# The role of Satellites in 5G

Barry G. Evans
Centre for Communication Systems Research
University of Surrey
Guildford, United Kingdom
b.evans.@surrey.ac.uk

*Abstract*—**In this paper we review some of the work of the' Satellite Working Group' in the European Technology platform NETWORLD2020 towards a strategy for satellites in 5G. We first review the 5G vision and its drivers as defined by the terrestrial mobile community via the 5GPPP Association. We then outline the areas in which satellite can contribute to an integrated system within 5G and detail the research challenges that this provides. Finally we give views on a technology roadmap to meet these challenges such that satellites are ready by 2020 to play their part in the integrated 5G roll out.**

***Keywords-5G, satellite communications,future internet.***

## I. INTRODUCTION

Mobile cellular communication systems have evolved through a series of standards known as 'Generations' from Analogue(1G) through GSM (2G) via IMT 2000 (3G) to today's LTE(4G) systems. Satellite mobile systems have developed independently of the terrestrial systems and have largely been proprietary e.g. the Inmarsat system. There has been a loose connection in that the latter have generally used the GSM network model and more recently there have been versions of GSM/GPRS and 3G adapted for satellites e.g. the ETSI GMR series of standards. The result of this separation between the communities is that it is very difficult to integrate the two networks and thus join them so as to provide seamless services over both. Very recently the community has woken up to this problem and work is on-going to enable some integration of 4G between satellite and mobile. Today we are at the start of working towards the next generation—5G, which is likely to be standardised by 2016 and be rolled out from 2020. The EU have set up a 5GPPP research programme to fund research towards this new standard which will commence in 2015. A group of companies have formed the '5GPPP Association' and have worked towards a definition of this research programme[1-2]and is also included within a new European Technology Platform—NETWORLD2020. The latter ETP merges the old terrestrial Net!works and the satellite ISI, ETP's such as to integrate these two key components of future communications. This provides the structure in which the two communities can now work together, for the first time, to develop an integrated 5G standard. Within NETWORLD2020 there is a Satellite Working Group that is producing a White Paper on the role of satellites in 5G. This paper is based on the work conducted for that paper but also contains some personal views of the author.

## II. THE 5G VISION

The vision of 5G mobile[3-5] 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 referred 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 e.g. 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, which will not entirely be homogeneous but a flexible heterogeneous network where the resources can be adapted dynamically (on demand) as the users demands in space, time and spectral resources and even between operator changes. This requires a fundamental redesign of the network which still has a legacy of cellular networking based upon 3G and which results in excessive and inefficient signaling, 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 total energy by 2020 at no reduction in performance or increase in cost. Thus 5G

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network design becomes a complex task involving link and area spectral efficiency together with energy efficiency.

## III. SATELLITES: FROM TODAY TOWARDS 2020

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 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 Ku 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 principally for broadcast services to mobile. More recently a return link standard has been added to this but is not as yet operational.

3GPP-like services exist via satellite to individual users, but as yet these have not been extended to 4G. Backhaul 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 are seen as ideal for satellite delivery. Satellite is also used extensively for low rate SCADA applications to/from pipelines, oil and gas remote installations 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.

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.

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For the period 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 despite limited spectrum. Higher frequency bands will 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 and on ground signal processing will enable improved connectivity and flexibility to meet changing traffic patterns and demands eg adaptive beam forming and hopping and interference management to increase capacity. Alternative architectures involving clusters of GEO's and possibly fragmentation of functions between the connected clustered satellites with ISL's will evolve. Following the innovations of using different orbits by O3b new non GEO systems are likely to appear possibly using all optical technology—between satellites and from satellite to ground.

Satellite and terrestrial system integration is already a trend and this will continue with the development of integrated standards to allow the two sectors to interconnect efficiently both at network level and at IP levels. In addition mobility management integration will evolve across the larger satellite and smaller terrestrial cells.

## IV. KEY AREAS WHERE SATELLITE CAN PLAY A PART IN 5G

The key areas in which satellites can play a part in 5G are discussed below.

- **Coverage**

Satellites can provide the wide coverage to complement and to extend the dense terrestrial cells, which is in line with the ubiquitous coverage targeted by 5G networks They will not be able to match the area spectral efficiency of the 5G terrestrial but they can provide larger cells in a heterogeneous arrangement which can also be used for critical and emergency services and possibly to relieve the terrestrial cells of signaling and management functions in a software defined network configuration.

- **Integration**

Integrating satellites with the terrestrial system is perhaps the key area that enables many advantages. Improving QoE by intelligently routing traffic between the delivery systems and caching high capacity video for onward transmission terrestrially. This can be empowered by the inherent multicast/broadcast capabilities of satellite systems, while propagation latency is no longer an issue thanks to intelligent caching. Off loading traffic from the terrestrial system to save on valuable terrestrial spectrum opens up the possibility of improving resilience and security using the two networks.

- **Backhaul**

One of the major issues in 5G is seen to be the increased demands on the backhaul with very large numbers of small cells. High throughput satellites can be used here to compliment terrestrial provision and provide backhaul in areas where it is difficult to do so terrestrially. In a virtualised and SDN it might also be possible to include some of the network node functions on board the satellite and thus save on physical sites on the ground.

- **Resilience, security and availability**

We have seen that this is a key feature in 5G and satellites can be used to provide an overlay network that can take over and keep alive the network in case of man-made or natural disasters. They will not be able to provide the full set of services but they are key to retention of critical and life-saving services. As 5G becomes not just a nice to have facility but an essential part of national infrastructures, it will be used more for strategic services.

- **IoT**

The inclusion of billions of sensors in the IoT all transmitting low date rate M2M and being scattered over wide areas makes it well suited to satellite collection and distribution. Here again integrated systems are forseen with new network architectures collecting from clusters of sensors and satellite being used to backhaul them to fusion POP's. Based on the wide satellite coverage, IoT economies of scale can be achieved and promote viable business models for a large number of bursty-low rate transmissions.

- **Spectrum**

The lack of spectrum was seen as one of the key drivers to the 5G network architecture. The demands on the design of the network could be relaxed if more spectrum could be made available. Frequency sharing on a dynamic basis between mobile and satellite systems can deliver major increases in the spectrum provided both sectors accept the sharing principles. Here techniques of data bases and cognitive radio can be built into future systems to allow such frequency sharing. This can be a win-win situation to both sectors and would be enhanced by an integrated approach.

## V. Addressing the 5G Key Areas

The NETWORLD2020 experts group have brigaded topics for consideration into four areas; services&requirements, software defined networks and virtualisation, connectivity and networks and air interface. In this section we present the inputs from the satellite WG to these four areas. The latter will eventually be combined into a single White Paper and then form the strategic research agenda for the ETP. It is noted that the 5G call (Nov 14) of the EU considers groupings of, Radio Network architectures and technologies, convergence beyond the last mile, network virtualisation and software defined networks and network management. There is clear commonality in these areas and in the following they are addressed as far as satellites are concerned.

**Services and user requirements:**

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 demonstration for example could 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 such 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 for multicast in satellite and cellular integration

QoE is becoming the byword for service provision 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 and QoE.

**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 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. A key enabler will be the definition of a new management paradigm that will facilitate E2E self-management at both the network and service levels. In particular this needs to map the state of underlying network infrastructure and terminals to the perceived QoE of the users. 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.

**Connectivity and Networks:**

The integration of satellite and terrestrial can be used to extend the 5G network to ubiquitous coverage.In each of these extended 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 gateway diversity schemes the availability can be provided. Other innovations are being made in interference management via spatial precoding design and beam/frequency/modcod allocation; complexity control with hybrid on-ground/on-board beamforming and precoding architectures; Power Allocation Algorithms for IDMA-based Multi-Beam Satellite Communication. All of these provide highly flexible and spectrally efficient satellite systems.

5G is addressing convergence on an access agnostic basis. In particular we need to design a converged control plane which works across different data planes using a software based architecture. These new control mechanisms and protocols will facilitate the interconnection of mobile and satellite systems.

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 optimal performance and the signaling load on the networks .

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.

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 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.

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 and 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.

**Air interface:**

The 5G air interface has the challenge of incorporating a range of different traffic types from high rate video down to the low rate IoT applications and serving applications with a range of latency requirements, while providing ubiquitous coverage. We see that the integration of satellite and cellular 5G is essential to extract the combined benefits of both sectors. The drivers in the satellite channel are however different from those in the cellular—signal to noise ratio is much lower, multipath is not so important but the channel is non-linear and suffers from more latency inhibiting adaption—depending on the satellite orbit. In this respect we need to adopt as far as possible flexible waveforms and air interfaces, which can be easily tuned depending on the channel they have to face. Hierarchical modulations are also an interesting tool for this reconciliation of the terrestrial and satellite air interfaces. Concerning the MAC, there is much to gain from an integrated terminal which uses as much commonality as possible with terrestrial, e.g. by 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 suitable for satellite and context aware multi-user detection, either centralized or decentralized, as a means to introduce QoE requirements. Aggressive frequency reuse combined with multiuser MIMO techniques can provide improved and flexible system throughput. For these techniques a feedback channel is important, it can be terrestrial; thus further fostering some integration. Receivers for bursty communications are an area of research that will benefit the role of satellites in IoT. Multicarrier schemes such as filter bank systems or other enhanced OFDM schemes with appropriate modulations that offer optimal spectral efficiency and frequency granularity are being investigated in terrestrial wireless but also have commonality to satellite systems.

It is quite clear that there is a spectrum crunch looming for cellular and a need to use spectrum more efficiently. Thus frequency sharing between cellular and satellite is one component that can contribute to solving this problem. At the moment frequency bands are segmented but this is wasteful and we need to allocate them more dynamically on the basis of demand. Techniques such as intelligent data bases and Cognitive Radio as well as smart antenna beamforming can be used to facilitate frequency sharing to the benefit of both sectors.

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## VI. Research Challenges

The vision of 5G, and the role of satellite in this vision, reveals a number of research challenges. 5G strives to provide a communication environment that addresses a wider set of societal challenges through a more flexible, programmable and secure infrastructure. At the same time providing enhanced QoE to users at a fraction of today's cost and energy utilisation. There will be in 5G an increased set of stakeholders and an increased range of services to be satisfied on a demand attentive basis. There are many challenges that are common across the satellite and terrestrial domains but in the following we list the key satellite challenges.

- **Integration challenge**—to enable satellites to extend the coverage of cellular systems in such a way as to improve quality and range of services, cost effectiveness and energy utilisation whilst reducing terminal costs
- **QoE challenge—**provide a guaranteed user experience across dimensions such as throughput, latency and cost per bit independently of the user's location.
- **Latency challenge—**match the latency demands of new interactive and immersive services below 100ms.
- **Spectrum challenge—**to enable the sharing of spectrum between satellite and terrestrial in the millimeter bands and above.
- **Energy reduction challenge**- The target is a reduction by 90% of today's energy by 2020 at no reduction in performance and increase in cost.
- **Localisation challenge—**provide in conjunction with terrestrial networks positioning capabilities down to the millimetre range to enable the IoT.
- **Resilience challenge—**provide an overall integrated 5G system that is intrinsically robust to attacks of both man-made and natural causes that is trusted by strategic authorities.
- **Multi service challenge—**provide an overall network structure that will efficiently accommodate M2M rate services as well as high rate video services and all those in between.

## VII. A possible 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
- Compatible air interface
- Integrated network standards for backhaul
- Spectrum sharing in the millimeter bands
- New satellite constellations to address IoT

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.

## VIII. Summary and Conclusions

In this paper the role of satellites in 5G has been addressed and the key challenges defined along with a possible roadmap to lead to operating systems by 2020. It has been emphasized that the satellite community must work closely with the mobile 5G community in studies, standardization and demonstrations if we are to realize the integrated system for 5G by 2020.

## Acknowledgment

The author would like to acknowledge the many contributions made by the members of the satellite working group of NETWWORLD2020 to the White paper on which this contribution is based.

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**Table 1 Technology Roadmap**

| Timeline/Technology | 2016-studies | 2016-2020-standards | +2020-Demo/operation |
|---|---|---|---|
| Integration | • 5G over satellite<br>• Backhaul interface<br>• 5G interface | • Satconverged network.<br>• ETSI/DVB/5GPPP<br>• Early lab demo's | • Fully integrated operatoin<br>• Inc IoT |
| Air interface | • Multi carrier on sat<br>• Latency/synch<br>• Cellar integration | • Incorporate into 5G standard.<br>• Lab demo's<br>• IoT Demo | • Demo fully integrated AI<br>• IoT Demo |
| Spectrum | • Sharing mechanisms<br>• Evaluate operation<br>• S/C/Ka | • Demo's<br>• Inc in standards<br>• Regulatory acceptance | • Franchised data bases<br>• Operation |
| Resilience | • Architectures<br>• Security<br>• Hand over | • Demo's<br>• Inc in standards<br>• Equipment | • 5G Demo<br>• operation |
| localisation | • simulation sat+cellular<br>• Demo's | • Demos' with services<br>• Inc standards | • 5G demo's<br>• Services operational |
| Satellites | • Orbit studies<br>• Frequency bands<br>• MBAntennas<br>• Interference/RA | • Specify 5G sat<br>• ESA ITT's for key elements<br>• In Orbit tests | • Satellite launch and early tests<br>• Operational with IoT |
| Ground segment/terminals | • Feeder diversity<br>• GBBF/OBBF<br>• Integrated terminal<br>• Energy minimisation<br>• Hand overs | • Demo integrated networking<br>• Terminal prototypes<br>• IoT terminals | • Demo's on satellite<br>• Service demo's<br>• operation |

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