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Abstract

This deliverable provides the interim outcomes of Task 2.2. As such, it reports the initial outcomes of Task 2.2 by providing: i) a detailed revision of the selected services based on the outcomes of D2.1 “NGSO based satellite access overview;” ii) an overview of the targeted performance of the DYNASAT system; and iii) a qualitative list of the expected advantages introduced by the bandwidth-efficient and spectrum sharing techniques discussed in D3.1 “Bandwidth Efficient Techniques selection” and D4.1 “DSA for non-geostationary satellites,” respectively.

Keywords: Non-Terrestrial Networks, Beamforming, MU-MIMO, spectrum sharing, NTN services, 3GPP

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** R: Document, report (excluding the periodic and final reports)*
DEM: Demonstrator, pilot, prototype, plan designs
DEC: Websites, patents filing, press & media actions, videos, etc.
OTHER: Software, technical diagram, etc

EXECUTIVE SUMMARY

This document reports the initial outcomes of Task 2.2 “Targeted Performances.” The objectives are to: i) dimension the system to meet the targeted performance; ii) perform the link budget and system-level simulations to support the system dimensioning; iii) estimate the benefits of the considered bandwidth-efficient and spectrum sharing techniques on the targeted performance; and iv) assess the energy efficiency and life cycle of the satellite network infrastructure in order to quantify the environmental impact.

It shall be noticed that document is an interim version of the outcomes of Task 2.

As such, it reports the part of the outcomes that are expected to be produced in the context of Task 2.2. In particular, it provides: i) a detailed revision of the selected services based on the outcomes of D2.1 “NGSO based satellite access overview;” ii) an overview of the targeted performance of the DYNASAT system; and iii) a qualitative list of the expected advantages introduced by the bandwidth-efficient and spectrum sharing techniques discussed in D3.1 “Bandwidth Efficient Techniques selection” and D4.1 “DSA for non-geostationary satellites,” respectively.

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ABBREVIATIONS

AWGN	Additive White Gaussian Noise
CA	Carrier Aggregation
CSI	Channel State Information
DC	Dual Connectivity
DSA	Dynamic Spectrum Access
FDD	Frequency Division Duplexing
FFR	Full Frequency Reuse
FR	Frequency Reuse
gNB	gNodeB
ISL	Inter Satellite Link
LEO	Low Earth Orbit
LOS	Line-of-Sight
LTE	Long Term Evolution
KPI	Key Performance Indicator
MBMS	Multimedia Broadcast Multicast Systems
MIMO	Multiple Input Mulitple Output
M-MIMO	Massive MIMO
MU-MIMO	Multi User MIMO
mMTC	massive Machine Type Communications
MN	Master Node
MNO	Mobile Network Operator
NB-IoT	NarrowBand Internet of Things
NGSO	Non-Geosynchronous Orbit
NR	New Radio
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
SISO	Single Input Single Output
SN	Secondary Node
SU-MIMO	Single User MIMO
SUE	Spectrum Utilization Efficiency
TDD	Time Division Duplexing
TN	Terrestrial Network
TR	Technical Report
UE	User Equipment
WI	Work Item

1 SERVICES AND REQUIREMENTS

The potential services have been detailed in D2.1, taking those reported in 3GPP TR 28.822 as a baseline. In this document, four services have been retained for further study during the project activities. In this Section, we will include:

- A short review of the selected scenarios.
- A set of target performance, for which 3GPP documents will be taken as a reference.

1.1 Service description

In D2.1, the following services were detailed based on an extension of those already provided in 3GPP TR 22.822, [1], which aim at providing service continuity, ubiquity, and scalability for 5G communications exploiting a non-terrestrial component:

- Smart good tracking (IoT via satellite).
- NB-IoT/mMTC global (IoT via satellite).
- Remote control and monitoring of critical infrastructure (IoT via satellite).
- Broadcast/multicast via satellite.
- 5G to premises.
- Emergency management.
- Optimal routing or steering over satellite.
- Global satellite overlay.
- Indirect connectivity.
- Satellite fixed/moving platform backhaul.
- Digital divide.
- Coverage extension.
- Maritime coverage.

The above defined services imply the inclusion of one or more satellite into the New Radio (NR) Radio Access Network (RAN), providing significant benefits to the overall system. However, not all of these use cases can fit the DYNASAT architecture, assumptions, and objectives. Indeed, the DYNASAT project aims at developing and demonstrating advanced techniques for bandwidth–efficient spectrum usage in the framework of NGSO mega-constellations to serve mass-market and professional equipments. Since Low Earth Orbit (LEO) systems are considered, latency will be at most 6 ms, which is enough for most of the NR networks. In particular, the selected services imply a pedestrian with a handheld equipment, such as a smartphone, that uses the 5G network.

Along these lines, each of the above services is classified taking into account: (1) the suitability to the DYNASAT architecture and assumptions, by considering the efficiency of the services provided through the NGSO mega-constellation; (2) the necessity for innovative bandwidth-efficient techniques and enhanced broadband connectivity; and (3) the necessity for spectrum sharing between the satellite and the terrestrial network component.

In Table 1, the evaluation of each service provided in D2.1 is reported for the sake of completeness. The scores are assigned based on the matching level between the service and the selection criterion, *i.e.*, low (L) corresponds to a limited matching, while high (H) to very a good matching.

#	Service name	Architecture	Enhanced broadband	Spectrum sharing	Score
1.1	Smart good tracking	L	L	M	4
1.2	NB-IoT/mMTC global coverage	L	L	M	4
1.3	Remote control and monitoring of critical infrastructures	L	M	L	4
2	Broadcast/multicast via satellite	H	M	L	6
3	5G to premises	L	M	M	5
4	Emergency management	H	M	H	8
5	Optimal routing or steering over a satellite	M	H	H	8
6	Satellite transborder service continuity	H	H	L	7
7	Global satellite overlay	L	L	M	4
8	Indirect connectivity	L	M	M	5
9	Satellite fixed/moving platform backhaul	L	M	M	5
10	Digital divide	H	M	H	8
11	Coverage extension	H	M	H	8
12	Maritime coverage	H	M	H	8

Table 1 service classification. L: low (1); M: medium (2); H: high (3).

Therefore, based on the classification reported in Table 1, the DYNASAT studies will address the following services first:

- Broadcast/multicast via satellite.
- Digital divide.
- Coverage extension.
- Maritime coverage.

Regarding the broadcast/multicast service via satellite, it is well known that there is an ever-increasing capacity request of broadband connectivity. Hence, in the context of enhanced Multimedia Broadcast Multicast Systems (MBMS), satellite networks provide advantages, in terms of efficient access option, to the users located in un or under-served areas and to users with the required Quality of Services (QoS), when the MNO is suturing due to the huge traffic request. For this use case, it is required that (1) 5G system should support both satellite and terrestrial Radio Access Technologies (RATs); (2) the 5G should implement techniques and procedures to make more efficient the content distribution, especially when both the terrestrial and satellite options are available; and (3) the UE should be able to connect to both a terrestrial and a satellite 5G network. Thus, in this service a possible scenario applicable to DYNASAT could be that of reducing the size of the terrestrial cell with the aim to implement spectrum sharing with a certain extent. Regarding the architecture, since we focus on the handheld equipment, the application of NGSO mega-constellation with direct-access is definitely suitable.

Digital divide refers to the gap between those who have access to digital solutions, such as internet and mobile communications, and those who experience a lack of connectivity. In this context, satellite constellations provide broadband solutions to places where is not feasible to develop massive terrestrial infrastructures. In this service, two types of broadband digital divide use case can be distinguished:

- Fixed: users are households and enterprise premises in areas not covered by terrestrial networks;
- Mobile: users are considered as outdoor pedestrians, connected to the satellite by handheld equipment. Some 5G terrestrial relays can be necessary.

It is this second use case that is interesting for DYNASAT, not only because it meets all the requirements but also because it is an interesting economical use case.

Coverage extension, also known as broadband service continuity, covers all the users who have already everyday connectivity and move to under-served areas. It mainly focuses on pedestrian users with handheld devices, which rely only on NTN services. Even with the objective of exploiting terrestrial bandwidths, no interference arises, since are used in remote areas. It is worth highlighting that this service is able to cover service 5, *i.e.*, Optimal routing or steering over a satellite.

The scenario of maritime coverage provides connectivity to users located in cruise ships near the cost. Indeed, moving away from the coast for some km, users loose connection with the terrestrial network. Within this use case, it is possible to use the terrestrial bandwidth without interference constraints. Depending to the distance to the land, satellites could be connected to the gNB on the coast, thus preventing the need of Inter Satellite Links (ISLs).

1.2 Target performance

In terms of system requirements, there are several 3GPP TRs and TSs providing preliminary values and definitions that can be taken into account as a baseline to be tailored based on the DYNASAT system needs. These are reported in Table 2.

Document #	Title	Sections of interest	Comments
TS 22.105, [2]	Services and service capabilities (Release 16)	5.4: range of QoS requirements	- range of BER and latency values per operating environment, including satellite access, for both real-time and non-real-time applications
		5.5: supported end-user QoS	- summary of applications - tables with end-user performance expectations per application (conversational/real-time, interactive, streaming)
		B.2: QoS related performance requirements for example end user applications	- more detailed (in terms of description) requirements for conversational real-time, interactive, streaming, background services - sub-service types are listed

TS 22.261, [3]	Service requirements for the 5G system; Stage 1 (Release 18)	6: basic capabilities	- requirements, management, and constraints for several basic 5G capabilities - network slicing, mobility, multiple access, resource efficiency, connectivity model, etc.
		7: performance requirements	- section 7.4 reports the KPIs for 5G via satellite, providing the requirements per receiver mobility scenario
TR 38.811, [4]	Study on New Radio (NR) to support non-terrestrial networks (Release 15)	4.2: 5G use cases where NTN has a role	- satellite and aerial access
		5: deployment scenarios	- deployment scenarios (D1, D2, D3, D4, D5)
TR 38.821, [5]	Solutions for NR to support non-terrestrial networks (NTN) (Release 16)	B: KPIs and evaluation assumptions	- Table B.2-1: Non-Terrestrial network target performances per usage scenarios

Table 2: Summary of 3GPP references related to the performance tartgets and assessment.

Moving from the requirements that are already available in 3GPP documents, a number of technical and economical Key Performance Indicators (KPI) have been defined in D2.1 in order to define targets of performance improvements for the bandwidth efficient techniques that are studied in DYNASAT for the different services that have been selected in the previous chapter.

The performance targets defined in D2.1 and listed in Table 3 and Table 4are equally applicable to the above services.

Measure	Indicators	Target
Performance with single radio link	*Link margin*	Up to a factor 10 of increased throughput, user density, link availability or mix
Experienced data rate with Power class 3 devices (SoA: 2 Mbps (DL), 0.25 Mbps (UL))	*Data rate*	Up to 20 Mbps (DL), 2.5 Mbps (UL)
Frequency re-use factor SoA: 3 in MSS, as per 3GPP TR 38.821 in clause 6)	*Frequency re-use factor*	1 (full re-use of spectrum in all beams)
Spectral efficiency SoA: 1 bps/Hz (DL), 0.5 bps/Hz (UL)	*Spectral efficiency in UL & DL*	Up to 3 bps/Hz (DL), 1.5 bps/Hz (UL)
Access to spectrum for satellite network infrastructure Spectrum allocated to Mobile Satellite Services	*Frequency bands allocation*	Spectrum allocated to Mobile Satellite Services as well as Mobile Services (Cellular)

Served capacity density	*Capacity per km²*	Up to 10 kbps/km² (DL), 5 kbps/km² (UL)
Percentage of capacity demand actually served	*% of total capacity*	20% for high-bandwidth demand services 100% for low-bandwidth demand services
Percentage of served service areas	*% service areas*	100% of service areas
Coverage improvement with protection areas	*Improvement compared to non-co-operative non coordinated spectrum sharing*	20 % smaller protection area
Spectrum Utilization Efficiency (SUE)	*Improvement compared to non-co-operative non coordinated spectrum sharing*	20 % higher SUE
Capacity in fully overlapping networks	*Improvement compared to non-coordinated spectrum sharing*	20 % higher capacity for satellite without losing mobile capacity

Table 3 Technical KPIs indicators and targets.

Measure	**Indicators**	**Target**
System CAPEX	*Given as variation in % to a reference CAPEX value of a reference system*	No more than x2 increase compared to 5G baseline architecture.
System OPEX	*Given as variation in % to a reference OPEX value of a reference system*	No more than x2 increase compared to 5G baseline architecture.
System TCO	*Given as variation in % to a reference TCO value of a reference system*	No more than x2 increase compared to 5G baseline architecture.
System Revenues	*Given as variation in % to a reference Revenues value of a reference system*	At least x2 increase compared to 5G baseline architecture.
IRR (Interest Rate of Return)	*Given as variation in absolute value (expressed as a %) to a reference IRR value of a reference system*	More than +3% variation compared to the IRR of the 5G baseline architecture.

Table 4 Economical KPIs indicators and targets.

2 BANDWIDTH-EFFICIENT AND SPECTRUM SHARING TECHNIQUES: EXPECTED BENEFITS

Satellite systems are expected to play a crucial role in the future 5G networks, [6]. The main motivation is that, thanks to their inherent characteristics, satellite systems can extend the terrestrial coverage, and internet access can be provided to rural areas and emerging countries, and in general to all scenarios where no terrestrial connectivity is available. Satellite systems can act as a backup network in case of terrestrial network outage and alleviate the need of network densification on the ground. Moreover, satellite communications can improve 5G network management, synchronization, and signalling, and allow efficient backhauling. In this chapter, the qualitative benefits and challenges obtained with the introduction of advanced bandwidth-efficient and spectrum sharing techniques are discussed.

In this section, an detailed overview of the qualitative benefits that are expected from bandwidth efficient and spectrum sharing techniques is provided, taking into account the peculiarities of the DYNASAT concept. The considered techniques are extensively described and characterised in D3.1, [7], and D4.1, [8], respectively.

2.1 Performance gain achievable with bandwidth efficient transmission techniques

In the last years, the 3GPP standardization group has promoted intense activities to study the integration of NTN in 5G systems (Release 15 [9] and Release 16 [10]). There is an on-going Release 17 standardization activity in 3GPP to specify the enhancements of NR to support NTN systems [11]. The objectives of this Work item (WI) are to address issues due to long propagation delays, large Doppler effects, and moving cells, which have been identified during the NTN Study Item (SI) [12]. The considered scenarios show a high interference level because several beams are originated from the same satellite. Therefore, scenarios applying frequency reuse 3 or a combination of polarization reuse and frequency reuse 2 have been discussed by the 3GPP standardization group. Transmissions with one transmit and one receive antenna (SISO) are considered. During the Study Item, system-level simulation results have been provided for single satellite systems.

The grand challenge for future 5G networks is to satisfy the increasing request of new services by living with the scarcity of the frequency spectrum. The study of more efficient ways to exploit the available bandwidth is therefore of paramount importance and resource sharing is probably the only option. In the context of satellite communications, the leading design paradigm has historically been based on interference avoidance. By transmitting signals that are separated in the time and/or frequency domains, it is ensured that a simple receiver structure can effectively recover the transmitted information. However, to meet the increasing requirements, the attention of the research community has recently shifted toward the interference management and exploitation paradigm. Interference is not avoided by design anymore, but a certain amount of controlled interference is intentionally introduced and mitigated or exploited, both at the transmitter and at the receiver sides, using specifically designed transceiver architectures. In the literature, it has been shown that this change of paradigm can allow to reach extremely high gains with respect to the interference avoidance approach of traditional systems.

For satellite systems, several bandwidth efficient techniques to be applied at the transmitter and/or at the receiver can be adopted. In this project, we study **bandwidth efficient transmission techniques** based on the interference management and exploitation paradigm, such as cooperative and coordinated precoding methods that leave unmodified the user terminal receiver on the ground, for application in advanced mega-constellations of NGSO satellites. The expected gain that can be achieved with the adoption of these techniques in the context of satellite networks is in terms of capacity for unicast and broadcast applications.

Multi-satellite MIMO cooperation techniques and interference mitigation techniques are considered in satellite scenarios with aggressive frequency reuse. Multibeam satellite architectures allow to reuse the same bandwidth in different beams. The service area is divided into small beams in order to reuse the frequency spectrum and hence to improve the spectral efficiency. Figure 1 schematically shows the forward link of a multibeam satellite system.

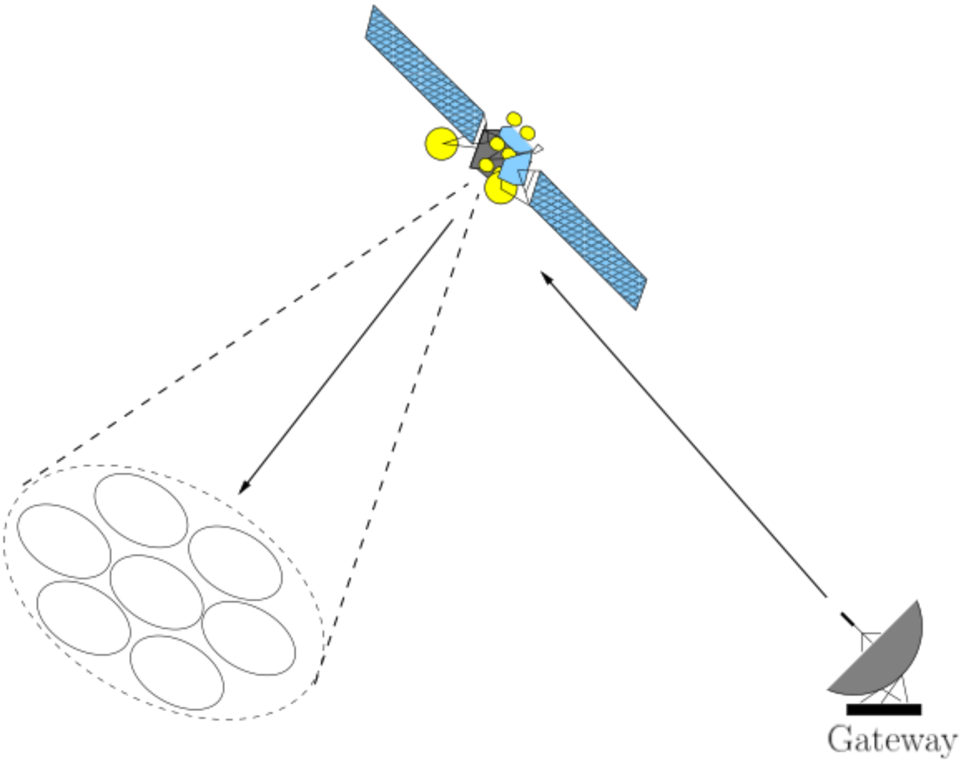

Figure 1: Forward link of a multibeam satellite system.

Signals are generated at the gateway (or at multiple gateways), then are sent to the multibeam satellite, that forwards the signals to the beams on the surface of the Earth, where the user terminals are located, represented by ellipses in the figure. A four-color scheme is the commonly adopted solution in most systems, as it ensures a low level of interference, whereas the more aggressive schemes, with a lower number of colors, ensure a more efficient usage of the bandwidth, at the price of an increased interference, which has to be managed at the receiver and/or at the transmitter to achieve the required performance. As an example, a 4-color frequency reuse scheme is shown in Figure 2, where beams with the same color use the same bandwidth. In a 4-color frequency reuse scheme, the interference is very limited and can be neglected at the receiver. A more **aggressive frequency reuse** can be adopted with the aim of improving the **system spectral efficiency**. Figure 3 depicts the case of a 2-color frequency reuse scheme, while Figure 4 is for the case of 1-color frequency reuse, also known as full frequency reuse (FFR) scheme. In this project, we study transmission techniques that allow to use FFR. We consider advanced precoding/beamforming techniques for MIMO schemes.

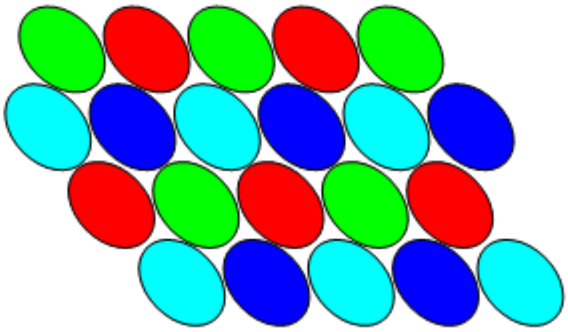

Figure 2: 4-color frequency reuse scheme (FR4).

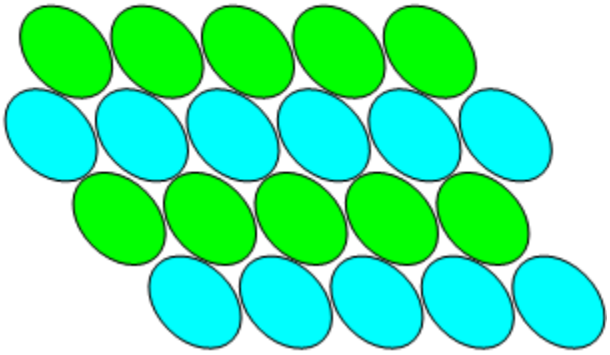

Figure 3: 2-color frequency reuse scheme (FR2).

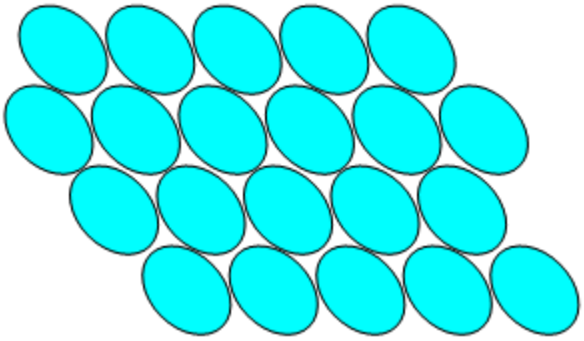

Figure 4: 1-color frequency reuse scheme (FR1).

The adoption of MIMO technology to satellite systems has been much slower than in terrestrial communications [13]. The shortcomings of the application of SU-MIMO to fixed satellite systems are due to the LOS channel, the space limitations on board a single satellite which do not allow for adequate antenna spacing or because the employment of more satellites gives rise to waste of spectrum, lack of synchronization in reception and high implementation cost. On the other hand, broadband fixed interactive multibeam satellite system accommodating a large number of fixed terminals within its multiple beams can benefit from the MU multiplexing gain when MU-MIMO precoding techniques are applied. MU-MIMO precoding techniques are in fact less sensitive to LOS or antenna correlation and allow for spatial multiplexing gain without necessitating satellite terminals with multiple antennas. This comes at the cost of the necessity of CSI at the transmitter, which is not an easy task in SatCom. In fact, it is not possible to use Time Division Duplexing (TDD) schemes to ease channel estimation because of satellite frequency regulation restrictions in millimeter wave bands. The adoption of M-MIMO in broadband satellite networks pose further challenges [14], such as difficulties from the implementation point of view, *i.e.*, wide adoption of transparent payloads with distributed gateways and four colors frequency reuse schemes not compatible with M-MIMO, very limited adoption of active array antennas with many radiating elements, and limitations in the amount digital processing implementable on-board. Moreover, benign channel model (essentially Additive White Gaussian Noise (AWGN) with no multipath fading) reduces the potential M-MIMO performance gain.

Recently, increased interest in MIMO transmission for NGSO satellite communications is emerging [15], [16]. This is due to the fact that LEO satellite communications are expected to be incorporated in future wireless networks and to some advantages with respect to the GEO counterpart, such as much less stringent requirements on power consumption and transmission signal delays. But most of the existing works on downlink precoding in multibeam satellite communications rely on exact instantaneous CSI. This assumption is not so realistic because of the long propagation delay between a satellite and UEs and the mobility of user terminals and satellites. In particular, for TDD systems, the coherence time of the channel is usually shorter than the transmission delay, while in FDD systems, it requires UL feedback from UEs, which introduces a great amount of training and feedback overhead due to mobility of UEs and more importantly could become outdated as a result of the long propagation delay.

In Dynasat, we will also investigate whether asynchronous NR-NR Dual Connectivity (DC) and Carrier Aggregation (CA) [17],[18],[19] would be beneficial for NTN and whether some enhancements are needed. In general, in Multi-connectivity defined by 3GPP the UE is able to utilize radio resources provided by multiple distinct schedulers located in two different NG-RAN nodes. We can define one Master Node (MN) and a Secondary Node (SN), connected via Xn interface. At least the MN is connected to the core network. Three cases of Multi-connectivity may be considered: involving TN and NTN access, involving NTN access inter-satellite and involving NTN access intra-satellite. When both MN and SN are NTN-based at least a partial coverage area overlap is required.

Multi-connectivity enhances performance in terms of data rate and reliability of the connection, providing additional robustness. Moreover, it provides seamless mobility by eliminating handover interruption delays, avoids the need to synchronize gNBs, and allows non-co-located deployments.

The satellite system considered in this project is a LEO constellation providing a global land and ocean 5G coverage. The constellation will be based in Mobile Satellite System (MSS) S band for service link and it will provide 5G services to UE be fix or mobile (*e.g.*, cars, vessels, …).

The bandwidth efficient techniques that are considered in this project can be divided in three main categories, *i.e.*, short, medium and long term techniques. For the short term, techniques with features that have little impact specifications to contribute to 3GPP Release 18 will be considered. In particular, Multi-connectivity techniques and MU-MIMO precoding techniques that do not rely on CSI knowledge at the transmitter will be evaluated. The techniques of interest for medium and long term are precoding techniques that rely on the knowledge of the CSI at the transmitter, and that can exploit the presence of two or more satellites. Massive MIMO techniques from terrestrial networks will be also extended to the mega-constellation scenario. The main issue to be solved in this case is the problem of obtaining channel state information at the transmitter in satellite frequency division duplex schemes. We expect a large gain in terms of system capacity with the adoption of such techniques.

Technique	Gain	Challenges	Cost
MU-MIMO precoding	-frequency reuse 1 -increased spectral efficiency -increased throughput -MU multiplexing gain	-CSI knowledge at the transmitter -space limitations on board a single satellite -limited amount of digital processing implementable on-board	-adoption of active array antennas with several radiating elements -implementation of user scheduling algorithm -Doppler and delay compensation at the user terminal

			-channel estimation at the user terminal
Multi-connectivity	-increased throughput -better coverage -seamless mobility -additional robustness	-different delay/delay variation between the MN and the SN -operating bands selection	-partial coverage area overlap -UE implementation cost -setting up and maintaining Xn via the ISL

Table 5: Qualitative performance gain, challenges, and implementation cost of the considered bandwidth efficient techniques.

Table 5 summarizes the qualitative performance gain, challenges, and implementation cost of the aforementioned bandwidth efficient techniques.

2.2 Performance gain achievable with spectrum sharing techniques

When we study the benefits of spectrum sharing, we can identify two different spectrum sharing options in Dynasat: coordinated and non-coordinated spectrum sharing. In non-coordinated spectrum sharing, the transmissions of the sharing systems are white noise to each other, and the spectrum users have a strict priority order. The secondary users are only allowed to transmit, when they do not cause harmful interference to the primary users. The metrics to evaluate the performance of a sharing arrangement are coverage, capacity and Spectrum Utilization Efficiency. By coverage, we mean the geographic area where a radio station can communicate. Capacity is the amount of traffic that a network can handle at any given time, and the Spectrum Utilization Efficiency (SUE) is expressed as a formula:

$$SUE=M/BST,$$

where M is the amount of information transferred over distance, B is frequency bandwidth, S is geometric space (usually area), and T is time denied to other potential users [20].

If we assume, that the primary use has discrete boundaries in time, frequency or geographic domain, all additional (coordinated or non-coordinated) spectrum use by the secondary user always improves coverage, capacity and spectral utilization efficiency. If non-coordinated spectrum sharing only brings benefits without any negative effects, shouldn't we use spectrum sharing in all bands and everywhere. Although the benefits are clear in the cases where the primary has discrete boundaries, another way to look at the question is to consider a case where the primary use does not have boundaries. In mobile networks, this case is in the coverage band deployments below 1 GHz. In those bands, the mobile networks cover the whole or almost fully the landmass of a country. Splitting the band to smaller frequency bands, time periods or geographic areas requires protection margins in all dimensions between the sharing networks and decreases the coverage, capacity and SUE.

The coordinated spectrum sharing is a middle ground between block licensed nation-wide networks and non-coordinated spectrum sharing. The transmissions of coordinated networks can overlap in frequency, time and geographic domains as long as they are coordinated. The benefit of coordination is that the margins in frequency, time and geographic domains are significantly smaller than in non-coordinated spectrum sharing. Coordination is very efficient when two cells are coordinating with each other: when one network is idle, the other network can transmit. Sharing becomes less efficient when one network covers several cells of the other network, as in order to transmit in the larger network, all cells which are covered by the larger network must be idle at the same time. In coordination, there can be several levels, a simple form of coordination is used in the European private LTE/5G networks, where the license terms often include a requirement for TDD synchronization.

The applicability of coordinated and non-coordinated spectrum sharing and benefits or negative impacts to the primary and secondary network or the total system are scenario dependent. In the following scenarios, we assume that both networks operate in the same frequency band and continuously. The first scenario is that the primary network has discrete boundaries, and the secondary network only fills gaps of the primary network with minimal or no overlap. For the primary network, there is no coverage, capacity or SUE impact. The coverage of the secondary network is improved in the areas where the primary network is not deployed, and it also gets full capacity and SUE improvement. Considering the whole area and both networks, coverage, capacity and SUE are improved significantly. The difference between coordinated and non-coordinated approaches is that the coordinated sharing has smaller geographic margins, and on the system level the coverage, capacity and SUE improvements are higher than in non-coordinated sharing (Figure 5).

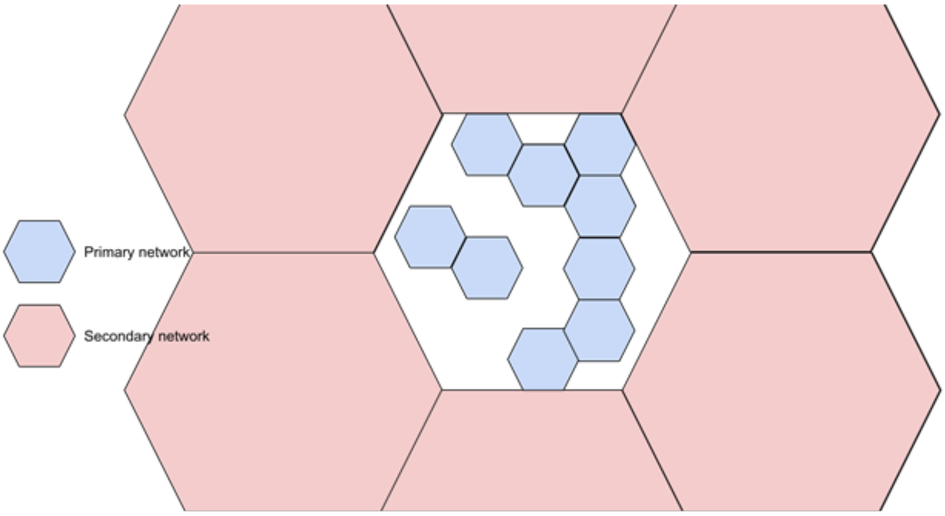

Figure 5: Secondary networks filling the gaps of the primary network.

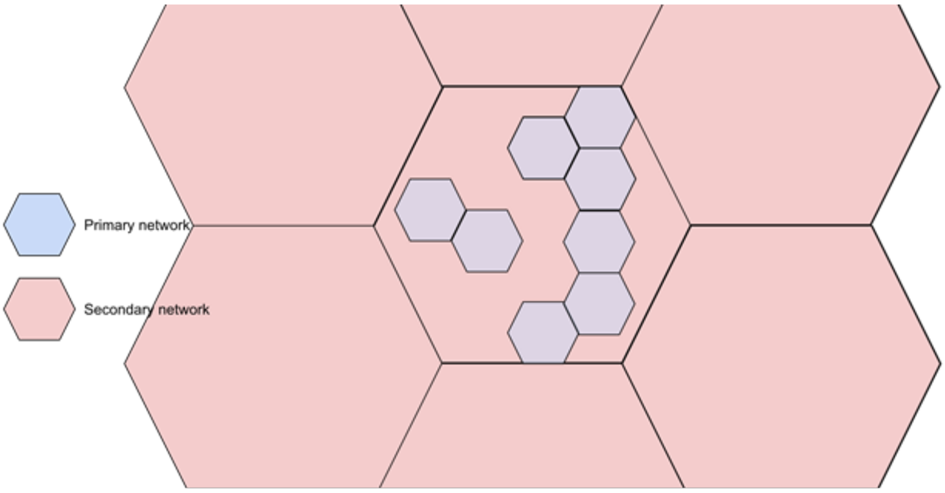

Figure 6: Secondary network with full coverage.

In the second scenario, the primary network has discrete boundaries, and the secondary network has the full coverage of the area. This scenario is only possible to deploy using coordinated spectrum sharing. The primary network has roughly the same coverage as without sharing. For simplicity, we neglect the decrease of coverage area due to increased interference from the secondary network. Capacity and SUE of the primary are decreased. The secondary network gets full coverage improvement and partial capacity and SUE improvement, depending on the amount of capacity available from the primary network. On the system level, taking into account both networks, the coverage is improved to maximum, but both capacity and SUE are decreased significantly due to fewer cells serving the time and frequency domain resources that are available for the secondary network (Figure 6).

In the last scenario, we assume that both networks cover the whole study area. The positive and negative effects for the primary and secondary networks are the same as in the previous scenario. On the system level, there is no coverage improvement and both capacity and SUE are decreased (Figure 7).

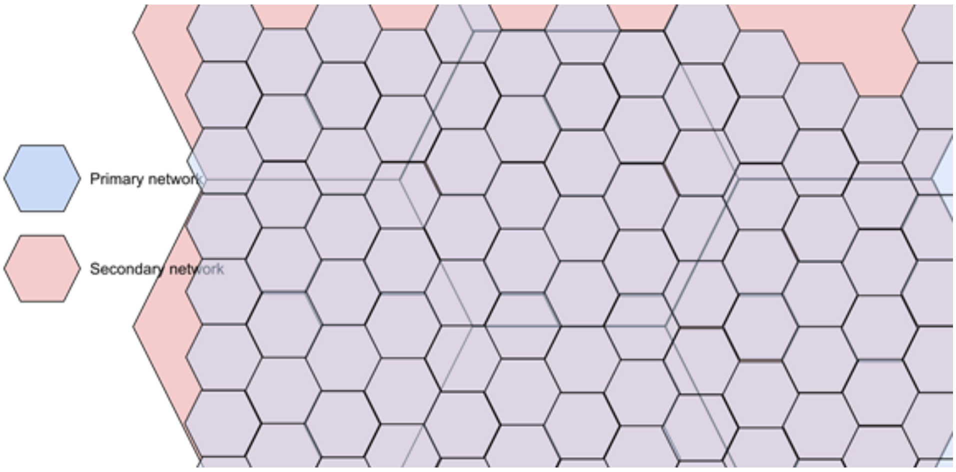

Figure 7: Both primary and secondary networks with full coverage.

As discussed above, the benefits depend on the scenario and environment. When the sharing networks use the same technology, *e.g.*, 3GPP or IEEE 802, coordinated spectrum sharing could be applied. On contrary, the non-coordinated spectrum sharing must be used between the different technology families. Non-coordinated spectrum sharing can only be applied where the primary and secondary users can be separated in frequency, time or geography. Also, in that case, coordinated spectrum sharing has provides more benefits than non-coordinated spectrum sharing by having smaller margins in frequency, time and geographic domains which result higher coverage, capacity and SUE improvement compared to non-coordinated spectrum sharing. Although coordinated spectrum sharing can be deployed for overlapping networks, the overlap should be minimized as it decreases capacity and SUE improvement of the combined network system. In practise, this limits the spectrum sharing to capacity bands, which are above 1 or 2 GHz or to the areas where there is no mobile coverage, like high seas.

3 TRL ASSESSMENT

The aim of this section is to define which TRL levels are considered in DYNASAT for each technology used in the scope of the project. It refers to the current TRL as well as the target/expected TRL afterwards.

3.1 BANDWIDTH-EFFICIENT TRANSMISSION TECHNIQUES

3.1.1 Multi-User MIMO (MU-MIMO)

Within WP3, the following techniques have been considered during Y1 :

- MMSE, which requires the estimation of the Channel State Information (CSI) vectors at the receiver and their knowledge at the transmitter
- Switchable Multi-Beam (MB), which only requires the knowledge of the UE position and the satellite ephemeris at the transmitter
- Spatially Sampled MMSE (SS-MMSE), which is another location-based technique

The above techniques are assessed in a mega-constellation satellite system in which :

- Each satellite is equipped with an active antenna array
- The satellites can communicate with each other by means of Inter Satellite Links (ISLs).
- The MU-MIMO techniques are implemented both at beam and feed level

In the past, some ESA projects targeted the implementation of precoding in a satellite communications system. In particular, the PreDem (Precoding Demonstrator for Broadband System Forward Links), and LiveSatPreDem (Live Satellite Demonstration of Advanced Interference Management Techniques), projects aimed at implementing and demonstrating the achievable spectral efficiency with MU-MIMO techniques over the DVB-S2(X) air interface. The latter study is the evolution of the former, aimed at reaching a TRL 5. The final outcome of the study was a precoding demonstrator with a precoding enabled GW, a satellite MIMO channel emulator, and a set of UEs. Thus, despite the objective of a TRL 5, this activity led to a TRL more likely to be 4.

Notably, the TRL level reached in the above studies do not apply to the DYNASAT scenario because of the following reasons :

- The ESA studies focused on a single GEO satellite, on beam space precoding, with a single GW. This represents a fundamental difference that brings the TRL to 3.
- The above studies were also focused on native satellite air interface (DVB-S2, DVB-S2X) and not on the 3GPP NR interface which was originally developed neither for satellite nor for precoding. This represents a further back step in TRL bringing the overall TRL for precoding in NTN to level 2.

As a consequence, the MU-MIMO techniques being studied in DYNASAT shall be considered to be classified as follows:

- Beginning of the project: TRL 2
- Current TRL: approaching TRL 3 (not yet completely achieved, since more considerations on signalling and measurements are needed, even for location based techniques)
- End of the project: a maximum of TRL 4 is reasonable to be assumed

The low TRL at the beginning of the project is further motivated by the limited scientific references related to the implementation of precoding in NTN systems. In fact, while the literature on precoding/beamforming in satellite communications is now quite vast, aspects related to the NR air interface are still missing. The only work that falls in this area is [21], in which the authors propose a precoding design integrated in satellite communication synchronisation and positioning, in a single satellite scenario with a payload equipped with a Uniform Rectangular Array (URA). Another work dealing with 5G, satellites, and precoding is [22], in which the authors focus on hybrid analog-digital precoding and power allocation for mmWave systems coexisting with a 5G satellite integrated network; however the authors do not take into to the NTN standardisation or air interface.

The above considerations and TRL analysis are in line with the DYNASAT proposal and DoA, with respect to the possibility of achieving (partly) TRL 5 and the objective of a plan for IoV/IoD targeting TRL 7. These activities will be performed during Y2 and Y3 and reported at the final project review.

3.1.2 Multi-Connectivity (MC)

If MC is a very well known (set of) features for Terrestrial Networks in 5G and previous generations (TRL 9), its interest has also already been identified for NTN by 3GPP. Just as many other topics, its current TRL would have to step back to TRL 3. Indeed, the concept has already been clearly described, notably in 3GPP standards, that demonstrates the critical functions of this technology. Multiple scenarios and possible environments have been discussed, including its applicability to the DYNASAT case.

The gain, challenges and technical cost are clear, however, the establishment of the technical and economic feasibility hasn’t been addressed yet. Actually, the work in the DYNASAT project is more oriented towards performance comparison and concept validation in different uses cases, rather than trying to make a full specification which would result of consensus between 3GPP actors, including SatCom and terrestrial. Since various techniques are already defined for terrestrial cases adaptations could be relatively fast after this consensus.

At the present time, considering the DYNASAT work, we assess TRL improvement will reach TRL 4 at the end of the project.

3.2 SPECTRUM SHARING TECHNIQUES

3.2.1 Coordinated Dynamic Spectrum Access (DSA)

Coordinated DSA is currently studied through simulations in DYNASAT. For implementation in operational systems Coordinated DSA will also require tight control of frequency band allocations between TN and NTN base stations. This will be done either directly or through network management (OAM). When assuming that we can utilize existing 3GPP interfaces, coordinated DSA can be considered to be at TRL 2, provided this topic is currently not set as priority item for 3GPP Release 19 and that scheduling process to be done in quasi real time is not trivial. Once (if) an agreement would be confirmed to address this issue use and/or adaptation of new interfaces could be made optional in base stations and if suitable algorithms are adopted by vendors, TRL could then progress very rapidly. Currently we estimate through the definition of the concepts and algorithms developed in DYNASAT, TRL 3 could be reached at the end of the project.

3.2.2 Non-Coordinated DSA

Non-coordinated DSA will communicate with TN and NTN only with a 3GPP OAM interface (to be identified/confirmed later in the project). Non-coordinated DSA is studied in the project through simulations and the development of a demonstration system. Due to the 3GPP standard interface and taking the research a step closer to a product implementation, and to the limited algorithms complexities and required amounts of exchanged information between systems we assess the TRL of non-coordinated DSA could be one level higher than that of coordinated DSA: Non-Coordinated DSA will reach TRL 4.

3.3 Prototyping

In terms of the demonstrations/prototyping done within WP5, three demonstrations over two separate software components are considered:

1. Multi-Connectivity over 5G NTN system level simulator and Magister SimLab simulation service developed by Magister Solutions

2. Coordinated Dynamic Spectrum Allocation (C-DSA) over 5G NTN system level simulator and Magister SimLab simulation service developed by Magister Solutions

3. Non-Coordinated Spectrum Sharing over a web service developed by Fairspectrum.

Demonstrations 1 and 2 are planned to be developed on top of the "5G NTN" packet-level system/network level simulator, which is operating in a non-real time mode. Together with Magister SimLab simulation service they form so called RAN Lab Demonstrator of DYNASAT project. 5G NTN system level simulator models the NR/NTN user plane protocol stack with sufficient accuracy as well as relevant parts of the NR/NTN control plane protocols.

With these assumptions, the target TRL of WP5 demonstrations is TRL 3.

Demonstration 3 will be developed as a cloud service just like a commercial system would be deployed. The interface to incumbent (TN OAM) will be similar to a commercial system i.e. a list of TN base stations and their operating parameters. The exact form of the list and the method to retrieve will be country specific, so that will be finalized in the system integration phase of a commercial deployment. The control of the licensee system (NTN OAM) will be carried out through 3GPP LSA - OAM interface. The interface has been developed for terrestrial networks, which have fixed base station locations.

If the required information from the spectrum management (LSA Controller) to the NTN OAM is just geographically defined beam availability, we can get relatively close to a potential commercial interface. If the required information includes satellite constellation, orbits, timing and other NGSO specific information, a significant change to the LSA – OAM interface will be required.

The same applies to the (?) in DYNASAT developed spectrum management system. As we do not have any base stations or OAM in DYNASAT, the TRL level of Non-coordinated DSA will be 4. The demonstration will be carried out as a proof-of-concept spectrum management system instead of a simulation system like in coordinated spectrum sharing. The incumbent and licensee interfaces to the system will be web user interfaces.

Table 6: TRL assessment for the technologies studied in the DYNASAT project

Technology	Current TRL (beginning of the project)	Expected TRL at the end of the project
MU-MIMO	TRL 2	TRL 4
Multi-Connectivity	TRL 3	TRL 4
Coordinated DSA	TRL 2	TRL 3
Non-Coordinated DSA	TRL 3	TRL 4

4 CONCLUSIONS

In this document, we summarized the initial outcomes of Task 2.2 “Targeted Performances.” More specifically, the following contributions have been provided:

- The description of the services considered of potential interest for the Project activities and highlighted those that will be retained for future activities.
- An overview of the 3GPP TRs and TSs providing relevant information with respect to the definition of the KPIs to be considered for the Dynasat services. Based on these, we also listed a set of economical and technical KPIs deemed of particular interest for the Dynasat techniques.
- A qualitative assessment of the benefits that can be obtained by introducing bandwidth efficient techniques in the Dynasat framework. In particular, MU-MIMO, DA, and CA.
- An overview of the gain that can be obtained with spectrum sharing techniques in terms of the Spectrum Utilization Efficiency in different spectrum sharing scenarios.

It is worth highlighting again that this document is an ad interim version of Task 2.2 outcomes and, thus, not all of the topics covered by Task 2.2 have been addressed. In the final version of this document, the complete summary of the studies performed within Task 2.2 will be provided. In particular, in addition to the contributions listed above, the following will be included:

- The definition of more detailed KPIs, in particular taking into account the 4 services that will be addressed during the Dynasat activities.
- The system dimensioning aimed at meeting the targeted performance
- Numerical results of the link budget and system-level simulations to support the system dimensioning
- A detailed estimation the benefits of the considered bandwidth-efficient and spectrum sharing techniques on the targeted performance better tailored to the 4 retained services
- The assessment of the energy efficiency and life cycle of the satellite network infrastructure in order to quantify the environmental impact.

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