A5 SatCom research topics in 5GPPP

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1) Foreword

Satellite systems are fundamental components to deliver reliably 5G services across the whole of Europe but also in all regions of the world at an affordable cost.

This document constitutes the vision of the roles for Satellite Communications (SatCom) in the future 5G converged network[17]. It has been prepared by the SatCom Working Group of NetWorld2020 using existing White Paper inputs[18]. It identifies the research topics that need to be carried out in the context of H2020 ICT 5GPPP program (Pre structuring model) to deliver on this vision.

2) Introduction

SatCom is already complementing and enhancing terrestrial networks in the delivery of broadcast, broadband (or even in the joint delivery of hybrid broadcast/broadband services) and narrowband services to fixed and mobile user terminals.

The 5GPPP first call is the sole opportunity to integrate SatComs solutions in the future 5G converged network infrastructure. This will allow to benefit from their inherent characteristics for an augmented service capability to address some of the major 5G challenges in relation to the support of multimedia traffic growth, ubiquitous coverage, Machine To Machine communications and critical telecom missions while optimising the value for money for the end-users.

This requires however to adopt a disruptive approach when designing the 5G network architecture by harnessing all network technologies to include SatCom solutions.

The research and innovation plan within H2020 ICT 5GPPP and H2020 Space should be steered to address the enablers of this vision.

3) SatCom trends

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

[17] "What is 5G (Really) About? White Paper" from the Networld2020 ETP

[18] " The role of Satellites in 5G—A White paper from the new-etp Satellite WG", May 2014

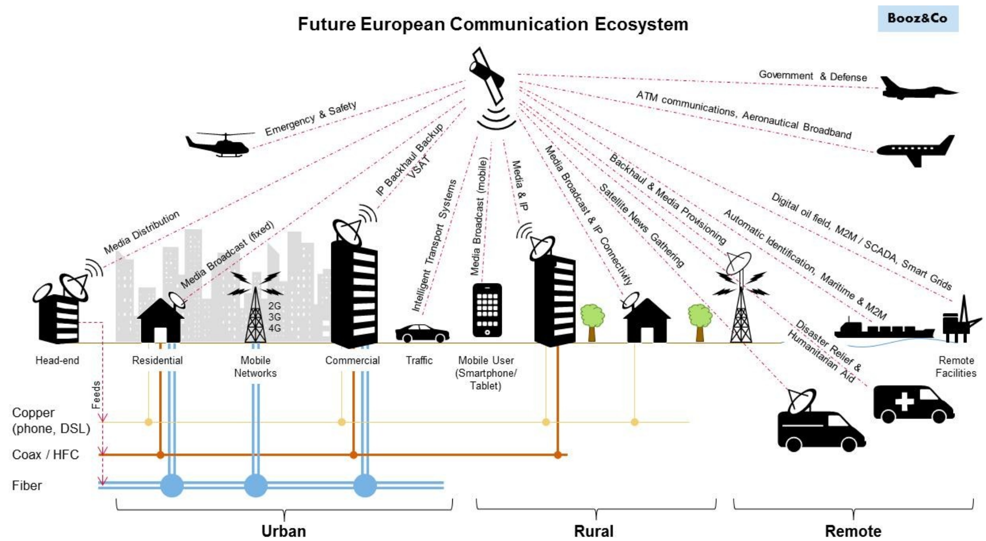

Figure 7-1: Sketch of satellite role in future communication systems[19]

The space components of communication systems are located in the outer space following different types of orbits – Geostationary Orbit (GEO), Medium Earth Orbit (MEO), High Elliptical Orbit (HEO) or Low Earth Orbit (LEO). SatComs operate in frequency bands allocated to Broadcasting, Fixed or Mobile Satellite services in low frequency bands (below 3 GHz, such as VHF, UHF, L and S band) or in higher frequency bands (above 3 GHz, such as C, X, Ku and Ka bands and above).

SatCom systems can address a wide range of services like 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 topology with the support of star and/or mesh topology with or without Inter satellite links and in in coverage

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

Link cost reduction is a key system design driver which impacts the space segment sizing in terms of satellite size and number of satellites (in constellations).

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.

4) SatCom added value integrated in 5G

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.

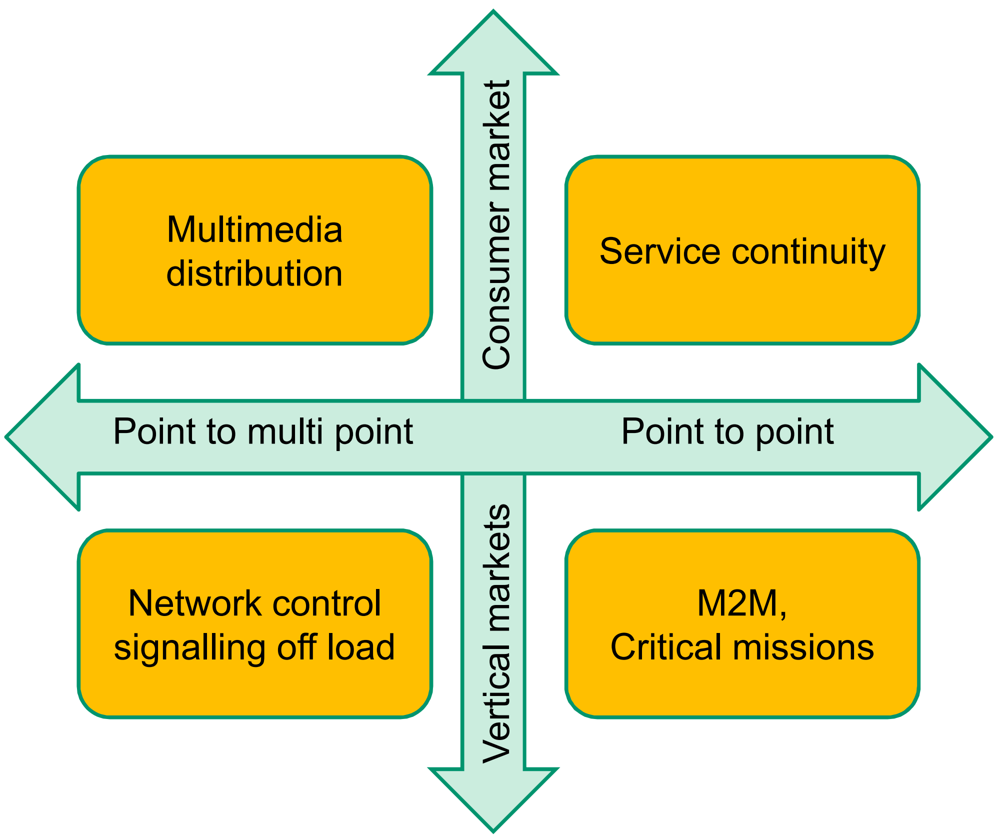

Figure 2: Satellite use cases in 5G

4.1.1 Service continuity

Description

With its regional (e.g.: single Geostationary satellite) or worldwide (e.g. constellation 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)

4.1.2 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.

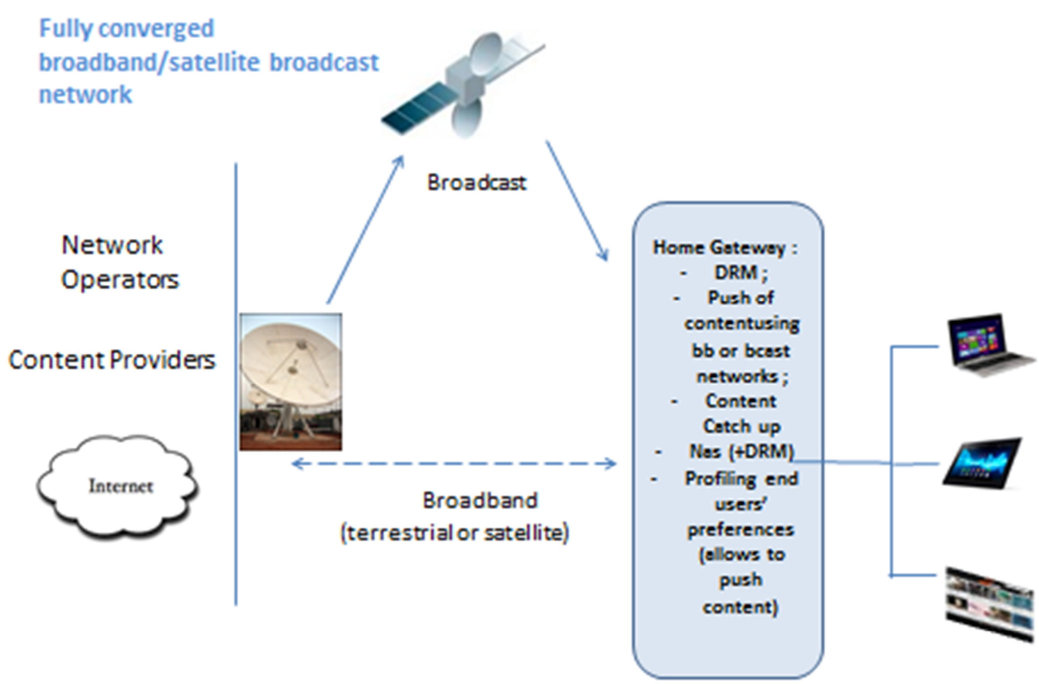

Figure 3: Converged multimedia distribution network

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 by an operator
- 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.

1. The first step consists in converting the format of the transport of content from different sources (broadband / broadcast) into a unified format -typically IP-compatible with the distribution in the local / domestic network and with the use on different devices and screens.
2. The second step introduces an early and limited interaction between network operators/content providers and final users (with issues regarding users' preferences, the popularity of contents and DRM).

The first and second steps have already been achieved by satellite operators.

3. The third step allows 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.
4. The last 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).

4.1.3 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

With the aforementioned M2M use cases, various topics of research challenges are addressed 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

4.1.4.1 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 services for critical telecom missions in a combining satellite, cellular and ad-hoc networks.

4.2 Contribution of Satellite systems to the 5GPP KPIs

4.2.1 Performance KPIs

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.

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.

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.

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.

4.2.2 Societal KPIs

Enabling advanced User controlled privacy

- N/A

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.

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.

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.

5) SatCom research topics for 5GPPP

5.1 Research topics identification

In order for Satellite systems to play in 5G the use cases and challenges identified in the previous section, it is necessary to address the following research topics.

5.1.1 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. millimeter 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)

5.1.2 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.

5.1.3 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

5.1.4 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)

5.1.5 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)

5.2 Research topics mapping to the 5GPPP pre-structuring model[20]

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			

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