D2.2
Business, Operational, and Technical Requirements for satellite eMBB

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<td>Satellite and Terrestrial Network for 5G</td>
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Executive Summary

In deriving the business, operational, and technical requirements for satellite eMBB, we followed these principles stated in the SaT5G proposal:

1. The implementation shall enable the plug-and-play integration of SatCom elements into 5G networks.
2. The implementation shall ensure the seamless integration of SatCom into 5G at network management and security levels.
3. The implementation shall enable eMBB services to end-users everywhere, specifically looking at the media and entertainment, transportation, health, logistics and agriculture industries verticals in both developed and emerging markets.
4. The provision of SatCom elements defined SaT5G shall not require any changes or adaptations to the user equipment.

We first provide a high-level overview of the satellite services sector as they stand today. There are many web-based descriptions available from many different service providers and satellite operators; however, these tend to lack both commercial and operational details and we aim to fill this lack here. Various ways of selling satellite capacity are frequently seen, and relevant case studies aligned to the SaT5G use-cases are identified.

We then undertake a qualitative Market Size Assessment of SaT5G use-cases, give a qualitative overview of the key stakeholders, and introduce the role of the broker.

An overview of KPIs relevant to SaT5G use-cases is presented. Starting with the high level 5GPPP KPIs we derive project-specific KPIs that support them. For example, a high level KPI is ‘1000 times capacity’, and in the SaT5G project this translates to KPIs related to multi-casting content to the network edge because this increases the number of bits that can be delivered to multiple users in a given time. Certain features are studied in detail by providing the KPIs and the specific values to validate the business, operational, and technical requirements which support each KPI. Several of the technical requirements are then derived from the SaT5G specific KPIs, and the ways in which the KPIs are related to the use-cases are defined.

The general requirements for business, operational and technical aspects are derived.

The business requirements are defined and the mapping of these requirements into the business case analysis of deliverable D2.3 is investigated. Then we give an overview of the business case evaluation and which metrics can be used to economically evaluate the SaT5G project. Finally, we explain the methodology followed by SaT5G to identify realistic targets for growth of revenue and/or reduction in costs per scenario.

We conclude with a study of SaT5G features.

The major business requirements have been found to be:

- satellite network functions compliant with standards bodies like 3GPP or ITU,
- virtualization requirements to be able to integrate satellites networks into multiple slices,
- and edge delivery and caching functionalities.

The major operational requirements are found to be:

- legal requirements, for example regulatory limits on transmit power, waveform and interference levels,
- the need for network management systems to allow maintenance and management of the network, billing, order placement and customer support systems,
- dynamic allocation of network capacity and network resources.

The major technical requirements are found to be:
- Management of end-to-end QoS;
- Management and orchestration to be integrated following the ETSI MANO specifications;
- End-to-end slicing with isolation between slices and appropriate levels of security;
- Support for IP multicast and multi-linking (parallel satellite and terrestrial paths).
1 Introduction

1.1 Context

The findings of WP2.2 “Business requirements”, WP2.3 “Operational requirements”, and WP2.4 “Technical requirements” are contained in this deliverable (D2.2). It derives the high-level business, operational, technical, and architectural requirements for the integration of satellite communication into 5G (in short SaT5G) following the guiding principles stated in the SaT5G proposal:

1. The implementation shall enable the plug-and-play integration of SatCom elements into 5G networks.
2. The implementation shall ensure the seamless integration of SatCom into 5G at network management and security levels.
3. The implementation shall enable eMBB services to end-users everywhere, specifically looking at the media and entertainment, transportation, health, logistics, and agriculture industries verticals in both developed and emerging markets.
4. The provision of SatCom elements defined SaT5G shall not require any changes or adaptions to the user equipment.

Building on the work documented in D2.1, specifically the scenarios for SaT5G use-cases, the analysis in D2.3 will then be an input to “Research to Prototype Development” in WP4 and “Validation and Demonstrations” in WP5.

The diagram below (see Figure 1-1) illustrates the WP2 dependencies with other SaT5G work-packages.

Figure 1-1 WP2 interdependencies with other WPs.
1.2 Document structure

Chapter 2 provides a high-level overview of the satellite services sector as they stand today, and how these compare with the SaT5G use-cases.

Chapter 3 provides a qualitative Market Size Assessment of SaT5G use-cases, gives a qualitative overview of the key stakeholders and introduces the role of the broker.

Chapter 4 provides an overview of KPIs relevant to SaT5G use-cases. Certain features are studied in detail by providing the KPIs and the specific values to ensure the business, operational, and technical requirements that support each KPI.

Chapter 5 is the main part of the document that describes and draws together the business, operational, and technical requirements, including requirements derived from the architecture.

Chapter 6 gives an overall summary of the requirements.

There are two annexes in this document. Annex 1 gives the spectrum bands used by satellite links, and annex 2 gives more detail on the requirements, starting with common requirements and then describing the requirements against each use-case.
2 Satellite services today

2.1 Overview

This chapter provides a high-level overview of the satellite services sector as it stands today. There are many web-based descriptions available from many different service providers and satellite operators; however, not unreasonably, these tend to lack both commercial and operational details.

Different ways of selling satellite capacity are frequently seen, and relevant case studies aligned to the SaT5G use-cases are identified in this section. It should be noted that satellites operate at a variety of different carrier frequencies; these are detailed in Annex 1.

2.2 Selling satellite capacity

At a high level there are essentially four ways used by satellite operators to sell their capacity:

- **Selling pure capacity only**: Typically sold as MHz to represent the proportion of the transponder capacity. The purchaser then provides the gateway ground station and related equipment and manages the service.

- **Selling pure capacity and gateway hosting**: Typically sold as MHz to represent the proportion of the transponder capacity. The seller provides the gateway ground station, whilst the purchaser then provides the related equipment and manages the service.

- **Selling data capacity**: Typically sold as Mbps. The seller provides the gateway ground station and the related equipment, whilst the purchaser then manages the service and creates their own service plans using the tools provided.

- **Selling managed service plans**: Typically sold as multiple numbers of sites getting predetermined service plans. The seller provides the gateway ground station and the related equipment along with determining the available service plans, and the purchaser then manages the end-users using the service plans and tools provided.

Of course, variations on these themes do exist depending on the addressed market, the satellite operator’s preferences and the purchasing party’s needs. Not all of these ways apply to selling backhaul capacity today.

As an illustration, Avanti has stated [1] at the time of drafting this document (2017) that:

“For service providers, Avanti offers three contract variants:

1. Hosted Network Operator (HNO): whereby the customer buys raw Mega Hertz of bandwidth and installs its own infrastructure at Avanti’s Gateway Earth Station”.
2. Guaranteed Virtual Network Operator (GVNO): whereby the service provider buys guaranteed Megabits of managed service and controls the system themselves by logging onto the satellites through Avanti’s “OSS” Customer Software system.
3. Shared Virtual Network Operator (SVNO): whereby the customer buys units of broadband service and Avanti manages the network for them. The customer commits to as minimum number of units per annum.

Subsequently in 2018 Avanti rebranded and refocussed its portfolio to become Pure, Adapt, Serve, and Connect [10]. The previous descriptions are retained as they provided a good sector specific description suitable for this deliverable.
Here HNO is equivalent to "Selling pure capacity and gateway hosting", GVNO is equivalent to "Selling data capacity" and SVNO to "Selling service plans". Other satellite operators have similar products but may use different terminology. In addition, there are a few satellite operators that are vertically integrated. This means they own and operate the satellite, the gateways and equipment together with managing the service and selling direct to the end-users; for example, both Viasat and Hughes in the USA offer this integration.

In addition, SES can address any backhaul use case via the industry’s only multi-orbit satellite fleet, local expertise in lifecycle services to tackle complex technical challenges, and an expansive, next-generation network of ground systems and remote site solutions. SES’s end-to-end managed services (see Figure 2-1) offload the financial and operational risk of deploying and managing the backhaul network and its required infrastructure. A fully managed service makes the backhaul link a seamless extension of your network. It easily and quickly integrates into the network via standards-based interconnection, all managed by our VSAT and data networking technology experts. Underpinned by a range of commercial pricing models that further mitigate business risk, our backhaul solutions make the economics of network expansion more attractive. This is particularly the case in under-served areas, where low population density and low ARPU pose a challenge to near-term profitability. Further details on SES managed cellular backhaul services can be found in https://www.ses.com/networks/signature-solutions/signature-telecom-mno/managed-mobile-backhaul.

The same basic concepts apply regardless of whether the satellite capacity is being used for broadband connectivity, backhaul, mobile or broadcast services.

For example, consider TV broadcast. TV broadcast takes up around 75% of communications satellite capacity, while broadband is less than 5%. We predict that this balance will shift significantly towards broadband with the increase in viable MEO and LEO systems. A large national TV service provider may wish to uplink their channels from a teleport operator and lease dedicated capacity from the satellite operator (analogous to pure capacity); whereas a smaller TV service provider may buy both TV uplink and satellite capacity to broadcast their channels (similar to selling data capacity); and finally a small TV service provider can provide a single channel to the satellite operator where this is multiplexed with other channels and then broadcast (like a managed service plan).

TV broadcast over satellite is primarily used by end-users to receive their Direct-To-Home (DTH) TV service packages. The same broadcast services may also be used to provide head-end services to small cable TV operators and to places like hotels and holiday resorts.

Mobile operators such as Inmarsat [2], Iridium [3] and Thuraya [4] tend to offer managed service packages with well-defined compatible communications devices to their resellers.
The relationship for the provision of satellite broadband services (and by analogy also mobile and direct-to-home services) is illustrated in Figure 2-2 below.

<table>
<thead>
<tr>
<th>Key roles</th>
<th>Vertical integration</th>
<th>Pure Capacity</th>
<th>Hosted Network</th>
<th>Data capacity</th>
<th>Managed Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite operations</td>
<td>Owns and operates satellites</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gateway operations</td>
<td>Owns and operates gateways</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hub operations</td>
<td>Owns and operates VSAT hubs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service management</td>
<td>Creates and manages service plans</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End user management</td>
<td>Sells service to end user</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2-2 Comparing operator roles for different categories of satellite broadband service.

### 2.3 Case studies for the provision of satellite services

This section looks at a few representative examples where capacity is sold for backhaul services. Note that as this section looks at the current deployments; it also uses current terms such as VSATs, VSAT hubs, and base stations where appropriate.

When comparing today’s products and services the following comparisons can be made with the SaT5G use-cases introduced in D2.1

- **use-case 1: Edge delivery & offload** – the closest would be TV broadcast to head-ends;
- **use-case 2: 5G Fixed backhaul** – this is the 5G variant of backhaul services;
- **use-case 3: 5G to premises** – this can be compared to broadband and DTH TV services;
- **use-case 4: 5G Moving platform backhaul** – this is essentially the 5G equivalent of mobile services to vessels and planes (not direct to the device).

#### 2.3.1 Selling pure capacity

The selling of pure capacity was the traditional approach by satellite operators. This has typically been at C and Ku band where the satellite architecture has allowed multiple gateways to share capacity with multiple different services taking advantage of this capacity. A reasonable list of satellite operators can be found at [5] specifically by looking at the companies supporting them scrolling along the bottom of the web page.

**Backhaul services**

One example of this is Africa Mobile Networks [6] (AMN) who combine the provision of satellite backhaul services with the provision of cellular base stations across a number of African countries. They state that they offer "Operators across Africa a simple and compelling solution - expanded coverage, more
subscribers, increased revenues, guaranteed positive margins and no capex”. They do this by buying capacity from one or more satellite operators.

They state that they have at least two teleports operational with plans for a total of four. They also provide the cell towers and management systems to offer the terrestrial licensed managed network operators a complete turnkey service (“The AMN service is a turnkey solution in which AMN will deliver traffic, and revenues, directly into the existing 2G/3G network infrastructure”). By reading related press releases this is understood to be carried as a L3 IP data stream.

Commitments for this kind of service typically vary from a few MHz to provide a limited 2G service to many tens of MHz to provide a wider ranging 3/4G service. The specialist VNO will use specific satellite and terrestrial equipment known to operate together satisfactorily and provide appropriate SLAs to their customers. These will be backed up by SLAs from the satellite operator covering satellite reliability and ability to deliver the promised radio performance.

Broadband

There are many examples of organisations buying satellite capacity and then providing satellite broadband services but finding publicly available details is not always easy. Some websites for example do not indicate whether they buy capacity (with or without gateway) or data capacity.

DTH and broadcast to head-ends

Conversely, a quick look for teleports shows that many of these access many satellites. For example, Arqiva [7] in the UK provide uplink services to many satellites. Interestingly they also manage a large part of the UK’s free-to-air TV transmitters and can host OTT services. A good, but not exhaustive, list of teleport operators can be found at [8].

Mobile services

As stated, mobile services are generally provided as managed services.

2.3.2 Selling capacity with gateway hosting

This tends to be the favoured approach for satellite operators with satellites which have separate gateway and user beams – typically used by HTS satellites in Ka band and sometimes also at Ku band – for the larger capacity requirements.

Backhaul services

One example of such an arrangement is the deal between Avanti and EE (e.g. [9]). In this case, Avanti has sold capacity over the UK for the EE 4G Emergency Services Network. In this case also Avanti provides dedicated VSAT hub systems and manages these on EE’s behalf. This capacity is used to provide emergency, and other ad-hoc satellite backhaul services, across the UK.

Such a commitment would represent a significant proportion of uncontended capacity within of one or more beams; for example, at Ka band a significant proportion of the typical ~650Mbps/~200Mbs throughput expected from professional VSATs. Within this service plans ranging from 2Mbps/1Mbps to 50Mbps/10Mps are typically created depending on the specific requirements of that location.

There may well be SLAs covering aspects such as service and link availability and possibly with site equipment reliability2. A modern VSAT will have an on-site mean-time-between-failures of five or more

---

2 Site reliability is one key point in determining site availability when combined with the mean time to repair which depends on the maintenance arrangements and equipment repair processes. Generally, VSAT equipment is swapped out on site and then checked back at the depot to minimise the on-site repair time. If the satellite operator is responsible for the on-site maintenance, they can offer a site availability SLA.
years depending on environment and other factors. Other SLAs cover response times for different categories of service requests.

Detailed service descriptions will be agreed and managed by the partners. Satcom and BS equipment are selected that are known to work together and tested by both parties before deployment to ensure that the best service is delivered to the end-users. The user-plane and control-plane traffic can be carried as either L2 or L3 (IP) traffic with some mutually agreed class of service management available.

In other cases, it is quite possible that the “EE equivalent” local operator could procure and manage their own VSAT hubs, if they had the expertise and desire to do so. An organisation such as France’s Orange with both MNO and satellite communications expertise in house would be capable of such an approach.

Broadband

Avanti market this service as “Pure” [10] and other HTS operators offer similar services (such as SES [11] and Eutelsat [12] amongst a number of others).

DTH and broadcast to head-ends

Many of the larger satellite operators (such as SES and Eutelsat) offer hosted TV uplink services (e.g. [13], [14]). In this context one might consider a TV operator with multiple channels (e.g. a couple of primary channels, the 1 hour delayed channels and the channels for repeats of shows no-one watched the first time being multiplexed on to a single 27 MHz carrier) being uplinked from a gateway owned by the satellite operator.

Mobile services

As stated, mobile services are generally provided as managed services.

2.3.3 Selling data capacity

This tends to be the favoured approach for satellite operators with satellites that have separate gateway and user beams (typically used by HTS satellites in Ka band and sometimes also at Ku band), for smaller capacity requirements that cannot justify the use of a whole VSAT hub.

Backhaul services

In such cases the satellite operator makes available sufficient control of the hub to allow the local operator to create service plans as well as manage the individual sites.

In another variation the satellite operator could sell the same capabilities to a satellite network VNO who then sells service to the local operator. This is commonly used when selling a related product, namely Wi-Fi hotspot services (e.g. [15], [16] and [17]).

Typical commitments are for a few tens of uncontended Mbps, perhaps with some capability to burst above the committed rate, depending on the arrangements available and agreed. These are usually agreed at IP (L3) level though on occasions L2 traffic is supported. There may well be SLAs covering aspects such as service and link availability, and others covering response times for different categories of service requests. Fairly detailed service descriptions will be agreed and managed by the partners. SatCom and BS equipment are selected that are known to work together and tested by both parties before deployment to ensure that the best service is delivered to the end-users.

Broadband

Avanti [10] and SES [11] market this along with similar services from other HTS operators such as Eutelsat [12], amongst a significant number of others.
DTH and broadcast to head-ends

Many of the larger satellite operators (such as SES and Eutelsat) offer hosted TV uplink services (e.g. [13], [14]). These would accommodate smaller requirements (single TV channel on a shared multiplexed carrier) that are analogous to this.

Mobile services

Inmarsat is the longest-established provider of mobile services to ships, planes and direct to end-users. They sell through reseller channels and only the end-user service descriptions are available. However, they clearly sell data to large aggregators (for example, see this press release about Inmarsat and Telespazio co-operating [18], and this one from Thales using Iridium broadband services [19]).

One example of an aggregated service Inmarsat offer is Fleet Data [20] which aggregates IoT data from across a fleet.

Another satellite provider of aggregated services to the mobile market is Viasat’s aviation product range addressing commercial and business aviation [21]; Eutelsat advertise something similar [22]. SES also offer something similar in the maritime environment, in addition the O3B satellites have been deployed providing high performance mobile backhaul services to cruise liners [23].

2.3.4 Selling service plans

Selling service plans tends to be the favoured approach for satellite operators with satellites that have separate gateway and user beams (typically used by HTS satellites in Ka band and sometimes also at Ku band). This caters for much smaller capacity requirements which cannot justify the development of an interface between the satellite operator management system and that of the local service operator.

Backhaul services

No examples of selling backhaul services as service plans per se have been identified. Some resellers are known to include Wi-Fi hotspots with the broadband access service plans.

Broadband

Typically used for the initial provision of satellite broadband service with the desire to move up the value chain at a later time as they grow their end-user base. Another variant is that used by Inmarsat for their L-band maritime service. In this case they sell air-time contracts with defined service plans to Value Added Resellers (VARs), for example see Inmarsat’s offering. In both cases, these are not cellular backhaul services. However, it is possibly in a 5G world that such a modus operandi may be implemented.

Typical service plans for Ka band GEO HTS satellite operators vary typically from around 2Mbps to around 25Mbps download when measured at the IP level. The consumer service plans also have monthly data capacity limits, whereas the commercial plans may either have much larger limits or none depending on the operator’s preference. These service plans are created within shared contended capacity.

Mobile

As mentioned above, Inmarsat is the longest established provider of mobile services to ships, planes and direct to end-users. They sell through reseller channels and only the end-user service descriptions are available. By and large, they offer standard packages that the resellers then offer their end-users – often with the installation of the complex mobile satellite antenna system in the plane or on the ship.
## 2.4 Summary

The following table (Table 2-1) shows the responsibilities undertaken by the different actors described in the case studies above that were considered in most detail – this can be compared with the theoretical diagram shown above in Figure 2-2.

<table>
<thead>
<tr>
<th>Satellite capacity sale type</th>
<th>Case study</th>
<th>Satellite operator</th>
<th>Gateway operator</th>
<th>Hub equipment operator</th>
<th>VSAT operator</th>
<th>BS operator</th>
<th>End-user service provider</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure capacity</td>
<td>Africa Mobile Networks</td>
<td>SatOp</td>
<td></td>
<td>Specialist satellite VNO</td>
<td></td>
<td></td>
<td>Local operator</td>
</tr>
<tr>
<td>Capacity + GW</td>
<td>Avanti / EE</td>
<td></td>
<td>SatOp</td>
<td></td>
<td></td>
<td>Local operator</td>
<td></td>
</tr>
<tr>
<td>Capacity + GW</td>
<td>Other possibility - not known</td>
<td>SatOp</td>
<td></td>
<td>Local operator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data capacity</td>
<td>Smaller operator deal</td>
<td></td>
<td>SatOp</td>
<td></td>
<td></td>
<td>Local operator</td>
<td></td>
</tr>
<tr>
<td>Data capacity</td>
<td>WiFi HotSpot service</td>
<td></td>
<td>SatOp</td>
<td>Satellite VNO</td>
<td></td>
<td>Local operator</td>
<td></td>
</tr>
<tr>
<td>Service plans</td>
<td>Initial broadband service</td>
<td></td>
<td>SatOp</td>
<td></td>
<td>N/a</td>
<td>Local operator</td>
<td></td>
</tr>
<tr>
<td>Service plans</td>
<td>INMARSAT</td>
<td></td>
<td>SatOp</td>
<td></td>
<td>N/a</td>
<td>VAR</td>
<td></td>
</tr>
</tbody>
</table>

Table 2-1 Typical roles for actors in the value chain.

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3 Note however that the VSAT hub equipment is dedicated to this specific satops customer.
3 Business analysis

3.1 General Requirements

This section explains first the overall objectives of SaT5G, the stakeholders and the value chains they would operate in, the use cases identified for analysis, and the environments they must consider. It ends in a description of the high-level shape the business analysis should take and the outputs required.

The overall objective for SaT5G is to identify and evaluate use cases where satellite technology is financially, operationally and technically viable as part of 5G network rollout. It should inform as to the environments in which scenarios are and are not viable and how the value of propositions is spread across stakeholders in the value chain. The environment considered would include geography, population density, existing infrastructure that could be leveraged, costs, propensity to pay, regulation and the level of vertical integration in the value chain.

In a traditional stakeholder value chain, and a significant point for this project is the separation between Service Provider (SP) and Network Operator (NO) functions. They could be different organisations, or an organisation may have both functions within it, but the organisation will be internally structured to separate them. For example, BT, Vodafone, Sky all have SP functions that provide services to end user customers, and ‘own’ them as afar as billing and service level agreements are concerned, and they have NO functions to provide connectivity. Note it is possible to be an SP without a network, examples are Virtual Mobile Network Operators (MVNOs) and Over-The-Top (OTT) service providers like Google and WhatsApp. In Figure 3-2 we have the concept of the ‘Integrating Service Provider’ which is like a one-stop-shop for the end-user and can integrate the services from other SPs as needed. Cascaded SPs are therefore possible.

The major roles are:

- **Service Provider (SP)**, which delivers services to the end-user, and supplies services in return for payment using the providers billing system. The SP may be a function inside a Company or organisation that also has a network operator function, or the SP may be a VMNO or an OTT other provider that does not have a network operator function. Service provision can include integrating services from other providers, imagine horizontally, in order to fulfil the service requirements from the end user, and in this case the SP function that owns the end user is called here the ‘Integrating’ SP. Each SP contracts with one or more network operations providers, imagine vertically, to fulfil transport requirements.

- **The Network Orchestration** creates the technical solution for the service providers contacting with one or more network operator(s) based on the service provider requirements.

- **The Network Operation function** manages and often owns the infrastructure that provides coverage, capacity and connectivity. This function has the objective of transporting data with the required QoS, for example within a certain time and with a certain reliability. The NO can be terrestrial or satellite, fixed or mobile. In the case of SAT-5G project, the satellite network operator does not own the satellites, but it does manage the network. Orchestration of the access, transport and core network parts as an integrated slicing architecture is considered here to be a NO function. The network operations functions are usually cascaded, for example the satellite NO function also requires a terrestrial backhaul to its earth stations that is provided by a fixed NO.

- **The Satellite Operation function** utilises the satellite system infrastructure, the space segment, and markets its capacity to the Satellite Network Operations function for the establishment of the satellite network.
• The Content Distribution role contains all of the distribution and security mechanisms and can initiate and close down paths across the network in the same way that an SP does, and the relationship between the content distribution role and the content provision role is analogous to the SP and its end user.

• Vendors sell or lease hardware to the SPs and NOs, but nearly always lease software and retain ownership of it. In a cloud network model, the role of the Ground Segment and Terminal Vendors is expanded in order to encompass also the VNF Providers, i.e. the developers of VNFs, which constitute crucial components of the cloud network service, along with their hardware counterparts.

• Regulation – regulated elements of the value chain may place limitations on the flexibility of certain value chains.

• Level of vertical integration in the value chain – a CP with end-to-end proposition coverage can consume elements at all levels at cost adding a margin only at the offered service levels. Once multiple organisations are involved margin is taken at many levels reducing the flexibility of the solution

3.1.1 Use cases for analysis

**Use case 1: Edge delivery & offload for multimedia**

a. Vertically integrated CP with network and content
b. MNO providing network and content provider deploying caches and content
c. MNO deploying NFV for network and storage serving content providers

**Use case 2: Satellite fixed backhaul**

a. Deploying satellite backhaul where fixed is either not possible or un/less economic

**Use case 3: Satellite to premises**

a. Satellite to augment limited performance on ADSL.
b. Use case flex to include content caching in the home router.

**Use case 4: Satellite to moving platform backhaul**

a. Updating content for on-board systems and grouped media request by the moving platform company.
b. Broadband access for passengers and individual media requests.
c. Business and technical data transfer for the moving platform company.

3.1.2 Considerations of the deployment environment

• Geography – ground condition, rurality etc. will all impact the costs of the line alternatives and satellite deployments.

• Population density – more dense geographies will favour terrestrial technologies more with shorter transmission lengths. Also, even high capacity satellite systems will not match terrestrial unicast capacity so in dense geographies where traffic levels are high satellite might struggle to support all requirements.

• Existing infrastructure – where network nodes are already connected by fibre or radio systems it will be challenging to cost justify satellite over existing system upgrade. Satellite may be more applicable in greenfield deployments or where existing landline is ADSL-based copper.

• Costs – different geographies will have different equipment and manpower costs which could influence the relative case of satellite vs. terrestrial or ptp microwave.

• Propensity to pay – different geographies will have different levels of prosperity so ability/willingness to pay will differ impacting the revenue side of a business case.
• State Aid – satellite will often find uses in rural geographies where it may be the best or only solution but is unaffordable as a commercial proposition. Thought should be given to how state subsidy might be applied.
• Regulation – regulated elements of the value chain may place limitations on the flexibility of certain value chains.
• Level of vertical integration in the value chain – a CP with end-to-end proposition coverage can consume elements at all levels at cost adding a margin only at the offered service levels. Once multiple organisations are involved, margin is taken at many levels reducing the flexibility of the solution.

3.1.3 Business case structure and sensitivity analysis

Business case analysis should look at the viability of a use-case and its associated environment from two perspectives:
1. Is there a viable solution where affordable price points could recover costs with a margin (accepting there may be state aid scenarios)?
2. Is there a positive case vs. an alternative solution, e.g., upgrading fixed access rather than overlaying satellite?

The modelling should not only provide a single shot view of the financials but allow for sensitivity analysis, especially a “what you have to believe” capability to turn a proposition viable. This will ensure maximum understanding of the cost and revenue dynamics of a use case/environment combination.

The approach to modelling will be documented as part of the Business Analysis in deliverable D2.3.

3.2 Market-size assessment of SaT5G use-cases

In this chapter, a new qualitative market-size assessment of SaT5G use-cases is presented, using the background and methods used in the D2.1 analysis. The proposed criterion employed is:
• Global satellite services market size in 2030;

and the proposed scoring employed is the following:
• €: 1-10 M€
• €€: 10-100 M€
• €€€: 100-1000 M€
• €€€€: >1 B€

Note that the assumed timeline for the forecast is 2030, as 5G is highly unlikely to generate anywhere near the numbers mentioned as early as 2025.
Table 3-1 Relevant market size of SaT5G use-cases.

<table>
<thead>
<tr>
<th>SaT5G use-case</th>
<th>Satellite use-cases for eMBB</th>
<th>Global Satellite Services Market Size in 2030</th>
<th>Justification Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>SaT5G use-case 1: “Edge delivery &amp; offload for multimedia content and MEC VNF software”</td>
<td>Providing efficient multicast/broadcast delivery to network edges for content such as live broadcasts, ad-hoc broadcast/multicast streams, group communications, MEC VNF update distribution.</td>
<td>€€€€</td>
<td>MEC is expected [24] to make CDNs up to 40% more efficient and as Cisco VNI [25] state that share of video traffic will grow from 60% to 78% by 2021 and as 70% [26] of all traffic already is encrypted a more distributed CDN system will be essential going forward.</td>
</tr>
<tr>
<td>SaT5G use-case 2: “5G Fixed backhaul”</td>
<td>Broadband connectivity where it is difficult or not economical to deploy terrestrial connections to towers, for example, maritime services, coverage on lakes, islands, mountains, rural areas, isolated areas or other areas that are best or only covered by satellites; across a wide geographic region</td>
<td>€€€ €</td>
<td>A study [27] of rolling out 5G (min. 50Mbps per end user) to rural areas of the UK would consume 79% of the total budget and require an alternative approach not relying on fibre. The demands for backhaul will be exponential.</td>
</tr>
<tr>
<td>SaT5G use-case 3: “5G to premises”</td>
<td>Connectivity complementing terrestrial networks, such as broadband connectivity to home/office small cell in underserved areas in combination with terrestrial wireless or wireline</td>
<td>€€€ €</td>
<td>Upgrade networks and deployment of FTTH on a large scale, encompassing less densely populated areas will be cost-prohibitive [28] and even the most advanced countries are far from achieving universal access [29] to fibre.</td>
</tr>
<tr>
<td>SaT5G use-case 4: “5G Moving platform backhaul”</td>
<td>Broadband connectivity to platforms on the move, such as airplanes or vessels.</td>
<td>€€€ €</td>
<td>Demand generated from broadband services to mobility segments is expected to reach 480 Gbps by 2025 [30] making it a key vertical going forward.</td>
</tr>
</tbody>
</table>

Further techno-economic analysis for the defined SaT5G use-cases will be conducted as part of WP2.5 and detailed in D2.3 deliverable document.
### 3.3 Theoretical background for the business analysis

In order to more clearly define the market and its stakeholders, this section gives a short definition of a stakeholder (actor) and roles. In addition, it introduces the value network representation. As there exist many definitions and interpretations of terms such as value networks, business models and business roles in literature, this section aims at providing clear definitions of those terms, as well as the different steps needed to analyse a certain process both qualitatively and quantitatively.

<table>
<thead>
<tr>
<th>Steps</th>
<th>Description</th>
<th>Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td><strong>Identification of the business roles:</strong> Business roles indicate “what is being done”. Roles are specific responsibilities that need to be undertaken when deploying and operating a network. Examples include the deployment of fibres and ducts, maintenance of the equipment, provisioning of services etc. Dependent on the level of detail needed for the specific analysis, a role should be seen as an indivisible task.</td>
<td><img src="image1" alt="Diagram of roles" /></td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td><strong>Value network:</strong> A value network depicts the interactions by value streams between roles. Each value stream represents a transfer of value, being tangible or intangible. Tangibles are goods, services or revenues, transported through a contractual transaction, while intangibles refer to knowledge or benefits which support the core product, but are not contractual. Each process can be represented by a unique value network.</td>
<td><img src="image2" alt="Diagram of value network" /></td>
</tr>
<tr>
<td><strong>Step 3</strong></td>
<td><strong>Identification of business actors:</strong> Business actors show “by whom” this is done. In this step, actors are identified, based on real world examples.</td>
<td><img src="image3" alt="Diagram of actors" /></td>
</tr>
</tbody>
</table>
Step 4: Value network configuration:
Actors take up different roles; an actor can therefore be mapped to the roles he takes, indicating the actor’s responsibilities in a value network configuration.
For each process, there is only one value network (interaction of roles), but there can be multiple value network configurations (where different actors take up different roles).

Step 5: Business model:
A business model represents the incoming and outgoing value streams of one actor in one specific value network configuration.

Step 6: Business case:
A business case is the quantitative evaluation of a business model. It combines all incoming revenues with outgoing costs in an economic analysis (Net Present Value, Internal Rate of Return, etc.).
Of course, the business case for each actor will depend on the value network configuration chosen, as the roles the actor takes up may differ.

Table 3-2 Definition of a stakeholder, roles, and value networks.

3.4 Generic Value Network: identification of key roles and their inter-relations

In this section we present the Value Network for the SaT5G use-cases. Figure 3-1 presents the main stakeholders that will play a role in a market that offers integrated satellite-5G services.
Figure 3-1 Generic SaT5G value network.
As the concept of the SaT5G project is the integration of the satellite communication in the 5G network, the main stakeholders are the satellite operator and the mobile network operator, next to them several stakeholders are involved in the business model and are described below:

- **Regulator**: which regulates and licenses the national spectrum to the different operators.
- **Spacecraft manufacturer**: manufactures and delivers satellites.
- **Service Provider** (SP): which delivers services to the end-user, and supplies services in return for payment using the providers billing system. The SP may be a function inside a Company or organization that also has a network operator function, or the SP may be a VMNO or an OTT provider who does not have a network operator function.
- The **Network Operator** (NO) function manages and often owns the infrastructure that provides coverage, capacity and connectivity. This function has the objective of transporting data with the required QoS. The NO can be terrestrial (Mobile Network Operator - MNO) or satellite (Satellite Network Operator - SNO), fixed or mobile. In the case of the SaT5G project, the satellite network operator need not own the satellites, but it does manage the network. Orchestration of the access, transport and core network parts as an integrated slicing architecture is considered here to be a NO function.
- **The Satellite Network Operator** function manages access to the satellite system infrastructure, the space segment, and markets satellite system capacity to satellite service providers or virtual satellite network operators.
- **The Content Distributor** role contains all of the distribution and security mechanisms (in relation to the content) and can initiate and close down paths across the network in the same way that an SP does, and the relationship between the content distribution role and the **Content Provider** role is analogous to the SP and its end user.
- **The vendors** sell hardware to the SPs (vendors: supply chain) and NOs (vendors: Core and RAN), but nearly always lease software and retain ownership of it. In a cloud network model, the role of the Ground Segment and Terminal Vendors is expanded in order to encompass also the VNF Providers, i.e. the developers of VNFs, which constitute crucial components of the cloud network service, along with their hardware counterparts.
- **The vendors (CDN)** role can be within two cases, the first is that the mobile operator manages content delivery network (CDN), and in this case a mobile network operator offers content services. This case is relatively simple since the same stakeholder owns both the network infrastructure and content resources (e.g. edge data centres). The second case is the collaboration between a mobile network operator and a third-party CDN provider. In this scenario, the common practice is that a CDN provider can deploy its content servers close to the mobile network edge, and in this case a pre-established Service Level Agreement (SLA) between the two stakeholders is required.

### 3.5 Introduction of a new stakeholder: the broker

As the SaT5G use-cases will require the interaction between multiple MNOs and SNOs, this interaction can be direct, but easily becomes complex if multiple stakeholders are involved.

In a traditional stakeholder value chain, a significant point for this project is the separation between Service Provider (SP) and Network Operator (NO) functions. They could be different organisations, or an organisation may have both functions within it, but the organisation will be internally structured to separate them. For example, BT, Vodafone, and Sky all have SP functions that provide services to end-user customers, and ‘own’ them as far as billing and service-level agreements are concerned, and they have NO functions to provide connectivity. Note it is possible to be an SP without a network, examples are Virtual Mobile Network Operators (MVNOs) and Over-The-Top (OTT) service providers like Google and WhatsApp. In Figure 3-2 we have the concept of the ‘Integrating Service Provider’ who is like a one-stop-shop for the end-user and can integrate the services from other SPs as needed. Cascaded SPs are therefore possible. Cascaded NOs are also possible, where for example a mobile operator will used a fixed or satellite operator to provide backhaul connections to base stations.
Following this integrated role, we propose to introduce the role of a **broker** to handle negotiations between the different network operators. This stakeholder would act as the only interface between MNOs and SNOs. The broker is thus responsible for matching the demand requests to the proposed satellite offers. Figure 3-3 shows the value networks, including the broker and the key stakeholders interacting with it.

We propose to use a business model of a single broker (more like a stock exchange) to deal in satellite resources. This would be the only interface between MNOs and SOs. The SOs would register offered services with the broker, with an asking price. The MNOs would register required services with the broker, with an offered price. The broker would then, for a small commission, match sellers to buyers. This simplifies processes for the operators and should ensure a more optimal allocation of resources. The exact responsibilities of the broker should depend on the specific scenario (how wide is the circle of influence in Figure 3-4), and will be studied in D2.3.
3.6 Business Case Evaluation

After the different stakeholders have been defined, the business case should be evaluated. This consists of modelling the costs of the integrated network offering and estimating the needed revenues to cover these costs. The models used for this business case evaluation are described shortly below.

3.6.1 Generic cost modelling

The first step in evaluating the economics of SaT5G project for possible future scenarios is to make a good estimation of all costs incurred. In order to do this, we start from a project lifecycle – planning, deployment, migration, operations, and teardown – as shown in Figure 3-5, and combine this with a zooming approach in which we increase the detail of the largest or most risky/unknown cost components first. The figure already gives an indication of the importance of the different cost components, by means of stronger and darker text and lines, in the total cost of the exploitation and upgrade of SaT5G network. Following this approach, the total cost of the network over its entire lifetime can be calculated, also referred to as the Total Cost of Ownership (TCO).
up with detailed cost components for which both input and calculation are easier to make. The outside plant deployment, for instance, consists of rolling out the physical network: installing the RAN equipment, the ST (Satellite Terminal) and the Satellite Gateway. The inside plant, on the other hand, consists mainly of equipment that should be installed in the users’ home/office (ST and home Hub, etc...). As cost calculations for network deployment in the streets are clearly different to equipment installations in central offices or customers' homes, different cost models (or cost modelling languages) should be developed.

This gives an overview of three modelling languages designed for evaluating the cost of:

- Network deployment (PNMN: Physical Network Modelling Notation);
- Equipment installation, possibly including maintenance (ECMN: Equipment Coupling Modelling Notation) and;
- Operational processes (BPMN: Business Process Modelling Notation).

All these three languages consist of a graphical user interface (GUI), which is used for visualization of the model. It allows to graphically represent the links between different types of equipment (ECMN) or activities (BPMN), which in turn simplifies discussions about the models. The backend of the GUI is then linked to a calculator, which uses specified input data to perform the needed calculations for obtaining the total cost of the network deployment, equipment installation or operational process. The figure below gives an example of an ECMN tree for scenario 2b.

![Figure 3-6 Example of an ECMN tree for scenario 2b (Satellite backhauls to a cell tower covering a region where there is no cost-effective terrestrial backhaul option).](image)

### 3.6.2 Direct revenue modelling

Once the full network, the equipment, and the operational expenditures are modelled, all costs of the business model can be calculated. Still, this is only part of the analysis and should be complemented with a modelling of the revenues for each activity in the business model. Given the costs and the number of paying customers, in combination with a desired profit margin or break-even point, the revenue model will calculate the needed charge per user. As such it has a notion of a fixed pricing scheme but also of an adaptive scheme aiming at break-even or a profit over break-even (cost-plus pricing) with an adjustable timing on when to get up to this point, or a revenue scheme that is adjusted to the yearly costs (running cost-plus pricing). For the Sat5G project, we will limit ourselves to cost-based pricing, as we want to calculate the necessary revenue to break even.

#### a) Fixed pricing

In a fixed pricing scheme, the provider directly indicates the price for the customers to pay. There are no additional parameters and calculations. Clearly the fixed pricing scheme can also make use of a timed predefined price.

#### b) Cost-based pricing (=cost-plus pricing)

In cost-based pricing the price the provider will charge, will be based on an intended profit margin over the time horizon. This profit margin can be fixed or changing over the time horizon.

The parameters in this pricing scheme are

- \( P \) expected profit margin (%)
- \( N \) time horizon, expected lifetime of the project

The inputs of this pricing scheme are

- TCO the costs per year, summed and discounted to TCO over \( N \) years
• A(i) the customers per year, or the absolute adoption in year i, determined following theoretical adoption curves, such as Rogers, Bass, or Fisher-Pry approaches.
• The discount rate, typically ranging between 5% and 10% in telecom network investments

For example, we can calculate the revenues needed (per subscriber and per month) based on the known TCO. The following formula (in which \( X \) is the monthly average revenue per user (ARPU)) is used:

\[
\sum_{i=1}^{N} 12 \times X \times A(i) \times \frac{1}{(1+r)^i} = (1 + P) \times TCO \text{ over } N \text{ years}
\]

Here \( X \) is multiplied by 12 to arrive at a yearly ARPU, and we include the absolute uptake (adoption) of customers and a discounting factor to incorporate the time value of money. By equating this revenue potential to the above calculated TCO, the needed monthly ARPU can be derived.

c) Running cost-plus pricing

In running cost-plus pricing the price will be based on a short-term part of the total costs. It can be mimicked by a repetitive cost-based pricing over the short term and with the repetition ending at the total time horizon. Typically the provider would want to have its costs of this year repaid by the customers of the same year taking into account an intended profit margin.

The parameters in this pricing scheme are

- \( P_i \): expected profit margin (%) per year
- \( N \): time horizon, expected lifetime of the project

The inputs of this pricing scheme are

- \( C_i \): the costs per year (which, when summed and discounted, amount to TCO over \( N \) years)
- \( A(i) \): the customers per year, or the absolute adoption in year i, determined following theoretical adoption curves, such as Rogers, Bass or Fisher-Pry approaches.
- \( R \): the discount rate, typically ranging between 5% and 10% in telecom network investments

The formula is thus adjusted to calculate a varying ARPU (\( X_i \) per subscriber and per month) based on the known yearly costs:

\[
\text{For year } i = 1..N: \quad 12 \times X_i \times A(i) = (1 + P_i) \times C_i
\]

Additionally the revenue model allows switching between revenue schemes at a given time or condition (e.g. critical customer mass reached). This revenue model allows answering questions on the main economic indicators such as profitability, minimal and advised pricing or payback period [132].
4 Key Performance Indicators

4.1 KPIs in 5G

5G systems aim to provide a converged network providing connectivity everywhere, and at all times. Satellites are an optimal solution for this in some cases, and they are also an efficient method to multicast/broadcast content to wide areas.

Standardisation bodies, like 3GPP for MNOs, are currently in the process of defining the new 5G network including the core entities and functionalities. To achieve a complete satellite network convergence with other networks, it is necessary to integrate the satellite network core into the 5G core at the standardisation level as well as at the technical and commercial levels. An integrated 5G core would mean deploying a single controller, which thereby simplifies the control processes.

At the moment, satellite networks operate in a separate way from other networks, making it impossible to steer traffic through terrestrial or satellite networks dynamically. For example, satellite networks are currently used by MNOs for backhauling to remote areas where a terrestrial network is not deployed. The satellite is regarded as ‘black-box’ which simply passes traffic. Since both networks are created independently, the solution is not plug-and-play and hence it takes a huge amount of time and effort to deploy and to optimize the end-to-end service.

Most of the business models for satellite spectrum usage are based on providing a fixed amount of bandwidth, that is, static capacity allocation. In other words, when the owner of the spectrum is not using it, no one else can use the capacity, resulting in inefficient spectrum usage. Efficient spectrum usage methods are fully studied for mobile networks. A step forward is to converge both spectrum resource managers, enabling end users to benefit from sufficient bandwidth available most of the time.

5G radio networks include millimetre waves for the first time. LEO and MEO orbits are suitable to use the same bands that are standardized for terrestrial networks. This provides the capability to transparently and dynamically connect end users to satellite or terrestrial links. However, the characteristics of lower orbits complicate the final solution. At the moment, 3GPP is starting to identify topics such as channel models, Doppler effects, etc. for LEO. Figure 4-1 and Figure 4-2 show two examples of Non-terrestrial Network (NTN) in 5G context being considered by 3GPP [31].

![Figure 4-1](image1)

Figure 4-1 NTN featuring an access network serving UEs and based on a satellite/aerial with bent pipe payload and gNB on the ground (Satellite hub or gateway level) [31].

![Figure 4-2](image2)

Figure 4-2 NTN featuring an access network serving Relay Nodes and based on a satellite/aerial with gNB [31].

The proposed features to integrate satellites networks into a converged 5G network are:

- Support plug-and-play satellite backhaul services using current communications satellites.
- Integrate the 5G satellite core with terrestrial core to form a 5G converged core.
- Dynamic satellite bandwidth allocation.
- Transparent end user usage between satellite and terrestrial radio resources.
The technical challenges that need to be addressed for the realisation of cost-effective solutions for 5G include:

- Virtualisation of SatCom network functions to ensure compatibility with the 5G Software-Defined Networking (SDN) and Network Functions Virtualization (NFV) architecture;
- Developing the enablers for a converged 5G-SatCom virtual and physical resource orchestration and service management;
- Developing a link aggregation scheme for small cell connectivity mitigating QoS and latency imbalance between satellite and cellular access;
- Leveraging 5G features/technologies in SatCom;
- Optimising/harmonising key management and authentication methods between cellular and satellite access technologies;
- Optimal integration of the multicast benefits in 5G services for both content delivery and MEC/VNF distribution.
- Caching of popular assets within the Edge Network to optimize content delivery in terms of network resource usage or QoE

Due to the specific scope of SaT5G, only the first two features will be studied in detail by providing the required KPIs to achieve this feature and the business, operational and technical requirements that support each KPI.

4.2 Defining the KPIs

4.2.1 Review of high-level KPIs

The 5G PPP website [32] defines the high-level KPIs of 5G as follows:

"The following parameters are indicative new network characteristics to be achieved at an operational level:
- 1000 times higher mobile data volume per geographical area.
- 10 to 100 times more connected devices.
- 10 times to 100 times higher typical user data rate.
- 10 times lower energy consumption.
- End-to-End latency of < 1ms.
- Ubiquitous 5G access including in low density areas."

The Next Generation Mobile Networks [NGMN] Alliance has produced a set of recommendations and requirements for 5G [33]. This introduces the concept of having use-case specific KPIs and how these can be measured.

The H2020 project Euro-5G “Supporting the European 5G Initiative” [34] included a refinement on the definition of 5G PPP KPIs after considering the worldwide context on 5G and defines reference test cases and measurement tools that are able to monitor the progress achieved towards the KPI targets. In section 2 it showed how the three IMT usage scenarios (eMBB, mMTC and URLLC) led to the spider diagram shown below in Figure 4-3.

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4 https://5g-ppp.eu/kpis/
They also look at two other categories which are out of the SaT5G scope and follow a similar exercise from which they derive a revised spider diagram illustrating the different 5G service requirements.

4.2.2 KPI assessments

The main assessment methods identified are:

- Measurements;
• Analysis (calculation);
• Simulations.

SaT5G follows these assessment methods as appropriate.

4.2.3 5G KPI identifications

The 5G IA Technical Board shared some extracts from PPP monitoring report (2016 – no further reference given), these are shown below:

In several documents, 3GPP describes the required network KPIs. At the moment, none of them is specifically dedicated to non-terrestrial networks. 3GPP series 32, for example, defines KPIs for RAN, IP Multimedia Subsystem (IMS) and the Evolved Packet Core (EPC). SaT5G envisions to enhance some of the current KPIs defined including the satellite requirements. To highlight some of the 3GPP documents, [35] section 7, provides the definition of the high level performance KPIs: peak data rate, peak spectral efficiency, bandwidth, control plane latency, user plane latency, latency for infrequent small packets, mobility interruption time, inter-system mobility, reliability, coverage, UE battery life, UE energy efficiency, spectral efficiency, area traffic capacity, user experience data rate, 5th percentile user spectrum efficiency, connection density, mobility, network energy efficiency. 3GPP [36] defines five categories, accessibility, retainability, integrity, availability and mobility. For each category, the formula with the specific parameters is provided. For an EPC core, the KPIs are described in [37] which also includes EPC utilisation. Similar to [36], [16] provides a brief description of each KPI and the specific formula to obtain the result.

The KPIs used to define satellite systems can be considered at different levels. At the highest level, satellite system design considers the satellite design, the service area, the transmission frequencies and representative ground segment system to define, for example, the link budget to determine the combination of throughput and service quality (e.g. packet error rate). Another example, a vHTS GEO satellite might use Ka band for the user beams providing broadband access via ~70cm antennas across a well-defined proportion of the visible earth surface (perhaps Europe, Africa and/or Oceanic coverage). At the same time, an HTS LEO satellite constellation of 600+ satellites might use Ku band for the user beams and cover the whole globe using flat panel tracking antennas.

It should be noted that modern satellite links of vHTS GEO system deliver a quasi-error-free link at IP level using adaptive coding (forward error correction, FEC) and modulation (ACM). As the link quality reduces, more error correction is applied to ensure the IP datagrams are delivered. Older systems cannot attain the required class of service if significant levels of ACM are applied, unlike many new systems.

Another factor that may be considered at this level is whether the satellite terminal is stationary or moving. This situation impacts factors such as service continuity during beam handover, allowable Doppler carrier frequency variations. and terminal antenna size.

The second layer that can be considered is the service provided by the satellite operator. They offer wholesale capacity on the satellite(s) for the satellite network operator to provide their services. Depending on the type of satellite and sometimes operator preference, this capacity can be sold today as satellite bandwidth, satellite throughput or satellite service plans (see also chapter 2 for more details). Clearly when offering satcom as a service and or slice capacity an automated variant on one of the latter two categories will be required.

Another layer that can be considered is the service level. This defines the type of data to be supported (e.g., eMBB, video streams, voice, mMTC/IoT, etc) and the throughputs needed. From this, SLAs are derived that can cover things such as CIR (Committed Information Rate or average bit rate), PIR (peak information rate or peak burst data rate), and carrier sizes. Next to be defined is support for class of service (CoS; if needed, each CoS may or may not have their own PIR and CIR values and some method for assigning data to the correct CoS needs to be defined). Other common parameters that can be specified but are not always needed include some statistical definition of link latency, the packet level jitter limits and overall link availability (covering equipment, weather and connectivity). These satellite KPIs will tend to be specific to the satellite operators’ missions. Sensible examples should be assumed when making further analysis (for example in the business analysis). Restricting the detailed
research to specific missions would be inappropriate given the SaT5G intent to incorporate many different satellite types into the 5G networks of the future.

Per-service KPIs will tend to be specific to the use-cases and scenarios. When a spacecraft operator defines its mission and spacecraft representative service KPIs are considered – and this may include multiple different terminal sizes for different services.

4.3 Satellite features and technical challenges

SaT5G has identified the following features to integrate satellites networks into a converged 5G network are:

- Support plug-and-play satellite backhaul services using current communications satellites;
- Integrate 5G satellite and terrestrial networks to create a global 5G network;
- Develop the next satellite generation compliant with 3GPP standardization body to support standard terminals and consequently, reduce the satellite costs;
- Dynamic satellite bandwidth allocation to make reduce terrestrial network operators’ costs and increase the satellite network usage;
- Transparent end-user usage between satellite and terrestrial radio resources.

SaT5G has studied the first two features in detail, by providing the KPIs and the specific values to ensure the business, operational and technical requirements which support each KPI.

4.4 KPIs specific to SaT5G

We start with the KPIs which are defined in the statement of work, together with SaT5G target values:

1. **Service creation time in minutes**: Integrated network management and orchestration, and the virtualised satellite ground segment in 5G network aim to significantly reduce service creation time. Hosting the virtualised 5G core at the network edge, for example in the satellite earth station, could accelerate the deployment time of 5G in remote geographies lacking other infrastructure, which are typically deployed last by mobile operators. The use of multicast to deliver network service updates will reduce the time for new service creation and changes especially for expected dense deployment of 5G networks.

   **SaT5G target**: Demonstrate the creation or change of service in less than 2 minutes using virtualised satellite infrastructure.

2. **1000x capacity**: With satellite broadcast capabilities, SaT5G will enable efficient delivery of video content and popular content for caching and other edge services which will offload 5G transport networks and optimise network dimensioning. Multicast content delivery will reduce the transport backhaul burden for especially video services which is expected to represent 75% of total traffic by 2025.

   **SaT5G target**: Demonstrate the integration into 5G using satellite multicast offload to increase backhaul traffic efficiency to potentially in excess of 1000x.

3. **Better/increased/ubiquitous coverage**: SaT5G aims to narrow the digital divide providing 5G services to unserved and underserved areas in Europe and around the globe in emerging economies (e.g., Africa and South America). Airborne mobile backhauling will also be tackled in SaT5G reinforcing the universal reach of satellite globally. Increased resilience for safety and business critical applications or services.

   **SaT5G target**: Demonstrate satellite backhaul delivering 5G services for xMBB to offer ubiquitous coverage and improved service and support of terrestrial backhaul for traffic offload and resilience.

4. **10 times to 100 times higher typical user data rate**: VHTS links combined with terrestrial access (e.g. xDSL, 5G cells) for up to 10 times higher user throughput, by exploiting broadcast delivery of
live and rich content to the mobile stations. Using multicast satellite backhaul and edge caching will allow users to experience very high data rate in excess of 100Mb/s for multimedia services.

SaT5G target: Demonstration of multi-link aggregation significantly improving end user perceived performance in excess of 50Mbps; demonstration of multicast satellite backhaul and edge caching in 5G network.

We place the SaT5G KPIs into four categories, which are Satellite segment, Performance, Caching and Traffic. Table 4-1 below maps high-level to SaT5G KPIs and shows which category they are placed in.

<table>
<thead>
<tr>
<th>High level KPI 5GPPP (from DoW)</th>
<th>Satellite segment</th>
<th>Performance</th>
<th>Caching</th>
<th>Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service creation in minutes</td>
<td></td>
<td>Service creation time, service modification time, capabilities provided (QoS), solution success rate, functional network entities deployed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000x capacity (bits delivered to end users in given time)</td>
<td></td>
<td>Caching algorithm efficiency, re-direction algorithm efficiency, origin streaming capacity</td>
<td>Multicast gain</td>
<td></td>
</tr>
<tr>
<td>Increased coverage</td>
<td></td>
<td>Satellite backhaul performance = satellite virtualisation performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10x to 100x user data rate</td>
<td>Peak data rate, handover</td>
<td></td>
<td></td>
<td>Multilink performance</td>
</tr>
</tbody>
</table>

Table 4-1 SaT5G KPIs and their relationship with 5GPPP KPIs.

The full list is as follows:

- **Satellite**
  - Peak data rate
  - Handover

- **Performance**
  - Time to create end-to-end network service
• Time to modify a service
• Capabilities provided by the satellite network
• E2e solution success rate
• Satellite virtualisation performance
• Functional network entities reliability

❑ Caching
  • Caching algorithm efficiency
  • Redirection algorithm efficiency
  • Origin streaming capacity (non-cached assets)

❑ Traffic
  • Multicast gain
  • Multilink traffic performance

4.4.1 More detail on KPIs

This section expands upon the SaT5G KPIs and shows how they will be measured or validated in the SaT5G project with targets where possible. This analysis will be used to derive the SaT5G requirements to meet the KPI targets. The outputs from the validation and measurements will be used as inputs to the modelling exercise in WP2.5.

**Satellite segment KPIs:**

*Peak spectral efficiency* is the highest theoretical data rate per satellite station pair (normalised by bandwidth), considering useful IP level data only i.e. excluding radio resources that are used for physical layer synchronisation, access overheads, reference signals or pilots, guard bands and guard times.

The SaT5G activity is validated on the Oulu test-bed, where the impact of modifying the NR random access procedures on the throughput is measured. The target is that the degradation is <2%.

*Handover performance* refers to mobility situations where terminals can detach/reattach the satellite system in combination with the terrestrial RAN system.

The SaT5G activity on satellite handover is validated on the Zodiac test-bed. Also to be validated are the NR access and attach procedures over satellite on the Oulu test-bed.

**Performance KPIs:**

For these KPIs, the use of network slicing is assumed.

*Time to create an end-to-end solution* is the time that the networks needs to deploy, to modify, or to remove a satellite connectivity from the network. Auto-detection and auto-configuration functionalities are required. For the end-to-end solution, the time consumed by the interface creation/removal between entities should be considered. The 5GPPP goal cited in the ITU-R workshop on IMT-2000 terrestrial radio interfaces (Munich, October 4th 2017) is 90 minutes.

The SaT5G activity is to validate on test-beds and the target time is 2 minutes.

*Time to modify a service.* Many things can be upgraded including VNF, SDN, satellite radio beams, etc. Here we set as a requirement the modification of the QoS of a service. The 5GPPP goal is 90 minutes.

The SaT5G design target time is 2 minutes, and will be validated on a test-bed if possible.
Capabilities provided by the satellite network indicate which services have been requested and which services have been finally provided to the end users. The average obtained per user will indicate what the real end user requirements are and therefore, it facilitates the automation of the network. The goal is to provide 100% of the requested services achieving the requirements for each QoS Class Identifier (QCI).

The SaT5G activity will be to assess the accuracy and repeatability of setting up a contract between MNO(s) and SNO(s) using a broker model. The accuracy and repeatability of the satellite network will be evaluated with two different service types, e.g. video and data, to be validated by emulation. The target is 100% over a number of trials.

End-to-end solution success rate provides a clear idea of the automatic deployment performance. This KPI is useful to evaluate how the time to create an end-to-end solution can be reduced through automation while maintaining a sufficiently high success rate. The goal is to achieve a 100% of success to create an automatic end-to-end solution.

The SaT5G activity is to assess the accuracy and repeatability of setting up an end-to-end service with two different QCIs, e.g. video and data. The target is 100% over a number (TBD) of trials, to be validated on test-beds.

Satellite virtualisation performance is a measure of resources taken by the VMs and by overheads and how virtualisation has improved deployment density.

The SaT5G activity is to measure metrics such as energy and space savings of virtualisation from the test-beds.

Functional network entities reliability is the dependability and stability of VNFs and their component VMs.

The SaT5G activity is to run multiple VNF instances and check stability, measuring CPU, RAM and HDD usage and looking for patterns symptomatic of memory leaks etc. Satellite specific VMs from different partners will be tested on the test-beds.

Caching KPIs:

Caching algorithm efficiency defines how well popular content is being cached within the edge network to optimize network resources and QoE. Metrics would be reduction in backhaul bandwidth for the same bandwidth consumption at the network edge, along with required additional MEC resources (CPU, RAM, HDD).

The SaT5G activity is to measure relative traffic levels and computing resources over emulator and satellite links on test-beds.

Redirection Algorithm efficiency indicates how users are redirected to the reference Point of Presence (POP). A reference POP is the theoretically best suited to deliver the session, based on localisation, load average and content presence. It includes directing of UE to the appropriate UPF, with associated DNS lookup and authentication.

The SaT5G activity is to validate breakout traffic algorithms on test-beds.

Origin streaming capacity is used to determine if the system is correctly sized for the non-cached assets (non-popular). Storage Usage on the MEC server => the cache storage should be nearly full at all time (nearly because we require some space for the new contents before removing the no longer popular assets).

The SaT5G activity is to validate breakout traffic algorithms on test-beds.

Traffic KPIs

Multicast gain is the gain in efficiency due to the use of multicast over satellite. This has two components, first the savings in satellite capacity due to multicast compared with multiple unicast, and second the savings in terrestrial network capacity through utilising the satellite for multicast. The gain is in terms of money saved in investing in the terrestrial network to get the same improvement.

The SaT5G activity is to validate on test-beds.
Multilink traffic performance is the cost-effectiveness of using satellite to bolster the broadband experience of users, when used in parallel with terrestrial connections. The gain is in terms of money saved in investing in the terrestrial network to get the same improvement.

The SaT5G activity is to validate on test-beds.
5 General Requirements

5.1 Business

This chapter first explains the importance of the business requirement analysis and how this study will be mapped into the business case analysis of WP2.5. Then it gives an overview of the business case evaluation and which metrics can be used to economically evaluate the SaT5G project. Finally, it explains the methodology followed by SaT5G to identify realistic targets for growth of revenue and/or reduction in costs per scenario.

5.1.1 Business requirement analysis

The business requirements analysis is the process of discovering, analysing, defining, and documenting the requirements that are related to a specific business objective. It also is the process by which we clearly and precisely define the scope of the project, so that we can assess the timescales and resources needed to complete it.

The Business Requirements Analysis consists of four steps:

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify Key Stakeholders</td>
<td>Identify the key people who will be affected by the project (see section 3.4)</td>
</tr>
<tr>
<td>Capture Stakeholder</td>
<td>Ask each of these key stakeholders, or groups of stakeholders, for their</td>
</tr>
<tr>
<td>Requirements</td>
<td>requirements from the new product or service. What do they want and expect</td>
</tr>
<tr>
<td></td>
<td>from this project? We can use several methods to understand and capture</td>
</tr>
<tr>
<td></td>
<td>these requirements</td>
</tr>
<tr>
<td>Categorize Requirementsa</td>
<td>The most used approach consists in separating the functionalb and non-functional requirements. While dividing the specifications into two neat categories is an orderly way to write the documentation, we should remember that in the real world the functional and non-functional requirements are always tightly intertwined [129].</td>
</tr>
<tr>
<td>Interpreting and Recording</td>
<td>Once we have gathered and categorized all of the requirements, determine</td>
</tr>
<tr>
<td>Requirements</td>
<td>which requirements are achievable, and how the system or product can deliver</td>
</tr>
<tr>
<td></td>
<td>them [131].</td>
</tr>
</tbody>
</table>

Table 5-1 Business requirement analysis.

Note a:

- **Business Requirements**: These define what the business is trying to achieve and why a project should be undertaken, or a solution implemented, it also defines the metrics that will be used to measure success.
- **Operational Requirements**: These define operations that must be carried out in the background to keep the product or process functioning over a period of time.
- **Technical Requirements**: These define the technical issues that must be considered to successfully implement the process or create the product.

Note b,c [129]:

- Functional requirements address which functions the system must perform. Thus, it is obvious which requirements fall in this category: those that state which functions the system must perform.
- Non-functional requirements address the degree to which the system must perform the requirements. Common examples of non-functional requirements are any that address usability, reliability, performance, or security.

Once we have gathered and categorized all the requirements, we may determine which requirements are achievable, and how the system or product can deliver them [131].
5.1.2 Business Requirement Analysis for SaT5G

Following the business requirement analysis steps described above, we start in SaT5G by identifying the different relevant stakeholders. Secondly, we describe several techniques for capturing stakeholder requirements. The main techniques used are firstly, the use-cases technique, by defining multiple use-cases to understand the functionality of the whole system; and secondly, the group-workshops technique by organizing conference calls and general assembly meetings. These requirements are categorized according to three types; namely, business, operational, and technical requirements. Finally, all required interpretation and description is done in detail in section 5.

Building on the basic value chain, a generic value chain for the SaT5G project is shown in Figure 5-1 below where functions replace stakeholders and illustrative company names are used – their use is purely illustrative and not intended to show any actual service offered by these organisations.

The generic value chain will now be customised for each of the SaT5G use-cases. The interactions below need to be considered:

- **Business requirements**: The SaT5G solution shall consider the business model interactions between stakeholders.
- **Business requirements**: If possible, the SaT5G business solution should consider a model to take into account that the same solution may be applied in different regions with different costs.
- **Technical requirements**: The SaT5G technical solution shall consider requirements that different regions have different regulations and therefore different technical constraints.

5.1.3 Improvement on the Business Case

During the business model analysis, we will face some scenarios in which the project will not be viable and to increase this viability we can proceed even by reducing the equipment costs or/and by saving energy by disabling some functionalities. SaT5G should be designed with the objective to minimize the TCO of the network infrastructure as well as operation and management, for any given service offering and in any defined scenario. In addition, the cost of the devices should be minimized to facilitate the service access for the customers.
Although central for any market, cost efficiency is even more important for low ARPU areas, i.e., unserved and underserved areas, because of economic constraints. Bringing connectivity to such areas in an economically sustainable way requires low-cost network infrastructures, low-cost devices, and low-cost operation and maintenance. In addition to minimizing the costs of the full-fledged technology, SaT5G therefore needs to offer options and possibilities for low-cost deployments tailored for low ARPU areas. Features of lower importance for low-cost deployments include:

- Lower availability: a high availability typically requires some redundancy of equipment. For ultralow cost networks the availability rate requirement can be lowered.
- Lower peak rates: Lowering peak rates can be enabled by removing features like higher order modulation, MIMO configurations, carrier aggregation support, etc.
- Energy-level dependent base stations activity: When the energy level of a base station operating off the grid (e.g., on battery) reaches a certain threshold, the base station may enter an energy saving mode where the service to regular users may be degraded (e.g., the transmit power may be reduced), or even shut down for periods in order to save energy for emergency services.
- Restricted areas of service: Consistency of user experience across a wide territory is not mandatory. Only minimum communication services may be available everywhere, with higher bandwidth being available only in some areas (e.g., where population is present).

In addition, some large-scale MTC services will generate only a very low ARPU, e.g., 100 times lower than current human users. The SaT5G system should enable economically viable deployments to address this market, by providing a sufficiently low associated TCO [133].

- Business requirement: The SaT5G business solution shall consider enhanced usage predictions in areas with low ARPUs.
- Technical requirement: the SaT5G solution shall be configurable, flexible and modular to reduce costs.

### 5.2 Operational

This section identifies the operational and deployment constraints which need to be considered within SaT5G.

From the guide produced by the IET's Communications Policy panel [38], the main points for consideration for policy makers in terms of 5G network implementation are:

- Focus on securing reliable universal coverage;
- High capacity urban coverage;
- Regulatory framework to reduce cost of spectrum for maximising coverage

#### 5.2.1 Laws and regulations

This subsection addresses the operational procedures, laws, regulations which must be observed.

#### 5.2.1.1 Spectrum

The CTIA was originally known as the Cellular Telecommunications Industry Association and has more recently operated under its initials only. It is a trade association representing the wireless communications industry in the United States. In a white paper [39] they note:

“It is important that spectrum be available to allow operators to deploy as early as they choose for business and technical reasons.”

Similar statements are being made in many administrations and no doubt future debate will be of major interest.

- Not a requirement: Spectrum sharing analysis is out of scope for SaT5G.
5.2.1.2 Taxation, license fees and other government charges

ARCEP (Autorité de Régulation des Communications Électroniques et des Postes) is an independent French agency in charge of regulating telecommunications in France. In a report [40] they consider many things including the impact of taxation and they write:

“decreasing taxes on base stations in locations that are hard to cover: Act No. 2016-1888 of 28 December 2016 on the modernisation, development and protection of mountain regions thus exonerates mobile base stations built in mountain regions between 1 January 2017 and 31 December 2020 from paying the IFER tax”

Accessing licensed spectrum requires payment of fees to the relevant administrative organisation such as Ofcom in the UK.

- **Not a requirement**: as license costs are out of scope of the SaT5G project, the business case the license cost of accessing the mobile/satellite spectrum shall not be assessed.

5.2.1.3 Reach and universal service obligation

The 5G PPP (5G Infrastructure Public Private Partnership) detail the high level KPIs [41] one of which is:

“Ubiquitous 5G access including in low density areas”

The universal service obligation for telephone coverage and in some countries Internet access has not been formally extended to 5G cellular coverage though many of the use-cases being discussed will require this. This is a clear driver for SaT5G but no specific requirement arises.

In general, coverage and availability requirements are set by the national governments and the service provider has to comply with it sometimes as a condition of the licence associate with the spectrum. It is the responsibility of the network operator.

5.2.1.4 Other legal requirements

Satellite terminals operating in well-defined Ka and Ku band frequencies do not need radio frequency clearance and simply need to be registered in a national database.

Terminals on moving platforms have different regulatory and legal requirements relating to their operations and registration. This covers matters such as operation near particular locations. In addition there are sector specific regulations covering installation in very different locations such as planes, trains and ships.

5.2.2 Operational and management system

This subsection reviews the management of the network including satellite and terrestrial parts; considering issues such as handover, billing, network maintenance, etc. Network slicing is also considered.

5.2.2.1 Accounting and billing

Today such arrangements are made on a case-by-case basis. They are currently typically on the following basis; pay a monthly/annual fixed price for bandwidth usage (either actually used or that reserved). It can also be possible to reserve additional bandwidth which needs to be paid for depending on usage.
This needs to be updated to represent the more flexible modus operandi envisaged by 5G with near real time slice management and other parties being involved in the use of slices (for example a reseller or integrator, or an IoT service provider).

- **Operational Requirement:** The SaT5G operational solution shall provide tools to allow the MNOs and SatCom operators to manage the capacity and billing including tools such as real-time monitoring, forecasting and auditing.
- **Operational Requirement:** The SaT5G operational solution should provide tools to allow the partners of the MNOs and SatCom operators reduced access to manage defined elements capacity and billing including tools such as real-time monitoring, forecasting and auditing.

### 5.2.2.2 Network management and OSS

Network management and monitoring functionalities are separate in the 4G backhaul scenario with the MNO and the satellite operator deploying separate tools to monitor and manage the network. Information on traffic passing through satellite network is made visible/accessible to the MNO as per their requirements and through separate tools. Some bespoke integration through APIs may be implemented.

### 5.2.2.3 In the 5G networks this needs to be merged. Network slicing

This is a fundamental requirement of 5G. Amongst other factors network slicing:

- Enables the application specific parameters to meet the KPIs;
- Allows third party managed services for network management;
- Enables third party operators to share the site to reduce operator costs in remote regions;
- Permits third party managed network security services at cell sites;

These factors affect VLAN translation mechanisms between the satellite backhaul network and the eNB and core.

### 5.2.3 Deployment constraints

This subsection reviews the issues around the deployment and maintenance of systems at the cell sites.

#### 5.2.3.1 Access rights

The balance between landowner rights and network developer rights is an ongoing debate however no specific requirements for SaT5G have been identified.

#### 5.2.3.2 Cost efficiency

To improve cost efficiency in network operations, third party managed services providers are employed nowadays providing services such as:

- Network transformation – managing operations and phase out of legacy equipment or updating with new technologies;
- Small cells as a service

The SatCom operator is experienced in operating satellite networks as is the MNO in operating terrestrial cellular networks. The work at the remote sites can be performed by in house teams and/or outsourced by both organisations. Perhaps a single field service team can perform both SatCom and cell mast work.
**Business Requirement:** The SaT5G business solution shall consider the case of trade-off between responsibilities between MNO and SatCom operator at the remote sites, and evaluate the role of an intermediate party such as a broker.

### 5.2.3.3 Network maintenance

In today’s networks demarcation points for the operators (MNOs and satellite service providers) are agreed prior to start-of-service; this can include:

- Managed service provider is responsible for the operational management of the services and satellite service provider does the installation and of remote segment / local gateway;
- SLA for incident/fault notification and fix times;
- Change management, problem management, technical care support;
- MNO/ third party responsible for spare parts management;
- Contact methods and escalation paths;

The SLAs are generally adapted to suit the geography – for example reaching a very remote location can take considerable time, perhaps needing access on bad roads (e.g. Africa) or ferries (e.g. Scottish Island) or be affected by winter weather (e.g. Snow).

**Operational Requirement:** The SaT5G solution should follow industry best practises and shall be supplemented by emerging 5G requirements as and when these are identified.

### 5.3 Technical

#### 5.3.1 Network management

The management of physical and virtual network functions is done by MANO systems.

**Technical Requirement:** The SaT5G technical solution shall conform to the emerging 5G standards for MANO such as those set out by ETSI (e.g. [42]). This should address all events such as control, management and reporting.

#### 5.3.2 Quality of Service expected in 5G networks

Quality of Service (QoS) requirements and their implementation date back to UMTS [43] where they were originated, and were then updated for LTE [44], [45], [43]. They are now being extended again to 5G but are still in the process of final standardisation. The concepts of having RAN and core network bearers, together with traffic classes and QoS attributes, has been maintained throughout the evolution.

The two main attributes that are implemented in LTE and will be extended to 5G are Maximum Bit Rate and Guaranteed Bit Rate (GBR). In LTE this was accomplished via QoS Class Identifiers (QCI) and Allocation and Retention Priority (ARP). Thus various traffic classes divided into GBR and Non-GBR had attributed to them delay and packet error rates plus a priority level which is used to accept or reject due to resource limitations.

Details about the QoS in RAN may be found in [46].

#### 5.3.2.1 QoS parameters in 5G

In 5G, new QoS flows are introduced together with parameters such as 5QI that identify the flows replacing the QCI concept in LTE, but ARP is retained in 5G and hence the QoS control is quite similar.

- **5G QoS Identifier (5QI)**
  - A 5QI is a scalar that is used as a reference to 5G QoS characteristics i.e. access nodespecific parameters that control QoS forwarding treatment for the QoS flow (e.g. scheduling weights, admission thresholds, queue management thresholds, link layer
protocol configuration, etc.). Standardized 5QI values have one-to-one mapping to a standardized combination of 5G QoS.

- Allocation and Retention Priority (ARP)
  - The QoS parameter ARP contains information about the priority level, the pre-emption capability and the pre-emption vulnerability. The priority level defines the relative importance of a resource request. This allows a decision to be made on whether a new QoS flow may be accepted or needs to be rejected in case of resource limitations (typically used for admission control of GBR traffic). It may also be used to decide which existing QoS flow to pre-empt during resource limitations.

- Reflective QoS Attribute (RQA)
  - The RQA is a new optional parameter which indicates that certain traffic (not necessarily all) carried on this QoS flow is subject to Reflective QoS.

### 5.3.2.2 5G QoS characteristics

The characteristics describe the packet forwarding treatment that a QoS flow receives edge-to-edge between the UE and the UPF in terms of the following performance characteristics. Standardized or pre-configured 5G QoS characteristics are indicated through the 5QI value and are not signalled on any interface. Signalled QoS characteristics are included as part of the QoS profile.

- Resource Type
  - The Resource Type determines if dedicated network resources related QoS flow-level Guaranteed Flow Bit Rate (GFBR) value are permanently allocated (e.g. by an admission control function in a radio base station). GBR QoS flow are therefore typically authorized "on demand" which requires dynamic policy and charging control. A Non-GBR QoS flow may be pre-authorized through static policy and charging control. There are two kinds of GBR resource types, GBR and Delay critical GBR.

- Priority Level
  - The Priority level indicates a priority in RAN scheduling resources among QoS flows. The Priority levels are used to differentiate between QoS flows of the same UE and are also be used to differentiate between QoS flows from different UEs.

- Packet Delay Budget (PDB)
  - The PDB defines an upper bound for the time that a packet may be delayed between the UE and the UPF that terminates the N6 interface. For a certain 5QI the value of the PDB is the same in UL and DL. In the case of 3GPP access, the PDB is used to support the configuration of scheduling and link layer functions (e.g. the setting of scheduling priority weights and HARQ target operating points). For delay critical GBR flows, a packet delayed more than PDB is counted as lost.

- Packet Error Rate (PER)
  - The Packet Error Rate (PER) defines an upper bound for the rate of PDUs (e.g. IP packets) that have been processed by the sender of a link layer protocol (e.g. RLC in RAN of a 3GPP access) but that are not successfully delivered by the corresponding receiver to the upper layer (e.g. PDCP in RAN of a 3GPP access).

- Averaging Window
  - The averaging window is defined only for GBR QoS flows. The averaging window represents the duration over which the GFBR and MFBR is calculated (e.g. (R)AN, UPF, UE).

### 5.3.2.3 Standardized 5QI to QoS characteristics mapping

- Reflective QoS
  - Reflective QoS enables the UE to map UL User Plane traffic to QoS flows without Session Management Function (SMF) provided QoS rules and it applies for IP PDU Session and Ethernet PDU Session. This is achieved by creating UE derived QoS rules in the UE based on the received DL traffic. It shall be possible to apply reflective QoS and non-reflective QoS concurrently within the same PDU Session.

- Reflective QoS Control
  - Reflective QoS is controlled on per-packet basis by using the RQI in the encapsulation header on N3 reference point together with the QFI, together with a Reflective QoS
5.3.2.4 QoS flows within the Core Network

The 5G QoS model supports both QoS flows that require guaranteed flow bit rate (GBR QoS flows) and QoS flows that do not require guaranteed flow bit rate (non-GBR QoS flows). The 5G QoS model also supports reflective QoS.

The QoS flow is the finest granularity of QoS differentiation in the PDU Session. A QoS flow ID (QFI) is used to identify a QoS flow in the 5G System. User Plane traffic with the same QFI within a PDU Session receives the same traffic forwarding treatment (e.g. scheduling, admission threshold). The QFI is carried in an encapsulation header on N3 (and N9) i.e. without any changes to the e2e packet header. QFI shall be used for all PDU Session Types. The QFI shall be unique within a PDU Session. The QFI may be dynamically assigned or may be equal to the 5QI (see later).

Within the 5GS, a QoS flow is controlled by the SMF and may be preconfigured, or established via the PDU Session establishment procedure ([47] clause 4.3.2), or the PDU Session Modification procedures [47] QoS flow.

Any QoS flow is characterised by:

- A QoS profile provided by the SMF to the AN via the Access and Mobility Management Function (AMF) over the N2 reference point or preconfigured in the AN;
- One or more QoS rule(s) which can be provided by the SMF to the UE via the AMF over the N1 reference point and/or derived by the UE by applying reflective QoS control; and
- One or more Service Data Flow (SDF) templates provided by the SMF to the UPF.

Within the 5GS, the QoS flow of the default QoS rule is required to be established for a PDU Session and to remain established throughout the lifetime of the PDU Session. The QoS flow of the default QoS rule shall be a Non-GBR QoS flow.

5.3.2.5 Control of QoS flows

The following options are supported to control QoS flows:

- For non-GBR QoS flows, and when standardized 5QIs or pre-configured 5QIs are used, the 5QI value can be used as the QFI of the QoS flow;
  - The default ARP shall be pre-configured in the AN; or
  - The default ARP and the QFI shall be sent to RAN over N2 at PDU Session Establishment or at PDU Session Modification and when NG-RAN is used every time the User Plane of the PDU Session is activated;
- For all other cases (including GBR and non-GBR QoS flows), a dynamically assigned QFI shall be used. The 5QI value may be a standardized, pre-configured or dynamically assigned. The QoS profile and the QFI of a QoS flow is provided to the (R)AN over N2 at PDU Session Establishment/Modification and when NG-RAN is used every time the User Plane of the PDU Session is activated.

QoS Rules

The UE performs the classification and marking of UL user plane traffic, i.e. the association of UL traffic to QoS flows, based on QoS rules. These QoS rules may be explicitly provided to the UE (using the PDU Session Establishment/Modification procedure), pre-configured in the UE or implicitly derived by UE by applying reflective QoS (see later). A QoS rule contains a QoS rule identifier which is unique within the PDU Session, the QFI of the associated QoS flow and except for the default QoS rule (see below) a Packet Filter Set (see later) for UL and optionally for DL and a precedence value (see later). Additionally, for a dynamically assigned QFI, the QoS rule contains the QoS parameters relevant to the UE (e.g. 5QI, GBR and MBR and the Averaging Window). There can be more than one QoS rule associated with the same QoS flow (i.e. with the same QFI).

QoS flow mapping
The SMF performs the binding of SDFs to QoS flows based on the QoS and service requirements. The SMF assigns the QFI for a new QoS flow and derives its QoS profile from the information provided by the PCF. When applicable, the SMF provides the QFI together with the QoS profile and a transport level packet marking value (e.g., the DSCP value of the outer IP header over N3 tunnel) for uplink traffic to the (R)AN. The SMF provides the SDF template i.e. Packet Filter Set associated with the SDF received from the PCF together with the SDF precedence value, the QoS related information, and the corresponding packet marking information, i.e. the QFI, the transport level packet marking value (e.g., the DSCP value of the outer IP header over N3 tunnel) for downlink traffic and optionally the Reflective QoS Indication to the UPF enabling classification, bandwidth enforcement and marking of User Plane traffic. For each SDF, when applicable, the SMF generates a QoS rule. Each of these QoS rules contain the QoS rule identifier, the QFI of the QoS flow the Packet Filter Set of the UL part of the SDF template, optionally the Packet Filter Set for the DL part of the SDF template, and the QoS rule precedence value set to the SDF precedence value. The QoS rules are then provided to the UE.

The principle for classification and marking of User Plane traffic and mapping of QoS flows to AN resources is illustrated in Figure 5-2.

![Diagram](image-url)

**Figure 5-2** The principle for classification and User-Plane marking for QoS flows and mapping to AN Resources [48].

In DL, incoming data packets are classified by the UPF, based on SDF templates according to their SDF precedence, (without initiating additional N4 signalling). The UPF conveys the classification of the User Plane traffic belonging to a QoS flow through an N3 (and N9) User Plane marking using a QFI. The AN binds QoS flows to AN resources (i.e. Data Radio Bearers of in case of 3GPP RAN). There is no strict one-to-one relation between QoS flows and AN resources; it is up to the AN to establish the necessary AN resources that QoS flows can be mapped to.

If no match is found and all QoS flows are related with a DL Packet Filter Set, the UPF shall discard the DL data packet.

In UL, the UE evaluates UL packets against the Packet Filter Set in the QoS rules, based on the precedence value of QoS rules in increasing order until a matching QoS rule (i.e. whose packet filter matches the UL packet) is found. The UE uses the QFI in the corresponding matching QoS rule to bind the UL packet to a QoS flow. The UE then binds QoS flows to AN resources.

If no match is found and the default QoS rule contains an UL Packet Filter Set, the UE shall discard the UL data packet.

The MBR (and if applicable GBR) per SDF, if received from PCF over N7, is signalled on N4. For further information regarding MBR and GBR over N7, see [49] [48].

- **Operational Requirement**: the SaT5G system will be capable of detecting when the required QoS is not achieved.
• **Technical Requirement**: the SaT5G system will be designed to support end-to-end QoS.
• **Technical requirement**: Conversational and non-conversational multimedia streaming QoS should...<indicate preference, qualitative objective and/or quantitative> such as: GBR, lowest latency, mid jitter
• **Technical requirement**: the SaT5G system will support pure data transfer QoS where it is indicated parameters like <indicate preference, qualitative objective and/or quantitative>: most probably non GBR type resource, etc.
• **Technical requirement**: the SaT5G system will support data in background where QoS should is identified by <indicate preference, qualitative objective and/or quantitative>: non GBR, high jitter / latency supported parameters.
• **Technical requirement**: in the SaT5G architecture, Mission Critical CoS should...<indicate preference, qualitative objective and/or quantitative>: strong requirement on PER and BER.
• **Technical requirement**: the SaT5G Network Management and Generic-purpose Service Management should...<indicate preference, qualitative objective and/or quantitative>: low processing delay.

### 5.4 Architectural

This section gives a view on the SaT5G architecture, and how business, operational and technical requirements arise from it.

#### 5.4.1 5G network architecture

5G network architectures are currently being discussed by standardisation bodies. In SaT5G, D3.1 is responsible to provide reference 5G architectures integrating satellite into 5G.

The most relevant standardisation body which specify future 5G system is 3GPP. SaT5G shall then rely on 3GPP work and specifications to design architecture integrating satellite in 5G, trying to be as compatible as possible to what has been defined so far, with minimum requirement to modify or adapt the standard. However, due to the inherent characteristics of a satellite link, some accommodation will be required. SaT5G WP3 deliverables have the responsibility of identifying these accommodations, based on the SaT5G use-cases.

In 3GPP, the SA WG2 group is in charge of 5G architecture at higher system level. Based on the services requirements elaborated by SA WG1, SA WG2 identifies the main functions and entities of the network, how these entities are linked to each other and the information they exchange.

So far, the SA WG2 has two relevant specifications focused on system architecture for 5G system [48] and procedures for the 5G system. Figure 5-3 illustrates a high-level functional architecture as defined in [48].
5.4.2 Integrating SatCom into 5G architectural requirements

- **Technical Requirement**: SaT5G solution should align with other related H2020 projects looking at this area such as 5GXcast where appropriate.
- **Technical Requirement**: SaT5G solution shall use IP multicast as the baseline assumption for the underlying delivery protocol.

5.4.3 SaT5G network topology

Despite the introduction of a satellite link for backhauling will not have an impact at system level as defined in SA WGs, the different procedures shall be studied, focusing on the format of the message defined in CT WGs in order to derive SaT5G architecture(s).

However, introduction of the satellite link may lead to a modification of the technical requirements of certain messages or even require introduce additional function/procedure/message. SaT5G architecture(s) shall clearly point out assumptions taken and required adaptation of the standards in order to contribute to the appropriate 3GPP WGs.

In D3.1, defined SaT5G network topologies are based on the use-case. The considerate use-cases are the SaT5G use-cases defined in D2.1.

5.4.4 SaT5G Network management architecture

In addition of 3GPP SA WG2 and CT WGs, SaT5G shall also consider specifications of 3GPP SA WG3 dealing with security, as well as specification of SA WG5 dealing with network management.

With the paradigm of Virtualization and NFV, it is assumed that 5G network would be managed dynamically which a certain level of flexibility. An Orchestration will be performed between the VNF and abstractions of the physical network in order to create logical networks.

The introduced of a satellite link with its own management constraints shall provide interfaces and enough flexibility to allow easy the management of the final global SaT5G network.

The Figure 5-4 shows the integrated management of 5G networks with satellite resource for backhauling proposed in SaT5G D3.1.
5.4.5 Slicing

5.4.5.1 Characteristics of slicing

Slicing allows multiple virtual networks to be created on top of a common shared physical infrastructure using SDN (configuration) and NFV (functions). The creation and deletion of a slice can be requested by more than one actor in the value chain, but the deployment and maintenance of the slice is the responsibility of the NO.

All the SaT5G use-cases will need to support network slices to integrate into the future networks such as 5G. A 5G Americas White paper [50] has the following in section 6:

“The requirements for 5G network slicing are currently in a proposed state and are listed in clause 5.2.3 of 3GPP Technical Report 22.891. These requirements are considered very stable at this point and will eventually be placed in a Technical Specification. Although there are only eight requirements listed as of version 14.0.0, they provide a strong, high-level view and direction for the next generation (NexGen) work of 3GPP”

It goes on to add that, based on 3GPP requirements, NOs shall have the following general requirements for network slicing operations:

- Create and manage network slices instances;
- Create and manage services to slices pairing function;
- Create network slices blueprints;
- Deploy and operate fault, configuration, accounting, performance and security (FCAPS) functions for the defined network slices. Configuration management (CM), fault management (FM) and performance management (PM) capabilities should be provided per slice so operators can monitor end-to-end service health, including relevant information about the slice’s performance relative to the required QoS from the slices, and also about the NFs’ performance;
- Create and manage slice components pairing function (e.g., CN slice to RAN slice pairing rules);
• Modification of network slices will be possible, such as adding, deleting and modifying network slices.

Referring to the referenced 3GPP report [51] and specifically to its section 5.2.3, this defines a list of potential operational requirements for Network Slicing:

• The NO shall be able to operate different network slices in parallel with isolation that for example, prevents one slice’s data communication to negatively impact services in other slices;

• The system shall have the capability to conform to service-specific security assurance requirements in a single network slice, rather than the whole network;

• The system shall have the capability to provide a level of isolation between network slices to confine a cyber-attack to a single network slice;

• The operator shall be able to authorize third parties to create, manage a network slice configuration (e.g., scale slices) via suitable APIs, within the limits set by the NO;

• The system shall support network slice elasticity in terms of capacity with no impact on the services of this slice or other slices;

• The system shall be able to change the slices with minimal impact on the ongoing subscriber’s services served by other slices: specifically, of new network slice addition, removal of existing network slice or update of network slice functions or configuration;

• The system shall be able to support end-to-end resource management for a network slice;

• The operator shall be able to create and manage network slices that fulfil required criteria for different market scenarios.

From these, we see that once a slice is created it can be used up to capacity without affecting other slices. This means there is no concept of booking or contention with slicing, and whereas this may be a reasonable assumption if the infrastructure is end-to-end optical fibre, we have a problem when we consider a radio or satellite link is one of the segments in the end-to-end path, because spectrum needs to be managed as a contended resource if the costs are to be feasible.

A single physical network will be sliced into multiple virtual networks that can support different RANs, or different service types running across a single RAN. The RAN can be sliced using spectrum, transmit points, or logical resources derived from the physical and MAC layers.

5.4.5.2 Slicing architecture and requirements

Figure 5-5 shows the concept of slices that run over an access network and a core network, with a pairing or mapping function in between. In this concept, each service has its own end-to-end slice. When the access network is wireless or satellite, and possibly also when it is fixed, the bandwidth will be contended and subject to the particular characteristics of the access network, such as high latency with GEO satellites. The specification and design of the pairing functions for satellite access is identified as a topic for research in this project.
Slices will also require orchestration and control, and a reference arrangement is shown in Figure 5-6.

Figure 5-5 Slices across access and core network.

Figure 5-6 Slice reference diagram.

In Figure 5-6, we show an orchestrator and controller for each segment or domain of the slice. Examples of domain types are satellite access, mobile access, fixed access, satellite transport, terrestrial transport, core networks and applications.

An overall orchestrator manages the end-to-end slice, and the slice typically consists of multiple domains which will be managed by lower tier orchestrators. Figure 5-7 shows the first level of orchestration in a generic slice architecture containing all envisaged functions, and it will need customisation for each use-case depending on deployment. Sa5G end-to-end slice definition includes also the applications function therefore, all the end-to-end elements are involved.

- **Operational requirement:** The SaT5G system shall support dynamic utilization of resources (compute, network and storage resources) in more than one geographic area in order to serve the differing needs of the users in each geographic area, subject to operator policy.
- **Operational requirement:** The SaT5G system shall support dynamic utilization of satellite link radio resources, subject to operator policy, to provide the end-to-end services and network slices requested.
• **Operational requirement**: The business requirement: the business model shall evaluate the implication of network slicing on the network costs

• **Technical Requirement**: The SaT5G technical solution shall be designed to achieve perfect isolation between slices for security reasons.

• **Technical Requirement**: The SaT5G solution shall be capable to be federated in multiple networks

![Figure 5-7 Generic view of the orchestrator slice architecture.](image)

Figure 5-7 shows in more detail the relation between the core network and the content distributors’ slices.

![Figure 5-8 Detail of the core network and content distribution slices.](image)

As said before, SaT5G also includes the transport network and the content network to create the end-to-end slice. Below Figure 5-9 shows the slice representation of the transport network where the satellite network orchestrator is included.
Slicing details of the transport network

Service Orchestrator: BT
Transport orchestrator: AVA
Template: eMBB over satellite

Template: eMBB 5G terrestrial network
Template: eMBB 5G sat network
Template: eMBB 5G sat core

Transport domain controller

Slice specific SON (Controllers)

Terrestrial network slice 1
Terrestrial network slice 2

Physical network resources

Figure 5-9 Details of the transport slice including satellite.
6 Summary

This study of SaT5G features concludes with the requirements for:

- Novel satellite network functions compliant with standard bodies like 3GPP or ITU;
- Performance requirements needed to consider a satellite network as part of a 5G network. The minimum requirement will be used also to decide which satellite functionalities shall be moved to the edge of the network. These performance requirements shall include the novel functionalities identified;
- Virtualization requirements to be able to integrate satellites networks into multiple slices;
- Edge delivery and caching functionalities.

The requirements are grouped into three different categories: business, operational and technical requirements.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Business</strong></td>
<td>SaT5G shall evaluate the total costs incurred to rollout a 5G satellite solution.</td>
</tr>
<tr>
<td>SaT5G solution shall enhanced the business model prediction in areas with low ARPU.</td>
<td></td>
</tr>
<tr>
<td>SaT5G solution shall consider the tangible and intangible interactions between stakeholders.</td>
<td></td>
</tr>
<tr>
<td>SaT5G solution shall analyse the impact of tax breaks.</td>
<td></td>
</tr>
<tr>
<td>SaT5G solution shall review the business case when a trade-off between responsibilities MNO and SatCom operator at the remote sites and evaluate the role of an intermediate party such as a broker.</td>
<td></td>
</tr>
<tr>
<td><strong>Operational</strong></td>
<td>SaT5G solution shall provide tools to allow the MNOs and SatCom operators to manage the capacity and billing including tools such as real-time monitoring, forecasting and auditing.</td>
</tr>
<tr>
<td>SaT5G solution should provide tools to allow the partners of the MNOs and SatCom operators reduced access to manage defined elements capacity and billing including tools such as real-time monitoring, forecasting and auditing.</td>
<td></td>
</tr>
<tr>
<td>SaT5G solution should follow industry best practices and shall be supplemented by emerging 5G requirements as and when these are identified.</td>
<td></td>
</tr>
<tr>
<td>SaT5G solution shall be able to adjust the network capacities dynamically based on the variation of demand and performance indicators. Specifically, the system shall allow both the CIR and PIR to be adapted and adjusted by the satellite network operator to suit the traffic needs.</td>
<td></td>
</tr>
<tr>
<td>SaT5G solution shall support dynamic utilization of resources (compute, network and storage resources) in more than one geographic area in order to serve the differing needs of the users in each geographic area, subject to operator policy.</td>
<td></td>
</tr>
<tr>
<td>SaT5G solution shall support dynamic utilization of satellite link radio resources, subject to operator policy, to provide the end-to-end services and network slices requested.</td>
<td></td>
</tr>
<tr>
<td>SaT5G solution should support foreseen rapid increases in signalling and user plane demand with a lead-time that can be as low as 5 minutes.</td>
<td></td>
</tr>
<tr>
<td>SaT5G solution shall manage different network slices - service profiles - with different degradation steps.</td>
<td></td>
</tr>
<tr>
<td>SaT5G solution shall define an OSS able to implement and bill VNF and SDN instantiations. These bills should be raised by the satellite network operator towards the organisation providing the end-to-end orchestration.</td>
<td></td>
</tr>
</tbody>
</table>
### Requirements Definition

<table>
<thead>
<tr>
<th>Requirements</th>
<th>SaT5G solution shall support industry best practise management of FCAPS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>SaT5G solution shall be designed to adapt to varying service availability requirements.</td>
</tr>
<tr>
<td></td>
<td>SaT5G solution shall support 5G QOS management mechanisms.</td>
</tr>
<tr>
<td></td>
<td>SaT5G solution shall be designed to meet standard satellite access operational requirements such as out of band and off-axis emissions, carrier control, etc.</td>
</tr>
<tr>
<td></td>
<td>SaT5G solution shall conform to the 5G network slice billing requirements.</td>
</tr>
<tr>
<td></td>
<td>SaT5G solution shall conform to the emerging 5G standards for MANO such as those set out by ETSI. This should address all events such as control, management and reporting.</td>
</tr>
<tr>
<td></td>
<td>SaT5G solution shall be designed to support multiple network slices both within the network and at individual satellite terminal locations.</td>
</tr>
<tr>
<td></td>
<td>SaT5G solution shall be designed to achieve perfect isolation between slices for security reasons.</td>
</tr>
<tr>
<td></td>
<td>SaT5G solution shall use IP multicast as the baseline assumption for the underlying delivery protocol.</td>
</tr>
<tr>
<td></td>
<td>SaT5G solution should be capable of cache synchronisation and multicast services through the satellite link.</td>
</tr>
<tr>
<td></td>
<td>SaT5G solution shall be for a consumer grade installation with low power consumption, high reliability, easy to setup and manage with a small physical footprint.</td>
</tr>
<tr>
<td>Not a requirement</td>
<td>Spectrum sharing analysis is out of scope for SaT5G.</td>
</tr>
</tbody>
</table>

#### Table 6-1 Summary of the requirements identified in D2.2.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Value</th>
<th>Validation in project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to create an end-to-end solution</td>
<td>90 minutes (5GPPP), 2 minutes (SaT5G – VMs deployed)</td>
<td>Yes</td>
</tr>
<tr>
<td>Modifying an end-to-end solution</td>
<td>2 minutes</td>
<td>Yes</td>
</tr>
<tr>
<td>Capabilities provided</td>
<td>100% of the requested services</td>
<td>Yes, with limited number of trials</td>
</tr>
<tr>
<td>End-to-end solution success rate</td>
<td>100% of the requirements</td>
<td>Yes, with limited number of trials</td>
</tr>
<tr>
<td>Virtualisation performance</td>
<td>Efficiency of virtualisation</td>
<td>Broad compute resources required shall be obtained</td>
</tr>
<tr>
<td>Functional network entities</td>
<td>99.9% of the time</td>
<td>Yes, with limited number of trials</td>
</tr>
<tr>
<td>Peak spectral efficiency</td>
<td>Degradation through using NR over satellite to be &lt;5%.</td>
<td>Impact of random access procedures</td>
</tr>
<tr>
<td>Handover performance</td>
<td>Success on the 95% of the attempts</td>
<td>Yes, with limited number of trials</td>
</tr>
<tr>
<td>Caching algorithm efficiency</td>
<td>[90%] of the cache contains popular content.</td>
<td>Yes, with limited trials</td>
</tr>
<tr>
<td>Redirection Algorithm efficiency</td>
<td>[99%] of users are correctly redirected to the correct UPF</td>
<td>Yes, with limited trials</td>
</tr>
<tr>
<td>Origin streaming capacity</td>
<td>[99%] of requests for non-cached content are successful</td>
<td>Yes, with limited trials</td>
</tr>
<tr>
<td>Multicast gain</td>
<td>Cost savings in satellite capacity and in relief on terrestrial networks</td>
<td>Inferred from test-beds</td>
</tr>
<tr>
<td>Multi-link performance</td>
<td>Bolstering of capacity to fixed premises, and saving of costs on</td>
<td>Inferred from test-beds</td>
</tr>
<tr>
<td>KPI</td>
<td>Value</td>
<td>Validation in project</td>
</tr>
<tr>
<td>-----</td>
<td>-------</td>
<td>-----------------------</td>
</tr>
<tr>
<td></td>
<td>terrestrial networks to provide equivalent performance.</td>
<td></td>
</tr>
</tbody>
</table>

Table 6-2 KPI values identified in D2.2.
7 References


[31] 3GPP, “3GPP TR 38.811 V0.2.1 (2017-11) - Study on NR to support non-terrestrial networks,” 3GPP, 2017.


[37] 3GPP, “3GPP TS 32.455 V14.0.0 (2017-04) - Key Performance Indicators (KPI) for the Evolved Packet Core (EPC); Definitions,” 3GPP, 2017.


[44] 3GPP, “3GPP TS 23.203 V15.0.0 (2017-09) - Policy and charging control architecture,” 3GPP, 2017.


[46] 3GPP, “TS 38.300 V15.0.0 (2018-01) - NR; Overall description; Stage-2,” 3GPP, 2018.

[47] 3GPP, “3GPP TS 23.502 V15.0.0 (2017-12) - Procedures for the 5G System,” 3GPP, 2017.


[49] 3GPP, “3GPP TS 23.503 V15.0.0 (2017-12) - Policy and Charging Control Framework for the 5G System; Stage 2,” 3GPP, 2017.


[67] “DVB-RCS2 – Security spec on satellite to terminal”.


[99] 3GPP TS 22.261, “Service requirements for next generation new services and markets,” [Online].


[112] 3GPP TS 33.401, “3GPP security.”

[113] 3GPP TS 33.402, “Non 3GPP access”.


[143] 3GPP, “Temporary Service for Users of Other Operators in Emergency Case,” [Online].


[155] 3GPP, “3GPP TS 23.107 V14.0.0 (2017-03) - Quality of Service (QoS) concept and architecture,” 3GPP, 2017.


### Annex 1  IEEE radio frequency band designations

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Frequency (GHz)</th>
<th>Typical satcom uses (2018())</th>
</tr>
</thead>
<tbody>
<tr>
<td>L band</td>
<td>1-2</td>
<td>Mobile services, IoT services</td>
</tr>
<tr>
<td>S band</td>
<td>2-4</td>
<td>Satellite radio</td>
</tr>
<tr>
<td>C band</td>
<td>4-8</td>
<td>Traditional continent-wide satellite links</td>
</tr>
<tr>
<td>X band</td>
<td>8-12</td>
<td>Military comms</td>
</tr>
<tr>
<td>Ku band</td>
<td>12-18</td>
<td>Satellite TV, broadband, and backhaul services</td>
</tr>
<tr>
<td>K band</td>
<td>18-27</td>
<td></td>
</tr>
<tr>
<td>Ka band</td>
<td>27-40</td>
<td>High throughput satellite services such as broadband and backhaul services</td>
</tr>
<tr>
<td>V band</td>
<td>40-75</td>
<td>May be used in future for satellite gateways</td>
</tr>
<tr>
<td>W band</td>
<td>75-110</td>
<td></td>
</tr>
<tr>
<td>mm band</td>
<td>110-300</td>
<td></td>
</tr>
</tbody>
</table>
Annex 2 Use-case requirements

This section defines the requirements identified for the use-cases defined in D2.1. The first section discusses the common requirements. This is followed by sections on each use-case.

### 7.1 Common requirements across use-cases

This first section presents an overview of requirements identified across use-cases.

**Business requirements**

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Economic/Business Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Service coverage</strong></td>
<td></td>
<td>The cost impact per end user shall be calculated</td>
<td>European continent shall be considered</td>
</tr>
<tr>
<td><strong>Service coverage</strong></td>
<td></td>
<td>The cost impact per end user should be calculated</td>
<td>Beyond the European continent should be considered</td>
</tr>
<tr>
<td><strong>Satellite backhaul cost</strong></td>
<td>Not Available (€/cell/mo)</td>
<td>Requirement: cost of the required satellite bandwidth per cell. With the number of cells using only satellite backhauling and assuming that the MNO get a final price from the satellite operator, it is possible to obtain a final price per cell and per month. Description: How to obtain the final value is complex task as there are a huge number of parameters to take into account. For instance, the MNO may reach an agreement with the satellite operator to cover the continent, the country or a region based on MNO requirements and satellite operator capabilities. NOTE: a site typically has 3 cells. <a href="http://www.groundcontrol.com/Maritime_VSAT/Marine_VSAT_Comparison.pdf">http://www.groundcontrol.com/Maritime_VSAT/Marine_VSAT_Comparison.pdf</a></td>
<td>The business case shall take into account traffic usage and forecasts for end-users. As a reference the ESA SPECSI study calculated a cost target in the region of “$15 (2020), $7 (2025) USD/Mbps/Month depending on geographic region”</td>
</tr>
<tr>
<td><strong>Backhaul upgrade costs</strong></td>
<td>Not Available (€/site)</td>
<td>Requirement: evaluate if an upgrade on the satellite backhaul is required during the 10 years defined by SaT5G. Description: based on the current satellite capacity, the expected grow in number of sites and the increase of traffic in remote areas, SaT5G should evaluate if an upgrade on the satellite backhaul is required and how much may cost it. NOTE: this information should be provided by satellite operators</td>
<td>Technical: The SaT5G satellite terminal shall be designed to minimise the need to upgrade during a ten-year refresh cycle. Business: as traffic information is not available, a reliable forecast cannot be done.</td>
</tr>
<tr>
<td><strong>Equipment SW upgrade</strong></td>
<td></td>
<td>Requirement: upgrade the equipment when required</td>
<td>Operational: The satellite</td>
</tr>
<tr>
<td>Title</td>
<td>Value</td>
<td>Economic/Business Requirements</td>
<td>Requirement for SaT5G</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>------------------------------</td>
<td>------------------------------------------------------------------------------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>upgrade program costs</td>
<td>included (MNO). HW upgrade not expected (MNO).</td>
<td>Description: In this scenario, the expected usage doesn't include more equipment for carrier aggregation so only SW upgrades are considered. This kind of upgrades are included by contract for the MNO.</td>
<td>backhaul solution shall support the addition and reduction of capacity without site intervention both planned and by the addition of a new slice.</td>
</tr>
<tr>
<td>Insurance costs</td>
<td>Not Available (month/site)</td>
<td>Requirement: in case new sites are not covered by current MNO insurance, the cost increase should be considered. Sites for scenario 2b includes vSAT that are not part of a typical deployment. Description: The insurance includes robberies, damages per catastrophes, etc.</td>
<td>We assume this cost is included in the satellite offering, no additional cost will be taken into account.</td>
</tr>
<tr>
<td>Cost to deploy each site</td>
<td>Not Available (£/site)</td>
<td>Requirement: total cost to deploy a new site. NOTE: total price or number of people involved is unknown</td>
<td>The business case shall consider the total costs to deploy a new site. Technical: The SaT5G satellite terminal shall be designed to minimise the TCO, the possibility of installation by non-satellite trained engineer should be considered.</td>
</tr>
<tr>
<td>Buy new Base Band Units (BBU) and new Remote Radio Units (RRU) to deploy macro cells.</td>
<td>Not Available (£/unit)</td>
<td>Requirement: buy new radio equipment to be deployed in remote areas to provide coverage. To deploy a new cell, the MNO has to buy the radio equipment. Description: The main two components of a macro cell are: the Base Band Unit (BBU) and the Radio Remote Radio Unit (RRU). The BBU is a rack of CPUs where the 3GPP protocol stack and proprietary vendors’ algorithms run. The RRU are the antennas.</td>
<td>The business case shall include the option to buy new radio equipment (BBU/RRU).</td>
</tr>
<tr>
<td>Buy servers</td>
<td>Not Available (£/unit)</td>
<td>Requirement: Buy servers to support caching content. The server characteristics is decided by the technical analysis.</td>
<td>The business case shall assume a new</td>
</tr>
<tr>
<td>Title</td>
<td>Value</td>
<td>Economic/Business Requirements</td>
<td>Requirement for SaT5G</td>
</tr>
<tr>
<td>------------------------------</td>
<td>----------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Sede server</td>
<td></td>
<td>Description: nowadays, macro cells are not ready to catch content. A new investment is required at the edge of the network to support this new functionality.</td>
<td>server is required to support caching with the option to use other servers if available.</td>
</tr>
<tr>
<td>Buy/rent land</td>
<td>Not Available (€/month)</td>
<td>Requirement: a new spot is required to build the mast for the new macro cell. The spot may be rent or bought by the MNO.</td>
<td>The business case shall include the option to build a new mast where needed</td>
</tr>
<tr>
<td>Site running cost only with vSat</td>
<td>Not Available (€/site)</td>
<td>The running costs include everything not included in other IDs.</td>
<td>The business case shall consider operational expenditures.</td>
</tr>
<tr>
<td>Spectrum</td>
<td>national license (MNO)</td>
<td>Requirement: buy new spectrum</td>
<td>Operational: The MNO shall be responsible for the provision of terrestrial spectrum and regulatory registration requirements; similarly the SatCom operator shall be responsible for the provision of satellite spectrum and regulatory registration requirements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Description: Spectrum is bought by the MNO and may be used in the whole country. As this is not use-case specific, spectrum licenses costs will not be included in the business analysis.</td>
<td></td>
</tr>
</tbody>
</table>

| Annex 2 table 1 Common business requirements |

**Operational requirements**

Content security is one of the key operational requirements concerning edge delivery of data including both multimedia mobile content and NFV software. Specifically, the common practice is that mobile content objects are encrypted end-to-end in order to prevent man-in-the-middle intrusions of data during transmissions. Concerning multimedia content, such an operational requirement is applicable to all the business scenarios.

As for the delivery of NFV software data, the corresponding operational requirements may concern the delay tolerance of the software readiness at its targeted network location. In this case the scheduling of network function software delivery through satellite links should be carefully planned according to the knowledge of such delay tolerance in order to seamlessly fulfil specific network operations during run time.
Deploying in-network content caching at the edge is an effective way to deliver video, webpages, etc. and:

1) provide a better user experience (lower latencies and channel switching times) for the end-user;
2) allow the operators to dimension their network and backhaul more cost-effectively; and...
3) in some scenarios, efficiently utilize its limited radio resources.

This use-case is related to the use-case category #14 in Annex A of the NGMN white paper [52] and to the technology building blocks, “UE centric network” and “smart edge node”, in Annex D of the paper.

Service requirement arising:

- The 3GPP system shall provide charging, Lawful Interception (LI) and QoS differentiation for content delivered from an in-network caching entity.
- The 3GPP system shall enable a flexible deployment of content caching entity located at multiple locations within the network (e.g. at various radio sites and local aggregation points).
- The 3GPP system shall support a content caching entity that is capable of being integrated within a device under the control of the operator.
- The authorized UE shall be able to receive cached content broadcasted by content caching entity.

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Operational Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>APIs for defining caching policies</td>
<td>N/A</td>
<td>Allowing the MNO to define specific policies on when, where and what to cache.</td>
<td>Definition of a dedicated policy configuration interface on caching policies</td>
</tr>
<tr>
<td>Reserved IP multicast addresses by the MNO</td>
<td>IP prefixes for general IP multicast:224/8 – 239/8 IP prefix for source specific multicast: 232/8</td>
<td>Availability of dedicated IP multicast addresses</td>
<td>Availability of dedicated IP multicast addresses</td>
</tr>
</tbody>
</table>

Annex 2 table 2. Common operational requirements

**Technical requirements**

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Technical Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class of Service (CoS)</td>
<td>Unique QoS Class Identifier (QCI) per CoS (Note 1)</td>
<td>Ensure the maximum values in terms of end-to-end packet delay, packet loss and packet error rates per traffic type (traffic guaranteed or not guaranteed) are achieved.</td>
<td>The SaT5G system shall support the multiple CoS. Each CoS bearer should be marked with DCSP flags outside any VPN connections</td>
</tr>
<tr>
<td>Reliability of satellite link</td>
<td>At least 99.9% for worst month</td>
<td>Link budgets to be designed appropriately</td>
<td>No special requirements</td>
</tr>
<tr>
<td>Virtualisation of satellite related functions</td>
<td>VNF image and VM specifications, VNF descriptors, network service descriptors</td>
<td>VMs are components of VNFs, and the VNFs are in the form of a software image. The image is loaded and run over the</td>
<td>SaT5G to make use of open-source software and standards eg OpenStack, JSON, XML, YML etc. ETSI OSM,</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Technical Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MEC Framework</strong></td>
<td></td>
<td></td>
<td>Ensure the correct usage of MEC framework</td>
</tr>
<tr>
<td></td>
<td>VM(s). The VNF specification is the compute resources it needs (RAM, CPU, storage, networking). The VNF is made visible to upper layers (such as OSM) using a descriptor file.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring, measurement and assessment of service</td>
<td>Service performance data model that identifies important parameters to guarantee the QoS/QoE. Means and tools to collect service performance metrics and analysis them are fundamental elements. Fast and precise decision making process to meet agreed QoS/QoE level and automatically react to delivery failures.</td>
<td>QoS/QoE will be measured at packet level using test-beds, if possible with load stress.</td>
<td></td>
</tr>
<tr>
<td>Virtualized elements isolation</td>
<td>A MEC infrastructure operated by a telecom operator might host more than one service provider (e.g. media content producer), need to guarantee an acceptable level of isolation over the virtualized components running over a common infrastructure.</td>
<td>Evaluate security and data flow isolation between VNFs and also between end-to-end service slices.</td>
<td></td>
</tr>
<tr>
<td>Support for multiple third party slices</td>
<td>Agreements needed between MNOs and service providers for RAN sharing.</td>
<td>Technical/Operational/Business The system shall support the provision of 3rd-party network slices, directly or through the intermediary role of the broker.</td>
<td></td>
</tr>
<tr>
<td>Coordination line between MEC and the remote data centre</td>
<td>The MEC domain will be under the control of a management and orchestration system while the other remote data centres will be managed and orchestrated by another set of solutions, a secure</td>
<td>MEC updates to be supported by the architecture of the project.</td>
<td></td>
</tr>
</tbody>
</table>
Annex 2 table 3 Common technical requirements.

7.2 Use-case 1: Edge delivery and offload for multimedia content and MEC VNF software

Additional business requirements for use-case 1
None

Additional operational requirements for use-case 1
None

Additional technical requirements for use-case 1

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Technical Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MEC Framework</strong></td>
<td><strong>Title</strong></td>
<td><strong>Value</strong></td>
<td><strong>Requirement for SaT5G</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>100Mbps (subject to RAN availability)</td>
<td>Assured 100Mbps user experienced data rate for supporting advanced content delivery services, including VoD and live streaming</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Able to support QoE-assured 4K/8K and AR/VR content delivery</td>
<td></td>
</tr>
<tr>
<td>Round trip latency from edge cache to UE</td>
<td>Up to 12ms</td>
<td>Bounded latency between the deployed caching point to the UE</td>
<td>Bounded latency between the deployed caching point to the UE</td>
</tr>
<tr>
<td>Charging and lawful interception</td>
<td>N/A</td>
<td>Shall provide charging, Lawful Interception (LI) and QoS differentiation for content delivered from an in-network caching entity</td>
<td>Shall provide charging, Lawful Interception (LI) and QoS differentiation for content delivered from an in-network caching entity</td>
</tr>
<tr>
<td>Caching point deployment</td>
<td>N/A</td>
<td>Shall enable a flexible deployment of content caching entity located at multiple locations within the network (e.g. at various radio sites and local aggregation points)</td>
<td>To identify the network locations where content caching can be deployed</td>
</tr>
<tr>
<td>E2E Data rate Downlink CDN nodes store</td>
<td>2.7Mbit/s average per satellite link</td>
<td></td>
<td>2.7Mbit/s average per satellite link</td>
</tr>
</tbody>
</table>
### Title

<table>
<thead>
<tr>
<th>Requirement for SaT5G</th>
<th>Technical Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>exclusively films (5GB – DVD quality) and series (~2.5GB)</td>
<td>Knowledge about the RAN condition</td>
<td>Monitoring of RAN conditions, can be obtained from Radio Network Information Service (RNIS)</td>
</tr>
<tr>
<td>It is assumed that films/series are multi-language. It's assumed 1 film/day (~2h) + 10 series/day (~1h) are updated. This leads to 2.7 Mbps average per satellite link</td>
<td>Knowledge on the satellite backhaul load</td>
<td>Information input from the satellite operator</td>
</tr>
<tr>
<td></td>
<td>Knowledge on the video playback conditions during playback</td>
<td>Require inference technique without relying on explicit signalling feedback from the UE to the mobile edge.</td>
</tr>
</tbody>
</table>

---

Annex 2 table 4 Additional technical requirements for use-case 1.
7.3 Use-case 2: 5G Fixed Backhaul

Since multicast support has not been formally standardised in 3GPP, to support such a feature for edge delivery requires the definition of new interfaces in the 3GPP architecture.

In order to trigger multicast of multimedia content to the mobile edge through satellite links, it is required that the corresponding decision-making logic should have the knowledge of learning and prediction of dynamic content popularity at different network locations, so that the content can be already multicasted to the mobile edge before a vast majority of content requests are issued by end-users.

**Additional business requirements for use-case 2**

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Economic/Business Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier aggregation costs</td>
<td>Not Applicable</td>
<td>Requirement: increase the capacity in a specific area.</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Description: Carrier aggregation is used to increase the capacity in one specific area. The MNO uses this solution for a permanent capacity increase. For temporary solution, other options are available. This solution will be not deployed in scenario 2b</td>
<td></td>
</tr>
<tr>
<td>Temporary cell costs</td>
<td>Not Available (€/site/day)</td>
<td>This kind of cells are deployed for specific events when the capacity in an area needs to be increased. As it is a temporary solution, we should consider the total costs per day. Based on technical requirements, this solution should be considered for scenario 2b.</td>
<td>If UC2b is adapted for temporary event use, the business case shall calculate the cost per day for the service</td>
</tr>
<tr>
<td>New agreements with other MNO(s)</td>
<td>Not Applicable</td>
<td>Requirement: new agreements between MNOs for RAN sharing.</td>
<td>Technical/Operational/Business</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Description: In UC2, the backhaul is a limited resource. How is shared between MNOs require a deep analysis.</td>
<td>The system shall support the provision of 3rd party network slices.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NOTE: for simplicity in iteration 1, WP2 agreed not to take this feature into consideration.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>NOTE: this and other use-cases should analyse if new inter-MNO agreements are required during iteration 2.</td>
<td></td>
</tr>
<tr>
<td>Number of users</td>
<td>350 families 3 customers per family</td>
<td>Requirement: define the number of users</td>
<td>The scenario 2b analysis should assume 100% of homes need cellular service with three end-users per home (but with an active-user-rate of 80%)</td>
</tr>
<tr>
<td>NFV Satellite costs</td>
<td>[53] considers cost benefits of virtualising SatCom ground segment</td>
<td></td>
<td>This is done for the 5G networks with network slicing but not for the satellite part as we only consider with the cost</td>
</tr>
</tbody>
</table>
## Economic/Business Requirements

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>New licences cost</td>
<td>Not available (€/site)</td>
<td>Requirement: when a new site is built, new licences are required including licences like construction license. These licences have a cost in terms of money and time. License costs are not taken into account in SaT5G.</td>
</tr>
<tr>
<td>Billing</td>
<td>Not Applicable for scenario 2b. Same as in terrestrial networks</td>
<td>We have agreed that in this scenario, no extra cost is charged to the end-user. The billing should remain as it is for the MNO clients. We can assume, the MNO and the Satellite Operator have a rate per bandwidth not per Mbyte. NOTE: other UC should consider the option to bill per slice. Business: The use of satellite backhaul shall not result in additional end-user charges (except perhaps for UC4)</td>
</tr>
</tbody>
</table>


### Additional operational requirements for use-case 2

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Terrestrial operator requirement</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>MNO Core network update</td>
<td>1 engineer / 5 days</td>
<td>Requirement: update MNO core network parameters to support satellite backhauling. Description: Due to the satellite characteristics, several parameters should be updated, as for example, the timers for the UE attachment. These parameters are exchanged between the MNO core network, the Radio Access Network (RAN) and the UE. The backhaul is transparent to these information exchange. NOTE: specific parameters are out of the scope of this project. NOTE: for terrestrial connections, the MNO core network parameters remains as they were.</td>
<td></td>
</tr>
<tr>
<td>ST equipment</td>
<td></td>
<td></td>
<td>The satellite terminal shall be compliant with the satellite operator</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Terrestrial operator requirement</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
</table>
| Site maintenance including base station and ST                        | NA (engineer/month/area) | The MNO has to ensure the core and the RAN works properly. 
NOTE: Terrestrial backhaul is out of the scope in this project. | The operational support model shall determine best approach to site maintenance. 
Technical: In common with current best practise the satellite terminal shall be designed for zero routine maintenance and with an MTBF in significantly in excess of 5 years |
| Backhaul maintenance                                                   | Requirement: evaluate the task required to maintain the satellite backhaul working properly. 
Description: in scenario 2b, the site is connected to the core network using a satellite backhaul only. 
Maintenance works are required in order to ensure the proper satellite backhaul work. 
NOTE: Only satellite backhaul is deployed in scenario 2b. 
NOTE: during the maintenance works, the service should not be interrupted. | Technical: The system shall be designed so that routine maintenance and single element failure at the satellite gateway shall not result in any degradation of end-user service. |
| Base station (RAN) SW upgrades/updates                                 | 1 upgrade / 3 months | Requirements: SW upgrade and updates task. 
Description: The SW base stations are upgraded or updated each 3 months (approx.) for several reasons: add new functionalities, bugs resolution, etc. The upgrades/updates are scheduled and ran automatically. The upgrades/updates should include triggers/alarms that are review by an engineer. In case an alarm is raised, human actions are required. | Operational: The system shall support routine software upgrades for the BBU and subsequent service should not be adversely impacted by them 
Technical: Where there are satellite terminal VNFs these shall not be affected by changes to the BBU VNFs |
<p>| Core network SW upgrades/updates                                      | 1 upgrade / 3 months | Same requirements and descriptions defined for RAN applies for the core network. | Operational: The system shall support routine software upgrades for the core and subsequent should not be adversely impacted by them |</p>
<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Terrestrial operator requirement</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial trial period</td>
<td>2 engineer / 1 month</td>
<td>This period includes since the base station is switched on until it is ready to provide service to end-users.</td>
<td>Technical: Where there are satellite gateway VNFs these shall not be affected by changes to the core VNFs</td>
</tr>
<tr>
<td>Test period</td>
<td>1 engineer / 1 day</td>
<td>Requirements: time to test a new site (between it is</td>
<td>Description: Once the parameters are adjusted during the initial trial, the same configuration is attempted with other base stations and core network so, the testing period is reduced drastically.</td>
</tr>
<tr>
<td>Deploy a base station</td>
<td>9 - 18 months</td>
<td>Requirement: Time required to build a completely new base station.</td>
<td>Business: The SaT5g business case shall allow for 12 months period to deploy a green-field base station</td>
</tr>
<tr>
<td>Backhaul upgrade programme</td>
<td></td>
<td>Requirement: list of backhaul components to be upgraded and its periodicity.</td>
<td>WP3 shall provide a list of VNF and PNF required to provide the satellite backhaul from BBU to the core</td>
</tr>
<tr>
<td>Equipment upgrade programme</td>
<td>Not expected for scenario 2b</td>
<td>Requirement: the equipment will be upgraded based on the project life period and the requirements.</td>
<td>Description: based on the requirements and the technology upgrade cycles, the equipment should be upgraded.</td>
</tr>
<tr>
<td>Title</td>
<td>Value</td>
<td>Terrestrial operator requirement</td>
<td>Requirement for SaT5G</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>---------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>NOTE:</strong> For this specific use-case, SW upgrades are the only ones considered.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>NOTE:</strong> it is pending to identify the requirements to upgrade the equipment.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>NOTE:</strong> scenario 2b doesn’t require any upgrade.</td>
<td></td>
</tr>
<tr>
<td>Carrier aggregation deployment</td>
<td>2 day</td>
<td>The effort in terms of time and engineering works are very low as most of the required elements are already in the site (like the mast, the cabinet, etc.). Carrier aggregation has a direct impact on the backhaul dimensioning as its main goal is increase the area capacity. Not applicable to scenario 2b.</td>
<td></td>
</tr>
<tr>
<td>Temporary cell deployment</td>
<td>1 month</td>
<td>The only difference between a cell and a temporary cell is that the temporary cell is deployed using a truck. For scenario 2b, there is no difference between permanent and temporary cell as in both cases, we need a satellite backhaul. We assume as self-contained solution in a truck including vSats, power supply, masts, etc.</td>
<td></td>
</tr>
<tr>
<td>New KPIs – Backhaul usage</td>
<td>Mbytes/time/cell</td>
<td>Evaluate the satellite backhaul usage. These inputs should be used by the algorithms that dynamically manage the bandwidth allocation.</td>
<td>The system shall report on backhaul traffic levels (used versus booked) for individual links and per network slice</td>
</tr>
<tr>
<td>New KPIs – Backhaul reliability</td>
<td>% time when the backhaul is working properly</td>
<td>We need to evaluate the reliability of the satellite backhaul link. In scenario 2b, this is a key important parameter since there is no other backup link with the core network.</td>
<td></td>
</tr>
<tr>
<td>New KPIs – Caching</td>
<td>Times the cached data has been downloaded</td>
<td>Cached Data should be identified and requested by automatic algorithms. The MNO has to control the performance of those algorithms.</td>
<td>The system shall automatically populate the data caches using rules that can be viewed and amended by the MNO. The system shall report on the efficiency of the caching</td>
</tr>
</tbody>
</table>
In addition the following points can be noted:

**Variable and bursty traffic**

There could be seasonal increase in the traffic, for example, increase in the number of users and user devices because of tourists visiting in summer. Factors like this will cause the average traffic levels to vary from day to day and month by month. The instantaneous traffic load will vary much more and depends on what all the end-users and their devices are doing at any moment in time – this can lead to traffic bursts will in excess of the average traffic levels.

3GPP put forward a requirement for a hotspot scenario which can be extrapolated to address the 5G backhaul situation. This situation is seen in 4G backhaul situations as well where additional capacity is required for a short period of time. SoTA network allow burstable capacity to be varied every hour.

**Operational requirement:** The SaT5G system shall be able to adjust the network capacities dynamically based on the variation of demand and performance indicators. Specifically the system shall allow both the CIR and PIR to be adapted and adjusted by the satellite network operator to suit the traffic needs.

**Flexibility and Scalability**

Because traffic varies depending on the time of the day and week, the network shall be scalable to ensure the network resources aren’t wasted depending on the network demands arising from the user and control planes.

**Operational requirement:** The SaT5G system shall support dynamic utilization of resources (compute, network and storage resources) in more than one geographic area in order to serve the differing needs of the users in each geographic area, subject to operator policy.

Using resources (compute, network and storage resources) in more than one geographic area by the system shall be supported without requiring manual re-configuration of neighbouring nodes, without service disruption, and while avoiding additional signalling due to unnecessary UE’s re-attachments (e.g. due to loss of call state information in the network).

The management of satellite link radio resources is an inherent part of offering mixed satellite services and this is where much of the expertise of satellite equipment vendors is focussed. The dynamic control of this is implicit in the provision of services and in future the slices supporting these.

**Operational requirement:** The SaT5G system shall support dynamic utilization of satellite link radio resources, subject to operator policy, to provide the end-to-end services and network slices requested.

**Operational requirement:** The SaT5G system support foreseen rapid increases in signalling and user plane demand with a lead-time that can be as low as 5 minutes’

**End-to-end Service delivery**

The satellite signal has degradation mitigation (Uplink/Downlink) as follows:

- Signal power;
- Symbol rate;
- Capacity adjustments

**Operational requirement:** Different network slices - service profiles - should have different degradation steps

"ISO/IEC 20000-1:2011 can be used by:"
• an organization seeking services from service providers and requiring assurance that their service requirements will be fulfilled;
• an organization that requires a consistent approach by all its service providers, including those in a supply chain;
• a service provider that intends to demonstrate its capability for the design, transition, delivery and improvement of services that fulfill service requirements;
• a service provider to monitor, measure and review its service management processes and services;
• a service provider to improve the design, transition, delivery and improvement of services through the effective implementation and operation of the SMS;
• an assessor or auditor as the criteria for a conformity assessment of a service provider’s SMS to the requirements in ISO/IEC 20000-1:2011.”

### Additional technical requirements for use-case 2 (backhauling)

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Technical Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral efficiency</td>
<td>1.5 bits/sec/Hz/cell in average in most common deployments</td>
<td>At the physical layer, this a representative value achieved between the eNB and the UE assuming the most common configuration MIMO 2x2. This value is not representative of the maximum capacity supported by a cell. [54]</td>
<td>The system design shall support traffic in line with the theoretical traffic volumes created in line with this</td>
</tr>
<tr>
<td>Max number of bits in the air between the eNB and the UE – backhaul dimensioning</td>
<td>195816 bits/millisecond using MIMO 2x2 at the physical layer. 391656 bits/millisecond</td>
<td>Assuming 25% of overhead, ~ 150 Mbps/cell is the value to dimensioning the backhaul to support the maximum capacity. A typical deployment has 3 cells ~ 450 Mbps/site MIMO 2x2. With the same reasoning than before, a special deployment with MIMO 4x4 will be able to support ~ 880 Mbps/site MIMO 4x4.</td>
<td>The system design shall support traffic in line with the theoretical traffic volumes created in line with this</td>
</tr>
<tr>
<td>End-to-End security</td>
<td>3GPP definition of the Security Gateway</td>
<td>In any communications, the MNO has to ensure a secure link between the core network and the final user. In this scenario, the satellite link has to be securitized. The services are similar to 4G without any additional requirement. We should proceed in the same way as if the link is terrestrial that is, we need a Security Gateway at the edge of the MNO core. Security between the RAN and the UE is out of the scope of SaT5G.</td>
<td>See operational requirements.</td>
</tr>
<tr>
<td>Integration of RAN-agnostic management at central management</td>
<td></td>
<td></td>
<td>Any specific management layer, software and interfaces of SaT5G terrestrial or SatCom subsystems shall come with</td>
</tr>
<tr>
<td>Title</td>
<td>Value</td>
<td>Technical Requirements</td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td>----------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Support of 4G EPC</td>
<td></td>
<td>The SaT5G system MAY address transition and multiconnectivity and retro-compatibility architecture, where the Core Network is a 4G EPC with minor changes requiring no procedure revisions (such as change of implementation parameters, timers, etc.).</td>
<td></td>
</tr>
<tr>
<td>PEP and Security</td>
<td></td>
<td>Overall security architecture shall be compatible with Transport and TCP PEP acceleration</td>
<td></td>
</tr>
<tr>
<td>Multicast triggers</td>
<td>Mechanism to invoke multicast when a threshold number of UEs request the same content</td>
<td>SaT5G to have ability to synchronise reception of multicast streams, and have low latency multicast processing.</td>
<td></td>
</tr>
</tbody>
</table>

Annex 2 table 7 Additional technical requirements for use-case 2.

### 7.4 Use-case 3: 5G to premises

**Additional business requirements for use-case 3**
### Economic/Business Requirements

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home hub Cost</td>
<td>Up to $120,</td>
<td>The SaT5G home hub cost shall be up to $120</td>
</tr>
<tr>
<td>Equipment upgrade programme</td>
<td></td>
<td>The SaT5G home hub cost shall decrease as well as the price of the components. Keeping the same price, the hub home shall improve its features</td>
</tr>
<tr>
<td>Home Premises Hardware</td>
<td></td>
<td>The cost of the hardware installed at the home premises shall be reduced. Hardware integration of the satellite terminal with the home gateway can be envisaged with the integration of the modem into the Outdoor unit of the satellite terminal in order to provide an Ethernet interface ready to be plugged in the home gateway provided by the ISP.</td>
</tr>
</tbody>
</table>

### Annex 2 table 8 Additional business requirements for use-case 3

#### Additional operational requirements for use-case 3

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite user antenna installation in buildings</td>
<td>A shared dish in new buildings</td>
<td></td>
</tr>
<tr>
<td>Satellite user antenna installation in houses</td>
<td>One dish per house</td>
<td></td>
</tr>
<tr>
<td>Home Hub installation</td>
<td>Plug-and-play installation</td>
<td>The SaT5G system shall support a plug-and-play home hub. VNF and network provisioning for xDSL/cellular, WiFi and LTE/NR shall be supported</td>
</tr>
<tr>
<td>Home Hub WiFi usage</td>
<td>For a Home Hub with WiFi and LTE/NR capabilities, monitor the WiFi usage in bytes, time, etc.</td>
<td></td>
</tr>
<tr>
<td>Home Hub LTE/NR usage</td>
<td>For a Home Hub with WiFi and LTE/NR capabilities, monitor the LTE/NR usage in bytes, time, etc. to be compared with macro cells in this area</td>
<td></td>
</tr>
<tr>
<td>Multi-Device Protocols I</td>
<td></td>
<td>New protocol stacks (e.g. native IP and Multicast-assisted Adaptive Bitrate (M-ABR)), which make the multi-device scenario significantly more attractive than it is today, shall be further investigated.</td>
</tr>
</tbody>
</table>
Multi-Device Protocols II

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Operational Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Digital rights management (DRM) and underlying protocol (e.g., DASH, HLS, HSS, etc) and their impact on the Home/Office Gateway design particularly in multi-screen environments shall be further investigated.</td>
</tr>
</tbody>
</table>

Multi-Device Protocols III

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Operational Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
</table>
|       |       |                          | Other critical elements towards the realization of this scenario which shall be further investigated:  
• Caching  
• Efficient caching management schemes  
• Implications of chunked video  
• Seamless blending of services  
• Network technology convergence  
• Lowering of costs for implementing certain technologies (chipsets) because they use maximum technical commonality  
• Standard end device functionality to provide access to all content independently on how it was delivered to that device. |

Annex 2 table 9 Additional operations requirements for use-case 3.

### Additional technical requirements for use-case 3 (Hybrid multiplay)

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Technical Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
</table>
| E2E Data rate Downlink | Home consumer: 10 Mbps  
Office consumer: 30 Mbps | • Broadband usage assumed as follows.10Mbps (DL) for Home consumer.  
This can be, e.g.:  
  o 1 TV HD channel (5Mbps) + 1 Streaming channel (5Mbps – DVD quality)  
  o 1 HD TV channel (5Mbps) + Internet connection (5Mbps)  
• 2Mbps (DL) for SOHO. This assumes:  
  FTP Transfer, internet, email, cloud application etc. | The SaT5G system should have the capability to combine satellite, terrestrial and satellite, and cellular connections. MP-TCP and/or MP-QUIC are proposed mechanisms to evaluate. |
| E2E Data rate Uplink   | Home consumer: 1 Mbps  
Office consumer: 3 Mbps |                                                                                         | The SaT5G system should be suitable for when satellite uplink is and is not available. |
| **Streaming QoE**  
(Start Buffering Time: Time between the click of ‘play’ button and the start of video playback) | From a terrestrial operator point of view, this parameter shall not exceed 2 seconds (Interactive application) | For SaT5G system, QoE shall not exceed 3 seconds for Interactive application |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Satellite User antenna</strong></td>
<td>For both home and SOHO services, a satellite dish of 0.7m shall be considered</td>
<td></td>
</tr>
</tbody>
</table>
| **Intelligent User GW** | - It shall support interfaces with xDSL/cellular and satellite equipment  
- It shall support Load balancing, multi-path capabilities  
- It shall support a Wi-Fi and/or LTE/NR femtocell connection | - It shall support interfaces with xDSL/cellular and satellite equipment  
- It shall support Load balancing, multi-path capabilities  
- It shall support a Wi-Fi and/or LTE/NR femtocell connection |
| **End-devices abstraction from actual physical delivery network** | The architecture and protocols shall provide a more robust satellite transmission scheme to every home/office premises and abstract the end-devices from the actual physical delivery network | |
| **Storage type** | RAM/SDD for Live  
HDD for VoD | The storage capacity has to be adapted according the streaming capacity. Using RAM/SDD/HDD will have an impact on the streaming capacity | Design of the in-premises computing equipment is not in scope. |
| **Satellite terminal installation procedure** | The development of cellular systems in millimetre wave bands will require such antenna technology. The expected market demand for such technology will be such that it will likely contribute to reduce the cost of active antenna technologies. Hence low cost active antenna can be considered in the future for satellite systems. | The installation procedure of the satellite terminal using auto pointing antenna device enabling self-installation shall be eased. |
| **Satellite terminal energy consumption** | The energy consumption of the satellite terminal at the home site shall be optimized through the implementation of energy saving features in the satellite radio interface. Some convergence with the energy saving features of the cellular system radio interface can be envisaged. | Not in scope of the project |
### 7.5 Use-case 4: 5G Moving platform backhaul

**Additional business requirements for use-case 4**

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Economic/Business Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>New satellite terminal equipment costs</td>
<td>To be developed</td>
<td>To upload contents to moving platforms high performance satellite terminal technology is envisaged to be used to fast update data bulks.</td>
<td>This SaT5G business case shall include the possibility to use optionally new satellite terminals for high throughput satellite (HTS) system.</td>
</tr>
<tr>
<td></td>
<td>(€/unit)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New antennas costs</td>
<td>To be developed</td>
<td>The satellite terminal technology will use antennas for the high performance satellite link; each moving platform imposes different constraints in terms of antenna size and geometry (e.g. aircraft case).</td>
<td>This SaT5G business case shall include the possibility to buy optionally new satellite antennas.</td>
</tr>
<tr>
<td></td>
<td>(€/unit)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New agreements between SNO and MNO</td>
<td>Not Applicable</td>
<td>Possibly new liaisons between satellite operators and mobile operators for cost effective resource utilisation.</td>
<td>Different business models will be investigated, with a focus on models that involve a mediator (broker).</td>
</tr>
<tr>
<td>New agreements between Service Providers (SP) and Content Providers (CP)</td>
<td>Not Applicable</td>
<td>Possibly new liaisons should be set in place between different business segments for using satellite link on moving platforms such as aircrafts.</td>
<td>Different business models will be investigated.</td>
</tr>
<tr>
<td>New servers for moving platform</td>
<td>Not Available</td>
<td>New servers for storing content and managing services (e.g. content management onboard aircraft). The server characteristics and requirements will be decided by the technical analysis.</td>
<td>Buy new servers for storing on-board system information (e.g. cabin management systems for aircrafts), update in-flight entertainment catalogues (e.g. movies and TV series in UHD/HD video quality and movies in 4k/5k video quality), control &amp; management of onboard communication networks (e.g. WiFi/mobile networks in case of aircrafts).</td>
</tr>
<tr>
<td></td>
<td>(€/unit)</td>
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</tbody>
</table>
### Economic/Business Requirements

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Economic/Business Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billing</td>
<td>Pricing models</td>
<td>As a business enabler the limited satellite bandwidth resource shall be monetised as a key part of the value chain.</td>
<td>The different revenue models will be investigated.</td>
</tr>
<tr>
<td>Multicast capacity over satellite</td>
<td>Multicast usage (%)</td>
<td>Economic effective utilisation of the limited satellite bandwidth resource.</td>
<td>Multicast shall be done over satellite. The bandwidth allocated will define how content will be pushed to the edge in case of grouped media requests (e.g., Live TV content, IFE management software upgrades/updates).</td>
</tr>
<tr>
<td>New RRU equipment costs (scenario 4b specifically)</td>
<td>Not Available (£/unit)</td>
<td>New radio equipment to be deployed for connectivity onboard moving platforms (e.g., Internet access to passengers on board aircrafts).</td>
<td>New LTE/NR radio terminals for high throughput performance including MIMO and higher spectral efficiency modulations.</td>
</tr>
<tr>
<td>Satellite virtualisation costs (scenario 4b specifically)</td>
<td>Not Applicable</td>
<td>Benefits of satellite gateway and terminal virtualisation.</td>
<td>Savings cannot be quantified as the satellite costs are an input to the business case model.</td>
</tr>
</tbody>
</table>


### Additional operational requirements for use-case 4

<table>
<thead>
<tr>
<th>Title</th>
<th>Value</th>
<th>Operational Requirements</th>
<th>Requirement for SaT5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic satellite bandwidth allocation</td>
<td>Algorithms &amp; SLAs</td>
<td>The SaT5G system shall allow transferring bulks of data to update board systems and media contents in different operational conditions. To achieve this, new functionalities are required to dynamically allocate limited backhaul resources.</td>
<td>Based upon technology evolution, this SaT5G use-case shall optionally support dynamic satellite bandwidth allocation based on traffic characteristics (traffic type, volume, etc.) to fulfill different demands (e.g. peak traffic).</td>
</tr>
<tr>
<td>Security end-to-end</td>
<td>IPSec/PEP</td>
<td>The SaT5G system has to ensure end-to-end security including the satellite backhaul link.</td>
<td>The system shall support as far as possible the same security level as a terrestrial backhaul (i.e. IPsec ARINC 848 standards in case of aircraft to ground secure communications).</td>
</tr>
<tr>
<td>Title</td>
<td>Value</td>
<td>Operational Requirements</td>
<td>Requirement for SaT5G</td>
</tr>
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</tr>
<tr>
<td>Backhaul maintenance</td>
<td>Engineering work (months/site)</td>
<td>Backhaul maintenance work as per programmatic maintenance of the moving platform (e.g. aircraft maintenance).</td>
<td>The system shall be designed so that routine maintenance and single element failure at the satellite gateway shall not result in any degradation of end-user service.</td>
</tr>
<tr>
<td>Network management</td>
<td>N/A</td>
<td>Limited network resources have to be managed as to optimise their utilisation.</td>
<td>Automated management of network resources with minimal human intervention.</td>
</tr>
<tr>
<td>Network maintenance</td>
<td>N/A</td>
<td>Operational management of the network include SLA for incident/fault notification and fix times, problem management and technical care support.</td>
<td>The SaT5G solution shall follow industry best practises and shall be supplemented by emerging 5G requirements as and when these are identified.</td>
</tr>
<tr>
<td>Accounting and billing</td>
<td>Month/annual fixed price for bandwidth utilisation either used or reserved</td>
<td>Currently, arrangements are made on a case by case basis. Also, it can be possible to reserve additional bandwidth paid depending on usage.</td>
<td>The SaT5G system shall allow capacity management and billing, based on resources utilization: real-time monitoring, forecasting and auditing.</td>
</tr>
<tr>
<td>Specialised skills to install, and maintain satellite equipment</td>
<td>Number of man-hours</td>
<td>Technical crew with specialised skills for the first-time satellite equipment installation and programmatic maintenance.</td>
<td>The SaT5G system will be designed to minimise human intervention, and to be aligned with moving platforms maintenance programme (e.g. aircraft)</td>
</tr>
</tbody>
</table>

Annex 2 table 12 Additional operations requirements for use-case 4.

### Additional technical requirements for use-case 4

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>End-to-end downlink rate</td>
<td>&gt;16 Mbps as per VSAT</td>
<td>Satellite link data rate available on moving platforms such as aircrafts sustainable by commercial satellite terminals.</td>
<td>The SaT5G system should use the available resources in the most efficient way.</td>
</tr>
<tr>
<td>End-to-end security</td>
<td>Rely on security measures such as PEP and IPsec anti-replay</td>
<td>Requirement to secure the satellite link to transfer content and data pertaining to the terrestrial network.</td>
<td>The SaT5G system shall target the same levels of security as in the terrestrial network.</td>
</tr>
<tr>
<td>Title</td>
<td>Value</td>
<td>Technical Requirements</td>
<td>Requirement for SaT5G</td>
</tr>
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</tr>
<tr>
<td>Storage dimensioning and management</td>
<td>Storage memory</td>
<td>There is increasing need to manage in efficient manner storage resources on board the moving platforms (e.g. onboard aircrafts where weight can be an issue).</td>
<td>Storage should have 20 TB capacity to store content on board: on average, 400-800 movies and TV series with DVD quality (5GB for movies and 2.5 GB for series).</td>
</tr>
</tbody>
</table>