Assessing satellite-terrestrial integration opportunities in the 5G environment

A business and technology oriented whitepaper positioning satellite solutions in the emerging 5G landscape

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1 Satellite as part of 5G

5G networks need to cater for new, as yet unknown uses, in addition to the optimization of the subscriber communication and significantly improving the user experience, handling an exponential increase of connected devices and serving the needs of a broad range of business verticals. To be able to deliver on all these, the 5G environment has to be open towards a very broad set of requirements expressing high variability, ensure high flexibility and embrace and integrate a broad range of technologies.

Recent progress within the satellite communications ecosystem, notably with high-throughput satellite (HTS) systems, is radically changing the competitive benchmark for satellite solutions, as compared to their terrestrial counterparts, in particular for backhaul solutions. In addition, emerging non-geostationary satellite constellations offer lower propagation delays and hence improved latency performance, which is relevant for certain applications. As a result, satellite networks evolve towards a huge amount of bandwidth available to meet the majority of use case performance requirements in a cost-efficient manner. In this context in the evolving 5G ecosystem satellite communication can become a technology of choice offering a competitive response in 90% of use cases and locations.

This whitepaper summarizes the benefits of satellite communication within a converged 5G environment and the specific elements that are required to realise those benefits. As we demonstrate, terrestrial and satellite solutions offer a good complementarity, and an integrated solution can cover a very broad and heterogeneous range of use cases from ubiquitous coverage through high speed networks to offering extreme reliability. Through its comprehensiveness a converged terrestrial-satellite 5G network is providing a future-proof environment with a complete coverage of the foreseen use cases and opening towards additional unforeseen ones.

Satellite network characteristics and benefits

- **The introduction of very High Throughput Satellites (HTS) brings down the communication costs significantly**
- **Non-geostationary constellations reduce the satellite communication latency drastically**
- **Satellite networks are better suited for specific verticals targeted by 5G than terrestrial only solutions, including:**
  - **Highly secure enterprise networks**
  - **Highly distributed (global) small/medium size networks**
  - **Content distribution**
  - **Dispersed M2M networks**
- **Satellite can usefully complement terrestrial solutions for a large number of heterogeneous use cases:**
  - **Ubiquitous coverage**
  - **High speed networks**
  - **Standby and overspill**

2 5G industry trends perspective

To achieve the expected success 5G networks have to surpass the limits of subscriber communication business and address the needs of a broad range of vertical industries and markets opening new revenue streams. The 5G community has already provided a number of documents describing those use cases, therefore here we constrain ourselves to a short critical summary of the different trends, especially addressing the need for satellite networks to supply the missing solutions for the most efficient deployments.

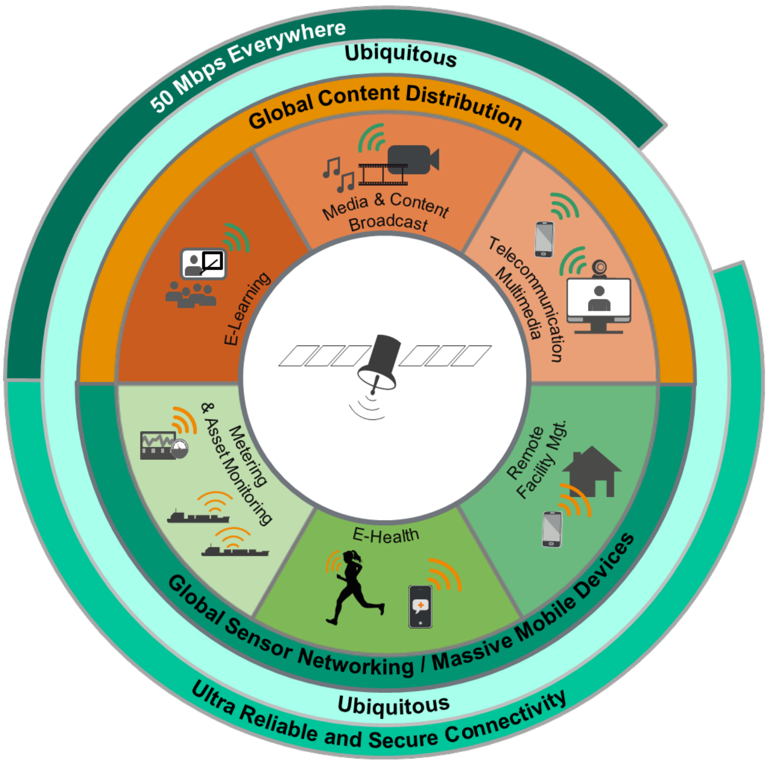

Figure 1 – Exemplary Use Cases

2.1 Ubiquitous coverage – Internet and multimedia communication

5G aims at providing a minimum of 50Mbps everywhere, independent of location. Currently, broadband rollout is failing in densely populated areas, as the systems cannot upscale fast enough. The demand for capacity is outstripping the ability to improve the infrastructure. There are also areas which are difficult to access, that are scarcely populated, and locations where the cost of the overall network should be very low.

Satellite solutions can support delivering on the ubiquitous coverage promise. They can fill in and provide additional capacity readily in urban areas and deliver connectivity in otherwise isolated areas, which are still persisting even in the high income countries due to geography, deployment costs and population distribution.

Aggregating multiple connections within a single centralized backhaul and using the new network techniques for edge processing, traffic offloading, backhaul resource sharing and compression next to the usage of intermittent alternative backhauls for the telco services gives the opportunity to use satellite networks as backhaul for the needed ultra-low cost networks.

2.2 Global media and content distribution

Traditionally the core market of satellite communications is media broadcast, and satellites remain unchallenged in broadcasting live events giving the same experience to a large number of users.

However, with the proliferation of smart mobile devices equipped with high resolution screens user media consumption trends are changing from classical linear TV broadcast in favour of on-demand consumption of streamed content in the format and at a time of the user convenience.

Because of this media streaming – which was already the most successful service of 4G networks – remains one of the key use cases for 5G. The change in 5G is that more and more content are being consumed on the move by mobile users and the high increase of bandwidth due to the improving definition (currently HD, but soon to be 4K and 8K UHD). A combination of technologies is needed to improve content distribution efficiency and support this trend. This includes the use of multicast mechanisms for the distribution of the most popular top of the charts movies, TV series and videos in combination with unicast streams catering for the content within the long tail and for the retransmission of lost packets. Considering such an environment, satellite networks could contribute with the very efficient distribution of content to local caches within the network as well as with the massive parallel content distribution to the individual users, broadcast to devices.

2.3 Global service requirements demand global networks

More and more enterprises require worldwide communication services for tracking and managing their assets. Such use cases include car maintenance, fleet management, container tracking, but increasingly the tracking of consumer devices. Such solutions require global networks that provide coherent communication capabilities no matter where the device is located.

Additionally, the change in the roaming perspective and the flexibility brought by network function virtualization terrestrial operators aim now at supporting their roaming users more directly, having a minimal need of the infrastructure provided by the visited operators. In order to be able to provide such services the operators will need new means to maintain a global network for a large number of relatively small size virtual infrastructures, which can be effectively deployed with small satellite ground systems having no additional visited domain backend infrastructure.

In the roaming case the number of devices connected by these networks is relatively small in comparison to the number of globally connected devices, thus none being sufficient to motivate by itself an economically viable independent network deployment. By combining terrestrial deployments with satellite networks such global reachability becomes possible, due to the transparent connectivity across borders while not using any visited network infrastructure (compared to conventional trunking, no roaming agreement is needed).

2.4 High speed platforms

One of the most interesting environments where a large volume of communication is needed is high-speed platforms. Such platforms include cars, trains, airplanes or unmanned aerial vehicles, and are specific network environments that are difficult to sustain by terrestrial network systems only.

Satellite communication is already in use to provide dedicated mission critical and secure networks for high-speed environments (including air navigation systems). With the cost sinking, increase in capacity and decrease of end-to-end delay satellite networks can supply the needed backhaul for high-speed mobility with the right mix of economic and performance characteristics.

2.5 Ultra-reliable and secure connectivity

In parallel to large scale operator networks, other telecommunication systems have always existed within specific environments where high reliability and security were critical. Examples would include industry automation, eHealth, remote control and facility management use cases for which the availability of the communication and the privacy of the exchanged information are both essential.

With the increasing number of connected devices and the associated capacity demand, as well as with the expansion of areas to be covered and with the need to communicate with external devices that do not pertain to the ultra-reliable environment, these dedicated networks are facing a huge increase in costs of deployment. An alternative to make them again viable is the convergence with the 5G ecosystem.

However, the current terrestrial-only operator networks have a specific level of reliability and security as required within the spectrum licensing, in the area of 5-nines, thus needing a boost in reliability levels within the network towards the ultra-high reliability required by certain vertical domains. Additionally, terrestrial-only operators are often bound to country borders, thus requiring inter-operator peering, and chaining connections reduces the reliability and the security of the overall network.

Satellite networks were conceived and traditionally used for highly reliable and secure communication. Building on this, satellite networks can contribute in 5G by convergence with terrestrial technologies to achieve the needed high security and reliability levels beyond the static secure locations (e.g. factories, hospitals) and offer a global coverage also towards mobile devices.

2.6 Massive number of devices

The deployment of a massive number of connected devices poses a clear operational challenge. The devices need to be maintained, their configuration and functionality updated and their software and firmware patched from time to time (over the air programming & provisioning– OTA), as security vulnerabilities are being discovered. To enable these 5G needs to support the efficient distribution of data on a massive scale and with a global reach. Satellites are well positioned to support this process in an efficient manner with their wide coverage and native broadcast capabilities, complementing local terrestrial data distribution as well as through the already existing capabilities to receive downlink satellite information (i.e. GPS system).

Regarding massive data aggregation satellite networks have already proved themselves to provide the required infrastructure in Earth observation. Similarly, satellites can offer shared uplink connectivity, and thus provide a backhaul alternative for a massive number of distributed devices.

2.7 The unknown use case

The history of the evolution of mobile communications through the different generations teaches us a lesson that at each stage and generation a new, unexpected usage emerged as very characteristic that was not planned when setting up the infrastructure. This was the SMS for the 2nd Generation, the IP connectivity (especially for mobile Internet access) for the 3rd Generation and smartphones with video capabilities for the 4th Generation.

Such use cases were possible mainly due to a settled technology level which allowed the application developers to concentrate on the delivery of a specific type of service, and due to the unforeseen change in the behaviour of the users in front of technology, the innovative way they made most out of it. This innovation in the usage usually comes from opportunities, which are available in the network, being part of the system, but having the main characteristics partially different from what is foreseen as the flagship parameters and metrics. For example, the continuous research for 5G low delay radio shadows at this moment the possibilities brought by single global networks for M2M devices, which businesswise may provide a more extensive and varied set of applications.

Because of the planned extreme flexibility of 5G we expect that the effect and impact of the so far unknown, unimagined use case(s) will be even greater than previously, and the most lucrative use case(s) will almost certainly come from the innovative use, and are likely to be different from what the engineers had in their mind when designing the technology.

2.8 Initial 5G roll-out

Initially the new 5G use cases will represent only a small part of the revenue, but of growing importance and significance. Because of this, as part of the initial deployment the most efficient technologies available at that time should be used. Here satellite networks with their ubiquitous coverage and already available infrastructure can play a major role and

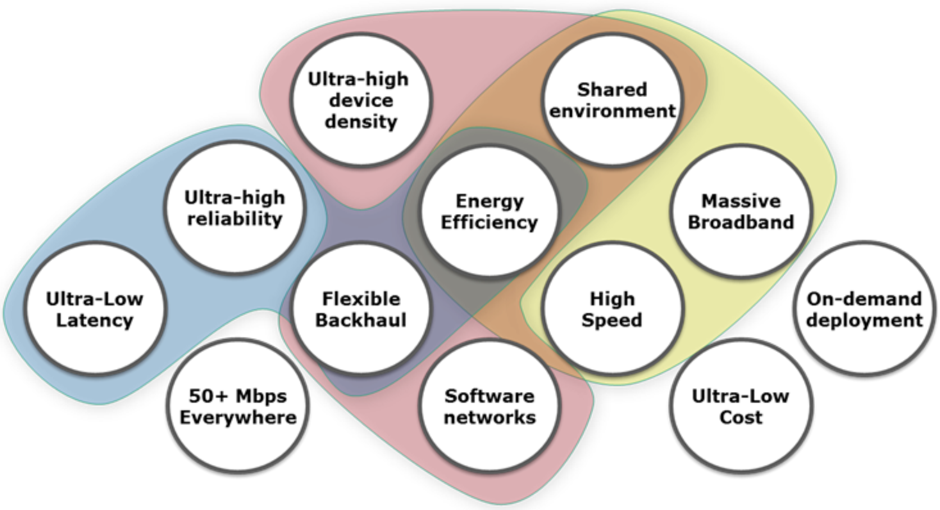

Figure 2 – Not all the new 5G characteristics are required by all the use cases

contribute to a fast roll out of new services, while the deployment of the 5G network technologies does not have the expected reach. For example, at the initial service roll-out a 5G deployment may rely on a full-fledged 5G network for a part of the urban areas and on a satellite backhauled with small modems for the rest of the customers.

3 A critical overview of the 5G Challenges

5G aims to provide the users with an entirely new experience, connecting everything in tight integration with the vertical markets. For this, the 5G environment is foreseen to integrate different enabling technologies coming from fixed, mobile, satellite and optical domains, leveraging them towards the requirements of different use cases.

5G has two major technology development directions:

- Development of new technology addressing specific advancements (e.g. high-bandwidth, lower latency, support for more devices, increased security);

- Combining and customizing existing and new technologies into specific solutions enabling the most efficient delivery of the foreseen services.

While development of new technology provides a specific added value to the existing network and gives the opportunity to address so far too demanding use cases, it also comes with a very large cost. Due to this limitation the technology advancements will not be combined in all the networks for all the use cases, and this flexibility is gracefully supported by the general trend of resource virtualisation also adopted in 5G.

Thus, in this situation, depending on the specific scenario considered, a mix between new technologies and existing ones will have to be considered where the existing technologies are providing the rest of the system functionality at the lowest costs possible while maintaining the expected level of end-to-end quality for the given network coverage.

In this context, technologies such as satellite networks which are going through an optimization regarding higher throughput and, with the emergence of non-geostationary satellite constellations, lower propagation delay at lower costs have to be re-evaluated as potential candidates for replacing or extending the current network and for providing the needed functionality for some of the new developments.

3.1 Latency

5G aims at very low latency over the radio network, in the order of the lower millisecond levels to support demanding new applications and uses. To make the best use of the 5G radio low latency the end-to-end service level communication has to have also a low latency, which due to physical limitations is not possible anymore without moving the functionality to the edge of the network, at a location close to the termination of the very low delay 5G radio network (Figure 3). Therefore, in order to meet the delay requirements the only economically feasible alternative is to make available compute capacity at the edge of the network and short-circuit the end-to-end network for the stringent latency services.

For having this short service data path, all the necessary functionality of the service should be available at the edge, making the backhaul delay and capacity characteristics beyond the edge node irrelevant for the actual service delivery delay. Thus, regarding the backhauling for the edge computing it is more important to provide a high level of reliability, security and safe sharing of the environment, characteristics where satellite networks excel, than low latency.

3.2 On-demand, flexible edge network deployments

Being able to deploy functionality at the edge of the network provides significant advantages from a number of aspects, including offloading the backhaul capacity and support to robust and secure local communications with low end-to-end data path delay.

However, due to deployment, energy and cost reasons edge nodes will be limited in terms of computing capacity, thus even though the overall capacity of the network is increased, the sharing of the resources becomes again dire, this time on multiple distributed nodes.

In order to be feasible, the edge nodes have to support on-demand, flexible deployments dimensioned based on the momentary needs of the services. A similar approach should be also taken for the central network nodes in order to support very fast service deployments, upscaling and downscaling.

For this to be possible a large amount of uniform information will have to be transmitted from the centralized service management nodes towards the edge including software installation and upgrade information (e.g. virtual machine images), configurations and runtime management commands.

Due to the large uniformity of the data that has to be distributed in a reliable and secure manner to a high number of edge nodes satellite networks offer an efficient solution with their native large scale broadcasting mechanisms.

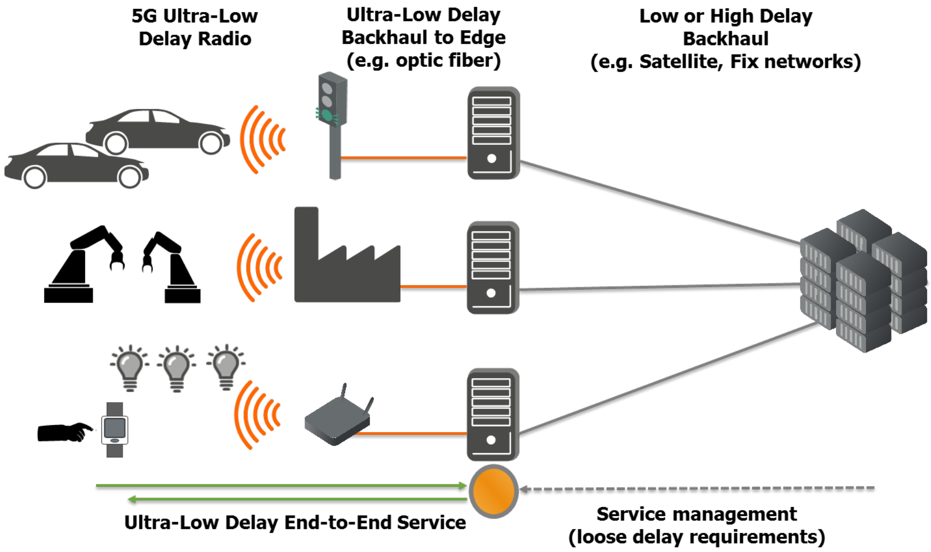

Figure 3 - Ultra-Low delay services need edge support. Backhaul delay requirements become loose.

3.3 Security and Privacy

New technologies and solutions focus on delivering the novel features and improved performance and security and privacy are of secondary concern. Whenever a new use case appears, there is a race between different stakeholders to carve out as much as possible from the emerging market. Due to the technology race concerns the focus is on the immediate availability of the service rather than ensuring high levels of robustness and security.

This situation has to change within 5G networks when catering for domains such as industrial communication, automation or eHealth, where security and privacy aspects are decisive. Additionally, passing through multiple network domains the current VPN based solutions encounter high variations in delay resulting in poor communication performance.

To limit the security and privacy concerns and give the opportunity to develop new added-value features without requiring an extra effort to ensure security and privacy, one initial deployment option is to use satellite networks. With their intrinsic security thanks to physical separation and encrypted communication satellite networks can physically isolate sensitive traffic with predictable communication delay.

Additionally, a single business relationship with a satellite network provider is sufficient to cover large geographic areas compared to the terrestrial environment where the local network operator has to peer with visited operators in order to ensure global coverage. This results in passing the data over multiple actors each being vulnerable to a varying degree to security and privacy threats.

3.4 Resilience and High Availability

With the extension of 5G towards a broad range of industry verticals the overall robustness of the network has to increase with at least one order of magnitude over what is possible by wireless systems today. Network availability is limited by failures of network components, for which simpler and flatter networks with distributed stand-by functionality would offer a solution.

Satellite networks require a minimum infrastructure on the ground and can have a very high availability. Due to these characteristics satellite networks are currently being used for highly reliable communications and for safety and security critical systems such as navigation information in the maritime domain. The large experience of the satellite industry gained through such applications can be leveraged for the benefit of other industries.

3.5 Mobility Support

5G aims to cover a large number of use cases that require support to mobility beyond the possibilities of current technology. This includes support to global networks spanning across different countries and to high speed platforms for the automotive, trains and airplanes. For such uses satellite networks have already proven themselves to be a viable alternative.

Actually, an integrated terrestrial and satellite solution would offer an efficient solution for both the relatively low speed mobile devices through terrestrial means and via satellite communication for the high speed mobility case offering a smooth hand-over and seamless user experience.

3.6 Ultra-high device density

Approaching the spectral efficiency limit for a large part of the telecommunication spectrum the only alternative for supporting the communication needs of the massive number of devices particularly in dense urban areas the used range of frequencies and communication technologies have to be re-considered especially in the direction of spectrum sharing between the different technologies. This includes the usage of higher frequencies (mmWave) and satellite networks.

Satellite networks can provide the means to address a very high number of devices at the same time and efficiently deliver some typical common services, for example distribute firmware updates. Additionally, in an integrated satellite-terrestrial solution the satellite network capacity can be used either as an infrastructure-less backup for the existing network, e.g. for emergency communications or as a supplement taking over specific part of the overspill data traffic and increasing the overall throughput of the system permitting higher peak rates and better reliability.

3.7 Software Networks

By adopting the paradigm to deploy network functions as programs on top of common off-the-shelf hardware in 5G the main focus of the technology completely shifts towards the dynamicity offered by software programs. Being the most customizable form of control, software programs represent the full convergence between the telecom and IT industry unleashing new forms of innovation.

In order to maximise the benefits of this flexibility the 5G ecosystem has to be able to program all the forms of communication technologies at the same time. A software is easier to customize and to adapt to the momentary needs than hardware. With different parametrizations the same piece of software is able to appropriately handle different communication technologies. Because of this, the convergence with satellite networks as one of the many communication technologies has become very straightforward. In 5G new transmission protocols, features and capabilities will be added to the system with a simple software upgrade.

3.8 A unified single infrastructure being shared

The full convergence of the telecommunications environment is probably the most important concept in telecommunications in the last 25 years. With the sharing of resources between multiple applications the network costs sank drastically. We have witnessed this happening recently in a more limited scale in a number of instances, e.g. in case of Radio Access Network and backhaul sharing, and regarding applications running in parallel over the same network with different QoS levels. Sharing decreases the need for parallel infrastructures and enables the operators to concentrate their infrastructure developments into areas where higher capacity is needed.

Once there is an integrated terrestrial-satellite infrastructure, the sharing of the infrastructure between multiple MVNOs becomes possible. This is one of the main triggers drastically reducing satellite network costs as multiple MVNOs can share the costs of the same infrastructure and of the same guaranteed network resources. Having a converged 5G system integrating terrestrial and satellite networks would allow the dynamic selection of the specific transport to be used depending on the application and its requirements and the current network load. This would permit to exploit further the network economics and decreasing the overall network costs while steering the communication to the most appropriate means of delivery.

3.9 Energy Efficiency

5G has set ambitious energy efficiency targets to itself. The terrestrial infrastructure consumes a lot of energy. Energy is required at each location where computing and storage resources are located requiring an energy distribution network to be available in most cases. This may become a deterring economic factor for a large number of deployments in rural or remote areas as well as for comparatively niche network requirements such as extra-capacity boost, distributed secure networks or for shortly used networks such as emergency networks or massive M2M deployments. By providing virtually infrastructure-less connectivity satellite networks offer significant energy savings, being exceptionally efficient for broadcasting to a massive number of connected devices as well as for highly distributed networks, such as island deployments.

4 Benefits of satellite communication in 5G environments

Satellite networks are already an intrinsic part of the 5G ecosystem. Indeed, a number of the promises and expectancies of the 5G environment cannot be fulfilled economically without a large area coverage that does not depend on expensive terrestrial deployments. However, with 5G, due to the further increase in scenario diversity and due to the reaching of some physical limitations (e.g. reaching the spectral efficiency for frequencies under 6GHz), the role of satellite will further increase, mainly depending on the speed of adoption of the new scenarios and on the trust created within the terrestrial communications community.

Why satellite networks are part of 5G? Mainly, because they provide communication characteristics that cannot be supplied by other technologies, **in many cases gracefully complementing the existing and the new terrestrial technologies**. Satellite provides the means to support the expansion of the use cases towards other domains, especially global and highly reliable and secure networks.

Furthermore, because **satellite networks became highly efficient in terms of CAPEX and OPEX** through the drastic decrease in satellite deployment costs as well as through making sharing of the environment a reality, and can support specific use cases such as overspill, hot standby networks and coverage, where service requirements exceeds what can be provided economically through terrestrial only solutions.

Even more, satellite can be combined with a range of terrestrial technologies for the last mile communication such as WLAN, LTE or DSL, and thus creating micro-systems which can support a large proportion of functions autonomously. In these situations satellite network is used only for backhaul to the Internet, the rest is being provided through intelligent applications at the edge.

Considering costs and edge network deployments, **integrated satellite-terrestrial solutions are cheaper than terrestrial only deployments in a number of 5G use cases.** With the current advancements of the satellite technology and by removing the need of terrestrial operators to rent and operate multiple infrastructure sites, the satellite networks are

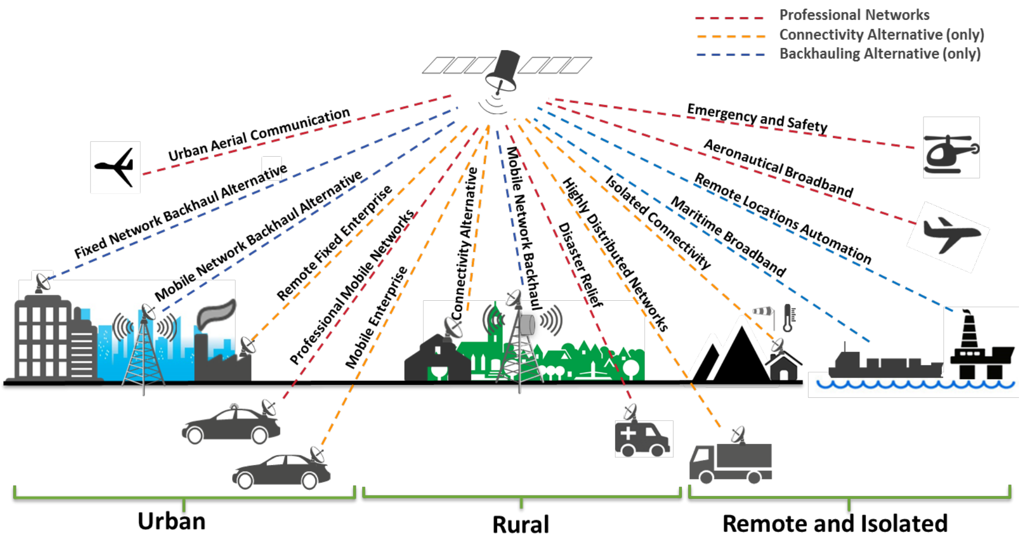

Figure 4 - Some of the interesting satellite network use cases in 5G (Source: Booz&Co)

extending well beyond their previous niche markets and are currently already highly efficient also in application areas such as urban and rural coverage, for which they would not have been considered previously.

Ultimately, satellite networks will compete with terrestrial networks in terms of which services to be supported. From this perspective the largest advantages of a satellite network are (in this order) the **uniform ubiquitous access** especially for the new highly distributed network infrastructures where different users of the same service are distributed across the world and the **broadcast capability**, all of these being the fundamental requirements of some of the 5G use cases (for example flexible and fast distribution of mega-scale updates).

With the requirement to have very low delay services there is an incentive to place services in the edge nodes resulting in less stringent requirements on the delay in the backhaul. This opens up further opportunities for satellite networks as **one of the most reliable and secure forms of backhauls**.

5 Towards an integrated 5G Architecture

To implement the 5G architecture several technologies need to be further developed, standardized and integrated. To fully benefit from the various network deployments and responding appropriately to the heterogeneous application requirements new adaptability, flexibility and dynamicity features need to be adopted at all communication layers.

In 5G, **the massive amount of devices demand the further diversification of spectrum usage** by deploying multiple parallel technologies like the new 5G radio, low frequency, LTE, WLAN, microwave, mmWave and satellite within a converged network system. Satellite networks have to prove their usability in heterogeneous cell size networks supporting diverse service delivery needs such as coverage, speed, security, handover support, infrastructure costs, etc.

Edge infrastructure relieves the extreme delay and large capacity constraints from the backhaul technologies, giving the possibility to use satellite communications in that segment of the network. Network Functions Virtualization (NFV) enables the delivery of diverse services with different communication needs over the same infrastructure, being a collection of appropriate resources. SDN enables the dynamic selection of the appropriate backhaul for each service, provided communication over the network is suitably parametrised.

An appropriate data plane should account for the different transmission environments, thus accounting for a large variation of data exchange and for a large variation of protocols such as massive IoT, massive broadband and ultra-reliable communications. In this context, splitting of the data path into multiple segments each adapted to a specific environment becomes one of the most efficient alternatives where satellite can provide its specific advantages.

With edge network placement, the 5G focus changes from component functionality to subscriber state transfer to the multiple entities, which can process requests on demand. Broadcasting state information will make the control plane virtually state independent, thus being easier to adapt to the communication needs.

5G makes very easy to create new comprehensive mobile virtual network operators (MVNOs) able to share and control the complete communication environment from radio to core, to backhaul and to applications. The MVNO concept gives the opportunity to further customize the offering of the operators both towards specific application domains (an MVNO for each set of devices) and to expand geographically for the roaming users. Additionally, different verticals might deploy their own MVNO through which they are able to operate global networks. To make this environment successful there is a need for a new set of cooperation mechanisms between operators, permitting on-demand, easy and fast set up of virtual infrastructures by operators according to their service needs and available infrastructure.

To be successful in 5G environments each technology needs standardized functions, interfaces and data models. Currently, this is taking place across a number of fora – network function virtualization at ETSI NFV, edge computing in ETSI MEC, SDN networks at ONF, communication protocols at IETF, device management and device connectivity in OMA and

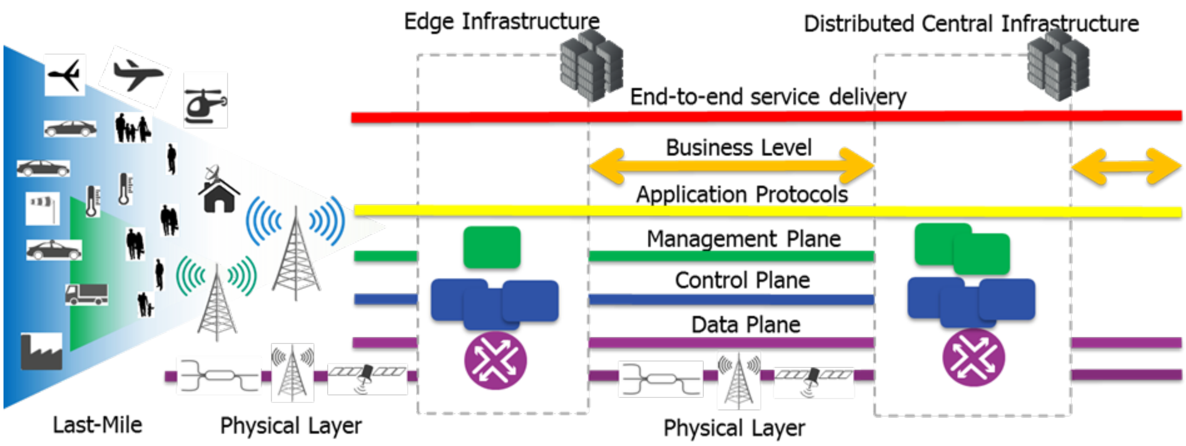

Figure 5 – 5G Architecture Layers

GSMA and especially the new access and the converged core network (including the interfaces dedicated to core networks) in 3GPP.

Satellite communications has its own strategy, bringing the required satellite parametrization as part of 5G products, by providing the advantages of the technology, adding the specific requirements and standardization items, R&D activities, testing and interoperation, and the parallel development of new 5G satellite based services. Finally, the complete integration of satellite with the terrestrial environment requires the allowance for satellite specific characteristics as part of the standards.

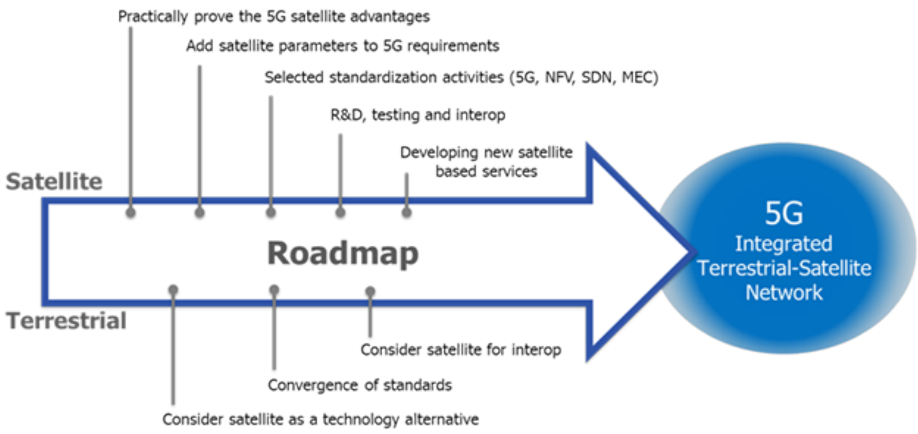

Figure 6 – Gracefully integrating satellite networks into 5G roadmap

Ultimately, the success of the new 5G system is highly dependent on the selected use cases and business models. Currently we can witness a four-fold approach:

- Optimizing existing communication – larger coverage, better capacity and/or lower delay. Here satellite networks can support and play a major role in increasing the coverage and to add extra capacity needs on-demand. Additionally, through its natural capabilities, satellite provides the best means for multimedia content delivery on a global scale;

- Maintaining and optimizing the business-to-business segment – the current B2B market segment could significantly profit from virtualization. Ensuring a secure connectivity on a global scale for highly distributed networks will extend B2B offerings towards worldwide coverage with local support from virtualized infrastructures;

- Dramatically extending the number of connected devices – a massive number of new devices is expected to come from the IoT for smart cities and other business verticals. M2M communication proved to be the most successful type of new device communication. However, there is a need for a new approach within the 5G system combining aggregation and broadcasting mechanisms to be able to compete with recent narrow-band solutions and to address a broad range of use cases including more complex ones;

- Addressing new markets – for a natural growth there is a need for network convergence towards industrial communications, automotive, emergency, safety and security and unmanned aerial vehicles, global small scale networks, roaming MVNOs. The new markets come with specific requirements which push the current communication system to the limit of requiring customization through alternative technologies. In this area the large expertise of satellite communications providing solutions for those markets for a number of years can be leveraged and further extended towards a convergence with terrestrial systems.

6 Why Satellite Networks provide an important piece of the 5G puzzle

5G aims to provide a true next generation communication network which has all the premises for a great success and ultimately enabling a fully connected digital society. 5G aims to include a comprehensive set of use cases from basic telecommunication services up to very advanced and reliable communication means for B2B and the communication needs of various markets.

To reach and deliver on its ambition a large number of new technologies have to be further developed in 5G. However, the major advancement needed has to come from the convergence of (when available) existing and new technologies towards customized deployments according to the services' needs. In this context, more important than the development of new radio technologies is the ability to provide an appropriate middleware, highly dynamic and flexible to suit all the needed parametrizations and deployments.

Coming to meet these requirements, recent advancements in satellite networks offer a very attractive proposition for a large number of use cases as well as the means to cost-efficiently integrate global network coverage within a single provider. Indeed, through the integration with low delay edge networks, satellite networks provide probably the most attractive alternative for highly distributed, private infrastructures especially towards the vertical markets which from a satellite perspective represent only a translation to more use cases and easier parametrizations of existing technologies.

With its secure and virtually infrastructure-less network, satellite communication provides

Satellite Networks for 5G

- **Diversification of the spectrum usage across multiple technologies to better address the transmission over the specific spectrum**
- **Edge networks to reduce the impact of the backhaul in the end-to-end system**
- **Adapted data path protocols to massive communication environments (including multicast and flexible paths)**
- **Segmenting the data path with data aggregation, caching and analytics nodes**
- **Stateless, highly distributed control plane**
- **Application protocols adaptation through the virtualization environment**
- **Large number of MVNOs for verticals and for roaming with infrastructure sharing**
- **Leveraging the broadcast and B2B know-how of satellite towards convergence**
- **Addressing the M2M communication needs in an efficient manner**
- **Participation within the main standardization organizations: 3GPP, ETSI NFV, ETSI MEC, IETF, ONF**

also the best alternative for initial deployments and service provisioning, as well as the means to support the communication needs of various vertical markets, enabling the immediate monetization of innovative solutions.

In order to benefit from the advantages that satellite networks offer in 5G and in the true spirit of 5G it should be possible to assign the services to the satellite link where the satellite link performance characteristics can comfortably exceed the techno-economic performance requirements of the service. This requires that standards support the appropriate parametrisation and facilitate the convergence of 5G equipment and thus, of the selected use cases.

7 Next steps

Up till now we have presented how satellite can contribute to the success of 5G and the opportunities 5G represents for satellite communication. In order to capitalise on the opportunity the satellite stakeholders should actively engage with major terrestrial players in research and development activities to explore in detail the possibilities outlined and develop adequate solutions. The EU funded H2020 research programme, and in particular its 5G-PPP strand, as well as the ESA ARTES research programme offers the funding framework for the necessary innovation.

Ultimately, any 5G solution developed needs to be standardised, conform to the standards developed in ITU and ETSI 3GPP. It is critical that aspects essential for the integration of satellite are sufficiently understood and covered in the relevant standards. Satellite stakeholders should act swiftly, as 5G standardisation is progressing at an expedited speed.

A Acronyms

ACM	Adaptive Coding and Modulation
ARTES	Advanced Research in Telecommunications Systems
B2B	Business to Business
ESA	European Space Agency
FSS	Fixed-Satellite Services
GEO	Geostationary Earth Orbit
GSO	Geo Synchronous Orbit
IoT	Internet of Things
LEO	Low Earth Orbit
M2M	Machine to Machine
MEO	Middle Earth Orbit
MNO	Mobile Network Operator
MVNO	Mobile Virtual Network Operator
MSS	Mobile Satellite Services
Mx-DMA	Cross Dimensional Multiple Access Technology
NFV	Network Functions Virtualization
OTA	Over The Air programming
SDR	Software Defined Radio
SDN	Software Defined Networks
UHD	Ultra-High Definition
VNO	Virtual Network Operator