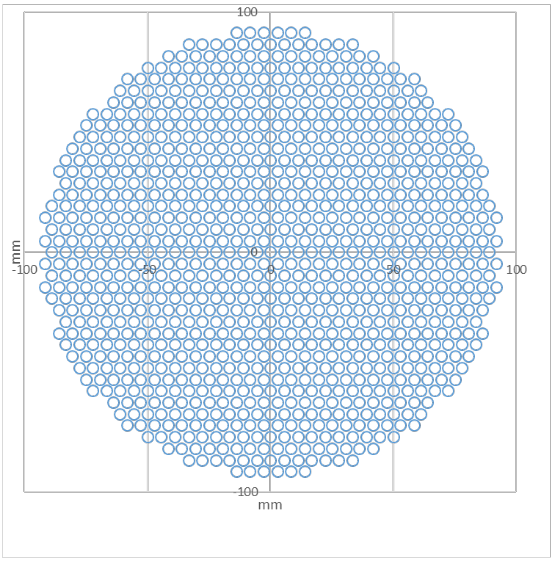
The following solutions are envisaged: antenna array of 512 to 1024 radiating elements.

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.

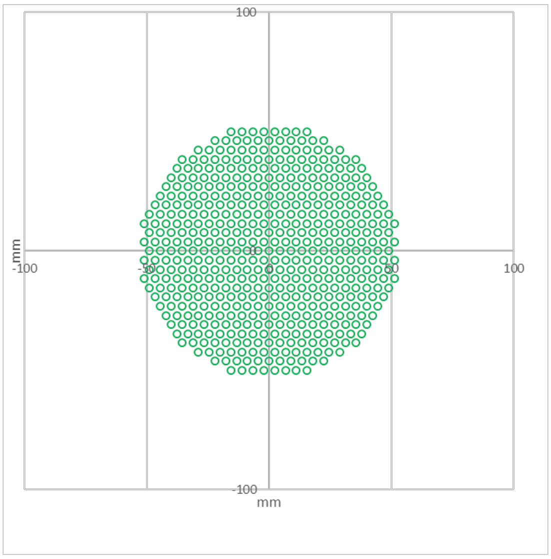
The Tx antenna shall be able to handle power dissipation and consequently low losses. The technology based on radiating aperture technology (waveguide) is preferable. It will include a polarization and a matching section or if this is not the case, then directly in patch antenna technology on PCB substrate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



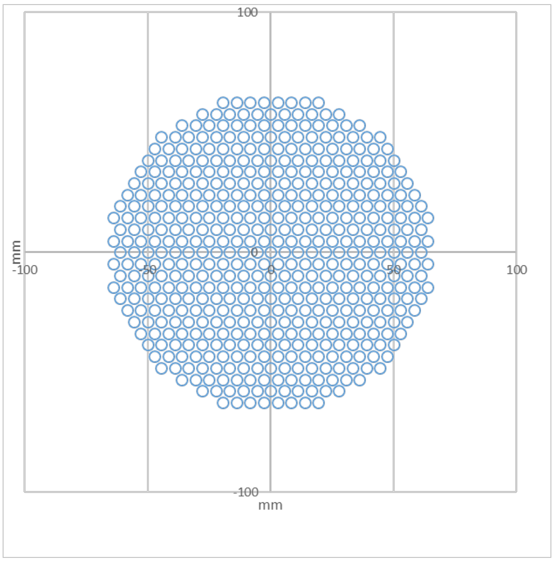
Rx 1024 RE



Tx 1024 RE



Rx 512 RE



Tx 512 RE

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 depends on the basic element, the BFIC 4x4 or 8x8 that with the elementary brick from which the whole architecture can be envisaged for builing 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.

4.3.4.1 Payload architecture

The payload architectures are presented in the FIGURE 4-84 to FIGURE 4-87.

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 architure 1 and 2 differs only in the presence or not of the 2 links ISL and Feeder.

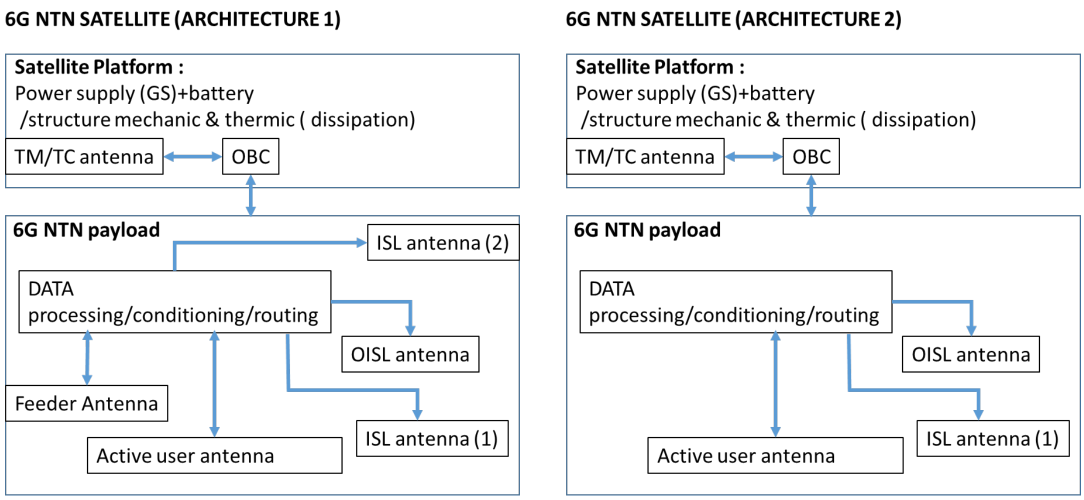


FIGURE 4-83 FUNCTIONNAL DESCRIPTION SATELLITE /PAYLAODS

The functional description of the payload and its interface description with the payload are illustrated in the FIGURE 4-83. The schematics of the payload has been detailed in the FIGURE 4-84.

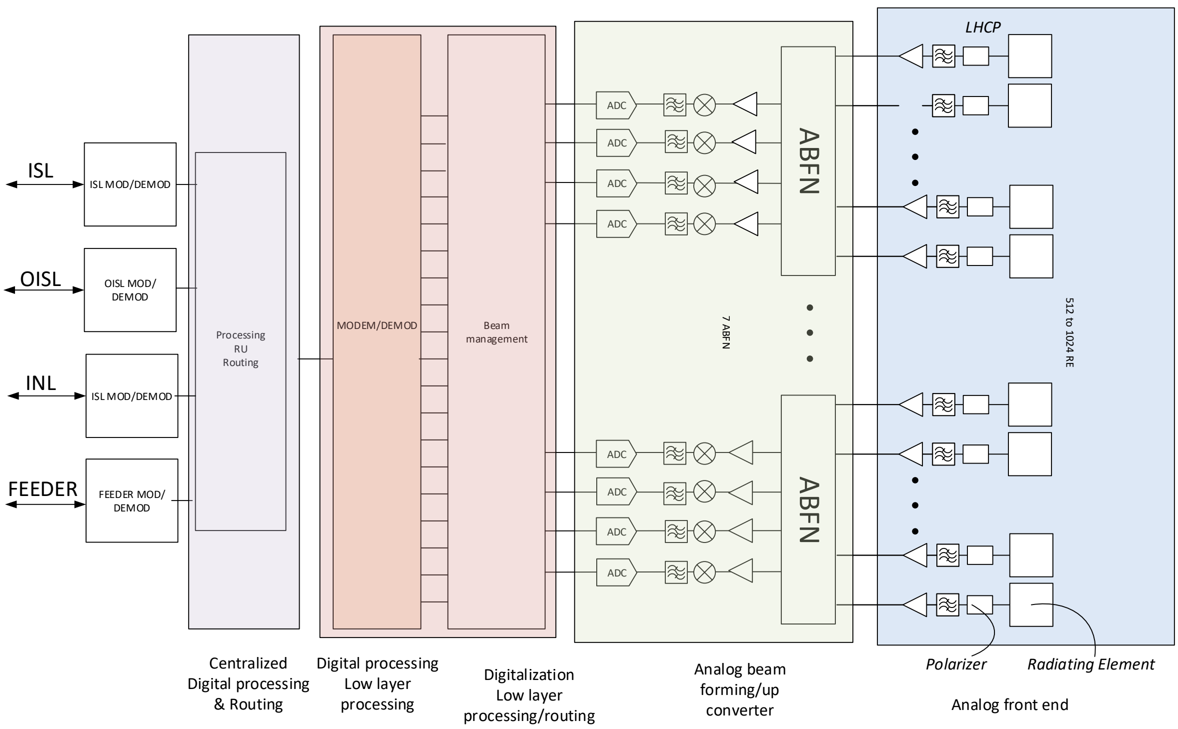


FIGURE 4-84 ARCHITECTURE 1 :V BAND RX ANTENNA SYSTEM

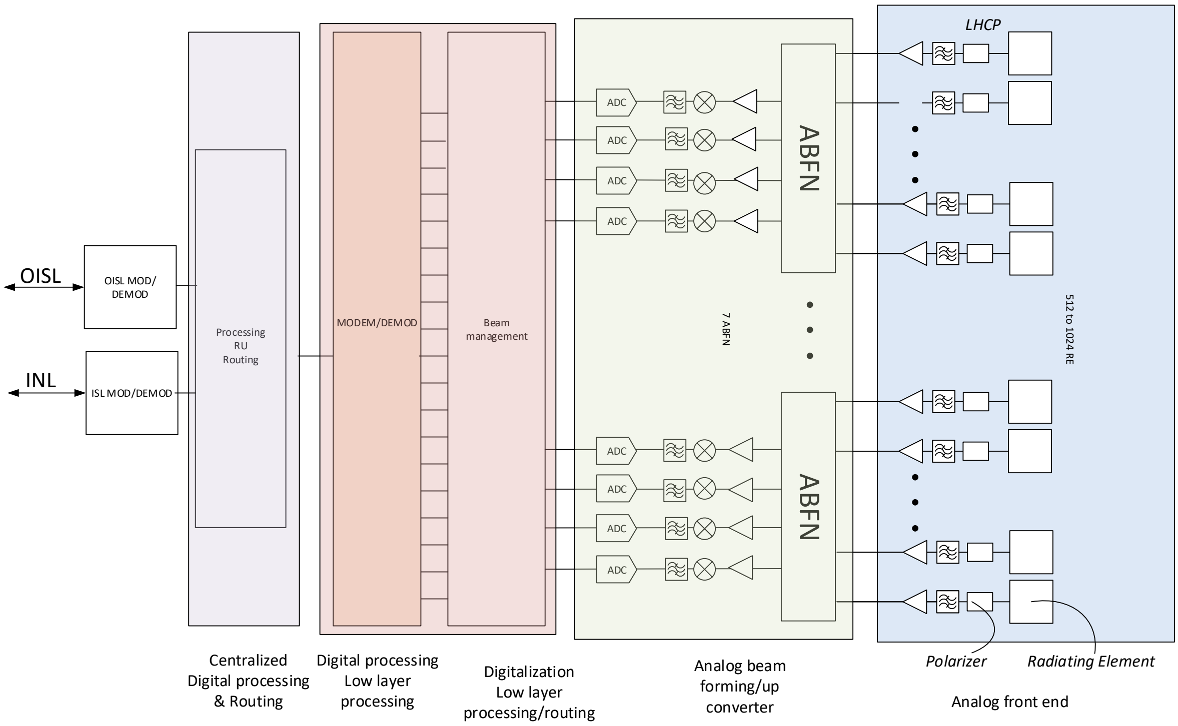


FIGURE 4-85 ARCHITECTURE 2 : V BAND RX ANTENNA SYSTEM

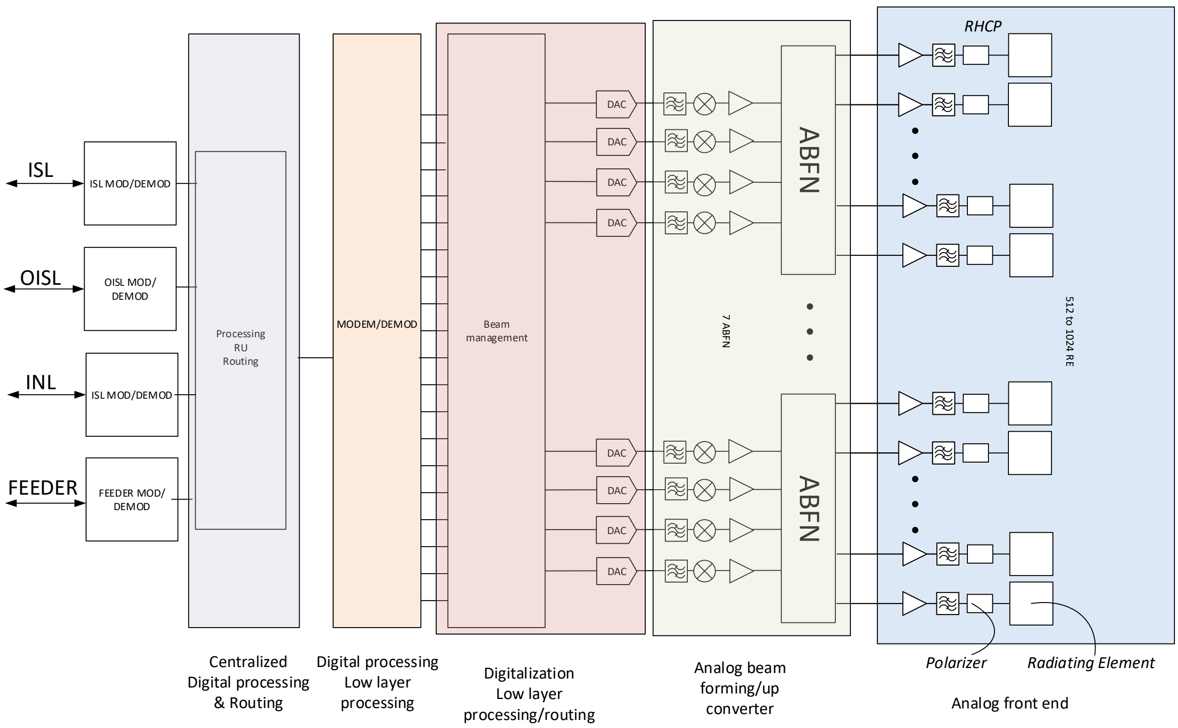


FIGURE 4-86 ARCHITECTURE 1 : Q BAND TX ANTENNA SYSTEM

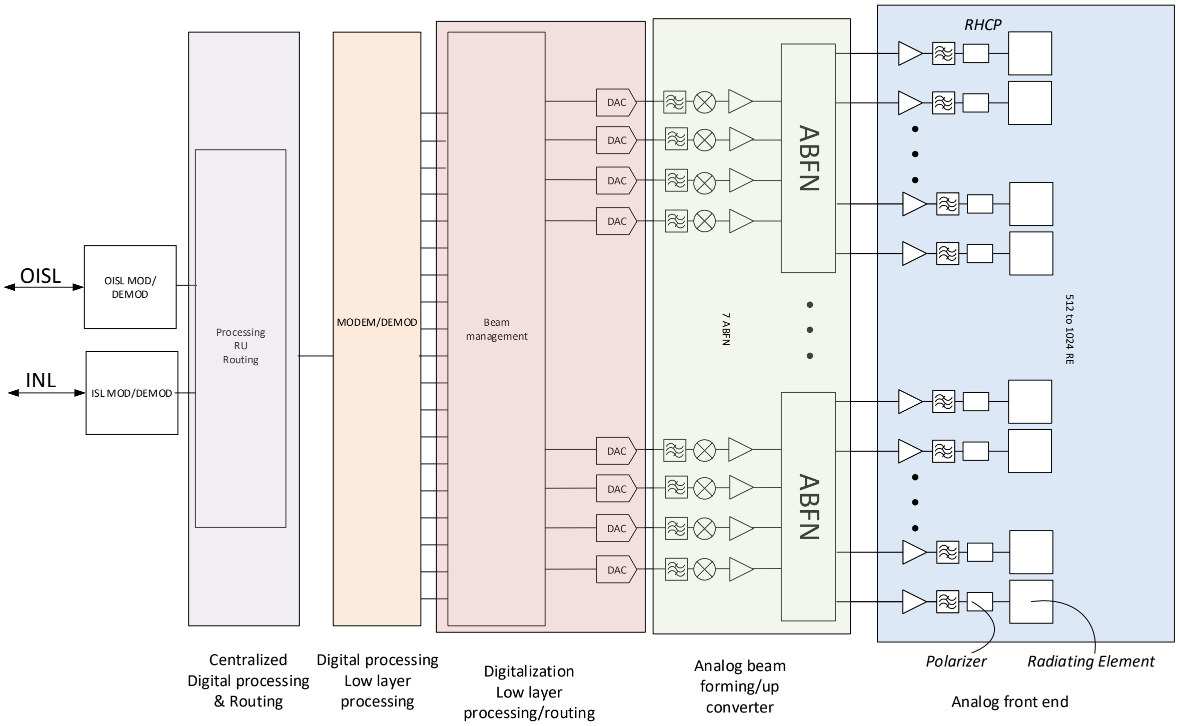
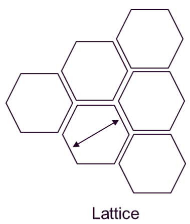


FIGURE 4-87 ARCHITECTURE 2: Q BAND TX ANTENNA SYSTEM

4.3.4.2 Radiating element model

The radiating model is a 0.741 λ elements as for the C-band. The lattice is hexagonal as shown in the FIGURE 4-88.



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 4-88 ANTENNA LATTICE

As mentionned 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 4-89. 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 4-89 SATELLITE ANTENNA RADIATING ELEMENT GAIN

The radiating element model is given in the figure FIGURE 4-90. In Tx and In Rx the same lattice have been taken as the two functions are separated in two separate antenna and associated payload.

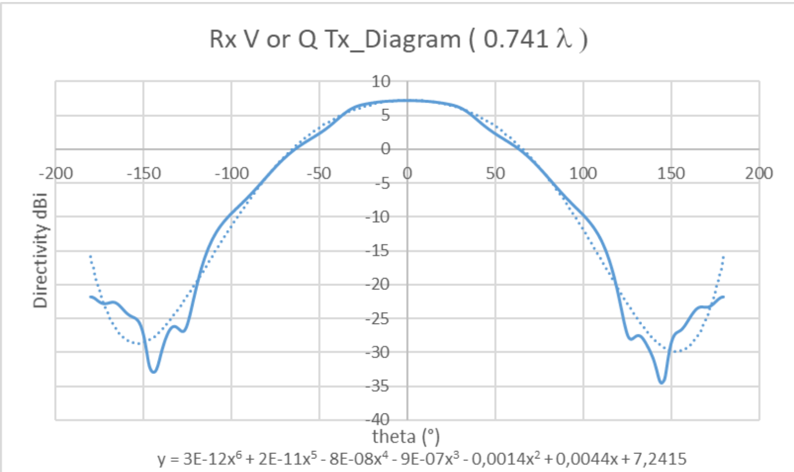


FIGURE 4-90 RADIATING ELEMENT DIAGRAMS FOR Q/V BAND (DIRECTIVITY)

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.

4.3.4.3 Antenna definition

The antenna panel is composed of 7 antenna of each function Rx and Tx as illustrated in the FIGURE 4-91. 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 4-84 à FIGURE 4-87.

Co-funded by the European Union

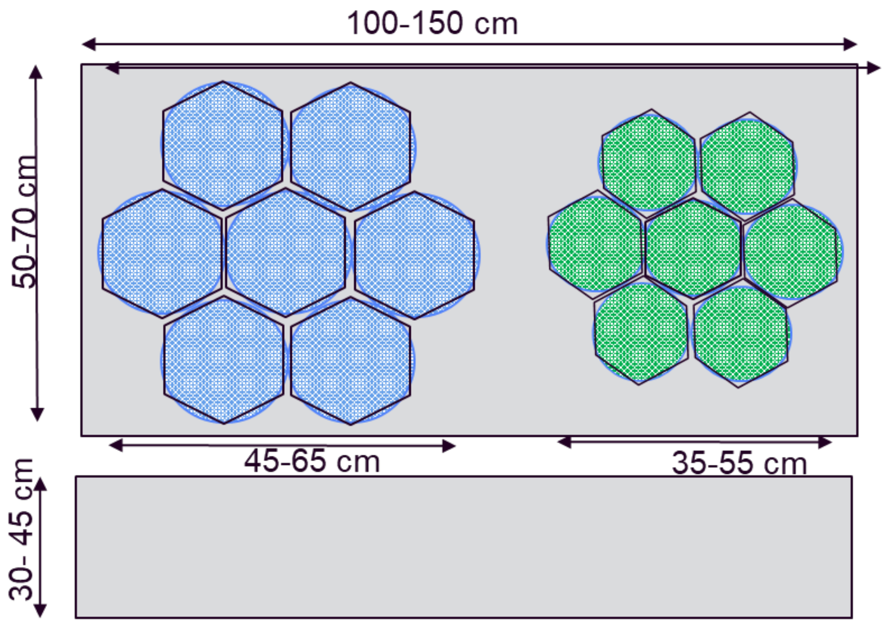


FIGURE 4-91 ANTENNA PANNEL

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 4-93 and FIGURE 4-92for 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.

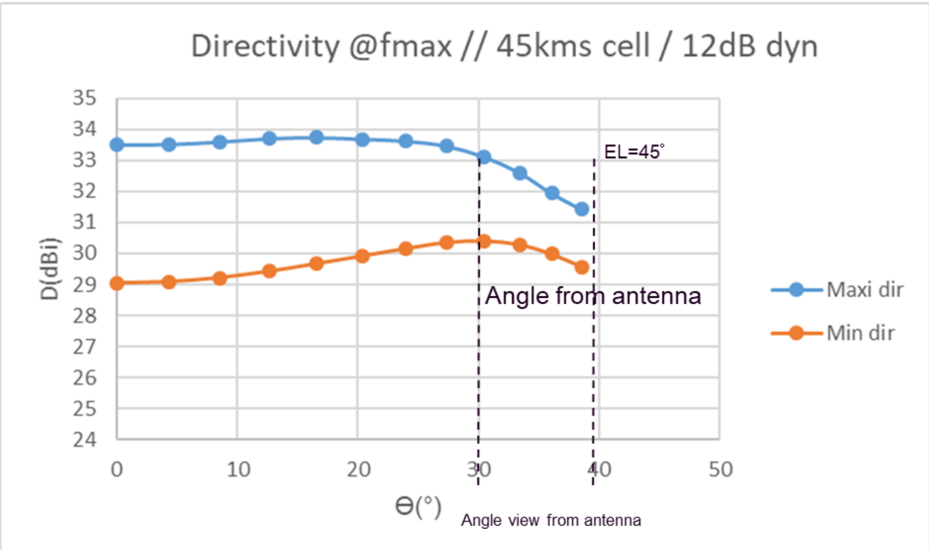


FIGURE 4-92 ANTENNA PERFORMANCES 512 RE IN DEPOINTING (DYN.=12 DB)

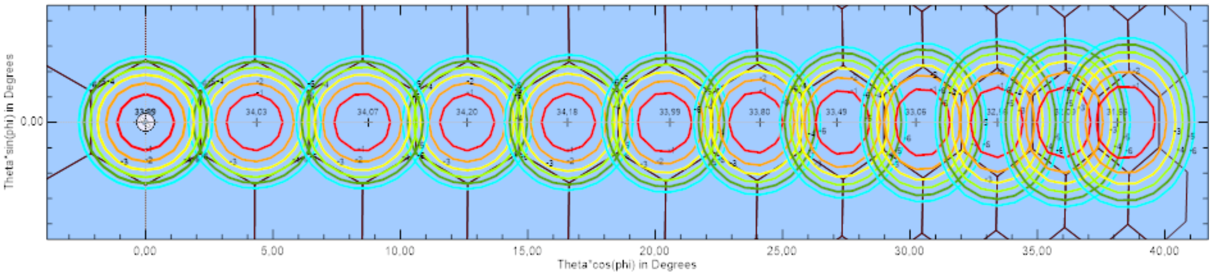


FIGURE 4-93 ANTENNA PERFORMANCES 512 RE IN DEPOINTING (DYN.=12 DB)

Similarly, performance for the same antenna but with beamforming dynamics limited to 6 dB is shown in FIGURE 4-94 and FIGURE 4-95 The roll-off is between 5 dB at nadir to 2 dB at the edge.

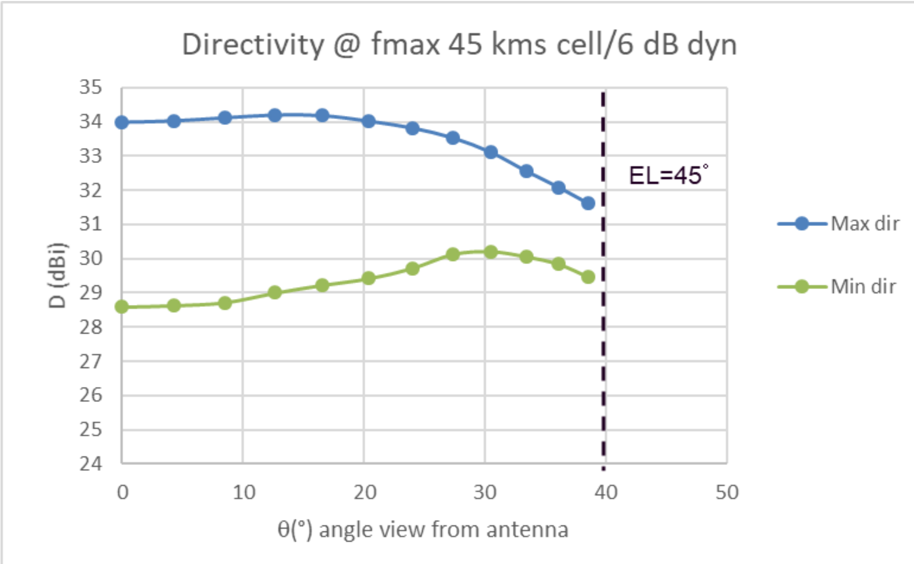


FIGURE 4-94 ANTENNA PERFORMANCES 512 RE IN DEPOINTING (DYN.=6 DB)

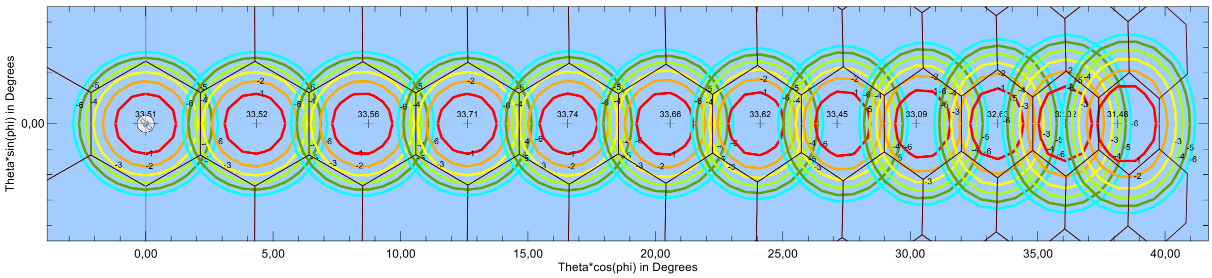


FIGURE 4-95 BEAM PERFORMANCES IN DEPOINTING 6DB

Performance at nadir is not optimal in terms of roll-off, but what is very dimensionning 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 relaxe the dynamic up to 12 dB in Rx.

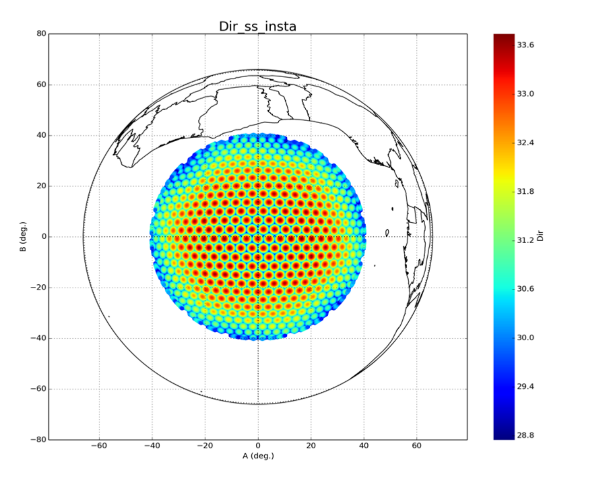
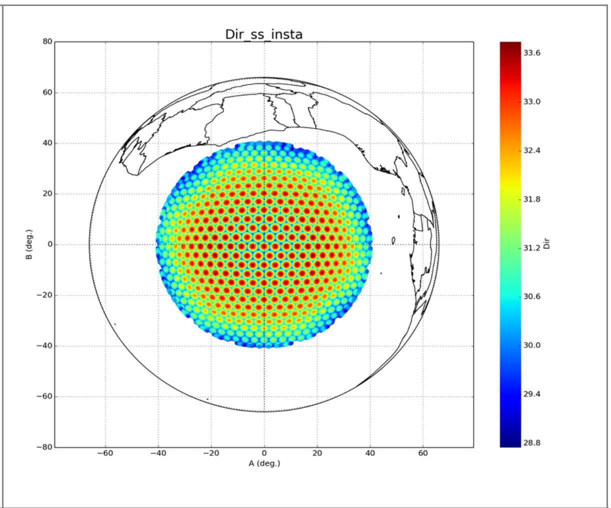
	
12 dB dynamic (Rx) DRA 512 RE 0.741 λ	6 dB dynamic (Tx) DRA 512 RE 0.741 λ

FIGURE 4-96 512 RE 12 DB AMPLITUDE & 6 DB AMPLITUDE

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

The flat panel is composed of 7 identical antenna pannels that have the same performances over the cells. Each antenna covers the same area: a coverage of EL min of 45° (red in FIGURE 4-98- (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.

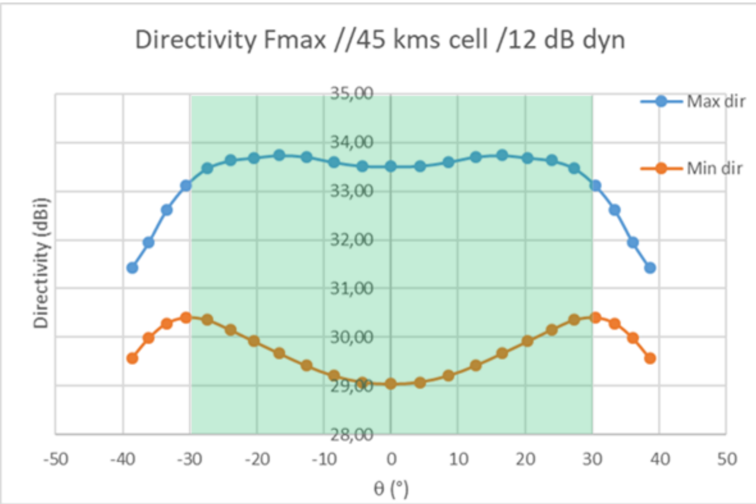


FIGURE 4-97 PERFORMANCE OF ANTENNA WITH SLIGH ANGLE

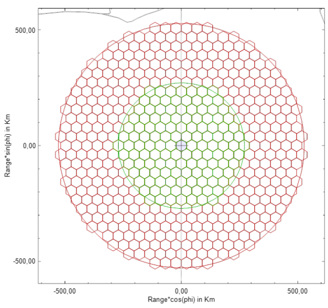
This optimization phasis to enhance the performance shall be evaluated with the restriction that it will induce in term of beam management. This feature could be taken as an axis of future improvments.

The coverage as defined could be optimized:

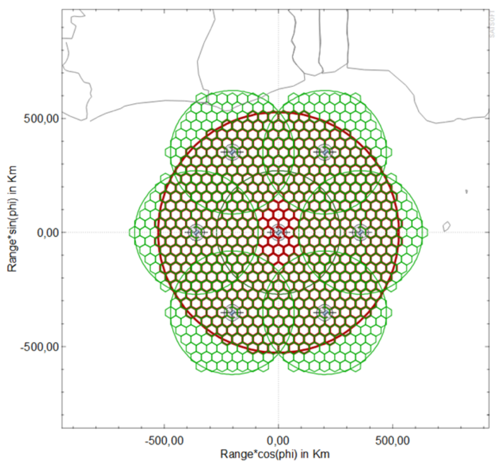
- a depointing angle could be applied allowing to defined an priority area for each antenna (green in FIGURE 4-98).

  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.



(a) preferred area (green)
(b) service area (red)



(c) coverage extension = difference between red area and green area

FIGURE 4-98 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:

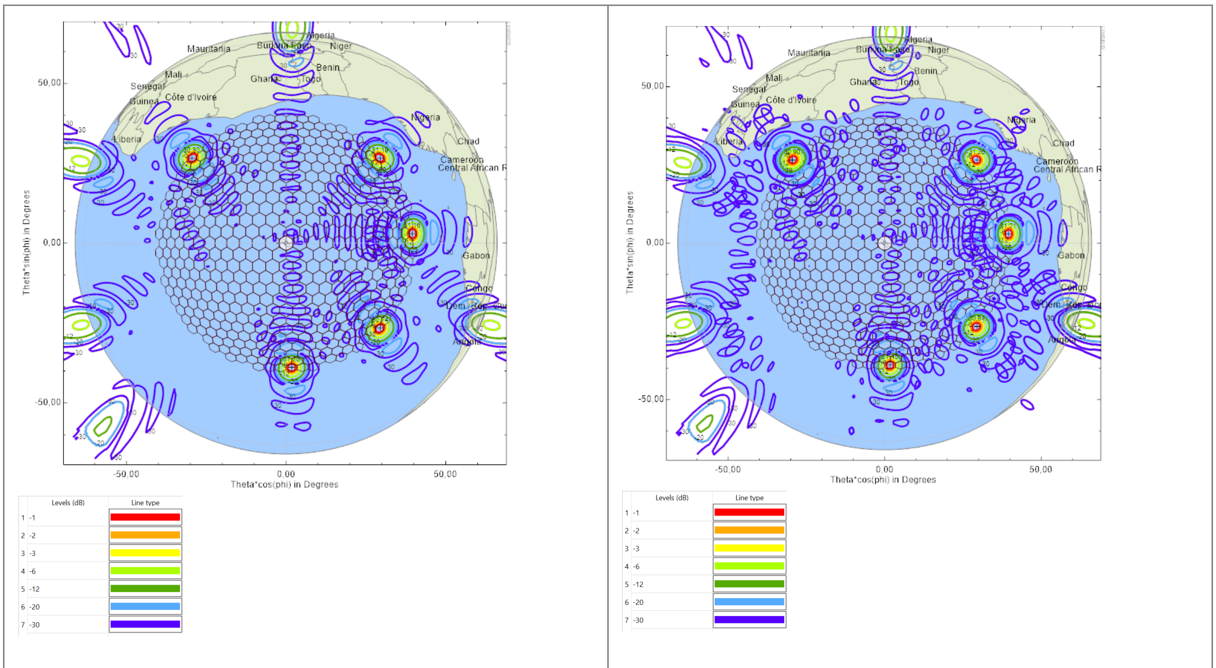
- C/I contraints (if a deterministic frequency reuse scheme is not used)
- Number of beams by sub area.

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.

4.3.4.4 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 0.741 λ. 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 somme 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.



12 dB dynamic	6 dB dynamic

FIGURE 4-99 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.

4.3.5 Link Budget

4.3.5.1 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 4-100 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.

4.3.5.2 Antenna performances

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

	SATELLITE				Directivity		GAIN	
	freq(GHz)	λ	lattice	lattice	NADIR	EL 45°	NADIR	EL 45°
		mm	lambda	mm	dBi	dBi		
Tx	40	7,5	0,741	5,5575	7,31	5,80	5,31	3,80
Rx	50	6	0,741	4,446	7,31	5,80	5,31	3,80

FIGURE 4-101 ELEMENTARY ELEMENT PERFORMANCES SATELLITE

	TERMINAL				DIRECTIVITY		GAIN	
	freq(GHz)	lambda	maille	maille	NADIR	EL 45°	NADIR	EL 45°
		mm	lambda	mm	dBi	dBi	dBi	dBi
Rx	40	7,5	0,741	5,5575	7,31	5,80	5,81	4,30
Tx	50	6	0,741	4,446	7,31	5,80	5,31	3,80

FIGURE 4-102 ELEMENTARY ELEMENT PERFORMANCES TERMINAL

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 4-103

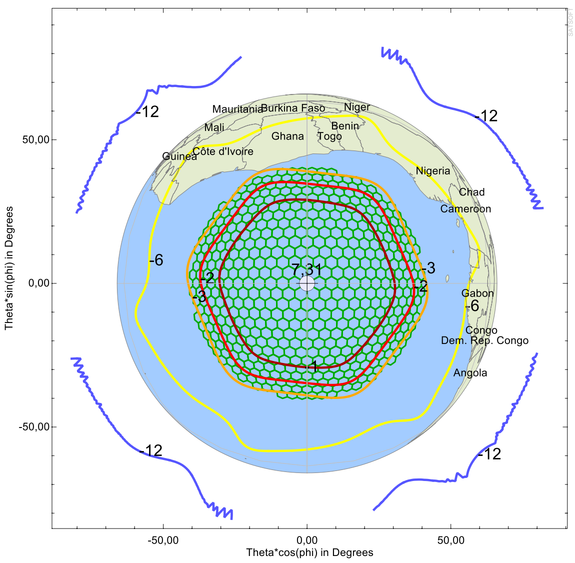


FIGURE 4-103- RADIATING ELEMENT MODEL 0.741 λ

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 discrenpency. 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 0.741 λ.

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.

SATELLITE		FREQ	Size (ϕ)	nb element	directivity			Gain	
	Antenna	GHz	m		nadir	El 45°	losses	nadir	El 45°
					dBi	dBi	dB	dBi	dBi
	Q Tx	40	0,13205	512	34,4	32,9	1,4	33,0	31,5
	V Rx	50	0,10564	512	34,4	32,9	2,0	32,4	30,9

FIGURE 4-104 SATELLITE ANTENNA PEFORMANCES

Terminal		FREQ	Size (ϕ)	nb element	directivity			Gain	
	Antenna	GHz	m		nadir	El 45°	losses	nadir	El 45°
					dBi	dBi	dB	dBi	dBi
	QRx	40	0,11	379	33,1	31,6	1,5	31,6	30,1
	VTx	50	0,09	379	33,1	31,6	2,0	31,1	29,6

FIGURE 4-105 TERMINAL ANTENNA PERFORMANCES

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

4.3.5.3 Satellite hypothesis: resume

The table of FIGURE 4-106 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 or 8
	Cell size	km	45
	Use of Scan Losses	-	YES
TX (downlink)	Downlink Frequency	GHz	40,00
	Antenna Size	m	0,13
	Number of ER	-	512
	Directivity ER (NADIR)	dBi	7,31
	Directivity ER (El 45°)	dBi	5,80
	Directivity ER (El 30°)	dBi	4,30
	Losses ER	dB	1,4
	Antenna gain (NADIR)	dBi	33,00
	Antenna gain (El 45°)	dBi	31,49
	Antenna gain (El 30°)	dBi	29,99
	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
	Directivity ER (NADIR)	dBi	7,31
	Directivity ER (El 45°)		5,80
	Directivity ER (El 30°)		4,30
	Losses ER	dB	2
	Antenna Temperature	K	240,00
	Ambiant Temperature	K	290,00
	Equivalent Temperature	K	767,33
	Antenna gain (NADIR)	dBi	32,40
	Antenna gain (45°)	dBi	30,89
	Antenna gain (30°)	dBi	29,39
	G/T (NADIR) Target	**dB/K**	**4,00**
	G/T (NADIR)	**dB/K**	**3,55**
	G/T (45°)	dB/K	2,04
SCS PRB	SCS	kHz	120
	Downlink BW	MHz	400
	Nb Downlink PRBs	-	264
	Uplink BW	MHz	400
	Nb Uplink PRBs	-	264

FIGURE 4-106 SATELLITE HYPOTHESIS

4.3.5.4 UE hypothesis: summary

The table of FIGURE 4-107 and FIGURE 4-106 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	0,1
	Number of ER	-	379
	Antenna Noise Figure (NF)	dB	4,20
	Antenna gain (NADIR)	dBi	31,59
	Antenna gain (45°)	dBi	30,09
	G/T (NADIR)	dB/K	3,06
	G/T (45°)	dB/K	1,56
SCS PRB	SCS	kHz	120
	Downlink BW	MHz	400
	Nb Downlink PRBs	-	264
	Uplink BW	MHz	400
	Nb Uplink PRBs	-	264
TX (uplink)	Uplink Frequency	GHz	50,00
	Antenna Size	m	0,08
	Number of ER	-	379
	Antenna gain (NADIR)	dBi	31,09
	Antenna gain (45°)	dBi	29,59
	Antenna gain (30°)	dBi	28,08
	Antenna transmit power	dBW	4
	Antenna transmit power	W	2,51

FIGURE 4-107 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 8.6 and 8.7.

4.3.6 Constellation 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 4-76) as the coverage is identical.

activity factor 100%	Aggregated throughput		nb of feeder	
nb active beams	Tx	Rx	Tx	Rx
18.2 dBW/MHz per beam	Gbps	Gbps		
nb active beams : 56	21612	60747	1259	3022
nb active beams : 28	11052	31968	644	1591

activity factor 30%	Aggregated throughput		nb of feeder	
nb active beams	Tx	Rx	Tx	Rx
18.2 dBW/MHz per bea	Gbps	Gbps		
nb active beams : 56	6483	18224	420	1007
nb active beams : 28	3316	9590	215	530

FIGURE 4-108 THE TABLE GIVES THE NUMBER OF FEEDER REQUIRED

4.4 LEO CONSTELLATION SATELLITE DESIGN

The FIGURE 4-109 give an "artistic" view of the two type of satellite (Feeder and User), the tables of FIGURE 4-110 the C-band satellites description and the table of FIGURE 4-111 the Q/V band satellites for Architecture 1 and 2.

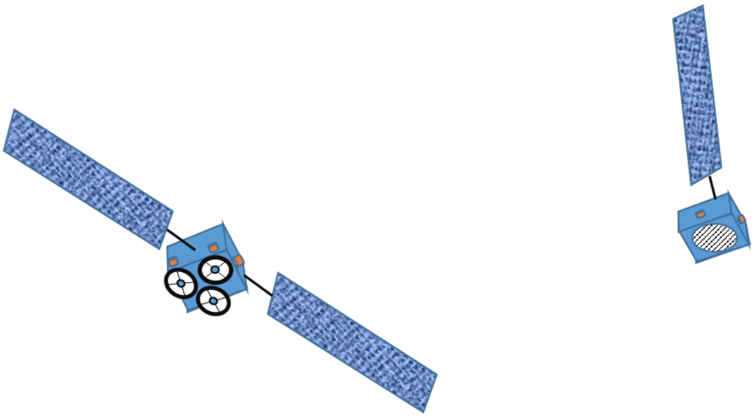


FIGURE 4-109 FEEDER SATELLITE & USERS SATELLITE (ARCH. 2)

In architecture 2, the feeder are on the earth deck of the feeder satellite and the user antenna on the earth deck of the User satellite.

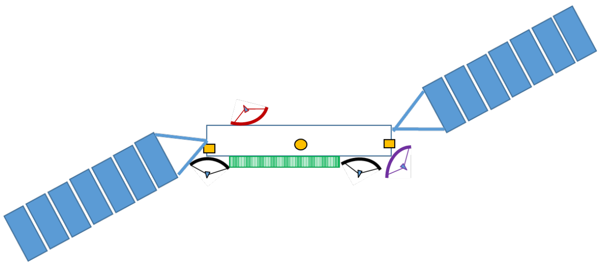
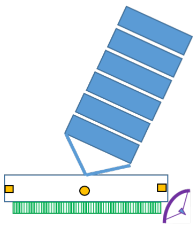
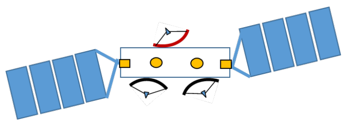
ARCHITECTURE 1	ARCHITECTURE 2	
User Satellite LEO C-band	User Satellite LEO C-Band	Feeder Satellite LEO C-Band
		
OISL (4) C-BAND DRA (1) Q/V band feeder (2) Q/V band INL (1) Ka band ISL (1)	OISL (2) C-BAND DRA (1) Q/V band INL (1)	OISL (8) Q/V band Feeder (2) Ka Band ISL (1)

FIGURE 4-110 SATELLITE DESCRIPTION C-BAND

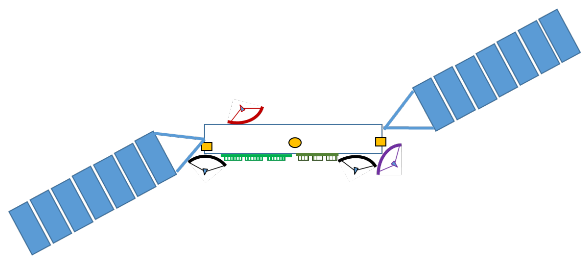
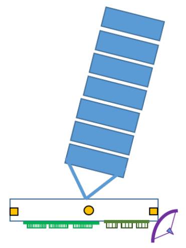
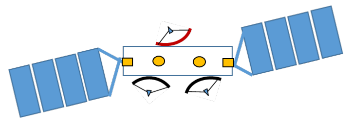
<table>
<tr><th>ARCHITECTURE 1</th><th colspan="2">ARCHITECTURE 2</th></tr>
<tr><td>User Satellite LEO Q/V-band</td><td>User Satellite LEO Q/V-Band</td><td>Feeder Satellite LEO Q/V-Band</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>OISL (4)
C-BAND DRA (1)
Q/V band feeder (2)
Q/V band INL (1)
Ka band ISL (1)</td><td>OISL (2)
Q-BAND DRA (7)
V-BAND DRA (7)
Q/V band INL (1)</td><td>OISL (8)
Q/V band Feeder (2)
Ka Band ISL (1)</td></tr>
</table>

FIGURE 4-111 SATELLITE DESCRIPTION Q/V-BAND

4.5 UAV PAYLOAD (HAPS) (FLEXIBLE)

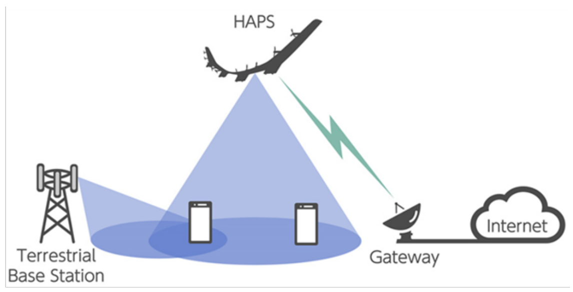
4.5.1 HAPS and Drones as a Station

4.5.1.1 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 temporarly 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 “scalabilty concept” of the 6G NTN.

4.5.1.2 State of art

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

 	 
Example project Thales Alenia Space [120]	Example: Arerial coverage (Softbank) [121]

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.

4.5.2 Mission descriptions

4.5.2.1 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.

4.5.2.2 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

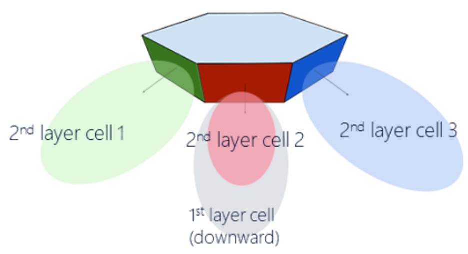
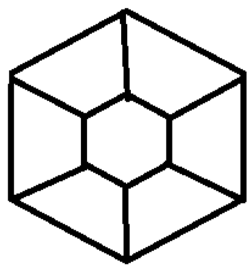
FIGURE 6 **Example of HIBS antenna design (for 7 cells deployment)**  	
Altitude 20-50 km: payload composed of 7 pannels	Face view of the panel: Central panel DRA of 2x2 elements Side panel: DRA of 4x2 elements Gain of 8 dBi per elements

FIGURE 4-112 EXEMPLE OF ANTENNA SOLUTIONS PROPOSED

The solution in [49] decribed in the figure FIGURE 4-112 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.

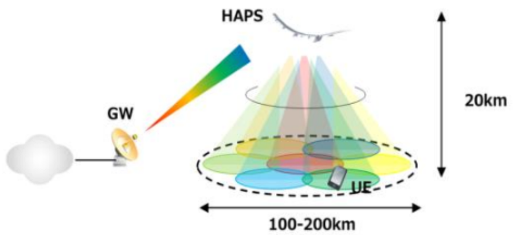
<table>
<tr>
<td>


Fig. 1. Overall structure of the HAPS system.

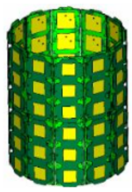
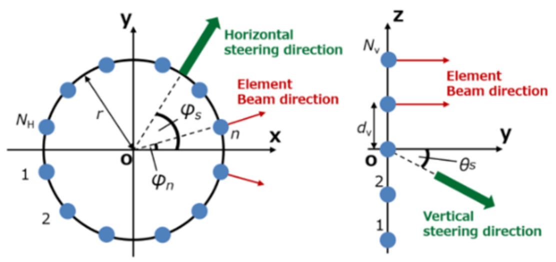



Fig. 2. Cylindrical array antenna.
</td>
<td>


(a) Circular array (b) Linear array
Fig. 3. Cylindrical array antenna.
</td>
</tr>
<tr>
<td>Coverage and antenna view</td>
<td>Steering</td>
</tr>
</table>

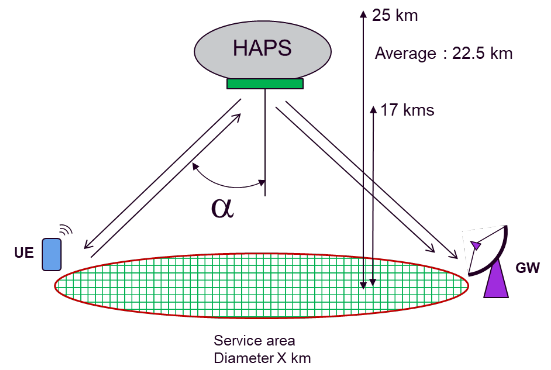
FIGURE 4-113 EXEMPLE OF ANTENNA SOLUTIONS PROPOSED IN [122]

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.

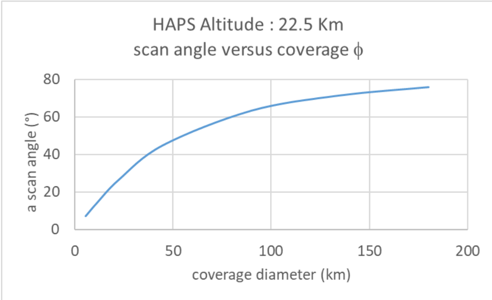
4.5.2.3 Coverage selection

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 4-114 gives the parameters that define the HAPS coverage.



HAPS	Service are	max angle	(UE--SAT-GW-SAT-UE)x2	
Altitude	coverage /diameter	α	RTT max	RTT min
(°)	km	(°)	ms	ms
22,5	5,625	7,13	0,30	0,30
22,5	11,25	14,04	0,31	0,30
22,5	22,5	26,57	0,34	0,30
22,5	45	45,00	0,42	0,30
22,5	90	63,43	0,67	0,30
22,5	135	71,57	0,95	0,30
22,5	180	75,96	1,24	0,30



Parameter definition	Max angle / RTT: between a UE at edge and nadir

FIGURE 4-114 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 4-114, 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 4-116) 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.

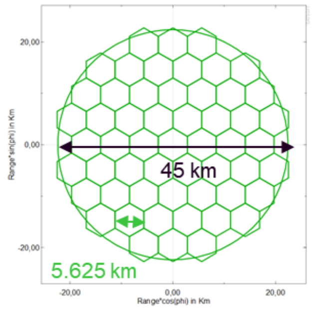
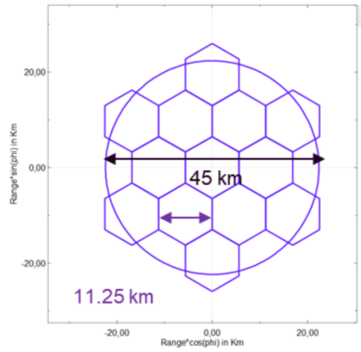
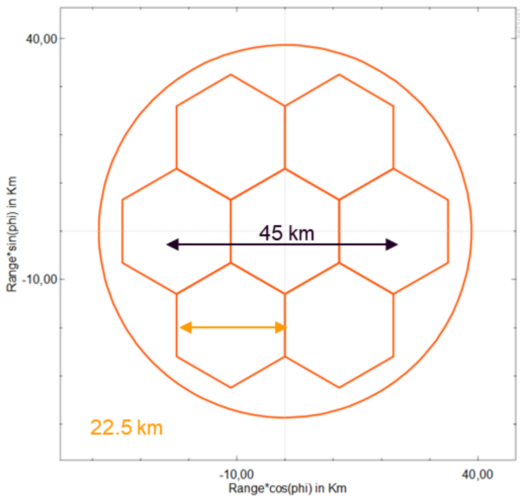
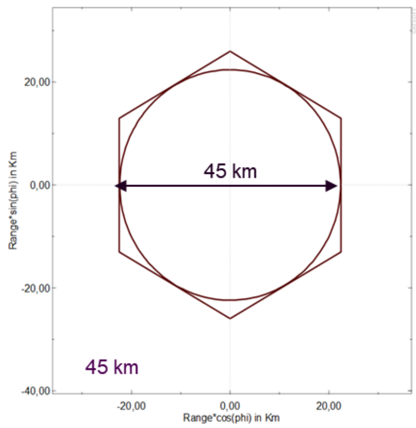
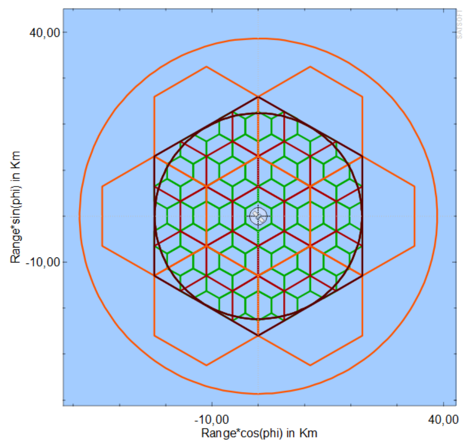
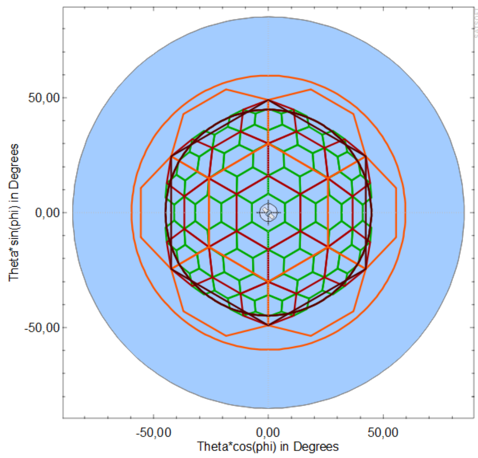
<table>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Cell size = 5,625 km. 54 cells</td>
<td>Cell size = 11.25 km. 13 cells</td>
</tr>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Cell size = 22.5 km. 7 cells</td>
<td>Cell size: 45 km. 1 cell</td>
</tr>
</table>

FIGURE 4-115 CELLS DEFINITIONS

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





Coverage view on earth (km)

Alt.= 22.5 km

Coverage view from HAPS (°)

Alt.= 22.5 km

Half cone angle of a beam to cover a cell (5,625 km,11.25, 22.5 & 45 km) versus Haps Altitude at nadir

	cell size			
	5.625 km	**11.25 km**	**22.5 km**	**45 km**
Altitude	**angle**	**angle**	**angle**	**angle**
km	**(°)**	**(°)**	**(°)**	**(°)**
17	9,4	18,3	33,5	52,9
22,5	7,1	14,0	26,6	45,0
25	6,4	12,7	24,2	42,0
delta (°)	3,0	5,6	9,3	10,9

Max scan angle versus HAPS altitude

Service Area 45 km with sub-cells		
Altitude 22.5 km		
cell size	**half cone angle**	**scan angle(max)**
km	**(°)**	**(°)**
5,625	7,1	45
11,25	16,05	45
22,5	26,7	45
45	45	0

FIGURE 4-116 COVERAGE IMPACT VERSUS HAPS ALTITUDE AND CELLS SIZE

The tables in FIGURE 4-116 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 4-116 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.

Co-funded by the European Union

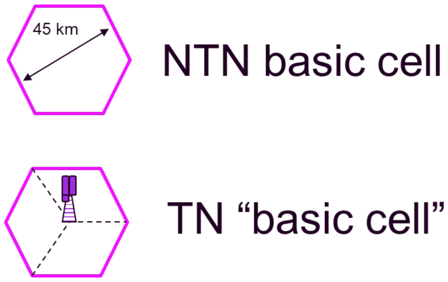


FIGURE 4-117 NTN CELL AND TN SECTOR COVERAGE COMPATIBILITY

4.5.3 Payload functionalities

The FIGURE 4-118 gives a view of all the link that the node (Haps_sta or Drone_sta) shall ensure.

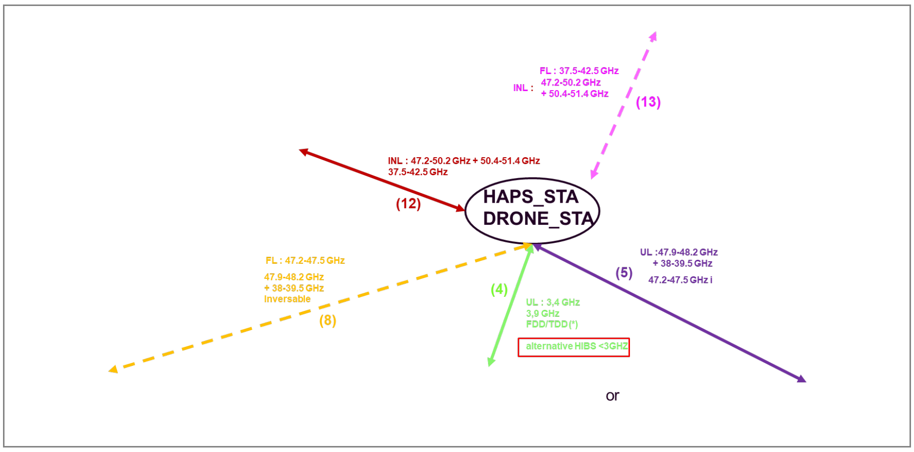


FIGURE 4-118 GEO CONSTELLATION AND THE LINK (USER, INTERNODES, FEEDER)

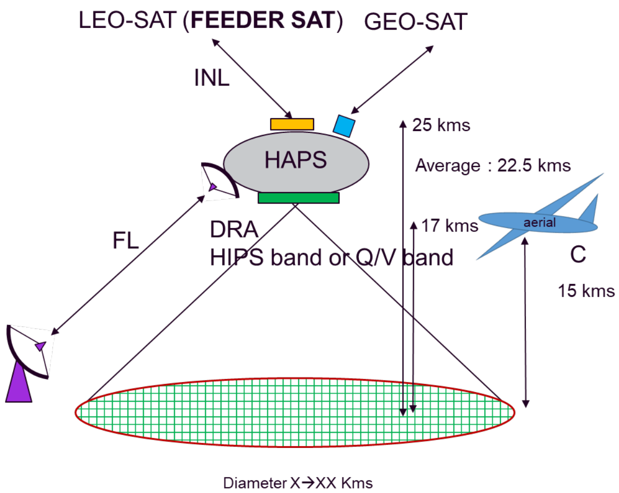


FIGURE 4-119 LINK DESCRIPTION FROM A HAPS

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 o r to a Feeder satellite in the case of architecture 2.

4.5.4 User Links S band (HIBS)

4.5.4.1 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):

		Frequency Range				Used Frequency		Channel Bandwidth		PRB						PRACH
	ID	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	Uplink Sat Rx / UE Tx	Downlink Sat Tx / UE Rx	Number of carriers	SCS bandwidth	PRB bandwidth	Nummber of PRB	PRACH bandwidth
		Fmin (GHz)	Fmax(GHz)	Fmin (GHz)	Fmax(GHz)	GHz	GHz	MHz	MHz	kHz	kHz	-	kHz	kHz	-	kHz
S	S2	1,98	2,015	2,16	2,2	2	2	20	20	180	180	12	15	180	106	1800

FIGURE 4-120 NUMEROLOLY 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 4-121 ALTERNATIVE FREQUENCY BAND

4.5.4.2 Orientation

The HAPS users link is in the HIBS bands at lower frequenbcy (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 environement). 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 optimuim 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.

4.5.4.3 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 El min of 45° but the avoidance angle shall not generate grating lobes towards will orient to take a RE of 0.55 λ.

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.

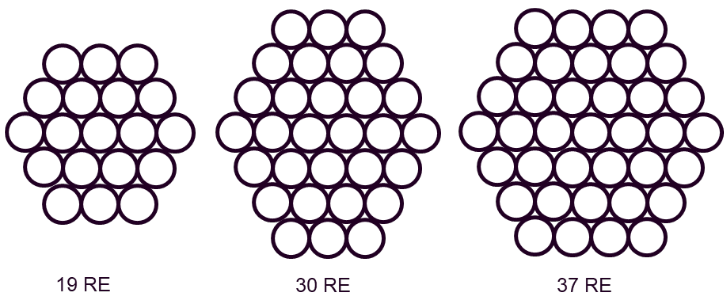


FIGURE 4-122 DRA SIZING

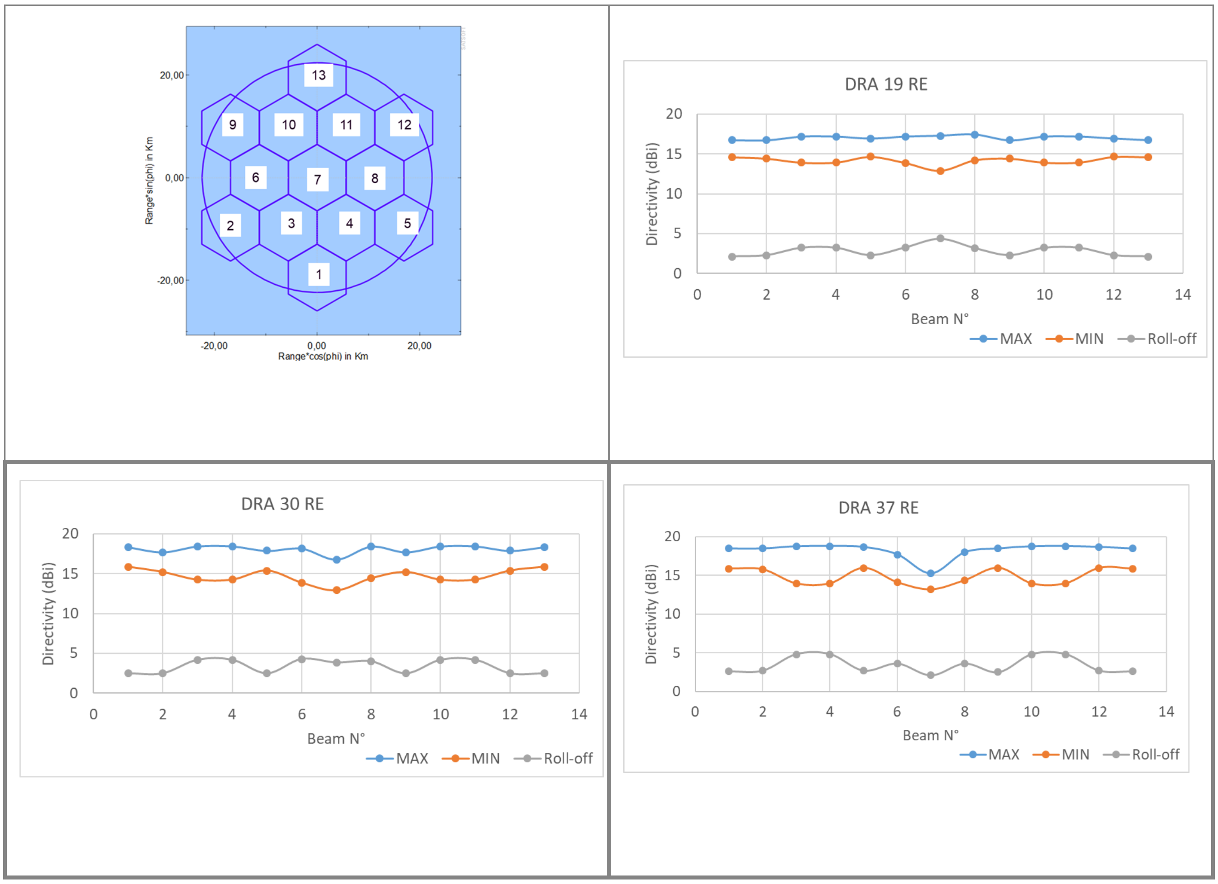


FIGURE 4-123 MAX/MIN DIRECTIVITY ANTENNA TRADE-OFF

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 4-123.

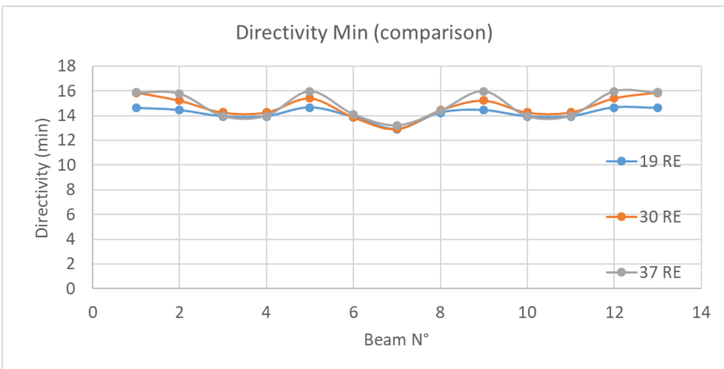


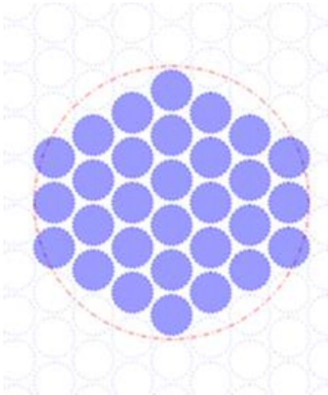
FIGURE 4-124 DIRECTIVITY MIN COMPARISON

The 30 RE DRA could be a compomise 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.

4.5.5 Solution S band Analysis

The following solutions 30 RE:



-

FIGURE 4-125 ANTENNA ARRAY GEOMETRY

The antenna have 30 RE in an hexagonal lattice. The spacing will be 0.55 λ 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.

4.5.5.1 Payload architecture

The payload architectures are presented in the FIGURE 4-127.

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.

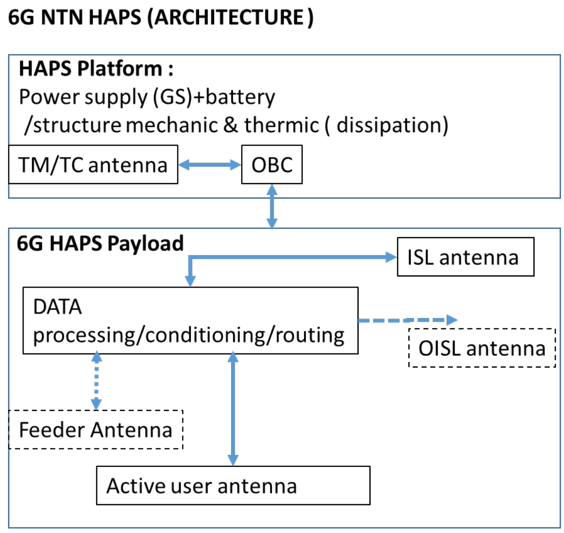


FIGURE 4-126 FUNCTIONNAL DESCRIPTION HAPS/PAYLOAD

The beamforming will be based on a DBFN.

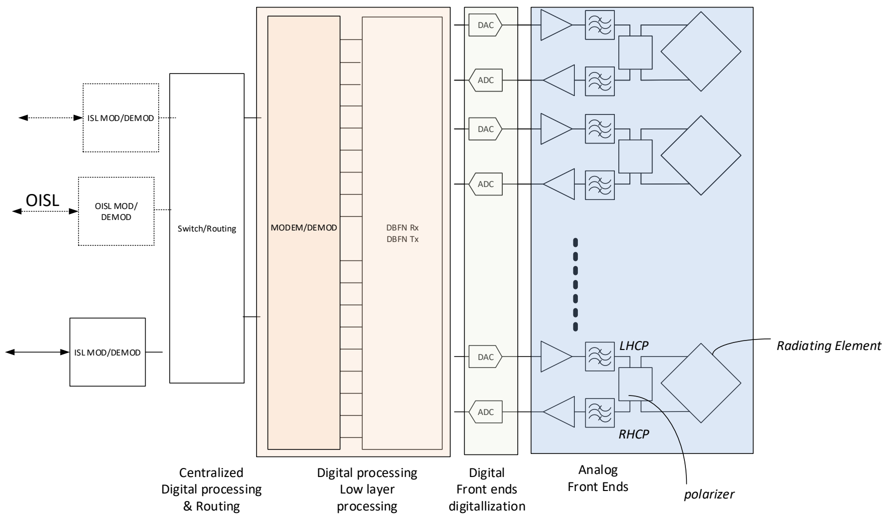
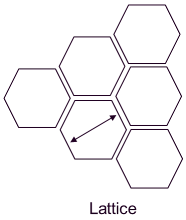


FIGURE 4-127 HAPS PAYLOAD ARCHITECTURE S BAND

4.5.5.2 Radiating element model

The radiating model is a 0.55 λ elements. The lattice is hexagonal as shown in the FIGURE 4-88.



	Freq (GHz)	Lambda	λ	mm
Tx	2	150	0,55	82,5
Rx	2	150	0,55	82,5

FIGURE 4-128 ANTENNA LATTICE

The radiating element model is given in the figure FIGURE 4-90. In Tx and In Rx the same lattice have been taken as the two functions are separated in two separate antenna and associated payload.

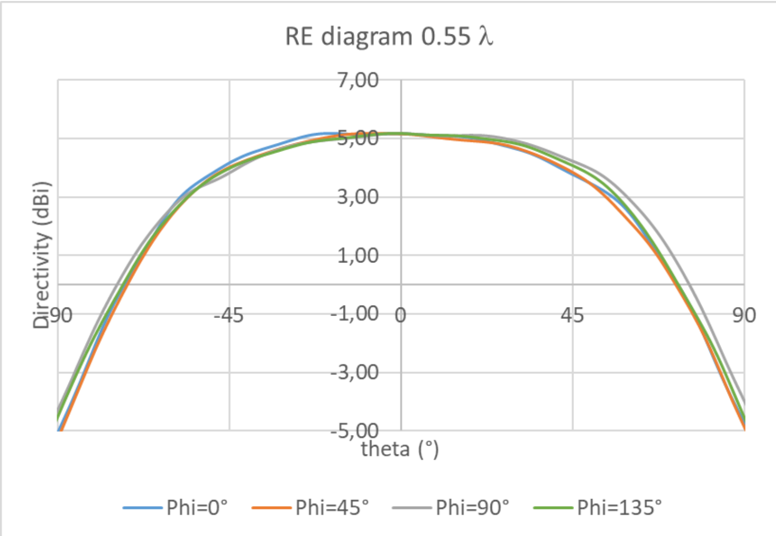


FIGURE 4-129 RADIATING ELEMENT DIAGRAMS FOR S BAND (DIRECTIVITY)

The radiating element size is 0.55 λ. Close to 0.5 λ, 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.

4.5.5.3 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 4-130, show the definition of the cells. Moreover the choice of the RE size to 0.55 λ lets margin to cover some cells outside the nominal region of 45 cell.

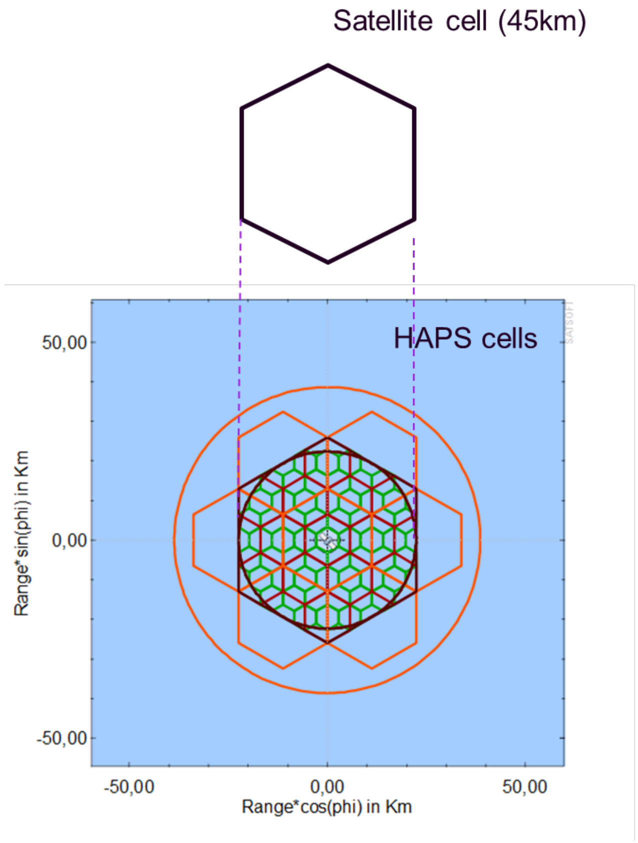


FIGURE 4-130 CORRESPONDENCE BETWEEN CELL DEFINITIONS (SATELLITE & HAPS) AND NESTINGS

The beams view for the different cell size are given in the following FIGURE 4-131 fo 5.615 kms cell, FIGURE 4-132 for the 11.25 km cell, FIGURE 4-133

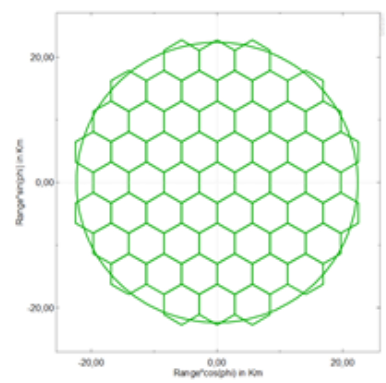
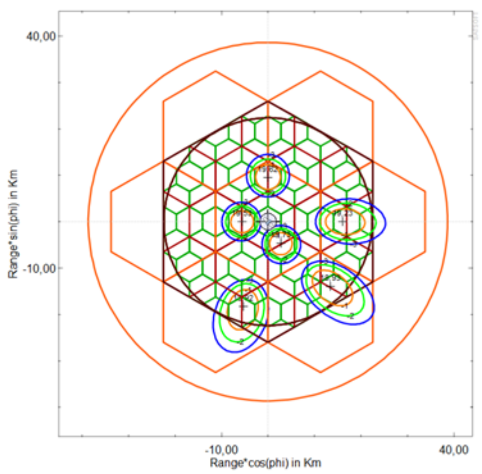
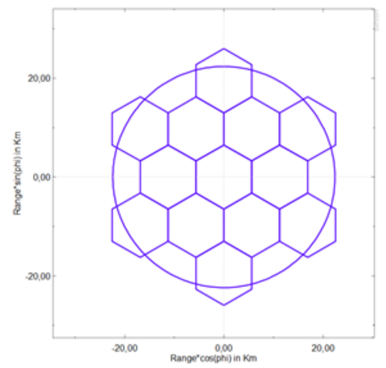
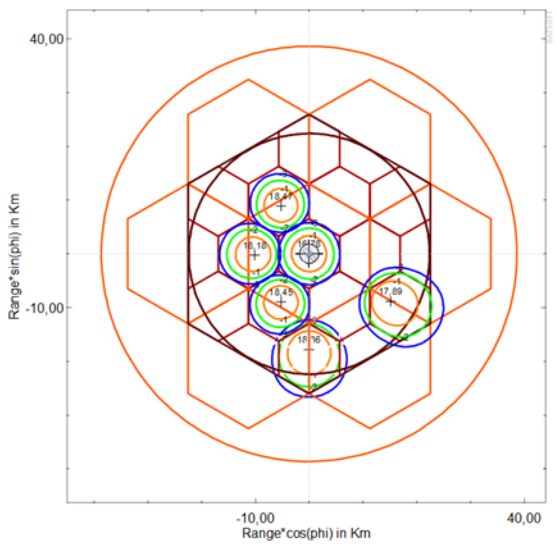
	
Cells 5.625 km (54 cells)	Beam on cells 5.625 km

FIGURE 4-131 BEAM ON COVERAGE COMPOSED OF CELLS OF 5.625 KM

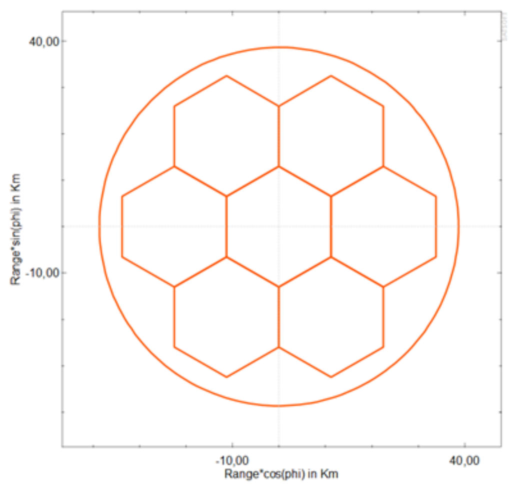


Cells 11.25 km (13 cells)

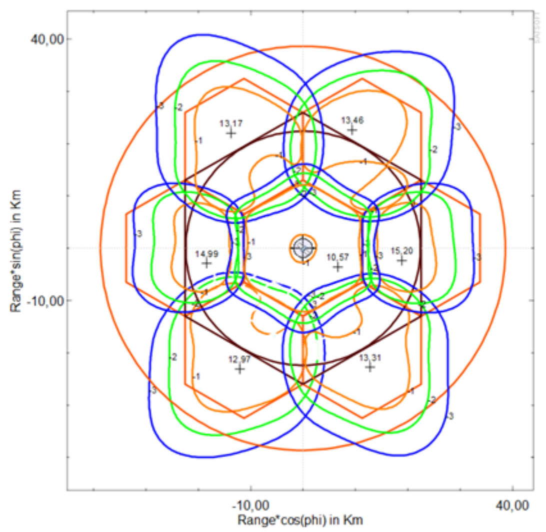


Beam on cells 11.25 km

FIGURE 4-132 BEAM ON COVERAGE COMPOSED OF CELLS OF 11.25 KM



Cells 22.5 km (7 cells)



Beam on cells 22.5 km

FIGURE 4-133 BEAM ON COVERAGE COMPOSED OF CELLS OF 22.5 KM

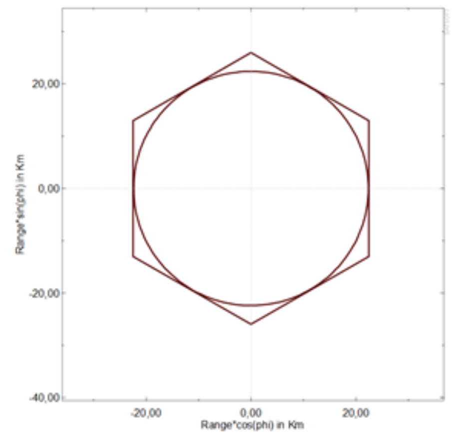
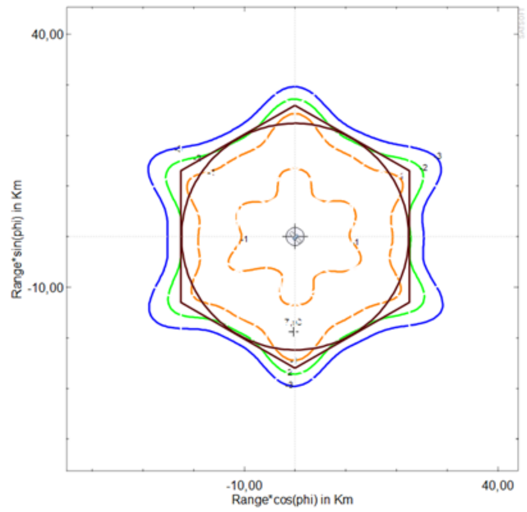
	
Cell: 45 km (1 cells)	Beam on cell of 45 km

FIGURE 4-134 BEAM ON COVERAGE COMPOSED OF A CELL OF 45 KM

The performance of the antenna among the cells are summarized in the FIGURE 4-135.

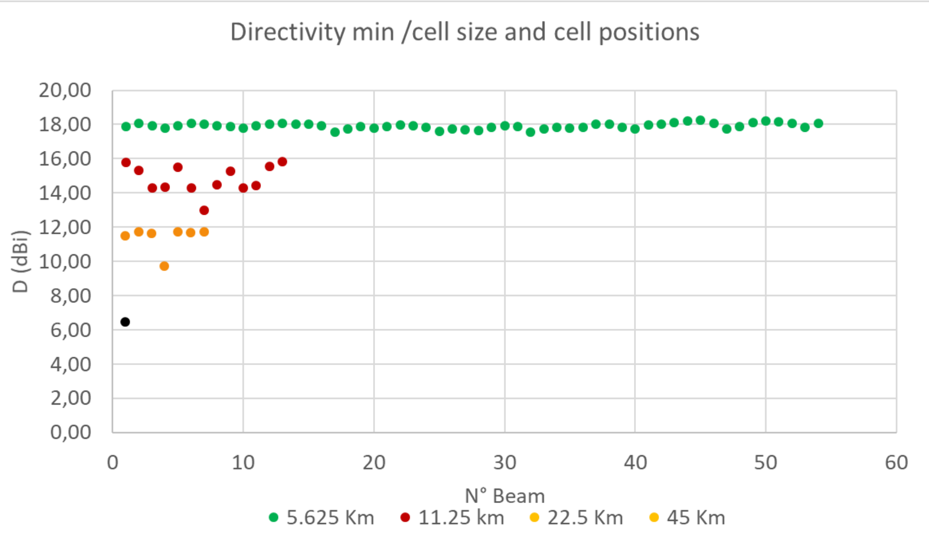


FIGURE 4-135 ANTENNA PERFORMANCES 30 RE

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.

4.5.5.4 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
- Freqeuency 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 4-136 give the PFD to confirm.

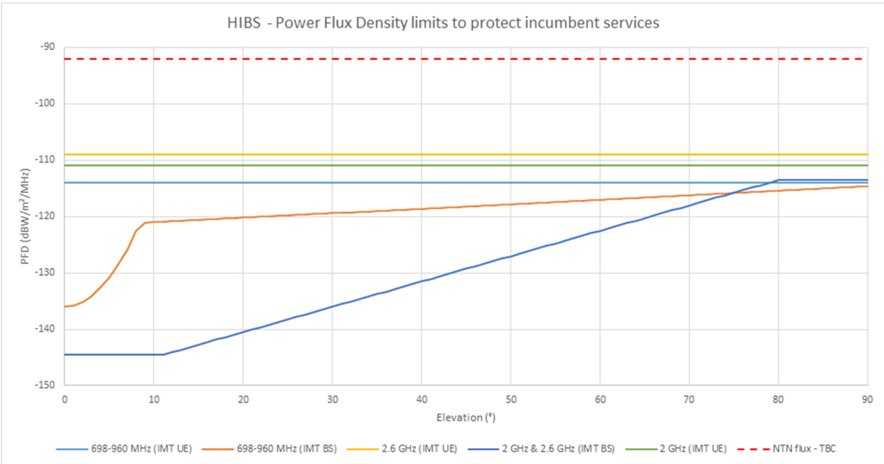


FIGURE 4-136 FLUX DENSITY LIMITS TO PROTECT MOBILE (IMT) SERVICES

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 4-137 with a power of 20 W per beam.

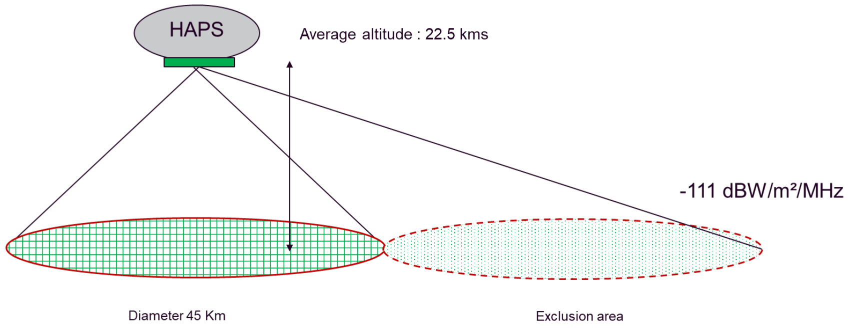


FIGURE 4-137 PFD LIMITS

4.5.6 Link Budget

4.5.6.1 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 4-138 CONSTANTS AND HYPOTHESIS

4.5.6.2 Antenna performances

The FIGURE 4-139 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)	(El 45°)	(NADIR)	(El 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 4-139 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 hemisphic 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.

					Directivity	Directivity	Gain	Gain
	Frequency	λ	lattice	lattice	(NADIR)	(El 45°)	(NADIR)	(El 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 4-140 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 mentionned in the chapter 3.1.3.

The lattice for the satellite antenna is fixed to 0.55 λ 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. Intgerated in a standard handeld 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 estimated the peak performances. It could be the basis of an antenna on the top of a vehicule 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.

4.5.6.3 HAPS hypothesis: resume

The table of FIGURE 4-106 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 (El 45°)	dBi	3,67
	Directivity ER (El 30°)	dBi	1,71
	Losses ER	dB	2
	Antenna gain (NADIR)	dBi	17,49
	Antenna gain (El 45°)	dBi	16,44
	Antenna gain (El 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 (El 45°)		3,67
	Directivity ER (El 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 4-141 HAPS HYPOTHESIS

4.5.6.4 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 (El 45°)	(dBi)	3,67
	Directivity ER (El 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 (El 45°)	(dBi)	3,67
	Directivity ER (El 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 4-142 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.

Co-funded by the European Union

4.5.6.5 Uplink

The exemple of link budget has been given for the uplink in the table of FIGURE 8-14.

PRACH Link Budget		Unit	Average Case (El 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
	Slant 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 4-143UPLINK BUDGET

The uplink performances evaluations in differents context 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 (El 45°)	(dBi)	3,67
	Directivity ER (El 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 (El 45°)	(dBi)	3,67
	Directivity ER (El 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 4-144PERFORMANCES EVALUATION IN DIFFERENT CONFIGURATIONS.

4.5.6.6 Downlink

		Unit	Average Case (El 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 4-145 DOWNLINK LINK BUDGET

4.5.7 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.

4.6 FEEDER LINK LEO GATEWAY

4.6.1 Introduction

In this part, only for Feeder link in LEO (link (6) defined in FIGURE 4-7 and FIGURE 4-80 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 cassegrenian 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.

4.6.2 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 4-146.

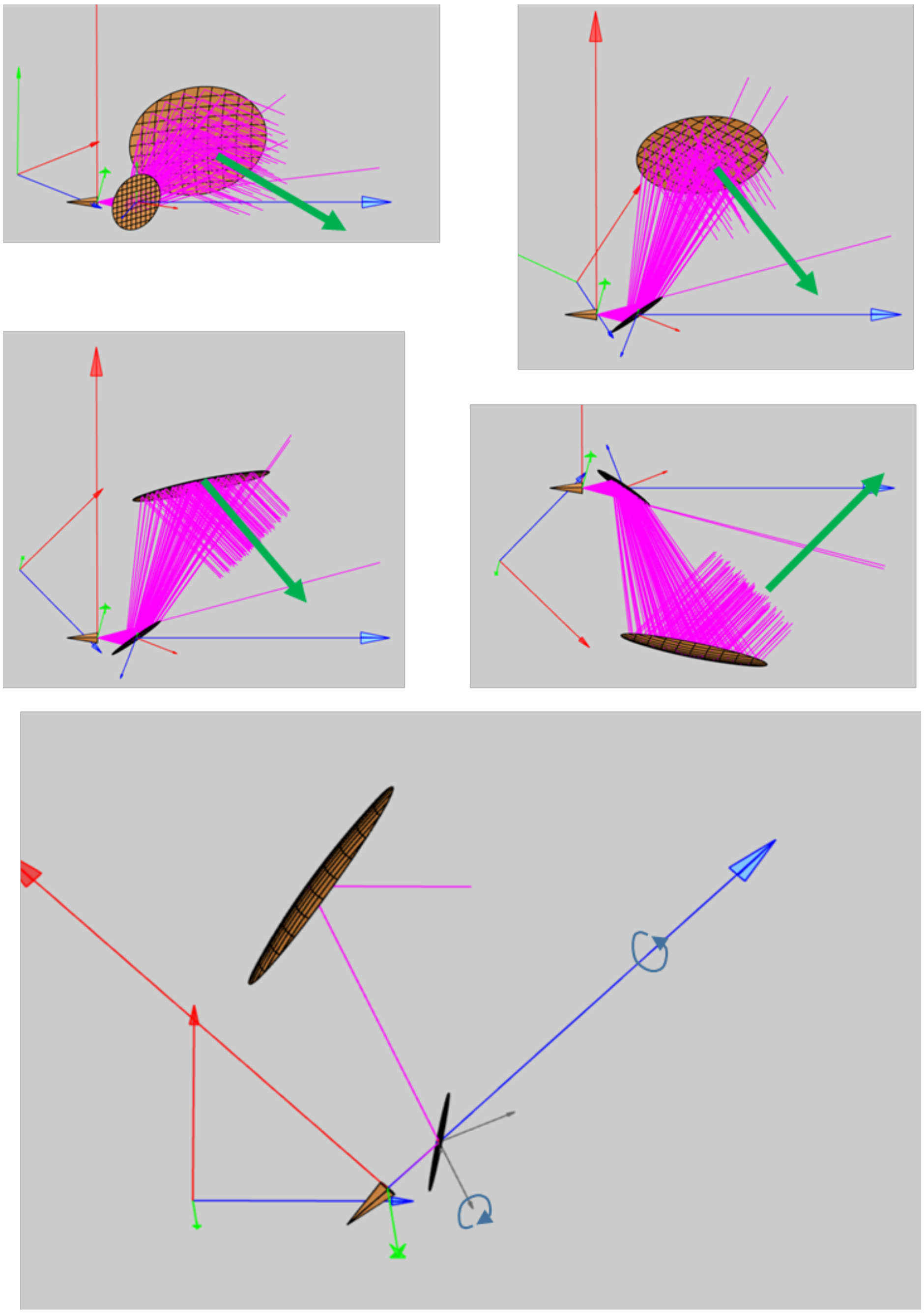


FIGURE 4-146 NEWTON BASED STEERABLE ANTENNA

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 stoked 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 4-147.

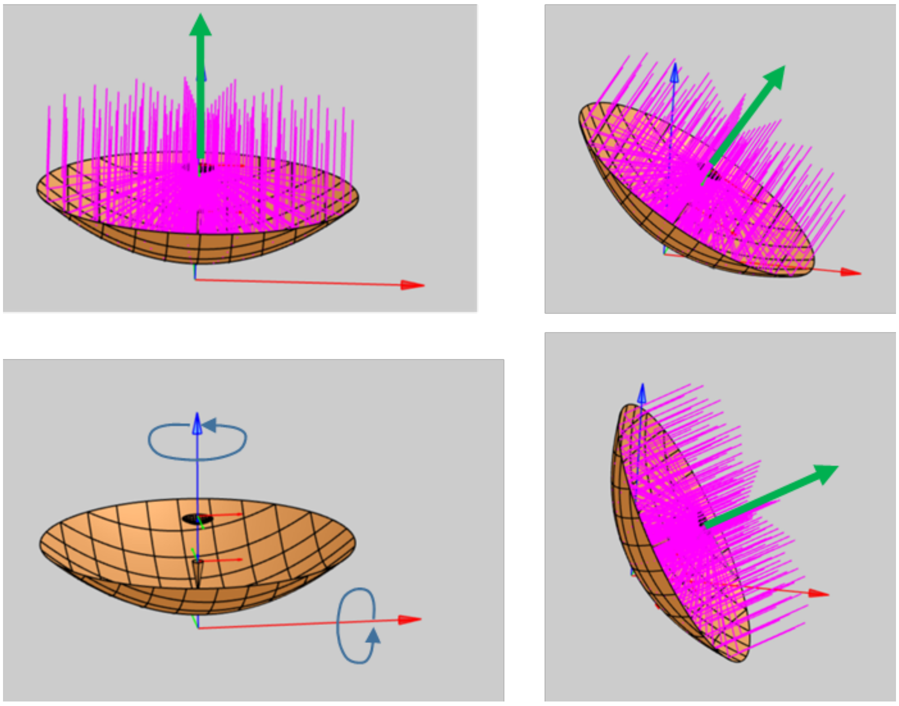


FIGURE 4-147 CASSEGRANIAN BASED STEERABLE ANTENNA

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.

4.6.3 Frequency band

The frequency band for the feeder link is defined in the table in the FIGURE 4-148.

	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 4-148 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]).

4.6.4 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 FIGURE 4-110 & FIGURE 4-111), 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 4-149) . 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 4-149). Moreover, to garanted a visibility to a gateway, a coverage of EL min of 10°- have been taken to evaluate the link budget performances.

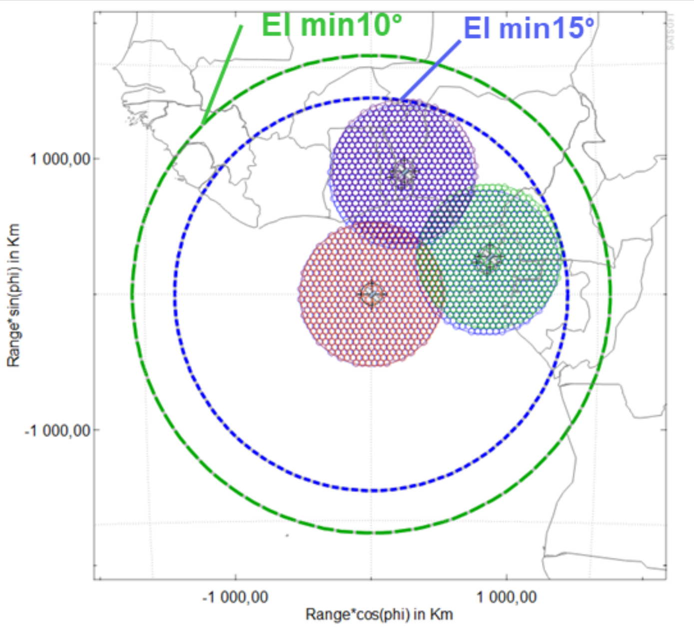


FIGURE 4-149 COVERAGE AREA OF A FEEDER SATELLITE

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

4.6.4.1 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 4-150 GATEWAY PERFORMANCES

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

4.6.4.2 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 4-151 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;

4.6.5 Feeder Solution (architecture)

The front end architecture is illustrated on the FIGURE 4-152. The antenna work in the two polarization RHCP & LHCP. The front is composed of two amplified access per function (Rx or Tx).

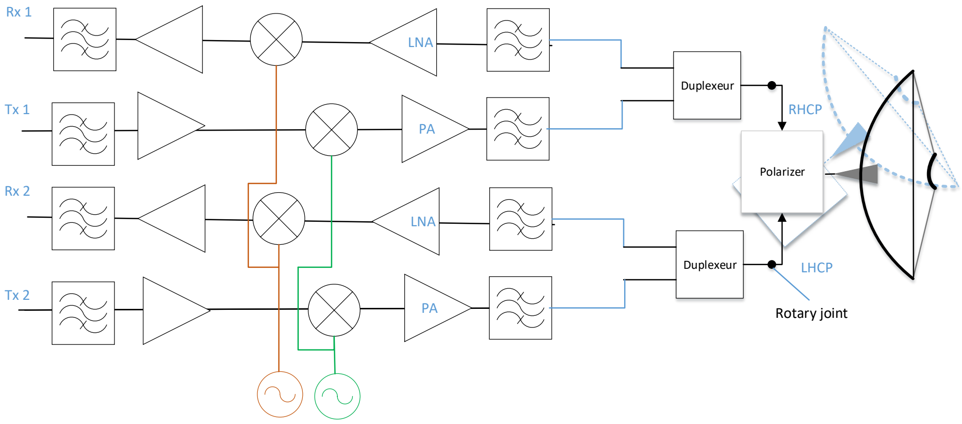


FIGURE 4-152 FRONT END ARCHITECTURE FEEDER

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

4.6.6 Link Budget

4.6.6.1 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 4-153 RESUME OF FEEDER HYPOTHESIS

4.6.6.2 Uplink

The Uplink link budget are given in the table of the FIGURE 4-154

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 4-154 LINK BUDGET UPLINK

Per antenna the throughput max in uplink is almost 1,6 Gbits/s.

4.6.6.3 Downlink

The downlink link budget is given in the table of FIGURE 4-155.

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
LOSSES	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 4-155 LINK BUDGET DOWNLINK

Per antenna tyhe throughput max in uplink is almost 1,4 Gbits/s.

Co-funded by the European Union

4.7 INL: LEO FEEDER SAT TO HAPS

4.7.1 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.

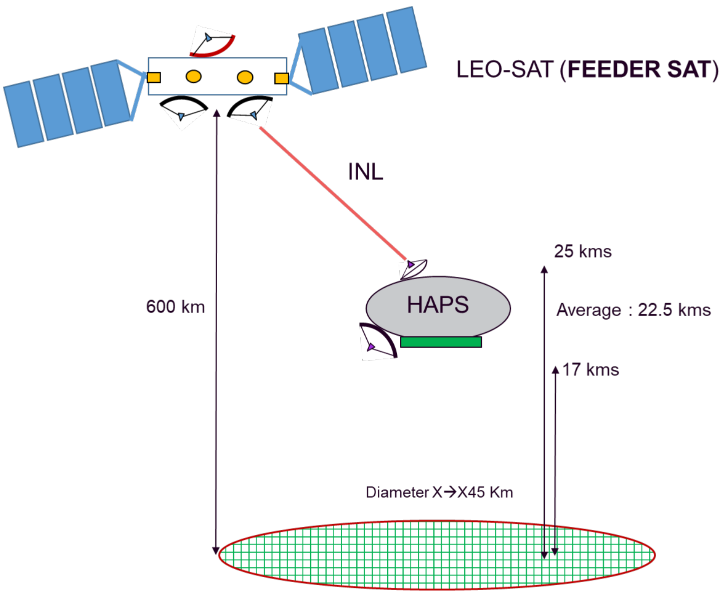


FIGURE 4-156 INTERNODE LINK

The accommodation of an antenna on the top of the HAPS is not yet confirmed, and coud be replaced by a electronically steerable as an antenna active antenna (1 beam or 2 beam) if some constraints appears 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.

4.7.2 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 4-157 PERFORMANCES HAPS ANTENNA AND FEEDER SATELLITE

The table in the FIGURE 4-158 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 4-158 FREQUENCY BAND

This table gives the maximum bandwidth available. A reduced bandwith 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
	Selected - Altitude	km	580
	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
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 4-159 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 (El 45°)	dBi	5,12
	Directivity ER (El 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 (El 45°)	dBi	5,12
	Directivity ER (El 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 4-160 HAPS ANTENNA

4.7.3 Link Budget

The budget have been establish for a bandwidth of 1 GHz for a first estimation.

4.7.3.1 Uplink budget

The table on FIGURE 4-161 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 4-161 UPLINK LINK BUDGET

4.7.3.2 Downlink link budget

The table on FIGURE 4-162 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 4-162 DOWNLINK BUDGET

Co-funded by the European Union

4.8 ISL RF LEO TO GEO

4.8.1 Introduction

The link between a LEO satellite and a GEO satellite will be based on a steerable cassegrenian 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.

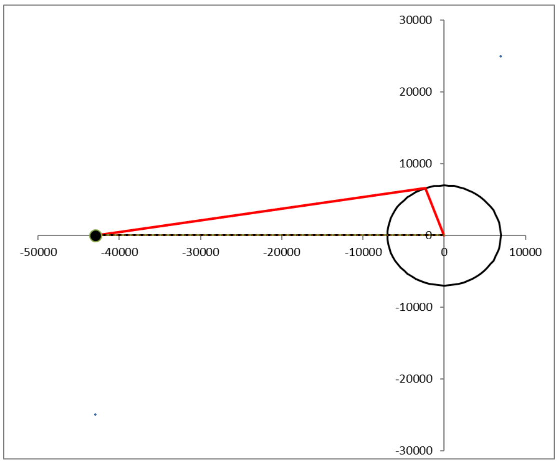


FIGURE 4-163 DISTANCE BETWEEN A LEO SAT AND GEO SATELLITE

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.

4.8.2 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.

4.8.3 Frequency band selection

The frequency band availables and possible for this link are presented on the table of FIGURE 4-164.

	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
	24,45	24,75	0,3	identification for terrestrial 5G
	25,25	27,5	2,25	Limitation to scientific applications- identification identication for terrestrial 5G
F2	32,3	33	0,7	
	59,3	66	6,7	
	66	71	5	identification for terrestrial 5G
	122,25	123	0,75	
	130	134	4	
	167	174,8	7,8	

FIGURE 4-164 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.

4.8.4 Antenna Architecture trade-off

Several architectures could be possible for this link. Exemple of architecture working in 2 band for maximum throughput see FIGURE 4-165.

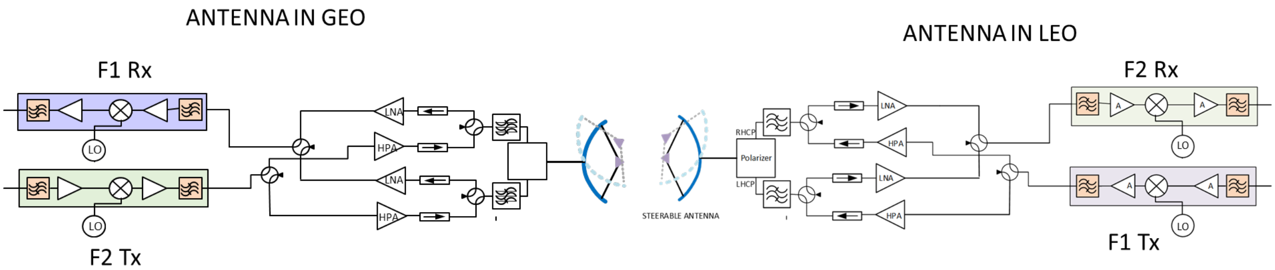


FIGURE 4-165 EXEMPLE OF ARCHITECTURE (BI-POLARIZATION FULL FLEXIBLE/FULL DUPLEX) TWO POLARIZATIONS

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 4-166 EXEMPLE OF LINKS

This could also be fully flexible if additional RF chain and allow to workin 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 illustred in the FIGURE 4-167.

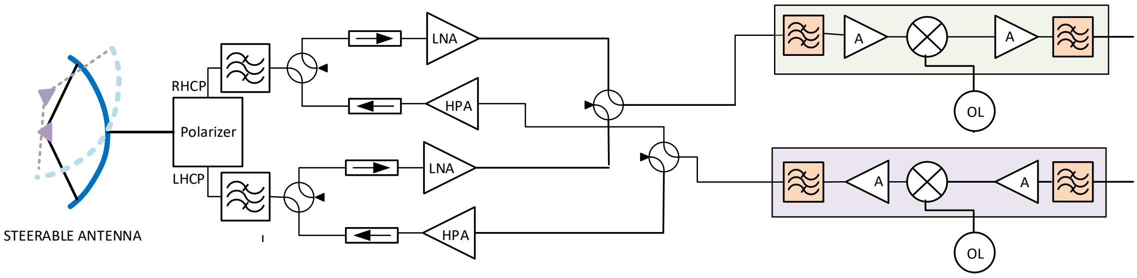


FIGURE 4-167 EXEMPLE OF ARCHITECTURE ONE POLARIZATION /ONE FREQUENCY/ POLARIZATION DISCRIMINATION (F1 OR F2)

	EXEMPLE OF LINKS					
case 1						
	Uplink	LEO-->GEO		FTx	FRx	RHCP
	downlink	GEO-->LEO		FRx	FTx	LHCP

FIGURE 4-168 EXEMPLE OF LINK (F=F1 OR F2)

The FIGURE 4-169 gives the gain variation according to aperture of the antenna

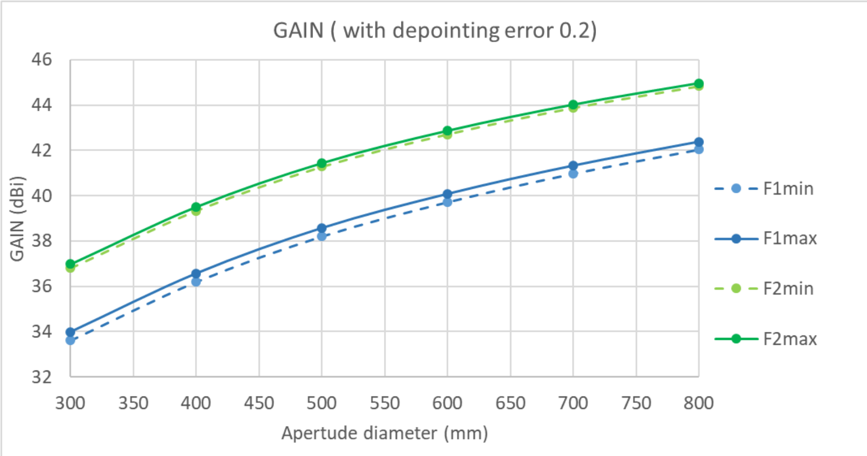


FIGURE 4-169 Example of achievable Gain versus aperture

The table in FIGURE 4-170 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 raisonnable 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 4-170 EXEMPLE ANTENNA PERFORMANCE FOR TWO APERTURES

Simplification in one frequency on working in one polarization by switching the appropriate link.

4.8.5 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		
BW available	**1**	**GHz**
Carrier BW	700,000	MHz
gain	41,15	
Frequency	23,05	GHz
Power SSPA	20	W
Power SSPA	13,01029996	dBW
EIRP Tx20	54,2	dBW
Power Control Back off	0,00	dB
C/Im up	15,0	dB
Distance between sat	40000,0	km
Free space loss	-211,7	dB
Rain/Atmos attenuation	0,0	dB
pointing loss	0,00	dB
link margin	0,50	dB
G/T	**15,9**	dB/K
C/No up	86,9	dBHz
C/I uplink	27	dB
C/N uplink	-1,3	dB
C/(N+I) uplink	-1,92	dB
DVB-S2X rate	**397,46**	Mb/s
Spectral Efficiency S2X	0,57	bits/s/Hz
Required C/N @ Rate	-2,03	dB
Residual margins	0,11	dB

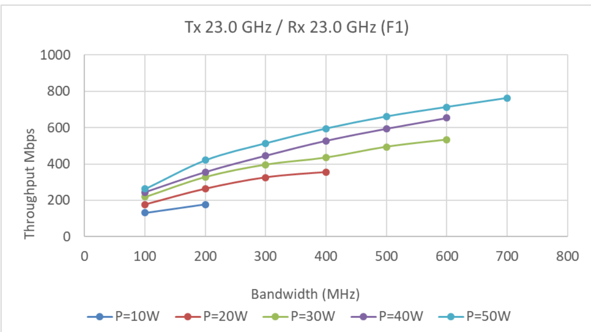
Link budget Frequency F1 Antenna (ϕ=700mm)

Tx 30 Rx 30		
BW available	**0,7**	**GHz**
Carrier BW	700,000	MHz
Gain	43,80	
Frequency	32,67	GHz
Power SSPA	20,00	W
power SSPA	13,01	dBW
EIRP Tx30	**56,8**	dBW
Power Control Back off	0,00	dB
C/Im up	15,0	dB
Distance between sat	40000,0	km
Free space loss	-214,8	dB
Rain/At attenuation	0,0	dB
pointing loss	0,00	dB
link margin	0,50	dB
G/T	**17,7**	dB/K
C/No up	88,4	dBHz
C/I uplink	27	dB
C/N uplink	0,1	dB
C/(N+I) uplink	-0,50	dB
DVB-S2X rate	**459,51**	Mb/s
Spectral Efficiency S2X	0,66	bits/s/Hz
Required C/N @ Rate	-1,24	dB
Residual margins	0,74	dB

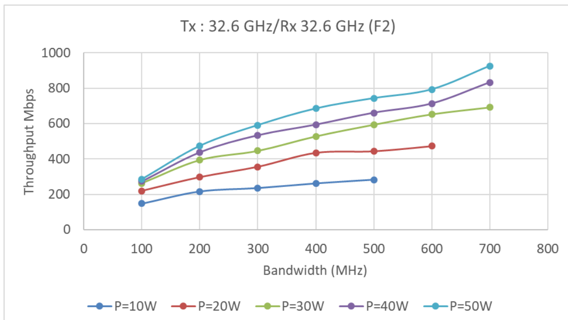
Link budget Frequency F2 Antenna (ϕ =700mm)

FIGURE 4-171 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 .



Throughput versus power (RF) Antenna (ϕ=700mm)



Throughput versus power (RF) Antenna (ϕ=700mm)

FIGURE 4-172

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 4-35 & FIGURE 4-39.
- 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 4-84 & FIGURE 4-91, 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 “thinked “ 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 SCALABILITY: INCREMENTAL NUMBER OF PAYLOADS

The FIGURE 5-1, 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 satellites are linked with the feeder satellite. All the links are done with OISL in document [19].

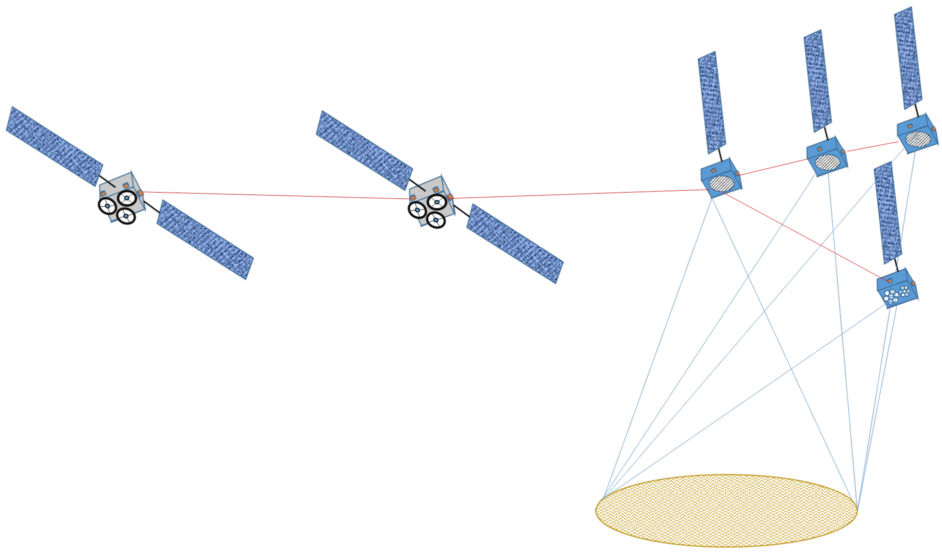


FIGURE 5-1 EXEMPLE OF SCALABILITY OF THE PAYLOADS

To increase the capacity on a coverage, it will be possible to add an additionnal user satellite which serve the save coverage by connecting it to the first user satellite FIGURE 5-1. 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:

<u>Example of constellation (C or Q/V) incremental deployment scenario:</u>

<u>To increase the capacity:</u> 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.

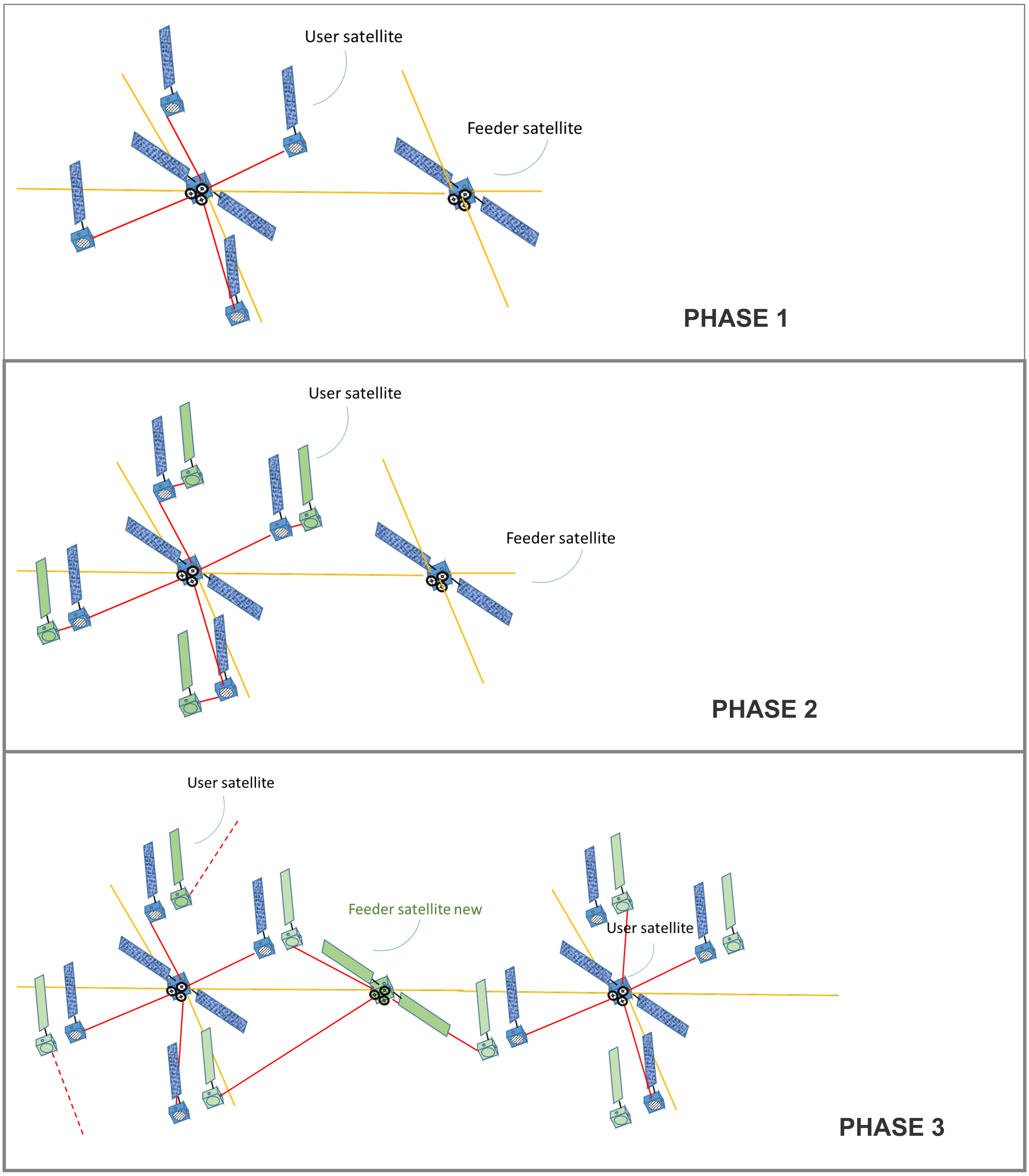


FIGURE 5-2 INCREASE IN CAPACITY

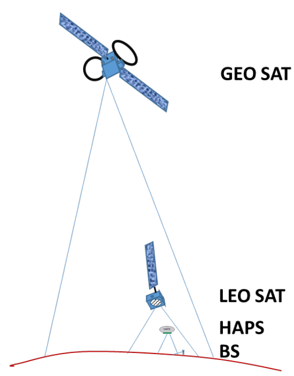
The scalability is as follow:

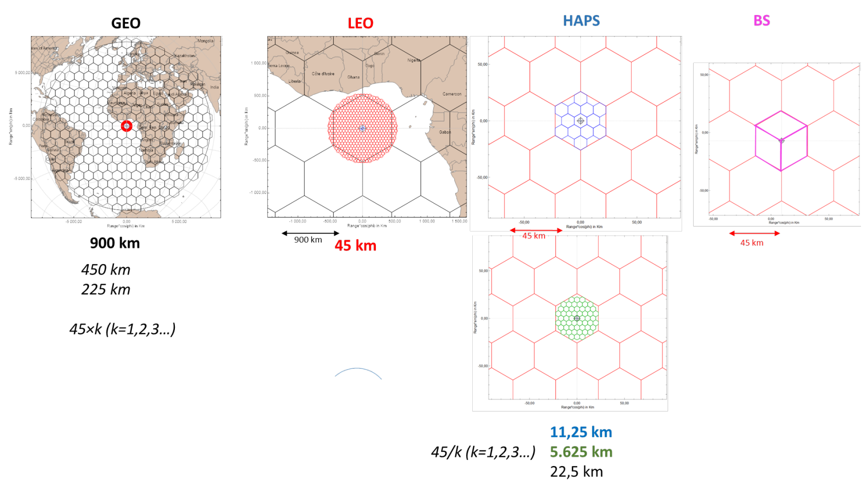
- PHASE 1: deployement of the initial Constellations feeder and users: for a given throughput
- PHASE 2: Add users satellites progressively on the existing structure: up to the interlink capacity
- PHASE 3: Deployment of additional new Feeder satellites (new generation, hight capacity). Connection establish 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

5.4 PAYLOADS SCALABILITY OVER COVERAGE

5.4.1 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 seeFIGURE 4-32), and for HAPS from 45 km to 11.25 km, 5,625 km (see FIGURE 4-130). 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.





View of the coverage of each element of the 6G NTN	Cell definition: GEO, LEO,HAPS. TN BS: illustration of sector cell coverage.

FIGURE 5-3 COMPATIBILITY OF COVERAGE AND CELL SIZE

The FIGURE 5-4 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.

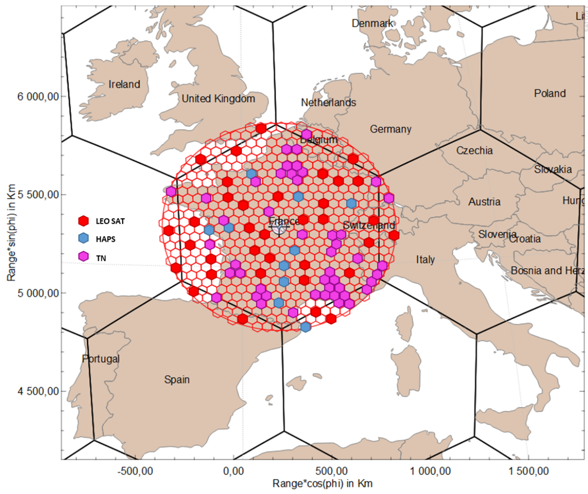


FIGURE 5-4 ILLUSTRATION OF SHAPING COVERAGE OVER A ZONE

6 CONCLUSION /PERSPECTIVE /NEXT STEP

First, from the global architectures elaborated [doc 3.5 of task 3.1] and constellations definition from task 3.4 and the terminal investigation in task 3.2. This work focus on the nodes payloads associated to this system definition. A trade-off have been performed in order to rapidly defined the axis of investigations for the payload. The payload for users links:

- C-band constellations
- Q/V band constellation
- HAPS

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. 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.

Moreover, the concept of scalability have been proposed through illustration over a principle of increasing capacity.

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.

The areas for further studies are identified as below:

- consolidate the feasibility of the double constellation concept (architecture 2) and assess its benefits and positive impact on functional architecture of the payload.
- finalize with the system definition task 3.5 with the functional split architecture, the impact in term of hardwares to embark. Evaluate the budget power consumption/dissipation.
- consolidate mass/volume for platform evaluation (input for task 3.4).
- refine and specify areas for technological improvement and propose a development plan.
- precise the concept of scalability and its impact on the payload design
- Verify that key performances are achieved, both in terms of cost and sustainability.

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8 APPENDICES

8.1 FRONT-ENDS DEFINITION

FRONT END DEFINITION								
FREQUENCY BAND	DESIGNATION	class	Band designation	Frequency band	Antenna type	Polarization	Characteristics	
C_BAND	*C_NTN_1*	NTN	*NTN C*	see doc 2.5 and §	wide coverage	linear	typ. NF=9 Gain : -3dBi, Tx=23 dBm	(1)
	C_NTN_2	NTN	*NTN C*	see doc 2.5 and §	wide coverage	linear	typ. NF=7 Gain : -3dBi, Tx=26 dBm	(2)
	C_NTN_3	NTN	*NTN C*	see doc 2.5 and §	wide coverage	linear	typ. NF=7 Gain : 0 dBi, Tx =26 dBm	(3)
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)
	QV_NTN_2	NTN	NTN Q/V	see doc 2.5 and §	directive /steerable	Circular	*NF=4 Gain 32 dBi Tx=37 dBm*	(5)
Terrestrial sub6 band	*C_TN_1*	TN	TN_C	terrestrial 3,6 GHz	wide coverage	linear	typ. NF=9 Gain : -3dBi, Tx=23 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)
	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					

FIGURE 8-1 TABLE RESUME OF THE FRONT-ENDS DEFINITION

Comments:

(1) Classical integrated front-end on handeld

(2) Professional handeld (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

8.2 GENERAL TRADE-OFF

ALTITUDE	250	KM		74,3°																							
Elevation (°) Terminal	α (°) Satellite (Antenna)	Distance sat-earth (km)	Compensation Isoflux (dB)	lat. relative au Nadir (°)	Rayon (Km) at Nadir	Km^2 au Nadir	nb sat i, view	real number	RTT	Max Relative Velocity m/s	doppler shift	spacing	Scan losse		ER directi		lattice	surface Elem	num.ER case	num. ER case	1038 ER (case	TOTAL LOSS	case 1	case 2	case 3	case 2	case 1 directivity-FSL-S
								of sat	ms	m/s	kHz (Source 3,	(avoid gratin	fmin	fmax	fmin	fmax	mm	mm^2	D=1750 fixed	D=2000 fixed	diameter (m)	dB	surface fixe	surface fixe	nb ER fixe	surface fixed	dBi
10	71,38	1009	12,12	8,62	959	2 886 546	177	360	13,4	7349,044404	91	0,576	2,8	5,3	1,5	0,2	44,3	1697,4	1417	1851	1,50	17,42	31,7	32,9	30,4	32,9	14,30
20	64,72	649	8,28	5,28	588	1 083 581	472	984	8,7	7012,376553	86	0,597	2,9	5	2	1,1	47,1	1917,4	1254	1638	1,59	13,28	32,1	33,2	31,3	33,2	18,80
30	56,45	474	5,57	3,55	396	491 703	1040	2244	6,3	6462,641188	80	0,632	2,5	4,1	2,8	2,4	49,5	2119,1	1135	1483	1,67	9,67	33,0	34,1	32,6	34,1	23,28
40	47,49	379	3,61	2,51	279	245 370	2083	4794	5,1	5716,541742	71	0,679	2	3,2	3,8	3,8	52,3	2364,6	1017	1329	1,77	6,81	33,9	35,0	34,0	35,0	27,06
45	42,88	347	2,85	2,12	236	175 324	2916	7015	4,6	5276,724434	65	0,702	1,8	2,8	4,3	4,5	54	2527,6	952	1243	1,83	5,65	34,3	35,4	34,7	35,4	28,63369115
50	38,21	322	2,20	1,79	199	124 754	4098	10434	4,3	4796,748067	59	0,731	1,6	2,5	4,8	5,2	56,2	2735,8	879	1148	1,90	4,70	34,6	35,8	35,4	35,8	29,94

ALTITUDE	400	KM		70°																							
Elevation (°) Terminal sol	ALPHA (°) Satellite (Antenne Bord)	Distance sat-sol (km)	Compensation Isoflux (dB)	lat. relative au Nadir (°)	Rayon (Km) au Nadir	Km^2 au Nadir	nb sat i, view	real number	RTT	Max Relative Velocity m/s	doppler shift	spacing	Scan losse		ER directi		lattice	surface Elem	num.ER case	num. ER case	1038 ER (case	TOTAL LOSS	case 1	case 2	case 3	case 2	case 1 directivity-FSL-S
							indicator	of sat	ms	m/s	kHz (Source 3,	(avoid gratin	fmin	fmax	fmin	fmax	mm	mm^2	surface D=1	surface D=20	diameter (m)	dB	surface fixe	surface fixe	nb ER fixe	surface fixed	
10	67,92	1440	11,13	12,08	1344	5 655 500	90	180	19,2	7106,442957	88	0,594	2,9	5,1	1,8	0,7	45,65	1805,1	1332	1740	1,54	16,23	31,9	33,1	30,9	33,1	15,72
20	62,16	984	7,82	7,84	873	2 390 409	214	432	13,1	6780,888946	84	0,628	2,9	4,9	2,2	1,5	48,29	2019,4	1191	1556	1,63	12,72	32,3	33,4	31,7	33,4	19,54
30	54,58	739	5,34	5,42	603	1 143 082	447	920	9,9	6249,301056	77	0,656	2,5	4	3	2,7	50,48	2207,2	1090	1423	1,71	9,34	33,1	34,2	32,9	34,2	23,74
40	46,12	598	3,50	3,88	432	584 741	874	1856	8,0	5527,831316	68	0,695	2,1	3,2	3,9	4	53,46	2474,6	972	1270	1,81	6,70	33,9	35,0	34,2	35,0	27,18
45	41,71	550	2,76	3,29	366	420 930	1214	2652	7,3	5102,532946	63	0,721	1,9	2,9	4,5	4,7	55,50	2667,5	902	1178	1,88	5,66	34,3	35,4	34,9	35,4	28,59
50	37,22	512	2,14	2,78	310	301 163	1697	3818	6,8	4638,401218	57	0,748	1,6	2,5	5	5,4	57,50	2863,7	840	1097	1,95	4,64	34,6	35,8	35,6	35,8	30,00

ALTITUDE	600	KM		65,7°																							
Elevation (°) Terminal sol	ALPHA (°) Satellite (Antenne Bord)	Distance sat-sol (km)	Compensation Isoflux (dB)	lat. relative au Nadir (°)	Rayon (Km) au Nadir	Km^2 au Nadir	nb sat i, view	real number	RTT	Max Relative Velocity m/s	doppler shift	spacing	Scan losse		ER directi		lattice	surface Elem	num.ER case	num. ER case	1038 ER (case	TOTAL LOSS	case 1	case 2	case 3	case 2	case 1 directivity-FSL-S
(°)	(°)						indicator	of sat	ms	m/s	kHz (Source 3,	(avoid gratin	fmin	fmax	fmin	fmax	mm	mm^2	surface D=1	surface D=20	diameter (m)	FSL+Scan lo	surface fixe	surface fixe	nb ER fixe	surface fixed	
10	64,18	1932	10,16	15,82	1762	9 687 084	53	104	25,8	6803,120656	84	0,615	2,9	4,9	2,1	1,2	47,3	1937,9	1241	1621	1,60	15,06	32,1	33,3	31,4	33,3	17,08
20	59,19	1392	7,31	10,81	1203	4 533 457	113	228	18,6	6491,462175	80	0,649	2,9	4,8	2,5	1,9	49,9	2155,2	1116	1458	1,69	12,11	32,4	33,5	32,1	33,5	20,26
30	52,33	1075	5,07	7,67	854	2 285 785	224	448	14,3	5982,563901	74	0,678	2,5	4	3,3	3	52,2	2355,7	1021	1334	1,76	9,07	33,1	34,3	33,2	34,3	24,02
40	44,44	882	3,35	5,56	619	1 201 989	425	874	11,8	5291,888451	65	0,717	2,1	3,2	4,2	4,2	55,1	2630,9	914	1194	1,86	6,55	33,8	35,0	34,4	35,0	27,26
45	40,26	815	2,66	4,74	527	872 778	586	1222	10,9	4884,742971	60	0,742	1,9	2,9	4,7	4,9	57,1	2821,1	853	1114	1,93	5,56	34,2	35,4	35,1	35,4	28,65
50	35,98	761	2,06	4,02	447	628 518	813	1710	10,1	4440,421647	55	0,77	1,7	2,5	5,2	5,6	59,3	3042,1	791	1033	2,01	4,56	34,6	35,7	35,8	35,7	30,02

ALTITUDE	800	KM		62,3°																							
Elevation (°) Terminal sol	ALPHA (°) Satellite (Antenne Bord)	Distance sat-sol (km)	Compensation Isoflux (dB)	lat. relative au Nadir (°)	Rayon (Km) au Nadir	Km^2 au Nadir	nb sat i, view	real number	RTT	Max Relative Velocity m/s	doppler shift	spacing	Scan losse		ER directi		lattice	surface Elem	num.ER case	num. ER case	1038 ER (case	TOTAL LOSS	case 1	case 2	case 3	case 2	case 1 directivity-FSL-S
							indicator	of sat	ms	m/s	kHz (Source 3,	(avoid gratin	fmin	fmax	fmin	fmax	mm	mm^2	surface D=1	surface D=20	diameter (m)	FSL+Scan lo	surface fixe	surface fixe	nb ER fixe	surface fixed	
10	61,05	2367	9,42	18,95	2109	13 851 370	37	72	31,6	6520,778378	80	0,635	2,9	4,8	2,3	1,6	48,9	2067,8	1163	1519	1,65	14,22	32,3	33,4	31,8	33,4	18,03
20	56,61	1769	6,89	13,39	1490	6 945 982	74	144	23,6	6222,054309	77	0,669	2,9	4,7	2,8	2,2	51,4	2291,6	1050	1371	1,74	11,59	32,4	33,6	32,4	33,6	20,82
30	50,31	1395	4,83	9,69	1079	3 646 957	140	286	18,6	5734,276269	71	0,696	2,5	4	3,5	3,3	53,5	2481,7	969	1266	1,81	8,83	33,2	34,3	33,5	34,3	24,33
40	42,90	1159	3,22	7,10	791	3 646 957	261	527	15,5	5072,265146	63	0,737	2,1	3,3	4,4	4,5	56,7	2783,4	864	1129	1,92	6,52	33,9	35,0	34,7	35,0	27,35
45	38,92	1074	2,56	6,08	676	1 435 494	356	720	14,3	4682,016968	58	0,762	1,9	2,9	4,9	5,1	58,7	2978,6	808	1055	1,98	5,46	34,2	35,3	35,3	35,3	28,71
50	34,83	1006	1,99	5,17	575	1 039 700	492	1008	13,4	4256,135813	52	0,793	1,7	2,5	5,5	5,8	61	3225,0	746	974	2,06	4,49	34,5	35,7	36,0	35,7	30,03

FIGURE 8-2 GENERAL TRADE-OFF TABLE

8.3 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 8-3 EXTRACT NUMEROLOGY 3GPP TR 38.811 V15.4.0 [16]

8.4 DOWNLINK C-BAND LINK BUDGET

The downlink budget is given in the table FIGURE 8-4.

DOWNLINK		Unit	Average Case (El 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
	EIRP	dBW	47,92	47,92
	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	0,78	2,28
	Figure of Merit: G/T	dB/K	-32,85	-31,34
	Polarisation mismatch loss	dB	3,00	3,00
	Effective G/T under satellite coverage	**dB/K**	**-35,85**	**-34,34**
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**	**-2,26**	**2,99**
	Spectral Efficiency	bits/s/Hz	0,3242	0,7542
	UE Rate	**Mbits/s**	**31,86**	**74,12**

FIGURE 8-4 DOWNLINK BUDGET (BEST CASE)

The hypothesis of power density are given in the table of FIGURE 8-5.

nb total cell	499	cells
NB	100	instantaneaous beams
Surf	1753,70	cell surface km^2
EIRP density	28	dBW/MHz per beam
nb PRB max	273	

FIGURE 8-5 HYPOTHESIS

The throughput for different case have been computed on the table below

Co-funded by the European Union

DOWNLINK	unity		remark 1	nb users	nb PRB		remark 2
1) PEAK Throughput Achievable per an user					Nadir	EL 45°	
Peak throughput	Mbits/s	124,8	1 user per cell, nadir, best conditions	1	273		all Power on one cell
peak Spectral density	bits/s/Hz	1,2700	1 user per cell, nadir, best conditions	1	273		all Power on one cell
peak troughput/km^2	kbits/s/km²	71,2	Dp_up/ cell surface	1			
2) PEAK Throughput Achievable per an user							
Peak throughput nadir cell	Mbits/s	74,12	1 user per cell, 100 cells, best conditions, nadir	100	273		Power on 100 cells (20% of coverage cell)
Peak Spectral density nadir	bits/s/Hz	0,7542	1 user per cell, 100 cells, best conditions, nadir	100	273		Power on 100 cells (20% of coverage cell)
Peak troughput/km^2 nadi	kbits/s/km²	42,3	Dpm_down/ cell surface	100	273		
aggregated Peak throughp	Gbits/s	**7,41**		100	273		
3) PEAK Throughput Achievable per an user							
Peak throughput edge cell	Mbits/s	31,86	1 user per cell, 100 cells, best conditions edge	1		273	Power on 100 cells (20% of coverage cell)
Peak Spectral density edge	bits/s/Hz	0,3242	1 user per cell, 100 cells, best conditions edge	1		273	Power on 100 cells (20% of coverage cell)
Peak troughput/km^2 edge	kbits/s/km²	18,2	Dpm_down/ cell surface	1		273	at edge
aggregated Peak throughp	Gbits/s	**3,19**		100			
4)Avergage Throughput Achievable per an user							
average Peak throughput d	Mbits/s	44,54	1 user per cell, 100 cells, best conditions, nadir to edge	1	273	273	Power on 100 cells (20% of coverage cell)
average peak Spectral dens	bits/s/Hz	0,4920	1 user per cell, 100 cells, best conditions, nadir to edge	1	273	273	Power on 100 cells (20% of coverage cell)
average peak troughput/kr	kbits/s/km²	25,4	Dpm_down/ cell surface	1			average of (2) & (3)
aggregated throughput	Gbits/s	**4,45**		100	273	273	100 cells distributed over the coverage
5) PEAK Throughput Achievable per an user (indoor)							
Peak throughput (indoor)	Mbits/s	124,8	1 user per cell, nadir, 10dB atten	1	273		all Power on one cell/max PRB
peak Spectral density	bits/s/Hz	1,27	1 user per cell, nadir, 10dB atten	1	273		all Power on one cell/max PRB
6) Throughput 1 PRB per user							
Average Throughput 1 PRB	Mbits/s	**0,52**	1 PRB per users/ 8 beams	1	1	1	Power on 8 cells (1.6% of coverage cell)
Average spectral efficiency	bits/s/Hz	**1,46**	1 PRB per users/8 beams	1	1	1	Power on 8 cells (1.6% of coverage cell)
Aggregated throughput	Gbits/s	1,14	1 PRB per users/8 beams	2184	1	1	Power on 8 cells (1.6% of coverage cell)
7) Throughput ALL power in 1 PRB 1 user							
Average Throughput 1 PRB	Mbits/s	0,52	in one beam (taken near nadir)	100	1	1	power on 1 PRB 1 user per cell
Average spectral efficiency	bits/s/Hz	1,46	in on beam (taken near nadir)	100	1	1	power on 1 PRB 1 user per cell
Aggregated throughput	Mbits/s	**52,00**	in one beam (taken near nadir)	100	1	1	power on 1 PRB 1 user per cell

FIGURE 8-6 PERFORMANCES RESUME (BEST CASE: CENTER OF THE CELLS)

7 cases have been considered in the table which give the performances of the payload for several dimensioning case. It will allow to evaluate the global performance capacity of the payload.

(1) all power available (48 dBW) on one beam best condition, all PRB used (273)

2) Power on 100 beams (28 dBW/beam) all PRB used (273) per an user at nadir

3) Power on 100 beams (28 dBW/beam) all PRB used (273) per an user at edge

4) Power on 100 beams (28 dBW/beam) all PRB used (273) per an user between nadir and edge.

5) All power (48 dBW) on 1 user at nadir, indoor condition (10dB attenuation)

6) Case of power on 8 cells, 1 PRB per user, number of users = 273x8

7) 100 beams, all power on one users and 1 PRB

These performances according to the requirement are summarized in the table below:

Need per user (objective)	Mbps	20	Mbps
activity factor	%	0,5	%
per user (need)	Kbps	100,00	Kbps
nb of users	per cell	445	per cell
surface cell	Km^2	1753,70	Km^2
density	users /Km^2	0,25398	users /Km^2

FIGURE 8-7 ACHIEVABLE THROUGHPUT /REQUIREMENTS

8.5 UPLINK C-BAND LINK BUDGET

The downlink budget is given in the table

PRACH Link Budget		Unit	Average Case (El 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	-	100	100
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
	Antenna Transmit Power	dBW	-7,00	-7,00
	Cable loss	dB	0,00	0,00
	Transmit Gain	dBi	1,97	3,47
	EIRP	dBW	-5,03	-3,53
	EIRP per PRB	dBW	-5,03	-3,53
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	**dB/K**	**4,99**	**6,50**
LOSSES	**Free space propagation**	**dB**	**162,49**	**159,83**
	Propagation losses computation	-	Computation [RD1] & [RD2]	
	UE location	-	Toulouse	
	Weather condition	-	Clear Sky	
	Propagation tool atmospheric loss computed	dB	0,06	0,04
	Zenith Attenuation	dB	0,04	0,04
	Atmospheric Path loss	dB	1,55	0,04
	Ionospheric Scintillation Loss	dB	0,00	0,00
	Tropospheric Scintillation Loss	dB	0,00	0,00
	Scintillation loss	dB	0,00	0,00
	Atmospheric loss	**dB**	**1,55**	**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**
	C/I	dB	12,00	12,00
RESULTS CONFIGURATIONS	Number of PRB per UE	-	1	1
RESULTS	**Obtained C/N**	**dB**	**5,00**	**9,52**
	Spectral Efficiency	bits/s/Hz	1,2201	1,7610
	UE Rate	**Mbit/s**	**0,439**	**0,634**

FIGURE 8-8 UPLINK BUDGET

<u>Computation of throughput in several dimensioning cases:</u>

UPLINK	unity		Remark		nb PRB per user	
1) PEAK Throughput Achievable per an user				nb of user	nadir	at 45°
Peak throughput	Mbits/s	4,8	1 user per cell, nadir	1	62	
peak Spectral density	bits/s/Hz	0,2156	1 user per cell, nadir	1	62	
peak troughput/km^2	kbits/s/km^2	2,74	Dp_up/ cell surface	1		
1') PEAK Throughput Achievable per an user				nb of user	nadir	at 45°
Peak throughput	Mbits/s	0,932	1 user per cell, edge	1		12
peak Spectral density	bits/s/Hz	0,2156	1 user per cell, edge	1		12
peak troughput/km^2	kbits/s/km^2	0,53	Dp_up/ cell surface	1		12
2) PEAK Throughput Achievable by the satellite						
Peak throughput 1PRB at nadir	Mbits/s	0,634	1 user per cell, nadir	1	1	
peak Spectral density 1PRB at nadir	bits/s/Hz	1,7610	1 user per cell, nadir	1	1	
Aggregated peak throughput on a nadir cell	Mbits/s	173,1	273 users on a cell at nadir	273	1	
Aggregate Max throughput 1PRB per user all beams	Gbits/s	17,3	273 user per cell nadir, 100 beams around nadir	27300	1	
3) MIN Throughput Achievable by the satellite						
Peak throughput 1PRB at edge	Mbits/s	0,439	1 user per cell, edge	1	1	
peak Spectral density 1PRB at edge	bits/s/Hz	1,2201	1 user per cell, edge	1	1	
Aggregated peak throughput on a edge cell	Mbits/s	119,8	273 users on a cell at edge	273	1	
Aggregate throughput 1PRB/user all beams	Gbits/s	12,0	273 user per cell edge, 100 beams at the edge	27300	1	
4) AVERAGE Throughput Achievable by the satellite						
Average Aggregate throughput 1PRB/user in 1 beam	Mbits/s	135,8	max user 273 per cell, nadir to edge, best conditions			
Average Aggregate throughput 1PRB/user all beams	Gbits/s	13,6	273 user per cell, cell distributed from nadir to edge	27300	1	
average throughput/Km^2	kbits/s/km2	77,4				
5) PEAK Throughput Achievable per an user (indoor)						
Peak throughput (indoor)	Mbits/s	0,465	1 user per cell, nadir, 10dB atten max PRB	1	6	
peak Spectral density	bits/s/Hz	0,216	1 user per cell, nadir, 10dB atten max PRB	1	6	
Peak throughput 1PRB	Mbits/s	0,340	1 user per cell, nadir, 10dB atten	1	1	
peak Spectral density 1PRB	bits/s/Hz	0,945	1 user per cell, nadir, 10dB atten	1	1	
6) AVERAGE Throughput Achievable per an user						
average Peak thoughput	Mbits/s	2,09	1 user per cell, nadir to edge, best conditions	1	62	12
average spectral density	bits/s/Hz	0,22	1 user per cell, nadir to edge, best conditions	1	62	12
aggregated peak throughput	Mbits/s	209,24	100 users on 100 beams	100	62	12
average throughput/Km^2	kbits/s/km^2	1,19		100	62	12

FIGURE 8-9 PERFORMANCES RESUME UPLINK (BEST CASE: UE AT CENTER OF THE CELLS)

The different cases computed in the table of FIGURE 8-9 are detailed below:

1) case of only 1 user per cell using the max of PRB at nadir

1') case of only 1 user per cell using the max of PRB at edge

2) Peak throughput 1 user per cell, 1 PRB, near nadir

3) Peak throughput 1 user per cell, 1 PRB, at edge

4) Agregated throughput per satellite: 1 PRB per user, 273 user per cell, 100 cells from nadir to edge

5) Peak throughput achievable in indoor conditions (attenuation of 10 dB) max PRB (6). At nadir

6) average case: 1 user per cell using max PRB from nadir to edge

The table of FIGURE 8-10FIGURE 8-10 give the performances obtained compared with the targets defined:

Need /users	Mbps	2,00	Mbps
Activity factor	%	0,01	
per user (need)	Kbps	0,20	Kbps
number users per cell	per cell	679088	par cellule
surface cell	km^2	1753,70	
density	users per Km^2	387	users per Km^2

FIGURE 8-10 ACHIEVABLE THROUGHPUT /REQUIREMENTS (DOC 2.2)

In uplink the density of users that the system could handle is high compared to the service in downlink. The limitation in downlink is the power over the area of coverage that limits the service. In the uplink, there is no limitation except the on board processing capacity.

8.6 DOWNLINK Q/V BAND LINK BUDGET

The hypothesis taken for the link budget is given in the table of FIGURE 8-11.

nb total cell	499	cells
N_B	8	instantaneaous beams
F_{BH}	62,375	Beam hopping factor
Surf	1753,70	cell surface km^2
EIRP density	18,2	dBW/MHz per beam
nb PRB	264	

FIGURE 8-11 HYPOTHESIS FOR LINK BUDGET

The table give the hypothesis for 8 instantaneous beams per antenna with un EIRP of 18.2 dBW/MHz per beam, the case of 4 beams with the same EIRP per beam is also considered.

DOWNLINK		Unit	Average Case (El 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
	Downlink Frequency	**GHz**	**40,00**	**40,00**
	Nb active spots during 1ms timeslot	-	4 or 8	4 or 8
	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**	**44,00**	**44,00**
	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
	Equivalent Temperature	K	712,78	712,78
	Receive Antenna Gain	dBi	30,09	31,59
	Figure of Merit: G/T	dB/K	1,56	3,06
	Polarisation mismatch loss	dB	0,00	0,00
	Effective G/T under satellite coverage	**dB/K**	**1,56**	**3,06**
LOSSES	**Free space propagation**	**dB**	**182,71**	**180,05**
	Propagation losses computation	-	Computation [RD1] & [RD2]	
	UE location	-	Toulouse	
	Weather condition	-	Clear Sky	
	Propagation tool atmospheric loss computed	dB	0,85	0,60
	Zenith Attenuation	dB	0,40	0,40
	Atmospheric Path loss	dB	1,91	0,40
	Ionospheric Scintillation Loss	dB	0,00	0,00
	Tropospheric Scintillation Loss	dB	0,35	0,23
	Scintillation loss	dB	0,35	0,23
	Atmospheric loss	**dB**	**2,26**	**0,63**
	Shadowing margins	**dB**	**0,00**	**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 used PRBs	-	1	1
RESULTS	**Obtained C/N**	**dB**	**13,81**	**13,53**
	Required C/N	dB	13,36	13,36
	Residual Margins	dB	0,45	0,17
	Spectral Efficiency	bits/s/Hz	1,7714	1,7714
	Rate per PRB	kb/s	2550,76	2550,76
	UE Rate	**Mbits/s**	**2,55**	**2,55**

FIGURE 8-12 DOWNLINK LINK BUDGET

DOWNLINK	unity		remark 1	nb users	nb PRB	
1) PEAK Throughput Achievable per an user					Nadir	EL 45°
Peak throughput	Mbits/s	**596,7**	1 user per cell, nadir, best conditions	1	264	
peak Spectral density	bits/s/Hz	1,5696	1 user per cell, nadir, best conditions	1	264	
peak troughput/km^2	kbits/s/km^2	340,3	Dp_up/ cell surface	1		
2) PEAK Throughput Achievable per an user						
Peak throughput nadir cell	Mbits/s	**414,01**	1 user per cell, 8 cells, best conditions, nadir	1	264	
Peak Spectral density nadir cell	bits/s/Hz	1,0890	1 user per cell, 8 cells, best conditions, nadir	1	264	
Peak troughput/km^2 nadir cell	kbits/s/km^2	236,1	Dpm_down/ cell surface	1	264	
aggregated Peak throughput nadir ce	Gbits/s	**3,31**	1 user per cell, 8 cells, best conditions, nadir	8	264	
3) PEAK Throughput Achievable per an user						
Peak throughput edge cell	Mbits/s	**273,39**	1 user per cell, 8 cells, best conditions edge	1		264
Peak Spectral density edge cell	bits/s/Hz	0,7191	1 user per cell, 8 cells, best conditions edge	1		264
Peak troughput/km^2 edge cell	kbits/s/km^2	155,9	Dpm_down/ cell surface	8		264
aggregated Peak throughput edge ce	Gbits/s	**2,19**				
4)Avergage Throughput Achievable per an user						
average Peak throughput distributed	Mbits/s	315,57	1 user per cell, 8 cells, best conditions, nadir to	1	264	
average peak Spectral density	bits/s/Hz	0,8301	1 user per cell, 8 cells, best conditions, nadir to	1	264	
average peak troughput/km^2	kbits/s/km^2	179,9	Dpm_down/ cell surface	1		
aggregated throughput	Gbits/s	2,52		8	264	264
5) PEAK Throughput Achievable per an user (indoor)						
Peak throughput (indoor)	Mbits/s	117,52	1 user per cell, nadir, 10dB atten	1	264	
peak Spectral density	bits/s/Hz	0,3091	1 user per cell, nadir, 10dB atten	1	264	
6) Throughput 1 PRB per user						
Average Throughput 1 PRB per user	Mbits/s	**1,57**	1 PRB per users/ 8 beams	2112	1	1
Average spectral efficiency	bits/s/Hz	**1,09**	1 PRB per users/8 beams	2112	1	1
Aggregated throughput	Gbits/s	**3,32**	1 PRB per users/8 beams	2112	1	1
7) Throughput ALL power in 1 PRB 1 user						
Average Throughput 1 PRB per user	Mbits/s	**2,55**	in one beam (taken near nadir)	8	1	1
Average spectral efficiency	bits/s/Hz	**1,77**	in on beam (taken near nadir)	8	1	1
Aggregated throughput	Mbits/s	**20,40**	in one beam (taken near nadir)	8	1	1
8) AGGREGATED MAX throughput 7	Gbits/s	**17,67**	56 beams, 264 users per beam	1848	1	1
9) AGGREGATED MAX throughput 7	Gbits/s	**8,84**	28 beams, 264 users per beam	924	1	1

FIGURE 8-13 DOWNLINK PERFORMANCES EVALUATION IN DIFFERENT CONFIGURATIONS.

1) 1 user one the cell, max number of PRB and all power on one cell.

2) power on 8 cells near nadir, 1 user per cell, best conditions

3) power on 8 cells at edge, 1 user per cell, best conditions

4) Average case, power on 8 cells, 1 users per cell, cells from nadir to edge

5) Power on one cell, indoor condition (10 dB attenuation), 1 user, best condition

6) case of 1PRB per user, 264 PRB per beam, 8 beams.

7) all power in one PRB, 8 users, 8 beams

8) aggregated throughput with 7 antenna 8 beams per antenna

9) aggregated throughput with 7 antenna 4 beams per antenna

8.7 UPLINK Q/V BAND LINK BUDGET

The exemple of link budget has been given for the uplink in the table of FIGURE 8-14.

PRACH Link Budget	UPLINK	Unit	Average Case (El 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	-	74	264
	Occupied Channel Bandwidth	MHz	106,56	380,16
	Total Channel Bandwidth	MHz	380,16	380,16
	Uplink Frequency	GHz	50,00	50,00
	Nb spots	-	4 or 8	4 or 8
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
	Cable loss	dB	0,00	0,00
	Transmit Gain	dBi	29,59	31,09
	EIRP	dBW	33,59	35,09
	EIRP per PRB	dBW	14,90	10,88
SATELLITE - RX	Satellite altitude	km	600	600
	Satellite figure of merit (G/T)	**dB/K**	**2,04**	**3,55**
LOSSES	**Free space propagation**	**dB**	**184,65**	**181,99**
	Propagation losses computation	-	Computation [RD1] & [RD2]	
	UE location	-	Toulouse	
	Weather condition	-	Clear Sky	
	Propagation tool atmospheric loss computed	dB	2,66	1,88
	Zenith Attenuation	dB	1,80	1,80
	Atmospheric Path loss	dB	3,31	1,80
	Ionospheric Scintillation Loss	dB	0,00	0,00
	Tropospheric Scintillation Loss	dB	0,40	0,27
	Scintillation loss	dB	0,40	0,27
	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	-	74	264
RESULTS	**Obtained C/N**	**dB**	**-4,47**	**-2,71**
	Nearest C/N	dB	-5,32	-3,62
	Residual Margins	dB	0,8545	0,9100
	Spectral Efficiency	bits/s/Hz	0,2110	0,3393
	PRB Rate	kb/s	303,782	488,592
	UE Rate	**Mbit/s**	**22,480**	**128,988**

FIGURE 8-14UPLINK BUDGET

The uplink performances evaluations in differents context is given in the table

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UPLINK	unity		remark 1		nb PRB	
1) PEAK Throughput Achievable per an user				nb user	nadir	45°
Peak throughput	Mbits/s	128,988	1 user per cell, nadir	1	264	
peak Spectral density	bits/s/Hz	0,3393	1 user per cell, nadir	1	264	
peak troughput/km^2	kbits/s/km^2	73,55	Dp_up/ cell surface	1	264	
2) PEAK Throughput Achievable by the satellite						
Peak throughput 1PRB at nadir	Mbits/s	**3,91**	1 user per cell, nadir	1	1	
peak Spectral density 1PRB at nadir	bits/s/Hz	2,71	1 user per cell, nadir	1	1	
Aggregated peak throughput on a nadir cell	Mbits/s	1031,71	264 users on a cell at nadir	264	1	
Aggregate Max throughput 1PRB per user all beams	Gbits/s	**8,25**	264 user per cell nadir, 8 beams ar	2112	1	
3) PEAK Throughput Achievable by the satellite						
Peak throughput 1PRB at edge	Mbits/s	**3,33**	1 user per cell, edge	1	1	
peak Spectral density 1PRB at edge	bits/s/Hz	2,31	1 user per cell, edge	1	1	
Aggregated peak throughput on a edge cell	Mbits/s	879,38	264 users on a cell at edge	264	1	
Aggregate Max throughput 1PRB per user all beams	Gbits/s	**7,04**	264 user per cell nadir, 8 beams at	2112	1	
4) AVERAGE Throughput Achievable by the satellite						
Average Aggregate throughput 1PRB/user in 1 beam	Mbits/s	925,08	264 user in one beam	264	1	
Average Aggregate throughput 1PRB/user all beams	Gbits/s	7,40	264 per cell, 8 beams nadir to edg	2112	1	
average throughput/Km^2	kbits/s/km2	527,50	264 user per cell, cell distributed fr	264	1	
5) PEAK Throughput Achievable per an user (indoor)						
Peak throughput (indoor)	Mbits/s	**15,099**	1 user per cell, nadir, 10dB atten	1	38	
peak Spectral density	bits/s/Hz	0,2759	1 user per cell, nadir, 10dB atten	1	38	
Peak throughput 1PRB	Mbits/s	**2,800**	1 user per cell, nadir, 10dB atten	1	1	
peak Spectral density 1PRB	bits/s/Hz	1,9442	1 user per cell, nadir, 10dB atten	1	1	
6) AVERAGE Throughput Achievable per an user						
average Peak thoughput	Mbits/s	64,0056	1 user per cell, nadir to edge, best	1	264	74
average spectral density	bits/s/Hz	0,3393	1 user per cell, nadir to edge, best	1	264	74
aggregated peak throughput	Mbits/s	6,4006	8 users on 8 beams	8	264	74
average throughput/Km^2	kbits/s/km2	36,4975		8	264	74
7) AGGREGATED MAX throughput 7 antenna /8 beams	Gbits/s	51,80	56 beams, 264 users per beam	14784	1	1
8) AGGREGATED MAX throughput 7 antenna /4 beams	Gbits/s	25,90	28 beams, 264 users per beam	7392	1	1

FIGURE 8-15PERFORMANCES EVALUATION IN DIFFERENT CONFIGURATIONS.

1) One user on a cell at nadir using all the 264 PRB

2) case of 264 users on each active 8 cells near nadir using one 1 PRB

3)) case of 264 users on each active 8 cells near edge using one 1 PRB

4) average case of 264 users on each active 8 cells from nadir to edge using one 1 PRB

5) case of Indoor (10 dB attenuation), 1 users per cell (8) using max number of PRB

6) On user on a cell from nadir to edge using 264 PRB

7) Aggregated throughput per satellite 8 beam per antenna, 7 antennas

8) Aggregated throughput per satellite 4 beam per antenna, 7 antennas

According to the requirements (see doc 2.3) the performances of the satellite is given below:

UPLINK		
8 beams per antenna		
Need per user	125	Mbps
activity factor	2	%
real need	2,5	Mbps
nb users per cell	370	
surface cell	1753,70	km^2
density	0,21	user/km^2
active surface %	1,60	%

4 beams per antenna		
Need per user	125	Mbps
activity factor	2	%
real need	2,5	Mbps
nb users per cell	370	
surface cell	1753,70	km^2
density	0,21	user/km^2
active surface %	0,80	%