NetWorld2020's – SatCom WG
The role of satellites in 5G

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1 Introduction

This document outlines the vision of the satellite working group of NETWORLD2020 as to the role that satellites will play in future 5G networks. It is seen that satellites will integrate with other networks rather than be a stand alone network to provide 5G and it is this integration that forms the core of the vision. Satellite systems are fundamental components to deliver reliably 5G services not only across the whole of Europe but also in all regions of the world, all the time and at an affordable cost. Thanks to their inherent characteristics the satellite component will contribute to augment the 5G service capability and address some of the major challenges in relation to the support of multimedia traffic growth, ubiquitous coverage, machine to machine communications and critical telecom missions whilst optimising the value for money to the end-users.

After elaborating on the 5G vision, this document presents the trends in satellite communications. So-called "satellite use cases" are then defined which illustrate how satellite services will contribute to the 5G KPIs. The document also identifies the associated research topics that need to be carried out in the context of H2020 ICT 5GPPP program to enable this satellite integration to 5G universal deployment. Lastly, the related technology roadmap is consolidated and the expected contribution of satellite communications to the 5G KPIs is assessed.

2 The 5G vision

2.1 What is 5G about

The vision of 5G mobile [1,2,3] is driven from the predictions of up to 1000 times data requirement by 2020 and the fact that the traffic could be 2/3rds video embedded. If one tensions this with the mobile spectrum available (by 2015 about 500MHz) there is, what is refered to as the 'spectrum crunch'—there just isn't sufficient to satisfy the demands. Although there can and should be moves to use the spectrum more efficiently eg by spectrum aggregation and sharing schemes this is still considered insufficient. Thus the conclusion is to move to a more dense network (Densification) and increase the area spectral efficiency by orders of magnitude. This leads to a network of much smaller cells, all of which will not be solely homogeneous but a flexible heterogeneous network where the resources can be adapted dynamically (on demand) as the users demand in space, time and spectral resources and even between operators varies. This requires a fundamental redesign of the cellular networks which still have a legacy of cellular networking based upon 3G which result in excessive and inefficient signalling inhibiting the adoption of new service types. The trend now is towards 'Information Centric Networks' designed with the user in mind and their requirements to access information efficiently and with a good QoE. This ties in well with the cloud approach to service delivery and network architecture—the 'software defined network approach'. Service providers will need to use this network in bespoke ways and thus virtualisation of functions is key so that a virtual provision can be made in a quick and easy way. Virtualisation and multi tenancy are key aspects of the 5G vision.

Another key driver for 5G is the emergence of IoT and the vision of Billions of objects being connected to the internet. This is the enabler to 'smart cities' and other such 'smart'; environments and the emergence of what is called 'Big Data' applications where massive amounts of data can be processed to feed a plethora of new applications. For 5G this implies being able to handle large quantities of low data communications efficiently covering widespread sensor networks and M2M communications.

There are two remaining pillars of the 5G vision. The first is ensuring availability, reliability and robustness. The abstraction or virtualisation techniques mentioned above and the cloud nature of the services raises complex issues for critical services and security as the point on which services or content could be delivered will be operated over several heterogeneous networks managed possibly by different entities. The whole end to end management then becomes a real issue. The second and increasingly important issue is that of reducing energy. The target is a reduction by 90% of today's energy by 2020 at no reduction in performance and increase in cost. Thus 5G network design becomes a complex task involving link and area spectral efficiency together with energy efficiency.

2.2 The 5G research KPIs

Several Key Performance Indicators (KPI) have been defined in the frame of the 5G PPP contact to qualify the 5G solutions, architectures, technologies and standards for the ubiquitous 5G communication infrastructures. The Performance an societal KPIs are recalled here while the next chapters will describe how satellite technologies integrated within the 5G network core will contribute to the achievement of such ambitious KPIs as presented in the next paragraphs.

<u>Performance KPIs:</u>

KPI #1: Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010.

KPI #2: Reducing the average service creation time cycle from 90 hours to 90 minutes (as compared to the equivalent time cycle in 2010).

KPI #3: Very dense deployments to connect over 7 trillion wireless devices serving over 7 billion people.

KPI #4: Secure, reliable and dependable Internet with zero perceived downtime for services provision.

<u>Societal KPIs:</u>

KPI #5: Enabling advanced User controlled privacy

KPI #6: Reduction of energy consumption per service up to 90% (as compared to 2010)

KPI #7: European availability of a competitive industrial offer for 5G systems and technologies

KPI #8: New economically viable services of high societal value like U-HDTV and M2M applications

KPI #9: Establishment and availability of 5G skills development curricula in partnership with the EIT

3 SatCom trends

Mobile satellites today provide services to air, sea and remote land areas via GEO operators (e.g Inmarsat, Thuraya) and non GEO operators (e.g. Iridium, Globalstar, O3b). These operate in L, S and more recently Ka bands, to both handheld and vehicle mounted as well as some fixed terminals. Air interfaces and network functions have tended to be proprietary although some integration with MSS and 3GPP network interfaces exist. Fixed satellites today provide backhaul services to cellular in C, Ku and Ka bands, and also services to moving fixed terminals on vehicles in C-, Ku-, X- and Ka-bands. Satellite has been an overlay, rather than integrated system except in S band where an integrated satellite and terrestrial MSS standard has been adopted.

3GPP like services exist via satellite to individual users, but as yet these have not been extended to 4G. Satellite services to ships, aircraft and fast trains using FSS satellites provide a full range of mobile and broadcast services to passenger vehicles. A growing area of interest is in the transport sector where safety services and V2V (Vehicle To Vehicle) are seen as ideal for satellite delivery. Satellite is also used extensively for low rate SCADA (Supervisory Control and Data Acquisition) applications dealing with remote installations such as to/from pipelines, oil and gas etc. Satellite is also used in cases of failure in the cellular system due to natural or made-made disasters. Increased data requirements for applications such as oil and other mineral exploration and security via UAV's has spurred the need for more spectrum and the use of higher frequencies such as Ka-band.

Although not the topic of this paper we should mention the GPS and Galileo navigation and positioning satellites which play a key role in location based services and in supporting mobile satellite and cellular systems management.

Looking towards the future to 2020/5 there will be a trend to larger and more powerful GEO satellites taking capacities from 100's Gbps to over a Terabit/s. Several hundreds of spotbeams will, via higher order frequency reuse increase the capacity in limited spectrum. Higher frequency bands may also be used—Q/V/W and also optical for gateway connections. Advances in satellite payload technology via new materials and optimised designs will enable up to 30m deployable antennas at L/S bands and increased payload powers from 20 to 30KW. On board signal processing will enable improved connectivity and flexibility to meet changing traffic patterns and demands e.g. adaptive beam forming and hopping and interference management to increase capacity. Alternative architectures involving clusters of GEO's and possibly fragmentation of link functions between the connected (possibly with ISL's) clustered satellites may evolve. Following the recent innovative use of different orbits, new non GEO systems are likely to appear possibly using all optical technology—between satellites and from satellite to ground and possibly using constellations of smaller and cheaper satellites.

Satellite and terrestrial system integration is already a trend and this will continue with the development of interoperability standards to allow the two sectors to interconnect efficiently both at network level and at IP levels. This form of technological complementarity, relying on network hybridation, is already a reality. Indeed, Orange proposes a Triple Play offer (internet, TV, phone) relying on the ADSL network for the internet service and on the satellite for the TV services to those subscribers who cannot receive it through ADSL.

In addition mobility management integration will evolve across the larger satellite and smaller terrestrial cells.

Satellite communications systems encompass a wide range of solutions providing communication services via satellite(s) as illustrated in Figure 1.

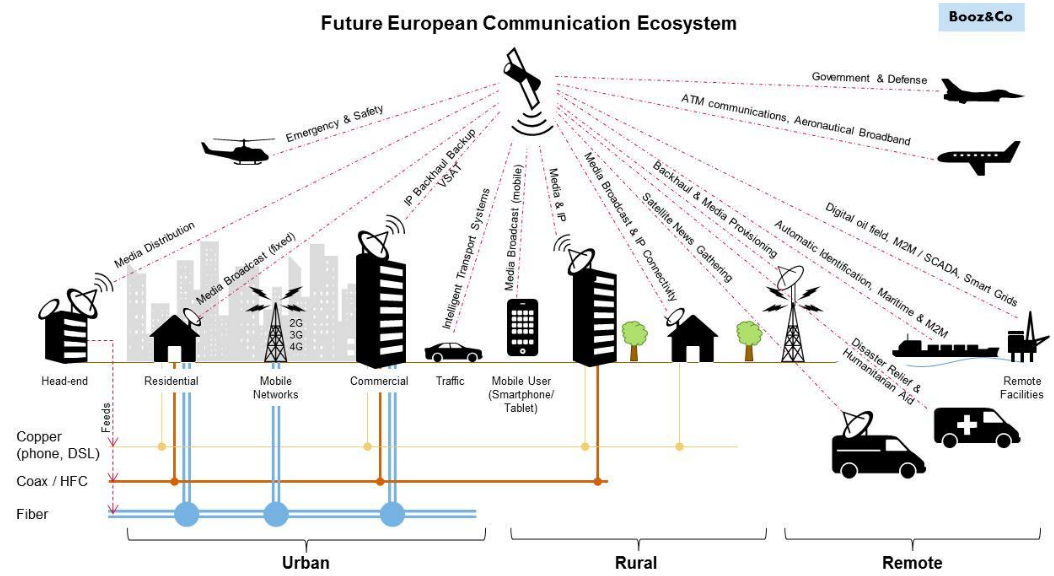

Figure 1: Sketch of satellite role integrated in future communication systems[1]

SatCom systems can address a wide range of services such as broadcast, broadband and narrowband services to fixed, portable and mobile terminals over global or regional coverage:

- Broadcast systems have been optimized to deliver TV programs.
- Broadband services support IP services
- Most mobile satellite services are delivering 3G-like services

Among others, the following main evolutions in capabilities are expected in both Geo Stationary Orbit (GSO) and Non Geo Stationary Orbit (NGSO) satellite systems.

Performance:

- Higher Service rate and throughputs thanks to multi beam payload and larger antenna for narrow beams to maximize the frequency re-use
- Increased spectrum efficiency
- Higher energy efficiency (W/km^2 and W/kbps)

Features:

- On board/ground processing to allow flexibility in bandwidth allocation across the satellite coverage, in the utilization of the allocated frequencies, in network topologies with the support of star and/or mesh with or without inter satellite links.

The progressive convergence of traditional broadcast services and the internet calls for a new role for SatCom. This process of convergence is, inter alia, about making sure users can access a maximum of high quality audio-visual content on any of their devices whether they live in urban or rural areas. In these latter areas, where Fiber To The Home (FTTH) is not to be implemented soon, and so for technical and economic reason, hybrid broadband/broadcast networks are particularly relevant. Satellites can proficiently be part of a hybrid network configuration, consisting in a mix of broadcast infrastructures and broadband infrastructures managed in such a way that it brings, seamlessly and immediately, converged services to all end-users in the EU.

[1] From Booz&Co, "Why satellites matter", http://www.esoa.net/news-info-30.htm

4 The satellite use cases

The contribution of the satellite solutions to the 5G KPIs will be further explained in this section through the identification of “satellite user cases” as the areas in which satellite can play a part in 5G. The associated research challenges are identified.

4.1 Use cases

Global coverage and dependability are and will remain the main added value of space-based communication services. Integrated in 5G network infrastructure, SatCom solutions are well positioned to target the 4 main types of use cases identified in Figure 2.

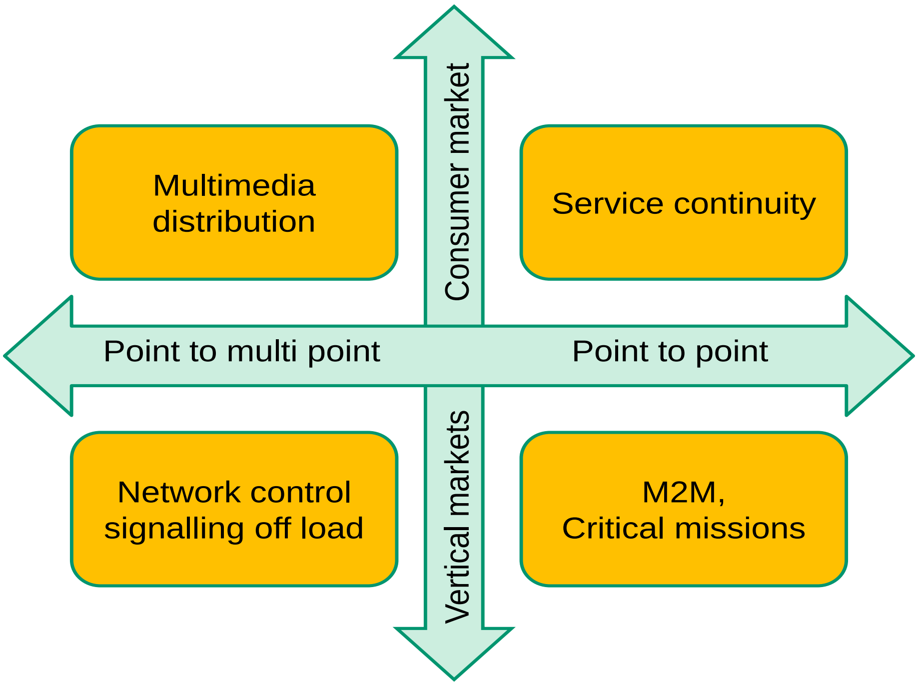

Figure 2: satellite use cases in 5G

4.1.1 Multimedia distribution

Description

Thanks to its natural broadcast capability over a wide area, SatCom solutions can effectively convey any user and control data (e.g. popular multimedia content) – for live TV (linear) or push VOD - to an unlimited number of terminals or network nodes. SatCom is well positioned to entertain everybody, anytime, from whatever source, without exceeding network capacities.

SatCom is typically the choice of means to distribute efficiently similar content (video, audio, rich media, files) to a high number of terminals inside the coverage simultaneously. Advanced terminal and user interfaces support in addition scheduling (time and/or frequency) within defined repetition intervals allows for distribution of updates of the aforementioned data types, thus allowing the delivery of most popular content on demand to satisfy individual customer needs. According to the latest forecasts, over 90 percent of all Internet traffic is expected to be video by 2015. This statistic single-handedly summarises the importance that video traffic will have in future networks. In order to offload the traffic, the simultaneous use of satellite broadcast for linear content (such as video, including UHD and HD video) combined with the use of broadband networks for the non-linear content, is the most cost and spectrum efficient means of transmitting audio-visual linear services including HDTV, 4K, both feeding local distribution networks with content and delivering this content directly to end-users. In addition, when used in a hybrid network, the satellite broadcast can facilitate the delivery of non-linear services e.g. by 'pushing' content to an equipment (belonging to the operator) at user's premises, in order to contribute to improve ICT overall cost and spectrum efficiency. The figure below gives a view of the ultimately resulting converged multimedia distribution network.

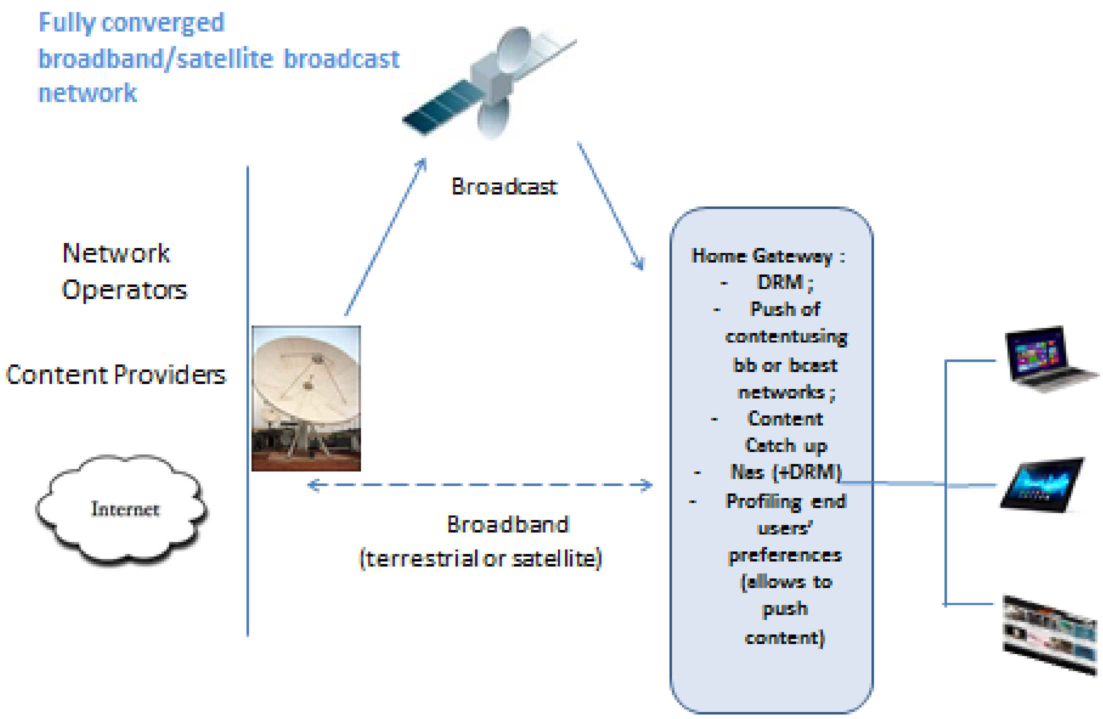

Figure 3: Converged multimedia distribution network

Indeed, recent evolution in the industry suggests that the delivery of most actual content (video, audio, rich media, files) to caches located at the network edges or at the user's premise (both under network operators' control) via broadcast channels is more and more required. The main driver here is the pressure to relieve the traditional broadband backhaul means with broadcast traffic to better support content specific to individual customers.

Software updates constitute a growing and increasingly critical category of data distributions to a plethora of devices, driven in part by responses to security concerns and/or actual breaches. Additional filtering by the embedded intelligence of devices allows for the down selection on specifics like localisation, versioning or other criteria.

Research challenges

The evolution of broadcast and broadband in the satellite industry and the upcoming hybrid networks require considerable R&D efforts to satisfy challenging future user requirements for performance, cost, QoS and QoE. The main challenges are:

- Parallel access to both broadcast and broadband networks by the final users, in a transparent manner
- Smart management of both broadcast and broadband resources
- Storage of content pushed directly to the user's premises under the control of the service provider.

In detail this requires substantial insights into the interfaces and requirements on the interfaces between broadcast and broadband networks, their respective and aggregated network management and the services delivered to the future customer expectations.

More specifically, the evolution from the current, separated provisions of the linear TV (unidirectional) service and broadband (bidirectional) services to the development of a fully integrated (bidirectional) hybrid broadband-broadcast service provision, calls for a few technological steps, each one raising specific issues. Already the format of the transport of content from different sources (broadband / broadcast) has been configured into a unified format -typically IP- compatible with the distribution in the local / domestic network and with the use on different devices and screens. Also an early and limited interaction between network operators/content providers and final users (with issues regarding users' preferences, the popularity of contents and DRM) has been made.

Additional steps are now needed as follows;

- To allow a full interaction between the final users and network operators/broadcasters: the broadcast technology is used to push content directly at the user's premise. An additional function of a full hybrid broadcast/broadband network is content pushing directly into a storage (e.g. an in-home Network Attached Storage – NAS, or an equivalent device inside the set-top box or the home gateway) which, although positioned at the user's premises, remains however a network termination unit, controlled by the network operator or the content rights' owner, and is not user equipment.
- The remaining step for a fully integrated network requires native IP audio-visual content on the broadcast channel, thus replacing the MPEG Transport Stream multiplexing. All contents will then have the same format, regardless whether they are delivered via the broadband or the broadcast channel.

The required intelligence for optimal data distribution strategies are still subject for substantial evolution to meet the ever increasing complexities (versioning, localization, costs).

4.1.2 Service continuity

Description

With its regional (e.g.: single Geostationary satellite) or worldwide (e.g. constellation o of geostationary or non-geostationary satellites) coverage, SatCom solutions are essential to provide the 5G service everywhere including also in remote areas, on board vessels, aircraft (In-flight services) and trains in a reliable manner. This is already the case with 3G given the costly deployment of cellular networks beyond urban areas and is beginning to be implemented in 4G as well.

Satellite systems can contribute to extend the 5G service coverage either providing backhaul or direct access service.

- On the one hand, satellites provide backhauling to interconnect a local area network made of base stations or access points:

  -The LAN may be deployed in an isolated area or on board aircraft, vessels or even trains. Hence, the cells of the local area network may either be isolated or may roam across other cells (e.g. Trains).

  -Satellite can offload the terrestrial backhaul and/or offer backup in cases of temporary need of extra-capacity

- On the other hand, satellite can deliver 5G service in a direct access provided that the terminal device can operate in the satellite network and frequency bands.

Research challenges

To provide a seamless service delivery to the 5G end-users while they roam between terrestrial and satellite backhauled cells, it is necessary to

- Ensure that the network protocols can cope with different latencies
- Support vertical hand-overs between the networks to enable terminals to always pick-up the best access technology available
- Define schemes that mitigate possible interference issues between satellite and terrestrial networks (millimetre wave as well as S band).
- Address SLA agreement issues between terrestrial and satellite service providers
- Investigate possible satellite and terrestrial network dual mode integration in 5G devices.
- Application dependent connection selection (in the access point).
- Business models for the access points (private, shared)

- Low cost, low energy consuming access points (SatCom backhaul, mobile connections)

4.1.3 Machine to Machine

Description

The inclusion of billions of sensors and actuators, commonly referred as Internet of Things (IoT), all transmitting low date rates and being scattered over wide and remote areas makes it well suited to data collection and control via satellite. In particular, monitoring/surveillance of various assets (vehicles, homes, machines, etc.) in remote locations, asset tracking (e.g. container) and transfer data and/or configuration to a group of widespread recipients requires satellite systems to ensure service continuity.

Research challenges

Various research challenges are associated to the aforementioned M2M use cases as described below.

Protocols for Battery Powered M2M Satellite Terminals. In contrast to the terrestrial M2M where battery powered terminals are starting to offer several years of battery life yet, satellite M2M might need to be reconsidered. Indeed, in contrast to the terrestrial Internet of Things (IoT) transceivers where the energy consumption is limited and its MAC protocols have been thoroughly re-examined recently, the satellite ones need to be re-considered in order to face extremely demanding battery life constraints. As a result, a battery powered M2M system would be available.

***Energy Efficient Waveforms and hardware*.** Despite so far the hardware satellite design has been attending other reasons than the energy efficient, it is becoming urgent to re-think the PHY layer in case the energy constraints are very high. This study must be accompanied by a carefully investigation on the hardware design since it encompasses the major energy impact.

Security and Integrity. Security is of paramount importance in M2M/satellite communication, ensuring that the whole system operates in a smoothly and safe way without any kind of attack and/or intrusion. This is of great importance in those attacks devoted to force the terminals to waste energy.

Unified Routing Approach. Due to its 'lossy' nature, IoT networks had to redefine the routing protocols in order to accomplish the different traffic and network features of M2M networks. In case the satellite component is present in the IoT scenario, those protocols need also the be revisited in order to incorporate the satellite nature where the delay plays a central role.

Service Differentiation. M2M services and applications have different requirements in terms of data rate, latency, security, etc. In that respect the M2M/satellite communication system, must be able to support end-to-end Quality of Service (QoS). For example an alarm notification, requires an immediately and real-time communication with the satellite, while other services which perform periodic reporting activities require only reliable communication.

4.1.4 Network control Signalling offload

Description

The architecture of 5G is based on a large number of small cells—densification. One of the major problems with this architecture is the increase in the amount of signalling needed which can reduce the data capacity considerably—it has been suggested by as much as 25%. In addition to this the base station signalling contributes to the overall energy usage within the system and prevents achievement of the energy reduction KPI's for 5G. In order to address this the concept of splitting the control (C) plane from the Data (U) plane has been proposed such that the C plane can be delivered via an overlay macro cell. In this architecture the base station just deliver data on the U plane saving capacity and energy. The proposal here is to make the macro cell a satellite cell so that the terrestrial spectrum can be saved.

Research challenges

The challenge here is to examine the latency issues with various satellite architectures including GEO and Non-GEO on the C plane distribution over the satellite. As a start the current 4G networking model can be taken and modelled with cellular and satellite overlay cells to assess the viability and the reduction in signalling capacity and energy that results. As the 5G networking structure develops such an integrated satellite-cellular architecture can be tested and feedback to the 5G standards made.

4.1.5 Critical telecom missions

Description

The combination of dependability and coverage are key assets to deploy or recover services (resilience). Hence satellite solutions (communication and navigation) are key to provide public safety or emergency communications in case of man-made or natural disasters or to monitor and control critical infrastructures (utilities, transport or even the telecom network).

In case of a crisis, commercial networks may often experience congestion or even failure and hence service needs to be recovered. Service continuity can be ensured thanks to the redundancy (cold or hot) of critical network links using satellite communications as a back-up.

In addition to legacy commercial networks (2G and 3G), civil protection organisations make use of dedicated narrowband networks (e.g. TETRA) operating in specific frequency bands. Soon, the dedicated networks will be upgraded to offer broadband features using the 4G/LTE technology. As per 5G, its flexibility to support M2M as well as very high speed broadband in various frequency band makes it suitable to support also advanced public safety communications sharing the same network infrastructure resources with the other commercial applications. Satellite solutions based on light weight nomadic terminals with high speed broadband capabilities will be necessary to support 5G services and improve response time to crisis.

Research challenges

To provide seamless, secured and dependable high speed broadband and/or mobile services for critical telecom missions in a combining satellite, cellular and ad-hoc networks.

To ensure maximum transparent interoperability among the various stakeholders of the emergency/critical situation.

5 Satcom research topics in 5G.

5.1 The key areas that satellites can contribute in 5G

From the use cases we can extract that the key areas for satellite as follows;

- Extending the coverage of 5G networks.
- Delivering multimedia closer to the edge to improve latency and QoE.
- Off-loading the terrestrial network e.g. by using satellite backhaul and by taking control traffic via satellite.
- Providing resilience by integrating satellite with terrestrial.
- Integrating virtualisation via software defined networking.
- Allowing improved utilisation of the spectrum between the systems.

5.2 Key research topics:

5.2.1 Service provision:

- Satellites will play an important role in the extension of 5G cellular networks to sea, air and remote land areas that are not covered by the small cell networks. With many more people expecting to have the same coverage when travelling (on cruise liners, passenger aircraft, high speed trains and in holiday villas) it is key that satellite allows seamless extension of 5G services.
- IoT coverage to wide areas involving sensors and M2M connections are ideal services to make use of satellite wide area coverage. The challenge is to design efficient low data rate communications in large numbers via the satellite.
- Transport services including V2V are again ideal for satellite with its wide coverage. In the safety market all new vehicles are likely to be mandated to include safety packages and given the need for ubiquitous coverage systems that follow on from the EU SAFETRIP system demonstration will play a key role.
- Localisation and positioning is key to many different 5G services. The integration of cellular and satellite positioning systems is a key challenge to enabling this vast range of services.
- Satellites are already used for earth resource data which is in itself used as an input to many new services. Coupling this with integrated satellite and cellular communications will provide a powerful new fusion enabling the innovation of services.
- Security services require high resilience and thus the use of satellite together with cellular delivery will help provide the several nines availability required. Most countries have fall back disaster and emergency networks which can benefit from an integrated satellite and cellular approach. There is increased use of surveillance using UAV's and the necessity for real time high definition video which is best delivered by satellite.
- Satellites have traditionally been used for broadcast purposes but as we move into the domain of CDN's the ability of satellites to download high data that can be cached for onward delivery becomes an attractive feature. The interplay with new (inter)network architectures, such as CDN is important to consider for SatCom/ cellular integration. Pervasive and targeted caching and naming of information and content transferred over the networks would more easily allow the inclusion of SatCom into an integrated Satellite-Terrestrial network by exploiting the broadcast/multicast and broadband capabilities and masking the longer propagation delay. This again reduces the demands on the terrestrial network. This fits well with the 5G aim to push large content to the edges and close to the users to improve latency. This can be done in a targeted manner for regions or for individual cells.
- QoE is becoming the byword for service provision and a major differentiator, but it is little understood at the moment. It is clear that peak and average bit rates are not the determining factor but sustainable bit rate links more to the QoE. Intelligent delivery of services using the systems that best suits the QoE to the user is another area in which satellite can play a part.

5.2.2 Software Defined Networks and Virtualisation:

There will be a paradigm shift in network design to allow networks to react to the demands of the users wherever they are—'demand attentive networks'. This will be brought about by virtualisation in the network and software that allows the dynamic reconfiguration of the network to give users the perception of infinite capacity for their application. The extension of current trends in virtualisation and "softwarisation" -especially in the domains of SDN and NFV- to satellite infrastructures is indeed a very attractive perspective for the satcom community. By exploiting SDN/NFV enablers, satellite equipment vendors developing specialised networking equipment for specific use (onboard or ground), have the potential to "open" their platforms by making them programmable and reconfigurable. As for satellite operators, the virtualisation paradigm is expected to be a very attractive revenue source, offering them the ability to monetize on their network by offering new services and by charging customers according to the actual usage of in-network resources. The application of NFV and "Cloud RAN" aspects to satcom paves the way towards the full virtualisation of satellite head-ends, gateways/hubs and even satellite terminals, thus entirely transforming the satellite infrastructure, enabling novel services and optimising resource usage. In this context, several enhancements/adaptations of current SDN/NFV technologies (e.g. extensions of the Openflow protocol) are envisaged, in order to be fully applicable to the satcom domain and exploit satellite-specific capabilities.

Virtualisation is considered as the key enabler for the efficient integration of the satellite and terrestrial domains. Via the unified management of the virtualised satellite and terrestrial infrastructures, fully integrated end-to-end network "slices" can be provided, integrating heterogeneous segments in a seamless and federated way. This will enable 'opportunistic integration' of the satellite and terrestrial resources.

5.2.3 Connectivity and Networks:

The integration of satellite and terrestrial can be used to extend the 5G network to ubiquitous coverage. For example to sea—cruise liners and yachts, to passenger aircraft, trains and even to remote locations such as holiday villas. In each of these domains users will expect to access their home 5G services. This can be achieved in a variety of network architectures facilitated by satellite's wide coverage. A simple example is via backhauling but this can be done in an intelligent manner by routing traffic either over the satellite or terrestrially depending on the content and the required QoE. Non-GEO satellite constellations are currently being researched to achieve optimal networking and latency. Intelligent gateways can be designed in a demand attentive manner to maximise the total resources available and multipath TCP and network coding can be combined to facilitate such schemes. Such satellite links are now being researched in the optical area which provides massive increase in capacity and with smart diversity schemes the availability can be provided.

The integration of network standards is seen to be crucial in these architectures. In particular how the satellite gateway interconnects into the 5G network interfaces. There are various scenarios of interconnection between the network entities that separate the control plane from the data plane that will determine the performance and the signalling load on the networks that needs to be minimised.

One of the major contributions that satellite can make to 5G is to off-load traffic from the terrestrial networks and in particular for the video based traffic which is the largest contributor to the spectrum demands. This can be achieved by traffic classification and intelligent routing and will thus reduce the demands on the terrestrial spectrum.

Integrated localisation schemes are key enablers to many new services in 5G.The notion of per-user integrated location and service management in cellular/satellite systems should be investigated either to help in spectrum sharing or to improve trunking systems. A Per-user service proxy can be created to serve as a gateway between the user and all client-server applications engaged by the user. The aim is that whenever the user's location database moves during a location handoff, a service handoff also ensues collocation of the service proxy with the location database. This allows the proxy to know the location of the mobile user to reduce the network communication cost for service delivery. Different users with vastly different mobility and service patterns can adopt different integrated location and service management methods to optimize system performance.

5.2.4 Air interface and Spectrum:

The 5G air interface has the challenge of incorporating a range of different traffic types from the high rate video down to the low rate IoT applications and serving applications with a range of latency requirements. We see that the integration of satellite and cellular 5G is essential to extract the combined benefits of both sectors. In this respect we need to adopt as far as possible a common AI. The drivers in the satellite channel are however different than those in the cellular—multipath is not so important but the channel is non-linear and suffers from more latency inhibiting adaptation—depending on the satellite orbit. There is much to be gained from an integrated terminal which uses as much commonality as possible with terrestrial via ideas of implementing software MAC for example. This needs to be coupled to the energy reduction that can be achieved in the terminal design. Multi-polarization MIMO as a scheme that requires reduced channel state information is suitable for satellite and context aware multi-user detection, either centralized or decentralized plus other forms of interference mitigation. Receivers for bursty communications is an area of research that will benefit the role of satellites in IoT. Multicarrier schemes such as filter bank systems with appropriate modulations that offer optimal spectral efficiency and frequency granularity are being investigated in terrestrial wireless but also have commonality in satellite systems.

Spectrum is an issue for both mobile and satellite systems. As mobile systems move into the millimetre wave bands, consideration needs to be given to co-existence of both sectors. One example of this is the 27.0 to 29.5 GHz band. In some regions of the world mobile is primary from 27.0 to 29.5 GHz but currently not active, whereas broadband satellite systems are using the band for uplinks. If satellite use of this band becomes impossible (as it will be if there are substantial numbers of mobile terminals) the band becomes fragmented and uneconomical for satellite.There are some opportunities to achieve a win-win situation, possibly using cognitive techniques so that both sectors can achieve more spectrum usage and also by keeping mobile's mm-wave usages above 31 GHz.. The use of frequency division duplex, already standard for satellite, is another area in which a spectrum gain could possibly be achieved.

6 Technology Roadmap:

A possible technology roadmap can be seen in Table 1. This is divided into three broad time periods—up to 2016, between 2016 to 2020 and 2020 and beyond. The first period is focused on studies aimed at solutions to the challenges. The second period is focused on turning the results of these studies into standards for 5G and some early demonstrations. The final period is devoted to pre-operational demonstrations and service delivery. Key areas in the studies are;

- Integrated architectures to increase coverage and deliver multimedia to the edge.
- Compatible air interfaces including advanced signal processing
- Integrated networks using SDN for off loading
- Spectrum enhancements in the millimeter bands
- New satellite architectures to improve backhauling

In the standards phase there is a clear need to work together with the mobile 5G groups in the air interface and networking areas rather than addressing separate standards bodies. In this and the follow on stage it is important to participate in common test beds that integrate satellite and mobile.

Timeline/Technolo	2016-studies	2016-2020-standards	+2020-

gy			Demo/operation
Integration	• 5G over satellite • Backhaul, SDN, intelligent routing • 5G satellite core network interface • Multimedia to the edge studies	• Sat converged network. • ETSI/DVB/5GPPP • Early lab demo's	• Fully integrated operation • IoT Demo
Air interface	• Multi carrier on satellite study • Latency/synch • Cellular integration	• Incorporate satellite into 5G standard. • Lab demo's • IoT early Demo	• Demo of fully integrated AI • IoT Demo
Spectrum	• Co existence mechanisms • Evaluate gains • Ka/Q/V/E	• Lab Demo's • Inc in standards • Regulatory acceptance	• Franchised data bases • Operational
Resilience	• Architectural studies • Security issues • Hand over issues	• Lab Demo's • Inc in standards • Equipment prototypes	• 5G Demo with sat and cellular • operations
localisation	• simulation sat+cellular • Lab Demo's	• Demos' with services • Inc in standards	• 5G network demo's • Services operational
Satellites	• Orbit studies for future systems • Frequency band	• Specify 5G sat • ESA ITT's for key elements	• Satellite Demo launch and early tests

	studies • MB Antennas • Interference/RA	• In Orbit tests of key elements	• Operational with IoT
Ground segment/terminals	• Feeder diversity studies • GBBF/OBBF optimisation • Integrated terminal studies • Energy minimisation • Hand overs	• Demo integrated networking • Terminal prototypes • IoT terminals	• Demo's on 5G satellite • Service demo's • IoT operation

Table1. Roadmap for satellite research and development towards 5G

7 Contribution of Satellite systems to the 5GPP KPIs

7.1 Performance KPIs

KPI#1 - Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010.

- Such capacity increase puts high constraints on the dimensioning of the wireless system at both the radio interface to the end-user device as well as the front and back haul interfaces. Introducing satellite broadcast/multicast resources to network edge (data distribution) will enable to off load part of the traffic to optimise the infrastructure dimensioning. Furthermore, high speed broadband satellite systems are needed for backhauling to extend the reliable delivery of 5G services to public transportations including aircrafts, vessels as well as trains and buses.

KPI#2 - Reducing the average service creation time cycle from 90 hours to 90 minutes (as compared to the equivalent time cycle in 2010).

- A seamless integration of satellite access networks in 5G, will result in a unified service delivery and aligned service creation time.

KPI#3 - Very dense deployments to connect over 7 trillion wireless devices serving over 7 billion people.

- Part of the M2M devices/traffic will be off loaded to satellite systems to ensure global service continuity. In addition, general control plane signalling can be off loaded to satellite systems to increase the network capacity for data transmission.

KPI#4 - Secure, reliable and dependable Internet with zero perceived downtime for services provision.

- Thanks to its dependability and wide area coverage characteristics satellite systems will constitute the necessary overlay network to enable a high network resiliency and to support rapid service deployment/recovery.

7.2 Societal KPIs

KPI#5 - Enabling advanced User controlled privacy

- Thanks to secure communication capabilities, the satellite can contribute to the user controlled privacy which is important for applications such as eHealth.

KPI#6 - Reduction of energy consumption per service up to 90% (as compared to 2010)

- With appropriate and reasonable developments at terminal level, broadcasting user data from a solar powered satellite platform over a wide area (data distribution) will constitute an energy efficient delivery and hence will contribute to optimise the energy consumption in the network.

KPI#7 -European availability of a competitive industrial offer for 5G systems and technologies

- 5GPPP constitutes a unique framework for European Satellite system research stakeholders to develop leadership with innovative technologies and products enabling smart integration of satellite solutions in 5G that can be commercialised worldwide and especially in emerging countries where coverage and dependability issues are even more acute than in Europe.

KPI#8 - New economically viable services of high societal value like U-HDTV and M2M applications

- Satellite systems are essential in the 5G network to enable a cost effective UHDTV service delivery (data distribution), the global service continuity for end-users as well as M2M application, the network resiliency as well as rapid service deployment for critical missions support (e.g. Public Protection Disaster Relief). Last but not least they will contribute to provide e-government and e-health applications at pan-European level.

Establishment and availability of 5G skills development curricula in partnership with the EIT

- The integration of satellite systems in 5G, will foster the need for common expertise and facilitate job mobility across satellite and terrestrial industry.

References:

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[3] 'Scenarios, requirements and KPI's for 5G mobile and wireless systems' ICT-317669-METIS/D1.1.April2013. www.metis2020.com/docum,ents/deliverables

[4] Horizon2020-Advanced 5G Networks Infrastructure for future Internet PPP—www.Net!works.eu

[5] EC H2020 5G Infrastructure PPP—Prestructuring model RTD&INNO strands—www.5g-ppp.eu

Appendix A: Mapping into the 5GPPP 2014/15 call.

Research topics identification

In this section we take the use cases and the research topics addressed in the paper and attempt to map them into the pre-structured projects addressed in the 5GPPP Association paper.

Service continuity

Backhauling service

- Air interface common building blocks between FS and FSS (P2)
- Enablers for improved spectrum efficiency of Satellite network in exclusive and shared band context (e.g. millimetre wave bands) => P4
- Common hardware/software building blocks (P5)
- Flexible transport/network protocol to cope also with extended latency => P7
- Joint satellite-terrestrial backhaul resource management => P7
- Vertical satellite/terrestrial network hand-over => P9
- QoE: Latency mitigation with smart caching scheme => P10
- SatCom integration with terrestrial network at network management, service level and security (P10, 11, 12 and 13)

Direct access service

- Air interface harmonisation (P2) (multi-bearer including satellite)
- Enablers for improved spectrum efficiency of Satellite network in exclusive and shared spectrum context => P2
- Integration of satellite access network with core network (P8)
- Integration of satellite as Wireless access network in the new RAN architecture for 5G (P6)
- Definition of new core network with a common unified control plane: intra-technology, inter/intra-domain (P8)
- Context management to optimize resources and allow handover between technologies (P8, P9)
- Vertical hand-over (P8, P9)
- Seamless service and network management integration with terrestrial network (P10, 11, 12 and 13)
- Network convergence (P6, P8, P9, P10, P12)

Multimedia distribution

- Efficient protocols and air interface for all kinds of data distribution spanning the range of small to largest data elements (for instance, SMS's on the small side to Ultra HD-movies and very large data bases on the large side) => P2, P5, P6, P7, P16
- Optimal data distributions strategies utilising broadcast or highly asymmetric data channels => P8
- Caching placement strategy, algorithms and protocols for an optimised QoE => P8, P9
- Efficient recovery of interrupted cache fills => P9
- Integrated network management => P11, P12
- Content rights management of distributed data as it propagates through networks => P13, P14, and P15
- Authentication (via satellite) that cached data is the latest, and is not spoofed => P13

- According to the different technological steps listed above, a network element (such as a Home Gateway) (P5) which enables the reception of broadcast / broadband content both in a :
    - transparent way for the final user ;
    - smart (software defined) way for the network operator ;
    - Plus push-VOD
- Full Frequency Reuse Multibeam HTS Systems for joint Broadband/Broadcast services => P2

Finally, even though broadcast is, by definition, more open than individual point-to-point communications, network security and integrity are still important. Hence 5G Infrastructure PPP Pre-structuring model project P13 must also include multimedia distribution.

M2M

- Optimized assignment of resources (e.g., appropriate spectrum bands, not conflicting with incumbents) by taking into account combined usage of terrestrial and satellite networks => P9
- Enablers for improved spectrum efficiency of Satellite network in exclusive and shared spectrum context => P2
- Improvement of end-to-end QoS/QoE and latency (e.g., serving latency-sensitive application) including satellite segment by taking into account energy and cost constraints => P9
- Common and generic modules for access agnostic network and service management => P9, P10, P11, P12
- Integrated system and gateway design => P1, P3
- Embedded chipsets with integrated cellular/satellite modules => P5
- Small omnidirectional antennas => P2

Network control Signalling off load

- Design a multi-RAT system that efficiently integrates legacy and 5G air interfaces-control plane and user plane design for novel 5G components (P1)
- Energy efficiency for network design (P2)
- Design signalling , protocols and MM across multi point/band layer networks(P6)
- Seamless integration of heterogeneous wireless and satellite systems (P7)
- Define a converged and flexible control plane for heterogeneous access and optimisation of service and data(P8)
- Conceive and design novel enabling technologies for a unified control and data plane structure(P9)

Critical telecom missions

To provide seamless and reliable services for critical missions, it is necessary to define:

- Integrated system design (comprising satellite and terrestrial networks) including handover procedures and required air interfaces for the professional services => P1, P2, P3
- Enablers for improved spectrum efficiency of Satellite network in exclusive and shared spectrum context => P2
- Satellite architectures for on-board-processing to support meshed networks for hub-less communication => P1, P6

- Satellite/terrestrial terminal architectures for seamless service provision => P5
- Handover protocols for professional mobile radio (PMR), satellites and alternative terrestrial networks => P6
- Intra-system frequency coordination methodologies and procedures incl. the influence on the terminal architecture; definition of service prioritisation (of professional and commercial services) is mandatory => P8, P11
- Mobility, security and QoS (P8)

Research topics mapping to the 5GPPP pre-structuring model[2]

The identified SatCom research topics have to be incorporated in all of the below projects so that the 5G can benefits from SatCom added value resulting in enhanced KPIs. If this is not possible, project proposals beyond the pre structured model will have to be considered to address the research topics identified in this paper.

Px	**Project strand name**	**SatCom use cases and external constraints**				
		Global service continuity	***Multimedia Distribution***	***M2M***	***Nwk control signalling off load***	***Critical telecom missions***
P1	5G Wireless System Design			X	X	X
P2	Air Interface and Multi-Antenna, Multi-Service Air Interface below xx GHz	X	X	X	X	X
P3	5G-MTC (Machine Type Communications) for Consumers and Professional Communications			X		X
P4	New Spectrum and mm-Wave Air Interface for Access, Backhaul and Fronthaul	X		X		
P5	Efficient Hardware/Software and Platforms for 5G Network Elements and Devices	X	X	X		X
P6	Novel Radio System Architecture		X	X	X	X
P7	Backhaul and Fronthaul Integration	X	X		X	
P8	Holistic 5G Network Architecture	X	X		X	X
P9	Enabling Technologies for Unified Control of Converged 5G System	X	X	X	X	
P10	5G Services E2E Brokering and Delivery	X	X	X		
P11	Cognitive Network Management	X	X	X		
P12	Service Level Management & Metrics for QoS & QoE	X	X	X		
P13	5G Network Security and Integrity	X	X			
P14	Virtual Network Platform		X			
P15	Service Programming and Orchestration		X			
P16	Multi-Domain SW Networks		X			

[2] EC H2020 5G Infrastructure PPP Pre-structuring Model RTD & INNO Strands (Version 2.0), Recommendation by 5G Infrastructure Association, May 2014