SATELLITE AND SPACE COMMUNICATIONS SSC

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IEEE COMMUNICATIONS SOCIETY

SSC Newsletter Vol. 27, No. 2, December 2017

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The Satellite and Space Communications (SSC) Committee is a volunteer group actively involved in advancing satellite and space communication technologies within the IEEE. This committee is approved by the IEEE Communications Society and is governed by the constitution and bylaws of the IEEE as well as the other twenty-three Technical Committees in the Society. The committee belongs to the Technical Committee Clusters of Communication/Signal Processing (C/SP).

SATELLITE & SPACE

- JOIN US -

All conference attendees are welcome to join us in the SSC Committee meeting.

Location: GC'17, Singapore
Room: 4011
Marina Bay Sands Hotel
Date: Wednesday Dec. 6, 2017
Time: 12:30-14:00

Future SSC Meetings

June 2018, Kansas City, USA
December 2018, Abu Dhabi, United Arab Emirates

ICC 2017 SSC Committee Activities:

Symposium on Selected Areas in Communications:
Symposium on Selected Areas in Communications:

SAC-SSC.1: Networking

Tuesday, December 5, 16:45 - 17:30
Room: 4613/4713

SAC-SSC.2: Physical Layer

Wednesday, December 6, 11:45 - 12:30
Room: 4611/4711

SAC-SSC.3: System

Thursday, December 7, 11:45 - 12:30
Room: 4611/4711

SAC-SSC.4: Applications

Wednesday, December 6, 16:45 - 17:30
Room: 4613/4713

IEEE GLOBECOM 2017
4-8 December 2017 // Singapore
Global Hub: Connecting East and West

HOW TO JOIN SSC COMMITTEE AND MAILING LIST

If you like to join SSC Technical Committee: Please send your name and e-mail address to the SSC Secretary, optionally include your mail address, telephone and fax numbers.
If you like to join SSC Mailing List: Instructions on how to subscribe/unsubscribe are available at https://comsoc-listserv.ieee.org/cgi-bin/wa?A0=ssc.

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MESSAGE FROM THE CHAIR

Dr. Tomaso de Cola

After 18 months since my mandate as SSC TC chair has started, I'm glad to see a good trend in the in the overall activity of the technical committee, certainly based on the lessons learnt during the previous commitments I had within the TC as secretary first and then as vice-chair. In particular, the satisfactory number of submissions in the SAC-SSC track in the recent ICC'17 and GC'17 editions represents a sign of continuity in the overall activity of the TC to encourage the SatCom community to improve their visibility in ComSoc. Moreover, the successful initiative of the IEE JSAC special issue with almost 100 submissions definitely confirms that SatCom technology is going to play an important role in the timeframe 2020-2030 and that ComSoc in certainly the main intellectual platform to let this evolution be illustrated. As reported in the short summary hereafter provided, important achievements have been recorded especially for what concerns the editorial initiatives, where two new ones have been finally approved. On the other hand, as far as paper submission to ICC/GC is concerned, I'm glad to see the good trend that our community is experiencing with a significant number of papers in the same order of magnitude as observed in the recent editions over 2016-2017 years. Important points still to be tackled are to identify distinguished lecturers and take advantage of the working groups to promote new activities within the committee. An additional point to be reminded is the conclusion of my mandate in June 2018, whereby new candidate elections will be announced during the forthcoming SSC meeting in GC'17 and then started in Spring 2018 in order to have the formal announcement of the new officers during the next ICC'18 meeting. As consolidated during the past, the election will be performed electronically in order to gather a significant number of candidates and also collects as many people as possible during the voting process.

Participation to TC Meetings. The SSC TC last meetings have a quite satisfactory number of attendees. In both GC'16 and ICC'17 we had about 30-40 attendees, hence testifying the increasing interest in the TC activities and also confirming the stability of our TC. Nevertheless, we have to continue to publicize our meeting and to invite members, past and new, to attend.

Operative Policies and Procedures (OP&P). The possibility to have a recognition for people particularly active in the SatCom domain in addition to the service award given during Globecom has been discussed during the last ICC'17 meeting and accordingly a new version of the OP&P has been prepared for approval at the forthcoming GC'17 meeting. The main changes introduced consist in a new award recognizing outstanding technical contributions to the SatCom domain, which will be assigned on a regular basis during ICC editions, starting from ICC'18. The main aim of this award will be to properly recognize the great and special effort in advancing satellite and space technology, properly supported by industry and research commitments in the form of high-level publications and/or patent submissions.

Membership Management. We proposed a two-fold approach: to continue with the acquisition of new members and, more importantly, to involve old and new members in the TC activities (as Symposium Chairs, Guest Editors, etc.). The former activity is proceeding at a slow pace, and we need more incisive action. For what concerns the second part, we deem it is producing adequate results: we nominate new representatives for IEEE ICC/GC and several members are working on interesting and prestigious editorial initiatives.

Extended Cooperation. It consists of strict cooperation with Industries, research institutes, standardization institutes (e.g., CCSDS, ETSI), and space agencies of several countries (NASA, JAXA, ESA, DLR). A first step is represented by the nomination of a Standardization Liaison coming from industry.

SSC Website and Mailing List. Maintenance and periodic update of mailinglist and website are performed by the committee secretary, in order to guarantee up-to-date material and possibly attract new members interested in SatCom-related topics.

Current Journals/Magazines. Two important editorial initiatives have been eventually approved. First of all, the preparation of the special issue about SatCom advances IEEE JSAC is ongoing. A larger number of submissions (about 100) have been received, out of which 25 have been eventually accepted, although it must be recognised that a larger quote of the technical papers has featured very interesting topics with very good quality. The first round of review has been completed and it was eventually agreed to have a double issue. Then, a special issue about integration of 5G and SatCom has been recently approved by IEEE Network with submission deadline on the 15th of February 2018. Finally a Feature Topic about Space Networks has been recently submitted to IEEE Wireless Communication Magazine, which is under review. Given the success of these initiatives, new proposals will be worked out by collecting ideas in the TC, as done during the past years.

Conference Activities (ICC/GC and others). In ICC/GC is consolidated the SSC Track. In the recent years the SSC track has been quite successful. The SSC track of GC'16 chaired by Tomaso de Cola received 41, whereas ICC'17 chaired by Igor Bisio received 58; finally the current SSC track in GC'17 received 56 submissions, whereas the forthcoming one in ICC'18 got 41. These numbers definitely confirm the good trend of our TC visibility. Concerning other conferences, the SSC TC has endorsed SPECTS2017 and, CITS 2017 conferences.

Standardization Activities. During the meeting in Atlanta (IEEE GC'13), we appointed the Standard Liaison, Dr. Henry Suthon, Principal Senior Engineer at Boeing (h.suthon@ieee.org), who has recently confirmed his commitment in this role.

Dr. Tomaso de Cola, Chair
Satellite and Space Communications TC

SCANNING THE WORLD

Prof. Song Guo

The second half of 2017 has focused much attention on the issue of **cybersecurity threat** in Aerospace and Satellite. Some relative highlights and other interesting news are gathered as follows.

On Nov. 7, a panel titled "Fact Vs. Myth: What We Know So Far As It Relates to Cyberattacks in Aerospace and Satellite" was held in the CyberSat 2017 Summit, in which the cybersecurity vulnerabilities had been attracted lots of discussion. Attendees from a variety of industries shared their thoughts and concerns about protecting sensitive data in the age of the Internet of Things (IoT) and automation, when threats are continuously evolving and attacks are increasingly bold and aggressive.

In particular, the problem that hardware manufacturers, service providers and others across the satellite ecosystem should collaborate to ensure secure cyberspace for their customers was under the spotlight. During another panel titled "How to Achieve End-to-End Protection?", experts agreed that one of the biggest challenges in cybersecurity today is the ongoing transition to an ecosystem where competing companies must cooperate on joint solutions for their shared customers.

In addition, the founder and Chief Executive Officer (CEO) of the U.S. **National Defense Group** has pointed out that cybersecurity is the potential weaknesses that satellite operators need to immediately address. For example, the Personal Security Products (PSPs) for any kind of device we would have in space are missing.

Then, how to address the cybersecurity threats for the government, military, and satellite industry?

Remarkably, during another panel titled "Military Satcom and Cybersecurity: The New Paradigm" at the 2017 CyberSat Summit, a group of experts mentioned that the deep learning could be the one of the most promising tools for those who have engaged in ongoing cyber warfare, because of its ability to quickly and efficiently monitor and catch malicious actors in cyberspace.

Some other exciting new technologies have been also emerged. For instance, the global High-Altitude Pseudo Satellites (HAPS) market is expected to grow at a Compound Annual Growth Rate (CAGR) of 15.2 percent between 2017 and 2023. HAPS are composed of unmanned aircraft, e.g., airplanes, airships and balloons, positioned above 20 km altitude in the stratosphere, for long-duration flights measured in months or even years. As reported, HAPS could offer advantages and complementary applications over satellites and terrestrial infrastructures at relatively low cost.

Another interesting story is that a company named TerraSense has launched a big data application to aid precise agriculture. This application is supported by a software paired with a hardware solution that offers predictability and artificial intelligence (AI) to the agricultural sector. This platform continually gathers many different soil quality data such as temperature, moisture, and pH through the advanced microclimate data and satellite imagery, allowing agricultural workers to know the real-time visibility and condition of their land. More importantly, combined with machine learning, predictive analytics, and AI, this software help its clients notice where the future problems may occur.

Prof. Song Guo, Vice Chair
Satellite and Space Communications TC

FORTHCOMING GLOBECOM AND ICC CONFERENCES

COSPONSORING / RELATED CONFERENCES AND WORKSHOPS

ICC 2018
May 20-24, 2018, Kansas City, USA
http://icc2018.ieee-icc.org
The International Conference on Communications (ICC) is one of the two flagship conferences of the IEEE Communications Society, together with IEEE GLOBECOM. Each year the ICC conference attracts about 2-3000 submitted scientific papers, a technical program committee involving about 1500 experts provides more than 10000 reviews, the conference being finally attended by 1500 - 2000 professionals from all around the world. IEEE ICC is therefore one of the most significant scientific events of the networking and communications community, a must-attend forum for both industrials and academics working in this area. We invite you to submit your original technical papers, and industry forum, workshop, and tutorial proposals to this event. Accepted and presented papers will be published in the IEEE ICC 2018 Conference Proceedings and submitted to IEEE Xplore®.

MILCOM 2018
October 2018, Baltimore, USA
http://www.milcom.org
MILCOM 2018 celebrates the 37th anniversary of the premier international conference for military communications. MILCOM offers industry the opportunity to discuss communications technologies and services with decision makers from all branches of the armed forces, the Department of Defense, federal agencies and multinational forces. The conference will feature an outstanding series of technical presentations, discussions and tutorials, as well as nearly 30,000 square feet of industry exhibits all under one roof. It will include more than 300 unclassified and restricted technical presentations, tutorials and panel discussions led by experts in defense communications.

GLOBECOM 2018
December 9-13, 2018, Abu Dhabi, UAE
http://globecom2018.ieee-globecom.org/
IEEE GLOBECOM is one of two flagship conferences of the IEEE Communications Society (ComSoc), together with IEEE ICC. Each year the conference attracts about 3000 submitted scientific papers and dozens of proposals for industry events. A technical program committee of more than 1,500 experts provides more than 10,000 reviews, and from this a small fraction of the submitted papers are accepted for publication and presentation at the conference. The conference attracts roughly 2000 leading scientists, researchers and industry practitioners from all around the world. IEEE GLOBECOM is therefore one of the most significant scientific events of the networking and communications community, a must-attend event for scientists, researchers and networking practitioners from industry and academia. IEEE GLOBECOM is a five-day event. Two days are dedicated to tutorials and workshops, while the remaining three days are dedicated to the IF&E program and the technical symposia. The program of the technical symposia includes oral or poster presentations of about 1000 scientific papers, grouped into 13 thematic symposia, and more than 15 parallel sessions. In addition to the technical program, IEEE GLOBECOM 2017 will feature an industry forum and exhibition (IF&E) program, including industry-focused workshops, tutorials, keynote talks from industrial leaders, panel discussions, a large exposition, and business and industrial forums.

CONFERENCES CALENDAR

CONFERENCE	DATE & LOCATION	INFORMATION
SPECTS 2018 International Symposium on Performance Evaluation of Computer and Telecommunication Systems	July 9-12, 2018 Bordeaux, France	http://atc.udg.edu/SPECTS2018/
ITC 2018 30th International Teletraffic Congress	September 3-7, 2018 Vienna, Austria	http://itc30.org/
ICTS 2018 International Conference on Computer, Information and Telecommunication Systems	July 11-13, 2018 Colmar, France	http://atc.udg.edu/CITS2018/
ICL-GNSS 2018 International Conference on Localization and GNSS	June 26-28, 2018 Guimarães, Portugal	http://www.icl-gnss.org/2018/
PIMRC 2018 IEEE International Symposium on Personal, Indoor and Mobile Radio Communications	September 9-12, 2018 Bologna, Italy	http://pimrc2018.ieee-pimrc.org/
VTC-Spring 2018 2018 IEEE 87th Vehicular Technology Conference (VTC-Spring)	June 3-6, 2017 Porto, Portugal	http://www.ieeevtc.org/vtc2018spring/

To all SSC members: If your postal address, telephone or fax numbers have changed, please update them with the committee secretary. You can review our current records on our web page at http://committees.comsoc.org/ssc/.

Towards 5G Satellite Systems

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Abstract — **The evolution of today's telecommunication networks towards 5G is well underway and foresees the integration of terrestrial and space-based communication systems. This article highlights a number of evolutionary integration-scenarios considering their opportunities and challenges, followed by a summary of results available from recent R&D work.**

INTRODUCTION

The evolution of telecommunication networks towards 5G is well underway, both from a standardization and from an implementation perspective. Standardization bodies such as ETSI [1], 3GPP [2][3] and 5G-PPP [4] all share the opinion that satellites will be integrated with terrestrial systems based on a converged, software-based, infrastructure. The level of integration will be determined on cost, performance and security gains offered by satellites in specific service delivery scenarios (5G use-cases). The lack of comprehensive analysis and proof of concept implementations regarding integration scenarios paired with a lack of interest from the terrestrial operators and vendors has led to a situation in which the potential of the satellite industry is not fully recognized nor enough exploited to date.

This article gives an overview of how the unique characteristics of satellites can be exploited in a future integrated 5G system and presents the challenges for a successful deployment. The results of a proof-of-concept integration scenario are presented and a roadmap of future activities suggested.

BACKGROUNF FOR 5G SATCOM

5G is a distributed system in which network functions are implemented in software and executed in virtualized infrastructure environments. Services are assembled on-demand from a pool of virtual functions instantiated and deployed in different Data Centers (DCs) and linked together over virtual network links, i.e. Service Function Chains (SFC). The SFCs are subject to continuous, reactive and proactive (automated) management assuring performance, security & privacy, resilience, energy, environment and cost targets. As such, communication can be executed through dedicated networks, using the same network functions, customized for the needs of the individual use cases. Such dedicated Network – SFCs are available as Network Slices that are deployed on demand and operated in a multi-tenant environment by means of Software Defined Networking management and orchestration architectures. Being a distributed software system, the network functions should be able to understand the underlying connectivity and adapt to available topology and resources and be properly synchronized. The "use-case-scenarios" defined by 5G are the starting point for the work undertaken at the different architectural and technological levels by standardisation, industrial, governmental and regulatory entities. The 5G initiative is predominantly driven by the terrestrial operators and as such lack a comprehensive set of requirements and use-case-scenarios specific to the satellite operators.

On the other hand, users will want one network for all their applications and developers of future applications and data protocols will not design their code to accommodate different propagation delays. This implies a seamless compatibility of satellite networks with the terrestrial 5G networks.

OPPORTUNITIES & CHALLENGES OF SATCOM

Anywhere delivery and more effective value chains

Cost-effective anywhere delivery is only possible via satellite communications. Service and data delivery to / from remote, sparsely - populated locations (both by humans and machines), e.g. in mountain-, sea-, polar – regions, will (continue to) be a clear market opportunity for satellite network operators. Compared with the terrestrial mobile service value chains, involving many peering relationships among national network operators, the SATCOM operators can provide a single global network and thus reduce the OSS and BSS costs related to the management of the value chains they participate to. This advantage over the terrestrial service providers will be even bigger in the future when considering that SATCOM resource owners will deploy mega constellations (thousands and tens of thousands of LEO satellites) offering fine-grained geo-location ubiquitous access, effective global transit / backbone (low and long range) routes will be provided by a cooperation between UAV / HAP, LEO, MEO and GEO platforms and that cloud computing resource owners will deploy their resources in space. The virtual operator business model will be thus more effective and efficient in space than on ground based infrastructures.

Interoperability with terrestrial networks will be needed in both B2C and B2B customer scenarios such as overlay (access, back-up), backhaul (access, core), backbone / transit for terrestrial systems. The interoperability at

IaaS, PaaS, SaaS levels and including facilitators (brokers, exchanges, federation managers) will be essential for achieving agile value chains in two-sided marketplaces. Several challenges related to data-interoperability will need to be addressed via emerging international space operations standards. An exemplary deployment for a LEO constellation with interworking capabilities with GEO satellites and other terrestrial networks is shown in Fig. 1 below.

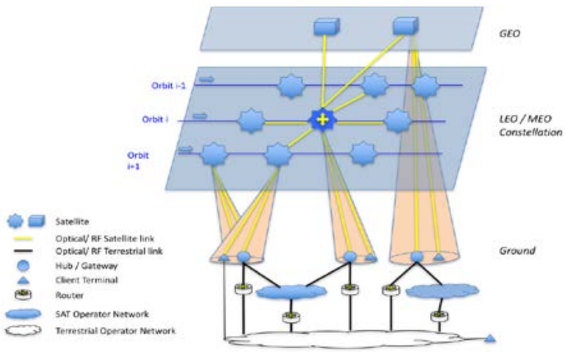

Figure 1: Integrated Terrestrial – Satellite Infrastructures

Accurate time services are decisive for the fine-grained determination of the satellite position and the location / synchronisation of (mobile) ground-based nodes and thus the primary input parameter for the management of deployment topologies and data flows.

Better Performance and Reliability

SATCOM has the potential to deliver solutions with better performance and reliability than the terrestrial ones, due to the specific characteristics of the satellite-links (1,5 higher propagation speed in optical free space communication vs optical fiber, applied to Inter-Satellite-Links (ISL) but also in some cases to Ground-Satellite-Links(GSL); lower signal attenuation; low, predictable Bit Error Rate (BER)), paired with the intrinsic point-to-multipoint / broadcast capability.

Capacity increases have already progressed rapidly due to spatial-reuse of frequencies in spots, fractional frequency re-use from a total link-allocated bandwidth (FFR schemes from the terrestrial LTE and WiMAX) and spectral efficiency gains through modulation codes (e.g. > 100 Gps in Ka band with narrow antenna beams). This will continue and will potentially exploit the predictive position of the satellite and the geo-location capability of ground nodes / terminals to devise even more efficient, adaptive hierarchical coding, complex FFR and resource-allocation time-dependent schemes (SON capability). Work will continue also in the Antennas (MIMOs / Beam forming, steering) and MAC protocols (RF, optical) for satellites.

Potential further performance improvements vs. the terrestrial solutions regard the SATCOM topology, transport protocols and traffic engineering algorithms. The shortest distance (straight line in contrast to terrestrial paths that are constrained by local geography) and the fixed and permanent connectivity of each satellite to its neighbors will contribute to achieving optimised transmission geometries for satellite constellations.

In contrast to the terrestrial case, the full-predictability and availability of the SATCOM connectivity opens the opportunity to use more efficient protocols for the data plane, without reconfiguration phases or reactive mechanisms. Predictable, pre-computed routes / forwarding tables can be downloaded off-line to the satellites of a constellation and the terrestrial GWs and managed (backed up routinely) via SDN controllers. SATCOM network can intrinsically provide assured-quality connectivity services via a fully meshed switched / routed network. Already today, LEO constellations are designed to use L2 transport protocols (e.g. MPLS supports circuit and packet –switching clients at the same time) as alternative to the more expensive IP routing. There is still work to do concerning new routing algorithms (implemented as VNF in an SDN controller) that use Cost Scoring based rules, Weights applied to latency, BW costs at GWs, regional restrictions, hop counts, energy costs, etc.

The processing latency will be managed by an adequate distribution of the VF-execution across space-based and ground-based DCs. New architectures and topologies of space-based DCs (edge, remote / central) will emerge as response to supporting of the different business use-case-scenarios.

Ultimately, the propagation latency of the connectivity services will be managed by an adequate size and topology of the constellation(s), by the dynamically, SDN-based, configuration of the client beams and by the Delay Tolerant Networking (DTN) and Caching capabilities.

Better Security

Compared to terrestrial networks, the satellite networks expose less vulnerability surfaces to malicious attacks and natural disasters. Also, a hardware-based root of trust deployed in space offer less vulnerability risks than when deployed on ground. These intrinsic properties make SATCOM the preferred candidate for delivering highly secure and/or mission-critical services (e.g. U.S. Cloud Constellation Corporation).

Machine Learning and Big Data

As for the terrestrial 5G systems, the 5G SATCOM will need to apply machine learning and big data processing in order to improve channel model, positioning, routing / forwarding, fault- and security attack - detection and resolution, etc.

Space generated Data

Sensor payloads will continue to evolve and enable new space-generated data based services: Remote sensing

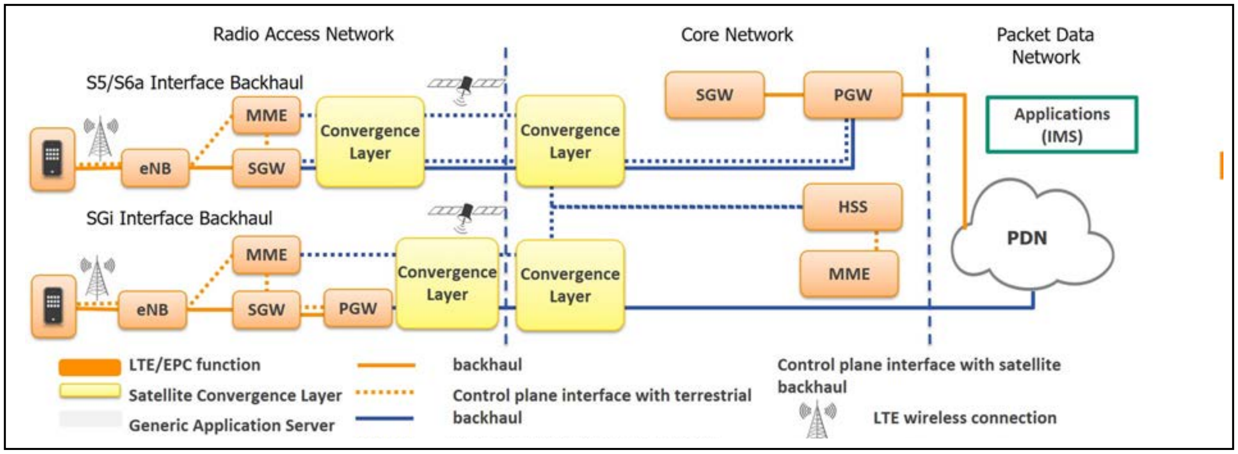

Figure 2 – System Architecture

(Vision / Imagery, Geophysical (temp, radiation, ---)), positioning and location, mobility profiles (UAVs, planes, users, …), enhanced context-based services, etc. In addition, such sensors and measurements will contribute to the improvement of our space population positional knowledge.

PROOF-OF-CONCEPT INTEGRATION SCENARIO

In the context of the project "SATINET", which was funded by the European Space Agency (ESA-7799) and involved several project partners from industry and academia, we were able to perform in 2017 a proof-of-concept test campaign that validated the feasibility of GEO-based Satellite Backhauling in a 4G / 5G terrestrial system and evaluated its performance.

The integrated testbed architecture is illustrated in Figure 2. It consists of a composition of multiple deployment options (3) of the network functions realized as VNFs and executed on the same hardware infrastructure. The VNFs are grouped into 3 sets of components: the LTE components, the Convergence Layer (CL) and the Satellite Emulator. For the specific usage into the proposed testbed, the Open5GCore [5] is configured to run a standard-conformant 3GPP Rel13 EPC deployment, including MME, HSS, SGW and PGW functionality.

For the satellite link, the CoSAT [6] emulator has been used. The Satellite Emulator was configured to reliably support a 300Mbps in a configuration emulating a satellite-to-moving train communication scenario. It consists of the data transport modules and the channel model.

The convergence layer (CL) consists of several components that support the satellite link integration. It contains a Performance Enhancement Proxy (PEP) in order to improve the performance of TCP connections over satellite. It uses the TCP-Hybla congestion control algorithm that was developed especially for satellite connections. The open source software PEPsal was used as a TCP Proxy, splitting the TCP connections into the two parts, which is a mandatory requirement for using the TCP-Hybla congestion control algorithm.

For the payload compression, zlib was used. As payload compression consumes a significant share of the used CPU power, and thus also limits the achievable throughput, zlib is configured to use the fastest compression instead of the default compression. Each IP packet is compressed on its own, without using the context of any previous IP packet. This selection was done due to the fact that in the case of the loss of a single compressed packet, the decompression of the following ones would be possibly affected. The traffic control takes care of scheduling the data for transmission, selecting a modulation and coding scheme according the status of the backhaul link, GSE encapsulation and BBFRAME assembly.

The setup depicted on the top of Fig. 2 allows for the devices to connect through the PGW located at the hub side and is well suited for data services that require persistent, guaranteed and secure connections. Mobility support between the satellite backhauled and the terrestrial network, as well as between different satellite backhauled PDNs is not supported.

The second setup depicted in the lower section of Figure 2 includes a remote-side PGW. In this case, high local mobility is supported and allow for zero packet loss in case of handovers between the satellite backhauled network and the terrestrial networks. QoS enforcement is based on the bearers assigned by the EPC and need to be maintained by the satellite connection. Both setups along with a reference EPC were deployed using Openstack as Virtual Infrastructure Manager on a hardware infrastructure consisting of 2 high-performance Dell PowerEdge M620 blade servers with 512 GB SSD harddrives with a RAID1 configuration.

The initial campaign consisted of functional tests which enabled the evaluation of the conformity and suitability of the proposed architecture for being later deployed in real systems. These included the following procedures: attachment, detachment, handover, tracking area update (TAU), service deactivation (idle mode) and service activation. Afterwards, a set of performance tests were made enabling the assessment of the optimization brought by the different features.

An increase of complexity in the unit tests was considered, starting with the simplest tests, continuing with typical telco benchmarking tests, and abstracting the real use cases as processing of sudden high load, specific linear loads and capacity evaluation. A complex realistic use case was finally tested and evaluated.

The overall data path delay as shown in figure 4 is rather uniform at a rate of 1500ms with specific spikes due to the delay variation when composing the BBFrames for the satellite link.

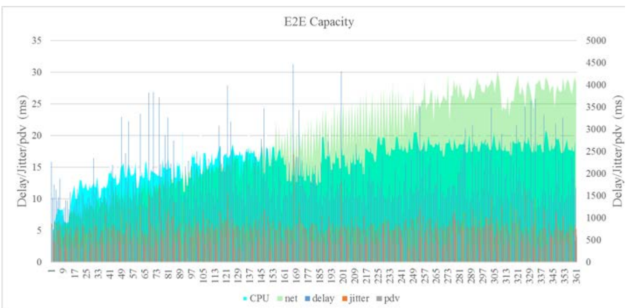

Figure 2: End to End Capacity

This is a large RTT delay as it includes the specific traffic control and compression modules. Without these modules, the foreseen 600ms RTT could be reached. Most of the delay is added by the satellite link emulator which adds the transmission delay of 540-550ms to all data flows. This delay can only be lowered by using another satellite constellation like for example LEO or MEO.

From a functional perspective, all the specific procedures selected worked as expected, thus it is possible to use a standard conformant EPC with modified timers to offer the service to LTE subscribers using a satellite backhaul with the MME and at least SGW located at the UE side ground segment. Further research into an optimal compression decision mechanism would greatly benefit the link capacity for particular applications. The satellite backhaul did not affect the usage of the terrestrial infrastructure components. Thus, if a component was dimensioned for a specific set of subscribers for the terrestrial system, the same dimensioning can be applied to the satellite network backhauled system.

From the workload perspective, the system proved to be able to cope with the expected load: 360Mbps data path, 1000 subscribers with 200 active sessions.

The testbed proved that an LTE system can be directly deployed with a satellite backhaul, and provided/used with COTS equipment.

CONCLUSIONS

The SATCOM has the potential to guarantee bandwidth, performance and security anywhere at competitive prices. To achieve and exploit this potential and stimulate investments, a number of steps are needed (see Fig. 4), including**:**

Closer involvement and cooperation with terrestrial players in the 5G activities, including technology, standardisation and regulatory issues.

Enablement of DevOps (APIs to programmable resources) and their inclusion in the value chains (e.g. via developer platforms and marketplaces).

Cross-disciplinary R&D: platform manufacturing and launching, positioning / location, space-generated data, telecommunications, IT Accelerated introduction of public private partnership (PPP) projects, e.g. regarding the PoC / large pilot projects for selected B2C and B2B services in various verticals, IPR transfer from the public to the private sector and investments.

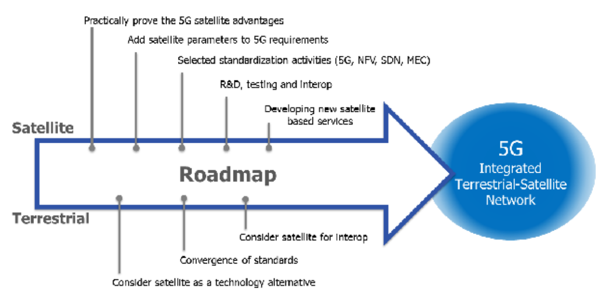

Figure 4: 5G SATCOM – Terrestrial Convergence and Integration Roadmap

AKNOWLEDGEMENTS

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REFERENCES

[1] ETSI Work Programme 2016-2017, www.etsi.org

[2] 3GPP 5G System Architecture TS 23.501 and TS 23.502, www.3gpp.org

[3] 3GPP TS 23.401, "General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access", www.3gpp.org

[4] 5G-PPP View on 5G Architecture, www.5g-ppp.eu

[5] Fraunhofer FOKUS Open5GCore – www.open5Gcore.net

[6] CoSat: The role of satellite in converged fixed/mobile/broadcast environment, http://telecom.esa.int/telecom/www/object/index.cfm?fobjectid=31572