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E-LETTER

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CONTENTS

Message from MMTC Chair

Dear MMTC colleagues:

Supported by our community, our IEEE ComSoc Multimedia Communications Technical Committee (MMTC) has made significant accomplishments recently.

Firstly, the Interest Group (IG) Groups have been formed successfully in the past months, and they work very well right now. In particular, several Special Issues, conferences, workshops have been approved, and hopefully these events will enhance our impact accordingly. Of course, MMTC will continually support any kind of academic events related to our topics.

Secondly, we are happy to announce that MMTC is participating in the development process of the IEEE 1907.1 standard, which is very important for our multimedia communication society. It is very welcome for MMTC members to join this group and actively contribute. More details can be found in the following links:
http://standards.ieee.org/develop/wg/1907.1_WG.html
https://standards.ieee.org/develop/project/1907.1.html

Thirdly, a new publication, the International Journal of Multimedia Communications will be established soon. The Editor in Chief, Prof. Jaime Lloret Mauri, is a member of our MMTC. The website of this journal is: http://www.oldcitypublishing.com/journals/ijmc-home/. It is very welcome for our members to submit their excellent works to this journal.

Last but not least, I would like to thank all the IG Chairs and co-Chairs for the work that they have already done and will be doing for the success of MMTC and hope that all of you will find the proper IG of interest to get involved in our community!

Liang Zhou
Asia Vice-Chair, IEEE ComSoc Multimedia Communications Technical Committee

EMERGING TOPICS: SPECIAL ISSUE ON CONTENT DISTRIBUTION OVER SDN AND NFV ARCHITECTURES

Guest Editors: Xiaoqing Zhu[1] and Harilaos Koumaras[2]

[1]*Cisco Systems, USA, xiaoqzhu@cisco.com*

[2]*NCSR Demokritos, Greece, koumaras@iit.demokritos.gr*

The networking industry has seen rapid and steady increase in the adoption of Software-Defined Networking (SDN) and Network Function Virtualization (NFV) technologies in recent years. For service providers and network operators, this opens up interesting new possibilities for enhancing the performance of media content delivery. While SDN improves network management visibility and programmability, an NFV-enabled infrastructure allows for dynamic resource provisioning and network service scaling according to user and traffic demand. This new and evolving networking paradigm – with more focus on software rather than hardware – also means finer granularity of control, faster adaptation capabilities, thus greater agility in innovation.

In this Special Issue, we bring to our readers a collection of four invited articles that address various aspects of SDN/NFV-enabled architectures for media content delivery. Authors from academia and industry share their individual perspectives regarding the opportunities and challenges brought forth by the rapid spread of SDN/NFV technologies, outlooks for the future of media content delivery in an increasingly mobile and heterogeneous environment, as well as ongoing research efforts in leveraging SDN/NFV for enhanced media content delivery.

The first article, "*Multimedia Content Delivery in SDN & NFV based Towards-5G Networks"* by Liberal et al., paints in broad strokes several leading trends in the evolution of cellular networks from 4G to 5G. The authors then focus their discussions around the potential implications of network *cloudification* through SDN and NFV, and how it can enable true convergence between Content Delivery Networks (CDNs) and 5G networks. Using Dynamic Adaptive Streaming over HTTP (DASH) as a case study, they further describe the evolution of media adaptation strategies from purely client-driven to a combination of core- and access network-assisted architecture. Finally, the article highlights a number of challenges and research opportunities in toward-5G networks.

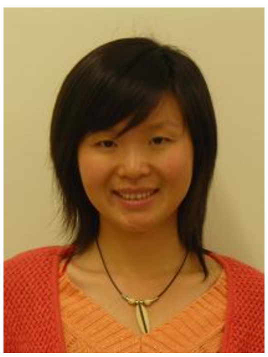
In *The Surrogate vNF approach for Content Distribution*, Herbaut, Xilouris, and Négru demonstrate the potential and benefits of novel media streaming solutions based on more flexible resource management over NFV infrastructures. The paper introduces the concept of Surrogate vNF which aims at taking advantage of the standards execution environments of Home Gateways to collaborate with vNFs deployed in operator Point-of-Presences (POPs). Simulation evaluations of the proposed solution show that it improves QoS for media delivery by mitigating violation of Service-Level Agreements (SLAs).

Taking a different approach, authors of the third article, *Caching of Viral Content in NFV Architectures*, shows how NFV-based data centers can be used for caching viral content (e.g., extremely popular YouTube videos) with improved energy efficiency. Krishnan et al. introduce an open NFV architectural framework for managing application viral behavior. The paper discusses ongoing work in the industry in the area of viral content caching, connecting it with the overall energy efficiency in the context of NFV. More specifically, the paper examines an integrated NFV architectural framework for managing viral content, where the application virality information can be modelled as a non-linear constraint along with the existing placement and scheduling constraints, which are typically linear.

Finally, Ferrús et al. present a conceptual framework for the combination of terrestrial and satellite communication segments, leveraging NFV/SDN as enabling technologies. Their article, *Enhancing Satellite and Terrestrial Networks Integration through NFV/SDN technologies*, starts with an excellent overview of multiple compelling benefits of a single, integrated telecom network. It then reviews key challenges and barriers that hamper such integration. The authors point out how the introduction of new SDN/NFV-based paradigms can help to facilitate a combined terrestrial/satellite networking infrastructure in term of more flexible integration, network service innovation, and end-to-end network resource management spanning both satellite and terrestrial segments. The paper further describes several ongoing research efforts along this direction undertaken by the UE H2020 VITAL research project.

This Special Issue has, by no means, presented a complete picture on the emerging topic of SDN/NFV-enabled innovations for media content delivery. In fact, given the highly active involvement of both academic researchers and industry practitioners in this field, we expect that more exciting results from expanded explorations will appear soon on the horizon. We nevertheless hope that our readers will enjoy sampling through the list of invited articles and get a flavor of the interesting possibilities offered by SDN/NFV for next-generation media delivery networks.

Our special thanks goes to all authors for contributing their interesting research work to this Special Issue and sharing with us their individual perspectives. We would also like to acknowledge the gracious support from the MMTC E-Letter Board.



Xiaoqing Zhu is currently a Technical Leader in the Chief Technology and Architecture Office (CTAO) at Cisco Systems. Her research interests span multimedia applications, networking, and wireless communications. At Cisco, she has worked on HTTP-based adaptive streaming, congestion control for low-latency interactive video, fog computing, media delivery over vehicular networks, and video traffic modeling and synthesis. Dr. Zhu has published over 60 journal and conference papers, receiving the Best Student Paper Award at ACM Multimedia in 2007 and the Best Presentation Award at IEEE Packet Video Workshop in 2013. She is author of 4 granted U.S. patents, with 16 applications pending. Within the research community, she has served extensively as reviewer, and TPC member for numerous journals and conferences. Previously, she was guest editor for several previous special issues in *IEEE Trans. Multimedia*, *IEEE Journal on Selected Areas in Communications*, and *MMTC E-Letters*. Dr. Zhu holds a B.Eng. in Electronics Engineering from Tsinghua University, Beijing, China, She graduated with M.S and Ph.D. in Electrical Engineering from Stanford University, California. Prior to joining Cisco, she interned at IBM Almaden Research Center in 2003, and at Sharp Labs of America in 2006.

Dr. Harilaos Koumaras was born in Athens, Greece in 1980. He received his BSc degree in Physics in 2002 from the University of Athens, Physics Department, his MSc in Electronic Automation and Information Systems in 2004, being scholar of the non-profit organization Alexander S Onassis, from the University of Athens, Computer Science Department and his PhD in 2007 at Computer Science from the University of Athens, Computer Science Department. Dr. Koumaras has been an active research associate since 2003 of Media Net Lab at the National Centre of Scientific Research "Demokritos”.

Multimedia Content Delivery in SDN & NFV based Towards-5G Networks

Fidel Liberal[1], Akis Kourtis[1,2], Jose Oscar Fajardo[1], Harilaos Koumaras[2],

[1]University of the Basque Country (UPV/EHU), [2]NCSRD Demokritos

Email:{fidel.liberal, joseoscar.fajardo}@ehu.eus, {akis.kourtis, koumaras}@iit.demokritos.gr

1. Introduction

Cellular technologies have quickly evolved from narrowband voice only specific purpose networks to becoming the predominant candidate for accessing multimedia services. Most current analysis [1][2] foresees an imminent explosion of Internet connections over broadband wireless networks, making seamless high speed connectivity finally a reality. Together with raising paradigms that will shape next generation cellular technologies, an equivalent evolution of content delivery networks (CDNs) is taking place to cope with the new challenges associated to myriads of mobile users accessing high quality services.

Among these paradigms, *cloudification* through software defined networking (SDN) and network function virtualization (NFV) entails several opportunities for true convergence between CDNs and 5G networks.

Efficient use of scarce network resources will no doubt become the main motto for these new scenarios. Foreseen solutions will strongly depend on the roles of the significantly different players involved, ranging from technology agnostic e2e service adaptation mechanisms traditionally found in Internet based CDNs, network assisted broadcast-like technologies of mobile telcos and content aware resource scheduling by broadband access equipment manufacturers.

The strategy towards the evolution of cellular networks from 4G to 5G can be summarized by the following trends [3]: 1) evolution of Ratio-Access Technologies (RATs), 2) cell densification, 3) composition of radio access technologies -- particularly 3G/4G and Wi-Fi offloading, 4) heterogeneous networks (HetNets), 5) flexible spectrum management, 6) cloudification, and 7) new scenarios -- device-to-device (D2D), machine-to-machine (M2M), and Internet of Things (IoT).
At first sight trends 1)-5) may appear independent of the service delivered but optimized allocation of radio resources demand a clear input of the content delivery needs in order to carry out network orchestration.

Additionally, in the meantime, hybrid approaches have been already proposed to pave the way for such transitions from 4G specific hardware based architectures to software based 5G platforms.

In the following sections we will focus on how *cloudification* of 5G through different SDN/NFV paradigms may affect content delivery or, on the other hand, how different content delivery mechanisms can be fitted into foreseen 5G network architectures with a particular focus on dynamic adaptive streaming over HTTP (DASH).

Towards 5G Evolution and SDN/NFV

Figure 1 depicts foreseen evolution for cellular networks from LTE (4G) towards 5G.

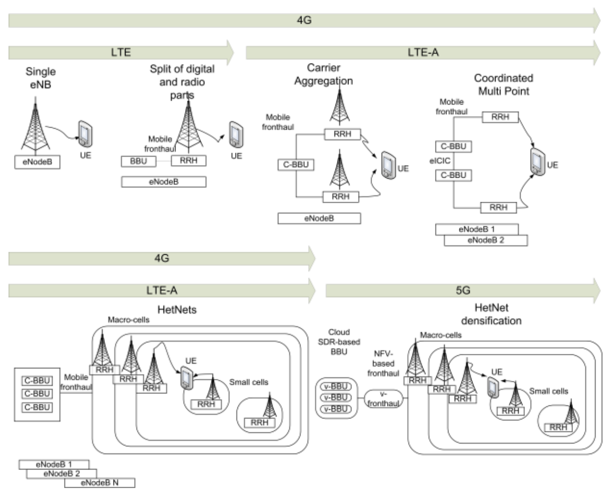


Figure 1. 4G to 5G Evolution

4G LTE technology was designed to cope with the requirements of a flat all-IP architecture. The eNodeB was introduced as the key element within the Radio Access Network (RAN), in charge of managing the allocation of radio resources and of implementing the Adaptive Modulation and Coding (AMC).

As a step forward to foster the deployment of LTE networks, the eNodeB was functionally split into the BaseBand Unit (BBU), capable of performing the digital functions, and the Remote Radio Head (RRH), which actually needs to be located at specific placements in order to perform radio transmissions.

The advent of LTE-Advanced brings new radio capabilities that leverage the achievable performance even in cell edges. First, Carrier Aggregation allows increasing the channel bandwidth by implementing a coordinated scheduling of radio resources. In this case, a Centralized BBU (C-BBU) is able to control several RRHs without further radio synchronization restrictions. Besides, Coordinated MultiPoint (CoMP) addresses the possibility to synchronize the transmissions to/from different eNodeBs.

The logical evolution of this network architecture towards HetNets resides on the co-sited deployment of a number of C-BBUs, each of them controlling a set of RRHs through high speed fronthaul connections and implementing coordinated control with almost negligible delays in the inter-eNodeB exchange of information.

Finally, the forthcoming 5G network is envisaged to be ruled by flexible NFV management, which allows the virtualization of all the RAN elements into virtual appliances. This way, programmable network control will enable a more user- and content-focused allocation of resources. Additionally, some initiatives such as the Mobile Edge Computing [4] are pursuing the flexible usage of general purpose HW/SW platforms at the Cloud RAN (C-RAN). Thus, some lightweight service instances would be able to run at the C-RAN, leveraging user-tailored proximity services.

Caching and CDNs

Various studies have observed that a large portion of the mobile multimedia traffic is generated by duplicate downloads of popular multimedia content [5]. Therefore, research activities in the CDN field have been focused in finding novel caching algorithms operating inside networks, which deliver high-demand content to customers via nearby caching gateways. This concept reduces inter-Internet Service Providers (ISPs) traffic. Additionally edge caching both minimizes content fetching time and, when combined with multicast/broadcast approaches (i.e. eMBMS), it can dramatically reduce radio resource consumption particularly relevant in towards-5G architectures.

The main goal of caching techniques is to attain the optimal trade-off between traffic bandwidth cost and storage cost. Traffic bandwidth cost remains quite expensive for ISPs, whereas storage cost constantly drops. However, available multimedia content is growing rapidly making it impossible to store a great amount of it, thus content demand has to be considered when caching.

Most caching alternatives can be classified as either web caching, which is based on uniform resource locator (URL), or packet redundancy caching, which is protocol-independent and packet oriented. Web caching creates a correlation between the requested content and its URL. The caching server is responsible to deliver the content to the user, when the user requests it from the corresponding URL. Packet redundancy caching offers more complex correlation between the content and the client request. The caching server in this case can store packets, or even chunks of content, which facilitates protocols like Dynamic Streaming over HTTP (DASH). In DASH, video content is encoded in various quality levels, and each quality sequence is divided into small “chunks”. When the client requests a video, depending on the network conditions, it receives the corresponding quality chunk. This enables the service to switch between different quality levels seamlessly, as the content is delivered through a CDN service.

In order to further improve and evolve current CDN technologies, next steps are heading towards the virtualization plane. The current proliferation of 4G networks and future 5G networks creates ample space for CDN technologies to be further extended and exploited regarding virtualized environments. On one hand, SDN is mostly focused on network controllability, which can be applied on a CDN-driven content delivery system, in order to facilitate and enhance network management and content delivery. On the other hand, NFV is related to the network data plane. Virtualized Network Functions (VNFs) which inspect network traffic, e.g. virtualized Deep Packet Inspection, can be used to add content-aware forwarding and caching in CDN environments.

In order to efficiently distribute the highest possible quality content in variable channels in towards-5G networks, SDN and NFV can provide scalable and fine-tuned adaptation loops between network and CDNs. Following Sections will analyse different alternatives and highlight challenges and opportunities.

2. Adaptation Strategies (DASH case study)

Figure 2 illustrates the evolution of adaptation strategies focusing in DASH-based media delivery. Different enhancements have been proposed over recent years to optimize the transmission of multimedia content over the Internet, with special interest in mobile environments.

Figure 2a illustrates the traditional DASH adaptation approach where the adaptation algorithm is deployed at the client device, in order to modify the source of the media content. Figure 2b represents the next evolution, based on the introduction of media-aware network nodes in the provisioning chain. Network-assisted adaptation mechanisms cooperate with the traditional client-driven approach to optimize the media delivery in multi-user scenarios. Such elements have been traditionally focused on network awareness but the interaction with the resource allocation and scheduling mechanisms of underlying radio networks was not typically allowed.

Finally, current 5G trends suggest the standardization and deployment of intelligent network nodes that will enable more powerful adaptation and prioritization frameworks over the whole transmission chain, and especially, at the edge of the mobile access network [6].

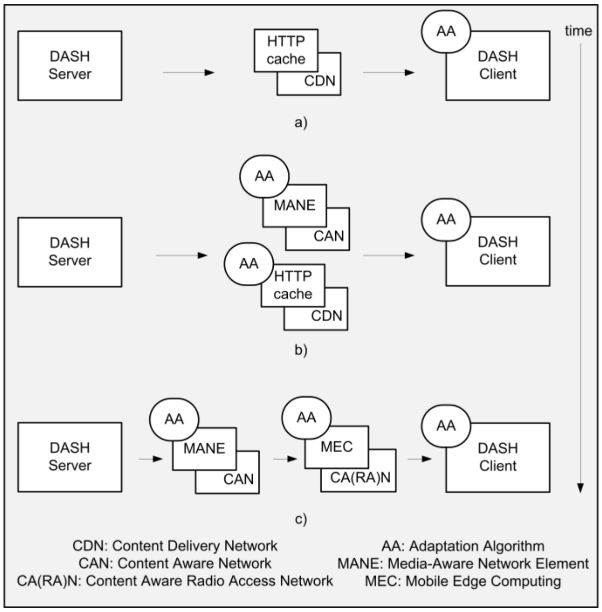


Figure 2. Evolution of mobile Multimedia adaptation strategies a) client-driven a; b) core network-assisted; c) core and access network-assisted.

In this scenario, SDN paradigm may be used to dynamically allocate network resources to different DASH clients [7, 8]. An SDN manager would then be used to dynamically modify video flows and/or network resources in order to achieve a QoE-based fairness between different users.

Figure 2c illustrates such approach aimed at including service adaptation capabilities into the 5G cloud-enabled RAN to integrate user awareness and enhance adaptation responsiveness. This way, the flexible architecture of the Cloud-RAN [9] will enable the convergence of SDN-based mobile networks and MEC-assisted close-to-the-user service instances.
In order to do so, channel and content aware adaptation algorithms would be in charge of making QoE-driven scheduling decisions. This way, the MEC will exploit the benefits of the multi-layer media delivery to incorporate network-assisted adaptations to the client-driven approach. In order to perform the channel aware estimations, the adaptation algorithm needs to be fed with low-level radio channel information (i.e. cell statistics and individual channel quality information). However, in multi-user scenarios, too fine-grain feedback granularity would entail a high load and traffic volume in the interface between MEC server and RAN monitoring elements.

3. Research challenges and opportunities
Cloudification trends in most networking areas and particularly in 5G and CDNs depict an exciting playground for improved multimedia services delivery in the near future. However, a number of challenges and research opportunities must be faced to ensure:

- **Network supported vs. implicit channel awareness**: Although MEC initiative defines specific mechanisms for retrieving channel information from the RAN, such deployment demands collaboration between radically different stakeholders, e.g., CDNs and mobile network operators (MNOs), which might jeopardize resulting architecture. As an alternative, over-the-top (OTT) CDNs and user equipment (UE) manufacturers could incorporate feedback mechanisms in multimedia players and devices and use crowdsourcing/Big Data techniques to infer implicitly channel and cell information to feed their adaptation algorithms and overcome MNO's resistance.
- **Analysis of the trade-off between improvements vs. quality feedback granularity**. Most research studies confirm that incorporating channel awareness in both radio resource scheduling and multimedia content delivery optimization loops result in enhancements in QoE and resource usage. A proper analysis of the complexity and overload of quality feedback mechanisms versus achieved improvements is of outermost importance in order to guarantee a business case for actual implementations.
- **Relevance of channel modelling in 4G+/5G environments**. Per user channel behaviour modelling in shared wireless channels remains a huge research challenge. A better understanding of 4G+/5G and realistic stochastic models will no doubt help refining channel feedback reporting rates and delay constraints as to relax initial requirements.
- **Impact of new codecs and transport mechanisms**. Recent multilayer video coding mechanisms (e.g., H265/HEVC) and transport mechanisms (e.g., QUIC and HTTP2.0) will affect existing DASH adaptation mechanisms and overall performance. Cross-layer effects with LTE-A and 5G networks need to be also carefully analysed as to better enhance the scheduling/service level adaptation proposals.
- **Role of eMBMS and other caching and broadcasting/multicasting schemes**. Caching mechanisms have been already incorporated into standardised broadcasting mechanism and integrated in 4G network nodes. However, their chances to become an actual alternative to "traditional" TV broadcasting mechanisms (i.e. DVB-T*) is still unclear.
- **Evolution of the ecosystem**. Major OTT Internet players, Cloud providers, Telco manufacturers, MNOs and broadcasters depict a tumultuous but challenging environment. The resulting ecosystem will no doubt determine the real applicability of joint CDN/5G integration initiatives.

Acknowledgments

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Fidel Liberal received his PhD from University of the Basque Country (UPV/EHU) in 2005 for his work in the area of holistic management of quality (both QoS and QoE) in telecommunications services. His research interests include quality management and multicriteria optimization for multimedia services in NGNs and 5G. He has co-authored more than 40 conference and journal papers.

Kourtis Michail-Alexandros, MSc was born in Athens, Greece, in 1989. He received the Diploma in Computer Science, and the Master's Degree in Computer Science from Athens University of Economics and Business, in 2011 and 2014, respectively. From January 2010 he is working at NCSR "Demokritos", in various research projects. Currently he is pursuing his PhD at the University of the Basque Country (UPV/EHU), Bilbao, Spain. His research interests include Video and Image Processing and Quality Assessment, Network Function Virtualization, Software Defined Networks and Quality of Service.

Jose Oscar Fajardo works as research fellow in the the University of the Basque Country (UPV/EHU), at the Faculty of Engineering in Bilbao. He received his M.Sc degree in 2003 and he is now Ph.D. candidate. He has lately worked in the FP7 ICT ADAMANTIUM (2007-2010) and FP7 SEC GERYON (2011-2014), where he has been involved in researching the adaptive management of mobile multimedia services under the framework of IMS. He has co-authored more than 25 journal and conference papers since 2005, mainly in the areas of QoS/PQoS/QoE and service performance assessment, and QoS-aware networking.

Dr. Harilaos Koumaras was born in Athens, Greece in 1980. He received his BSc degree in Physics in 2002 from the University of Athens, Physics Department, his MSc in Electronic Automation and Information Systems in 2004, being scholar of the non-profit organization Alexander S Onassis, from the University of Athens, Computer Science Department and his PhD in 2007 at Computer Science from the University of Athens, Computer Science Department. Dr. Koumaras has been an active research associate since 2003 of Media Net Lab at the National Centre of Scientific Research "Demokritos".

The Surrogate vNF approach for Content Distribution

Nicolas Herbaut[1], George Xilouris[2] and Daniel Négru[1]

[1]CNRS-LaBRI, University of Bordeaux, France

[2]NCSR Demokritos, Greece

Email:{nicolas.herbaut, daniel.negru}@labri.fr , xilouris@iit.demokritos.gr

1. Introduction

Since the introduction of high speed Internet technologies such as xDSL and FTTx, End-Users' demands for Internet services have grown at an exponential rate. According to Akamai, the average bandwidth has continued to globally increase by 65% in the second quarter of 2014 compared to 2013 [1]. In order to cope with this drastic growth, new solutions have been raised for efficient content delivery emerge, such as Content Delivery Networks (CDNs), distributed streaming and adaptive streaming (MPEG DASH). The proliferation of virtualization solutions and the current trend of exploitation within Telco environment e.g. Network Function Virtualization (NFV) created the appropriate environment for the combination of the above evolutions to enhance streaming technologies and architectures in order to respond to mass demands.

The rise of internet videos traffic and its inherent volatility is a challenge for the actors responsible for delivering the quality of service customers expect. From Content Providers (CP) to Content Delivery Networks (CDN) to Service providers (SP), every actor struggles with finding a proper way to fulfill the expected Quality of Service while maintaining a decent profit margin. For example, Liu et al. [2] showed that 20% of VoD video streaming session experienced a re-buffering ratio greater than 10%.

A current trend towards facilitating media distribution in the industry is the concept of replacing costly middle boxes by software, deployed on commodity servers. ETSI's ISG NFV [3] ongoing standardization efforts are all about making the Cloud Computing promise that offers low cost and increased elasticity to the IT world, a reality for the Telcos. In the current deployment model for NFV, it is anticipated that datacenters (at various capacities) are deployed in selected places within the Telco operator's network infrastructure (usually at the edges of the Telco infrastructure footprint) capable of providing IT resource virtualization for the deployment of VNFs. These places are called Network Function Virtualisation Infrastructure Point of Presence (NFVI-PoP). These deployments support both network and IT resource virtualization. The trend of using small scale datacenters i.e. micro-datacenters or even smaller, provides the opportunity to make available NFV infrastructures closer to the end-users and for smaller groups, enhancing the network usage efficiency. In [4], Spagna et al. describe the design principles of Application of such an operator-own CDN.

In this paper, we introduce the concept of Surrogate vNF which aims at taking advantage of the standards execution environments of Home Gateways to collaborate with vNFs deployed in operators POPs to achieve greater QoS in the context of media delivery. After detailing the concept, we show how it can be applied for content distribution and we present an evaluation of the solution.

2. SvNF Concept

Home Gateway Initiative (HGI) has undertaken the effort of providing requirement and recommendations for digital home equipment. Among their activities they have released the Open Platform 2.0 suite which captures home gateway software modularity requirements and provides remote test tools that form a cornerstone of many of the operators' and vendors' home gateway strategy. HGI has selected the OSGi platform (reviewed in [5]) for providing a modular service platform in order to realize the proposed suite [6]. The intention is to create a modular system that allows installing, updating, uninstalling, starting and stopping of additional software modules, while the underlying firmware image remains untouched. The choice of this execution environment allows the secure and scalable deployment of third-party applications that can interact safely with the operations of the device [7].

Embracing this architecture, a SvNF is implemented as an OSGi (Open Services Gateway initiative) bundle that acts like a regular module from the HG standpoint, except that it delegates any significant operation to a vNF that is instantiated at the (NFVI-PoP).

As shown in Figure 1, SvNF modules register themselves in the runtime environment only if any suitable vNF is available to them. Otherwise the HG falls back to legacy mode and continues using the native implementation of the service. This means that for each HG located in the customer premises a virtualized instance located at the nearest to the customer location (i.e NFVI-PoP) is assigned. Figure 1 illustrates the semantics of OSGi lifecycle. The dependence from the software resources are extended with the addition of network resources as well.

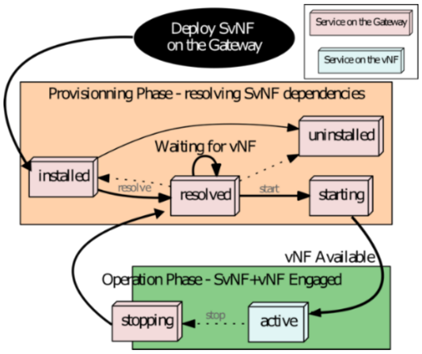

Figure 1 Adaptation of the OSGi lifecycle to SvNF

3. Application to Content Distribution.

In Figure 2, we present the high level design of the System. We can see that SvNF supports both Original Content Distribution mode when the content is retrieved as usual from the CP network (possibly supported by CDN) but also Enhanced Content Distribution mode through regional POPs when available. Depending on the context, End-Users requests will be served by either the existing Content Provider Distribution Network or by the SP-managed regional POP, in an hybrid fashion like Broberg et al. suggested in [8], for regular CDN providers.

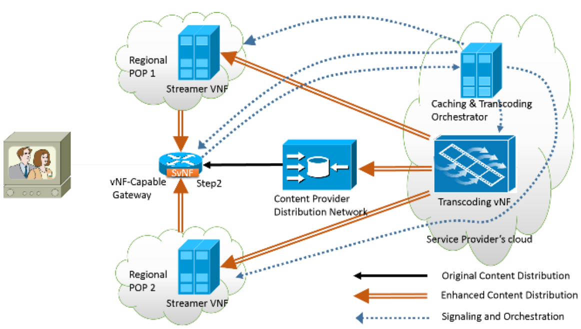

Figure 2 SvNF applied to Content distribution

A signaling channel between the SvNF and the Caching Orchestrator is necessary to update HG routing decisions and to push monitoring measurements back. Another configuration channel is used toward POPs for the Orchestrator to decide which content to provision according to monitoring data and allows Streamer vNFs to scale out when needed. Thanks to NFV approach, we are also able to perform media transformation in the network through the transcoding vNF. This reduces the amount of data stored in the system, as new formats/qualities of the media can be produced on the fly.

Closely related to the SDN approach [9], our proposal effectively promotes the separation of control signaling (ie. Control) and Content distribution (ie. Data) planes. However, leveraging on the flexibility brought by vNFs, we extend it to the point that not only virtual networks are created to enhance Control Distribution, but even application data is provisioned to the network according to the demand. This Application Defined Network [10] working on layers 4-7 is made available in a residential scenario by deploying custom software to the Home Gateways, with limited impacts on the hardware thanks to the SvNF concept that follows the standards.

4. Evaluation

An NS3 simulation model was implemented in order to model the Content Distribution Architecture (see Figure 2). A set of 200 HG were considered along with their respective SvNF instances. During the simulation 300 videos were concurrently streamed over HTTP over a period of 60 seconds with a target bitrate of 320kbps per video, with 10MB per video. The acquired simulation data were analyzed and the SLA violations were calculated. An SLA violation is considered when 50% of the target bitrate is not reached 15s after the request. To reflect the fact that the regional POPs are closer to the clients than the CP Networks, we introduced respectively a 25ms and 50ms delay on the links that interconnect either the POP or the CP respectively in the simulation model. This hypothesis is conforming to a French network of Service Provider characteristics [11].

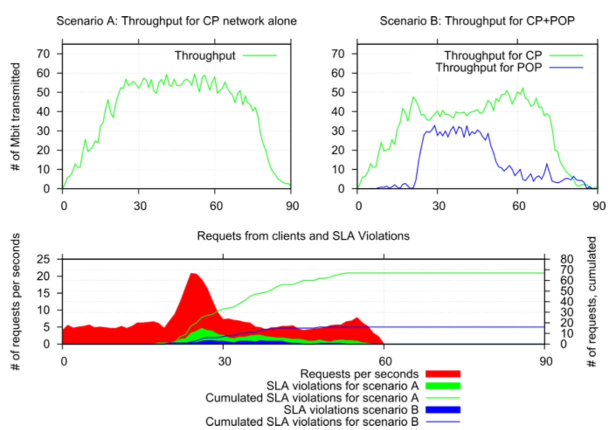

Figure 3 Evaluation of the System

The experiment simulated two scenarios: i) Scenario A, where the CP Network is the only source for video download and (ii) Scenario B, where one regional POP was added. The global available server capacity was fixed throughout the experiment, therefore, for scenario B the sum of the link capacity of the CP server network and the POP network link is the same with the capacity allocated to CP network for scenario A. Video replication to the POP happens when a video has been requested 4 times from the CP Network. Figure 3 sums up the results of the simulation.

We can see that even if the global bandwidth remains the same, having a regional POP with great network performance and lower delay is able to mitigate SLA violations due to a sudden peak in consumption, from 70 down to 20 violations.

The choice of which video is served by the POP is crucial to those benefits. Provisioning video with few views per second makes the regional POP bandwidth saturated with videos that could have been served easily by the CP. The best scenario is letting the regional POP absorbing flash crowds for very popular videos, while leaving the long tail to the CP, like in this example.

5. Conclusion

In this paper we demonstrated the advantage of having a software deployed on the gateway collaborating with vNF in operator regional POPs to achieve better media distribution. In this case, SvNF is a cheap way to get the flexibility of SDN for the gateways coupled with the elasticity of vNF.

As next steps we plan to extend our work by deploying and testing under a real environment focusing more on the workload characterization for the vHG w.r.t the storage performance. Additionally we plan to study how this approach could be extended in a multi-tenant scenario.

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Nicolas Herbaut received a Master’s Degree in Mathematical Engineering at Institut National des Sciences Appliquées de Rouen in France, in 2004. In 2014 he became a PhD candidate at Bordeaux University. His current research interests include, Programmable Networks, Network Function Virtualisation and Cloud Computing.

Georgios Xilouris received his B.Sc. in Physics from University of Ioannina, Greece in 1999 and his M.Sc. in Automation Control Systems and Robotics from National Technical University of Athens in 2001. He joined the Institute of Informatics and Telecommunications of NCSR Demokritos in 2000 and since then, he has participated in numerous EU-funded projects, as well as in National funded projects. His current research interests include, Network Function Virtualisation, Network Management, Network Performance, Programmable Networks, Digital Television (DVB), Satellite Communications, Cloud Computing and IT services.

Dr. Daniel NEGRU received his PhD from the University of Versailles Saint Quentin en Yvelines in 2006 in the field of Broadcast and Internet convergence solutions at the network and service levels. In 2007, he became Associate Professor at ENSEIRB School of Engineers / University of Bordeaux (UB), specializing in multimedia and networking. From 2010 to 2014, he has been coordinating the ICT FP7 ALICANTE IP project that tackles networking and multimedia research fields. He has participated to more than 10 collaborative research projects at the national or European level, published more than 50 papers, incl. high level ones in prestigious journals and conferences, such IEEE Communication Magazine, IEEE Multimedia, Globecom, ISCC, FIA etc. In 2013, he received his Habilitation à Diriger des Recherches (HDR) from the University of Bordeaux.

Caching of Viral Content in NFV Architectures

Ram (Ramki) Krishnan[1], Dilip Krishnawamy[2], Diego Lopez[3], Peter Willis[4]
[1]Dell Inc., [2]IBM Research, [3]Telefonica, [4]BT

Email: ramki_krishnan@dell.com, dilikrish@in.ibm.com, diego.r.lopez@telefonica.com, peter.j.willis@bt.com

1. Introduction

Network Operators use a variety of proprietary hardware appliances. Hardware appliances deliver good performance typically. However, they are complex to manage, and not easy to scale up/down in capacity and not cost effective. NFV [1] is a movement by network operators around the world to address the aforementioned issues. NFV involves the implementation of network functions in software that can run on a range of industry standard server hardware, and that can be moved to, or instantiated in, various locations in the network as required, without the need for installation of new equipment. NFV Points of Presence (PoPs) [2] data centers (DCs) are in-network infrastructures that typically face unique challenges in terms of capacity, energy efficiency and other aspects as compared to large scale cloud data centers.

NFV has many use cases [3], notable of which is the virtualization of the CDN (vCDN). The goal of vCDN would be to address virtualization of all the CDN components, but the biggest and immediate impact would be on the cache nodes given the growth in content especially in mobile networks [5] and improving the overall application Quality of Experience.

Also, energy efficiency is one of the important goals identified by the ETSI NFV Virtualization Requirements document [4]. In NFV systems, since VNFs are virtualized in general purpose servers, servers are the predominant energy consumers – hence, optimizing for server energy consumption is key to overall energy efficiency.

In the above context, caching viral content such as an extremely popular YouTube video, pose interesting challenges and opportunities. This article discusses the work ongoing in the industry in the area of viral content caching, connecting it with the overall energy efficiency in the context of NFV.

Currently, the allocation of VMs for vCDN follows a static model based on weekday prime-time characteristics, business hours etc. This model results in substantial resource over-provisioning, since a lot of content viewed over websites like YouTube and shared over social media like Twitter follow a virality pattern during anytime of weekday or weekend [6]. Additionally, many industry standard servers consume substantial power in the active idle state, which results in severe energy inefficiency. For example, Dell PowerEdge R720 Rack Server has a peak power utilization of 303 Watts and consumes 87.5 Watts (approximately 30% of peak) in the active idle state – an exemplary depiction appears in [7].

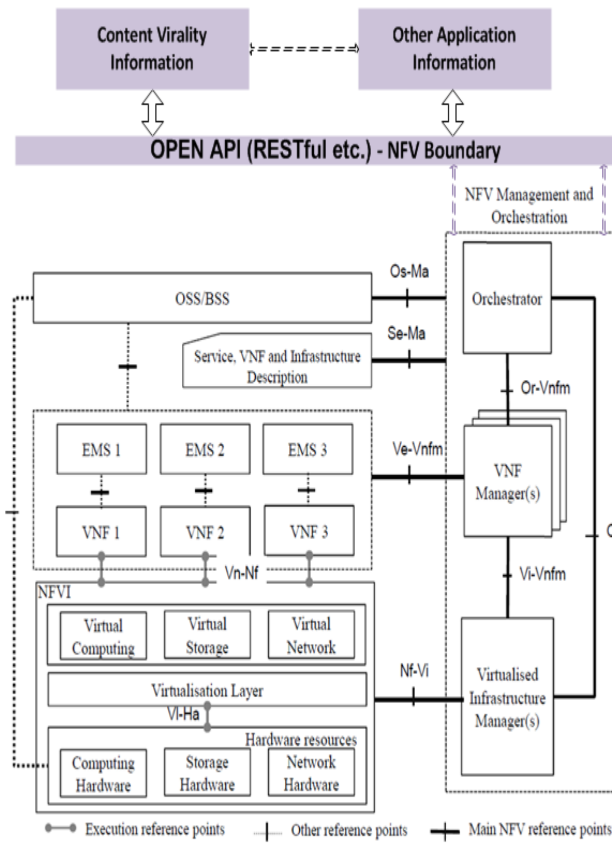


Figure 1: Open NFV Architectural Framework (Proposed in [8])

2. Ongoing Work

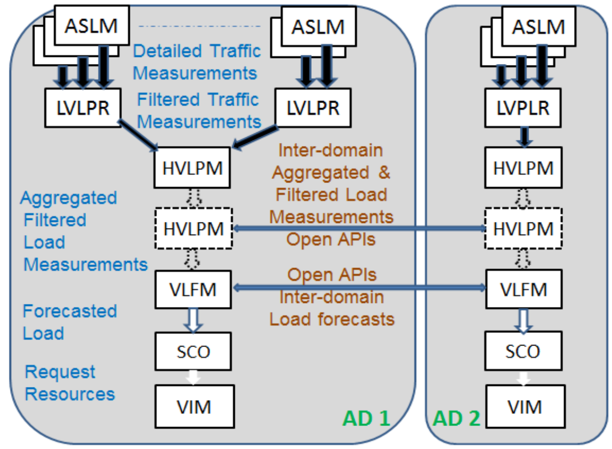
Work in [8] proposes an open NFV architectural framework for managing application viral behavior. This is adapted from the definition of the ETSI NFV Architectural Framework [11] and extended in this paper to show support for content virality management. The paper proposes the availability of information about viral characteristics through open interfaces as depicted in Figure 1. Open APIs could be designed to exchange information across RESTful mechanisms [12] or a pub/sub framework. Content virality information can be streamed in real-time from applications such as YouTube, and submitted to the Virtual Network Function Manager (VNFM) [2] through the appropriate APIs. This information can be used by VNFM to populate newly allocated vCDN resource pools with the optimal Virtual Network Function (VNF) [2] capacity needed for content caching which can be consolidated to a minimal set of VMs and physical servers. Besides content virality information, this paper suggests that the architecture could optionally provide a generic open API framework for handling other application information, such as information regarding firewall services, in real-time if available. There is an ongoing ETSI NFV proof of concept [9] in this area.

Work in [8] extends the open virality architecture to generic cloud and NFV applications with inter domain aggregation. The approach is based on the service chain concept [17], so user traffic to an application is routed through a set of successive network service functions that process the traffic. [17]. The service chain orchestration, part of the NFV Orchestrator functionality shown in Figure 1, will translate the forecasted load into the necessary resource allocation for each VNF, consolidating the resource requirements for the application/event to a minimal set of software and hardware resources able to satisfy the demand with an optimal energy consumption. This is depicted in Figure 2.

In [16] a policy-constraint-based placement and scheduling framework for NFV architectures is proposed for the NFV infrastructure as service (NFVIaaS) use case [3]. The focus is on NFVIaaS placement across distributed NFV DCs of a service provider, with various resource constraints such as compute, energy and service request requirements as specified by a second service provider. The primary goal is to optimize resource utilization of compute and energy in the NFV infrastructure of the first service provider. An ETSI NFV proof of concept [10] in this area is being currently carried out.

The typical proactive/reactive NFVIaaS placement policies within a NFV DC are rules of the type

- There can be at most one active physical server with utilization less than X%
- No more than one VM of the same High Availability group must be deployed on the same physical server
- Limit maximum energy consumption per NFV DC to Y watts



Legend:
AD – Administrative Domain
VIM – Virtual Infrastructure Manager
SCO – Service Chain Orchestration
VLFM – Viral Load Forecasting Model
HVLPM – Hierarchical Viral Load Pattern Recognition
LVLPR – Local Viral Load Pattern Recognition
ASLM – Application specific Load Monitoring

Figure 2: Open Virality Architecture for Generic Network & Cloud Apps (Proposed in [8])

A practical implementation of this proof of concept is in progress using OpenStack Congress [13], one of the components of the OpenStack open source framework [14]. Additionally, [15] proposes a generalized policy framework for NFV architectures.

3. Future directions for managing viral content

By combining the work in [8] and [16], an integrated NFV architectural framework for managing viral content is possible. In the integrated architectural framework, the application virality information can be modelled as a non-linear constraint ([8] models the primary envelope function for a viral video access statistics as a log-normal function) along with the existing placement and scheduling constraints which are typically linear. The key benefit of this approach is maximizing energy efficiency while addressing all the NFV DC constraints and leveraging the application virality information.

More generally, in NFV systems, one needs to worry about efficient resource management across multiple resource vectors such as computing, networking, storage, or energy. For vCDN capabilities, these multiple vectors need to be jointly addressed besides just considering caching the most relevant videos. With in-network data center NFV scenarios, one needs to take account of multiple vectors such as: computing constraints at an in-network vCDN VM to serve multiple video streams, or networking bandwidth to deliver the video from the in-network data center to users, or constraints on the limited network bandwidth between the in-network data center and a remote video server that necessitates caching at the in-network data center, or storage constraints based on limited constraints to store content locally in the in-network data center, or time-varying energy costs. In addition, an in-network data center may support other functions, so that the fraction of resources allocated for vCDN functionality needs to be planned for, based on past and emerging trends for video usage in a given geographical region served by the in-network data center.

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Ram (Ramki) Krishnan is an industry expert in the area of Networking and currently Distinguished Engineer and CTO of NFV in Dell. He is a recognized innovator with 20+ US patents and several conference papers. He is co-chair of NFV Research Group in IRTF. He is also a thought leadership speaker in conferences such as ONS, OpenStack, and OpenDaylight etc.

Dr. Dilip Krishnaswamy is a senior research scientist at IBM Research. Previously, he was a platform architect at Intel, and a senior researcher in the office of the chief scientist at Qualcomm. He has a PhD in electrical engineering from the University of Illinois at Urbana-Champaign. He is an inventor on 27 granted US patents and has authored over 60 research publications.

Dr. Diego R. Lopez is a Senior Technology Expert on network middleware and services within the GCTO Unit of Telefónica I+D. Diego is currently focused on identifying and evaluating new opportunities in technologies applicable to network infrastructures, and the coordination of national and international collaboration activities. Diego is actively participating in the ETSI ISG on Network Function Virtualization (chairing its Technical Steering Committee), the ONF, and the IETF WGs connected to these activities, acting as co-chair of the NFVRG within the IRTF.

Peter Willis researches the future of networks covering everything from photonics to network applications. He has been researching and developing Network Functions Virtualization since 2011, published the first carrier testing results in June 2012 and is the author of the often used "Classical Network Appliance Approach v NFV Approach" diagram. Peter previously worked on the development of PBB-TE, BT's 21st Century Network Architecture and BT's Internet service.

Enhancing Satellite & Terrestrial Networks Integration through NFV/SDN technologies

Ramon Ferrús[1], Oriol Sallent[1], Tinku Rasheed[2], Arianna Morelli[3], Harilaos Koumaras[4], George Agapiou[5], Christelle Boustie[6], Patrick Gélard[6], Rachid Mestari[7], Haritos Makis[8], Thierry Masson[9]

[1]Universitat Politècnica de Catalunya (UPC), Spain;[2]Center for REsearch And Telecommunication Experimentation for NETworked communities (CNET), Italy; [3]INTECS S.p.A., Italy; [4]National Centre for Scientific Research "Demokritos" (NCSRD), Greece; [5]Hellenic Telecommunications Organization S.A. (OTE), Greece; [6]Centre National d'Etudes Spatiales (CNES), France; [7]Synaptec SAS, France, [8]HellasSAT, Greece; [9]One Access, France

1. Introduction

The combination of satellite and terrestrial components to form a single/integrated telecom network has been regarded for a long time as a promising approach to significantly improve the delivery of communications services [1][2]. Multiple compelling benefits are expected:

- *Improved service coverage and footprint expansion.* Satellite can complement terrestrial offerings and provide coverage extension to un-served or poorly served areas (e.g., rural areas) as well as connectivity to terrestrial vehicles (e.g., trains, buses), aircrafts, and vessels.
- *Rapid, dynamic and/or infrastructure-independent service deployment.* Satellite links can provide backhauling solutions for ad hoc deployment of fixed or mobile terrestrial systems (e.g., deployment of a transportable base station for a large event or disaster scenario).
- *Increased network resilience.* Satellite can provide redundancy for critical communication links. In addition, terrestrial equipment such as base stations could support fallback/safe operational modes over backup satellite backhauls to improve service availability and network resilience in face of potential failures of terrestrial backhaul links.
- *Broader range of service provisioning with lower costs for customers and operators.* Satellite broadcast/multicast capabilities can be exploited for off-loading video or other high bandwidth traffic that otherwise may not be cost-efficiently delivered over the terrestrial infrastructure (e.g., feed of Content Delivery Network (CDN) nodes placed at terrestrial network edges). Moreover, satellite broadcast/multicast capabilities can help operators to deliver high quality video content to home networks.
- *Improved Quality-of-Service/Quality-of-Experience (QoS/QoE) for end users.* Combined pooling and management of both satellite and terrestrial network resources can improve service delivery in areas where QoS/QoE delivered by terrestrial access alone may be not satisfactory (e.g. higher speed broadband Internet access in low density populated areas with limited xDSL coverage).

The integration of satellite and terrestrial networks to fully achieve the above-mentioned benefits still has to deal with many challenges as of today. Despite the important and continued advances in satellite communications technologies, satellite communications offerings have not evolved at the same pace as terrestrial communications systems have done due to much lower economies of scale and inherent associated technological complexities [3]. Historically, the use of satellite as a means of communication was restricted to satellite niche areas (e.g., professional use in areas where there are no terrestrial networks) and to Direct-To-Home TV market (DTH), the first service with strong commercial interest. Now with Ka band satellite communication systems, satellite bidirectional broadband services (Direct-To-Customers) begin to emerge. Thanks to the emergence of the satellite broadband services, the satellite industry is keen to develop and deploy flexible and also cost-effective solutions to prepare the future satellite system infrastructure. Some of the key limitations of current SatCom platforms under the focus of the satellite industry are the following:

- Establishment and configuration of networking services across satellite and terrestrial segments is mostly performed manually, thus involving considerable setup and reconfiguration delays, as well as high associated operating and maintenance costs.
- New network technologies, algorithms and protocols cannot be rapidly introduced into the market since they involve time-consuming and costly SatCom and terrestrial hardware upgrades and are thus associated with significant CAPEX investments.
- Lack of flexibility in the management of the satellite resources to achieve a better match with users' demand and optimization of the resources in use.
- SatCom services are mostly associated with plain connectivity (with or without QoS), without the ability to insert on-demand in-network services (e.g. firewalling, proxying for traffic optimization, caching, media transcoding, etc.) for network-side traffic processing.
- Many satellite specific settings and the lack of common prevalent standards for the integration

with terrestrial systems do not provide transparency for the applicability and continuity of policies for routing, QoS, security, management and connectivity (Ethernet, MPLS, etc.) and so on across both segments.

- Limited control by service providers for global resource management when relying on multiple satellite network operators' platforms. The satellite network operators enable service providers to connect their customers to the information servers hosted in data centers. This interconnection is achieved by providing connectivity from the satellite ground segment to terrestrial network nodes. The purpose of a service provider is to be able to offer its entire catalog of services to its customers through different network infrastructures (provided by different operators) in a transparent manner. Service providers are facing some difficulties, such as the management of various resources transmitted on various transport infrastructures, consisting of a set of equipment managed by each operator independently and with specific characteristics (terrestrial/satellite).

In this context, the satellite industry is clearly committed to revisit and revamp the role of satellite communications in the context of next generation 5G networks [4][5]. Indeed, considering the actual and future challenges being pursued under 5G, it is of utmost importance that the standardized network architecture be based on multiple layers and heterogeneity of network technologies, including satellite communications.

2. NFV/SDN as enabling technologies

In the terrestrial domain, limitations such as the lack of automation, limited flexibility in scaling/upgrading networking equipment and services noted above for satellite communications are also present but gradually being confronted via a major technological transition sustained in the still emerging concepts and technologies related to network function virtualization (NFV) and software-defined networking (SDN). In addition to network flexibility, NFV/SDN technologies are also expected to result in reduced equipment and, remarkably, lower operational costs. Indeed, the adoption of NFV/SDN architectural frameworks enables the creation of more intelligent networks that are open, programmable and application aware. It creates network abstractions that are essential for the integration and consistent operation of the underlying networking functions, facilitating the combination of diverse technologies (satellite/terrestrial access systems, core networking equipment, service delivery platforms, etc.) for the deployment of optimized network architectures tailored to specific application' requirements. This gives operators greater control over their equipment, simplifying network management to a great extent and more ability to create innovative services, allowing also the centralized management and control of networking devices from multiple vendors. SDN applicability can cover many distinct operational areas, ranging from the control of fine-grained, distributed enforcement of QoS polices with an integrated network-wide view (which leads to better end user experience) to the real-time control of network resources in a localized area when coping with a congestion situation. Therefore, being able to tap into NFV and SDN is claimed to be of utmost importance for the satellite communications industry, keeping it aligned to mainstream technological evolution driven from the more large scale markets of fixed/mobile broadband communications and data centers and definitively paving the way for fully integrated terrestrial and satellite network services. Ultimately, unified terrestrial and satellite networks sustained on NFV/SDN technologies and exploited through smart and advanced resource management mechanisms will result in a win-win solution for both domains as well as for the end-users.

3. Integrated terrestrial and satellite networking infrastructures

This paper advocates for the introduction and exploitation of the NFV/SDN paradigms and technologies into the satellite networking domain, as central enablers towards improved and more flexible integration of satellite and terrestrial segments, network service innovation and business agility, and network resources management. An illustration of such conceptual approach is depicted in Figure 1.

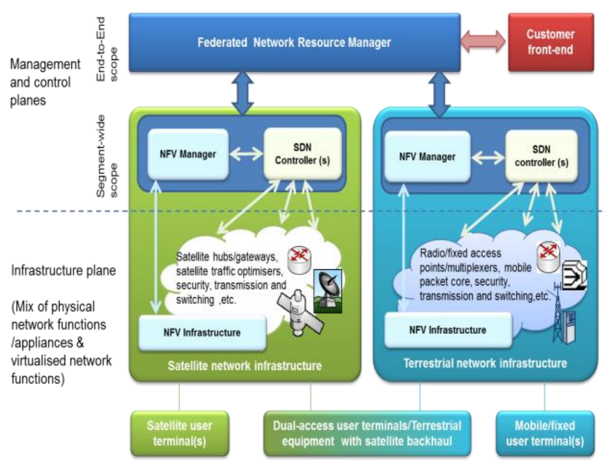

Figure 1. Conceptual framework for the combination of terrestrial and satellite communications segments.

The realization of a given end-to-end network service may require the combination of a number of constituent, interconnected network functions across the different segments (e.g. satellite hubs/terminals, terrestrial access points/base stations, switching/routing, mobility packet core functions, policy enforcement, caches and video transcoding/adaptation, network/transport/application optimization, security functions). In this respect, as illustrated in Figure 1, it is anticipated that some network functions within both terrestrial and satellite segments will be virtualized network functions (VNFs) running on top of NFV-Infrastructures (NFVI), which include the physical resources and the virtualization layer for the use of these resources by the VNFs. The NFVI can span across several locations and data centers. Therefore, the infrastructure plane of both satellite and terrestrial segments is considered to comprise of a mix of network functions implemented as bespoke hardware appliances together with virtualized network functions running on top of a number of NFVI platforms.

Above the infrastructure plane, the management and control plane inside each of the involved terrestrial and/or satellite infrastructure segments will host two central functions: a (set of) NFV manager(s) and a (set of) SDN controller(s). The former will be in charge of the segment-wide network orchestration and management of NFV (infrastructure and software) resources, focusing on virtualization-specific management tasks (e.g. control of the lifecycle of all VNFs running in the NFV infrastructure). On the other hand, the SDN controller(s) will exploit a number of programmatic interfaces to the different network functions, regardless of whether they are virtualized on top of the NFVI or implemented in specialized hardware, to consolidate the execution of some control plane functions in a segment-wide, centralized point.

On this basis, the proposed approach for the combination of the terrestrial and satellite segments also introduces the concept of the federated network resource manager. This entity, illustrated in Figure 1, provides a set of APIs to the operator/customer front-end for the specification of the end-to-end service and network description. Based on this network specification, the federated network resource manager would make decisions regarding the availability of the resources requested by the operator/customer and will enforce the decided resources in a unified way, to the underlying infrastructures, regardless of whether it is a satellite or a terrestrial one. To that end, the federated network resource manager is to be responsible for the coordinated management and operation of both NFV resources and SDN-enabled control plane functionalities of the deployed end-to-end network service across the satellite and terrestrial segments. In this way, consistent end-to-end policies can be enforced.

The proposed overall architecture shall be able to provide virtualized network services (Network as a Service, NaaS). Simultaneous provision of multiple network slices on the same platform will be supported (i.e., multi-tenancy). Each network slice can have a distinct policy and be controlled by a different entity (e.g. mobile/fixed network operator, service content provider, enterprise, etc.). Virtualized network services could be offered as per demand and on a dynamic basis, subject to e.g. time and availability of resources.

The development of the conceptual framework described in this paper is currently being undertaken by EU H2020 VITAL research project [6].

4. Conclusions

NFV and SDN technologies can become key facilitators for the combination of terrestrial and satellite networks. Enabling NFV into the SatCom domain will provide operators with appropriate tools and interfaces in order to establish end-to-end fully operable virtualized satellite networks to be offered to third-party operators/service providers. Enabling SDN-based, federated resource management paves way for a unified control plane that would allow operators to efficiently manage and optimize the operation of the hybrid network.

The proposed solution is expected to bring improved coverage, optimized communication resources use and better network resilience, along with improved innovation capacity and business agility for deploying communications services over combined networks.

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Ramon Ferrús (ramon.ferrus@upc.edu) is Associate Professor at the Universitat Politècnica de Catalunya (UPC). His research interests include network architectures, protocols, radio resource and spectrum management in wireless communications. He has participated in several research projects within the European Commission 6th and 7th Framework Programmes as well as in research and technology transfer projects for private companies. He is co-author of one book on mobile communications and one book on mobile broadband Public Safety communications. He has co-authored over 100 papers published in peer-reviewed journals, magazines, conference proceedings and workshops.

Oriol Sallent (sallent@tsc.upc.edu) is a Professor at the Universitat Politècnica de Catalunya (UPC). He has participated in a wide range of european projects with diverse responsibilities as WPLeader and Coordinator partner and contributed to standardisation bodies such as 3GPP, IEEE and ETSI. He has published 200+ papers mostly in IEEE journals and conferences. His research interests include, among others, Cognitive management in cognitive radio networks, Dynamic spectrum access and management, Self-organising networks and radio network optimization, Integration of satellite and terrestrial networks and QoS provisioning in heterogeneous wireless networks.

Dr. Tinku Rasheed is a Senior Research staff member, heading the Future Networks Area within CREATE-NET. Before joining CREATE-NET, Dr. Rasheed was research engineer with Orange Labs for a period of 4 years. He received his Ph.D. degree from the Computer Science Department of the University of Paris-Sud XI., in 2007, M.S. degree in 2003 from Aston University, U.K. and bachelor degree in 2002 in Telecommunications from University of Kerala, India. Dr. Rasheed has extensive industrial and academic research experience in the mobile wireless communication area, end-to-end network architectures and services. He has several granted patents and has published more than 60 articles in major journals and conferences. He is a member of the IEEE and ACM.

Ms Arianna Morelli (F) received her Master's Degree in Telecommunications Engineering in 2003 from the University of Pisa. She has been working at Intecs since 2007 on system design and development for telecommunications systems in the professional and defence domains. Since 2009 she has been involved in the FP7 SANDRA Integrated Project, with a focus on Software Defined Radio (SDR). Since 2013 she is involved in CROWD project which aims to define new mechanisms to influence the behaviour of the future extremely dense networks She is the Intecs delegate within ETSI TC RRS.

Dr. Harilaos Koumaras was born in Athens, Greece in 1980. He received his BSc degree in Physics in 2002 from the University of Athens, Physics Department, his MSc in Electronic Automation and Information Systems in 2004, being scholar of the non-profit organization Alexander S Onassis, from the University of Athens, Computer Science Department and his PhD in 2007 at Computer Science from the University of Athens, Computer Science Department. Dr. Harilaos Koumaras is an active researcher in the field of evaluation of the perceived quality of multimedia services, including video and picture quality assessment, media distribution over SDN/NFV, video traffic modeling, digital terrestrial television and video compression techniques. Dr. Koumaras has been an active research associate since 2003 of Media Net Lab at the National Centre of Scientific Research "Demokritos".

Dr. George Agapiou is a telecommunications engineer, holding a PhD from the Georgia Institute of Technology. He is the Head of the Measurements and Wireless Technologies Research Laboratory of the Hellenic Telecommunications Organization (OTE S.A.) where he tests and evaluates major technologies, terminals and services. He has participated in various IST, STREP, Eurescom, e-ten, FP6, FP7, H2020 research projects with major role and has published more than 50 papers in scientific journals and proceedings. His research interests include next generation wired and wireless access networks and novel broadband technologies and services.

Mrs Christelle Boustie (F) received the Diploma in Space Telecommunications from the Aeronautical and Space Institute (SUPAERO) of Toulouse (France) in 1999. In 2000, she joined the Centre National d'Etudes Spatiales as Engineer in space ground station development. Since 2008, she is working in mobile space telecommunication research area, as first telecommunication system Engineer, and now as satellite communication project manager. More recently, she had in charge at CNES the technical coordination of activities for the French collaborative project M3 and the Celtic collaborative project ENGINES.

Gelard Patrick began his professional experience at ABS (Alcatel Business System) on PABX during 4 years before joining the CNES in 1990 as protocol engineering expert at information systems division. For over eight years now, he works in CNES at Network and telecommunication unit as a terrestrial and satellite networking expert. He has been involved in multiple projects in satellite communications (Agora, ATF, Athena-Fidus, MM2G, THD, SMILE). It has now been five years that he has in charge of research axis "terrestrial and satellite infrastructure convergence". This led him to work on subject R&T like "Software Defined Networking and Virtualization for Broadband Satellite Networks".

Mr. Rachid Mestari (M) is computer science and telecommunication expert since 1985. He created and managed several independent companies in the field of software development and communication networks. His main activities have been on physical layer (L1) and Data Link communication (L2) with focus on wired Ethernet communication. After, he specialized in system design and performance analysis. His current areas of interest are satellite communication, convergence of terrestrial and satellite network, sensor and IP ad hoc networks, including QoS and Security.

Makis Haritos is a network Engineer currently working for Hellas-Sat the Greek Satellite operator specialized in Core routing switching, telecom and VoIP services over ground and satellite carriers. Studied as a freshman in Montgomery College in Maryland (MD) Washington DC and then transferred to an American College in Athens Greece graduating in Computer Hardware and digital electronics major. Working in telecom industry in Athens Greece since 1996 on various projects covering a wide range of technologies. Started as a Netware Novell engineer, then switched to Open VMS Alpha systems, Wireless networks, Frame Relay networks, Unified communications and Nortel ATM voice switching. Some of the companies include Equant/Sita (Orange), Ceres Shipping, Ideal Systems, Lannet Telecoms and finally Hellas-sat since 2006.

INDUSTRIAL COLUMN: SPECIAL ISSUE ON 5G FOR ACTIVE HEALTHY AGEING

Guest Editor: David Soldani, Huawei European Research Centre (ERC), Germany
david.soldani@huawei.com

The global ageing is one of the greatest transformations of our time and the *Silver Dollar*, defined as the public and consumer expenditure related to population ageing and specific needs of the people over 50, is becoming the 3rd largest economy in the world, i.e. US$7 trillion per year, with private spending power of the elderly generation reaching $15 trillion by 2020, globally.

This Special Issue of the E-Letter focuses on the latest progresses on key enabling technologies to help older persons live better, independently, whilst reducing cost and effort of long-term care. In EU, today, this is about 50% of the Government expenditure, growing by more than 4% of GDP until 2060. The editor is immensely grateful to disclose six key original contributions from industry and academia on their views and latest results on 5G solutions to Active and Healthy Ageing (AHA), age-friendly and safe environments, including homes.

In the first article, entitled “5G: The Nervous System of the Silver Economy” the authors present the main stakeholders and actions taken in Europe to address the ageing population problem, and discuss new business models and the crucial enabling technologies for AHA, namely: *Sensing, Reasoning, Interacting, Acting and Networking*, using 5G networks, which are expected to become the new lifeblood of the *Silver Economy*.
In the second article, titled “Full Field Communication for the Silver Economy – Use Cases and Enabling Technologies”, Atanas, Pablo, Onay, and Qing paint the full field communication (FFC) system and how it applies to the Silver Economy. Also, they provide an overview of the key FFC enabling technologies, i.e. 3D audio, full parallax (“holographic”) visualization and 3D scene capturing and reconstruction.

In the third article, entitled “Toward Cloud Service Robotics in Active and Healthy Ageing Applications”, Filippo presents a case study of the Robot-Era system using three cooperating robots, i.e. DOmestic RObot (DORO), COndominium RObot (CORO) and Outdoor RObot (ORO). The main challenges of Cloud robotics connected to Wireless Sensor Network (WSN) and Context Awareness Monitoring system (CAM) for an ambient assisted living (AAL) are also discussed.

The fourth article, entitled “Independent Active Ageing - the Role of 5G and Autonomous Vehicles”, by Ciarán, Vince and Mario, explore the potential benefits of 5G wireless technologies in enabling timely, localized and personalized interactions between elders and service providers in mobility scenarios. They emphasize how ongoing *vehicular research* is fast converging to enable future autonomous vehicular solutions that scale from rural countryside to dense urban deployment scenarios to support, sustain and maintain active, healthy and independent living amongst spread ageing populations.

The fifth article, titled “5G Radio Access Technologies for Active and Healthy Ageing”, by Malte, Zhao and Egon, presents three key enabling access technologies for 5G wireless, as identified and researched by the EU METIS project. The focus is on FBMC/OQAM, which is a candidate waveform for 3GPP standards, providing new degrees of freedom for PHY system design and meeting all requirements for AHA wireless solutions.

In the sixth article, entitled “Requirements and Design Principles for Next Generation Networks”, Riccardo T. and Riccardo G. introduce new design aspects for 5G, based on key emerging technologies, such as SDN and NFV, and propose a solution to access agnostic core, network slicing, tailored C/D-planes and augmented D-plane, which are expected to be the cornerstones of NG network design, truly suitable for AHA networking.

David Soldani received a M.Sc. degree with *magna cum laude* in Engineering from the University of Florence, Italy, in 1994; and a D.Sc. degree in Technology with *distinction* from Aalto University, Finland, in 2006. In 2014, he was appointed Visiting Professor at the University of Surrey, UK. He is one of the top experts in multi-disciplinary, transformative frontier research. He has been active in the ICT field for more than 20 years, working on 200+ research and innovation projects for 2G, 3G, 4G and now 5G, and contributing to 500+ quality deliverables – from strategic research and innovation strategies and plans formulation down to modeling, simulations, emulations and innovative proof of concepts with partners and customers. Areas of his responsibility and expertise include, but not limited to: future wireless, computing, network and multimedia technologies. He represents Huawei in the Board of the 5G Infrastructure Association, within the EU H2020 5GPPP Initiative, and Steering Board of NetWorld2020 ETP in Europe.

5G: The Nervous System of the Silver Economy

David Soldani†, Rahim Tafazolli‡
†Huawei European Research Centre, Germany; ‡University of Surrey, UK
Email: david.soldani@huawei.com, r.tafazolli@surrey.ac.uk

1. Introduction

The global ageing is one of the greatest transformations of our time. By 2050, the number of older persons (60+) is expected to grow from 841mn in 2013 to 2bn+ and the related costs for the public administration will be up to 50% of the total GDP in 2010 [1]. The global scenario is illustrated in Figure 1. The extreme case is in Japan, where the population could drop to 107mn from 128mn, with 55mn out of workforce by 2050, i.e. 40mn above 65 and 5mn below 14. China, Europe, North America and Australia will face similar challenges. (In [2], ageing population and scarcity of primary resources are the most important causes of the 3rd world war.) Two are the main reasons: 1) We are living longer and 2) women have less than 2.1 children on average. By 2050, the global life expectancy at birth is 80+ with a gender gap of 5 years, with women living longer [1]. Children are no longer a value for families and many people choose not to reproduce. The entire pattern of traditional life, as we know it, is thus collapsing, and no clear alternative patterns have emerged yet. Raising many children, in our industrial and urban society, is currently unaffordable and it will be worse in the future. The cost of raising children will not decline, nor will there be ways found to put 6 year olds to work. Besides, the rate of infant mortality is not going to rise. Therefore, in the 21st century, the trend toward having fewer children definitely continues [2].

Longevity, namely the *Silver Dollar*, defined as the public and consumer expenditure related to population ageing and specific needs of the population over 50, is a great opportunity in front of us, looking at consumer markets and the needs to improve the sustainability of the public expenditure linked to ageing [3].

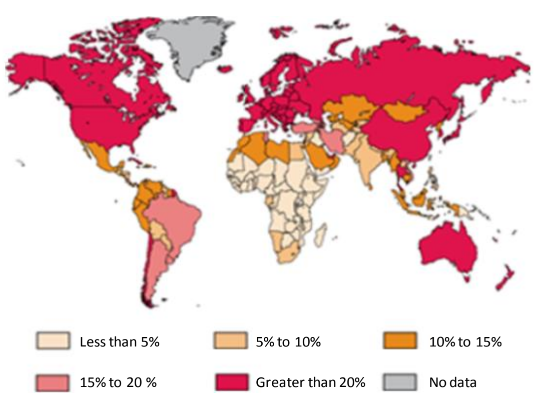


Figure 1. 2050: Percentage of population above 65 [1]

In [1], the *Silver Economy* is presented as the 3rd largest economy in our planet, i.e. US$ 7 trillion per year, and, the private spending power of the elderly generation reaches $15 trillion by 2020, globally. In Europe, the public spending is currently 25% of GDP or about 50% of Government expenditure and it will grow by more than 4% of GDP until 2060 [3].

This letter presents the main stakeholders and actions taken in EU to address this problem, and discusses the new business models and enabling 5G technologies for age-friendly and safe environments, including homes.

2. Main Stakeholders and EU Public Investments

As depicted in Figure 2, the *primary stakeholders* of the Silver Economy are the older persons (classified as: active, fragile and dependant) and informal caregivers (relatives, caretakers, etc), who are currently handling 60% of the requests [4]. The *secondary stakeholders* are the formal caregivers (service provider, volunteer, nurse, etc). The *tertiary stakeholders* are technology providers (industry, institutes, enterprises, etc.); and the *quaternary stakeholders* are related policy makers and insurance companies (public and private parties) [4].

The primary stakeholders are truly expecting to *live independently* and *remain active*, as long as possible. This could be achieved by preventive, supporting and compensating actions [4]. The value chain (and related solutions) includes: *mobility* (support systems), *health care* (Tele-health), *housing* (Smart Homes) and *social care* (Tele-care). The *Ambient Assisted Living* (AAL) encompasses all these aspects [4], see Figure 3.

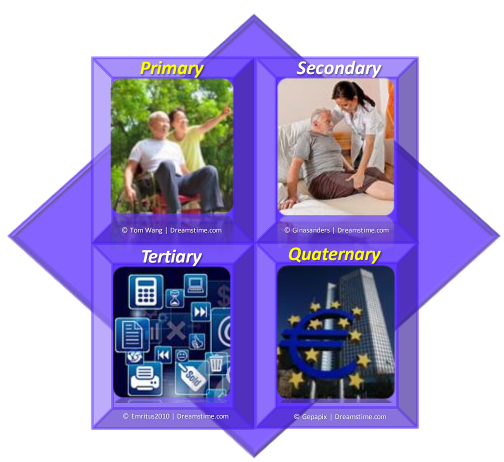


Figure 2. Main stakeholders of Silver Economy [4]

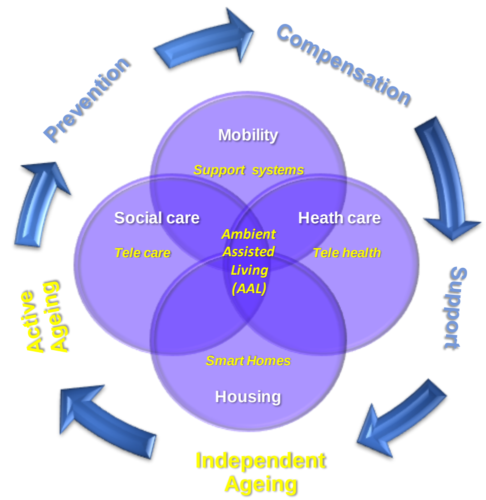
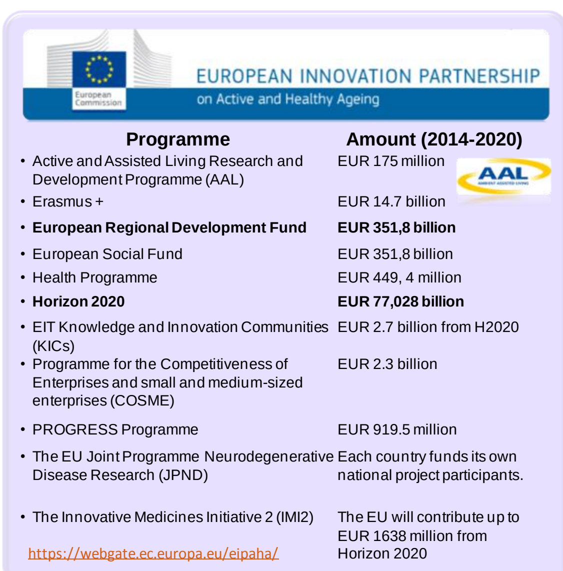


Figure 3. Business model and related technologies [4]

An overview of the EU funding and corresponding research & innovation initiatives for *Active & Healthy Ageing* (AHA) is illustrated in Figure 4. In Europe, in 2014-2020, the European Commission makes available more than €100bn public funds. The majority of the investments are within the EU Horizon 2020 Research Framework Programme and Regional Development Fund (ERDF), at Member State level [3]. Another important action is the *Ambient Assisted Living* Research & Development Programme focusing on *ICT solutions for ageing well*. In 2015, within this research framework, the open call on "Living active and independently at home" is on "ICT for supporting active and independent living of older adults in their homes". The indicative total funding set aside from the European Commission and Member States is €34mn.


EUROPEAN INNOVATION PARTNERSHIP
on Active and Healthy Ageing

Programme	Amount (2014-2020)
Active and Assisted Living Research and Development Programme (AAL)	EUR 175 million
Erasmus +	EUR 14.7 billion
European Regional Development Fund	**EUR 351,8 billion**
European Social Fund	EUR 351,8 billion
Health Programme	EUR 449, 4 million
Horizon 2020	**EUR 77,028 billion**
EIT Knowledge and Innovation Communities (KICs)	EUR 2.7 billion from H2020
Programme for the Competitiveness of Enterprises and small and medium-sized enterprises (COSME)	EUR 2.3 billion
PROGRESS Programme	EUR 919.5 million
The EU Joint Programme Neurodegenerative Disease Research (JPND)	Each country funds its own national project participants.
The Innovative Medicines Initiative 2 (IMI2)	The EU will contribute up to EUR 1638 million from Horizon 2020

https://webgate.ec.europa.eu/eipaha/

Figure 4. EU funding related to healthy ageing

3. Vision and Key Enabling Technologies

AHA systems and services for safer houses and age-friendly environments require the deployment of five crucial enabling technologies, namely [4]:

1) ***Sensing***: sensors for mechanical, optical, magnetic, video, audio, olfactory and chemical measurements.
2) ***Reasoning***: IT components and logical techniques, i.e. artificial intelligence (AI), capable of deducing, inducing or other forms of reasoning that analyze the sensor data and make decision on possible actions (actuation) to be taken.
3) ***Interacting***: Human–machine interface components and actors, both software and hardware, that allow simple interaction processes and bridge capabilities between people and service/machines.
4) ***Acting***: automated systems, autonomous vehicles, robots that proactively/reactively act for providing useful services (physical and cognitive support).
5) ***Networking***: wireless and wireline communication technologies that connect the different parts of the system so that they can also collaborate. Using 5G, the connectivity is guaranteed with a large degree of reliability, dependability, high speed and extremely low latency, in order to provide the overall assistive service, which the system is being designed for [5].

The network and services vision for an age friendly and safe housing and environments are shown in Figure 5. In this context, 5G, defined as the next generation of ubiquitous ultra-high reliability, mobility, capacity and low latency infrastructure [5]-[7], is an integral part of the networking solution to serve the main needs of the elderly. In other words, 5G is expected to become the new lifeblood of the digital economy and connected society, and the '*nervous system*' of the silver economy, once it is established. Age-friendly environments, safe housing, facilitated through the use of smart sensors and Tele-monitoring, as well as tailor-made solutions for remote control, will help people live independently, whilst reducing the cost of long-term care.

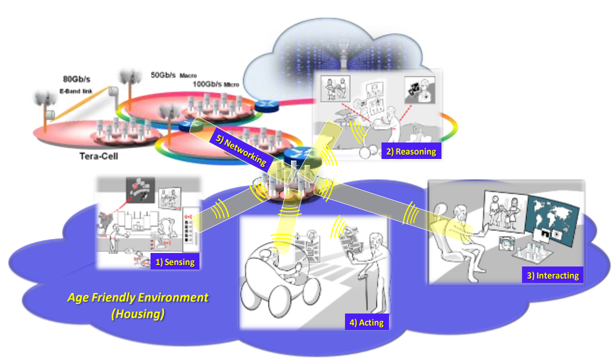


Figure 5. 5G for age friendly and safe environments

4. Deployment Scenarios

In order to realize the AHA vision, two scenarios could be considered for massive adoption and market uptake of the proposed five enabling technologies, as depicted in Figure 6: *indoor* and *outdoor* deployment.

In the indoor case, wireless high speed connectivity may be reached transmitting at frequency above 6 GHz (mmW). The age friendly housing is characterized by microphone and camera arrays for high quality sound-light-field capturing, multiple laser projectors and loud-speakers arrays for holographic rendering and sound-field reproduction, respectively, and service robots for performing cognitive tasks the elderly cannot do. The home environment should provide at least 10 Gb/s end-user experience, which is the expected link level speed using 5G wireless technologies [5]. In practice, a single view transmission, with resolution of 2-8K, after video compression, may require up to 30-50 Mb/s and “zero-latency”, from client to server, for adaptive luminance (brightness), chrominance (color), resolution, and view point adaptation. This means around 1Gb/s for real full parallax holography experience, using a “retina display” with more than 100◦ vision (multiple views).

In the outdoors, 5G wireless using frequencies within the cellular band (below 6GHz) should provide ultra-reliable high speed connectivity to robots, cars, drones for performing cognitive tasks and autonomous driving. The enabling technologies should make also possible to achieve an end-to-end latency below 5ms for motion (remote) control and 1ms for tactile Internet [5].

The reasoning system running on high performing computing platforms communicate with all the devices using the next generation software (service) defined 5G network with much simplified and unified connection, mobility, security, and routing management [7].

As shown in the Figure 6, technologies for sensing, rendering and interacting should be deployed in Phase I. Connected cars (with and without network assistance) should be integrated in the system in Phase II. In Phase III, the deployment of connected mobile robots and drones completes the indoor and outdoor age-friendly environments.

5. Conclusions

In order to realize this vision, the list of challenges to overcome is not limited to technological issues, such as architecture, standardization and certifications. Beyond services and technological challenges, for a large scale adoption of AAL solutions within the society and rapid market uptake, other important non-technical barriers need to be overcome. For instance, some of the main aspects that should be unquestionably addressed are [4]: ethical issues; laws and regulations; dependability of AAL devices – in terms of reliability, maintainability and maintenance support performance of devices that have to operate in human-inhabited environments – and green technologies.

Managed services, where 3rd parties could accelerate the development/deployment of integrated offerings by managing the whole value chain on a fee-per-service basis, appear to be the most viable business model in front of us [4]. The target would be to create an environment where the technical solutions (offering) can succeed and scale: *platforms* with a back-and-forth relationship with customers and suppliers may achieve this goal [8]. They can deliver great products and attract teams of “*smart creatives*” to develop different applications to help older persons live independently for longer, while reducing the cost of long-term care.

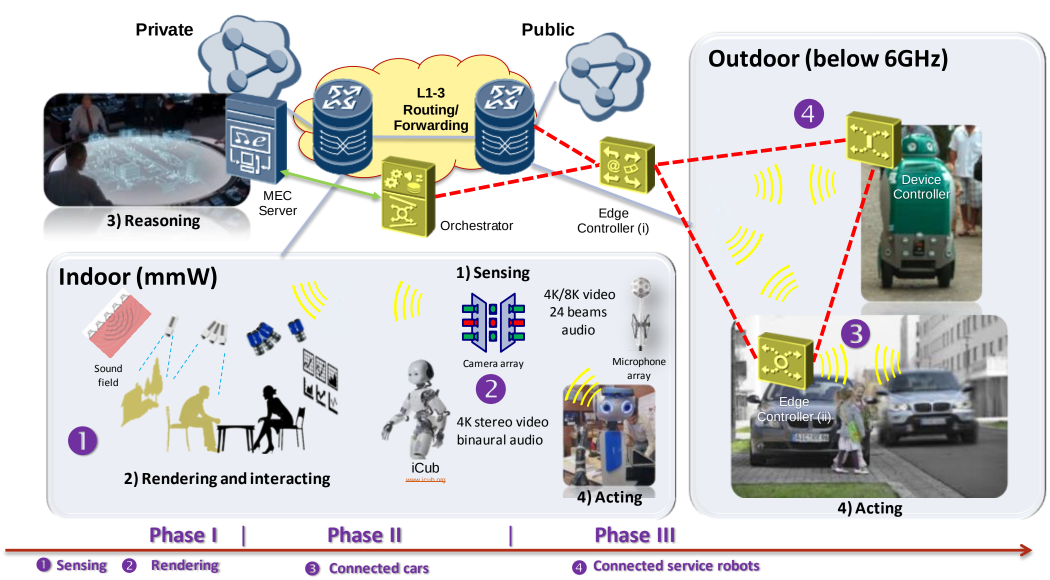


Figure 6. 5G deployment scenarios

The value proposition and business success of new players will be dependent on their unique technical offerings and scale, possibly using open platforms that enable innovation.

Appropriate regulations need to be created and put in place without constraining innovation: there will be always needs for space in the regulatory environment that allow new players to enter markets with disruptive solutions and new offerings [8].

The 5G system is expected to connect carrier grade platforms of information and knowledge, which enable more effective research and inform smarter health-care policies. Within this technological framework, many reasoning systems and computer-aided intelligence will emerge. Full connectivity of 5G, artificial intelligence and big data will help improve human quality of life. Some would find what presented in this paper as a chilling and unrealistic view of the future, whereas *we find it feasible, inspiring and business viable*.

Ultimately, we would like to state clearly that the views expressed herein are solely those of the authors and do not necessarily represent the ones of their affiliates.

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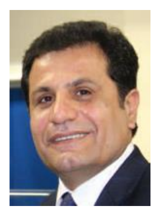
David Soldani received a M.Sc. degree with maximum score and *magna cum laude approbatur* in Electronic Engineering from the University of Florence, Italy, in 1994; and a D.Sc. degree in technology with *distinction* from Aalto University, Finland, in 2006. In 2014, he was appointed Visiting Professor at the University of Surrey, UK. He is one of the top experts in multi-disciplinary, transformative frontier research. He has been active in the ICT field for more than 20 years, successfully working on 200+ Research, Innovation and Customer Services projects for 2G, 3G, 4G and now 5G, and contributing to 500+ quality deliverables – from strategic research and innovation strategies and plans formulation down to modeling, simulations, emulations and innovative proof of concepts with partners and customers. Dr. Soldani is currently Vice President (VP) of Huawei European Research Centre (ERC) and Head of Central Research Institute (CRI) in Europe. Prior to that, he was a Scientific Director at Nokia and NSN. Areas of his responsibility and expertise include, but not limited to: future wireless, computing, network and multimedia technologies. He represents Huawei in the Board of the 5G Infrastructure Association, within the EU H2020 5GPPP Initiative, and Steering Board of NetWorld2020 European Technology Platform in Europe.



Rahim Tafazolli is director of the Institute for Communication Systems (ICS) and the 5G Innovation Centre (5GIC), Faculty of Engineering, and Physical Sciences, University of Surrey. He has published more than 500 research papers in refereed journals and international conferences, and as an invited speaker. He is the editor of two books, Technologies for Wireless Future. He is currently chairman of EU NetWorld2020 Technology Platform Expert Group and a board member of the U.K.

He was appointed a Fellow of the Wireless World Research Forum in April 2011 in recognition of his personal contribution to the wireless world. He also heads one of Europe's leading research groups.

Full Field Communication for the Silver Economy – Use Cases & Enabling Technologies

Atanas Boev, Pablo Hoffmann, Onay Urfalioglu, Qing Zhang

Huawei European Research Centre, Germany
Email: {atanas.boev, pablo.hoffmann, onay.urfalioglu, qing.zhangqing} @huawei.com

1. Introduction

At the Mobile World Congress 2015, Huawei introduced the concept of *full field communication* (hereafter denoted as FFC) along with a prototype called "MirrorSys" [1]. The concept is to ensure realistic capture, transmission, and reproduction of light, sound and the overall "atmosphere" of a scene with precision surpassing the human perceptual capabilities. For example, the initial MirrorSys prototype has a 220 inch diagonal display and its resolution matches the human visual acuity at a distance of 2.4 m [1].

The notion of *Silver Economy* is that the demographic ageing is not only a burden to the economy, but can also benefit businesses which target services optimized for the elderly [2]. The European Commission (EC) has launched a number of initiatives to help the European industry adapt to the new market realities [3].

In this paper, we discuss how the FFC concept aligns with the direction undertaken by EC, and how the full field acquisition and rendering can be of help to the aging population. We try to avoid the common pitfall of seeing the aged society as merely having larger amount of today's senior citizens. We hypothesize that the 65 year old and older people in the future will be more active, more connected, and will use more network bandwidth than their today's counterparts. This paper is organized as follows. In the next section we discuss the use cases of full field communication related to the elderly. Section 3 presents an overview of enabling technologies for 3D audio acquisition and rendering. In Section 4, we overview the state of the art in lightfield visualization – autostereoscopic, multiview, volumetric and holographic displays. Section 5 discusses the enabling technologies for 3D video capture and scene reconstruction, and in Section 6 we draw our conclusions.

2. Use cases

One of the first things to come to mind as a use case of FFC for the elderly is ***telemedicine***. Telemedicine integrates information and communication technologies with the purpose of delivering effective health-care services over long distances. Considering the increasing ageing population, leveraging telemedicine technologies for the elderly patient has profound implications in the older adult's quality of life and autonomy in their own home. To manage increased chronicity, elderly patients need to constantly update their health systems and physicians about their vital signs, and this makes remote patient monitoring a critical telemedicine component. In order to enable successful adoption, telemedicine products must be designed to facilitate positive attitude of the patient towards the technology. The pervasiveness (advancements and popularity) of wireless mobile technologies has created a tremendous amount of momentum toward increased access to healthcare via telemedicine [4]. This approach requires systems with an innovative combination of high connectivity, robust and responsive networks, data interoperability, home automation and smart environments. The European program Ambient Assisted Living (AAL) has been designed to promote the creation of such systems [5].

Another possible use case is the ***home robot***. Home robots are useful in a variety of applications. We foresee a home robot which incorporates a number of cameras, microphones, and a display that would enable natural interaction with elderly people.

In one scenario, a robot can continuously observe the subject of interest and trigger an alarm to automatically contact the health center in certain situations. For example, recent advances in Computer Vision and Machine Learning enable the detection of a falling person [6]. In another scenario, the elderly may call for the robot anywhere within his home to establish a communication with another person/institution to report his condition. This can be enabled by gesture recognition and/or speech recognition, e.g. as described in [7]. In the future, robots may be also helpful in mechanical tasks, such as cleaning, transport, etc.

The information which describes a 3D scene as seen from any given direction is known as the scene's *lightfield* [8]. A typical showcase for hyper-realistic scene capture and visualization (i.e. FFC) is ***telepresence***. The current trend towards easier roaming of workforce around the world is likely to lead to increased need of videoconference calls between relatives. This trend, combined with the generally decreased mobility of the elders will emphasize the need of live-like telepresence. We imagine it as a full-head parallax, high frame rate, very high resolution video transmission as shown in Figure 1. The full-head parallax will ensure continuous "look-around" effect allowing the 3D scene to be seen from various horizontal and vertical angles, and provide stereoscopic image without the need of glasses. We project that the field-of-regard will surpass 45 degrees in both dimensions with view density of 0.5 degrees per view. The frame rate will exceed 60 frames per second, and the resolution will be around 300 dpi. If we imagine a life-size display of 2m by 2m, the total uncompressed data rate will exceed 700 TB/s. Such data rate suggests that an effective lightfield compression is going to be a critically needed factor for enabling FFC.

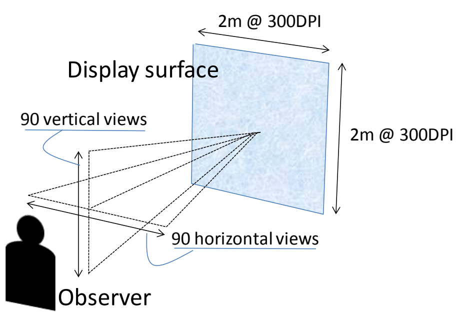


Figure 1. Full field telepresence display parameters

3. Enabling Technologies for 3D Audio

Owing to the hearing loss associated with ageing, the silver population is by far the largest market sector for assistive hearing devices or hearing aids which aims at improving the life quality of the hard of hearing. Sound and its perception, audition, undoubtedly play a fundamental role in communication. Not surprisingly, in task-oriented applications of networked robots in smart environments, or assisted living environments, empowering robots with *assisted listening technologies* is critical. This enables robots to perform well in various auditory tasks such as speech/speaker identification, source localization, speech synthesis, and acoustic scene analysis and description [9]. A relevant area to further research and develop in this context corresponds to binaural audition in ubiquitous robotics [10].

From a user- or listener-centered standpoint we always consider 3D audio in relation to the correct sound signals at the two ears. In this respect, *binaural technology* [11] enables the acquisition, processing, transmission, and reproduction of the full acoustic spatial information of a given environment. That is, with binaural technology we can faithfully acquire and reproduce the relevant acoustic cues that humans use for spatial sound perception. These cues are differences in time and level between the sounds arriving at the two ears (i.e. interaural differences), and spectral cues produced by the filtering effect of our anatomy, i.e. torso, head and ears.

In robot-mediated health-care applications, sound is typically provided via a loudspeaker that may roughly approximate the radiation pattern of the human voice. If we assume humanoid robot, sound acquisition can be enabled by using miniature microphones placed at the "ears" of the robot, as depicted in Figure 2. In this way, the complete acoustic environment in which the robot is physically placed is captured in a two-channel audio format, i.e. one audio channel for each ear.

Sound is then transmitted and reproduced to the doctor/physician who can experience the acoustic environment of the patient. The most straightforward method to reproduce binaural sound is over headsets or headphones [12] because they provide the desired channel separation. The use of loudspeakers is also possible as long as some additional signal processing is introduced to reduce the crosstalk that exists in such a setup. Transmission is done over 4G/5G networks. CD-quality audio with 44.1 kHz and 16 bit requires about 1.4 Mb/s, and higher quality audio, e.g. 48 kHz and 24 bit requires about 2.3 Mb/s. Considering a nominal 150 Mb/s capacity of 4G networks bandwidth, high quality audio transmission corresponds to about 1 to 1.5% of the available bandwidth. Due to design constraints it is likely that the robot ears are different from the Doctor's ears. As a consequence the spatial cues captured by the robot will deviate from those the doctor is accustomed to. It is well known that such deviations from the individual acoustic characteristics introduce errors that affect the natural spatial hearing ability of the listener, i.e. the doctor. However, it is also known that by introducing dynamic cues, e.g. by coupling the doctor's head to that of the robot so the doctor's head movement will be actuated by the robot, the effect of the errors introduced by the above-mentioned deviations can be ameliorated. In this respect, the availability of dynamic cues considerably improves the quality of the immersive experience, not only in terms of realism but also in terms of improving speech understanding and the naturalness of the auditory experience.

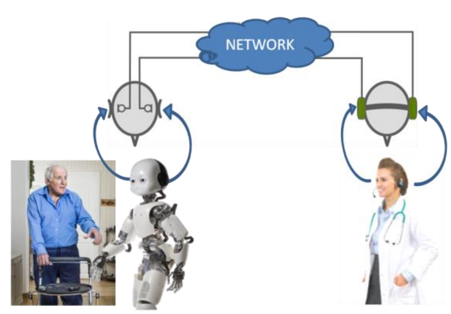


Figure 2. Illustration of the acquisition, transmission and reproduction of binaural audio in a robot-mediated telemedicine application

4. Technologies for Holographic Visualization

First, we should make the distinction between the two alternative uses of the word "holography". The first is the scientifically accurate definition, meaning a method for recording the lightfield of a 3D scene illuminating the scene with a laser beam and storing the interference pattern, as it was described by Dennis Gabor in [13]. The second meaning of “holography”, as used by the general public, denotes any semi-transparent, borderless image that does not appear on a visible surface. Still, as many 3D display and 3D projector vendors misuse the term, its non-scientific meaning is rapidly becoming the norm.

One of the main features of a display, considered “holographic” is its ability to provide **head parallax**. In fact, laser-based holography is not the best method to record an image with head parallax. The laser illumination poses restrictions on the size of the scene, and the resulting interference pattern is hardly ever compressible. The current state of the art for digital video holography provides frame rate of less than 5 FPS [14]. One alternative approach is to record a so-called “**multi-view**” image, which describes the outlook (“view”) of a 3D scene as seen from a predefined number of observation positions. If each view is cast in the same direction it was taken from, the overall effect is a 3D scene seen with head parallax [15]. Of course, one should take proper care of interpolating the intermediate observation positions [16]. Multi-view displays are able to provide different images to each eye of the observer, and create binocular 3D effect without the need of glasses, thus they are also known as autostereoscopic displays [15]. Two approaches for building of a head-parallax display should be mentioned as being suitable for creating a hyper-realistic telepresence. One is the **back-projected lightfield displays** built by Holografika KFT, which, at least in theory can be scaled up to provide infinitely dense lightfield [17]. The other is the HR3D display developed by MIT Media Lab, which uses **adaptive parallax barrier** and has potential to provide high view density using a thin display film [18].

Additionally, there are two popular display techniques, which fall into the more general (and less accurate) description of “holographic display” – i.e. provide a semi-transparent, “floating” multilayer image. One technique is used in the the Musion Eyeliner ™, which is a modern-day **Pepper’s ghost** image, and uses a metalized semi-transparent reflective mirror, tilted at 45 degrees, in order to overlay projected image over a scene from the real world (e.g., as was done for the Tupac’s “hologram” at Coachella 2012) [19]. The other technique is to use a back-projected semi-transparent diffuser film – one example is the Clearview holographic projection screen by ProDisplay [20]. This approach produces similar effect, albeit with reduced quality, however using much less space than the Pepper’s ghost setup.

5. Enabling Technologies for 3D Video Capture and Reconstruction

The technologies for depth sensing of the scene can be mainly divided in two categories: passive and active sensing. In **passive sensing**, two or more cameras enable a 3D-reconstruction of the environment [21]. In this approach, multiple cameras are calibrated and rectified in order to compute a so called depth-map of the scene. A depth-map assigns each pixel within the capture image a depth value of the corresponding point in the scene. This way, a dense depth capture can be determined and the 3D-geometry of the environment can be computed. On the other hand, in **active sensing**, an electromagnetic emitter is used to help measuring the distance of the scene. **Time-of-flight systems** [22] are mainly based on emitting electromagnetic radiation (e.g. laser or infrared beams) and measure the time the beam needs to be reflected for each point in the scene. **Structured-light sensors** project a specific pattern in infra-red domain onto the scene to estimate the 3D-structure, as realized in the Kinect device [23]. Yet another class is represented by **Light-Field cameras**, as described in [24], [25] which capture a significant part of the lightfield and are so capable to estimate the 3D-scene.

6. Conclusions

We have presented the Full Field Communication system and discussed how it aligns with the needs of the future elders on an aging society. We discussed potential use cases of FFC in a state of silver economy. We provided an overview of the parameters of a Full Field Communication system, as well of the key FFC enabling technologies – namely 3D audio, full parallax (“holographic”) visualization and 3D scene capturing and reconstruction.

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Atanas Boev is a researcher with expertise in lightfield displays and human stereopsis. He got the best demo award at Tampere Innovation Days 2010, best student paper award in Electronic Imaging 2011, and Nokia Scholarship award in 2010. He defended his PhD with distinction in Tampere University of Technology, Finland in 2012. In 2013 he was visiting researcher at Holografika KFT, working on lightfield rendering algorithms. In 2014 he worked as post-doctoral researcher in Tampere University of Technology doing research on DSP methods for lightfield displays. Currently, he is a research engineer in the Huawei European Research Centre in Munich, Germany.

Pablo F. Hoffmann received an acoustic engineering degree from Universidad Austral de Chile in 2000. Later he went to Aalborg University, Denmark, where he received a M.Sc. degree in electrical engineering in 2003 and Ph.D. degree in 3D sound in 2008. He worked as postdoctoral fellow and later as assistant Professor at Aalborg University conducting research in technological and psychoacoustical aspects of 3D sound in multimodal interfaces for teleconferencing and training applications. Dr. Hoffmann is currently a senior R&D Engineer at Huawei Technologies GmbH working on spatial sound capturing, transmission, and rendering techniques. Dr. Hoffmann is a member of IEEE.

Onay Urfalioglu studied Physics at the Leibniz University of Hannover, obtaining a physics diploma in 2000. From 2000 to 2006, he worked on Computer Vision and 3D-Video processing methods at the Institute for Information Processing at the Leibniz University of Hannover, where he obtained his Ph.D. degree. From 2006 to 2007, he was with the ISTI/CNR as a research fellow for Multimedia Signal Processing. He continued his post-doctoral research activities at the Bilkent University/Ankara on Signal Processing and Machine Learning methods until 2011. From 2011 to 2012, he was with HMI GmbH working on Computational Linguistics and Machine Learning research. Since 2012, he is a Project Leader at the Huawei European Research Center working on 3D Video, Computer Vision and Machine Learning technologies.

Qing Zhang received his B.Sc. and M.Sc. from Peking University and Xi'an Jiaotong University in 1987 and 1996, respectively. Since 1996, he has been in Huawei for 19 years, leading the multimedia technology research and product development, including video conferencing, multimedia gateway, audio coding and interactivity. He is now the director of Media technology lab in Huawei European research center, in charge of the soundfield and lightfield technology research. He has been involved in several standardization activities of ITU-T, MPEG and 3GPP, contributed to video telephony, multimedia conference, and audio codec standards. In 2009, he received a national award for science and technology achievement. He owns more than 70 patents.

Toward Cloud Service Robotics in Active and Healthy Ageing Applications

Filippo Cavallo

Scuola Superiore Sant'Anna, The BioRobotics Institute, Pontedera (PI), Italy
Email: f.cavallo@sssup.it

1. Introduction

The current demographic statistics and projections indicate that the increase of life expectancy and the reduction in births are increasing the percentage of the population 65+ and inevitably impacting the social and economic balance of society [1]. Indeed, the higher risk in old age to become ill or to have physical and cognitive decline, could mean an increasing request and consequent higher cost of social and health care.

The advances and continuous convergence of mobile, cloud, communication, electronic, artificial intelligence and interacting technologies can significantly extend the possibility to augment the human physical and cognitive capabilities of elderly persons and care takers thus allowing re-thinking new models of integrated care that may contribute to the economical and societal sustainability of health and care systems [2]. Furthermore, these technologies are the basis for providing services and systems that may help to improve quality of life, stay healthier, live independently, and manage any reduced capabilities related to the ageing with a proactive and patient-centered approach [3].

The rise of mobile technology, the wireless communication, the rapid growing of internet services and resources and the wide penetration of smartphones and tablets make concrete the idea to connect robots to internet and to the Cloud, thus defining a new paradigm for robotics and automation from standalone and networked robotics to cloud robotics. Standalone robots require high level computational capabilities and expensive sensor technologies to autonomously perceive the surrounding environment and consequently plan and operate appropriate tasks. In the last years, standalone robots have been integrated in smart environments [4] and, leveraging the use of wireless communications, extended the effective sensing range and improved their planning and cooperation capability, also with other robots or agents. In this new paradigm, called *networked robotics* [5], robots are able to provide a number of dedicated services to the users anywhere and anytime. Networked robots, similarly to standalone robots, faced inherent physical constraints as all computations were conducted onboard of the robots or on wireless devices, which had limited computational capabilities [6].

Recently the *cloud robotics* paradigm extended the concept of networked robotics. Prof. Inaba first introduced the concept of the "Remote-Brained Robotics" [7], opening the way to use parallel powerful computers and providing complex services to the user that the robots alone were not able to provide. As a matter of fact the Internet, the vast computational resources and the storage capacity have the potential to define a new paradigm with significant benefits for robotics and automation.

According to Keohe et al. [8], robots could obtain four potential benefits from the Cloud: "*1) Big Data: access to remote libraries of images, maps, trajectories, and object data; 2) Cloud Computing: access to parallel grid computing on demand for statistical analysis, learning, and motion planning; 3) Collective Robot Learning: robots sharing trajectories, control policies, and outcomes; and 4) Human Computation: using crowdsourcing access to remote human expertise for analyzing images, classification, learning, and error recovery*". In this context, Cloud Service Robotics (CSR) could be defined as the integration of different agents that allow an efficient, effective and robust cooperation between robots, smart environments and humans, to provide continuous services to senior citizens. CSR could be applied in many robotic applications, enabling robots to offload CPU-heavy tasks and access base knowledge to expand robot consciousness beyond their physical body.

In this letter, the case study of the Robot-Era system is presented and the related Cloud Robotics challenges are discussed.

2. A Case Study: the Robot-Era System

The Robot-Era case study is characterized of a number of services for assisted living, provided by a plurality of complete advanced robotic systems, integrated in intelligent indoor and outdoor environments.

The Robot-Era architecture integrates a multi-robot system able to work in different environments such as outdoors, condominium and homes. It also includes Wireless Sensor Networks (WSNs), constituting the Ambient Intelligence (AmI) infrastructure that supervises the environments and localizes the user. Other agents of the system include the elevator and the user interfaces, i.e. tablet and microphone.

The multi-robot system is composed of three robotic platforms, each working in its own environment [5], i.e. domestic, condominium and outdoor environment (see Figure 1). The DOmestic Robot (DORO) is conceived to act in domestic environments and is composed of the SCITOS G5 mobile robotic platform (Metralabs, Germany) that integrates a rear and front laser sensor for safe navigation, avoiding obstacle, and for self-localization and the Jaco arm (Kinova, Canada) for manipulation tasks. The head of the robot has a pan-tilt unit, an Asus XtionPro and high resolution cameras used for object detection. Multicolor LEDs, mounted on the eyes, and speakers provide feedback to the user.

The robot brings a removable tablet that the user can use for service requests. As a whole the robot dimensions are 160 cm x 60 cm x 60 cm (H x L x W) with a weight of about 50 Kg. The COndominium RObot (CORO) has to navigate between floors via the elevator. Most of the hardware and software is shared with DORO. It does not have an arm, but it mounts a roller mechanism in order to be able to exchange goods with an Outdoor RObot (ORO). ORO is a mobile autonomous robot designed to transport objects in an urban environment and consists of a mobile base, based on a mechanical chassis with two central actuated wheels and four passive rear wheels with shock absorbers, a container for the objects, whose motor actuators are used to open/close it, a robotic head multicolor LEDs in the eyes, a touch screen used primarily for human-robot interaction and laser and GPS sensors for obstacle detection and localization. The whole robot dimensions are 150 cm x 100 cm x 80 cm (H x L x W) with a weight of 150 Kg.

Figure 1. The Robot-Era robots, from left to right: DORO, CORO and ORO

The main source of context information is the Wireless Sensor Network (WSN), designed for *multiple user localization*, using the Received Signal Strength Indicator (RSSI), and for *home monitoring*, integrating proximity sensors, pressure sensor placed under a chair or bed, switches on doors or drawers, and temperature, humidity and light sensors.

Context awareness is an important asset of the Robot-Era system in order to provide localization-based services to users. The system continuously monitors several parameters related to the state of the user and of the environment. The Context Awareness Monitoring (CAM) system was developed to estimate the home status and the user position, making them available through the Cloud Infrastructure (CI). It fuses heterogeneous information from a set of WSN nodes installed in the home, and worn by the user.

The development of specific robotic services provided by the cooperation of the robots and intelligent environments were justified by investigating elderly needs through several focus groups, involving more than hundred stakeholders in Italy, Germany and Sweden. Table I summarizes the principal nine services and scenarios that were requested by elderly persons.

Table I – List and description of the Robot-Era services

Service/Scenario	Description
Communication	DORO is used remotely by caregivers to monitor and assist elderly people at home.
Indoor escort support	DORO is used to assist elderly people in walking activities, above all during the night.
Reminding	DORO is used to remind events and to support in therapeutic treatments.
Objects transportation	DORO is used to grasp and bring objects for physically impaired people.
Outdoor walking support	ORO is used to support people in outdoor walking activities.
Laundry support	DORO and CORO cooperate to transport laundry.
Food delivery	DORO and CORO cooperate to deliver food in assisted facilities.
Drug and shopping delivery	DORO, CORO and ORO cooperate to transport shopping box from the grocery to the home.
Garbage collection	DORO, CORO and ORO cooperate to transport garbage from the home to the rubbish bin.

3. Cloud Robotics Services

The analysis of the services and scenarios in Table I highlights that there are different Cloud robotics solutions that could significantly improve and optimize the work performed by the robots. The Cloud is used for:

- Managing and orchestrating fleets of robots, e.g. for shopping and garbage (see Figure 2); a context aware and a planner module in Cloud could be used to respectively understand the environment and activate properly the robots or any other agent. (E.g. one caregiver that is able to assist several elderly people at home, avoiding frustrating, time and money consuming transportations.)

- Assembling and storing sensors data collected from all agents (smart homes, wearable sensors, robots); appropriate algorithms are executed and data are processed with the computational capabilities of the Cloud to produce context awareness and any kind of information useful to improve the perception of robots. (E.g. for user localization, as illustrated in Figure 3, etc.)
- Reducing the required computational capabilities of the robots. For instance, a part of the software architecture for navigation, manipulation, interaction, etc. is implemented on the Cloud instead of on the robot. (E.g. speech recognition, localization, etc.)
- Enabling agents and users to share information. (E.g. robots can get users' calendar information, weather conditions, news, etc. or specific robotic oriented database for object recognition, tags, etc.)
- Providing a common interface for different users and robots in a social network approach. (E.g. users and robots can twit each other to speed up and improve the communication.)

Figure 2. CORO and ORO orchestrated by the Planner Module to help each other and cooperate. In this case, they exchange objects (the shopping bug) to bring goods from the street to home

4. Conclusions

In conclusion, Cloud robotics is the integration of different agents that allow efficient and improved cooperation between robots, smart environments and humans, to provide useful and high quality services to citizens. Cloud robotics introduces some important benefits to robotic applications over traditional robotics [10]: offloading computation-intensive tasks to the cloud, accessing and sharing a vast amount of data, accessing and sharing knowledge, sharing of capabilities and information acquired, increasing storage, exploiting the capabilities of mobile robots to have a greater exchange of information with the environment and reducing the cost of a single robot. Additionally Cloud robotics allows the deployment of inexpensive robots with low computation power and memory requirements by leveraging the communications network and the computing resources offered by the cloud infrastructure.

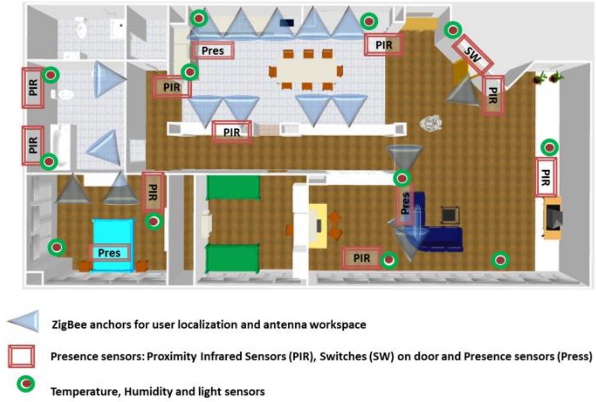

Figure 3. Distribution of sensors in the domestic environment to localize users and facilitate the robot to interact with him/her

Cloud robotics has some technical challenges, related to the amount of data exchange, the delay deadline to complete the task, the allocation of the correct virtual machine in order to optimise the execution of the offloaded tasks and the decision to consider whether it is more advantageous to execute the task within the network or with a standalone robot [11].

The communication challenges are also a key point of cloud robotics, because packet delivery failures and communication outages are inherent in any wireless communication system. Strategies and research have to focus their resources to develop faster and safer communication modalities in order to prevent the loss of important data and support the exchange of a large amount of data. It is clear how *the development of the 5G technologies in this context has become a key point*, allowing each robot to easily communicate with the cloud. Trust, dependability and security issues are major considerations in cloud robotics.

A robot needs trust to launch task delegation on a public cloud, especially when the computation and network traffic incur monetary costs. The computing environments in the cloud should be verifiable by a user or a trusted party, e.g., to ensure there is no hidden or malicious code running besides the delegated tasks. Moreover, confidential data, logically private to clone devices, may be stored in the public cloud storage. Therefore, strong integrity and confidentiality protection are needed to secure application data.

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Filippo Cavallo, MScEE, PhD in Bioengineering, is Assistant Professor at the BioRobotics Institute of Scuola Superiore Sant’Anna, Pisa, Italy, focusing on cloud and social robotics, ambient assisted living, wireless and wearable sensor systems, biomedical processing, acceptability and ICT and AAL roadmapping. He was visiting researcher at the EndoCAS Center of Excellence, Pisa, Italy working in Computer Assisted Surgery (2005-2007); at the Takanishi Lab, Waseda University, Tokyo, Japan working on wireless sensor network (2007); at Tecnalia Recerch Center, Basque Country, Spain working on wearable sensor system for AAL. He has managed different European and National projects and is author of various papers on ISI journals and conferences.

Independent Active Ageing - the Role of 5G and Autonomous Vehicles

Ciarán Mc Goldrick[1], Vince Rabsatt[2], and Mario Gerla[2]
[1] School of Computer Science and Statistics, Trinity College Dublin, Ireland
[2] Department of Computer Science, University of California, Los Angeles, USA
Email: Ciaran.McGoldrick@scss.tcd.ie, {rrabsatt, gerla}@cs.ucla.edu

1. Introduction

The world population continues to increase, with UN estimates projecting an increase from current levels of approximate 7.3bn to as high as 24.8bn in 2150. Many analysts question the sustainability of this growth, highlighting pressures on food supplies, energy resources and the detrimental impact of so many people on our environment. A notable facet in this population growth is the *ageing population* demographic in developed countries. Advances in knowledge, understanding and treatment of medical conditions mean that people are living longer, and with better quality of life, than in previous generations.

These life-improving advances are not limited solely to the medical sphere - science and engineering are contributing significantly to supporting, sustaining and maintaining active, healthy and independent living amongst these ageing populations. Mobile and wireless technologies have been playing an increasingly important role in this domain - enabling timely, localized and personalized interactions between individuals and service providers. In this context we explore the potential benefits that 5G offers an ageing population. We consider a number of end-user mobility scenarios, and highlight how ongoing vehicular research is rapidly converging to enable future autonomous vehicular solutions that scale from rural countryside to dense urban deployment scenarios.

2. Autonomous Vehicles

For most people their ability to freely move around and independently travel when and where they wish is considered a basic entitlement. As people age their mental and physical acuity can become compromised, leading to an erosion of capacity and subsequent curtailment of many of the activities and accesses they had previously taken for granted. These restrictions commonly have their origins in physical or mental impairments that are overseen and managed by healthcare providers. Autonomous vehicles not only help empower ageing populations, by restoring their capability for safe, independent travel, but they also provide a powerful, non-invasive, non-threatening modality by which to monitor, interact with, and respond to their passengers state of being.

2.1 Capabilities and 5G Communication

Autonomous vehicles must be capable of operating entirely independently of a human passenger or operator. They must respect national laws, safety requirements and social conventions in their activities. They should be capable of independently replenishing their energy source, and should be able to appropriately react to evolving situations. For empowering and enabling an ageing population we expect autonomous vehicles to, at a minimum, i) be able to safely operate in all driver use case scenarios and ii) safely operate in driverless mode. For maximum utility they should be able to operate both independently of, and in collaboration with, other vehicles and services. In rural areas, the independent mode of operation might be most common, although not exclusively so. In urban areas, the collaborative mode of operation will predominate. All autonomous vehicles will have sensor arrays - both externally and internally. The external sensors will provide the primary control inputs for the vehicle - through visual, acoustic and light signaling. The internal sensor arrays will integrate capabilities of benefit to all passengers, but of particular significance for an ageing population. As nanoscale, body and personal area networks gain traction in the context of the Internet of Things, and automated and implantable healthcare devices become commonplace, the vehicle becomes an increasingly significant actor in the communication chain. The vehicle provides power for wireless charging of embedded body devices, can act as a trusted interrogator and aggregator of embedded and wearable device data, can function as an in- situ diagnostic agent (using seat embedded sensors, cameras and audio prompting via the entertainment system) and can provide alerting to emergency personnel as necessary. All these capabilities depend on reliable, secure, highly available wireless communication capabilities at proximate, local, National and Transnational scales, but also on the seamless integration of fixed and mobile devices across the many different communication complexities and device scales that form the Internet of Things. The deployment of 5G over the next decade will provide new architectures, technologies and hardware that inherently provide the functionalities and capabilities necessary to support truly autonomous vehicles on a global scale.

Figure 1. Vehicle Platoon.

2.2 Cost and efficiency

Autonomous vehicles can reduce the cost of individual vehicular ownership, or even wholly remove the necessity to own a vehicle at all. In urban areas, public transport systems are fairly extensive, providing acceptable end-to-end travel times between destinations. In such locations, car ownership can be construed as having a discretionary aspect. Services such as ZipCar and other pooled car share schemes supplement the public transport system for those eventualities where a vehicle is required. However in rural areas, or areas with a poor public transport infrastructure, vehicular ownership is perceived as (and often is) essential for everyday activities such as food shopping, medical appointments, social outings, etc. Noting that rural depopulation (or rural flight) of young people to urbanised areas is a global phenomenon, autonomous vehicles and, in particular, autonomous driving vehicles can provide significant benefits to ageing populations in rural settings where individual car ownership may be financially impractical or unnecessary. Service providers, and/or the State, may provide local ”fleets” of autonomous driving vehicles for use as on-call taxis, medical transport, or even as fire trucks.

2.3 Autonomous Driving

Safe, reliable and efficient autonomous driving is a key requirement for future autonomous vehicles. Whilst the term ”autonomous vehicles” can be construed to include both land based and airborne vehicles, we will focus on autonomous driving as a key requirement for either. In that context we will first focus on challenges and advances in vehicular platooning and collaborative cruise control in multi-lane urban traffic scenarios, and subsequently project the metaphor into the rural setting. We will then consider a specific mobility phenomenon, that of shockwaves in traffic flows, that is of particular significance to ageing and elderly drivers.

3. Vehicular Platooning

In urban environments it is common for drivers to access a highway in order to reach their destination, and

Figure 2. Advance Traffic Management System.

in this environment a large number of vehicles utilizing the highway at peak times will likely lead to traffic congestion [1]. High utilization potentially poses a challenge to elderly drivers who may face vision changes or declining motor skills and reflexes due to the natural ageing process [2]. In the case of autonomous vehicles, if highway throughput is not managed properly, traffic efficiency can suffer. Platooning is seen as a promising application that facilitates travel in groups of vehicles, at relatively small inter-vehicular distances, all autonomously following their leading vehicle, illustrated in Figure 1. Vehicular platooning offers reduced fuel consumption, increased safety, and improved traffic capacity, leading to shorter travel times and less traffic congestion [3] - all of benefit to ageing and increasingly infirm populations.

The coordination of a platoon relies on a vehicles ability to obtain downstream information from other vehicles and a control system to regulate the distance between vehicles and maintain stabilization. Vehicles equipped exclusively with radar use Adaptive Cruise Control (ACC) to sense an immediate neighbors position and speed. However, when coupled with wireless communication, Cooperative Adaptive Cruise Control can be achieved. CACC allows a vehicle to receive information such as acceleration from the platoon leader and the immediate preceding vehicle, which further reduces the inter-vehicle distance required [4].

The leading vehicle of a platoon can be controlled by a human driver [5], or a central entity via the Internet, such as an advanced traffic management system (ATMS) [6] shown in Figure 2. The central entity can manage the selection of platoon leaders and provide acceleration patterns. Advances in 5G network technologies will make this a feasible option, given its design goal of accommodating high traffic volumes, providing increased system capacity, and provisioning for seamless and ubiquitous communication [7]. Intra-platoon dynamics will continue to exploit vehicle to vehicle (V2V) communication via Dedicated Short Range Communication (DSRC). In this system the central entity will have coarse-grain control over multiple platoons, leaving fine-grain control to the platoon leader.

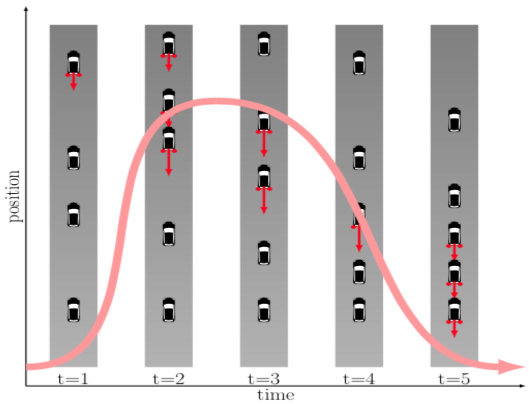

Figure 3. Formation of a shockwave upwards.

Advances in Internet of Things (IoT) deployments will also contribute to the quality of information obtained by the system. Roads will be outfitted with tags and sensors to send useful information to traffic control sites, and vehicles and roadside infrastructure will assist in collaborative decision making and autonomous actuation in both centralized and local contexts [8]. Whilst autonomous driving and coordinated platooning offer many compelling benefits in future transport modalities, it is important to note that they do not account for unforeseen eventualities, such as accidents, breakdowns, etc., in normal operation. The systems can respond safely to such eventualities e.g. by braking or taking avoiding action, but at the cost of introducing a delay or slowdown in the vehicular flow. In heavy traffic conditions this can give rise to traffic shockwaves, which radiate back from the site of the original incident and, indeed, can give rise to subsequent accidents and incidents.

3.1 Managing and preventing Traffic Shockwaves

Shockwaves can be particularly problematic for senior and impaired drivers, whose responsiveness and reaction times can be impaired. Fortunately modern V2V technology can help ensure their safety and wellbeing, and that of fellow road users, thereby empowering them to remain active and mobile in their later years. A primary cause of shock waves is the combination of high traffic demand, unexpected driver actions and physical perturbations such as ramps, construction sites or lane reduction.

Figure 3 demonstrates the formation of a shock wave in a simple one-lane road scenario. Stop-and-Go traffic often seems to appear out of nowhere and the resulting congestions are often referred to as phantom jams. As one can see from Figure 3, vehicles are not able to react until the incident that triggered the wave is in line of sight of the driver. This results in hard braking manoeuvres in order to avoid a crash. Immediately afterwards the motorists accelerate again when leaving the congested area. It is clear that, for less alert or responsive drivers, such scenarios increase the potential for accident.

To help in this situation, many Advanced Driver Assistance Systems (ADAS) are implemented in luxury class vehicles. An example of such a system is the Adaptive Cruise Control System (ACC) that can maintain minimum safety headway to the vehicle ahead. Such systems can react much more quickly than a human driver to abrupt downstream vehicle manoeuvres, and can thereby operate effectively with much smaller safety distances. The wider effectiveness of such systems is curtailed by the Line of Sight constraint we previously identified.

To overcome the line of sight limitation and effectively mitigate shockwaves, a new communication protocol - Density Re-distribution through Intelligent Velocity Estimation (DRIVE) was developed in [9]. A new Vehicle to Vehicle (V2V) communication protocol (DRIVE) is introduced to extend the awareness horizon far beyond the line of sight. With DRIVE it is possible to anticipate velocities upstream in the traffic flow in order to prevent congestions. A key novelty of DRIVE is the approach proposed for estimating the traffic conditions in the interspace between two communicating vehicles without knowing the percentage of participants [9]. The DRIVE protocol is fully compliant with the IEEE 802.11p standards. Message propagation can be realized by the use of the Cooperative Awareness Message. DRIVE is a connectionless and event driven networking protocol, meaning that vehicles broadcast their messages in a burst, only in case of a significant slowdown or if the velocity falls below a given threshold. Each message has a certain Time To Live (TTL) to ensure that it reaches the neighbors that are within transmission range. The aim of the protocol is to redistribute the upstream vehicular density in a way that avoids the formation of a shock wave in case of a temporary peak in traffic demand.

When a slowdown event is detected, the leading vehicle sends a message containing the actual location and vehicle dynamics. The next vehicle in the information chain receives this message, adapts its velocity according to the recommendation by DRIVE, and sends a notification containing its own slowdown information further upstream rebroadcasting the received message. This chain of messages ends if the system determines that no action has to be taken, there is no vehicle within transmission range to receive a message or if the maximum propagation radius for a distinct message is reached. Simulation and small scale testbed results have shown that even a relative small percentage of DRIVE equipped cars (say 20 to 30%) can dramatically reduce the shockwave occurrence [9]. Again, this is a clear example of 5G technology (as a reliable carrier for V2V messaging) helping make the driving experience safe and comfortable for the elderly.

3.2 Perils of Platooning

As with many disruptive technological advances, autonomous vehicle technology will pose some significant challenges for the current status quo. Employment opportunities in traditional professional driving roles e.g. truck drivers, chauffeurs, taxi drivers, will inevitably contract. The economic models underpinning provision of public transport, public parking and tolling services will be further undermined and eroded. Demand for vehicle crash repair and crash economy services will contract as accidents become fewer. The co-existence of autonomous vehicles with other road users, humans, livestock and even unpredictable physical phenomena, remains largely unexplored and unevaluated, and it is likely that significant advances will be made in these areas in the coming years. The most significant of technical risks and perils to autonomous vehicles and V2V communications is that of system failure - either through systems failure or attack. Current V2V systems are predominantly designed around use of wireless and cell communication technologies. For instance, jamming such transmissions in a local area is already quite tractable using off-the-shelf technology. Current research is exploring the use of *side-band* and *out-of-band communication techniques* in order to provide increased robustness and redundancy in V2V communication systems.

4. Societal Benefits

Many of the more obvious societal and individual benefits of autonomous vehicles have already been espoused in this article. The societal potential of Autonomous Vehicles becomes more compelling when considered in the context of the more widespread deployment and integration of Internet of Things (IoT) technologies. Consider autonomous ambulance/medivac units which are locally based, or located where medical services are sparse. Initial responder protocols and diagnostic procedures can be affected in the vehicle and remotely advised to the local medical center. Follow-up appointments and procedures can be instantly scheduled or the patient can be immediately transported to the nearest hospital as required. In tandem, other autonomous ambulances in the wider locality can be dynamically relocated in order to satisfy overall service provision guarantees across the region.

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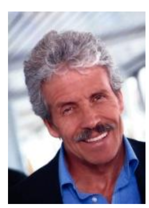
Dr. Ciarán Mc Goldrick joined the Computer Science Department in Trinity College Dublin, Ireland in 1999. He currently leads activities in Wireless and Cognitive Communications and Control, Network Security and Computer Science Education research and innovation. His current research incorporates VLC and secure, collaborative vehicular control.

Vince Rabsatt received his M.Sc. in Computer Science from the University of California, Los Angeles, USA in 2014. He is now pursing a PhD at the University of California, Los Angeles. His research interest include intervehicle communication, platooning, and shockwave mitigation.



Dr. Mario Gerla is a Professor in Computer Science at UCLA. During his Ph.D. program at UCLA he worked on early ARPANET protocols under Prof. Leonard Kleinrock. Since joining the UCLA Faculty in 1976, he has contributed to several network designs including wireless (ODMRP and CODECast) and Internet transport (TCP Westwood). At UCLA he has developed a Vehicular Testbed for safe navigation and intelligent transport. He was elevated to IEEE Fellow in 2002 and was recently recognized with the MILCOM Award (2011), the IEEE Ad Hoc and Sensor Network Award (2011) and the Sigmobile Life Achievement Award (2015).

5G Radio Access Technologies for Active and Healthy Ageing

Malte Schellmann, Zhao Zhao and Egon Schulz

Huawei European Research Center
Email: {malte.schellmann, erc.zhaozhao, egon.schulz}@huawei.com

1. Introduction

The further enhancement of mobile broad band (MBB) and the proliferation of the 'Internet of Things' (IOT) are expected to become the key drivers for the further development of mobile radio networks towards their next generation (5G). Following current forecasts for the year 2020 and beyond, a tremendous number of communicating machines will complement the human-centric communication prevalent in today's mobile networks, providing novel electronic services to the society that will make everyday life not only more comfortable, but increase personal safety and the overall quality of life.

Those envisaged electronic services cover a broad range of promising use cases, starting from road safety applications that improve the safety of traffic participants by increasing awareness for threatening situations with the help of digital communication means (Figure 1), spanning over intelligent domestic appliances that improve the daily operation and facilitate their use, and finally reaching the services for maintaining the people's health conditions (e-health) and quality of life.

Compared to human-centric communications, the foreseen machine based IOT services pose a large set of novel and diverse requirements to the mobile radio system, which need to be addressed with innovative solutions increasing the flexibility of the system and its capabilities at reasonable costs. Reliability and short latency will play a crucial role therein. For some of the novel services, end-to-end latency will have to be in the order of a few milliseconds, and reliability is required to achieve values in the order of up to 99.999% ('the 5 nines'), which are substantially tighter constraints than we are used to from human-centric communication.

Figure 1. Use cases for road safety applications (from [2])

An example is given in the context of road safety applications, where this high latency and reliability requirement have to be provided simultaneously to facilitate immediate response times for accident avoidance. When it comes to vehicular traffic and persons being inside a car, ubiquitous reliable access even at high speeds becomes mandatory. For the context e-health services, it is further required to provide access to the network at anytime and everywhere, calling for high coverage and guaranteed provision of a minimum data rate for those services. Translating the requirements driven by the 'Internet of Things' into numbers yields four of the five overall goals defined for the future 5G system by the FP7 METIS project [1]. These characterize the expected improvement of the overall system performance compared to LTE Rel.11 as the reference system, being state of the art at the stage of the METIS project start in the year 2012, and are given as follows [2]:

- 1000x traffic volume.
- 10 – 100x number of connected devices.
- 10x longer battery life.
- 5x reduced end-to-end latency.

The METIS project identified three novel system functionalities that are considered key enablers to achieve the METIS overall goals and thus may become integral core components of the 5G system. They constitute three of the five METIS 'Horizontal Topics' and are listed as follows [3]:

- Ultra-Dense Networks (UDN): High density of cells provides large throughput per area with a more homogeneous distribution of achievable data rates.
- Device-to-Device communication (D2D): Allowing for direct communication between devices reduces the delay and offloads traffic from the network.
- Moving Networks (MN): Using cars as moving base stations allows for dynamic cell deployment, where the infrastructure follows moving users.

2. The enabling radio access technologies

The above overall goals can be conveniently addressed by three key enabling radio access technologies as identified and researched by the METIS project in [4], which are briefly sketched in the following:

1) **Advanced multi-carrier waveforms**: The classical multi-carrier waveform orthogonal frequency division multiplex (OFDM) can be improved by pulse shaping in a bid to provide good spectral containment properties of the transmit signals.

This novel waveform property enables partitioning the spectrum available for mobile radio transmission into independent sub-bands that can be individually configured to optimally adapt to the particular requirements of a selected service. Thanks to the good spectral containment of the filtered multi-carrier signals, interference between individually configured sub-bands can be kept to a minimum even if those signals are only loosely synchronized. This allows for independent and uncoordinated operation of different services in the transmission band and enables an asynchronous system design. Under this research framework, waveforms incorporating additional filter components such as Filtered OFDM (F-OFDM), universal filtered OFDM (UF-OFDM) [5], and Filter Bank based Multi Carrier (FBMC) [6] have been proposed and are currently thoroughly investigated. For the above reasons, the advanced multi-carrier waveforms with pulse shaping can be considered key enablers for providing the desired flexibility for the 5G air interface.

2) **Non-orthogonal multiple access**: Novel multiple access schemes allow for overloading the time-frequency resources by multiplexing users in the power and the code domain, resulting in non-orthogonal access, where the number of simultaneously served users is no longer bound to the number of orthogonal resources. As shown by evaluations in [4], this approach can achieve gains in user and system throughput of up to 50% compared to conventional LTE designs using orthogonal user multiplexing, while the number of connected devices can be increased by a factor of 2-3. Candidate schemes are non-orthogonal multiple access (NOMA) [7] and sparse code multiple access (SCMA) [8].
3) **Contention based massive access**: Novel medium access control (MAC) schemes enable access of a large number of devices with weightless connections (i.e. minimal signaling overhead). For reducing signalling overhead, scheduled access is avoided and replaced by random access schemes. Coded random access and coded access reservation are two promising candidate schemes operating on MAC layer, which make use of repeated transmissions following a code pattern to enable resolving collisions. An advanced physical layer (PHY) processing for enhanced MAC uses code division multiple access (CDMA) codes and compressive sensing techniques at the receiver to resolve potential collisions already on PHY layer. Details of all schemes including performance evaluation results can be found in [4].

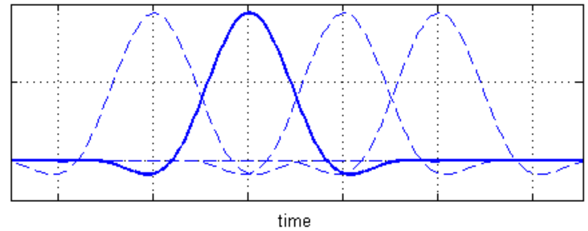


Figure 2. Overlapping prototype pulses in FBMC

3. A case study: FBMC enabling low latency access

FBMC as a type of advanced multi-carrier scheme provides additional degrees of freedom for the system design and allows to flexibly responding to the diverse requirements posed by the various services envisaged for the future mobile networks. In FBMC, the single subcarrier signals are individually filtered with a prototype filter, which can be enabled by very efficient digital multi-rate signal processing (e.g. Polyphase Networks). Spectral containment of the multi-carrier signals is achieved by choosing prototype pulses with steep roll-off in the frequency domain. The steep roll-off can be realized by expanding the length of the pulse in time domain and allowing successively transmitted FBMC symbols to overlap, thus relaxing the strict time localization of the symbols as inherent to OFDM. An orthogonal pulse design ensures that the overlapping FBMC symbols can be (near to) perfectly reconstructed without creating any mutual interference. For an illustration of the pulses and their mutual overlap, see Figure 2, where the selected division of the x-axis represents the size of the original symbol length of an equivalent OFDM system.

Since each of the FBMC subcarrier signals are filtered with the prototype pulse, a sub-band can be constituted by the aggregation of adjacent subcarriers of any number, yielding the desired spectral containment and thus offering maximum flexibility for the spectrum bandwidth partitioning. This feature enables the concept of 5G 'customized' waveform, where specific waveforms can be designed and tailored to meet the individual requirements of a selected radio service, enabling the efficient coexistence of various services in a given spectrum bandwidth. An illustration of the power spectral density (PSD) of an FBMC multi-carrier signal is shown in Figure 3, highlighting the favorable coexistence property of FBMC based 'customized' waveforms.

Owing to its orthogonal waveform design and the long tail of the prototype pulse slowly decaying to zero (see Figure 2), the FBMC waveform is very robust against time synchronization errors and can tolerate timing errors of up to the size of one symbol length of an equivalent OFDM system (also referred to as the

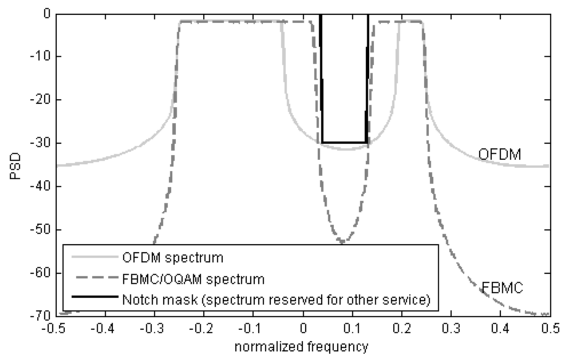


Figure 3. Power spectral density of FBMC and OFDM

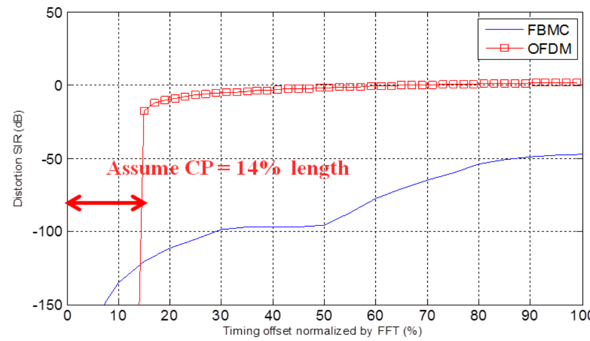


Figure 4. Distortion in terms of signal to interference ratio (SIR) caused by timing offsets for FBMC and OFDM

'FFT window size'). The robustness of FBMC against timing offsets is illustrated in Figure 4, which is compared to that of an OFDM system with an assumed cyclic prefix (CP) length of 14% of the FFT window size. The Offset-QAM (OQAM) modulation leads to the maximum bit rate, without the need for a guard time or cyclic prefix as in OFDM. Beyond this, this feature can beneficially be used to enable asynchronous transmission in mobile radio uplink transmission, where conventionally the closed-loop signaling of timing advance (TA) adjustment is required for OFDM based waveforms. For FBMC based systems, requiring only a very rough synchronization on symbol level, the TA procedure can be removed completely, thus substantially reducing signaling overhead and access latency.

4. Conclusions

The 5G Radio Access Technology (RAT) sees a surge of technical innovations and advances in order to meet the goals of providing enhanced MBB and IOT wireless services to humans and machines in the world. Compared to its predecessors (2G, 3G, and 4G), the 5G RAT is to provide massive connections with much higher reliability and lower latency. Moreover, it has to respond to the diverse requirements of a multitude of different services, calling for an air interface providing much more flexibility than in today's systems. Selected radio access technologies that could serve as key enablers for 5G have been presented and discussed in this paper, with a special focus on FBMC as a waveform candidate providing new degrees of freedom for the PHY system design.

Tremendous societal impacts are foreseen by the introduction and proliferation of novel radio services that will facilitate unprecedented functionalities, yielding improvements in public and traffic safety, health and medical support, as well as enabling smart households. This will eventually foster an active and healthy ageing life in our society.

Acknowledgment

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Dr. Malte Schellmann received the Dipl.-Ing. (M.S.) degree in electrical engineering and information technology from the Technische Universität München, Germany, in 2003 and the Dr.-Ing. (Ph.D.) degree from Technische Universität Berlin, Germany, in 2009. In 2004 he joined Fraunhofer Heinrich Hertz Institute, Berlin, where he worked on practical methods for the spectrally efficient transmission in multi-user MIMO-OFDM systems. He contributed to the German research projects 3GeT and ScaleNet and the European projects WINNER, WINNER II and WINNER+. In 2009 he joined the Huawei European Research Center (ERC) in Munich, where he works as a senior research engineer on radio access technology research for 5G, focusing in particular on new waveform design. In the European FP7 project METIS, he was leading the research on radio link concepts. He authored more than 50 papers and 3 book chapters.

Dr. Zhao Zhao received his M. Sc. from Shanghai Jiaotong University in 2007 and Dr.-Ing. (summa cum laude) from Leibniz University of Hannover in 2012, both for Electrical Engineering. Since 2012, he joined Huawei European Research Center in Munich as Senior Research Engineer. He is involved with several FP7 projects such as METIS and is now focusing on air interface research for 5G, including coding and modulation, baseband signal processing.

Dr. Egon Schulz received his diploma degree in theoretical physics from the University of Siegen, Germany, in 1982 and his PhD from the Institute of Electrical Engineering, Technical University of Darmstadt, Germany, in 1988. From 1982 to 1988, he was employed as a research assistant for communication systems. In 1988 he joined the Mobile Network Division at Siemens AG, Munich. He developed radio link control strategies for GSM and other standards. Dr. Schulz was a member of the GSM Standardization. From 1992 to 1993 he was a professor of telecommunication at University of Darmstadt. In 1993 he returned to Siemens AG as director for System Engineering for wireless local loop. From 1998 he was involved in the UMTS standardization. Since 2000 he has been serving as director for future radio concepts. In 2002 he received the Best Paper Award of the ICCCAS 2002, Chengdu. Dr. Schulz is an author of more than 100 papers and an inventor of more than 150 patents. He was involved in numerous national projects (BMBF) such as FleetNet, WIGWAM, IPonAir, ScaleNet and EU-projects like BRAIN, WINNER, TRUST and E2R. He was the project owner of the Sino-German Project Joint Research B3G (JRB3G) between German and Chinese Research Institutes. Dr. Schulz participated in the 863 (MOST) funded research projects FuTURE. In 2005, he was elected as vice chairman of the FuTURE Forum in China. He was involved in the first realtime MIMO-OFDM 1 Gbit/ transmission and LTE Field trial. In July 2009 he joined Huawei's European Research Center (ERC) in Munich as director of the Wireless Innovation Center. His current working area is 5G and was involved in the European Research 5G Flagship METIS. He is also involved in 5G-PPP Research Projects at ERC.

Requirements and Design Principles for Next Generation Networks

Riccardo Trivisonno, Riccardo Guerzoni

European Research Center, Huawei Technologies, Munich, Germany
Email:riccardo.trivisonno@huawei.com

1. Introduction

The evolution of Mobile Broadband (MBB) networks towards the fifth generation (5G) has been recently making the headlines within the telecommunication research and business communities. As it has been stressed until becoming almost trivial and annoying, the consolidation of Cloud Computing, Software Defined Networking (SDN) and Network Functions Virtualisation (NFV) technologies *might* enable radical changes in next generation MBB systems. Not only the development, deployment, operation and management of networks could radically change over the next decades, but also network architecture, design principles, procedures and protocols could be significantly affected by the introduction of SDN and NFV paradigms.

Guessing what exactly 5G will look like is a very hard exercise, but some hints can come by analyzing traffic, service and device trends. The definition of 5G is currently undertaken by Third Generation Partnership Project (3GPP) organisation, which recently agreed on *Release 14* timeline, expected to standardise the early 5G system. Release 14 will follow two parallel tracks: the Radio Access Network (RAN) working group will initially address “scope and requirements” as well as “channel modeling”; the Service and System Aspects (SA) working group has kicked off the SMARTER study item, investigating 5G use cases and related requirements, which will trigger the subsequent system architecture work.

In the following sections, current MBB trends and the status of SMARTER are reviewed. Upon facts and evidence, cornerstones for 5G architecture are cast.

2. Traffic, Service and Device Trends

Examining up-to-date statistics collected worldwide [1], some conclusions are straightforward: the growth of data traffic appears to be *driven by device capabilities* and *limited only by the availability and the cost of network resources*. Additionally, the penetration of personal devices makes *mobile* traffic increasingly relevant. Figures make these statements crystal clear [1]: global mobile data traffic increased of about 69% during 2014, reaching the total amount of 30 exabytes (nearly 30 times the total Internet traffic recorded in the year 2000). Additionally, on average a 4G connection generated 10 times as much traffic as a non-4G connection, and smartphones generated nearly 70% of the total handsets traffic although representing only 29% of the total mobile devices population. Two other significant aspects emerged from 2014 statistics: nearly 109 million wearable devices generated 15 petabytes per months, and 46% of mobile data traffic was offloaded onto fixed networks via WiFi or femtocell access.

It is relevant to highlight mobile data traffic is expected to increase nearly tenfold between 2014 and 2019, more than half of all devices connected to the mobile network will be “smart” devices and there will be 11.5 billion connected devices by 2019, including Machine to Machine (M2M) modules, against an expected world population of 7.6 billion people. Finally, another trend worth mentioning: a higher percentage of mobile and portable devices are expected to support multi RAT capability, e.g. the percentage of WiFi and Cellular capable tablets is expected to increase from the 18% registered in 2014 to over 30% by 2019.

From all the above evidence, few key high level requirements and some sound design principles for 5G can be derived: together with the ability to handle 10 times more capacity than legacy systems and to connect an increased number of a multitude of different devices, 5G network should feature an access agnostic core, capable of tailoring connectivity to application/service requirements and device access and service capabilities.

3. Use Cases and Requirements Analysis

Apart from trends analysis, the design of 5G networks requires the definition of key use cases and relating requirements. The following table compares requirements defined in the 5GPPP [2] and NGMN 5G white papers [3]. Needless to say, the figures provided refer to scenarios further to come, compared to the 5 year forecasts provided in the previous section. In any case, KPIs focus on capacity (both at system and link level), end to end latency, energy efficiency and reliability.

	5GPPP	NGMN
System Capacity	≥ 10 Tb/s/km2	300Tb/s/km^2
Link Capacity	≥ 10 Gb/s (peak) ≥ 50Mb/s (guaranteed)	100Mb/s (DL) 50Mb/s (UL)
Latency	1/5 X e2e, ≤ 1 ms (T. Int.)	<1ms e2e RTT
Energy	1/10 X compared to 2010	x2000 bits/J
Reliability	≥ 99.999% aggregate service reliability	99.999% on availability

The work currently undertaken by 3GPP SA1 tries to make a step further. SMARTER study item is a feasibility study on new services and markets technology enablers [4]. The study aims to identify the market segments and verticals whose use cases and requirements shall be met by 5G. The study is expected to develop a wide set of use cases covering various new and legacy scenarios and to identify the related high-level requirements. Use cases with common characteristics will be then grouped together, and the resulting set of few use cases will trigger the next stage of the work. The ultimate goal is to highlight current 3GPP EPS deficiencies, making it unable to fulfill 5G requirements. The discussion on system requirements and architecture evolution is expected to start in SA2 in December 2015.

A wide list of use cases, including related service and operational requirements, is already available in the latest version of [4]. 5G system is expected to support ultra-reliable communications for mission critical services, including Industrial Control (low latency communications between sensors and actuators), Mobile Health Care (e.g. remote monitoring, diagnosis and treatment requiring high rates and availability), Real Time Vehicles Control (e.g. for road traffic control, accidents prevention etc). The support of this class of services will require significant improvements in terms end-to-end latency, ubiquity, security, availability and reliability, considering performance of current deployed mobile networks.

Other use cases, separately listed in [4], leading to a challenging combination of requirements (in terms of low latency, high reliability and availability, and high connection capacity) are Virtual Presence, Tactile Internet and Connectivity for Drones. Virtual Presence consists of enabling real time 360° audio-video communication possibly using wearable devices (special glasses, micro cameras, microphones and earphones) allowing people remotely located to interact as if they were in close proximity one another. Tactile Internet, characterized by "*extremely low latency in combination with high availability, reliability and security*" aims at making the "*cellular network an extension of our human sensory and neural system*" [4]. Quantitative performance requirements still have to be defined.

Another use case on the list is Lifeline communications for natural disaster: 5G should enable robust communications in case of natural disasters (e.g. earthquakes, tsunamis, floods, hurricanes, etc). Basic communication services, such as voice and text messages, should be provided to the population affected by disasters. The ability to signal their location should also be provided, to aid rescue operations. Network robustness, resiliency and efficiency, as well as handset energy consumption are critical requirements for this use case.

Two other key use cases are MBB for Indoor and for Hotspot scenarios. The first case refers for example to MBB network deployment in offices, working environments and corporate facilities, where the coverage of each access node is quite limited and mobile users frequently upload/download on/from servers massive amount of data. This use case will require 5G system to provide user data rates of Gb/s order of magnitude, with peak up to tens of Gb/s, and system capacity of Tb/s/km^2 order of magnitude. At the same time, flexibility and efficiency of the backhauling infrastructure will be required. The second case, although wider as it is targeting both indoor and outdoor scenarios in dense urban areas, leads to a very similar set of requirements. Additionally, system optimization will be achieved exploiting context information, as e.g. user mobility profile is different when indoor compared to outdoor, and traffic volume and type of an urban area is likely to change according to the time of day. Complementary to the latter two, [4] includes also the MBB services with seamless wide area coverage: all services supported by 5G system shall be provided with continuity as users roam according to any mobility pattern (e.g. while walking in urban areas, driving in rural zones, or traveling by high-speed trains). Supporting this use case will require ubiquitous high capacity (~100Mb/s) and low latency (~ tens of ms), as well as high mobility management (up to 500km/h).

In [4], beyond use cases, authors addressed some key enabling technologies: Network Slicing, On Demand Networking, and Flexible Application for Traffic Routing. From what discussed so far, it appears clear 5G shall support a wide variety of use cases, characterized by heterogeneous and sometimes incompatible requirements. Hence, it seems unreasonable to imagine a single control plane architecture suitable to support any service or application. Moreover, in order to have a robust and reliable handling of data traffic generated by the multitude of supported services, isolation among different data planes might also be required. These considerations lead to the definition of *network slicing*: a slice is a collection of interconnected logical network functions, relating to control and data plane, as well as network management and orchestration, supporting the communication service requirements of a particular or multiple use cases. On Demand Networking and Flexible Application for Traffic Routing refer to the ability of 5G system to make use of context information to optimize network resource management and to augment the data plane according to service characteristics.

Finally, the need to migrate services from earlier generation networks and the coexistence with legacy systems will pose relevant requirements to 5G.

4. 5G Design Principles

Some of the requirements hereby analyzed will lead to Radio Access techniques and architectural enhancements (e.g. to boost system spectral efficiency, increase peak capacity and reduce latency on the radio link); others will probably require radical changes in the end to end system architecture.

Not aiming at being exhaustive, we identified some key design principles which could cast the foundations for next generation system architecture:

- Access Agnostic Convergent Core;
- Network Slicing;
- Tailored C/D- plane architecture/procedures;
- Augmented D-plane

Access agnostic convergent core

This principle is originated from the traffic trends discussed in Section 2 and from the need of flexibly selecting access technologies to suit application/service requirements. The access stratum functional blocks of the access technologies plugged-in to the 5G core (such as connectivity management, mobility management, authentication and authorization, etc.) shall seamlessly interact with the correspondent core control plane functions, leveraging an common set of primitives to define QoS (latency, guaranteed bandwidth), mobility, security and reliability requirements for the communication. The concept of service area shall evolve to include multiple access technologies. The convergent 5G core shall have holistic view of the access technologies available in a service area and receive reporting from devices about wireless and wireline access nodes in the neighborhood, even for new paradigms like moving networks (MN) and ultra dense networks (UDN). The access technologies are expected to evolve toward more flexible handover, re-selection and reachability strategies, tailored on service requirements, especially in terms of latency.

Network Slicing

The concept of *5G network slice* goes beyond virtualized infrastructure slicing (which is an *enabler* for 5G), implemented by SDN controllers and cloud hypervisors to isolate portions of the infrastructure and flexibly assign network, compute and storage resources to service overlays.

5G network slices shall belong to different administrative domains and, within the same domain, support different performance targets. Yet, assignment of resources to service providers shall support the capability of expanding and shrinking the allocated resources. The Management and Orchestration Plane defined by ETSI NFV MANO [6] maps service requirements to the underlying infrastructure. The 5G control plane instantiation is described in [5] in compliance to the management and orchestration principles defined in [6]. Within each administrative domain, network slices shall differentiate themselves by performance guarantees. Performance differentiation can be implemented by appropriate assignment of infrastructure slices, placement and configuration of Control Plane (C-plane), Data Plane (D-plane) and Augmented D-plane functions. In this sense the role of the edge of the 5G core is fundamental: edge routing elements should be capable of discriminating signaling and data received from access stratums and external PDNs in order to route them to the appropriate network slice. Differentiation of treatment shall be based on determining application performance requirements, functional requirements in the D-plane, device type (static, mobile, fast moving) and communication context.

Tailored C/D-plane

As a consequence of our analysis of the contributions to C/D-plane latency in 4G networks, we concluded that 5G core is expected to support adaptive C/D-planes. Taking 4G system as baseline, in [5] we decomposed C/D-plane logical elements into sets of applications or modules, which can be dynamically instantiated in the cloud infrastructure according to network operation or service requirements. The concept of configurability of the C/D-plane is twofold. From one side it means adapting configurable C-plane procedures to performance requirements of applications and devices. From another side, it regards the selection of the set of functional blocks involved in the C-plane: network functions can be either centralized or distributed, depending on service functional and performance requirements. For instance, a device attachment procedure can be carried out involving a centralized Authentication and Authorization (AA) functional block if latency is not an issue. In case of tight latency requirements, the central AA may delegate local dedicated AA blocks at the edge. For devices requiring very low latency, always-on and always-attached schemes shall be considered, resulting in the implementation of flexible security strategies. Similar analysis should be applied to other C-plane procedures such as Service Request, Tracking Area Update, Reachability, and Handover. All of them should consider the heterogeneity of the access networks plugged-in to the converged 5G core.

Augmented D-plane

We define Augmented D-plane a set of interconnected logical network functions (distributed in the SDN-based infrastructure) meant to provide flexible and efficient instantiation of advanced services in the D-plane by implementing application-dependent forwarding graphs.

Augmented D-plane functions can be simple firewalling and load balancing as well as application specific functions such as video streaming cache, IoT data aggregation in Wide Area Monitoring and Control Systems (WAMCS), IoT publish/subscribe apps for low latency/fast mobility vertical applications. For instance, WAMCS applied to smart grids require low latency in C/D-plane procedures. In order to speed up attachment or service request procedures, authentication could be skipped for always-attached PMUs (Phasor Measurement Units: GPS-synchronized units that collect measurements in various location of the grid), delegating it to a service-specific certification hierarchy implemented by WAMCS components; this solution results in an Augmented D-plane, capable of taking in charge some control plane functions (such as authentication in this case) for specific applications. Similar strategies can be applied to massive MTC communication to unload the control plane from recurrent authentication of the devices.

Delay Critical Static Machine Type Communication

As example, Figure 1 illustrates the logical architecture of a 5G Network Slice supporting delay critical static MTC. The C-plane includes a generic Access Network element (AN) and a basic set of logical core network functions. AN could include any fixed or wireless technology, to be used according to each device RAT capabilities or upon operator network load conditions.

The Connectivity Management Local function (CML) provides connectivity to the attaching devices; the Flow Management function (FM) configures the SDN based D-plane, including the Last Hop Routing Element (LHRE) connected to the AN element, to forward data to a destination MTC server, while Dynamic Host Configuration Protocol (DHCP) function is responsible for devices address allocation. Authentication and Authorization (AA) are performed by two functions. As the devices deployment could be unplanned and upon user discretion, operator is not aware of devices location.

For this reason, at the first attachment, device credentials are retrieved from a centralized function (AA General Purpose, AAGP), containing records for all devices population. During this phase, to make next attachments and data transfer faster, device credentials are transferred to a local AAL (AA Local) function, implemented on an edge point of presence, closer to the device. The reduced size of AAL database and its proximity to the devices shall ensure faster authentication and authorization, this significantly affecting control plane latency. Finally, being the devices static, the D-plane does not include any anchoring element. Data are forwarded from device to server though forwarding paths set up proactively on the SDN infrastructure at device attachment.

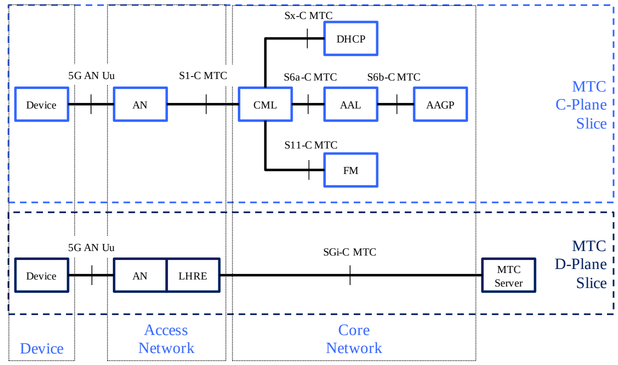

Figure 1. C/D-plane for MTC Slice

4. Conclusions

This letter provided and up to date review of telco trends and requirements for next generation networks. Based on those, key 5G design principles have been identified and briefly described. Together with SDN and NFV enabling technologies, access agnostic core, network slicing, tailored C/D-planes and augmented D-plane are expected to be the cornerstones of next generation network design and an integral part of the networking solution to serve the main needs of the elderly population.

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Riccardo Trivisonno (MSc and PhD in Telecommunications Engineering from University of Bologna) has worked for 15 years in R&D for mobile network industry. He has been with Huawei Future Network Technologies dept since 2011, working on next generation network architecture and technologies.

Riccardo Guerzoni (MSc in Telecommunications Engineering from University of Ferrara) has been working for 16 years in mobile network industry. He has been with Huawei European Research Center since 2011, working on network orchestration and application of SDN techniques to 5G.

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Multimedia Goes Beyond Content

Departments

Call for Papers

IEEE INFOCOM 2016

April 10-15, 2016, San Francisco, CA, USA
http://infocom2016.ieee-infocom.org

IEEE INFOCOM 2016 solicits research papers describing significant and innovative research contributions to the field of computer and data communication networks. We invite submissions on a wide range of research topics, spanning both theoretical and systems research. The topics of interest include, but are not limited to:

- Big data for networks
- Cellular networks
- Cloud computing
- Cognitive radio networks
- Cooperative networking
- Cross-layer optimization and control
- Crowdsourcing
- Cyber-physical systems
- Datacenter networking
- Delay tolerant networks
- Energy efficiency
- Fault tolerance, reliability and survivability
- Flow and congestion control
- Function computation and data aggregation
- Game theory in networks
- Information security and privacy
- Information centric networking
- Interference management and mitigation
- Internet of Things
- Localization
- Location-based services
- Medium access control
- MIMO-based networking
- Mobile computing
- Mobility management and models
- Multimedia networking
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- Network coding
- Network economics and pricing
- Network management
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- Network virtualization
- Optical networks
- Overlay and peer-to-peer networks
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- Smart antenna based networking
- Smart grid
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- Social computing and networks
- Software defined networking
- Vehicular networks
- Web applications and content distribution
- WLAN, WPAN, RFID, and NFC
- Wireless access networks
- Wireless security and privacy
- Wireless sensor networks

Important Dates
Abstract Due: **Friday, July 24, 2015 (11:59pm EDT)**
Full Paper Due: **Friday, July 31, 2015 (11:59pm EDT)**
Notification of Acceptance: **Friday, November 20, 2015 (11:59pm EDT)**

Call for Papers

IEEE 83rd Vehicular Technology Conference (IEEE VTC2016-Spring)

15-18 May 2016, Nanjing, China
www.vtc2016spring.org

The 2016 IEEE 83rd Vehicular Technology Conference will be held in Nanjing, China, 15-18 May 2016. Over the past six decades, VTC has established itself as one of the premier conferences in the world on mobile communications and vehicular technology. As the first-ever VTC to be held in mainland China, VTC 2016-Spring will feature world-class technical sessions, workshops, and tutorials in, but not limited to, the following technical areas:

TECHNICAL TRACKS

1. Antenna Systems, Propagation, and RF Design
2. Signal Transmission and Reception
3. Cognitive Radio and Spectrum Management
4. Multiple Antenna Systems and Cooperative Communications
5. LTE/LTE-A, 5G, and Wireless Heterogeneous Networks
6. Green Communications and Networks
7. Ad-Hoc, M2M, and Sensor Networks
8. Wireless Networks: Protocols, Security and Services
9. Satellite Communications Networks and Systems, Positioning and Navigation
10. Vehicular Communications, Networks, and Telematics
11. Future Trends and Emerging Technologies in Wireless Communications and Networks
12. Electric Vehicles, Vehicular Electronics, and Intelligent Transportation

Prospective authors are encouraged to submit full papers through the TrackChair web site: vtc2016spring.trackchair.com

Important Dates for regular papers
Submit papers for review by: **September 20, 2015**
Acceptance notices sent: **December 20, 2015**
Final papers due: **February 21, 2016**

Call for Workshops

Workshops provide invaluable opportunities for researchers and industry practitioners to share their state-of-the-art research and development results in areas of particular interest. We invite submissions of cutting-edge workshop proposals to complement the technical program of VTC2016-Spring in the aforementioned technical areas. For topics outside these focus areas, please consult with the respective workshop chairs prior to a proposal submission.

Important Dates for Workshops
Proposal submission deadline: **August 5, 2015**
Notification of acceptance: **August 15, 2015**

Call for Papers

IEEE Consumer Communications & Networking Conference (CCNC 2016)

9-12 January 2016 - Las Vegas, NV, USA
http://ccnc2016.ieee-ccnc.org

IEEE Consumer Communications and Networking Conference (CCNC), sponsored by the IEEE Communications Society, is a major annual international conference. Taking advantage of its co-location with the International CES (the world's largest tradeshow on consumer technology), CCNC is organized with the objective of bringing together researchers, developers, and practitioners from academia and industry working in all areas of consumer technologies.

Submissions are welcomed in the following regular Tracks in Consumer Communications Networking:

- Social, P2P and Multimedia Networking, Services and Applications
- Cloud Services and Networking
- Networking and Applications in Computer Games
- Wireless Communications
- Wireless Networking and Mobility
- Emerging Consumer Communications and Networking
- Sensing, Smart Spaces and IoT
- Security, Privacy and Content Protection
- Mobile and Wearable Devices, Services and Applications
- Consumer Communications and Networking Standards
- Vehicular Communications and Applications in Water, Land, and Sky
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- Content-Centric Internet of Things (CCIoT)
- Indoor positioning systems: from research prototype to real- world deployment
- Wireless Models and Simulations for Consumer Communication and Networking
- Wireless Communications and Applications Issues for eHealth

Affiliated Workshops

A number of workshops will be held in conjunction with the main conference. Workshop papers will be included and indexed in the IEEE digital libraries (Xplore) along with papers from the main conference. As in the past, CCNC 2016 will also feature Work-in-Progress Posters and Live Demonstrations. Please visit http://www.ieee-ccnc.org for more information on Research Papers, Industry Papers, Tutorials, Special Sessions, Keynotes, Plenary Lectures, Panels, Demonstrations, Workshops, Paper Submission Guidelines and Author Requirements.

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Important Dates

Technical paper submission: **July 24, 2015**
Acceptance notification: **September 4, 2015**
Final camera ready: **November 2, 2015**

Call for Papers

IEEE International Workshop on Cloud Computing Systems, Networks & Applications

Organized in conjunction with IEEE Global Communications Conference (GLOBECOM 2015)
San Diego, CA, USA, 6-10 December, 2015
http://www.ieee-ccsna.org/ccsna_gc15

The IEEE International Workshop on Cloud Computing Systems, Networks, and Applications (CCSNA-2015) aims at the crossroads between scientists, researchers, practitioners and students from diverse domains in Cloud computing research. The Workshop aims at attracting contributions of system and network design that can support existing and future applications and services. Researchers are encouraged to submit original research contributions in all major areas, which include, but not limited to:

• Cloud computing systems and networking- principles, designs, analyses, and performance

- Theoretical analysis for cloud systems
- Cloud system and network design
- Optimization for cloud computing, networking & applications
- Green cloud systems and networking
- Storage, data, and analytics for clouds design and networking
- Virtualization for cloud computing systems and networking
- Modeling and performance analysis for cloud system, network and storage
- Intra-cloud/inter-cloud computing and networking
- Cloud computing architectures and cloud solution design patterns
- Cloud migration, composition, federation, bridging & bursting
- Cloud provisioning and migration
- Cloud DevOps
- Cloud system design with FPGA, GPU, and APU
- Network Programmability, Software-Defined Networking and Virtual Ethernet Switching

• Big data, data centers, and cloud managements

- Big data storage and networking
- Real-time resource reporting and monitoring for cloud management
- Cloud quality management and service level agreement (SLA)
- Cloud configuration, performance, and capacity management
- Cloud workload profiling and deployment control
- Autonomic business process and workflow management in clouds
- Collaboration, management, and administration of clouds and services
- Quality of service on clouds and applications, including reliability, availability
- Scalability, performance, and load balance
- Knowledge engineering and data mining techniques and systems on clouds
- Data center network management, reliability, optimization, and bridging
- Distributed data center architectures
- Cloud traffic engineering and control-plane architectures

• Cloud services, applications, security, and interdisciplinary topics

- Cloud system and storage security
- Mobile cloud system design
- Cloud media and storage design
- Security, privacy, and compliance management for clouds
- Self-service cloud portal, dashboard, and analytics
- Innovative cloud applications and experiences
- Economic, business and ROI models for cloud computing
- Mobile-aware networking, protocols, and infrastructures
- Content and service distribution in clouds
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- Cloud for service discovery
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- Multimedia service provisioning on clouds
- MapReduce
- Resilience, fault tolerance
- Security, privacy, and compliance management for public, private, and hybrid clouds

• Surveys

- Surveys on any topics above

Important Dates

Technical paper submission: **July 15, 2015 (firm)**

Acceptance notification: **September 1, 2015**

Final camera ready: **October 1, 2015**

Call for Papers

International Conference on CYber physiCaL systems, iOt and sensors Networks

Rome, Italy, 26 October, 2015

http://cyclone-iot.org

The International Conference on CYber physiCaL systems, iOt and sensors Networks (CYCLONE 2015) will focus on theoretical, simulation and experimental activities related to Wireless Sensors and Actuators Networks, Cyber Physical Systems, IoT, Platforms, Sensor Cloud. Contributions from federated and large scale experiments will be highly appreciated, particularly the ones showing the applicability of open hardware/software solutions. Key persons from the manufacturing sectors showing the relevance of sensing devices and specific hardware components will be invited together with people illustrating more and more "softwarized" and de-verticalized solutions.

On this background, CYCLONE aims at bringing together researchers from academia and industry to identify and discuss technical challenges, exchange novel ideas, explore enabling technologies, and report latest research efforts that cover a variety of topics including, but not limited to:

- Cyber-physical systems: theory, tools, applications, testbeds and field deployments
- loT platforms: Theory tools, testbeds and field deployments
- Sensor Network applications: Transportation, energy, water, agriculture, ecology/environment, supply chains, medical, assistive technology, social networks, robotics
- Topics related to Wireless Sensors and Actuators Networks, Cyber Physical Systems, loT, Platforms and Sensor Cloud: Security, privacy control, optimization, machine learning, game theory, mobile and cloud computing, model-based design, verification, data mining, signal processing, human-in-the-loop, shared or supervisory control

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Important Dates

Technical paper submission: **August 10, 2015 (extended, firm)**

Acceptance notification: **August 30, 2015**

Final camera ready: **September 6, 2015**

Call for Papers

IEEE Access: Special Section on Advances in Vehicular Clouds

http://www.ieee.org/ieee-access

Submission Deadline: **November 1, 2015**

A vehicular cloud is a type of cloud that consolidates the computing and storage resources of vehicular clients and internet servers for the processing of transportation data to promote and support an Intelligent Transportation System (ITS). Vehicles carry significant amount of useful local traffic information.

A vehicular cloud provides a convenient platform for vehicles and people to share sensing data and computing resources for ITS applications. Obtaining instantaneous local traffic condition from nearby vehicles for route planning, collaborative image reconstruction of an event such as car accident, and big data processing of traffic information for local authority to improve transportation systems are some examples of vehicular cloud computing applications. The advancement of vehicular clouds relies on development of several key technologies. At the vehicle level, we expect improved driving experience with new technologies in sensors, human computer interaction, and automation. At the network level, we expect improved connectivity and reduced latency in communication networks such as cellular networks and Vehicular Ad-hoc Networks (VANETs). At the system level, we envision a new architecture for vehicular cloud to emerge in order to encourage development of ITS applications.

Similar to cloud computing, research issues such as computing and sensing resource virtualization, big data processing, real-time data processing and collaboration among vehicles, and efficient information dissemination will be some important research topics. The realisation of vehicular clouds involves research in several discipline including sensor technology, vehicular technology, wireless communication technology, and various technologies in computer science such as software engineering, artificial intelligence, big data analytics, and others. The research in vehicular clouds is interdisciplinary surrounding ITS applications. Besides, the concept of vehicular clouds is new, with growing interest from the research community.

The goal of this Special Section in IEEE Access is to collect articles about ideas, concepts, models, technologies, approaches, methodologies, and practices of vehicular clouds and to create awareness on this latest development in ITS that has the potential to improve and revolutionize transportation systems.

Topics of interest include, but are not limited to:

- Ideas, concepts and models of vehicular clouds
- Protocols, algorithms, technologies and approaches for vehicular clouds
- Communication and resource management for vehicular clouds
- Architecture design of vehicular clouds
- Green vehicular clouds to support environmentally friendly transportation systems
- Security, privacy, and trust for vehicular clouds
- Big data for vehicular clouds
- Storage and data processing for vehicular clouds
- Mobile agents for vehicular clouds

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Call for Papers

IEEE Transactions on Cloud Computing: Special Issue on "Mobile Clouds"

Mobile cloud computing represents one of the latest developments in cloud computing advancement. In particular, mobile cloud computing extends cloud computing services to the mobile domain by enabling mobile applications to access extern al computing and storage resources available in the cloud. Not only mobile applications are no longer limited by the computing and data storage limitations within mobile devices, nevertheless adequate offloading of computation intensive processes also has the potential to prolong the battery life.

Besides, there is also an incentive for mobile devices to host foreign processes. This represents a new type of mobile cloud computing services. Ad-hoc mobile cloud is one instance that mobile users sharing common interest in a particular task such as image processing of a local happening can seek collaborative effort to share processing and outcomes. Vehicular cloud computing is another instance of mobile cloud computing that exploits local sensing data and processing of vehicles to enhance Intelligent Transportation Systems.

This Special Issue will collect papers on new technologies to achieve realization of mobile cloud computing as well as new ideas in mobile cloud computing applications and services. The contributions to this Special Issue may present novel ideas, models, methodologies, system design, experiments and benchmarks for performance evaluation. This special issue also welcomes relevant research surveys. Topics of interest include, but are not limited to:

- Trends in Mobile cloud applications and services
- Architectures for mobile cloud applications and services
- Mobile cloud computing for rich media applications
- Service discovery and interest matching in mobile cloud
- Collaboration in mobile clouds
- Process offloading for mobile cloud computing
- Mobile device virtualization
- Mobile networks for cloud computing Mobile cloud monitoring and management
- Security and privacy in mobile clouds
- Performance evaluation of mobile cloud computing and networks
- Scalability of mobile cloud networks
- Software defined systems for mobile clouds
- Self-organising mobile clouds
- Mobile vehicular clouds
- Disaster recovery in mobile clouds
- Economic, social and environmental impact of mobile clouds
- Mobile cloud software architecture

Important Dates
Paper submission: **July 30, 2015 (extended)**
First Round Decisions: September 15, 2015
Major Revisions Due: November 15, 2015
Final Decisions: December 15, 2015
Publication: 2016

Submission & Major Guidelines
This special issue invites original research papers that present novel ideas and encourages submission of "extended versions" of 2-3 Best Papers from the IEEE Mobile Cloud 2015 conference. Every submitted paper will receive at least three reviews and will be selected based on the originality, technical contribution, and scope. Submitted articles must not have been previously published or currently submitted for publication elsewhere. Papers should be submitted directly to the IEEE TCC at https://mc.manuscriptcentral.com/tcc, and must follow TCC formatting guidelines. For additional information, please contact Chuan Heng Foh (c.foh@surrey.ac.uk).

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