THE ROLE OF SATELLITES IN 5G

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ABSTRACT

The next generation of mobile radio communication systems—so called 5G—will provide some major changes to those generations to date. The ability to cope with huge increases in data traffic at reduced latencies and improved quality of user experience together with major reduction in energy usage are big challenges. In addition future systems will need to embody connections to billions of objects—the so called Internet of Things (IoT) which raise new challenges. Visions of 5G are now available from regions across the World and research is ongoing towards new standards. The consensus is a flatter architecture that adds a dense network of small cells operating in the millimetre wave bands and which are adaptable and software controlled. But what place for satellites in such a vision? The paper examines several potential roles for satellite including coverage extension, content distribution, providing resilience, improved spectrum utilisation and integrated signalling systems.

Index Terms— 5G, satellite communications, network architectures, signalling

1. 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. Recently we are waking 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 come into operation around 2020 and be standardised by 2016. The EU have set up a 5GPPP research programme to fund research towards this new standard which commences in 2015. A group of companies called the '5GPPP Association' have worked towards a definition of this research programme [1] and it 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.

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1.1. The 5G vision

The vision of 5G mobile [2-4] 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 be 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 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 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, with lower latency 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 quan-

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tities 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 or increase in cost. Thus 5G network design becomes a complex task involving link and area spectral efficiency together with energy efficiency.

2. 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.

2.1. Coverage and integration

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 signalling and management functions in a software defined network configuration.

Integrating satellites with the terrestrial system is perhaps the key area that enables many of the advantages. One of which is 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. Furthermore, traffic can be offloaded from the terrestrial system to save on valuable terrestrial spectrum, thus opening up the possibility of improving resilience and security using the two networks.

2.2. Resilience and Overspill

Satellites have an important potential role to play in supporting the overall resilience by complementing other communications infrastructures. Satellites can support a resilient 5G network to mitigate the problems of overload/congestion to meet the 5G KPI "ensure for everyone and everywhere access to a wider portfolio of services and applications at lower cost". The opportunities that are in scope here include:

- Placing intelligent router functionality (IRF) at the RAN will allow making intelligent decisions concerning the backhaul of traffic to the wider network from both stationary and moving RANs. The IRF will need to make decisions concerning traffic routing over heterogeneous links including satellite taking into account the needs of the applications. Under normal conditions, only a small part of the traffic will be transferred over the satellite link. However in times of congestion and network stress (e.g. high load, backhaul failure), or if the moving RAN travels out of range of its alternative terrestrial radio link, the traffic would flow over the satellite link in a seamless manner until the terrestrial connections are restored. In this way satellite capacity can be shared over a large number of sites with a low cost per site for the satellite traffic and an ultra-high availability from the point of view of the end user.
- For cells placed in rural areas satellite delivery would ensure high data capacity made available even to the digitally deprived. This will require the creation of different bandwidth pools to separate traffic for control plane, dedicated real time applications such as voice and best effort data.
- In urban areas where there is a spike in demand (e.g. uploading of video files, downloading of video content), data availability would be guaranteed since the macro-overlay satellite capacity would handover as the user moves across different network cells (e.g. moving in a crowd or on mass transport systems).

2.3 Content multicast and caching

Satellites have a major role in content caching near the edge, bringing content closer to the user in order to achieve the 5G KPI target of "zero perceived delay" and "providing 1000 times higher wireless area capacity in access" to multimedia rich content:

- Global coverage with low number of intermediary autonomous systems based on satellite network;
- Ultra low content access latency – providing near instant access to multimedia rich content;
- Offloading the cache content population from terrestrial networks.

Today service providers employ a Content Delivery Network (CDN) for better access to the content and/or to reduce backbone costs – known as an access centric CDN and content owners employ CDNs to enhance service for end user – known as a content centric CDN. Both CDN techniques are expected to be widely used in 5G networks putting pressure and increasing expectations for immediate and continuous access to rich multimedia content. All predictions indicate that there will be a huge growth in video downloads on mobile devices. Caching content close to the edge using efficient multicast delivery will improve the end user QoE and reduce backhaul traffic load. This form of content delivery can be managed using Information Centric Network (ICN) systems or other variations incorporating SDN/NFV with a centralised controller function that optimises delivery using satellite links when appropriate to provide immediate and on demand content access. The need to deliver rich multimedia content will drive content caching close to the 5G Radio Access Networks (RANs). Hence, how the natural capability of satellite to multicast data over a wide geographic region can be integrated into the CDN/ICN systems designed for 5G specifications needs to be investigated. Furthermore, the most beneficial scenarios for multicasting with impact of different content types and the use of satellite to provide resilience need to be investigated.

2.4 Internet of Things over satellite network

It is expected trillions of sensors and devices will be connected through the 5G infrastructure. The sensors and devices will serve many different and diverse applications. There are many national and supra-national initiatives to reduce energy consumption and increase energy efficiency. One of the expected implications is global wide deployment of trillions of monitoring systems as part of the Internet of Things (IoT) connected over 5G infrastructures. Each IoT device will naturally consume power when actively connected to the network. The feasibility of uploading IoT services over satellite and using different orbital architectures (e.g. GEO, MEO and LEO) has yet to be made. New evolutionary techniques to reduce power consumption of satellite terminals deploying 5G networks delivering IoT services needs to be addressed including:

- Adapting the air interface to allow the satellite terminal to reduce its power consumption when idle;
- New physical and data link layers to minimise energy consumption;
- Modification to the IETF protocols.

All of the above aim to meet the 5G KPI target "facilitating very dense deployments of wireless communication" links to connect over 7 trillion wireless devices serving over 7 billion people.

2.5 Cognitive management of software networking across satellite/terrestrial interfaces

Mobile soft core networks are new innovative platforms being developed by mobile industries to allow greater flexibility for network deployment in environments with limited planning, build and operational support. This will need:

- Seamless management and orchestration of heterogeneous satellite and terrestrial network elements;
- Orchestration of user application or network service requesting QoS classes across these heterogeneous network elements;
- Virtualising of satellite gateway functions.

In order to meet the target 5G KPI "ensuring for everyone and everywhere access to a wider panel of services and applications" and "reducing the average service creation time cycle from 90 hours to 90 minutes". This goal can be achieved by allowing the orchestrator to manage the different technologies in an automated manner. This will be possible by the abstraction level that will be provided for the orchestrator. The orchestrator will manage the various technologies according to its specific capabilities and options and according to the requested services and applications.

2.6 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.

3. AN INTEGRATED NETWORK APPROACH

Integration between two different realms of satellite communications and mobile wireless / terrestrial systems players has always been difficult due to the stove pipe approach of each sector. When integration has happened it has usually been as a result of massive re-engineering and cost. As a result, current satellite networks support mainly 2G network backhaul for fixed sites with limited connectivity (e.g. aircrafts and ships) or emergency situations while 3G and LTE networks are now following an extensive engineering effort for standards adaptation towards the specific satellite characteristics.

The recent emergence of a new 5G ecosystem with its convergence requirements provides a unique opportunity to overcome some of the integration barriers, which existed in the past through development of a single environment from the initial development stages. At the same time, it paves the way in order to enable two parts of the telecommunication industry to work together in order to define and specify a single 5G system with a holistic perspective. This ensures that satellite communications can address some of the potential challenges in supporting the different envisaged requirements for 5G networks.

We propose an integrated network ecosystem as shown in Fig. 1 with integration at the RAN as well as the core network. As satellite provides the coverage extension to sea and air we envisage this to include mobile RAN's as well. This ecosystem could provide the following use cases;

- Inter-Cluster Satellite Link for Remote Clustering;
- Inter-Cluster Satellite Link for Edge Communities;
- Inter-Cluster Satellite Link for Overflow Communities;
- Remote IoT System with Satellite Integration;
- Entertainment Update with Satellite Integration for air(Connected Aircraft) and sea (Connected ships);
- Freight and logistics;
- Lorry monitoring and communications – dual mode terrestrial and satellite;
- LEO satellite providing low latency control plane offloading;
- Dual mode IoT sensors using terrestrial networks when connectivity is available and switch to satellite when out of reach.

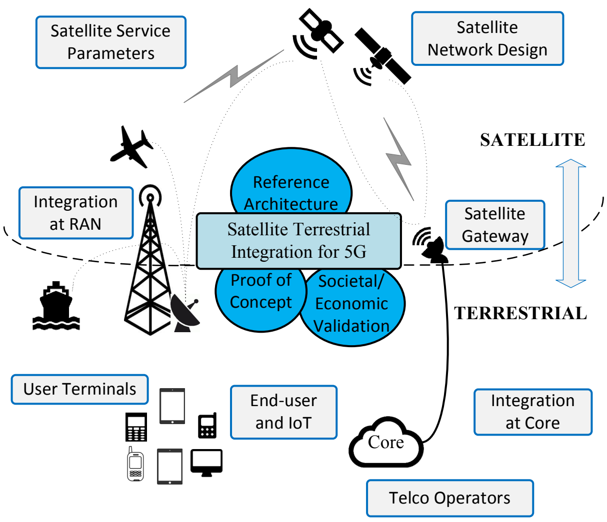

Fig. 1. Integrated network ecosystem

The 5G network architecture is currently being researched and will evolve over the next two years. Cloud RAN is considered by most as an on-going evolution for 5G (split-out of the Radio Interface Equipment at the base site and group processing in a centralised fashion of the base band signal) and brings capacity and coverage gains to the radio interface. This technique may be operated for a cluster of local cells on a small scale and/or a very large scale across a city deployment. Other operators still want a more distributed approach where the transmission to support large bandwidth CPRI (C-RAN) backhaul is less available and techniques for more traditional base station deployment evolution are also being evaluated. In the core network, Cloud computing is also being developed where a traditional LTE core network is being split into its constituent parts and devolved to be closer to the RAN, typically operating as small clusters and offering flatter and closer to the user service. Research is progressing to reduce signalling and operate more predictive approaches to signalling coordination based on SDN and NFV principles. A major change in the way that we use mobile networks has also accelerated the idea of bringing Content Centric Networking techniques to Mobile Networks and a lot of work is now in process to make ICN much more a central and built in feature of 5G.

The core is evolving to operate more meta-data and profiling in its mobile network operation to improve signalling and overall data latency. Typical examples are much more extensive User Profiles that are selectively exposed to support a variety of applications under selective levels of security. In evolving ideas of 5G mobile networks, the Core network is devolving towards the RAN, content and signalling optimisations are evolving and the radio system is becoming a more efficient system rather than pure radio interface. The common 5G term of “One size does not fit all” is also apparent for a network seeking to satisfy Interactive usage services, User Content services, MTC and broadcast. So, 5G is highly likely to comprise a small base set of common features with packages of standardised additional features to be applied for various combinations of targeted use, making the environment ideal for the integration of various other communication technologies, such as satellite networks.

4. INTEGRATED SIGNALLING AND ENERGY SAVINGS

The 5G environment includes a large number of very small, dense cells for delivering high rate communication services close to the user. The challenge with this architecture is the exponential increase in the amount of signalling capacity needed and the consequence of limited capacity for user data services. In addition to this, the base station signalling contributes to the overall system energy usage and hampers energy reduction. In order to meet the 5G KPI target “for energy reduction”, it is proposed to split the control (C) plane and the data (U) plane. In this architecture the base stations will deliver data on the U plane using terrestrial link when present and to route the C plane via an overlay macrocell backhauled over a satellite link [5]. Consequently, this gives the network operator more flexibility, since the small/data cells can be activated on demand to deliver user-specific data only when and where needed. Thus, the energy consumption is improved, since the split architecture also leads to longer data cell sleep periods, due to their on demand activation [6]. In the rural context however, the focus will be to identify C plane traffic that can be managed locally and only utilize the satellite link when required.

4.1. Evaluating integrated signalling and energy savings

Advanced satellite payloads and enhanced on board processing can enable the satellite to cache specific user information, e.g. user ID parameters, thus reducing the required physical resources transmitted for user authentication. This results in an increase in the physical resources available for data transmission from the U plane. In the terrestrial split C/U plane architecture, one of the C-plane signalling channels that are used to support data transmission is the Physical Hybrid ARQ Indicator Channel (PHICH), which is responsible for providing ARQ acknowledgements. However, in the integrated architecture, it is possible to loosen the acknowledgment restrictions and reduce the resources reserved for the PHICH, since reliability can be further guaranteed by the upper layer protocols [5]. By doing so, the amount of resource elements available for data transmission is increased. A comparison of the number of resource element used for U-plane signalling in Long Term Evolution (LTE), LTE-Advanced and the integrated architecture, where the U plane and C plane are decoupled, is shown in Fig. 2. As it can be seen, significant reduction in overhead is achieved with the integrated architecture since the U-plane’s frame structure can be optimized to suit the local environment. This leads to an increase in capacity as shown in Table 1, where low earth orbiting (LEO) satellites provides C plane functionality. Furthermore, Table 1 also shows that using LEO satellites for C-plane functionality results in significant reduction in power consumption as a result of its wider coverage compared to the terrestrial eNodeB in LTE-A.

4.2. Challenges of integrated signalling

Similar to the terrestrial C/U plane split architecture, the satellite integrated split architecture must also meet the 5G engineering requirements. In addition to this, the requirements for managing ultra-dense cells must also be met in such integrated architecture. These requirements include handover and mobility management, backhauling management and data cell discovery. Since the data cells have small coverage area, excessive data cell to data cell handovers, which can be managed by implementing satellite aided user-path prediction, is expected in such architecture. Also, since the small cells are in various sizes, they would have varying backhauling cost, hence the backhaul has to be planned effectively to minimize cost while guaranteeing QoS. User association with the data cells in the conventional split architecture are managed by the macro cells which provide control plane functionalities, whereas in the integrated architecture, satellites will handle control signalling and, hence, user-data cell association. One of the propositions in the conventional split architecture is for the macro/control cells to handle data transmission for high mobility and low rate users in order to reduce handover failures; the feasibility of satellites serving high mobility and low data rate has to be investigated.

In order to progress the integrated technology in relations to 5G, satellite latency has to be addressed. The specified round trip latency for 5G, which is as low as 1 ms, can be achieved in the data plane of the integrated architecture. However, this cannot be achieved in the control plane of such architecture since the round trip propagation delay for low-earth orbiting (LEO) satellites such as Iridium, Orbcomm and Globalstar constellations are about 8.6 ms, 9 ms and 15.6 ms, respectively, while it can be about 540 ms for geosynchronous satellites. As a result of this latency, control plane offloading, i.e. from satellite C-plane to terrestrial C-plane and vice versa becomes a challenge. Hence schemes towards achieving a low latency control plane need to be investigated.

Specifying the functionality of each plane and dimensioning their physical layer frames is a challenge in both the conventional and the integrated split architecture. This challenge arises from the fact that certain user activity such as handover requires several functionalities such as broadcast and synchronization functionalities, while the frame control signal is required for more than one network functionality [6]. Hence, the signalling and functionalities of associated with each plane must be correctly allocated. Moreover, the ability of satellites to cache certain user information and its associated latency and channel condition issues further add to the challenge experienced with the conventional split architecture.

Energy efficiency has been identified as an important metric for 5G. The energy efficiency of a communication system is closely related to its power consumption model. The power consumption model for macro and small base station already exist in literature, whereas that of the satellite technology is yet to be presented. A holistic evaluation of the energy saving achievable with the integrated architecture requires an exact representation of its power consumption model. Another feature of the split architecture is an energy efficient dynamic switching mechanism for the data cells. Such a mechanism must be energy efficient and also designed such that the appropriate numbers of data cells are switched off.

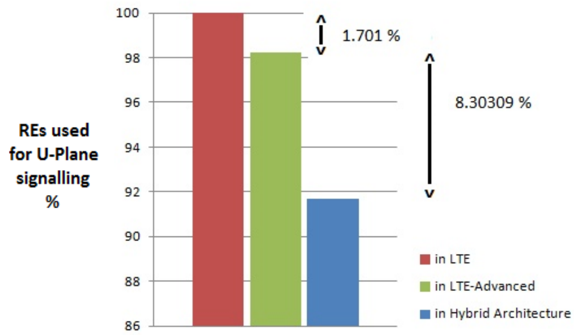

Fig. 2. Percentage of resource elements used for U-plane signalling.

Technology	U-plane capacity [Gbps/km^2]	C-plane power consumption [m/W/km^2]	Total power consumption [mW/km2]
LTE-A	358.81	0.061459	12.173
Hybrid with LEO satellite	363.3	0.059116	12.171

Table 1. Capacity and power consumption comparison

5. CONCLUSIONS

This paper has presented the key areas in which satellites can play a part in the 5G network. The examined potential area include: coverage extension, content distribution, providing resilience, and integrated signalling and energy saving. Some initial results were presented to show the gains achievable in the integrated architecture. We have also highlighted a number of research challenges associated with using satellite in 5G networks.

6. REFERENCES

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

[2] Thompson J. et al, “5G Wireless Communications Systems—properties and challenges” IEEE Comms Magazine,” Feb 2014.

[3] Cost IC 1004 White Paper on Scientific Challenges towards 5G Mobile Communications, 2013.

[4] ‘Scenarios, requirements and KPI’s for 5G mobile and wireless systems’ ICT-317669-METIS/D1.1, April 2013.

[5] T. Spathopoulos, O. Onireti, A. H. Khan, M. A. Imran and K. Arshad, “Hybrid Cognitive Satellite Terrestrial Coverage: A case study for 5G deployment strategies”, in *Proc. CrownCom*, 2015.

[6] A. Mohamed, O. Onireti, Y. Qi, A. Imran, M. Imran, and R. Tafazolli, “Physical Layer Frame in Signalling-Data Separation Architecture: Overhead and Performance Evaluation,” in *Proc European Wireless*, 2014.