MULTIMEDIA COMMUNICATIONS TECHNICAL COMMITTEE
IEEE COMMUNICATIONS SOCIETY
http://www.comsoc.org/~mmc

E-LETTER

Vol. 9, No. 5, September 2014

IEEE COMMUNICATIONS SOCIETY

CONTENTS

Message from MMTC Chair

Dear MMTC colleagues:

It is really a great honor for me to serve as the Asia vice-chair for this vital ComSoc Committee during the period 2014-2016! As part of my duties, I have contributed to the initial setting of the Interest Groups (IGs) and I am starting to work on the promotion of Special Issues (SIs)/symposiums/workshops with top journals/conferences.

Actually, these two activities interact with each other, and the core challenge is to form attractive, active, and enthusiastic IGs. As a result, I really believe that these IGs represent the core of our networking and scientific activities and I warmly invite all of you to select one or more IG(s) to get involved by contacting the chair(s) so as to take part as key member. The activities of the IGs include, among others, the editing of special issues in major journals, the organization of workshops, sessions and conferences with the involvement of the MMTC, the setting of invited talks through conference calls that can be of interest for our community and the rest of the ComSoc members. While these are the major activities, some others can be carried out following the specific IG topics, such as the contribution to standardization activities.

Essentially, these two activities will not success without strong support from our IG leaders and contributing members. At first, I will be working with all the IG Chairs to first identify a list of potential journals and conferences that are relevant to each IG. This list will be shared with all the members who have the interest to propose potential topics for a chosen venue. Then, we will socialize the topics with EiC(s) and Chair(s) to develop the full proposal on SI or symposium or workshop. It is our hope to achieve the largest efficiency via our collaborative efforts, ideally each IG can at least organize one SI or symposium or workshop per year. We also encourage multiple IGs to collaboratively propose topics that are relevant. In addition, we also hope IGs can take more constructive roles in our TC activities, for example, advertising the IG members to submit their papers to the multimedia symposium in ICC/Globecom.

I would like to thank all the IG chairs and co-chairs for the work they have already done and will be doing for the success of MMTC and hope that any 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 5G MOBILE COMMUNICATIONS TECHNOLOGIES AND SERVICES

Guest Editor: David Soldani
Huawei European Research Institute (ERI), Germany *david.soldani@huawei.com*

The advanced 5G infrastructure will not only be a plain evolution of the current network generations, but, more significantly, a true revolution in the ICT field: 5G will enable new secure, dependable, ultra reliable and delay critical services to "everyone and everything", such as cognitive objects and cyber physical systems. "Full 3D Immersive Experience" and "Anything as a Service" are the most important drivers for a global adoption and market uptake of new technology components. The network is expected to become the "Nervous System" of the true Digital Society.

This Special Issue of the E-Letter focuses on the latest progresses on 5G research. The editor is immensely grateful to disclose six key contributions from industry and academia on their views/solutions for meeting the 5G technical challenges, and share their latest results.

In the first article, entitled "5G: The Nervous System of the True Digital Society" the authors paint a vision of the advanced 5G infrastructure and new-fangled services. Also, they provide some insights into how the 5G mobile communications system will look like and argue how a massive adoption and exploitation of Mobile Edge Computing (MEC), Software Defined Networking (SDN), Network Functions and services Virtualization (NFV) will make the 5G technologies feasible and business viable.

In the second article, entitled "Performance Assessment of Different Relaying Techniques for 5G Vehicular Nomadic Nodes", Zhe and Peter conclude that nomadic relays (e.g., on-board of parked vehicles) significantly improve the network performance in terms of coverage and capacity. In particular, L2 Decode & Forward (DF) is a good choice for coverage extension and in-band L3 DF results preferable for improving throughput.

In the third article, entitled "Robotics-Derived Requirements for the Internet of Things in the 5G Context", Giorgio reviews the most important requirements to provide connectivity to a complex robot designed for human-robot interaction, envisioning a future where swarms of robot helpers will be an integral of our daily life.

The fourth article, entitled "On the Needs for a New Air Interface for 5G", by Frank, Berna and Martin, gives the background, drivers and the vision of a new 5G air interface, flexible and scalable enough to accommodate efficiently the stringent and conflicting requirements of the existing mobile broadband services, and emerging services such as Internet of Things (IoT).

The fifth article, entitled "Energy Efficiency and Spectrum Efficiency Co-Design: From NOMA to Network NOMA", by Shuangfeng, Chih-Lin, Zhikun and Qi, investigates the system Spectrum Efficiency (SE) and Energy Efficiency (EE) for Non-Orthogonal Multiple Access (NOMA) technique. Also, Network NOMA (N^2OMA) design is addressed and one precoding solution is proposed to mitigate the inter-cell interference, leading to a much better overall EE and SE.

In the sixth article, entitled "Building a New Multi-Facial Architecture of 5G", Josef, Ömer, Gerd, and Patrick provide the background, drivers and vision of a new 5G network architecture from three different angles, i.e. topology, functional and logical views.

David Soldani received a M.Sc. degree with maximum score and "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 more than 150 R&D projects for 2-5G generating original contribution to any quality deliverable: From strategic research and innovation to modeling, simulations, emulations and innovative proof of concepts with stakeholders. Dr. Soldani is currently Vice President (VP) of Huawei European Research Centre (ERC) and Head of Central Research Institute (CRI) in EU. Areas of his responsibility include, but not limited to: Future Wireless, Network, IoT and Multimedia Technologies. Dr. Soldani represents Huawei in the Board of the 5G Infrastructure Association, in Brussels, and Steering Board (SB) of NetWorld2020 European Technology Platform (ETP), in Europe.

5G: The Nervous System of the True Digital Society

David Soldani[†], *Antonio Manzalini*[‡]
[†]*Huawei European Research Centre, Germany;* [‡]*Telecom Italia, Italy*
david.soldani@huawei.com, antonio.manzalini@telecomitalia.it

1. Introduction

The advanced 5G infrastructure, defined as ubiquitous ultra-broadband network supporting Future Internet, is not only an evolution of current network generations, but, more significantly, a revolution in the ICT field: it will enable efficiently new ultra reliable, dependable, secure, privacy preserving and delay critical services to everyone and everything, such as cognitive objects and cyber physical systems (CPS). “Full Immersive Experience”, enriched by “Context Information” and “Anything as a Service” are the main drivers for a massive adoption of the new enabling technology components and market uptake, beyond today’s “Client-Server” model, where the network has been reduced to a mere pipe of bits. As shown in Figure 1, the network is expected to become the “Nervous System” of the true Digital Society. This challenge calls for a complete redesign of services and system, and a re-thinking of architectures, interfaces, functions, access, non-access protocols, related procedures and advanced algorithms, e.g. for identity and mobility management, establishment, maintenance and reconfiguration of ICT services, as well as any type of resource in cyber physical systems. This will be especially true at the edge, i.e. around the end user (or prosumer), where “intelligence” started already migrating a few years ago and massive processing and storage capabilities are progressively accumulating.

As of today, many challenges are still to be addressed to meet the expected key performance indicators, e.g. in terms of throughput (1000x more in aggregate and 10x more at link level), latency (1 ms for remote control of robots, or tactile Internet applications and below 5ms for 2-8K change in view at 30-50Mb/s), coverage (seamless experience), battery lifetime (10x longer), QoS, etc. This paper gives some insights into how the advanced 5G infrastructure may look like to be flexible enough, thus meeting foreseen and unknown traffic and service requirements and their vicissitudes. It also presents how massive adoption and exploitation of edge cloud computing, software (defined) networks and network functions and services virtualization will make the 5G infrastructure feasible and business viable. Many RTD and innovation activities are ongoing at global level: most of effort is currently being placed on research; after that, intensive standardization activities and large field test trials will follow to accelerate the industrial pre-adoption; commercial products will be most probably available in the market after 2020. The rough roadmap applies to 5G networks and devices for human and, especially, machine type of traffic (MTC).

2. Vision

Today, for the first time in history, we are witnessing the convergence of three things, i.e. “cloud computing”, “terminal computing power” and “connectivity at high speed”, into a single point: the smart phone, all realized over the “bit pipe networks” of the Internet Service Provider (ISP), denoted in this letter as “Client-Server” model. As Google said in 2010, *the smart phone is the extension of what we do and what we are: the mobile is the answer to pretty much everything* [1]. It is now time to go beyond this model and design the next generation of ubiquitous ultra-high broadband infrastructure, denoted as 5G, which will support the Future Internet and provide delay-critical and ultra reliable, secure and dependable services to billions of smart objects and cyber physical systems, such as cars, robots and drones, and new mobile terminals [2]. This will materialize the fundamental shift in paradigm from the “Client-Server” model to the new concept of “*Neural Bearer*” – not limited to the single dimensional case of end to end connectivity – efficiently enabled by the 5G open and flexible infrastructure, *5G Operating System* (5G OS), where “Anything” may be offered as a Service, such as: Data as a Service (DaaS), Network as a Service (NaaS), Knowledge as a Service (KaaS), Machine as a Service (MaaS), Robot as a Service (RaaS), Security as a Service (SaaS), and so forth [3], [4]. With 5G, the ICT will find application to generate new services at low cost for improving our lives and not only for communicating. Communication services will become commodities, for free, and, looking at the new business models, will monetize those applications, machines and things that will be offered as a service, meaningful to what really matter to us and thus achieve the actual Information Oriented Society, i.e. *The Digital Society*.

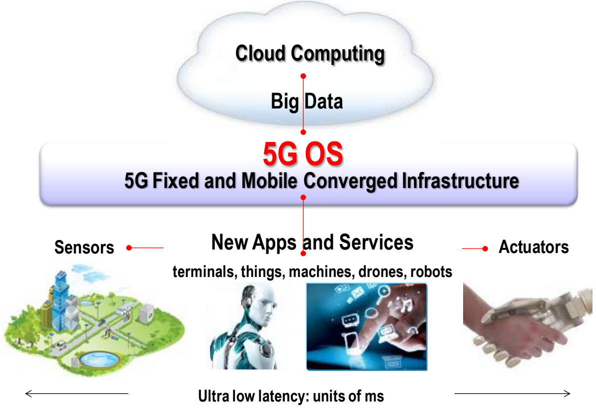


Figure 1 New ecosystems based on a 5G OS

3. Network, Services and Service Capabilities

The 5G key capabilities and recommendations from the global stakeholders are depicted in Figure 2. The IMT-Advanced (4G, 3GPPLTE) was designed for improving capacity, user data-rates, spectrum usage and latency with respect to IMT-2000 (3G, 3GPP UMTS). IMT for 2020 and beyond (Future IMT, 5G) will be, above all, suitable for "massive and mission-critical machine communication". Latency, Reliability, Speed, Mobility and Spectrum are the most important key performance indicators for 5G [5].

Looking at the spectrum utilization, frequencies below 6GHz (cellular band) are mostly suitable for macro-coverage (0.5-2km radius). The cellular band is expected to increase at least twice as much as it is today, i.e. from 300 to 984 MHz should be allocated already at WRC-15 [6]. In the range from 6 to 30GHz, about 2.5GHz could be made available for micro-coverage (50-100m radius). Frequencies from 30 to 90GHz (visible light) would be particularly suitable for fronthauling and backhauling, and local deployments (10m radius). In this range, about 40GHz could be made available for massive machine communications. These larger carrier bandwidths and spectrum at higher frequencies need to be identified at WRC-18/19 [7].

A high level vision of network and services in horizon 2020 and beyond is depicted in Figure 3. Most of the intelligence is expected to be placed and orchestrated at the edge of the network, i.e. in the aggregation, access segments up to the End Users premises [8]. Moreover, in the last mile an enormous quantity of processing and storage capability will be accumulated, thus ensuring better levels of QoS. Virtualized network functions, services and related states will be optimally located around the prosumer (machine or human being). This will make it possible to efficiently deliver the expected experience and meet the target performance: 1000x higher wireless area capacity, 10Gb/s link speed for true immersive experience, hyper connectivity to 100B of things and, especially 5x lower E2E latency than 4G (1ms is the target for tactile Internet) and 90% energy saving per provided service [2]. The network services and service capabilities [9], as well as Access and Non Access Strata [10], will evolve for providing delay-critical and ultra reliable, secure, privacy preserving, and dependable services, such as full immersive (3D) experience and vehicle to vehicle communications.

The concept of bearer service – set of quality/capability parameters, currently defining the single "virtual pipe" between service application entities in mobile terminal and related peers in the gateway to external packet data networks (PDN-GW) – will be replaced by a "*Neural Bearer*" or, simply, a "*Bearer Graph*" that will enable multidimensional carrier grade communication paths, i.e. well beyond the scope of the current bidirectional communication chains, as depicted in Figure 3.

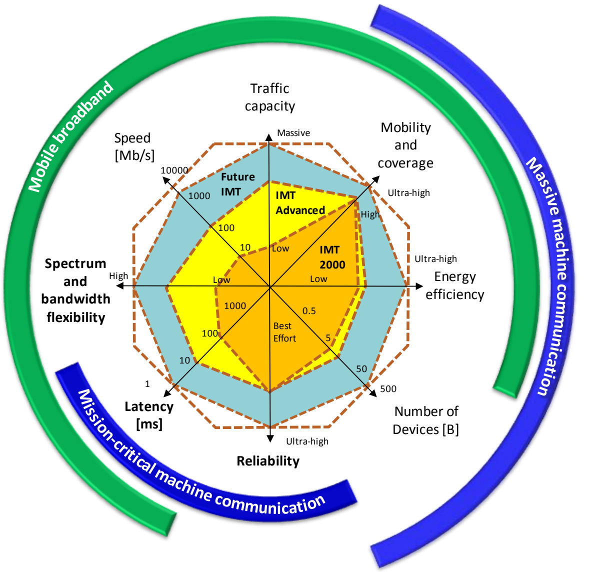


Figure 2 5G capabilities: a global perspective [5]

New technology enablers for establishing, maintaining and reconfiguring the bearer graph connecting multiple cognitive mobile objects, forming ephemeral networks (with and w/o network assistance), will allow operators to meet the performance targets, especially in terms of latency and speed, which are currently unachievable implementing today's and upcoming 3GPP mobile services and SDN solutions, being limited to transport and network layers of the infrastructure [11].

In Figure 3, the robot, as all other connected cognitive objects, is expected to be handled as a new device type with own capabilities. Control entities for establishing, maintaining and reconfiguring the new bearer service, in dual mode mobility, are distributed in the network, as well as in other vehicles around the robot in question, i.e. at the edge.

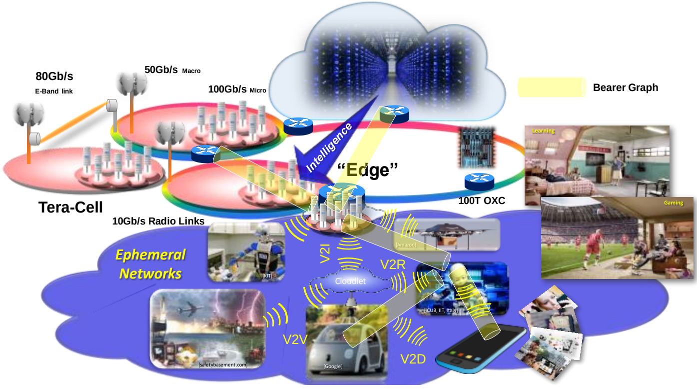


Figure 3 5G networks and services vision

In this case, the head of the robot is connected to a car, a device and to three peer entities in the network, including the Internet. The vehicle (robot) to X (V2X) networking, denoting X any other fixed or mobile node, consists of a local, opportunistic, and multi-hop communication with direct connections among objects, whenever beneficial and achievable. The proposed concept goes well beyond the current 3GPP Device-to-Device (D2D) proximity services, limited to a single-hop and typically relying on assistance from the network infrastructure, and the well known ad hoc networks (MANET), based on multi-hop routing with limited network performance [12], [13]. The proposed "neural bearer" may enable several carrier grade communications, i.e. Layer 1-7 links, simultaneously, through different radio interfaces with the availability of multiple transceivers, which is currently not possible in D2D, especially due to low battery consumption and hardware integration constraints. As depicted in Figure 3, the protocols of the new non-access stratum enable entities located in the different connected nodes to exchange information, knowledge and any kind of service among them. In this sense, the notion of "bearer graph" defines capabilities beyond what is currently possible with "relay control", in "in-coverage" and "out-of-coverage" modes [12]. The service applications may run on each of the connected nodes and exchange services among themselves in a secure, reliable, dependable and low latency manner, not limited to the bidirectional communication chain "Client-Server". The 5G Operating System will be capable of unifying the control and forwarding planes of future fixed and mobile networks composed of heterogeneous devices, machines, nodes up to the Cloud. The 5G OS will transform the advanced 5G infrastructure in the "ultra-low latency nervous system" supporting new service paradigms, such as "Anything as a Service", looking at a true Digital Society at the horizon 2020 and beyond.

The socio-economic and business implications of this vision are enormous. Today the main "control variables" of our "complex" economy are still human intelligence, attention, efforts and time: humans are still the most productive part of the current economy. As a matter of fact, we are witnessing the migration of industries to regions where labor costs are much lower. This vision will help us create a pervasive "machine intelligence" capable of reshaping this economy equation by taking over a lot of cognitive tasks that humans can do and improving quality of lives. *Organizations should focus on harnessing and leveraging 5G technologies around machine intelligence, big data and connected vehicles and simultaneously create new and different jobs*. We believe the advanced 5G infrastructure to be the most important catalyst of the Second Machine Age [14]: 5G will power intelligent Machines to "flood the landscape of jobs". There will be a number of socio-economic benefits: reduction of human efforts in jobs subject to computerization and robotization, aiming at bringing down operating costs with much higher product quality, worker safety and improved operational conditions; increasing local production; reducing long distance transportation, and "optimizing" many socio-economic processes. As a result, human labor costs will no longer drive investments and the number of jobs created will be far greater than the numbers lost due to automation 0. *The network will be transformed from a sterile pipe to the nervous system of the Digital Society, and Network Operators, leveraging their edge assets, will have a chance of playing new business models, and be in a much stronger position in the value chain, e.g., opposed to the OTT, which will remain confined to the "Client-Server" model*.

Last, but not least, in order to rapidly profit from 5G, first the environment around cognitive mobile objects needs to evolve to host them. For instance, a robot does not need to recognize that in front of it there is an object: the entity in the proximity may report the robot its identity instead, and the robot may retrieve all necessary information on it from the Edge cloud. This largely simplifies the machine learning process and robots would mostly need to compute the geometry of the physical environment around them. This is depicted in Figure 4, where the five 5G fundamental technology components – namely: 1) *Sensing* (massive amount of sensors); 2) *Rendering/Actuating* (new devices, beyond smart phones); 3) *Edge computing* (storage, memories and plenty of computational power for a "Zero Latency" Cyber World, where virtual objects meet each other); 4) *Control and Orchestration* (intelligent functions at the edge, pervasive, ephemeral); and 5) *Networking* (high speed connectivity through new waveforms and optical fiber carrying digital/modulated signals) – are shown.

Ultimately, as it has been repetitively stressed for car-to-car communication, in this letter, we also argue that *cooperation among many stakeholders is required to successfully introduce the 5G enabling technologies*.

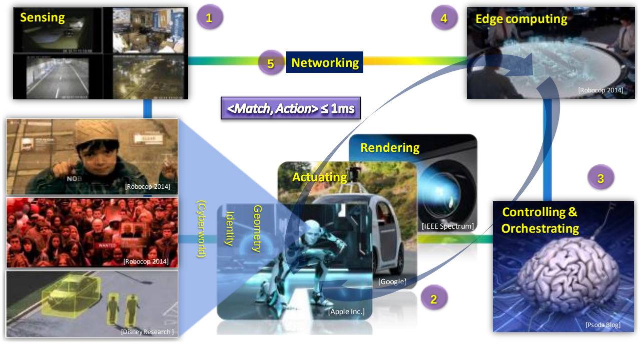


Figure 4 Fundamental 5G technologies

4. Key Enabling Technologies

A possible architecture for implementing the bearer graph concept introduced in Section 2 is illustrated in Figure 5. Only 3 levels of controllers are defined in the proposed architecture: *Device Controller* (responsible for selection of fixed and mobile access technologies, subject to limitations imposed by upper layers); *Edge Controller* (performs delay-constraint tasks, e.g. radio resources management and adaptive Layer 1-3, such as: HARQ, modulation and coding schemes selection, wireless scheduling and handover control in connected mode. It also handles L1-L3 routing and forwarding, end-to-end, w/o network assistance); and *Orchestrator Controller* (enables coordination of cloud computing and distributed networking capabilities for efficient resources administration, optimization and any service composition at multiple levels of substrate abstraction).

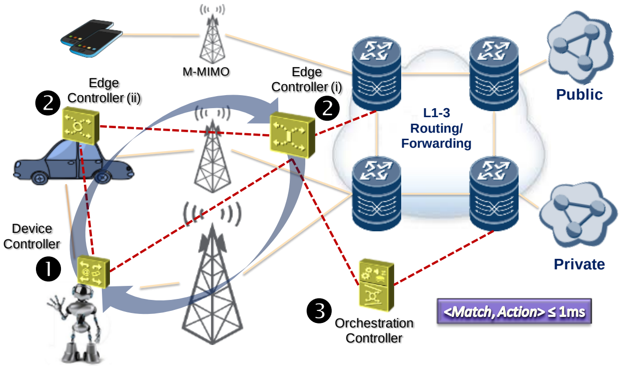


Figure 5 Proposed 5G logical network architecture

The control of multi-hop paths may be based on tables, following the <*Match*, *Action*> principle, analogue to Software Defined Networking (SDN) using OpenFlow [8]. The translation function may be performed at the edge: tell me what you want, not how to do that, which can be done in a proactive or reactive manner, targeting <*Match*, *Actions*> in less than 1ms. The internal packet forwarding may be optimized through orchestration. Beyond this, the three levels of controllers present interfaces to the outer world for any type of application.

6. Conclusion

The 5G Operating System will transform the advanced 5G infrastructure into the “ultra-low latency nervous system” supporting “Full Immersive Experience” and “Anything as a Service” for a true Digital Society, at the horizon 2020 and beyond. We believe that Europe can make this vision happen though crucial investments in 5G technologies and related measures and actions to strengthen the know-how in each Member State, ensure EU leadership in the field of ubiquitous ultrafast broadband infrastructure, re-enforcing privacy and data protection, and supporting the most important plausible scenarios expected at the horizon 2020 and beyond. 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.

References

[1] Eric Smith, “Google keynote speech,” Mobile World Congress (MWC), Barcelona, Spain, Feb. 2010.
[2] European Commission, “Leadership in enabling industrial technologies,” Horizon 2020 WP, 2014 – 2015.
[3] D. Soldani, “Report on the 5G European Summit (5G ES 2014),” European Parliament, Feb. 19th, 2014.
[4] A. Manzalini, R. Saracco, “Software networks at the edge: a shift of paradigm,” IEEE SDN4FNS, Trento, Nov. 2013.
[5] ITU towards “IMT for 2020 and beyond.”
[6] http://www.huawei.eu/research-and-innovation/spectrum.
[7] Huawei, “5G: A Technology Vision,” WP, Feb. 2014.
[8] A. Manzalini, et al., “Software-defined networks for future networks and services: main technical challenges and business implications,” IEEE SDN4FNS, Jan. 2014.
[9] 3GPP TS 22.105, “Services and service capabilities.”
[10] 3GPP TS 24.301, “Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS).”
[11] https://www.metis2020.com/documents/deliverables/.
[12] X. Lin, J. G. Andrews, A. Ghosh, R. Ratasuk, “An overview on 3GPP device-to-device proximity services,” Submitted to IEEE ComMag, Sep. 2013.
[13] 3GPP TS 23.303, “Proximity-based services (ProSe).”
[14] E. Brynjolfsson, A. Mcafee, *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*, W. W. Norton & Company, Inc., 2014.
[15] Capgemini Consulting: Digital Transformation Review – Gearing. N. 05, Jan. 2014.

David Soldani is currently VP of the Huawei European Research Centre, Germany, and Visiting Professor at the University of Surrey, UK. Areas of his responsibility include, but not limited to: Future Wireless, Network, IoT and Multimedia Technologies. Dr. Soldani represents Huawei in the Board of 5G Infrastructure Association and Steering Board (SB) of NetWorld2020 European Technology Platform (ETP) in Europe.

Antonio Manzalini is currently Senior Manager at Future Centre of Telecom Italia. He has been actively involved in many European Projects, leading some of them in the area of future networks and autonomic computing. In 2008, he was awarded with the International Certification of Project Manager by PMI. He is author of one book and published and presented many papers. His current RT&D interests are mainly in the area of software defined networks and virtualization, primarily for the development of 5G networks, products and services.

Performance Assessment of Different Relaying Techniques for 5G Vehicular Nomadic Nodes

Zhe Ren and Peter Fertl
BMW Group Research and Technology, Germany
{*zhe.ren, peter.fertl*}*@bmw.de*

1. Introduction

Future fifth-generation (5G) networks have to cope with challenging requirements such as increased data rates, increased traffic volume, a massive number of connected devices, and ubiquitous coverage [1].

In the 5G research project METIS, the concept of nomadic network nodes has been introduced as a key component of future networks that allows for a very flexible network deployment [2]. In particular, a Nomadic Relay Node (NRN) describes a network node that provides relay-like communication capabilities. However, in contrast to a traditional fixed or moving relay (defined according to [3]), there is an inherent uncertainty with regards to its temporal and/or spatial availability, i.e., a nomadic node may shut-down its service, change its geographical position and then become available again (hence, the term “nomadic”). For example, the on-board communications infrastructure that will be deployed in future vehicles may serve for such purposes while the vehicle is parked. Although nomadic nodes are stationary in principle, the inherent uncertainty with regards to their availability resembles a network that is “moving” or “movable”. While the location of operator-deployed relay nodes is optimized by means of network planning, nomadic nodes are randomly distributed and operate in a self-organized fashion. Furthermore, nomadic nodes are assumed to be densely populated (e.g., parked vehicles) which allows activating only those nodes that best serve the current capacity, coverage, load balancing or energy efficiency demands while causing the least additional interference. Therefore, they provide a very flexible tool for dynamic network extension.

Naturally, the concept of nomadic nodes poses several challenges such as interference management, mobility management, and network integration. In this work, we focus on performance assessments of different relaying techniques and protocol implementations for nomadic relay nodes in future networks. We analytically formulate the effective Signal-to-Interference-plus-Noise-Ratio (SINR) and user end-to-end (E2E) Spectrum Efficiency (SE) achieved with the different techniques. Finally, we present system level simulations that provide a performance comparison in a heterogeneous network with nomadic nodes for practical settings.

2. Relaying Modes

We focus on the application of existing relaying techniques and standards (see [4] and [5]), namely, the following types of Relay Nodes (RN):

- Layer-1 (L1) Amplify-and-Forward (AF) RN;
- Layer-2 (L2) Decode-and-Forward (DF) RN;
- Layer-3 (L3) In-band or self-backhauling RN.

While a L3 RN has the same Radio Resource Management (RRM) functionalities as a standard Base Station (BS), a L1 and L2 RN is not seen by the User Equipments (UE) as a cell with separate cell ID. As pointed out in [5], L3 RNs are equivalent to BSs from the terminals’ perspective, for guaranteeing backwards compatibility, whereas L1 and L2 RNs are transparent to the UEs and should be centrally maintained by the BSs through dedicated interfaces.

In the following, we denote the *direct*, *relay* and *access link* to be the UE-BS, RN-BS and UE-RN connections, respectively. Furthermore, UEs served directly by BSs and via RNs are denoted as *macro* UEs and *relay* UEs, respectively. We apply these three types of relaying modes to the nomadic network and analytically formulate the effective E2E SINR and the E2E SE. For clarification, we denote the received power, SINR and SE of link (i,j) as P_{ij}, τ_{ij}, and r_{ij}, respectively. Furthermore, we assume the same noise power level (σ) for all the elements in the network. The sets of BSs, active RNs, and UEs are referred to as B, R, and U, respectively. Note that the SINR is calculated assuming worst case interference, i.e., all of the active BSs and RNs are transmitting at full power and full load.

L1 AF NRN

The L1 AF NRNs (also known as repeater) amplify the signals as well as the interferences received on the relay links. For simplification, we follow the framework of [6] and [7] and assume that the amplified signals do not generate significant interference to other UEs. Further, by assuming a comparable interference level for all three links (i.e., direct, relay, and access link), the effective E2E SINR at UE j connected to the network via BS i and NRN k can be computed according to [6] as:

$$\tau_{ee} = \frac{\tau_{ik}\tau_{kj} + \tau_{ij}(1+\tau_{ik})}{1+\tau_{ik}+\tau_{kj}}, \qquad (1)$$

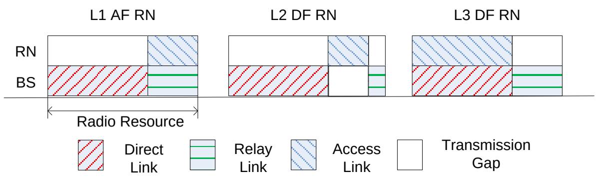


Figure 1 Resource allocation shown for the three different relaying modes

where τ_{ij}, τ_{ik}, and τ_{kj}, refer to the SINR of the direct, relay, and access link, which can be expressed as:

$$\tau_{ij} = P_{ij} / \Big(\sum_{d \subset B \backslash i} P_{dj} + \sigma\Big), \tag{2}$$

$$\tau_{ik} = P_{ik} / \Big(\sum_{d \subset B \backslash i} P_{dk} + \sigma\Big), \tag{3}$$

$$\tau_{kj} = P_{kj} / \Big(\sum_{d \subset B} P_{dj} + \sigma\Big). \tag{4}$$

Note that (1) also covers direct link communication without relaying through a NRN by setting τ_{kj} = 0, which results in $\tau_{ee} = \tau_{ij}$. Indeed, the relay UEs are not aware of the two-hop communication via the NRN k and therefore (using Shannon approximation) the corresponding E2E SE can be expressed as:

$$r_{ee} = \log(1 + \tau_{ee}). \tag{5}$$

Note that in our SINR and SE expressions we neglect the commonly used coefficients that account for signaling overhead and other system losses.

L2 DF NRN

Widely studied in the literature of information theory, a DF relay does not amplify interference (see [8] and [9]). However, it requires half-duplex operation or advanced interference cancellation techniques to combat the self-interference. In this work, we assume half-duplex narrow band relays, i.e., the allocated resources must be shared by relay link and access link in an orthogonal manner, as depicted in Fig. 1. Since the NRNs only transmit at certain resource blocks with limited transmission powers, we neglect the interference that these RNs induce to the other links. Therefore, the same expressions for the link SINRs apply as in (2)-(4). The E2E SINR of UEs can be computed as:

$$\tau_{ee} = \begin{cases} \tau_{ij} & \text{for macro UEs,} \\ \min\{\tau_{ik}, \tau_{kj}\} & \text{for relay UEs,} \end{cases} \tag{6}$$

where the direct link SINR is applied to the macro UEs and the minimum SINR of the two hops is used for relay UEs. This is a useful metric, since certain services require a minimum SINR and those services can be only delivered through multi-hop communications if all the links achieve the SINR target. As we assume an optimized resource split between relay link and access link [7], the E2E SE of a relay UE can be written as the harmonic mean of the two links:

$$r_{ee} = 1/(1/\log(1 + \tau_{ik}) + 1/\log(1 + \tau_{kj})). \tag{7}$$

Note that for the E2E SE of a macro UE, (5) applies.

L3 DF In-band NRN

For the L3 in-band relay we assume a half-duplex DF RN. Unlike L2 relays, L3 NRNs are seen by the UEs as full BSs and, for their access link transmissions, can reuse all the resources that a BS uses for the direct link. Therefore, access links and direct links are interfering with each other, which is similar to a heterogeneous network with femtocells. In this case, the SINR of direct and access link can be computed as in (8) and (9), respectively:

$$\tau_{ij} = P_{ij} / \Big(\sum_{d \subset B \bigcup R \backslash i} P_{dj} + \sigma\Big), \tag{8}$$

$$\tau_{kj} = P_{kj} / \Big(\sum_{d \subset B \bigcup R \backslash k} P_{dj} + \sigma\Big). \tag{9}$$

Assuming that relay link transmissions are configured orthogonally to access link transmissions of other RNs [10], this yields a relay link SINR of:

$$\tau_{ik} = P_{ik} / \Big(\sum_{d \subset B \backslash i} P_{dj} + \sigma\Big). \tag{10}$$

For the computation of the E2E SINR for UEs (6) still holds when inserting (8)-(10) in the equation.

Since the Shannon SE formula in (5) applies only to one-hop transmissions and different amounts of resources can be allocated on the first and second hop for L3 NRNs, the E2E SE is tricky to derive. Denoting b_{ik} and b_{kj} as the resources allocated to the relay link and access link, respectively, we can express the E2E SE for relay UEs as:

$$\begin{aligned} r_{ee} &= \min\{b_{ik} \log(1 + \tau_{ik}), b_{kj} \log(1 + \tau_{kj})\} / b_{ik} \\ &= \min\{\log(1 + \tau_{ik}), b_{kj} / b_{ik} \log(1 + \tau_{kj})\}. \end{aligned} \tag{11}$$

Since the L3 NRN uses the same resources for the access link transmissions and for the direct link transmissions (cf. Fig. 1), the computation of the E2E SE is only based on the resources allocated to the relay link. Therefore, as written in the first row of (11), the E2E SE of the relay UEs can be expressed as the bottleneck throughput at either the relay or the access link divided by the resources allocated to the relay link. For macro UEs the E2E SE can be computed using (5).

The resource allocations of the three relaying modes are summarized in Fig. 1. It can be concluded that L2 NRNs trade relay/access link interference with resource reuse when compared to L1 NRNs. However, with L3 RNs a more aggressive resource reuse can be achieved by allowing interference between direct and access links.

3. Performance Assessment

We evaluate a network with 19 tri-sector BSs with hexagon layout containing 1000 UEs and 300 NRNs.

Table 1 Simulation Parameters

Parameter	Value
Carrier Frequency	2 GHz
System Bandwidth	10 MHz
Penetration Loss	20 dB
Antenna Configuration	1 Tx and 1 Rx
eNB Transmit Power	46 dBm
RN Transmit Power	23 dBm
Thermal Noise PSD	-174 dBm/Hz
UE Noise Figure	5 dB
Shadowing Correlation	20 m for access link, 50m for both direct/relay link

A total number of 100 simulation runs are carried out to generate sufficient statistics. At the beginning of each run the 300 NRNs are randomly distributed. Then, during the simulation run, we simulate the nomadic node availabilities according to the birth-death process used in [11]. The channel and system simulation parameters are listed in Table 1 and are chosen according to 3GPP specifications [4]. A round robin scheduler is assumed such that all UEs connected to the same BS (directly or via an NRN) equally share the available resources. A Reference Signal Received Power (RSRP) based cell selection and activation scheme is applied, where each UE connects to the NRN or BS with the strongest RSRP. Those NRNs which do not serve any UEs are deactivated and thus do not add additional interference to the overall network. Note that this activation/de-activation mechanism is quite idealistic, since it requires that all nomadic nodes are active before starting the selection process and allow for collecting RSRP measurements. Nevertheless, this approach is still valid and allows for fair performance comparison. Note that, based on this selection mechanism, our simulations show that 80 out of the 300 nomadic nodes are simultaneously active in the network on average.

Results Discussion

The coverage performance of the different relay modes applied to the nomadic network is compared in Fig. 2, in terms of the cumulative distribution function (CDF) of the E2E SINR at the UE. It can be easily concluded from Fig. 2 that applying L2 NRNs yields the best performance in terms of coverage, since the desired signals are amplified without causing additional interference to other nodes in the system (due to the orthogonality of relay and access link transmissions). Our results show that the E2E SINR is boosted by up to 5 dB for this relay mode. The other two relaying modes only show a marginal improvement of the coverage performance of about 1.5 dB compared to a network with only macro BSs.

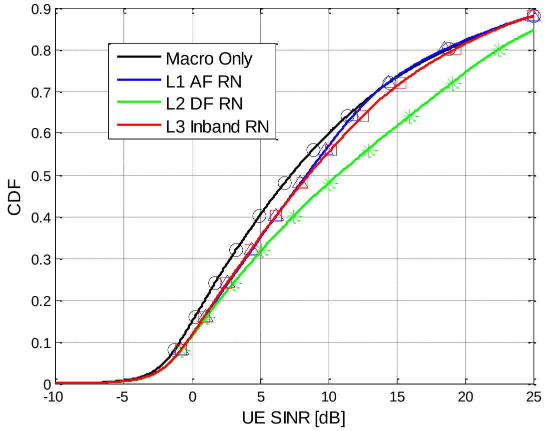


Figure 2 CDF of E2E SINR at the UE

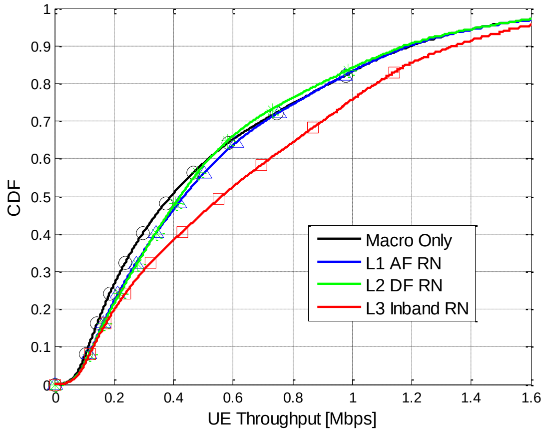


Figure 3 CDF of E2E throughput at the UE

The capacity performance of the different relay modes in the nomadic network is expressed in terms of the CDF of the E2E throughput at the UE (shown in Fig. 3). Note that here the E2E throughput is computed as the product of the E2E SE and the bandwidth allocated to the UE. For L3 NRNs the E2E throughput at the UE can be significantly improved compared with macro only deployment and the other relay modes. Only a limited performance gain is seen for L1 NRNs, whereas for L2 NRNs even slight performance degradation can be observed at high SINR regions. The latter is due to the fact that for L2 NRNs the corresponding BSs do not fully exploit all the available resources; note that here the resources are shared between direct, relay, and access link in an orthogonal manner (cf. Fig. 1).

4. Conclusion

In this paper, we discussed a novel and flexible deployment approach that can cope with the dynamic capacity and coverage demands of future 5G networks – vehicular nomadic relay nodes. By conducting a large-scale system level simulation, we assessed the performance of various relaying modes in a nomadic relay network. Our results showed that deploying nomadic relays (e.g., on-board of parked vehicles) can significantly improve the network performance in terms of coverage and capacity. In particular, for the purpose of coverage extension deploying L2 DF RNs is a good choice for nomadic nodes. However, for improving the E2E throughput of UEs L3 DF in-band RNs are preferable.

For further research on vehicular nomadic nodes we recommend to study more intelligent activation and de-activation mechanisms as well as interference management algorithms based on the L3 relaying techniques.

Acknowledgement

Part of this work has been performed in the framework of the FP7 project ICT-317669 METIS, which is partly funded by the European Union. The authors would like to acknowledge the contributions of their colleagues in METIS, although the views expressed are those of the authors and do not necessarily represent the project.

References

[1] P. Popovski, V. Braun, H. P. Mayer, P. Fertl et al., “D1.1 Scenarios, requirements and KPIs for 5G mobile and wireless systems.” Deliverable D1.1, EU-FP7 Project METIS (ICT-317669), 2013, www.metis2020.com.
[2] P. Popovski, V. Braun, G. Mange, P. Fertl, et al., “D6.2 Initial report on horizontal topics, first results and 5G system concept.” Deliverable D6.2, EU-FP7 Project METIS (ICT-317669), 2013, www.metis2020.com.
[3] 3GPP TR 36.836, “Mobile Relay for E-UTRA.”
[4] 3GPP TR 36.814, “Further Advancements for E-UTRA, Physical Layer Aspects, (Release 9)”.
[5] M. Iwamura, H. Takahashi, and S. Nagata, “Relay technology in LTE-Advanced,” *NTT DoCoMo Technical Journal* 12.2, pp. 29-36, 2010.
[6] K. T. Riihonen and R. Wichman, “Power allocation for a single-frequency fixed-gain relay network”, in *Proc. of IEEE PIMRC,* Athens, Greece, Sept. 2007.
[7] A.B. Saleh, S. Redana, B. Raaf, T. Riihonen, J. Hämäläinen, and R. Wichman, “Performance of amplify-and-forward and decode-and-forward relays in LTE-Advanced,” in *Proc. of IEEE VTC 2009-Fall*, Sept. 2009.
[8] G. Kramer, M. Gastpar, and P. Gupta, “Cooperative strategies and capacity theorems for relay networks,” in *IEEE Transactions on Information Theory,* vol. 51, no 9, pp. 3037-3063, June 2005.
[9] D. Soldani, S. Dixit, “Wireless relays for broadband access,” IEEE Communications Magazine, Vol. 46, pp. 58-66, Mar. 2008.
[10] A.B. Saleh, Ö. Bulakci, S. Redana, B. Raaf and J. Hämäläinen, “A divide-and-conquer approach to mitigate relay-to-relay interference”, in *Proc. of IEEE PIMRC,* Toronto, Canada, Sept. 2011.
[11] Ö. Bulakci, Z. Ren, C. Zhou, J. Eichinger, P. Fertl, and S. Stanczak, “Dynamic nomadic node selection for performance enhancement in composite fading/ shadowing environments”, *Proc. of IEEE VTC 2014-Spring,* Seoul, Korea, May 2014.

Zhe Ren received his Bachelor and Master Degree in electronic and electrical engineering from the University of Technology, Munich, Germany, in 2009 and 2011, respectively. In 2012, he joined BMW Group Research and Technology with focus on 5G and future automotive communication systems. Also, Zhe Ren is currently associated with the Technical University of Berlin, Germany, working towards a Ph.D. degree in wireless communication.

Peter Fertl received the Dipl.-Ing. and Dr. techn. degrees in electrical and communication engineering from the Vienna University of Technology, Austria, in 2005 and 2009, respectively. From 2006 to 2009 he used to be a research and teaching assistant at the Institute of Communications and Radio-Frequency Engineering, Vienna University of Technology, with focus on wireless multi-user multi-antenna communications and relay networks. Since 2010 Dr. Fertl holds a position as project manager and research specialist at BMW Group Research and Technology, where he is responsible for next-generation wireless communication technologies with focus on future automotive connectivity. He is coordinating BMW participation in the EU 5G-flagship project METIS with focus on V2X communications, nomadic relay networks, and ultra-reliable low-latency transmissions.

Robotics-Derived Requirements for the Internet of Things in the 5G Context

Giorgio Metta
Istituto Italiano di Tecnologia, Genoa, Italy
giorgio.metta@iit.it

1. Introduction

Recent advances in robotics indicate that a vigorous market of personal or service robot is certainly possible in the near future. There is a clear demographic trend that would make robotics very appealing to a large sector of the consumers, health care and industrial market, in particular, as generic helpers in the household or factory.

The EU Commission has published statistics that illustrate the dramatic shift in the population distribution from now to 2050. In particular, the number of people out of the working age (i.e. >65 years old) will be as much as one third of the population [1]. Therefore, for each person over 65, there will be at most two other individuals to take care of her/him. Barring dramatic societal changes, the overall cost of health care will top 29% of the European GDP [2]. Robotics appears to be the most feasible technology to deploy effective solutions.

Such a pervasive use of robots will require a robust infrastructure to connect to/from the robot sensors as well as to the traditional telecommunication means (Internet, mobile, etc.). In this letter, we analyze the requirements in terms of data types and bandwidth needed to perform typical robotic tasks.

2. Robot helpers

The future robotic helpers are typically envisioned as machines with autonomy, highly sophisticated sensors, complex mechatronics and flexibility to be deployed in the most disparate applications [3]. They will effectively be the next generation of personal devices, with one major difference if compared to current digital technology: robots will physically interact and change the state of the environment by pressing buttons, levers, moving objects, and occupying space.

One important aspect of the use of robots whenever they share space with people is safety. In spite of the use of compliant robots, force control, etc. absolute safety is only obtained when the robot is guaranteed not to touch a person unless the task requires it to do so. Therefore the use of visual sensors is mandatory. Computer vision algorithm for example will recognize and track the interaction with people and foresee contacts avoiding them when dangerous and, on the contrary, controlling them when needed.

Further, robots will need large knowledge bases to deal with the variety of tasks, objects, people that are encountered in everyday life. These will need to be accessible with certain deterministic latencies to guarantee the continuity of the robot action.

Robots will form part of the machine to machine communication (M2M) paradigm being able to team up to solve tasks, to exchange important information about the ongoing state of the operative environment, etc. Specific protocols and data distribution services may be required to make the joint use of robots and telecommunication infrastructure as effective as possible, especially in the 5G context.

Robots will be remotely-operated to various extents and/or partially monitored (human in the loop approach) particularly in the first commercial applications where full autonomy is unlikely (for regulatory as well as technical reasons). They will require highly reliable and efficient connectivity especially with respect to the overall latency.

Finally, computational infrastructure in the cloud is expected to be needed for robots to perform demanding tasks such as learning. In that case training data have to be transferred, elaborated by machine learning techniques (which may take days to complete) and returned to the robot in the form of specific algorithms (or their parameters).

3. A case study: the iCub

The iCub [4] is a humanoid robot developed by the Istituto Italiano di Tecnologia (Italian Institute of Technology, IIT) and supported by a stream of EU projects in the sixth and seventh framework programs. The iCub is about 1m tall (see Figure 1) and designed to resemble a four-years-old child. The robot principal application domain is research and in particular the study of artificial cognitive systems including AI, learning, vision, control, etc.

The iCub is, to the best of our knowledge, the only robot equipped with a full body skin system that provide tactile information in more than 4000 sensing points distributed along the entire body [5]. The iCub mechanical design sports highly dexterous hands (9 degrees of freedom, 22 joints), a controllable visual system that includes vergence and three degrees of freedom (DoF) in the head, a torso with additional three DoF and legs with special compliant actuators.

From the sensorial point of view, besides the skin system, the iCub has cameras, microphones, force sensors, gyroscopes, accelerometers that are managed by a distributed computation architecture. The robot software system is intrinsically networked. Information is distributed to a cluster, elaborated and finally transformed into control signals to generate the robot behaviors [6].

This data processing paradigm is in a sense ready to be transformed into "cloud computing" provided a reliable infrastructure is available. On top of that, the iCub can function as a data collection device, by providing its sensory data to other devices, to other robots, or to human operators [6].

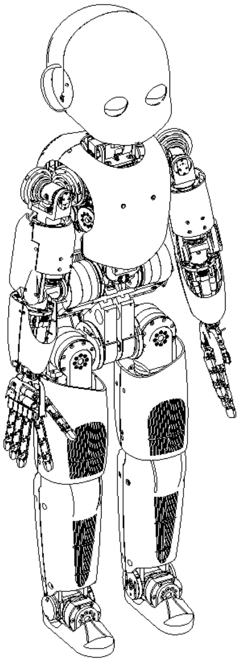


Figure 1 The iCub robot platform

The iCub is not fully autonomous. Although batteries can be easily fitted, the connectivity with the main computers requires a bandwidth in the range of 1Gbit/s. This accommodates the real-time streaming of two image streams at 30 fps at the resolution of 640x480 (which is the minimum required for most applications). Images are typically sent using Multicast protocols to a set of computers for parallel processing. In a typical laboratory setting, the iCub is tethered. Gbit/s Wi-Fi is now available commercially and in the near future may represent a good substitute for the cable. If we imagine robots working in open/public spaces, then we need to think of something else as for example 5G networks.

4. Typical data stream and processing

The robot data processing can be divided into two main categories: local and remote. Tight real-time control loops are typically executed locally. On the other hand, visual processing cannot be handled locally (because of the computational load/amount of data) and therefore is managed by networked computers (remote). As long as we can rely on the Gbit/s network, it is clear that the distinction is somewhat academic. In the future though, if the robot has to become fully autonomous, then it is also fundamental to consider where to compute, what to compute and how to transmit it given the available bandwidth (e.g. 5G).

The following table summarizes the data rates and estimated bandwidth for all robot sensors and control signals.

Sensor name	Specs	Bandwidth
Cameras	2x, 640x480, 30fps, 8/24bit	147Mbit/s uncompressed
Microphones	2x, 44kHz, 16bit	1.4Mbit/s
F/T sensors	6x, 1kHz, 8bit	48kbit/s
Gyroscopes	12x, 100Hz, 16bit	19.2kbit/s
Tactile sensors	4000x, 50Hz, 8bit	1.6Mbit/s
Control commands	53DoF x 2-4 commands, 100Hz/1kHz, 16bit	3.3Mbit/s (worst case), 170kbit/s (typical)

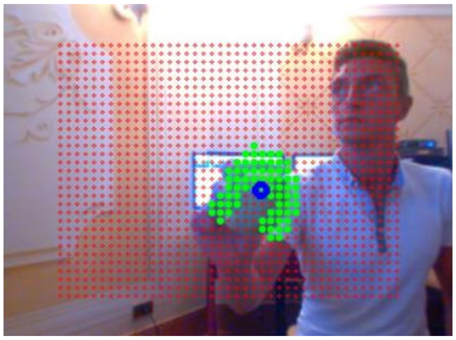
Clearly, image data are the most demanding. It is instructive to briefly discuss the type of processing typically required to extract iconic information from the data streams for a given set of task.

For a helper robot to be useful in the household or factory, it has to be able to move from A to B (independently), fetch objects/tools, use them and possibly go back to A if required by the task. We can list the hypothetical control/processing modules as:

- **Walking controller**: uses vision to do localization and mapping (SLAM) to build a representation of the environment, avoid obstacles;
- **People detector**: uses vision to identify people, their body postures and actions for interaction [7];
- **Object detector/recognition**: uses vision to identify objects (relevant to the task at hand), tools and machines (also potentially relevant to accomplish a task) [8].

All these subsystems require 3D vision obtained from lasers or stereo cameras, motion estimation (optical flow calculation), feature extraction (e.g. SIFTs, HoGs, etc.), and clearly synthetizing a number of controllers that use this information to actually effect proper behaviors. An example of the image processing is shown in Figure 2.

The calculation of the 3D structure of the environment requires camera calibration and then binocular disparity estimation. If this is carried out “on board”, then iconic 3D information about surfaces or 3D features can be transmitted outside the robot for further processing (e.g. object identification). SLAM is likely to be done on board in order to generate walking patterns with minimum latencies. Map information can be exchanged with servers to dynamically load/update the maps. A swarm of robots can for example maintain a shared updated map of the environment.


(a)

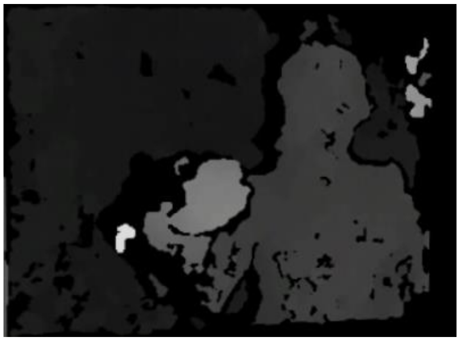

(b)

Figure 2 Examples of image processing for human-robot interaction: (a) optical flow computation used for object tracking; (b) binocular disparity and 3D structure estimation (see [10])

Optical flow is computed by processing sequences of images and estimating the pixel-level variations due to motion. Efficient methods are now available. The same information can be used to compress the image stream similarly to the various MPEG or H26xx formats. Motion estimation is useful for action recognition and to predict the movement of objects/people in the scene in order to task the robot consequently.

In object recognition instead, we need to extract local visual features, group them, and further elaborate on them to build classifiers of various sorts. Machine learning has been particularly successful recently on these tasks. Clearly also in this case there is a serious tradeoff between on board computation (feature extraction is demanding) and the bandwidth required to send images to external servers.

It must be said, that the recent development of image processors (GPUs) for the mobile world may come to rescue here [9]. A set of GPUs may in fact be hosted directly on the robot taking care of all the heavy post-processing and subsequently communicating only sporadically to the servers where global knowledge is stored. In this case, objects would become only a set of parameters that can be loaded once (e.g. as function of the task, location, etc.) and maps can be loaded and updated by parts.

More importantly perhaps, latencies have to be controlled and guaranteed. A controller may need a reply from an external server within a given deadline otherwise the robot may need to stop. Also, in human-robot interaction, answers from remote servers need to be fast enough in order not to disrupt the user experience (in the few milliseconds range). This is to be considered in the preparation of the protocols and the hardware infrastructure of the future generation network (e.g. 5G).

4. Conclusion

In this letter, we briefly surveyed the overall requirements in terms of connectivity of a complex robot designed for human-robot interaction believed to become the paradigmatic robot helper of the near future. We imagine a future where swarms of robot helpers will form part of our daily life.

We broadly observed that vision is the most demanding sensory modality in terms of data rates. We also argued that vision is strictly necessary to guarantee the robot safety at all time and that some of the visual information may need to be transmitted outside the robot (either to guarantee the robot’s autonomy or for tele-operation).

We do not support a brute force approach (transmit everything) but rather a more parsimonious definition of the computational resource allocation leading to a specialized channel for iconic information in the form of object identities, shapes, surfaces, as well as, actions, people and in general scene maps.

Furthermore, specialized QoS channels may be required if remote controlled operations with safety constraints need to be supported. In that case, maximum message delays need to be specified as well.

We believe that robots will be heavy "users" of the future mobile infrastructure and would be utterly important to prepare the underlying protocols already for this scenario.

Clearly, this paper is highly speculative and high level. It is only claiming that this is a likely scenario and therefore that it is useful to be ready to complement robotics with telecommunication infrastructure. On the other hand, additional resources need to be integrated. We mentioned briefly the need of new low-power visual processing (GPUs) but also efficient batteries that guarantee hours of independent use of the robot. New materials are important for robotics and will certainly constitute a fertile line of research in the near future.

References

[1] http://ec.europa.eu/economy_finance/articles/structural_reforms/2012-05-15_ageing_report_en.htm

[2] http://europa.eu/rapid/press-release_IP-05-322_en.htm

[3] B. Gates. (2007, January 1st, 2007) A robot in every home. Scientific American.

[4] A. Parmiggiani, M. Maggiali, L. Natale, F. Nori, A. Schmitz, N. Tsagarakis, J. Santos-Victor, F. Becchi, G. Sandini, and M. G., "The design of the iCub humanoid robot", International Journal of Humanoid Robotics vol. 9, pp. 1-24, 2011.

[5] P. Maiolino, M. Maggiali, G. Cannata, G. Metta, L. Natale. 2013, "A Flexible and Robust Large Scale Capacitive Tactile System for Robots. IEEE Sensors Journal. 13(10) pp.3910-3917.

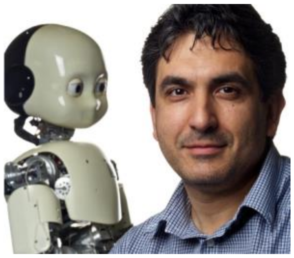
[6] P. Fitzpatrick, G. Metta, L. Natale. 2008, "Towards Long-Lived Robot Genes", Robotics and Autonomous Systems, 56(1) pp.29-45.

[7] S.R. Fanello, I. Gori, G. Metta, F. Odone. 2013, Keep It Simple And Sparse: Real-Time Action Recognition. Journal of Machine Learning Research. pp. 2617-2640.

[8] I. Gori, U. Pattacini, V. Tikhanoff, G. Metta. "Three-Finger Precision Grasp on Incomplete 3D Point Clouds", IEEE International Conference on Robotics and Automation (ICRA2014). Hong Kong, China, May 31-June 7, 2014.

[9] NVIDIA Jetson TK1 development kit website: http://www.nvidia.com/object/jetson-tk1-embedded-dev-kit.html

[10] I. Gori, S.R. Fanello, F. Odone, G. Metta. "A Compositional Approach for 3D Arm-Hand Action Recognition", IEEE Workshop on Robot Vision (WoRV). Clearwater, Florida, USA, January 16-18, 2013.



Giorgio Metta is director of the iCub Facility department at the Istituto Italiano di Tecnologia (Italian Institute of Technology, IIT) where he coordinates the development of the iCub robotic platform/project. He holds an MSc cum laude (1994) and PhD (2000) in electronic engineering both from the University of Genoa. From 2001 to 2002 he was postdoctoral associate at the MIT AI-Lab. He was previously with the University of Genoa and since 2012 Professor of Cognitive Robotics at the University of Plymouth (UK). He is deputy director of IIT delegate to the international relations and external funding. In this role he is member of the board of directors of EU Robotics AISBL, the European reference organization for robotics research. Giorgio Metta research activities are in the fields of biologically motivated and humanoid robotics and, in particular, in developing humanoid robots that can adapt and learn from experience. Giorgio Metta is author of approximately 250 scientific publications. He has been working as principal investigator and research scientist in about a dozen international as well as national funded projects.

On the Need for a New Air Interface for 5G

Frank Schaich, Bell Labs, Alcatel-Lucent AG, Germany, frank.schaich@alcatel-lucent.com
Berna Sayrac, Orange Labs, France, berna.sayrac@orange.com
Martin Schubert, Huawei European Research Center, Germany, martin.schubert@huawei.com

1. Introduction

Cellular technology has been renewed about every decade since the introduction of 2G (second generation wireless). In the 1990s, GSM became widespread and offered voice services all around the globe. With the rising success of the World Wide Web, data services became the key driver for the next generation of cellular technology. Around 2000, the introduction of 3G enabled the rapid growth of mobile data services. Around 2010, 4G (LTE - Long Term Evolution) has brought major improvements for wireless broadband internet services. The next generation (5G) is expected for 2020. In this letter, we discuss requirements and possible solutions for a new 5G air interface.

Looking at current 5G forecasts [1], we see that a) the demand for wireless data is predicted to increase significantly (1000x higher data volumes and 10-100x higher user data rates), and b) the number of connected devices is predicted to increase by a factor of 10-100, which means that up to 300,000 devices need to be served per access point. At the same time, latency should be reduced by a factor of 5. These requirements clearly cannot be handled by 4G. The ICT landscape is going through a radical and accelerating transformation, with a significant impact on economic and societal growth. This transformation is driven by new trends and emerging concepts, such as fully integrated, wearable user devices, immersive media services, and ubiquitous access to globally connected knowledge, social media, etc. Wireless connectivity anywhere, anytime and between every-*body* and every-*thing* (smart houses, cars, cities, offices etc.) is gaining momentum, rendering our daily lives easier and more efficient. This momentum will continue to rise, resulting in the need to enable wireless connections between people, machines, communities, physical things, processes, content etc. anytime, in flexible, reliable and secure ways.

This letter gives the background, drivers and the vision of a new 5G air interface to be flexible and scalable for accommodating stringent and conflicting requirements of existing Mobile Broadband (MBB) services, and emerging services like Machine-to-Machine (M2M). The focus here is on frequencies below 6 GHz, although we acknowledge that millimeter-wave bands constitute an integral part of 5G. We will present our vision of how this new air interface should look like: from global targets to promising technologies, detailing the path to follow for each global target.

2. Background and Drivers for a New Air Interface

The air interfaces for 2G, 3G, and 4G were all designed for specific use cases with certain KPIs in mind (throughput, capacity, dropped/blocked call rates etc.). However, the emerging trend of connecting everything to the Internet (Internet of Things, IoT and Internet of Vehicles, IoV) brings up the need to go beyond such an approach. At some point in time a massive amount of actors and sensors being placed anywhere in the landscape (e.g. fire sensors in areas with high danger of forest fires) need to access the wireless communication network (Massive Machine Communications, MMC). Another variant of the IoT is related to sensor and actor messages to be transmitted between the respective communication partners (e.g. between vehicles) with very low response times and very high reliability (Mission Critical Communications, MCC). Finally, Multimedia Broadcast and Multicast Services (MBMS) will become increasingly important.

The inclusion of the above mentioned use cases pose new challenges due to the broader range of service and device classes, ranging from IoT to short range MBB communications (e.g. WiFi) and from high-end smart-phone to low-end sensor. Furthermore, each service type/device class has more stringent requirements than ever (e.g. air interface latency in the order of 1ms) and some of these requirements are conflicting (e.g. to support very low latencies, energy and resource efficiency may not be optimal). So, the challenge is not only to increase the user rates or the capacity (as has always been so far) but also to master the heterogeneity and the trade-off between the conflicting requirements (see Figure).

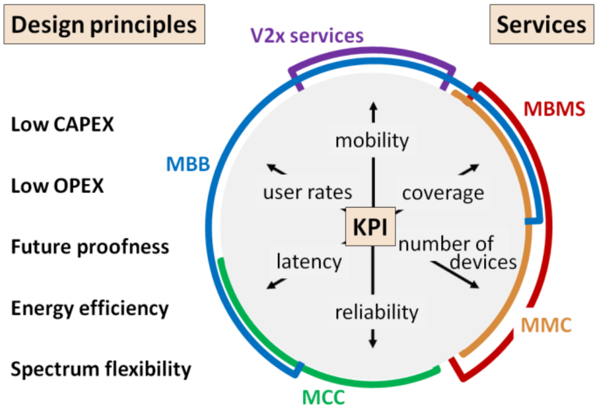


Figure 1 Design principles, services and related KPIs

Research on 5G has already started. The South Korean IT R&D program “5G mobile communication systems based on beam-division multiple access and relays with group cooperation” was established in 2008 [2]. In the UK, a 5G Innovation Centre at the University of Surrey was set up [3]. In 2012, the FP7 European projects METIS and 5GNOW started R&D activities on 5G gathering the major European actors in wireless communications [1], [4]. NGMN has started working on 5G requirements and is expected to publish a whitepaper at the end of 2014 [5]. The European Commission has put forward the 5G PPP (Public Private Partnership) initiative within the Horizon2020 research framework, in order to launch collaborative R&D activities in Europe [6]. All this forms the basis of further research leading to standardization rendering 5G a reality in 5-6 years.

In a nutshell, while 4G is well designed for delivering MBB services as asked for today, it will reach its limits. Additionally, the introduction of new services in the framework of the IoT is rather cumbersome and inefficient. So, to design a new system from scratch is more effective and opens the door to introduce new concepts (e.g. user centric processing) and to integrate current technologies (e.g. CoMP) more efficiently.

3. Global Targets for 5G and Technology Options

In order to guarantee wide adoption and sufficient added value compared to 4G, a future 5G system should be designed to meet the following objectives: a) low OPEX and CAPEX, b) to efficiently support the rich service mix and to enable a satisfied customer base and c) future proof.

In this letter, we focus on the air interface. Other aspects like e.g. overall end-to-end architecture are of similar importance, but beyond the scope of this letter.

Low OPEX and CAPEX

To keep operational and capital expenditures low is of high importance for any commercial product. For wireless communication systems, energy and resource efficiency are the key factors for achieving low OPEX and CAPEX. The former helps to keep the power bill in check while the latter enables the operator to maximize the benefits of his investments (spectrum and infrastructure).

Regarding energy efficiency the key element is to design the system in a way that the actual *energy consumption follows the load*. One feature to achieve this is the deactivation of network elements/functions when not required.

High resource efficiency (both infrastructure and spectrum) is one of the key elements to avoid unnecessary expenses. So, the system has to operate efficiently in fragmented spectrum scenarios and the air interface has to enable high spectral flexibility. When talking about efficiency, CoMP (Collaborative Multi-Point), single-site MIMO and LSAS (Large Scale Antenna Systems) come into mind. So, the air interface design has to natively support all these flavors of multi-antenna procedures in a very efficient way. Another path to high energy and spectral efficiency is the introduction of simplified protocols (e.g. support of connectionless network access) and the support of contention based access, as otherwise the introduction of MMC into the overall system would be linked with high energy and resource consumption both at the base station and at the connected device.

Moreover, the provision of *capacity where needed* is relevant for the target of low OPEX and CAPEX. Elements to achieve this are the support of moving networks and the opportunistic use of nomadic nodes. In areas with high capacity needs the installation of ultra dense networks with air interface solutions eventually tailored to this is an option. Finally, efficient integration of small cells in hot-spot areas is a way to deliver high capacity where needed. All these features and technologies naturally require adjustments and modifications not only for the air interface, however, a smart design of the air interface helps minimizing the required efforts and maximizing the achieved gains.

Support of rich service mix and user experience

Today’s services and customer satisfaction is closely linked with the abilities of smart-phone technology. By 2020, we will see many other types of “smart” technologies, driven by the evolution of machine communication, the Internet of Things (IoT), and the Internet of Vehicles (IoV). Examples are smart cities, smart factories, smart cars, etc. A common feature among all these smart technologies is their reliance on wireless connectivity. Wireless communication is the enabler that connects everything and that allows seamless access to the vast information stored in the cloud.

This imposes new requirements on the air interface:

Mobile broadband services aim at wireless internet access, thus throughput per area is an important performance measure. This is typically achieved by densification, i.e. by reducing the cell size. Other main factors are larger bandwidth, as well as the usage of multi-antenna technologies (MIMO and beamforming).

Mission critical services are typical for machine communication, for example V2V communication, automation, or teleprotection. The challenging goal is to achieve end-to-end latencies of 1ms. Such low latencies are needed, e.g., by collision avoidance systems for cars, protection of industrial plants against short-circuits or other failures, etc.

Massive Machine Communication aims at supporting a massive number of low-cost, low-energy devices. So, for the air interface to support this, new aspects such as massive access, efficient support of small messages and very low energy-consumption and overall complexity at the device are to be taken into account.

Finally, the support of broadcast/multicast might become an important enabler for merging wireless communication services with traditional broadcast services. For achieving this, the air interface has to include means to efficiently serve a group of users with the same content at the same time (multicast).

Future proof

The landscape of services relying on fast wireless communications is constantly changing. Naturally, the introduction of new features must not disturb the support of legacy services and devices, so backwards compatibility is of high importance. Some aspects of 4G are complicating the integration of new features under this premise. The definition of the downlink control channel of 4G for example is less suited to integrate new device and service classes having different needs than today's smart-phones accessing the internet. One means to improve on this is the introduction of *service/user specific control channels*.

Another element of 4G complicating the introduction of new service and device classes is the need for strict synchronicity. No device is allowed to transmit data before being precisely aligned both in time and frequency. This is feasible for high-end devices streaming video, but unbearable for low-end devices relying on battery power transmitting every once in a while a few bytes. Additionally, by allowing devices to transmit data in such a *connectionless* manner the control channels are heavily relieved.

Finally, for 5G to be future proof, we need to design the air interface protocols in a highly *flexible manner* to better support the expected (and for sure to some extent unexpected yet) multitude of diverse device and service classes emerging in the coming years.

Enabling technologies

As of today, we have proposed somewhat abstract air interface concepts to achieve the global targets. For implementing those concepts true enabling technologies are required.

A very crucial component of the air interface dictating its characteristics is the waveform. While OFDM has some nice properties, recent research results have indicated that the use of *multi-carrier modulation formats by applying filtering* per sub-band (UFMC [7]) or even per sub-carrier (FBMC) may help the system in coping with fragmented spectra and connectionless transmissions, e.g. from MMC devices. Figure illustrates the superior spectral characteristics of those waveforms compared to OFDM.

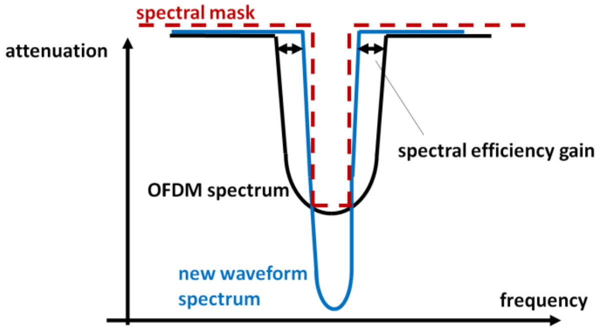


Figure 2 Spectral waveform characteristics

Thanks to this the inter-carrier interference arising from frequency-adjacent bursts which are not perfectly aligned in time and frequency is heavily reduced [7]. So, they do not need to follow the complete RACH procedure for being tightly aligned. This helps reduce the overhead and energy consumption.

To better support the increasing space of requirements and to enable user/service specific control signaling, the *frame design* of 5G needs to be much more flexible than for 4G. E.g. link adaptation may be extended beyond pure MCS selection by adapting waveform characteristics on a per user base. Thanks to UFMC and FBMC dividing the band into multiple virtually isolated sub-bands, each user transmission may be tailored to its characteristics (e.g. channel), instead of applying a single compromise as e.g. done in 4G.

In order to integrate the various types of multi-antenna technologies (from single-site multi-user MIMO, up to CoMP and massive MIMO) into 5G with highest efficiency, the *reference symbol and feedback design* of 4G needs to be revisited. CoMP and M-MIMO strategies pose new challenges to precision and signaling due to rapid spatial fluctuations (Figure 3).

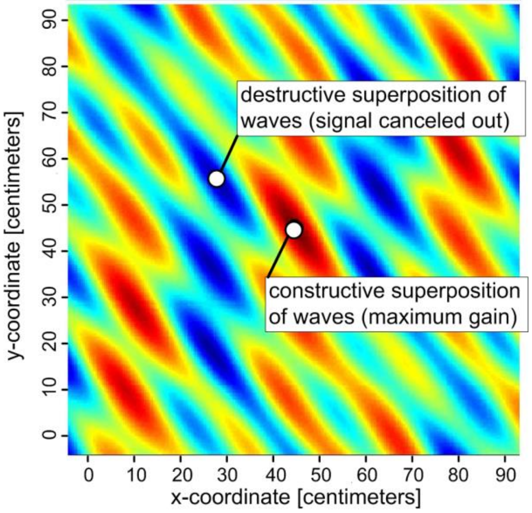


Figure 3 Spatial field strength distribution resulting from distributed CoMP technology

In order to support a very high number of MMC devices, *contention based access procedures* and efficient *activity detection mechanisms* have to be integrated into the system in addition to scheduled transmissions. Since many MMC applications (e.g. temperature sensors) involve the transmission of very small packets in a sporadic manner only, treating them as scheduled transmissions would introduce significant overheads.

Further air interface technologies enabling 5G to outperform 4G are efficient support of *localization mechanisms* (e.g. to enable location based services), *overloaded multiple access with advanced multi-user detection* (to better utilize the multiple access channel), and *hybrid MAC/RRM protocols adapted to the multitude of service classes* (to enable a highly scalable system being able to follow the changing mix of device and service classes both temporal and areal).

4. Conclusion

Things are moving fast on the application service layer. Service creation is on a much faster time scale than mobile communication systems are evolved. Very often those new services include highly different characteristics and requirements both connected to the actual transport of the data (such as typical packet size and frequentness) and to the originating devices (such as low-end sensors requiring extremely energy efficient operation).

New solutions dedicated to a given use case may be designed e.g. SigFox [8]) or existing technologies such as 4G may be evolved accordingly (e.g. [9]). However, a more scalable and less cumbersome approach is to design a new generation of mobile networks (5G) to be flexible enough and support the expected high range of services and device classes. One key enabler is the air interface.

In this paper, we have briefly introduced the history of cellular communications, highlighted ongoing and soon-to-start research activities, given some insights into new use cases mobile communications will face in the years to come, defined the global targets 5G needs to reach, and have outlined the key technology enablers to meet these requirements. Every new generation of mobile communications brings the opportunity to do things differently and better. We should not miss the chance to design a future-proof communication system with a much larger set of supported services beyond pure human initiated data/voice communications.

References

[1] FP7 project METIS. https://www.metis2020.com
[2] Korean IT R&D program of MKE/IITA: 2008-F-004-01.
[3] 5GIC. http://www.surrey.ac.uk/ccsr/business/5GIC/
[4] FP7 project 5Gnow. http://www.5gnow.eu/
[5] NGNM. http://ngmn.org/workprogramme/5g-initiative.html
[6] 5G PPP. http://5g-ppp.eu/
[7] F. Schaich, T. Wild, "Relaxed synchronization support of Universal Filtered Multi-Carrier including autonomous timing advance," IEEE ISWCS14, Barcelona, Aug. 2014.
[8] http://www.sigfox.com/en/
[9] Alcatel-Lucent, Ericsson, Huawei, et al., "A choice of future M2M access technologies for mobile network operators," M2M SIG White Paper, Mar. 2014. http://www.cambridgewireless.co.uk/docs/Cellular%20IoT%20White%20Paper.pdf

Frank Schaich received his Dipl.-Ing. degree in electrical engineering from the University of Stuttgart, and worked as a research assistant at the University's Institute of Communications working towards his doctorate. 2007 he joined Alcatel-Lucent's wireless access physical layer group. Dr. Schaich served as work package leader for the European Union's FP7 projects PHYDYAS, which investigated alternative waveform designs and corresponding transceiver functionalities, and ACCORDANCE dealing with fixed-mobile convergence issues and architecture options for CRAN. Currently his main focus is on developing solutions for the next generation of wireless cellular communication systems in the framework of 5GNOW and METIS. Dr. Schaich is project manager for a new project proposal in the framework of horizon 2020 targeting the definition of the air interface for 5G.

Berna Sayrac received the B.S., M.S. and Ph.D. degrees from the Department of Electrical and Electronics Engineering of Middle East Technical University (METU), Turkey, in 1990, 1992 and 1997, respectively. She worked as an Assistant Professor at METU between 2000 and 2001, and as a research scientist at Philips Research France between 2001 and 2002. Since 2002, she is working as a senior research expert at Orange Labs. .

Martin Schubert is a Principal Researcher at Huawei European Research Center in Munich, Germany. He received his doctoral degree in electrical engineering from the Technische Universität, Berlin, Germany, 2002. From 2003-2012, he has been with the Fraunhofer German-Sino Lab for Mobile Communications (MCI), where he worked as a Senior Researcher. Dr. Schubert has published more than 120 papers in internationally recognized conferences and journals. He was a corecipient of the VDE Johann-Philipp-Reis Award in 2007, and he coauthored the 2007 Best Paper Award of the IEEE Signal Processing Society. From 2009-2013 he has been Associate Editor of the IEEE Transactions of Signal Processing. He has contributed to FP6 MASCOT (multiple-access space-time coding), FP7 SAPHYRE (resource sharing), and FP7 METIS (5G enablers).

Energy Efficiency and Spectrum Efficiency Co-Design: From NOMA to Network NOMA

Shuangfeng Han, Chih-Lin I, Zhikun Xu, Qi Sun
Green Communication Research Center, China Mobile Research Institute, Beijing, P. R. China
{*hanshuangfeng, icl, xuzhikun, sunqiyjy*}*@chinamobile.com*

1. Introduction

The anticipated thousand fold wireless traffic increase by 2020 and global recognition of the importance of green communications pose very tough challenges on 5G communication system design [1]. Non-orthogonal multiple access **(**NOMA**)** is considered to be one of several promising technologies that could improve the sum capacity [2, 3, 4] of 5G. It is well known that NOMA using superposition coding at the transmitter and successive interference cancellation at the receiver achieves the capacity region of the downlink broadcast channel and outperforms orthogonal multiple access [5]. Originally NOMA was designed to maximize the system spectrum efficiency (SE), with little attention given to the energy efficiency (EE).

In this letter, the EE-SE co-design of NOMA is investigated. An energy efficient two-user single cell NOMA design is presented. Further, network NOMA (N^2OMA) design is addressed. One precoding solution is proposed to mitigate the intercell interference, leading to much improved overall EE and SE. Numerical results are given to demonstrate the validity of the analysis.

2. Energy Efficient Single Cell NOMA Design

In this section, the linear EE-SE relationship of a two-user NOMA is first analyzed to indicate a simultaneous increase of EE with SE. One EE-optimized SE selection approach is further presented.

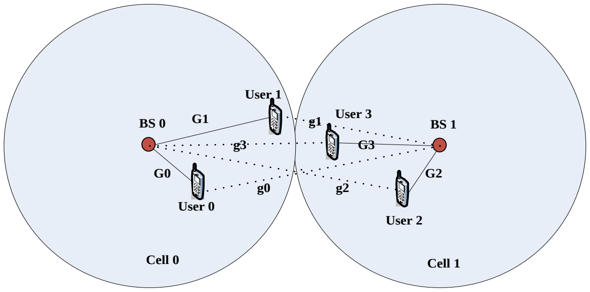


Figure 1 Network NOMA with 2 cells and 4 users

A cellular system with two cells and four users (each user has one antenna) is depicted in Figure 1. In each cell a two-user NOMA scheme with superposition coding is adopted (e.g. user 0 and user 1 are served by single antenna base station (BS) 0 and user 2 and user 3 are served by single antenna BS1). The large scale channel gains of these users to BS0 are G_0, G_1, g_2, and g_3. And the large scale channel gains of these users to BS1 are g_0, g_1, G_2 and G_3. We assume $G_0 > G_1$ and $G_2 > G_3$. Consider the single cell NOMA of cell 0, the total power consumption P_{total} at BS0 is modeled as following,

$$P_{total} = \sum_{k=0}^{1} P_k + P_{static} \ ,$$

where P_k (k=0,1) is the power consumption of the power amplifier (PA) for the kth user, and P_{static} is the static power which includes circuit power and processing power. Assume L_0 and L_1 are the channel power gain of user 0 and user 1 respectively, with L_0 being larger than L_1. The sum rate of the two-user NOMA is expressed as [5],

$$C_{cell0} = W\log\left(1 + \frac{\eta_{PA} P_0 L_0}{W N_0}\right) + W\log\left(1 + \frac{\eta_{PA} P_1 L_1}{W N_0 + \eta_{PA} P_0 L_1}\right),$$

where W is the system bandwidth, η_{PA} is the PA efficiency, and N_0 is the thermal noise density. The relationship between the total EE η_{EE} and the total SE η_{SE} for the above NOMA is,

$$\eta_{EE} = C_{cell0} / P_{total} = W\eta_{SE} \Big/ \left(\sum_{k=0}^{1} P_k + P_{static}\right).$$

Recall that the EE-SE relationship based on Shannon's theory is monotonic, where a higher SE will always lead to a lower EE. When the circuit power is considered, however, there exists a green point on the EE-SE curve where the maximum energy EE is achieved. Interestingly, with a fixed $P_{total,}$ the EE-SE relationship of the above two user NOMA is linear, with a positive slope of W/P_{total}. This indicates that an increase in SE will simultaneously bring an increase of EE. Any point in the EE-SE curve can be realized via proper power allocation between user 0 and user 1. The left (right) end point of the curve is achieved when all the power is allocated to user 1 (user 0). When the total power is adjustable, e.g. via downlink power control, the slope of the above curve is also adjustable. Suppose the SEs of user 0 and user 1 are η_{SE0} and η_{SE1}, the EE-SE relationship can then be derived as,

$$\eta_{EE} = \frac{\left(\eta_{SE0} + \eta_{SE1}\right)\eta_{PA} L_1 W}{\left(\left(2^{\eta_{SE0}} - 1\right)\eta_{PA} L_1 + \left(2^{\eta_{SE1}} - 1\right) + \left(2^{\eta_{SE0}} - 1\right)\left(2^{\eta_{SE1}} - 1\right)\eta_{PA} L_0\right) W N_0 + L_1 \eta_{PA} P_{static}}.$$

In practical system operation, each user may have a specific SE requirement. Suppose the SE of a user with a strong channel is given (e.g. η_{SE0} is given), it can be proven [6] that there exists a unique SE value for user 1 which yields the maximal EE performance, since the denominator of the above EE expression is concave and

EE is a quasi-concave function of η_{SE1}. This EE optimization oriented scheduling helps to enhance the total EE, while satisfying all users' SE requirements.

2. Energy Efficient N^{2}OMA Design

In this section, the single cell NOMA is extended to the network NOMA, with a zero-forcing (ZF) precoding scheme applied to users with weak channel conditions to efficiently mitigate the intercell interference.

Four-user N^{2}OMA model

Consider the two cells with four users in Figure 1 and assume BS0 and BS1 can cooperate with each other for joint data transmission and reception. The four users' received signals are modeled as,

$$\mathbf{y} = \mathbf{HWs} + \mathbf{n},$$

where $\mathbf{H}$=[$\mathbf{h}_0$, $\mathbf{h}_1$, $\mathbf{h}_2$, $\mathbf{h}_3$]^T is the 4×2 downlink channel, with $\mathbf{h}_i$=[h_{i0},h_{i1}] being the channel vector of the ith user (i=0,1,2,3), and h_{ij} (j=0,1) being the complex channel response between the ith user and the jth BS antenna. $\mathbf{W}$=[$\mathbf{w}_0$,$\mathbf{w}_1$,$\mathbf{w}_2$,$\mathbf{w}_3$], with $\mathbf{w}_i$ (i=0,1,2,3) being the 2×1 precoding vector. $\mathbf{s}$=[s_0,s_1,s_2,s_3]$^\mathbf{T}$ is the transmit signal vector for the four users, with s_i being the data symbol for the ith user. The transmit signal on the ith (i=0,1) BS antenna is $w_{0i}s_0 + w_{1i}s_1 + w_{2i}s_2 + w_{3i}s_3$.

The precoder $\mathbf{W}$ can be designed in various ways, e.g. to maximize the sum capacity or the total EE. Some attempts have been made in the design of $\mathbf{W}$, like the work in [3]. However, user 0 and user 1 (one NOMA user pair), user 2 and user 3 (another NOMA user pair) should have highly correlated channels. This requires dynamic user selection for each NOMA user pair. Otherwise, there may exist severe inter beam interference. Moreover, the multi-user ZF precoding which is applicable in a single cell may not be feasible in a networked NOMA scenario, since a beam generated via geographically separated BS antennas may not easily cover more than one spatially separated user for intra beam NOMA. A coordinated superposition coding scheme was proposed in [4], where two coordinated BSs use Alamouti code to transmit to a cell edge user to achieve a reasonable transmission rate without degrading the rates delivered to users in close proximity to the BSs.

It's anticipated that 5G may be ultra dense networks (UDN), where there may exist severe intercell interference. Therefore, in an interference-limited scenario like the cell edge of UDN, a multi-user precoding scheme can potentially help to mitigate the interference. 5G is also anticipated to be a cloud radio access network (C-RAN) [1], which significantly facilitates central processing of various signals. The channel state information of users in the NOMA scheme can be made available and processed at the central processor with negligible latency, thus motivating the N^{2}OMA scheme with multi-user precoding.

Proposed N^{2}OMA precoding approach

There may exist significant gaps between the large scale fadings, e.g. G_i can be much larger than g_i. For a proposed complexity-reduced approach, a 2×2 precoding matrix $\mathbf{W}$ is applied only to signals s_1 and s_3. If we denote the 2×2 downlink channel of user 1 and 3 as $\mathbf{H}_{13}$=[$\mathbf{h}_1$, $\mathbf{h}_3$]^T, the ZF precoder $\mathbf{W}$ is the normalized pseudo-inverse of $\mathbf{H}_{13}$, i.e., $\mathbf{W}=(\mathbf{H}_{13})^H(\mathbf{H}_{13}(\mathbf{H}_{13})^H)^{-1}$, with the corresponding effective channel gain of $1/[(\mathbf{H}_{13}(\mathbf{H}_{13})^H)^{-1}]_{0,0}$ and $1/[(\mathbf{H}_{13}(\mathbf{H}_{13})^H)^{-1}]_{1,1}$ for user 1 and user 3 respectively. Differently from the precoding on s_1 and s_3, there is no precoding on s_0 and s_2. The motivation is as following: the transmit power of s_1 and s_3 should be much higher than that of s_0 and s_2, since user 1 and user 3 cannot cancel the interference from user 0 and user 2. Therefore severe intercell interference is mainly between user 1 and user 3 (as they are close to each other). Eventually, the transmit signals from BS0 and BS1 are $s_0+w_{0,0}s_1+w_{0,1}s_3$ and $s_2+w_{1,0}s_1+w_{1,1}s_3$, respectively. The base station will inform user 0 and user 2 about the precoding matrix $\mathbf{W}$ and s_1 and s_3. Therefore, the interference from user 1 and user 3 to user 0 and user 2 can be cancelled well. Assuming the power of s_i is P_i, the signal to interference and noise ratio (SINR) of each user is expressed as,

$$\left(\begin{array}{l}
SINR_0 = \dfrac{|h_{0,0}|^2 P_0}{|h_{0,1}|^2\left(P_2 + |w_{1,0}|^2 P_1 + |w_{1,1}|^2 P_3\right) + N_0 W} \approx \dfrac{|h_{0,0}|^2 P_0}{N_0 W} \\
SINR_1 = \dfrac{\left(\left[\left(\mathbf{H}_{13}(\mathbf{H}_{13})^{\mathbf{H}}\right)^{-1}\right]_{0,0}\right)^{-1} P_1}{|h_{1,0}|^2 P_0 + |h_{1,1}|^2 P_2 + N_0 W} \\
SINR_2 = \dfrac{|h_{2,1}|^2 P_2}{|h_{2,0}|^2\left(P_0 + |w_{0,0}|^2 P_1 + |w_{0,1}|^2 P_3\right) + N_0 W} \approx \dfrac{|h_{2,1}|^2 P_2}{N_0 W} \\
SINR_3 = \dfrac{\left(\left[\left(\mathbf{H}_{13}(\mathbf{H}_{13})^{\mathbf{H}}\right)^{-1}\right]_{1,1}\right)^{-1} P_3}{|h_{3,0}|^2 P_0 + |h_{3,1}|^2 P_2 + N_0 W}
\end{array}\right)$$

subject to,

$$P_0 + |w_{0,0}|^2 P_1 + |w_{0,1}|^2 P_3 \le P_{max},$$

$$P_2 + |w_{1,0}|^2 P_1 + |w_{1,1}|^2 P_3 \le P_{max},$$

where P_{max} is the maximal transmit power of each base station antenna. As can be seen from above equations, the SINRs of the cell center users 0 and 2 are almost same with that in the single cell case, since the intercell interference is very small to them. Also, thanks to the joint ZF precoding transmission to users 1 and 3, the SINRs of these two users do not depend on each other (note that without a joint transmission scheme, the cell edge users 1 and 3 suffer from severe mutual interference). The interference from users 0 and 2 to users 1 and 3 is also not significant, since the power of users 0 and 2 is much lower than that of users 1 and 3.

The above solution requires that the channel information of the users 1 and 3 should be available at both base stations, which then calculate the corresponding precoding matrix for joint transmission to user 1 and user 3. The precoding matrix and modulation/coding scheme should be known at user 0 and user 2 for successful successive interference cancellation. Also, the power allocation to each user should satisfy the SINR requirement of each user and the power constraint of each BS antenna. Otherwise, the N^{2}OMA scheme is not feasible for these users.

3. Numerical Results

In this section, the numerical results of single cell NOMA and the proposed N^{2}OMA scheme are given.

EE-SE analysis of a single cell NOMA

Consider a single cell NOMA superposition coding with user 0 and user 1. Assume L_0=-77dB, L_1=-97dB, W=20MHz, η_{PA}=0.24, and P_{static}=100W. As shown in Figure 2, the EE-SE curves for user 0 and user 1 are depicted in the blue and red lines respectively, assuming the total power is allocated to just one user. Due to the disparity of channel fading between these two users, the EE-SE performance of user 1 is much lower than that of user 0. Three solid green lines are depicted for the EE-SE performance of a two user NOMA scheme, with total transmit power being 5W, 20W, and 40W (maximal power) respectively. Compared with single user (user 1) transmission, the two-user NOMA achieves much better performance.

Given SE of user 0 (e.g. 6bps/Hz), the EE optimization via proper selection of user 1 SE (SE1) is also illustrated in Figure 2. As shown by the total EE vs. SE 1 curve, as SE1 increases from 0 (which is actually 6bps/Hz at the x-axis) to 3.4bps/Hz (9.4bps/Hz at the x-axis), the EE also increases and reaches its maximal value at the 3.4bps/Hz SE1. As SE1 continues to increase, the EE performance will degrade. Therefore, if the minimum SE requirement of user 1 is not larger than 3.4bps/Hz, the base station can schedule user 0 and user 1 with 6bps/Hz and 3.4bps/Hz SE respectively for an optimal EE performance.

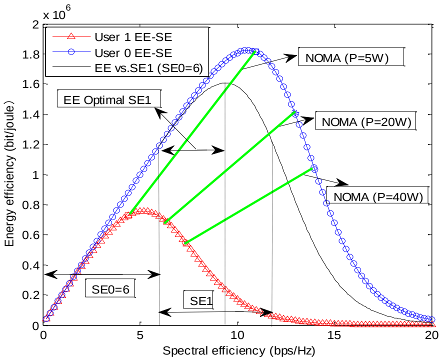


Figure 2 EE-SE analysis of single cell NOMA

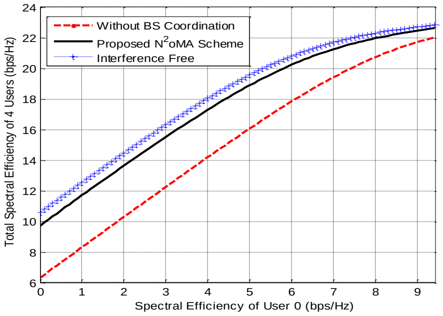


Figure 3 User 0 SE vs. the total SE

EE-SE analysis of the proposed N^{2}OMA

Consider the network NOMA scenario depicted in Figure 1, with power gains of **H** being [-77, -117; -97, -107; -77, -117; -97, -107] dB. As shown in Figure 3, three curves are simulated, with x-axis being the SE of user 0 and user 2 (we assume they are same just for ease of illustration) and y-axis being the total SE of four users. To ensure the SE performance of user 1 and 3, the maximal power allocation to user 0 and user 2 is one fourth of the total transmit power. Also, the maximum power 40W is used for both base stations. The interference-free scenario corresponds to the ideal network NOMA performance, where users within each NOMA user pair don't suffer from interference from the other NOMA user pair. As can be predicted, when there is no inter-BS coordination, severe intercell interference (mainly between user 1 and user 3) will degrade the total SE performance. As shown in Figure 3, a large gap exists between the interference-free scenario and the without-BS-coordination scenario, e.g. 4.2bps/Hz at 0 bps/Hz user 0 SE vs. 3bps/Hz at 6bps/Hz user 0 SE.

With the proposed N^{2}OMA ZF precoding scheme, two base stations transmit jointly to user 1 and user 3 to mitigate the mutual interference and user 0 and user 2 will detect and subtract the signals of user 1 and 3 first before detecting their own signals. As shown in Figure 3, the performance loss compared to the interference-free (ideal) case is very small. While the performance gain over the without-BS-Coordination scenario is significant. Note that the performance gain is dependent on the channel conditions of the four users. As the SE of user 0 increases, the gap between the three curves seems to decrease. The main reason is that more power allocated to user 0 and user 2 will bring greater SE performance improvement, since their channel is much better than those of the other users.

4. Conclusion

In this paper, the EE and SE co-design in NOMA has been investigated. The EE-SE relationship of single cell NOMA is shown to be linear with a slope of W/P_{total}. One EE-optimized SE selection approach is further presented. Furthermore, the single cell NOMA is extended to network NOMA, with a distributed multi-user ZF precoding scheme applied to users with weak channel conditions. The validity of the analysis is demonstrated via numerical simulations.

References

[1] Chih-Lin I, Corbett Rowell, Shuangfeng Han, Zhikun Xu, Gang Li, and Zhengang Pan, “Towards Green & Soft: A 5G Perspective,” *IEEE Communications Magazine*, vol. 52, no. 2, pp.66-73, Feb. 2014.

[2] Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, Anxin Li, K. Higuchi, “Non-Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access,” in *Proc. of VTC*, pp.1-5. 2013.

[3] Beomju Kim, et.al. “Non-orthogonal Multiple Access in a Downlink Multiuser Beamforming System,” in *Proc. of* MILCOM, pp.1278-1283, 2013.

[4] Jinho Choi, “Non-Orthogonal Multiple Access in Downlink Coordinated Two-Point Systems,” *IEEE Communications Letters*, vol.18, no.2, pp.313-316, Feb. 2014.

[5] D. Tse and P. Viswanath, Fundamentals of Wireless Communication, Cambridge University Press, May 2005.

[6] JunLing Mao, Gang Xie, Jinchun Gao, Yuanan Liu, “Energy Efficiency Optimization for Cognitive Radio MIMO Broadcast Channels,” *IEEE Communications Letters*, vol.17, no.2, pp.337-340, Feb. 2013.

Shuangfeng Han received his M.S. and Ph.D. degrees in electrical engineering from Tsinghua University in 2002 and 2006 respectively. He joined Samsung Electronics as a senior engineer in 2006 working on MIMO, MultiBS MIMO etc. From 2012, he is a senior project manager in the Green Communication Research Center at the China Mobile Research Institute. His research interests are green 5G, massive MIMO, full duplex, NOMA and EE-SE co-design.

Chih-Lin I received her Ph.D. degree in electrical engineering from Stanford University. She has been working at multiple world-class companies and research institutes leading the R&D, including AT&T Bell Labs; AT&T HQ, ITRI of Taiwan, and ASTRI of Hong Kong. She received the IEEE Trans. on Commu. Stephen Rice Best Paper Award and is a winner of the CCCP National 1000 Talent program. Currently, she is China Mobile’s chief scientist of wireless technologies and has established the Green Communications Research Center, spearheading major initiatives including key 5G technology R&D; high energy efficiency system architectures, technologies and devices; green energy; and C-RAN and soft base stations. She was an elected Board Member of IEEE ComSoc, Chair of the ComSoc Meetings and Conferences Board, and Founding Chair of the IEEE WCNC Steering Committee. She is currently an Executive Board Member of GreenTouch and a Network Operator Council Member of ETSI NFV. Her research interests are green communications, C-RAN, network convergence, bandwidth refarming, EE-SE co-design, massive MIMO, and active antenna arrays.

Zhikun Xu received his B.S.E. and Ph. D degrees in signal and information processing from Beihang University (BUAA), Beijing, China, in 2007 and 2013, respectively. After graduation, he joined the Green Communication Research Center (GCRC) of China Mobile Research Institute as a project manager. His current interests include green technologies, cross-layer resource allocation, advanced signal processing and transmission techniques

Qi Sun received the B.S.E. and Ph.D. degree in information and communication engineering from Beijing University of Posts and Telecommunications in 2009 and 2014, respectively. After graduation, she joined the Green Communication Research Center of the China Mobile Research Institute. Her research interests include MIMO, cooperative communication and green communications.

Building a New Multi-Facial Architecture of 5G

Josef Eichinger, Huawei European Research Center, Germany, joseph.eichinger@huawei.com
Ömer Bulakci, Huawei European Research Center, Germany, oemer.bulakci@huawei.com
Gerd Zimmermann, Deutsche Telekom Innovation Laboratories, zimmermanng@telekom.de
Patrick Marsch, Nokia Networks Research, Poland, patrick.marsch@nsn.com
Hugo Tullberg, Ericsson, hugo.tullberg@ericsson.com

1. Introduction

Observing the current market trends, the Information and Communications Technologies (ICT) landscape is going through a radical and accelerating transformation, with a significant impact on economic and societal growth. This transformation is enabled by new trends and emerging concepts, such as fully integrated group communication, “virtual zero latency”, “zero distance” and “Full 3D immersive” services, ubiquitous access to connected knowledge and social media globally, etc. The vision of wireless connectivity or communication anywhere, anytime and between every-*body* and every-*thing* (smart houses, cars, cities, offices etc.) is gaining momentum, as it is expected to render our daily lives easier and more efficient. This momentum will continue to grow, resulting in an increasing demand on wireless connectivity between people, machines, communities, physical objects, processes, content etc., anytime, in flexible, reliable and secure ways. There is an increasing consensus that this will be the beginning of the Fifth Generation (5G) wireless and mobile communications system.

In the horizon 2020 and beyond, it will be necessary to support 1000 times higher mobile data volume per area together with a broad range of diverse requirements imposed by widespread adoption of high-end devices, such as smart phones and tablets, and various wireless communication services (e.g., UHD video streaming or live video chats) [1]-[3]. Mobile computing based on both end user devices and cloud application computing platforms will further push that trend which is to be addressed within the 5G framework of *Extreme Mobile Broadband* (xMBB) [4]. This clearly requires certain disruptive features with respect to legacy technologies [5], which will go beyond the natural evolution of the IMT-Advanced technologies w.r.t. requirements such as higher data rates per user and capacity per area, as well as a reduced latency.

Besides xMBB, the Internet of Things (IoT) with an envisioned massive connectivity of billions of smart devices and the integration of *massive machine type communication* (M-MTC or MMC) [2] requires new solutions to strongly reduce the power dissipation and cost on the device side and to minimize the signaling effort for low data chunks in the wireless network. M-MTC concerns massive deployments of, e.g., low-cost battery-powered sensors and actuators, remote-controlled and remote-read utility meters being placed anywhere in the landscape. In addition to massive numbers of simple devices, 5G will also need to accommodate for the more complex and bandwidth-extensive interactions between smarter devices in private and industrial households, e.g. in the context of remote video processing and object recognition e.g. by robots, which may in sum consume a substantial portion of the overall radio resources. 5G systems must provide vast up- and down-scaling capability, since it is expected that there will be 10-100x more connected devices per one human user of communications systems [4], either owned by the user himself or by a third party.

A further essential challenge is the requirement to support highly reliable and latency-critical services [3]. *Ultra-reliable MTC* (U-MTC) [4] relates to the capability to provide a given service level with a very high probability under a guaranteed end-to-end (E2E) latency. Example applications would be autonomous driving or vehicular communications, where for instance information on a sudden road hazard needs to be propagated to many cars with only a few ms E2E latency, or industrial automation, where in some cases an E2E latency of 0.5ms is needed at a reliability in terms of block error rate of 10^{-9} [6].

Similar requirements apply in remote control, robotics or surgery, where haptic feedback requires E2E latencies on the order of 1 ms. While existing wireless standards may be able to be extended to higher reliabilities at the price of spectral efficiency (e.g. through redundant transmission), it is clear that the E2E latencies stated above require a completely new system architecture with a native support of UR-MTC from the beginning.

This letter is organized as follows. Section 2 provides the background, drivers and the vision of a new 5G Architecture, flexible and scalable to accommodate the stringent and sometimes conflicting requirements of the evolutionary (xMBB) and the emerging services M-MTC and U-MTC, as illustrated in Figure . Section 3 is devoted to our vision of the new architecture from three different points of view, namely, the *topology*, *functional* and *logical* views. Finally, Section 4 will conclude the paper.

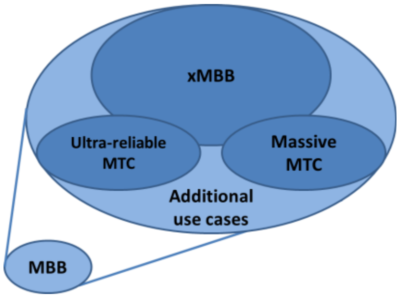


Figure 1 Evolutionary and emerging path of present MBB in 4G to 5G use cases

2. Background and Drivers for a New Architecture

The traditional definitions of network nodes and assignment of certain functionalities to network nodes limit the achievable flexibility and scalability of the current wireless and mobile communications systems. Accordingly, this conventional approach will disappear in future generations, where the association of network to functionality will be updated or removed based on instantaneous service requirements. Furthermore, user devices will become active network elements. As an active network element, a user device may be the end-point for a service but also may act as an intermediate service point for other devices. This implies that user devices will support a unified mechanism supporting D2D and relaying or self-backhauling with the same approach. Hence, a more generic approach to support all kinds of forwarding of data via wireless interfaces is needed to meet the diverse application requirements while minimize the overall cost, energy dissipation and complexity. The generalized concept of a data forwarding functionality will be independent of network node association, i.e., whether it is deployed in a radio infrastructure node or in a mobile device. For instance, with aforementioned enhanced definitions, radio nodes in vehicles will enable on-demand densification of the radio networks [7].

5G systems will see new connectivity approaches emerge, rethinking the conventional cellular operation. Wireless network elements can have multiple connections to multiple network nodes on a multi-generation and multi-layer perspective. As opposed to current LTE, multiple connections will be supported natively. The connections and the associated functionalities will be activated on-demand based on instantaneous service needs. For example, a minimum connection mode will be tailored for energy optimized operation, whereas, additional connections will be enabled for sporadic usage of high-data rate applications. Such an approach will not only efficiently support the service needs but also enable efficient utilization of the network resources in accordance with device capabilities.

There is a clear trend to move typical core network functions closer to the radio edge, e.g., gateway functions and caching, e.g. driven by very tight latency or high reliability requirements. Management of localized traffic flows will further contribute to the reduction in latency. It can be inferred that localized services e.g. for MTC can be managed e.g. by Mobility Management Functions (MMFs) deployed close to the area where the involved devices are in operation. Note that in 5G we may not only see a handover of radio functionality among network nodes, but ultimately also the application layer will be moving along with the entities actually requiring a localized service. It is worth noting that thanks to separation of network node to functionality association (i.e., flexible function split), mobility management functions do not need to be clustered under a certain network node, e.g., MME in LTE, and distributed MMFs can be utilized.

Flexible spectrum usage becomes more important to reuse existing bands and to react *flexibly* to new operator demand and regulatory requirements and finally to apply 5G radio *flexibly* in licensed and unlicensed bands. Rethinking of the carrier aggregation concept of LTE is necessary in combination with flexible spectrum sharing concepts. Thus, it is a must for 5G to deliver mechanisms for a flexible usage of the fragmented spectrum with respect to the different regulatory and regional requirements. The current practice of using dedicated licensed spectrum will remain the main stream, but it will be extended by new regulatory tools and approaches of sharing the spectrum and optimizing its use [4].

3. Dynamic RAN for a New Radio Access Network

As explained above, the 5G system needs to efficiently handle diverse requirements, multiple layers and a variety of air interface parameterizations in the access and the backhaul domains. It further has to control and cope with the dynamics of traffic, user behavior, and active groups of nodes in all levels of deployment. In the sequel, we describe the generic METIS network architecture fulfilling these requirements from the topology, functional and logical point of view [4].

Topological View of 5G Architecture

From the topological point of view, as sketched in Figure 1, the system must accommodate a number of technical enablers and changes in communication paradigms. First of all, the network topology will comprise various flavors of decentralized, centralized or more localized, small scale Cloud-RANs (C-RAN) [8], where the latter for instance resemble multiple small cells connected via fibre or wirelessly to a macro site. It is expected that C-RAN deployments will dominate in the future, but complex stand-alone access nodes will also exist in 5G in areas where infrastructure cost or other constraints do not allow for or justify C-RAN deployments. It is also a trend to distribute the radio processing functions between the centralized and the decentralized processing based on the requirements given by the delay and the bandwidth of the network. Further, the 5G system topology will consist of traditional access nodes as well as new virtual access nodes where classical cell concepts are replaced by more device-centric communication paradigms. Clearly, 5G network topology will be scenario and use-case specific, e.g., depending on whether human-based, M-MTC or U-MTC dominates in a certain area.

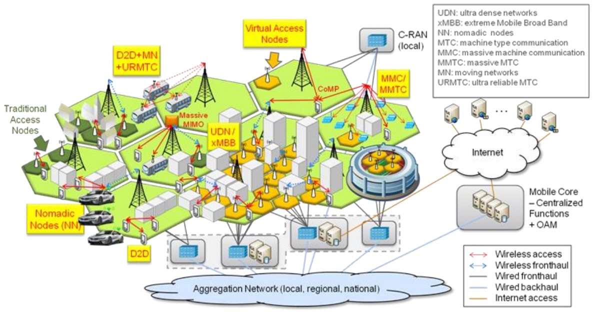


Figure 2 Generic 5G network architecture (high-level topological view)

Further topological features of the agile RAN will be the on-demand activation of radio cells based on fixed or even nomadic nodes [7] on different layers with different coverage areas. Also, short range communication between groups of nodes with or without permanent infrastructure support must be supported.

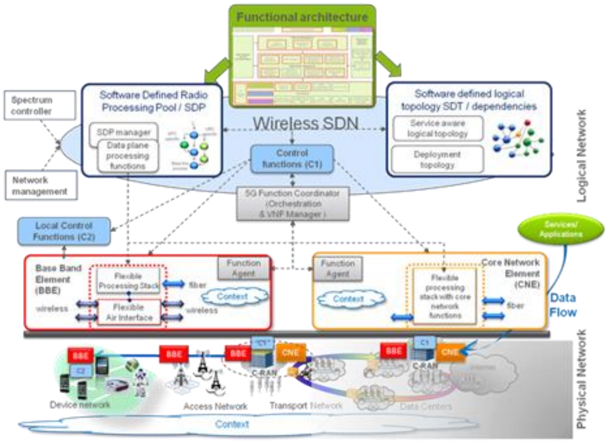


Figure 3 Generic 5G network architecture (high-level functional/logical view)

Functional View of 5G Architecture

From the functional point of view, 5G must support a huge set of different radio processing and control functions to manage the requirements of xMBB, M-MTC and U-MTC. There are strong dependencies between the processing steps with respect to delay and required bandwidth for the data exchange for a certain service like U-MTC. Not all of these functions are required anytime and everywhere. Most of these functions will be purely software defined functions. Some others will be implemented in HW accelerators or even distributed among the network nodes. 5G must define an open framework to add new processing or control functions in a cost efficient way. An adoption of SDN [9] and NFV [10] to the demands of RAN will simplify the mapping of the diverse requirements to the available logical and physical distributed resources. It also increases flexibility with respect to integration of decentralized core functions in C-RAN processing units like local MMF, local breakouts as well as Content Delivery Networks with caching capabilities.

Logical View of 5G Architecture

From the logical architecture point of view, the METIS architecture foresees only a few different types of nodes. Data processing and forwarding nodes are in charge to process the data with respect to the base band and core network processing schemes applied in order to deliver the data packets with the required latency and reliability to the next node. As shown in Figure 3, one here differentiates between Base Band processing Elements (BBE) that provide all user plane processing functions with respect to the radio functions and include wireless interfaces, and Core Network Elements (CNE) tailored to core network data processing and forwarding functions. Both logical nodes are connected to the wireless SDN controller, which consists of four main functionalities:

The Software Defined Processing (SDP) manager defines how data plane forwarding and processing functions, all defined in the SDP database, are linked to realize a desired service.

The Software Defined Topology manager (SDT) uses network status information to determine which network elements participate in the data plane operation, their virtual topology and finally the logical data plane topology and the topology of the selected nodes for each service. It also takes into account changes of the physical topology of the networks, for instance in the case of newly activated nomadic nodes [7], involving dynamic self-backhauling, or in the case of newly formed D2D groups.

The 5G Function Coordinator has the task to map the logical data plane topology to physical resources, given the logical data plane topology for each service.

Last but not least, there is a controller connected to the BBE and CNE required to perform e.g. RRM functions. This is foreseen to be split in a logical centralized controller and a second controller responsible for the wireless specific control tasks. As a unique property of the 5G system, the latter edge controller will be able to take over the control of its associated subnet in case of missing or weak network connections.

5. Conclusion

The 5G architecture has to support the delivery of service flows with strongly diverging requirements. To cope with that issue the architecture will be based on a software-defined networking principle going beyond SDN approaches applied so far for fixed networks (wireless SDN). Only in that way a future-proven network infrastructure can be realized providing sufficient efficiency, scalability and versatility to handle the variety of existing services, to allow fast introduction of new ones, and to bring deployment and operational cost to a low level.

The architecture described in this article is based on few logical nodes for processing of radio-, core- and transport-related functions. These nodes can be flexibly adjusted via NFV orchestration and controlled via SDN layer which can be separated in centralized and localized units with the latter ones for dedicated functions required only in certain wireless environments.

References

[1] Cisco, “Cisco Visual Networking Index: Global Mobile Data Traffic Forecast, 2013–2018”, February 2014.
[2] Ericsson, “Ericsson Mobility Report: On the pulse of the networked society”, June 2014
[3] ICT-317669 METIS project, “Scenarios, requirements and KPIs for 5G mobile and wireless system”, Deliverable D1.1, May 2013, https://www.metis2020.com/documents/deliverables/
[4] ICT-317669 METIS project, “Intermediate system evaluation results”, Deliverable D6.3, August 2014, https://www.metis2020.com/documents/deliverables/
[5] Stefania Sesia, Issam Toufik, and Matthew Baker, "LTE – The UMTS Long Term Evolution – From Theory to Practice", Second Edition including Release 10 for LTE-Advanced, John Wiley & Sons, 2011, ISBN 978-0-470-66025-6
[6] A. Frotzscher et al., “Requirements and current solutions of wireless communication in industrial automation”, 5G Technologies workshop, ICC 2014, June 2014
[7] Oe. Bulakci, J. Eichinger, Z. Ren, C. Zhou, P. Fertl. S Stanczak “Dynamic Nomadic Node Selection for Performance Enhancement in Composite Fading/Shadowing Environments”, VTC2014-Spring
[8] NGMN Alliance, “Suggestions on potential solutions for C-RAN,” White Paper, January 2013.
[9] D. Kreutz, et al., “Software-Defined Networking: A Comprehensive Survey”, June 2014, http://arxiv.org/abs/1406.0440
[10] ETSI ISG NFV (Operator Group), “Network Functions Virtualisation – Network Operator Perspectives on Industry Progress,” Updated White Paper, October 2013.

Josef Eichinger is Principal Researcher at Huawei's European Research Center in Munich, Germany and received his Dipl.-Ing. degree in electrical engineering from the applied university of Augsburg, and has worked more than 20 years on research of mobile radio systems and the product development. Currently his main focus is on developing solutions for the next generation of wireless communication systems and is member of the EU Project METIS.

Ömer Bulakci received the M.Sc. degree in communications engineering from the Technical University of Munich, Munich, Germany in 2008, and the doctoral degree in communications engineering from the Aalto University School of Electrical Engineering, Espoo, Finland, in 2013. He has contributed to the standardization of relaying in 3GPP LTE Release 10. Since October 2012, he has been conducting research toward 5G mobile and wireless communications networks and contributing to EU project METIS at Huawei European Research Center, Munich, Germany. He is an author or a coauthor of 33 technical publications.

Patrick Marsch is heading a radio research department in Nokia Networks, Wroclaw, Poland. He holds a M.Sc. and Ph.D. degree from Technische Universität Dresden, Germany. He has published 50+ conference and journal papers, received three best paper awards and received the Johann Philipp Reis Prize for pioneering research in the field of Coordinated Multipoint.

Gerd Zimmerman is senior expert in Deutsche Telekom Innovation Laboratories (T-Labs). He received the Dipl.-Ing. and Dr.-Ing. (Ph.D.) degree from University of Kaiserslautern (Germany). Since 1994 he is involved in DT Group in diverse R&D projects with focus on wireless technologies and networks. He is also participating in regulatory and standardization bodies like ITU-R and 3GPP. Since 2009 he is with T-Labs with main activities on LTE and beyond. He is member of IEEE and FP7 Project METIS.

Hugo Tullberg is Senior Researcher at Ericsson Research, Stockholm, Sweden. He holds an M.Sc.E.E degree from Lund University and a Ph.D. degree from University of California at San Diego. He is the technical coordinator of the EU FP7 project METIS.

INDUSTRIAL COLUMN: SPECIAL ISSUE ON TECHNOLOGIES, SERVICES AND APPLICATIONS FOR SMART CITIES

Guest Editors: Mischa Dohler[1] and Periklis Chatzimisios[2]
[1] King's College London, UK, mischa.dohler@kcl.ac.uk
[2] Alexander TEI of Thessaloniki, Greece, pchatzimisios@ieee.org

This Special Issue gathers a collection of six selected papers that present a variety of concerns and latest advances relating to technologies, services and applications for Smart Cities.

The first article “Applying Internet of Things paradigm to Smart City: communication model and experimentation” presents Padova Smart City, a pilot implementation of urban IoT within a Smart City framework. The authors further discuss the general architecture of urban IoT systems and in particular the Padova Smart City trial test.

The second article "The Smart City Innovation Ecosystem: A Practical Approach" provides a detailed description about the approach that cities should follow in order to implement the Smart City paradigm and how societal innovation can be promoted through the implementation of specific services. Furthermore, the article discusses the model adopted by SmartSantander and the new opportunities that the smart city paradigm brings.

The third article "Crowdsensing in Smart Cities: the ParticipAct Experience" presents an overview of the state-of-the-art in crowdsensing platforms for Smart City solutions. In particular, the authors classify crowdsensing and participatory services by focusing on the requirements of participatory service platforms. Moreover, the authors report details about their ParticipAct Crowdsensing Living Lab testbed within the University of Bologna and the carried out crowdsensing campaigns.

The authors of the fourth article “Towards a Cloud of Things Smart City" introduce the concept of the Cloud of Things (CoT), a horizontal integration of different IoT networks silos and the associated cloud computing. Furthermore, by taking into account the requirements a smart city should fulfill, they show (through the developed VITAL architecture) how the combination of IoT and CoT can result in smarter and more sustainable cities.

The fifth article “Smart Cities: Business Case Stories" discusses certain successful use cases of Smart City services and their value propositions. In particular, the business and use cases as well as the technological aspects of multi-application Smart Cities are presented and described in detail.

The last article "On the Estimation of the Free Size of Parking Places in Smart Cities by Using Wireless Sensor Networks" first introduces research and available solutions about the estimation of the free size for parking places in smart cities by using Wireless Sensor Networks. Subsequently, the authors present the implementation of a promising fuzzy inference system, they evaluate through simulation its energy consumption by also providing certain parameter optimization.

We would like to thank all the authors for their contribution and hope these articles will stimulate further research on Smart Cities and help by providing an up-to-date sketch of currently hot topics on this research area.

Finally, we want to express our gratitude to Dr. Shiwen Mao, the IEEE MMTC Vice Chair of Letter & Member Communications, for his invaluable support in coordinating this Special Issue.

Enjoy your reading!

Mischa Dohler is full Professor in Wireless Communications at King's College London, Head of the Centre for Telecommunications Research, co-founder and member of the Board of Directors of the smart city pioneer Worldsensing, Fellow and Distinguished Lecturer of the IEEE, and Editor-in-Chief of the Transactions on Emerging Telecommunications Technologies.
He is a frequent keynote, panel and tutorial speaker. He has pioneered several research fields, contributed to numerous wireless broadband and IoT/M2M standards, holds a dozen patents, organized and chaired numerous conferences, has more than 200 publications, and authored several books. He has a citation h-index of 38 (top 1% in telecommunications).

He acts as policy, technology and entrepreneurship adviser, examples being Richard Branson's Carbon War Room, the House of Lords UK, the EPSRC ICT Strategy Advisory Team, the European Commission, the ISO Smart City working group, and various start-ups. He is also an entrepreneur, angel investor, passionate pianist and fluent in 6 languages. He has talked at TEDx. He had coverage by national and international TV & radio; and his contributions have featured on BBC News and the Wall Street Journal.

Periklis Chatzimisios serves as an Associate Professor at the Alexander TEI of Thessaloniki (Greece). Recently, he has been a Visiting Academic/Researcher in University of Toronto (Canada) and Massachusetts Institute of Technology (USA). Dr. Chatzimisios is involved in several standardization activities serving as a Member of the Standards Development Board for the IEEE Communication Society (ComSoc) (2010-today) and lately as Secretary of the IEEE 1907.1 Standardization Working Group.

He holds editorial board positions for several IEEE/non-IEEE journals and he is acting as the Director for the E-Letter of the IEEE Technical Committee on Multimedia Communications (MMTC). He is the author/editor of 8 books and more than 80 peer-reviewed papers and book chapters on the topics of performance evaluation and standardization activities of mobile/wireless communications, Quality of Service/Quality of Experience and vehicular networking. His published research work has received more than 1300 citations by other researchers.

Applying Internet of Things paradigm to Smart City: communication model and experimentation

Andrea Zanella ♭ *and Michele Zorzi* ♭ ♮

♭ *Dep. of Information Engineering, University of Padova, Padova Italy*

♮ *Patavina Technoogies s.r.l., Padova, Italy*

{*zanella, zorzi*}*@dei.unipd.it*

1. Introduction

In a nutshell, the “Smart City” vision consists in the pervasive application of the Information and Communication Technologies (ICT) to an urban scenario, in order improve the *efficiency* of modern cities, from both the economical and the social perspective. In fact, the systematic application of ICT in public affairs can potentially reduce the operational costs, while improving the quality of the services offered to the citizens and promoting the development of the urban economy [1,2].

In this context, the Internet of Things (IoT) paradigm can play a major role, by enabling seamless and uniform access to the data generated by a plethora of heterogeneous devices that will form the sensory system of the Smart City [3,4].

From a system perspective, however, the realization of an urban IoT, together with the required backend network services and devices, lacks an established best practice because of its novelty and complexity. Even if some urban IoT systems are currently being deployed worldwide [5] there is still no widely accepted consensus on the networking architecture and protocols that they should use.

A possible general reference framework for the architecture of an urban IoT is based on a web-service approach. This model has been deeply studied in recent years, e.g., [6-10], proving its feasibility on strongly resource-limited devices, as typically used in IoT scenarios, and resulting in a flexible and interoperable system.

In this document we briefly describe the main network components of an urban IoT system, and we discuss a proof-of-concept deployment of an urban IoT realized in the city of Padova. A more detailed discussion of both the general architecture of urban IoT systems and of the Padova Smart City trial test can be found in [10] and [11], respectively, from where most of the following material has been extracted.

2. Web-service approach for IoT service architecture

Building a general architecture for an IoT system is a very complex task, mainly because of the extremely large variety of devices, link layer technologies, and services that may be involved in such a system. Hence, a primary characteristic of an urban IoT infrastructure is its capability of integrating different technologies with the existing communication infrastructures, in order to support a gradual evolution of the IoT, with the interconnection of other devices and the realization of novel functionalities and services.

A promising approach to the design of IoT services is hence to replicate the architecture and structure of the web services that are currently used in the Internet, in order to greatly facilitate the adoption and use of the IoT services by both end users and service developers. However, the most common protocols for web-based communications, such as XML, HTTP, and IPv4/IPv6, are characterized by a human-readable text-based syntax, whose verbosity and redundancy are unsuitable for resource-constrained devices.

For this reason, important standardization bodies, such as IETF, ETSI and W3C, are actively working to develop low-complexity counterparts of these protocols. This effort has led to the definition of the Efficient XML Interchange (EXI), the Constrained Application Protocol (CoAP), and IPv6 for Low power Wireless Personal Area Network (6LoWPAN), which are the binary-based siblings of XML, HTTP, and IPv4/IPv6, respectively.

EXI defines two types of encoding, namely schema-less and schema-informed. While the schema-less encoding is generated directly from the XML data and can be decoded by any EXI entity without any prior knowledge about the data, the schema-informed encoding assumes that the EXI encoder and decoder share an XML Schema that maps the XML tags into much more compact numeric identifiers. The great efficiency of this last encoding method, however, is contrasted by its lower usability, since developers are required to define an XML Schema for the specific messages involved in their application [6].

The pivotal role played by HTTP in the Internet is taken by CoAP [12] in the proposed IoT architecture. Once again, CoAP gives up the human readability principle of its syntax to embrace a much more resource-efficient binary representation of the different commands. Furthermore, while HTTP is based on the reliable TCP transport service, CoAP directly implements some basic reliability mechanisms on top of the unreliable, but extremely light UDP transport service. However, CoAP supports the *Representational State Transfer* (ReST) paradigm by implementing the ReST methods of HTTP (GET, PUT, POST, and DELETE), and the corresponding response codes, thus being easily interoperable with HTTP.

Even though regular Internet hosts can natively support CoAP to directly talk to IoT devices, the most general and easily interoperable solution requires the deployment of an HTTP-CoAP intermediary, also known as *cross-proxy*, that can straightforwardly translate requests/responses between the two protocols, thus enabling transparent interoperability with native HTTP devices and applications. Furthermore, the proxy logic can limit the amount of traffic injected into the IoT clouds by caching the data generated by the peripheral nodes, which can either get polled proactively by the proxy, or asked to send a report as a result of predetermined events.

For what concerns the network layer, the exhaustion of public IPv4 addresses mandates the adoption of 128-bit long IPv6 addresses to uniquely identify each IoT node. However, the long address field introduces overheads that are not compatible with the scarce capabilities of constrained nodes. For this reason, the 6LoWPAN protocol [13,14] defines a standard compression format for IPv6 and UDP headers, which is typically operated by a gateway element that interfaces the IoT cloud with the rest of the world. The gateway can possibly (but not mandatorily) implement the HTTP-CoAP proxy, thus becoming a *plug-and-play* IoT enabler.

3. Padova Smart City: an experimentation

Padova Smart City (PSC) is a multi-party project that involves the municipality of Padova as financial sponsor and final user of the system, the Department of Information Engineering and the Human Inspired Technologies research centre of the University of Padova for data mining, data post-processing, and service design aspects, and Patavina Technologies s.r.l. [1], a spin-off of the University of Padova specialized in the development of innovative IoT solutions, as software developer and system integrator. The project architecture is detailed in [11] and briefly reported here for the reader's convenience.

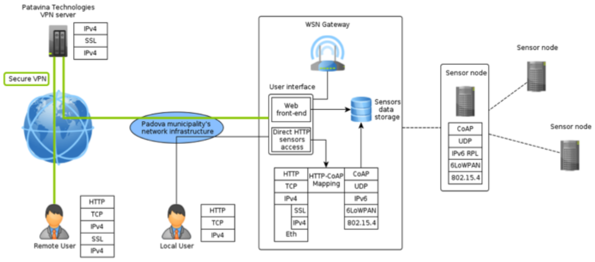


Figure 1 Padova Smart City system architecture

The system consists of a few IoT sensor nodes placed on streetlight poles and connected to the network of the city municipality by means of a gateway. IoT nodes, instead, communicate through a wireless interface that is compliant with the IEEE 802.15.4 standard. A sketch of conceptual architecture of the PSC system is given in Fig. 1.

Nodes are equipped with photometer sensors that directly measure the intensity of the light emitted by the lamps and by any other source whose light reaches the sensor. The wireless IoT nodes are also equipped with temperature and humidity sensors, which provide data concerning weather conditions. Finally, one node is equipped with a benzene (C_6H_6) sensor, which monitors air quality.

IoT nodes are powered by small batteries, so that each unit is self-contained and can be easily placed in any location, with the exception of the benzene sensor that needs to be continuously powered and, hence, has been placed within the control box that governs a line of streetlights, where a DC power source is available.

The sensor nodes are packaged in a transparent plastic shield that protects the electronic parts from atmospheric phenomena, while permitting the circulation of air and light for the correct measurement of humidity, temperature, and light intensity.

As shown in Fig. 1, the PSC system embraces the web service paradigm described in the previous section. The transcoding between unconstrained and constrained protocol stacks is performed by the WSN gateway that also hosts a database to collect the measurements generated by the sensor nodes. In order to save battery and storage space, nodes read the sensory data every 5 minutes. The average of three consecutive readings is then stored in the node’s buffer, so that each value covers a time interval of 15 minutes. Since the payload field of an IEEE 802.15.4 radio packet can carry up to 7 values for each sensor, every 105 minutes nodes will move the data collected in the local buffer into a radio packet that will be delivered to the gateway in a multi-hop fashion. However, any other node can also

---

[1] http://patavinatech.com

asynchronously read the data collected by each node by using the CoAP protocol.

The main objective of the PSC is to provide a convenient way to monitor the status of public street lighting and promptly recognize failures and malfunctions. Despite its simplicity, this service embodies the win-win principle of Smart City applications, in that it improves the quality of the service offered to citizens by reducing the time for failure recognition and repair, and decreases the maintenance costs incurred by the public administration for the periodic inspection of the public lighting system. Furthermore, the different environmental parameters collected by the PSC can be used to get a picture of the air quality in the city, and to gain deeper insights into the interplay of different elements of a complex urban ecosystem.

As an illustration, Fig. 2 and Fig. 3, taken from [10], report an example of the type of data that can be collected with the PSC system. Other examples can be found in [11]. The plots show the temperature and benzene readings over a period of seven days. Dots refer to the actual readings, while lines are obtained by applying a moving average filter over a time window of one hour (approximately 10 readings of temperature, and 120 readings of the benzene sensor, whose sampling rate is larger since the node is powered by the grid). It is possible to observe the regular pattern of the light measurements, corresponding to day and night periods. In particular, at daytime the measure reaches the saturation value, while during nighttime the values are more irregular, due to the reflections produced by vehicle lights. A similar pattern is exhibited by the humidity and temperature measurements (not reported here for space constraints) that, however, are much more noisy than those for light.

The benzene measurements also reveal a decrease of the benzene levels at nighttime, as expected due to the lighter night traffic, but quite surprisingly there is no evident variations in the daytime benzene levels during the week end (Oct. 26-27). To better analyze this aspect we report in Fig. 4 the traces of the benzene (lower green line) and humidity (upper blue line) in two consecutive days, namely a Sunday (first 24 hours with gray background) and the following Monday (see [11]). We can observe that, indeed, the benzene level is slightly lower on Sunday, in particular during the morning. Instead, the benzene peak around 6 pm is clearly distinguishable in both days.

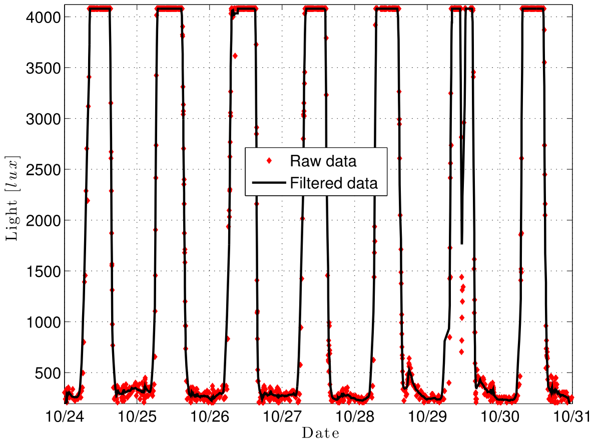


Figure 2 Light readings provided by PSC system

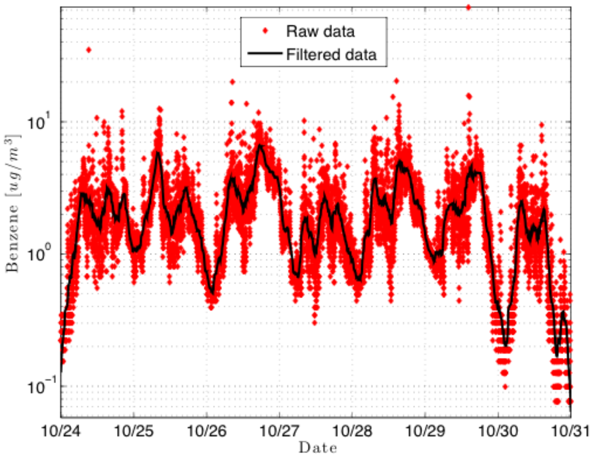


Figure 3 Benzene readings provided by PSC system

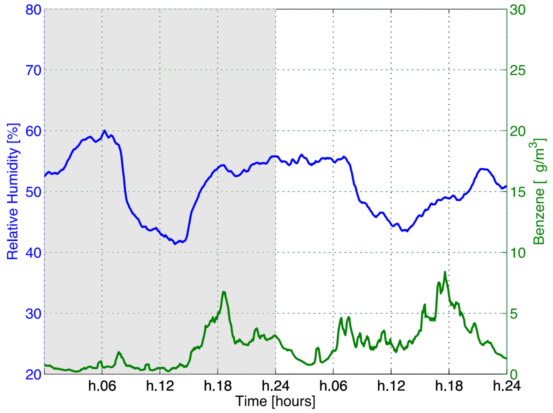


Figure 4 Benzene and humidity readings in two days

4. Conclusion

In this paper we presented Padova Smart City, a pilot implementation of urban IoT within a Smart City framework. We illustrated the system architecture, which adheres to the web service paradigm. As an example of the possible utilizations of the data collected by such a system, we also reported some snapshots of sensor signals, namely light and benzene level in the air. As future work, we plan to couple the sensor data with location information provided by the GIS database and with other data that are collected by the municipality using dedicated systems (e.g., traffic intensity, parking occupancy, weather conditions, and so on) and to apply more sophisticated data analysis techniques to reveal correlations among different signals and get refined information from the raw data.

References

[1] Pike Research on Smart Cities. [Online]. Available: http://www.pikeresearch.com/research/smart-cities.

[2] N. Walravens, P. Ballon, "Platform business models for smart cities: from control and value to governance and public value" *IEEE Communications Magazine*, vol. 51, no. 6, pp. 72-79, Jun. 2013.

[3] J. M. Hernández-Muñoz, J. B. Vercher, L. Muñoz, J. A. Galache, M. Presser, L. A. Hernández Gómez, and J. Pettersson, "Smart Cities at the Forefront of the Future Internet," *The Future Internet, Lecture Notes in Computer Science*, vol. 6656, pp. 447-462, 2011.

[4] C. E. A. Mulligan, M. Olsson, "Architectural implications of smart city business models: an evolutionary perspective" *IEEE Communications Magazine*, vol. 51, no. 6, pp. 80-85, Jun. 2013.

[5] SmartSantader. [Online] http://www.smartsantander.eu/.

[6] FP7 European project: "SENSEI - Integrating the Physical with the Digital World of the Network of the Future." Deliverable D4.8 – "Efficient WS&AN Island Solutions." [Online]. Available: http://www.sensei-project.eu/

[7] A. Castellani, S. Loreto, A. Rahman, T. Fossati and E. Dijk. "Best Practices for HTTP-CoAP Mapping Implementation." *draft-castellani-core-http-mapping-07*. s.l. : IETF, 2013.

[8] A. Castellani, M. Dissegna, N. Bui, M. Zorzi, "WebIoT: A web application framework for the internet of things," *Proc. of IEEE WCNCW*, pp. 202-207, 2012

[9] A. Castellani, M. Gheda, N. Bui, M. Rossi, M. Zorzi, "Web Services for the Internet of Things through CoAP and EXI," *Proc. of IEEE ICC*, June 2011.

[10] A. Zanella, N. Bui, A. Castellani, L. Vangelista, M. Zorzi, "Internet of Things for Smart Cities," *IEEE Internet of Things Journal*, vol.1, no.1, pp.22-32, Feb. 2014

[11] A. Cenedese, A. Zanella, L. Vangelista, M. Zorzi, "Padova Smart City: an Urban Internet of Things Experimentation" in *Proc. of IEEE IoT-SoS*, 2014.

[12] Z. Shelby, K. Hartke, C. Bormann, and B. Frank, "Constrained Application Protocol (CoAP)." *draft-ietf-core-coap-18* s.l.: IETF, 2013.

[13] G. Montenegro, N. Kushalnagar, J. Hui and D. Culler. "Transmission of IPv6 Packets over IEEE 802.15.4 Networks."' *RFC4944*. s.l. : IETF, Sep 2007.

[14] J. Hui and P. Thubert. "Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks." *RFC6282*. s.l. : IETF, 2011.

Andrea Zanella (S'98-M'01-SM'13) is Assistant Professor at the Department of Information Engineering (DEI), University of Padova (ITALY). He received the Laurea degree in Computer Engineering in 1998 from the same University. In 2000, he was visiting scholar at the Department of Computer Science of the University of California, Los Angeles (UCLA). In 2001, he got the PhD degree in Electronic and Telecommunications Engineering from the University of Padova. Andrea Zanella is one of the coordinators of the SIGnals and NETworking (SIGNET) research lab. His long-established research activities are in the fields of protocol design, optimization, and performance evaluation of wired and wireless networks. Since 2013, he is Associate Editor of the IEEE Internet of Things Journal.

Michele Zorzi (S'89-M'95-SM'98-'07) received his Laurea and PhD degrees in electrical engineering from the University of Padova in 1990 and 1994, respectively. During academic year 1992-1993 he was on leave at the University of California at San Diego (UCSD). In 1993 he joined the faculty of the Dipartimento di Elettronica e Informazione, Politecnico di Milano, Italy. After spending three years with the Center for Wireless Communications at UCSD, in 1998 he joined the School of Engineering of the University of Ferrara, Italy, where he became a professor in 2000. Since November 2003 he has been on the faculty of the Information Engineering Department at the University of Padova. His present research interests include performance evaluation in mobile communications systems, WSN and Internet-of-Things, and underwater communications. He was Editor-In-Chief of IEEE Wireless Communications from 2003 to 2005 and of IEEE Transactions on Communications from 2008 to 2011. He served as a Member-at-Large of the Board of Governors of the IEEE Communications Society from 2009 to 2011, and is currently its Director of Education.

The Smart City Innovation Ecosystem: A Practical Approach

Verónica Gutiérrez, José A. Galache, Juan R. Santana, Pablo Sotres, Luis Sánchez, Luis Muñoz,
Network Planning and Mobile Communications Laboratory, University of Cantabria, Spain
{veronica,jgalache,jrsantana,psotres,lsanchez,luis}@tlmat.unican.es

1. Introduction

Recent studies [1] have predicted that by 2050 seventy percent of the world population will live in urban areas, while more than a half of them already lives in cities. Different urban-environment stakeholders (technicians, city planners, politicians, researchers, etc.) are urged to take measures aimed at guaranteeing the fulfilment of some key quality criteria related to the sustainability and efficiency in the city processes. From a pure engineering approach the city represents a unique ecosystem for testing and assessing new services and technologies, Information and Communications Technologies (ICT) in particular. The fact that cities represent a strategic meeting point between the citizens (urban society) and the technology creates an additional dimension that can be exploited within crowd-sourced creativity scenarios and living labs. This is what we are calling societal innovation, meaning that the human beings are immersed in a context that stimulates the conception of new ideas and solutions, addressing the problems related to their ecosystem.

So far, innovation in the Future Internet (FI) context has been led by commercial companies and research centres, with low involvement of other stakeholders. A more holistic approach, where all the relevant representatives are involved, is needed. In this sense, the Internet of Things (IoT) and its ecosystem, as a very active branch of the FI, give to the research community a unique opportunity to innovate with technologies and services, involving multiple stakeholders. The deployment, test and evaluation in the context of a city scenario enable the possibility to conceive new city services or improve a wide range of existing ones such as waste management, integral traffic management, energy efficiency, etc. To accomplish this, it is necessary to augment the urban environment with a number of IoT related technologies that allows us to capture information about the real world environments, to detect events and to influence the course of such events through the use of actuators.

In this framework, this letter presents a novel approach that aims at conciliating new FI architectures with services relying on IoT technology, thereby resulting on the creation of a societal innovation laboratory within the scope of a Smart City. Our proposal for a societal innovation laboratory is underpinned by the deployment of a large-scale IoT infrastructure carried out within the SmartSantander project [2] (in the city of Santander, Spain). This facility allows experimental assessment of the cutting-edge research on IoT-related fields and, simultaneously, supports the provision of impact-generating Smart City services directly perceivable by all the stakeholders [3].

The letter is organized as follows. Section 2 describes the approach that cities should follow to implement the Smart City paradigm and how societal innovation can be promoted through the implementation of specific services. Section 3 elaborates the itinerary followed in Santander to create a urban living lab that supports service provision and experimentation within the urban landscape. Finally, Section 4 summarizes the model adopted by SmartSantander to make its facility sustainable as well as the main incentives to encourage the different stakeholders to be part of the new opportunities (e.g. technologies, business opportunities, standardization activities, etc.) that the smart city paradigm brings to the different actors.

2. Towards the Smart City paradigm

The design and realization of smart services and applications in a city is a challenging task. From a technological point of view, the underlying ICT technologies are diverse, often largely heterogeneous and many of them are emerging technologies such as the IoT with a low degree of maturity. The lack of experience and established benchmarks for IoT deployments for Smart City services makes technology and investment choices for cities a risky endeavour that may lead in some cases to incompatible system deployments that are difficult to integrate or to suboptimal service offerings. Similarly, the lack of support for the diversity of IoT technologies and the unavailability of standardized APIs for developers makes it also difficult for service developers to implement and trial new Smart City services.

Cities would greatly benefit from an experimental environment that allows flexible trial and evaluation of different potential solutions, in order to gain a better understanding of the performance trade-off and suitability. Similarly application developers require an environment that allows them to rapidly prototype and trial novel urban services/applications over heterogeneous IoT technologies and deploy them in realistic environment with easy access to potential users without requiring substantial investments in infrastructure from their part.

At the same time it is important to involve citizens into the innovation loop in order to ensure that emerging Smart City services fulfil their demands and are acceptable by society at large. In order to derive tangible requirements, it is important to involve them so as to consider their personal opinion when ranking different kinds of services.

The involvement of end users adds another dimension to evaluation capabilities of the platform by allowing not only the assessment of technical performance of IoT solutions, but also their societal implications and user acceptance. This aspect is the one that promotes what the authors have called societal innovation, being the engagement of communities towards the development of new concepts and solutions tackling societal needs (more effectively than alternatives) and creating new social relationships or collaborations. Through continuous user feedback on services usability or encouraging participatory engagement of crowd sourcing ideas or service content, the full potential of societal innovation can be achieved.

3. SmartSantander IoT facility

Funded by the 7th Framework Programme, SmartSantander project was conceived as an essential tool for achieving the European leadership in IoT technologies, which would enable the scientific community to experiment and evaluate services and applications for Smart Cities under real-life conditions. The project aimed at the deployment of 12,000 IoT devices in the city of Santander (see Figure 1). Nowadays, the goal has been achieved placing the city in the vanguard of technological innovation.

Figure 1 SmartSantander IoT facility deployment

The deployment of a research-oriented IoT infrastructure in the heart of a city, and the considerable investments required to create and amplify it to the necessary scale, motivate the exploitation of the facility beyond the experimental research community. The facility was conceived not only to act as a testbed for research with IoT technologies, but also for the development and evaluation of IoT enabled Smart City services and applications.

To build such facility, the project analysed, designed and developed several services that were ranked as a priority by the local authorities, regional government and end users, which are described next.

A. Environmental Monitoring

Due to global warming, governments around the world are devoting significant effort and resources to the management of the environment. The city of Santander, likewise, is also involved in this activity and is trying to carry out an effective policy for environmental management. More than 1,000 fixed nodes have been deployed in street lamps and façades within the city. They monitor parameters such as CO, temperature, noise level and light intensity.

To extend such infrastructure to other areas of the city, IoT devices have been deployed on vehicles such as municipal public buses, parks and gardens ones and taxis. Hence, we are able to cover a much wider area on a much more efficient way. Mobile nodes send the retrieved information to the SmartSantander platform, and also, may interact with the corresponding static nodes placed at streetlamps and facades.

B. Parking Management

One of the most common use cases when invoking the Smart City paradigm addresses integral traffic control. There are several components in such a use case. Among them, management of limited parking including specific spaces for people with disabilities, control of load and unload areas and traffic prediction are the most relevant elements to be considered.

With the aim of reducing CO emissions and other pollutants, as well as petrol consumption, ICT are becoming a transversal enabler. In this sense, IoT technology, characterized by its pervasiveness, is becoming a very attractive solution both technically and economically speaking. Around 650 parking sensors have been installed at Santander downtown area in order to detect the occupancy of outdoor parking lots. Additionally, 10 panels have been deployed at the main streets' intersections, showing the number of free parking spots and giving directions.

Drivers looking for available parking places within the city, may use both smartphone applications as well as panels installed in the city (see Figure 2):

Catedral	0 libres
Paseo Pereda	0 libres
C/ General Mola	0 libres
C/ Hernán Cortes	0 libres
C/ Daoiz y Velarde	0 libres
C/ Peña Herbosa	0 libres
C/ Bonifaz	0 libres
C/ Santa Lucía	0 libres
C/ Gándara	1 libres

Figure 2 Parking spots information

C. Traffic intensity

Nowadays, the assessment and classification of vehicles in road traffic is mainly accomplished by inductive loops placed under the pavement. These inductive loops allow monitoring vehicle passing and provide us information on several parameters of the traffic (vehicle speed, traffic congestion and traffic accidents, between others).

Already existing solutions in the city have been complemented with wireless sensors deployed in road lanes that collect information about cars speed, occupancy and count and send such information to the SmartSantander platform.

D. Parks and gardens irrigation

The Parks and Garden Irrigation service is aimed at complementing the automated irrigation systems currently deployed at parks and gardens within the city of Santander. It offers a wide data set acquired in a distributed way, gathering the information of interest from multiple locations within each area.

Agricultural IoT devices and weather stations have been deployed in three major parks of Santander. A total of 48 IoT nodes, covering an area of 55,000 m2, have been deployed at key positions inside these three areas, equipped with special agricultural sensors measuring parameters such air temperature and humidity, soil temperature and moisture, atmospheric pressure, solar radiation, wind speed/direction and, rainfall among others. All the information captured by the sensors is sent to the SmartSantander platform and merged on an application that provides parks management technicians with accurate information on the green areas status.

E. Tourist and Cultural information

In the majority of cities there is a huge amount of information that may be of interest for tourists and citizens but is not readily accessible because it is so disperse. To avoid that, a service has been implemented to unify the way to access all data sources and presenting them in a context-sensitive, location-aware manner to the end users using Augmented Reality (AR) technology.

The service includes information about more than 2700 places in the city of Santander, classified in different categories: beaches, parks and gardens, monuments, buildings, tourist offices, shops, art galleries, libraries, bus stops, taxi ranks, bicycle hire points, parking lots and sports centres. Furthermore, it allows real-time access to traffic and beach cameras, weather reports and forecasts, public bus information and bike hire service, generating a unique ecosystem for end users when moving around the city.

SmartSantanderRA application, shown in Figure 3, is available for both Android and IOS smartphone applications. More than 20,000 people, who actively use the application, have downloaded it.

Figure 3 SmartSantanderRA application screenshots

F. Participatory Sensing: Pace of the City

Participatory Sensing service aims at exploiting the use of citizens' smartphones to make people to take an active role in the generation of data for the SmartSantander Platform. Citizens, Santander City Council and the local newspaper are connected through the SmartSantander platform so that they can report, share and be notified of events happening in the city. Users also utilise their mobile phones to send physical sensing information, e.g. GPS coordinates, compass, environmental data such as noise, temperature, etc, feeding this information into the same platform.

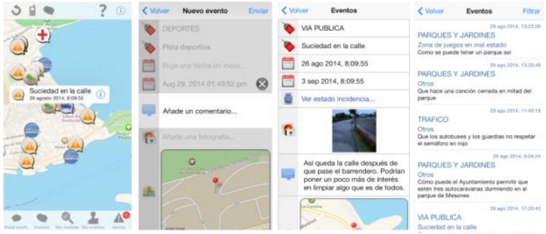


Figure 4 Pace of the City application screenshots

Since the Pace of The City application was launched two years ago, the application has attracted 7,000 downloads. During this time, users have reported more than 5,000 events. 40 per cent of them have notified the municipal services in order to deal with the corresponding incidence. Municipal services were reorganized to adopt this application as the main way to report incidences. This has permitted to improve the response time to the citizen claims reducing the time to find out a solution for an incidence from 40.76 to 13.2 days.

4. Building a new economy model for the city

In many cases, both social innovation and the development of new Smart City services can lead to novel added-value meta-applications and can create new opportunities for novel entrepreneurship and business growth. Nowadays, with Web 2.0 and mobile phones, users are not only consumers but also producers of content, leading to a new stage of evolution, with the emergence of data-centric applications and services based on open data and big data. The growth of available data, their potential for added-value services and the availability of standards seem to set the conditions for new cycle of network effects and innovation.

All the infrastructures and services within the Smart City need a platform, which harmonizes the services provided to the citizens. According to the experience we have gained during the three years running the SmartSantander project, there is no doubt that the Smart City platform is the constituent block, which will facilitate the sustainability of the experimental facility whilst simplifying the management of the city.

SmartSantander facility has been conceived to be integrated with FIWARE [4] and through FI-LAB [5], the open innovation lab created under the FIWARE umbrella, companies and entrepreneurs will be able to access to a plethora of data generated by citizens, sensors and services, among others.

In order to really make sustainable and expand such facility, the best way forward is to postulate that every urban service provider within the city of Santander has to rely, as much as possible, on the deployed infrastructure. In addition to using the platform, the urban utilities themselves have to deploy the appropriate infrastructure for improving their services provision. Furthermore, aiming at guaranteeing that the facility remains sustainable, the new tenders that the municipality will create in the future for the urban services has to allocate a budget for infrastructure maintenance and renewal.

Besides that, the potential of Open Data is already established in a number of sectors in government and business. The European Union has adopted an open data strategy to support transparency and to create a €32 billion a year market for public data [6]. Published datasets can cover a number of areas of activity including transport, health, agriculture, business, law and education.

Governments can make datasets available for use by citizens or organisations, who can then add value to them. The research community can share datasets and facilitate research collaboration. Businesses can publish datasets to enable and participate in open supply chains. Additionally, sensors and devices composing IoT facilities can generate huge amounts of information that may be used to develop new services based on the big data paradigm.

Finally, different stakeholders (SMEs, entrepreneurs, service developers and the research community) can innovate by adding value to the aforementioned open available information and to the big data generated within the Smart City infrastructures.

5. Conclusions

Smart cities are perfect ecosystems for cross-fertilizing ideas and actions in response to the crucial needs we all might be facing in the coming years to improve the quality of life and efficiency at the city level. Immersing urban society in a technologically advanced scenario fosters crowd-sourced creativity potential, leading to leverage the societal innovation paradigm.

By making the IoT infrastructure presented in this letter attractive to a wide range of involved stakeholders, namely Future Internet researchers to validate their cutting-edge technologies; entities that are willing to use the experimental facility for deploying, validating and assessing new services and applications; and communities of users generating insights into the acceptance of IoT-based services deployed in a live environment, we have described a novel approach for making the city a place for innovation.

In this sense, several Smart City services have been implemented covering a twofold intention. On the one hand, it helps closing the gap between technology and the urban society as they are invited to be part of the loop. On the other hand, it promotes new business opportunities on which the Smart City paradigm is exemplifying the societal innovation that the approach proposed in this letter is enabling.

Future work to be carried out in the city will involve the deployment of new use cases, some of them oriented to strengthen the participation of the citizenship in the definition of new end-user services as well as their involvement in the validation of the proposed technological approaches. Furthermore, it is of utmost importance to go on with the assessment of the participatory sensing service with the tools available within the proposed architecture. Last but not least, the platforms deployed in the city domain are revealing very attractive for interoperability studies.

References

[1] “Urbanization and health”, Bulletin of the World Health Organization, Volume 88, Number 4, pp. 245-246, 2010.

[2] Luis Sánchez, Luis Muñoz, José Antonio Galache, Pablo Sotres, Juan R. Santana, Verónica Gutiérrez, Rajiv Ramdhany, Alex Gluhak, Srdjan Krco, Evangelos Theodoridis, Dennis Pfisterer, “SmartSantander: IoT Experimentation over a Smart City Testbed”, Computer Networks, Volume 61, 14 March 2014, Pages 217–238.

[3] Galache, J.A., Santana, J.R., Gutiérrez, V., Sánchez, L., Sotres, P., Muñoz, L., “Towards Experimentation-Service duality within a Smart City scenario”, The 9th International Conference on Wireless On-demand Network Systems and Services: WONS 2012, 9-11 January 2012.

[4] FI-WARE platform, http://www.fi-ware.org/

[5] FI-WARE Open Innovation Lab (FI-LAB), http://www.fi-ware.org/lab/

[6] Kroes, N., “Public data for all – opening up Europe’s public sector”, Blog of Neelie Kroes Vice-President of the European Commission, http://blogs.ec.europa.eu/neelie-kroes/public-data-for-all-%E2%80%93-opening-up-europes-public-sector/

Verónica Gutierrez received the Telecommunications Engineering degree by the University of Cantabria, Spain, in 2000, where she is currently a senior researcher. She is active on different European projects framed under the smart city paradigm, such as SmartSantander, as well as others like RADICAL leveraging the Living Lab concept, sharing experiences within smart cities framework. Her research interests are on participatory sensing, augmented reality and middleware platforms for IoT-based smart city services development. She is currently working in the realization of her Ph.D.

José Antonio Galache received both Telecommunications Engineering and Ph.D. degrees by the University of Cantabria, Spain, in 2004 and 2013 respectively. Since 2004, he has been working as researcher in the Communications Engineering Department of the University of Cantabria. His main lines of research are related with wireless routing protocols, WSNs technologies, middleware platforms for managing heterogeneous networks, M2M communications and management of IoT deployments mainly associated to smart cities. He has been involved in different European projects framed under the smart city paradigm, highlighting SmartSantander and ClouT projects. Finally, he is author of more than fifteen articles in national and international journals and congresses.

Juan Ramón Santana is a Telecommunication Engineer graduated in 2010 in the University of Cantabria, where he is working as research fellow. Prior to this occupation, he did an internship in the University of Strathclyde (Glasgow) working on IoT solutions for six months. Some of the projects in which he is currently involved are SmartSantander and EAR-IT, European collaborative projects under the Seventh Framework Programme, related to the Smart City paradigm. He has multiples areas of interest including WSN, M2M communications and Mobile phone application research.

Pablo Sotres works as research fellow in the Network Planning and Mobile Communications Laboratory, which belongs to the Communications Engineering department at the University of Cantabria, Spain. He received Telecommunications Engineering degree by the University of Cantabria in 2008. He is currently involved on different European projects framed under the smart city paradigm, such as SmartSantander; and related to inter-testbed federation, such as Fed4FIRE.

Luis Sánchez received both the Telecommunications Engineering and Ph.D. degree by the University of Cantabria, Spain, in 2002 and 2009 respectively. He is assistant professor at the Dept. of Communications Engineering at the University of Cantabria. He is active on meshed networking on heterogeneous wireless scenarios and optimization of network performance through cognitive networking techniques.

Luis Muñoz received both the Telecommunications Engineering degree and Ph.D. from the Polytechnical University of Cataluña (UPC), Spain, in 1990 and 1995, respectively. He is head of the Network Planning and Mobile Communications at the University of Cantabria, Spain. His research focuses on advanced data transmission techniques, heterogeneous wireless multihop networks, Internet of Things, smart cities and applied mathematical methods for telecommunications. He has participated in several National and European research projects belonging to the 4th, 5th, 6th and 7th Framework Program in which he is technical manager of SmartSantander. He has published over 150 journal and conference papers. He serves as editor of several journals and he has been invited to participate in the Steering Committee and Technical Program Committee of the most relevant international conferences. In parallel to this activity, he serves as consultant for the Spanish Government as well as for different companies in Europe and USA. Last but not least, he has served as expert of the ETSI and European Commission.

Crowdsensing in Smart Cities: the ParticipAct Experience

Paolo Bellavista, Giuseppe Cardone, Antonio Corradi, and Luca Foschini
DISI – University of Bologna, Italy
{paolo.bellavista, giuseppe.cardone, antonio.corradi, luca.foschini}@unibo.it

1. Introduction

Recent advances in ICT made possible in 2013 the shipment of more smartphones than feature phones, so marking a trend that brings the former to permanently outnumber the latter. The explosive and widespread diffusion of smartphones enable data availability and gathering, provided by sensors, such as accelerometers, barometers, cameras, and microphones. That information can be so densely available in urban areas to lay a large ground for *crowdsensing*, in the sense of allowing for a very large-scale fine-grained sensing by exploiting all personal resources and people's mobile activities/collaborations. At the same time, Smart City initiatives and projects, which are the central theme of this e-letter, can also make available several resources and data to be managed and harnessed safely, sustainably, cost-effectively, and efficiently to achieve measurable economic/societal advantages. Information gathered from people and the Internet of Things is one of the most valuable resources potentially available to city stakeholders, but its huge volume makes difficult its integration and processing, especially in a real-time and scalable manner.

The ability to harness the power of the above collective intelligence (even if inaccurate) to self-organize spontaneous collaboration of citizen groups involved with other people, via collective actions, in order to get a common goal with a tangible effect also on the physical material world, namely, e-Participation and e-Inclusion, is still largely unexplored [1]. We consider essential to fill that gap by proposing a new class of pervasive services, called *participatory services*, to emphasize their fundamental feature to provide people with the innovative opportunity to participate and act collectively in the cyber-physical world. In short, the main objective of participatory services is to close the loop between immaterial and material world scenarios in the pervasive cyber-physical system of a Smart City: they should go in the direction of facilitating positive behaviors by preventing potentially dangerous/inefficient situations and of enabling smarter e-Governance with a high participation of interested citizens, thus fostering an increased sense of belonging.

However, to become really effective technologies, we believe that participatory services still have to face a number of challenges, which can be grouped and classified by considering either a more social or technically-oriented perspective. From the more *social point of view*, there are many duties involved in people's participation: the effective identification of people actually willing to participate in crowdsensing campaigns, how to keep them involved (e.g., by providing attractive crowdsensing and participatory services, entertainment, and rewards), and how to foster their participation with active collaboration actions in data collection campaigns, for instance that require people to operate at specific locations (e.g., to take a picture of a monument or to tag a physical place). From the *technical point of view*, it is of primary relevance to balance sensing accuracy/precision and user resource utilization to avoid making the crowdsensing process cumbersome to users. In addition, there are hard technical challenges related to the efficient processing of incoming data to clean up corrupted entries, and the storage of data in a format that allows fast space-time queries, only to mention a few examples of central research topics. The boundary between social and technical challenges is even not clear cut: for example, the technical problem of minimizing global resource overhead by entrusting a minimal subset of users in a crowdsensing campaign requires analyzing large datasets to extract proper geo-social/preferences profile, for example to identify and infer which users are most likely to successfully harvest the required data.

In this perspective, this short contribution aims at giving a rapid but useful overview of the state-of-the-art in crowdsensing platforms for Smart City solutions with a twofold approach. On the one hand, we will concisely sketch an original design model and taxonomy to classify crowdsensing and participatory services: in particular, we will focus on the requirements of participatory service platforms, including the "traditional" sensing support at mobile devices, but also most original socio-technical needs, such as to control all policies and driving the whole large-scale deployment environment through a Smart City management supervisor, in charge of strategies to orientate the participating behavior and to analyze the currently available crowdsensing information. On the other hand, we will rapidly report about the most relevant and original aspects of our recent experience with our ParticipAct Crowdsensing Living Lab testbed, an ongoing experiment at the University of Bologna, which involves 150 students for one year in crowdsensing campaigns that can both access passively smartphone sensors and require active collaboration.

2. Crowdsensing for Smart Cities: a Taxonomy

Worldwide, large cities are extremely important in social development: 50% of the world population lives in cities, the top 100 urban centers account for 25% of the global Gross Domestic Product, and by 2050 urban population will be almost 6.4 billion people; socially, the tightly knit collaborative community of cities promotes free flow of ideas, leading to exponentially greater innovation. Since cities account for more than 75% of global energy consumption and are responsible for 80% of greenhouse gases, they must be considered the central focus for driving worldwide sustainability. The high population density and the many and many interconnected issues make effective city management a challenging task, but at the same time future smart cities provide countless opportunities of fostering people collaboration.

Several significant government and industrial research efforts are currently underway and confirm the impact that smart technologies may have on society in the near future. The European Digital Agenda has funded many projects, such as European Digital Cities [2], InfoCities [3], IntelCity roadmap [4], and EUROCITIES [5], to promote smart urban services. Around the world, the government of South Korea is building the Songdo Business District, a green low-carbon area that aims at becoming the first full-scale realization of a smart city [6]. Also many corporate initiatives are on the way. Among them a significant one is the IBM Smarter Planet project that promotes the deployment of several “smarter systems” to improve social progress [7], from smart grids and traffic managers to cheaper/safer healthcare. A similar effort led by Intel aims at using London as a testbed where users and the existing city infrastructure are exploited to improve city efficiency, e.g., to manage traffic flows, predict extreme weather conditions, and monitor water supplies [8].

Although new communication trends and developments have disclosed new forms of interaction, the whole information management cycle is today mostly focused around the virtual, immaterial, Internet computing world. People use their devices to communicate with their friends, to sense surrounding physical environment (e.g., making a photo/video, sampling a change of physical position through onboard GPS, etc.), and to upload significant amounts of user-generated information about it to the Internet. Socially-enabled services automatically connect and facilitate the delivery of interesting information to people sharing common interests and goals. At the same time, one of the main functions required to enable truly intelligent next generation Smart Cities is sensing the physical world. The more traditional Smart City solutions follow the approach to equip city areas of interest with many fixed monitoring sensors, and to deploy several (often overlapping) fixed sensing infrastructures covering the whole city and typically requiring high installation and maintenance costs.

Crowdsensing aims at overcoming the above issues and calls for the possibility to exploit the power of collective (though imprecise) intelligence to self-organize spontaneous and impromptu collaboration of large groups of people, participating with other people and opportunistically exploiting available physical devices and machines in their vicinity, in order to achieve a common sensing over the material physical world. In other words, while crowdsourcing aims to leverage collective intelligence to solve complex problems by splitting them in smaller tasks executed by the crowd, crowdsensing splits the responsibility of harvesting information (typically urban monitoring) to the crowd to enable collaborative corrective and management actions over Smart Cities.

Crowdsensing is a great example of a new class of *pervasive services*, we call them *participatory* ones, to clearly point out their crucial and groundbreaking feature of providing people with the chance to participate and act collectively. In short, the main aim of participatory services, and of crowdsensing as an important example and building block of them, is to close the loop between immaterial and material worlds in next generation large scale pervasive computing Smart City scenarios. Indeed, crowdsensing changes usual Smart City sensing by dynamically involving and coordinating several users in sensing campaigns and by exploiting smartphone computing&communication capabilities as a means to opportunistically involve mobile volunteers (see Fig. 1).

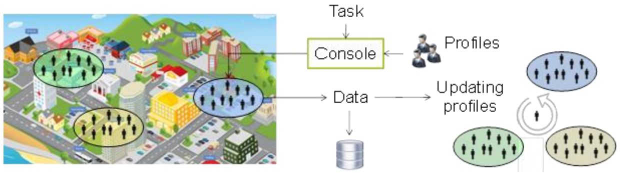


Figure 1 Smart City crowdsensing based on opportunistic involvement of volunteers

Effective support for crowdsensing in Smart Cities calls for various new features that include: i) management of crowdsensing campaigns (typically called *tasks*, to be delivered and accepted by volunteers); ii) efficient and smartphone-enabled sensing of data; and iii) accurate data post-processing and mining for profiling users and city areas (along space and time dimensions) to evaluate users’ effectiveness in completing assigned tasks (typically for future crowdsensing campaigns) and to analyze crowdsensing performance.

Each of these features relates to some original taxonomy directions crucial to fully understand the design decisions and tradeoffs available when putting together a crowdsensing platform. In particular, *campaign management* can be differently structured depending on i.a) how to promote user participation, i.b) which dimensions could be specified in task definition, i.c) how task/user state is maintained, and i.d) how and according to which strategies task assignment is performed. For what relates to *smartphone-based sensing*, most relevant dimensions of classification include: ii.a) which kind of sensing actions are enabled (e.g., active or passive ones [9]), ii.b) the possibility to have spatio-temporal awareness, and ii.c) how local sensor management is made efficient. Finally, about *data processing*, relevant classification directions relate to iii.a) adopted techniques for data fusion, interpolation, and integration, and iii.b) how user profiles can progressively improve task assignments in crowdsensing campaigns. For the sake of briefness, a more detailed discussion of the above orthogonal taxonomy dimensions and of how they can be used to analyze the design choices made so far in state-of-the-art platform proposals for Smart City participatory services is available in [9].

3. The ParticipAct Crowdsensing Living Lab

As a side-effect result of our state-of-the-art analysis, we felt the need of a new crowdsensing infrastructure, i.e., *ParticipAct*, started within the city of Bologna and connected with the students of the University of Bologna. ParticipAct intends to give the possibility of verifying on the field any desired crowdsensing strategy and of identifying suitable crowdsensing policies. The ParticipAct experiment engages 150 smartphone-provided students for one year of active participation: enrolled students can passively collect data by their smartphones, but also can do some requested activities within their usually traversed localities. We name ParticipAct the complete supporting infrastructure that allows local sensing actions, efficient transfer of client-sensed data to the server-side infrastructure, and server-side post-processing, mining, and maintenance of the overall Smart City data. The role of controlling all policies and driving the whole scenario is given to a supervisor that is also in charge of strategies to orientate the participating behavior.

The nature of ParticipAct requires client-server architecture: a client running on user devices as a smartphone app currently available for Android-based devices, takes care of receiving/running tasks and sending the associated results to a server, that can store, analyze, and use them. The ParticipAct client is the component that takes care of receiving tasks, asking users whether they want to run them (immediately or postponed), managing data collection, and uploading results. The ParticipAct client comprises two main components: the task manager and the sensing manager (Fig. 2). These components orchestrate the full lifecycle of tasks on user devices, and are responsible for both interacting with users and efficiently (mainly in terms of power consumption optimization) accessing smartphone sensors.

The task manager takes care of overseeing the whole task lifecycle on smartphones. It has five main responsibilities: i) receiving tasks from the server and keep their state synchronized ii) providing users with an interface to control task execution; iii) implementing the Graphical User Interface for active sensing actions that require user interaction; iv) driving sensing actions; and v) uploading sensed data, by temporarily storing them in a local database, and then sending them to backend components opportunistically or with batching optimizations. For the sake of space limitation, we will not detail here all the internal functions of our client, for which we refer interest users to [10]. The sensing manager, instead, builds atop MoST, an open-source Android sensing library that provides a uniform access layer to all physical and logical sensors [11]. MoST relevantly eases the burden of app developers who are willing to efficiently use sensor data by providing data processing and power management, while taking into account concurrency issues due to access to shared resources. The result is to make local sensing activities un-intrusive and minimizing impact on user experience.

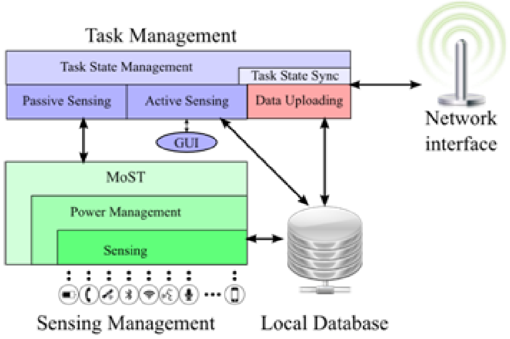


Figure 2 The architecture of the ParticipAct client

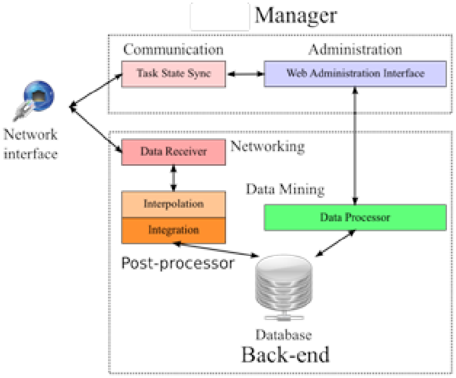


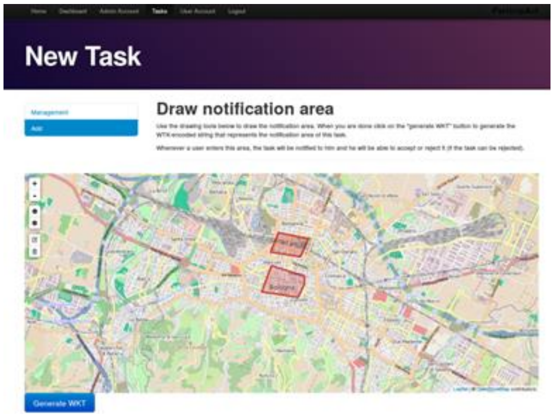
Figure 3 The architecture of the ParticipAct server side

The server side of ParticipAct provides management, storage, and analysis of crowdsensed data. At the highest level comprises two main parts, as shown in Fig. 3: the Back-end and the crowdsensing Manager. The Back-end takes care of receiving, storing, and processing sensed data, while the Manager provides the administrative interface to design, assign, and deploy sensing tasks.

In addition to the communication components, the Back-end includes interpolation and integration post-processing functions as well as data processing functions to derive user profiles. As regards the Manager, it is the administrator-facing part of ParticipAct that exploits the data processing/mining features exported by the Back-end to provide administration features. The Web

Administration Interface (Fig. 4) is the point of interaction of managers of crowdsensing campaigns with the ParticipAct system. ParticipAct adopts a template-based definition model that allows full administration of the whole crowdsensing, including management of user profiles, design and assignment of tasks, and data review. The Web Administration Interface does not require any specific technical knowledge and provides easy step-by-step wizards for each complex operation (e.g., creating a new task), thus minimizing the access barrier to ParticipAct also for city administrators. For instance, one of its core functionality is tapping into results provided by the Data Processor to automatically assign tasks to users that are more likely to successfully execute them.

As a practical example of ParticipAct usage, we concisely describe here our Mobility Mode Analysis (MMA) module. MMA exploits geolocalization and physical activity recognition to infer from raw data which are the preferred routes of users and how they travel along these routes. MMA integrates punctual and disconnected raw data to provide a more meaningful view of users by allowing to easily and quickly answer questions such as which are the preferred areas for walking/driving/biking, which is the preferred mobility mode by time and/or place, and so on. MMA integrates with Foursquare API for searching venue tags in an area, with Google Directions and Places API for dynamically obtaining info about train stations and bus stops, with OpenStreetMap for determining the shapes of roads and railways, and with the local Bologna bus company for bus routes. Implementation details and experimental results about MMA on top of the ParticipAct platform are available at http://participact.ing.unibo.it/



New Task

Draw notification area

Use the drawing tools below to draw the notification area. When you are done click on the "generate WKT" button to generate the WTK encoded string that represents the notification area of this task.

Whenever a user enters this area, the task will be notified to him and he will be able to accept or reject it (if the task can be rejected).

Figure 4 The ParticipAct Web Administration Interface, showing the interactive page for the definition of the geonotification area of a task

4. Conclusive Remarks

Crowdsensing enables new Smart City scenarios without the need for costly infrastructure investments [12]. We claim the need of identifying a proper taxonomy of the first sparse research proposals in this novel field, in order to clarify the related design dimensions and their consequences on resource utilization and performance tradeoffs. In addition, we believe that our ParticipAct platform could pave the way to a new generation of real-world large-scale crowdsensing testbeds able to truly verify any step in the whole crowdsensing process, from task scheduling to incentive and mobile sensing.

References

[1] B.J. Fogg, "A Behavior Model for Persuasive Design", Int. Conf. Persuasive Techn. (Persuasive'09), pp. 1-7, .2009.
[2] http://www.digital-cities.eu/
[3] http://www.infocities.eu/
[4] http://intelcities.iti.gr/intelcities
[5] http://www.eurocities.eu/
[6] http://www.songdo.com
[7] http://www.ibm.com/smarterplanet/us/en/overview/ideas
[8] http://www.ucl.ac.uk/news/news-articles/May2012/240512
[9] P. Bellavista, et al., "Crowdsensing in Smart Cities: Technical Challenges, Open Issues, and Emerging Solution Guidelines", book chapter in "Social, Economic, and Environmental Sustainability in the Development of Smart Cities", IGI Global, 2014.
[10] G. Cardone, et al., "Fostering ParticipAction in Smart Cities: a Geo-social Crowdsensing Platform", IEEE Communications Magazine, Vol. 51, No. 6, 2013.
[11] G. Cardone, at al., "MSF: an Efficient Mobile Phone Sensing Framework", Int. J. Dist. Sensor Networks, 2013.
[12] P. Bellavista, "Pervasive Computing at Scale: Challenges and Research Directions", IEEE Int. Conf. Sensors, 2011.

Paolo Bellavista is an associate professor at the University of Bologna (UNIBO), Italy. His research activities span from mobile computing and pervasive middleware to location/context-aware services and vehicular sensor networks, from big data adaptive stream processing to adaptive and scalable multimedia. He serves on the Editorial Boards of IEEE TC, IEEE TNSM, IEEE TSC, Elsevier PMC, Elsevier JNCA, and Springer JNSM.

Giuseppe Cardone graduated and received his Ph.D. in computer science engineering from UNIBO. He is now working at Google, UK. His interests include performance and scalability issues of distributed systems, wireless sensor network management, urban and mobile sensing, and power-aware middleware solutions.

Antonio Corradi graduated from UNIBO, received an M.S. in electrical engineering from Cornell University, USA, and now is a full professor at UNIBO. His research interests include distributed and parallel systems, middleware for pervasive and heterogeneous computing, infrastructure support for context-aware multimodal services, network management, and mobile agent platforms.

Luca Foschini graduated and received his Ph.D. in computer science engineering from UNIBO, where he is now an assistant professor. His interests include distributed solutions for systems/service management, management of cloud computing, context-aware session control and adaptive mobile services, and mobile crowdsensing.

Towards a Cloud of Things Smart City

Riccardo Petrolo, Valeria Loscri, Nathalie Mitton
Inria, France
Lastname.firstname@*inria.fr*

1. Introduction

Cities are growing steadily and urban living poses major challenges in our daily lives. In this context, Information and Communication Technologies (ICT) together with local governments and private companies, play a key role for implementing innovative solutions, to make smart cities a reality. In this context, the Internet of Things (IoT) is an enabler for a broad range of applications and services. The IoT goes through a larger and larger set of heterogeneous devices able to join the Internet spread within the cities among the citizens. It now makes sense to consider the scenario of these heterogeneous devices interconnected to each other and to exploit their synergy by involving their sensing and actuation resources in the Cloud. Nevertheless, there are still some challenges to face such as: 1) the interoperability among different ICT systems; 2) a huge amount of data to be processed provided in real-time by the IoT devices deployed in the smart systems; 3) the significant *fragmentation* deriving from the multiple IoT architectures and associated middleware; 4) heterogeneous resources mashup, namely how to orchestrate resources of the various Clouds. Concerning the last item, the concept of IoT, with underlying physical objects abstracted according to thing-like semantics, seems a valid starting point for the orchestration of the various resources. In this context, the Cloud concept could play the role to connect the IoT with the *Internet of People* through the *Internet of Services*, by the means of a horizontal integration of various silos.

In this paper, we introduce the concept of the Cloud of Things (CoT), starting from the traditional Cloud computing concept (Section 2). The CoT concept goes beyond the interconnection and hyperlink of things. It is a horizontal integration of different IoT networks silos and the associated cloud computing. The development of the convergence of diverse IoT platforms and Clouds goes through implemented abstraction, virtualization and management of things. A precise design of these mechanisms will permit the development of a technological-agnostic architecture, where the integration and deployment of diverse devices and objects can be considered by neglecting their underlying architecture. Based on the requirements a smart city should fulfill (Section 3), we show how the combination of IoT and CoT can make the cities smarter and more sustainable. We illustrate the Cloud of Things concept through the description of the VITAL architecture developed in the framework of the FP7 VITAL project, a CoT-based architecture, able to meet many critical requirements of a smart city, and we will show how this platform can be considered to bridge different and heterogeneous IoT silos and be effective solution to be applied for the realization of a smart city (Section 4).

2. Toward a Cloud of Things

Cloud Computing attracts the attention from both academy and industry across the world, thanks to its ability of transforming service provision models over the entirely current IT industry with reduced upfront investment, expected performance, high availability, fault-tolerance, infinity scalability, and so on. The services can be divided in three layers [12]:

- *Infrastructure as a Service (IaaS)* which offers computing resources such as processing or storage;
- *Platform as a Service (PaaS)* to allow software developers to write their applications according to the specifications of a particular platform independently of the underlying hardware infrastructure;
- *Software as a Service (SaaS)*, the most visible layer for end-users, focuses on the actual software applications accessed and used.

In addition to the above main layers, some others are also introduced and discussed in literature such as Data as a Service (DaaS), Network as a Service (NaaS), Identity and Policy Management as a Service (IPMaaS). In [2] authors introduce XaaS (everything as a service model) that promotes the *pay as you go* method, allowing the consumption of a service by paying only for the amount of resources used. Within the IoT context, such an approach leads to the Cloud of Things [9], which deals to implement indexing and querying services of *things*, and provides them to final users, developers, provides. One interesting model to enable a CoT [13] focuses on the *Sensing as a Service (SeaS)* model based on IoT infrastructure, relying on four conceptual layers (See Fig. 1):

- *Sensor and Sensor Owners Layer:* sensors and how to manage them with possible publication in the cloud.
- *Sensor Publishers* to detect available sensors and get permission to publish them in the cloud.
- *Extended Service Providers* to select sensors from multiple publishers based on customer's requirements.
- *Sensor Data Consumers* that need to register to consume sensors data.

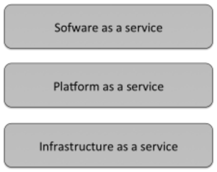


Figure 1 Cloud Computing service models [12]

The advantages and benefits promised by the *Sensing as a Service* model are numerous, and just to name the majors we have: *sharing and reusing of sensor data* (if someone has already deployed the sensors, others can get access to them by paying a fee to the sensor owner), *reduction of data acquisition cost* due to the shared nature, *collect data previously unavailable* (thanks to the business model, companies are stimulated to "sell" them sensors data). In the last few years, researchers have mainly focused on representing the observation and measurement data from sensor networks, according to the Sensor Web Enablement (SWE) proposed in [4] by the Open Geospatial Consortium (OGC). However, these standards do not provide facilities for abstraction, categorization, and reasoning rather offered by [7], within the W3C Semantic Sensor Network Incubator group (SSN-XG) defined an OWL2 ontology, answering the need for a domain-independent and end-to-end model for sensing applications by merging sensor-focused (e.g. SensorML), observation-focused and system-focused views. It has received consensus of the community and has been adopted in several projects like Spitfire EU Project. Solutions handling heterogeneous communications for resource-constrained devices are provided by 6LoWPAN and CoAP [8]. 6LoWPAN allows the integration of sensor to the Internet thanks to transmission of IPv6 packets. In order to convert IPv6 packets to 6LoWPAN and vice versa, a gateway (i.e. border router) takes care of the necessary tasks such as header compression and enables the seamless usage of IPv6 across the heterogeneous network architectures. CoAP is an application layer protocol designed for energy-constrained devices. It deals with Constrained RESTful Environments (CoRE) [16], providing a lightweight alternative to HTTP. Devices supporting CoAP provide flexible services over any IP network using UDP. Any HTTP client or server can interoperate with CoAP-ready endpoints by simply installing a translation proxy between the two devices [6]. Summing up, IoT devices can be connected to the Internet, their data can be annotated using a sensor ontology (i.e., SSN ontology), encoded in standard Web formats (i.e., RDF), and made available on the Cloud, establishing therefore the *Cloud of Things*.

3. Smart City Requirements

As remarked in [1], the main ICT-based services and solutions requirements in the Smart City domain can be classified as: 1) *service/application*, considered from the point of view of the citizens and 2) *operational*, seen from the city authorities and administrators of the networks point of view. Concerning the *service/application* aspects, the end-users devices equipped with multiple radio technologies and the several sensors and actuators deployed all over the cities, make possible the individuation of novel services and applications for the citizens. These services will have specific features, like: a) *user-centric*: based on the specific context and the preferences of the users, b) *ubiquitous*: reachable everywhere and from any devices, and c) *highly-integrated*: based on the integration of services and data from several and different applications or on the social cooperation of multiple users. Of course, beyond the citizens, also the stakeholders of a city, like educational institutions, healthcare and public safety providers, governmental organizations, etc. will be in conditions to exploits the key features of these new services that make the city more sustainable. On the other hand, the Smart City concept considered from the point of view of the administrations and the providers of the networks are translated in a network infrastructure that is: a) *highly-interconnected*: by overcoming the heterogeneity of the devices and the IoT platforms, it is possible to provide ubiquitous connectivity, b) *cost-efficient*: the deployment and organization of the network should be as much automatic as possible and independent from the human intervention, c) *energy-efficient*, able to realize an efficient resource utilization, in order to meet the main requirements of *green* applications d) *reliable*: connectivity of the network should be guaranteed above all in the case of exceptional and adverse conditions. The real scenario we can currently observe is characterized with an high level of *fragmentation* of technologies, lack of ubiquity in terms of both connectivity and coverage. This *fragmentation* is mainly due to the presence of many access networks usually managed by different operators (i.e. UMTS, WiMAX, WiFi, etc.). Even if some steps ahead have been moved recently, most of these initiatives are related to specific cities and do not consider general architectures. By considering the main IoT platforms and the CoT concept, we will try to explain how the main requirements of a city to become a smart city, can be fulfilled and at the end we will show how the VITAL platform can play the role of "interconnecting" heterogeneous ICT silos and devices.

4. IoT and CoT for a Smart City

Despite there is not yet a formal and universally accepted definition of "Smart City", in [10], authors try to delineate the concept, defining a Smart City as a city which functions in a sustainable and intelligent way, by integrating all its infrastructure and services into a cohesive whole and using intelligent devices for monitoring and control, to ensure sustainability and efficiency. This interpretation makes evident, therefore, that Smart City concept needs *interoperability* between the different IoT deployments that are, today, mainly closed and vertically integrated to specific application domains [15].

These solutions are based on multiple architectures, standards and platforms, which have led to a highly fragmented IoT landscape and making challenging the realization of the Smart City concept. According to [11], the IoT structure divided into 5 layers:

- *Device Layer*: to identify and collect objects specific information by the sensor device;
- *Network Layer*: to send data collected by the Device Layer to the information processing system;
- *Middleware Layer*: to process information and take automatic decision based on the results;
- *Application Layer*: to provide global application management based on the information processed through the Middleware;
- *Business Layer*: to manage the overall IoT system.

Within the context of Smart City [5], the *Cloud of Things* can make a better use of distributed resources, achieve higher throughput and tackle large scale computation problems [14], enabling therefore, the horizontal integration of various (vertical) Internet of Things platforms and so the Smart City vision. Moreover, it allows users to express the service they want providing the relevant data back to them quickly without asking the users to manually select the sensors.

Certainly, CoT needs to deal with several research challenges, the major residing in the heterogeneity and of sensor types (e.g., NFC, RFID), and in communications (e.g. Wi-Fi, ZigBee) and their interoperability with the cloud. It is therefore important to define an *abstraction level*, in order to bridge the gap between the disparate technologies. A solution to overcome the obstacle is provided by the *data abstraction*, that includes methods and solutions to structure, annotate, share and make sense of the IoT data and facilitate transforming it to actionable knowledge and intelligence in different application domains.

Data access could be implemented at low-levels (e.g., device or network layers) using low-level programming languages and operating systems.

Regarding the various sensor type, the use of the technologies developed in the semantic web such as ontologies, semantic annotation, linked data [3] and semantic web services has recently gained momentum in this field. These technologies promote interoperability among IoT resources, information models, data providers and consumers and simplifies effective data access and integration, resource discovery, and knowledge extraction [2].

5. VITAL as a CoT-based Smart City platform

One of the most important objectives of VITAL is about the integration of sensors and interconnected objects among multiple IoT platforms and ecosystems. The project explores the convergence and federation of multiple IoT platforms by taking into account the cost efficiency of the deployments. In the context of VITAL, a very key factor is represented by the virtualization of interfaces that in combination with cross-context tools that enable the access and management of heterogeneous objects supported by different platforms and managed by different administrative stakeholders let us to define the VITAL platform as a Cloud of Things architecture.

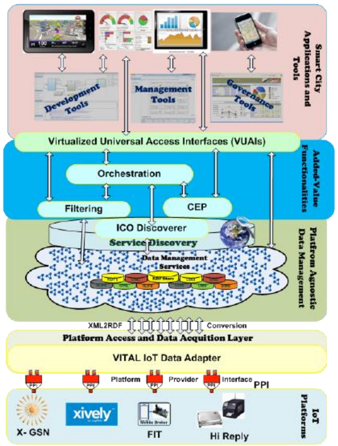


Figure 2 The VITAL platform

As we can observe in Figure 2, the data and services access of the heterogeneous objects involved in VITAL, is based on the implementation of the VUAIs (Virtualized Universal Access Interfaces), that makes possible to consider a single virtual access by making the architecture platform-agnostic. These key features of VITAL make this platform able to embrace the CoT philosophy. The VUAI layer is built upon a so-called meta-architecture and migration layer and includes several connectors to communicate and interconnect different IoT platforms and clouds. In practice, this module deals with issues related to the management of the overall VITAL infrastructure, built on top of existing IoT architectures and clouds platforms and enable heterogeneous mashup. The VUAIs allow the implementation of a kind of abstraction, where "objects" handler that point to physical items, can be discovered, selected and filtered and also allocated by following a Things as a Service (TaaS) paradigm. In this sense the VITAL as CoT platform is something that goes beyond the interconnecting and hyperlinking "things" of the IoT paradigm. VITAL also includes a datastore for data like geographical information and smart city stakeholders. Of course, it is expected that the management of this kind of information giving location awareness and other context related information can be effectively exploited in the optimization of computing and sensing of the management of the various clouds. The CoT paradigm implies the implementation of querying services and indexing of things, the aggregation of heterogeneous resources based on a given thing-like semantics and provided to the final stakeholder (final user, developer, etc.). Moreover, the CoT concept explicitly has to consider mechanisms to abstract, virtualize and manage things as performed in VITAL. It is worth to outline that VITAL is based on W3C SSN ontology, that is considered ideal as basis for unifying the semantics of different IoT platforms, since it is domain independent and extensible. Several additional concepts have to be considered to enhance the ontology starting from information about city-wide, stake-holders, IoT system, etc. The ontology update with additional functionalities will allow the migration of smart city application across different urban environments.

6. Conclusion and Future Challenges

In this paper we have shown the necessity to bridge the gap between the different IoT platforms and how the Cloud computing can stand as a valid bridge of the IoT, Internet of people through the Internet of Services. This novel perspective allows the realization of a horizontal integration of various vertical platforms like the VITAL CoT-based platform a very promising solution for the fragmentation issues in the context of Smart Cities. There are still different challenges related to the Cloud of Things in smart cities, from both technical and privacy point of view:

- *Big Data.* The overall IoT data produced by *things* is growing up fast and can be processed by *engineering* to perform data management such as query, and storage efficiently; and *semantic*, to extract the meaning of the information from massive volumes of data.
- *Privacy & Security.* One of the main problematic is to define mechanisms in order to let "sensor owners" the decision to publish or not the data. Other issues may come from the cyber-crime. The system must be prone to cyber-terrorism and cyber-vandalism.

References

[1] Aloi G., et al. STEM-Net: an evolutionary network architecture for smart and sustainable cities. Trans. on Emerging Telecommunications Technologies 25, 1 (2014).
[2] Banerjee, P., et al. Everything as a Service: Powering the New Information Economy. Computer 44, 3 (2011).
[3] Berners-Lee, T. Linked data. W3C Design Issues (2006).
[4] Botts, M., et al. Sensor Web Enablement: Overview And High Level Architecture. OGC White Paper OGC 07-165 (2007).
[5] Caragliu, A., Del Bo, C. and Nijkamp, P. Smart cities in Europe. Tech. Rep. 0048, University Amsterdam, 2009.
[6] Castellani, AP, Gheda, M, Bui, N, Rossi M. and Zorzi, M. Web Services for the Internet of Things through CoAP and EXI. Proc. conf. on Communications Workshops (ICC) (2011).
[7] Compton, M., et al. The SSN ontology of the W3C semantic sensor network incubator group. Web Semantics: Science, Services and Agents on the World Wide Web 17 (2012).
[8] Costantino, L., et al. Performance analysis of an LTE gateway for the IoT. In Proc. WoWMoM (2012).
[9] Distefano, S., Merlino, G., and Puliafito. Enabling the Cloud of Things. In Proc. Innovative Mobile and Internet Services in Ubiquitous Computing (2012).
[10] Hancke, GP. And Silva, BCA. The role of advanced sensing in smart cities. Sensors 13, 1 (2013).
[11] Khan, R., et al. Future Internet: The Internet of Things Architecture, Possible Applications and Key Challenges. In Proc. Of Int. conf. on Frontiers of Information Technology (FIT) (2012).
[12] Patidar, S., Rane, D., and Jain, P. A Survey Paper on Cloud Computing. In Proc. Second Int. conf. on Advanced Computing & Communication Technologies (2012).
[13] Perera, C., Zaslavsky, A. B., Christen, P., and Georgakopoulos, D. Sensing as a service model for smart cities supported by Internet of things. Trans. Emerging Telecom. Technologies 25, 1 (2014).
[14] Rimal, B. P., et al. A Taxonomy and Survey of Cloud Computing Systems. In Proc. Joint conf. on INC, IMS and IDC (2009).
[15] Sanchez, L., et al. SmartSantander: Experimentation and service provision in the smart city. In Proc. of WPMC (2013).
[16] Taherkordi, A., and Eliassen, F. Restful service development for resource-constrained environments. In REST: From Research to Practice. 2011.

Riccardo Petrolo is a PhD student since october 2013 at Inria Lille - Nord in the FUN Research Group. His PhD topic focuses on IoT, virtualization and discovery in the Smart City concept within the FP7 VITAL project. In 2012, he received his Master's Degree in Engineering and telecommunication from "Mediterranea" University of Reggio Calabria, Italy.

Valeria Loscri is a permanent researcher of the FUN Team in Inria Lille Nord Europe since October 2013. She got her Master degree in Computer Science and PhD in Systems Engineering and Computer Science in 2003 and 2007 respectively, both at University of Calabria (Italy). In 2006 she spent 6 months as visiting researcher at Rice University under the supervision of Prof. Knightly, where she worked on the MAC layer of wireless mesh networks. She is involved in several programs and organization committees such as SWANSITY 2014, WiMob 2014, IDCS 2014, ICCCN 2012. Her research interests focus on performance evaluation, self-organizing systems, robotics networks, nanocommunications.

Nathalie Mitton received the MSc and PhD. degrees in Computer Science from INSA Lyon in 2003 and 2006 respectively and her Habilitation à diriger des recherches (HDR) in 2011 from Université Lille 1. She is currently an Inria full researcher since 2006 and from 2012, she is the scientific head of the Inria FUN team. Her research interests are mainly focused on self-organization, self-stabilization, energy efficient routing and neighbor discovery algorithms for IoT. She is involved in the set up of FIT platform and in several program and organization committees such as AdHocNets 2014, WiMob 2013, MASS 2012, WPMC2012, iThings 2012, Comnet-iot 2012, etc. She also supervises several PhD students and engineers.

Smart Cities: Business Case Stories

*Xavier Vilajosana+, Ignasi Vilajosana+, Francesc Domingo+ and Jordi Ortuño**
+Worldsensing, Spain
**Barcelona City Council, IMI, Spain*
{xvilajosana, ivilajosana, fdomingo}@worldsensing.com
jortunor@bcn.cat

1. Introduction

As city's population density grows, the Smart city concept is becoming more and more important element for the urban development strategy. Most of the cities are facing traffic congestion, environment pollution and the resources to handle these issues are very limited. Generally, the Smart city concept is seen as a tool to alleviate these problems, however, the Smart City introduction only related to the introduction of ICT infrastructure to optimize costs, improve services provisioning and reduce environmental footprint is not taking off.

The latter is attributed to the fact that there are no transversal Smart cities departments, the market is fragmented, the funding is scarce and there is no clear regulatory environment. As a result, the adoption of a Smart city holistic approach is very slow [1][2]. However, we are observing a nascent trend where the introduction of the smart cities is based on specific smart use cases[2] [3]. Use cases relate to specific improvement opportunities in specific areas of the city which show a clear benefit for multiple stakeholders. They usually involve a multidimensional approach and several technologies, stakeholders, service providers and receivers. The scope is narrower but they show normally clear answers to specific city problems.

2. The Smart City Enablers

The *Use Cases* intend to prove the concepts and methodologies to systematically manage a service based on ICT technologies before introducing smart services in a broader scale. Small to mid-scale city related business cases are becoming enablers when trying to introduce a State-of-the-Art technology that could significantly improve the quality of life of any city's entire population.

Notably, multiple Smart City solutions have become available over the last years with several blue-chip and start up players heavily investing in marketing and technology solutions for the creation of Smart Cities solutions [3][4].

However, most of these technologies and platforms alone are either too transversal or only partially solving city challenges. With this approach they do not take into account that cities are complex institutions, vertically segmented and sometimes decision makers only have a vague notion of the Smart City concept. Although they normally recognize the potential of the technologies, they usually do not know how ICT can be used within a large part of the operationalization of the Smart City services or simply the projects are too large and risky to be developed. Use Cases are seen as an opportunity to solve specific multidisciplinary city challenges and test new procurement processes, new technologies and foster inter-departmental collaboration.

Use Cases identification and development represents an opportunity to systematically introduce the Smart City services. For that reason, throughout this article, we try to take a closer look to some successful use cases and their value propositions. Finally, we discuss how the use case's underlying ICT infrastructure can help to introduce more transversal Smart City technologies.

3. Smart City Use Cases

Behind the ordinary public services offered by cities and the typical technologies offered by vendors (traffic management, parking meters, or LED lightning) we find that cities face specific needs which strongly impact citizen's welfare, service efficiency or specific optimization of resources and do not fit to specific out of the box solutions.

They aim to improve the quality of life for their residents by creating smart services, enabling greater mobility, efficiency, safety and sustainability. These scenarios usually involve multiple technologies and target a clear goal in a delimited area.

Well known smart city use cases are those related to improving traffic and drivers experience moving to city center (e.g., Moscow, London, Los Angeles, San Francisco, Barcelona (see Figure 1)), Adapting historical areas to new uses (Hamburg) or improving efficiency of operations taking advantage of construction contracts (Barcelona).

---

[2] Hamburg harbor project press release
http://www.traffictechnologytoday.com/news.php?NewsID=58543

[3] Smart Barcelona press release
http://w2.bcn.cat/bcnmetropolis/dossier/els-reptes-de-la-barcelona-intel%E2%80%A2ligent/

For example, cities like London, Moscow or San Francisco adopted parking and traffic management solutions to reduce traffic and enhance drivers experience in their cities while increasing the park meter income accounting and parking enforcement.

In all the cases the underlying technology is based on a set of sensors that are able to trace and capture the presence of a vehicle in the instrumented area. The presence information is correlated to parking meters payments and used to improve payment enforcement and alleviate car ballot times. The same technology is applied to load and unload areas in the city to enforce maximum allowed parking time. Traffic management is improved by analyzing time to destination matrices and flows of traffic which are announced to car drivers to inherently load balance the congestion [5].

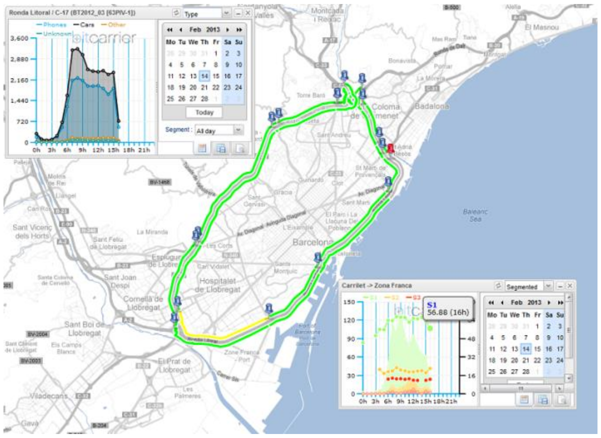


Figure 1 Traffic density map in the first ring of the city of Barcelona.

Some cities are rebuilding their historical centers and adapting them to new realities. For example the City of Hamburg is rebuilding the harbor area to make it more citizens friendly, to reduce traffic and pollution but at the same time improve harbor operations. The project consists on deploying a combination of technologies such smart street lighting; smart traffic systems to optimize vehicle flows and detect incidents earlier; an environment and infrastructure monitoring for predictive maintenance; The Port Authority is also planning to capture and analyze emissions data, in order to be able to provide more reliable forecasts on noise, temperatures, humidity, and pollution.

Barcelona in its own is addressing Smart City technology introduction by covering strategic axis including mobility, lighting and water management amongst others which impact city sustainability. Indeed, the city is introducing smart solutions including, pollution, acoustic, seismic and smart lighting in any refurbishment of a city artery as well as introducing the electric vehicle and its infrastructure to support low emission policies and improve city efficiency.

As an example we present the case of city lighting which is well addressed in the city of Barcelona. Lighting is an important community service, which can consume as much as 40 percent of a city’s energy budget. Legacy street lights are failure prone and costly to manage, which add to lighting costs. Consequently, street lighting has emerged as a leading smart city application and smart strategies such the proposed by Barcelona accelerates their absorption. Barcelona is replacing existing street lights with LED-based lamps enabling utilities and other street light operators to significantly cut energy and operations costs.

4. Smart City Technology

Technologically, we see the smart city concept being split in three main areas, a) the capillary: sensing and actuation technology deployed around the city instrumenting infrastructures which report data; b) the Fog: those gateways and intermediate nodes that filter, aggregate, take local decisions and compute relevant information that is sent to the cloud [6] while providing an horizontal infrastructure; and c) the big data: massive storage and analytics applications running on the cloud that are inferring knowledge, anticipating events, and continuously optimizing the city operation.

The Capillary Nodes

Key enablers of aforementioned applications are wireless communications and sensing and actuating technologies combined to the evolution of low power microcontrollers and transducers. Analogously to multimedia technologies, the smart city ecosystem is being populated by multi-network technologies, based on multiple paradigms but with one common denominator, overcome signal propagation problems due to the nature of cities (buildings, moving metals, outdoors, underground sensors, etc..) whilst enabling dense coverage. One flavor of that technologies are those based on multi-hop low power mesh networks, known as Low Power Lossy Networks (LLNs), enabled by IEEE802.15.4/e and IETF 6TiSCH [7] [8] standards that proved to work in relatively small deployments, mostly above one meter over the ground level [9]. Recently Low Power Wide Area Networks (LPWAN) emerged with revolutionary ideas, providing very restricted data-rates and robust modulations; they enable star topologies covering distances in the order of few kilometers. This leverages the cost of multi-gateway deployments required by LLNs and enforces the concept of metropolitan area networks, all at the cost of restricted data rates, few standardization support and considerable constrains imposed by ETSI regulations. In opposition (in terms of network capabilities) we find new IEEE 802.11 variants (e.g., IEEE 802.11ac) which appear as clear contenders for real time streaming of sensor data and multimedia content at the cost of higher energy consumption.

And finally the ubiquitous cellular networks, which are quickly moving to higher data rates and reduced energy footprints, are becoming the real candidates to lead the IoT, but still at the M2M level, operators and providers need to work on reasonable business models.

Fog Computing

In several of the smart city scenarios, applications and services do not fit well to the Cloud paradigm, including applications that require low and predictable latency, geo-distributed applications, fast moving applications and large scale distributed control systems [6]. The Fog computing concept appears as a “man in the middle” to support those scenarios and to optimize the processing of huge amounts of data. The Fog computing relies on distributed gateway nodes that are able to extract information from raw data, take local decisions and communicate to the Cloud only that relevant information, leveraging the requirements of massive data storage of cloud systems. Vendors like CISCO are taking advantage of the concept providing horizontal infrastructures to cities, for example using WiFi technologies to enable multi-vendor deployments managed by the same infrastructure (e.g., Hamburg harbor)

Big Data and Cloud Computing

Massive data storage and analytics are key enablers of the Smart City concept and where 70% of the value resides. By analyzing data from the cities, human behavior can be characterized and cities accommodated to the needs of the society. Several trade-offs need to be faced by the adoption of Cloud based smart city technologies. One of the most challenging aspects is the convergence of existing ICT infrastructure (e.g., Cities rely on their SCADA systems and specific applications which control red lights, pipes, traffic, etc…) to new applications that integrate the management and operation of wider sets of technologies introduced by smart city use cases. City councils usually are reluctant to adopt vendor specific platforms but in contrast they require some level of integration to their existing infrastructure, usually at API level or at database level [10][11]. The later indicates that city control panels will not be provided by single vendors nor will be based on a single technology. We are seeing a clear movement of the city ICT management to dedicated service providers offering enterprise cloud services and application integration. But data integration services will be handled in more ad-hoc manners, having multiple sources of data, multiple formats and providing standardized data formats and interfaces. In this role big players such as SAP, ORACLE, IBM, CISCO, MICROSOFT, etc… are providing enterprise level Extraction, Transformation and Load (ETL) integrated tools and powerful data visualization frontends that are able to infer knowledge from massive sets of distributed and heterogeneous sources of data.

Yet, in scenarios where cities need to have a holistic vision of the Smart solution set, information analysis becomes bidirectional, for governments who might be interested on improving the services offered to the citizens and also to be aware of the information flowing through the city. For example, in cities like Barcelona this is achieved by integration services provided by the city (named Sentilo) which are required to be integrated by smart city providers and contractors.

5. Concluding Remarks

This article has gone through our vision of current smart city development in terms of business cases, use cases and technological aspects. We are seeing a slow take off of the paradigm by means of focused *Use Cases* where ICT infrastructures clearly increase citizens’ welfare. We envisage massive adoption of Smart City technologies constrained by the success of ongoing use cases. Technologically we see wireless communications as clear enablers but still technology fragmentation and operator business models are limiting large deployments. Fog Computing is enabling horizontal multi-vendor infrastructures which facilitate multi-application smart cities while enterprise cloud infrastructures and powerful (ad-hoc) analytics sitting on top of heterogeneous and distributed sources of data concentrate 70% of the value behind the smart city paradigm. Finally, we see, Smart Cities as welfare enablers, economy boosters and technology test-fields that are in their way to be consolidated through very detailed *Use Cases*. Some people claim the emergence of a several billion dollar market but still the horizon is being drawn, and the most challenging aspect is the combination of complex disciplines that have to deal with complex structures of the society.

References

[1] I Vilajosana, I.; Llosa, J.; Martinez, B.; Domingo-Prieto, M.; Angles, A.; Vilajosana, X., "Bootstrapping smart cities through a self-sustainable model based on big data flows," Communications Magazine, IEEE, vol.51, no.6, pp.128,134, June 2013 doi: 10.1109/MCOM.2013.6525605

[2] Mischa Dohler, 2013. Designing Smart Cities in 2013. https://connect.innovateuk.org/web/design-sig/article-view/-/blogs/designing-smart-cities-in-2013. [Accessed: 28 July 2014].

[3] FastPrk. Worldsensing. www.worldsensing.com

[4] City Solver. BitCarrier. www.bitcarrier.com

[5] Traffic Technology Today."World's largest Intelligent Parking system deployed in Moscow". Jan 2014. http://www.traffictechnologytoday.com/news.php?NewsID=55759

[6] Flavio Bonomi, Rodolfo Milito, Preethi Natarajan, and Jiang Zhu. Fog computing: A platform for internet of things and analytics. In Nik Bessis and Ciprian Dobre, editors, Big Data and Internet of Things: A Roadmap for Smart Environments, volume 546 of Studies in Computational Intelligence, pages 169--186. Springer International Publishing, 2014

[7] Palattella, M.R.; Accettura, N.; Vilajosana, X.; Watteyne, T.; Grieco, L.A.; Boggia, G.; Dohler, M., "Standardized Protocol Stack for the Internet of (Important) Things," Communications Surveys & Tutorials, IEEE , vol.15, no.3, pp.1389,1406, Third Quarter 2013 doi: 10.1109/SURV.2012.111412.00158

[8] M.R. Palattella, P. Thubert, X. Vilajosana, T. Watteyne, Q. Wang, T. Engel, " 6TiSCH Wireless Industrial Networks: Determinism Meets IPv6", in S. C. Mukhopadhyay (Edt), " Internet of Things: Challenges and Opportunities", Springer-Verlag, Lecture series of Smart Sensors, Instrumentation and Measurements, to be published in 2014.

[9] Albert Angles, Pere Tuset,Xavier Vilajosana ,Jose Lopez Vicario, Antoni Morell, Ignasi Vilajosana. "A generic empiric propagation model for low power wireless networks operating at the 868 MHz band in smart cities" IET Microwaves, Antennas & Propagation.

[10] Gordon Falconer, Shane Mitchell, 2012. Smart City Framework A Systematic Process for Enabling Smart+Connected Communities. http://www.cisco.com/web/about/ac79/docs/ps/motm/Smart-City-Framework.pdf [Accessed: 27 July 2014].

[11] P. Fritz, M. Kehoe and J. Kwan, "IBM Smarter CitySolutions on Cloud," White Paper, 2012, http://www-01.ibm.com/software/industry/smartercities-on-cloud. [Accessed: 27 July 2014].

Xavier Vilajosana is CIO of Worldsensing. He is also associate professor at the Open University of Catalonia (UOC). From January 2012 to January 2014, Xavier was visiting Professor at the University of California Berkeley holding a prestigious Fulbright fellowship. In 2008, he was visiting researcher of France Telecom R&D Labs, Paris. Xavier has been one of the main promoters of low power wireless technologies. He is author of different Internet Drafts and RFCs, as part of his standardization activities for low power industrial networks. Xavier is contributing actively at the IETF 6TiSCH WG. He is author of 6 patents and more than 25 high impact journal articles. He holds an MsC degree on Computer Sciences from the Universitat Politècnica de Catalunya (UPC) and a PhD on Computer Science from the Universitat Obertat de Catalunya.

Ignasi Vilajosana is the CEO of Worldsensing and Endeavor Entrepreneur; he has strong experience in all stages of company start-up and development. Ignasi has over 10 years of experience in the geophysical sector. He holds a PhD in Physics where he has authored numerous high impact publications. He also has a strong background in fund-raising, strategy and business growth projects. Recently he has received business training to lead Worldsensing strategy.

Francesc Domingo holds a Master in Project Management and a degree in Telecommunications for the University Ramon Llull in Barcelona. He has been involved within the traffic and smart city industries for more than 10 years. He has strong technical background and business focus that combines with his strategic technological vision. Francesc has been key to developed the growth of Worldsensing traffic division internationally. He is author of several publications and frequent speaker at international smart city events.

Jordi Ortuño is Project Coordinator of the Smart Cities Projects in IMI (Barcelona City Council). He has strong experience in IT and Consulting projects both private (automotive mainly) and public Administration. He holds a Bachelor in Economics and he is in charge of Mobility Projects where he is a member of Live platform (Logistics for Electric Vehicle Deployment).

On the Estimation of the Free Size of Parking Places in Smart Cities by Using Wireless Sensor Networks

Ioakeim Samaras and John Gialelis
Industrial Systems Institute/ATHENA RC, Science Park of Patras, Patras, Greece
{*samaras, gialelis*}*@isi.gr*

1. Introduction

The smart city concept is increasingly becoming a reality. However, the mathematical models that describe the behaviours of many of the systems and applications used in these cities remain unknown. In particular, one such smart city application problem is the estimation of the free size of parking places using wireless sensor networks (WSN) placed in the ground below these places [1].

Expert systems seem to be a remarkable solution for emulating the behavior of a specific system whose mathematical model is unknown [2]. However, the knowledge of this behavior is a prerequisite while it often includes the vague and uncertain representation of numerical data [3]. Nevertheless, fuzzy set theory can deal with such data representations. In particular, a fuzzy rule-based expert system contains fuzzy rules in its knowledge base and derives conclusions as outputs from the user inputs [4]. These features constitute a fuzzy inference system (FIS) [4].

For the above reasons, the usage of FISs in order to solve the problem of the estimation of the free size of parking places using WSN becomes attractive. This feature will enable backbone networks to inform drivers via Internet whether their vehicle can fit into a specific parking place or not. As a result, redundant vehicle movements in the city in order to reach vacant parking places with smaller size than the size of the vehicle can be avoided. Therefore, this paper examines available related solutions in the literature and analyzes and discusses their contributions.

This work is organized as follows. In Section 2, related studies are demonstrated. Then, in Section 3, the implementation of the most promising study and its computation cost are discussed in detail. Also, in Section 4, simulation results related to the energy consumption of the wireless sensor motes (WSM) of the WSN used in the aforementioned study are presented. A data fitting and optimization problems are solved in Section 5 in order to find the optimal parameters of the FIS. Section 6 concludes the paper.

2. Related work

Most of the studies related to parking facilities for smart cities are focused on improving the quality of service which informs the drivers about the status of a parking place, i.e. whether it is occupied or not. Also, the guidance, the information storage, the parking assistant, and the payment facilities are of paramount importance.

For example, in [5] an intelligent parking space inventory control system that is based on a combination of fuzzy logic and integer programming techniques is proposed. It concerns the parking reservation and revenue management and makes online decisions about whether to accept or reject a new driver’s request for parking based on the available parking places and the vehicles arrivals and departures. Its purpose is to maximize the parking revenue when the future traffic arrival patterns are known. Then, based on the aforementioned maximization, the rules of a fuzzy logic are defined and are used in order to accept or not a driver’s request. Moreover, in [6], parking places and vehicles are equipped with sensors which sense the location and status of the aforementioned places. This information is shared with other vehicles in order to achieve efficient vacant parking place discovery. Also, in [7], an agent-based model for parking in the city is demonstrated. This model simulates the behaviour of each driver in a spatially explicit environment and is able to capture the complex self-organizing dynamics of a large collective of parking agents. Furthermore, in [8] an intelligent agent-based system is presented which considers negotiable parking prices that take place between vehicle drivers and vehicle park operators (such as gateways) while the optimal parking place for a driver is selected. It includes capabilities, such as planning, and execution monitoring which are used in order for a driver to be informed more effectively about the prices of vacant parking places. Additionally, in [9] a system that allows users to reserve parking places through Internet is presented. In this system, the driver uses the Bluetooth technology in order to be recognized at the entry points of a parking lot. Furthermore, in [10] the WSMs are equipped with magnetic sensors in order to determine the status of fixed parking places. On the contrary, in [11] and [12] the WSMs are equipped with light sensors for the same purpose. In [13], ultrasound sensors, located on the roof of a parking lot with fixed parking places, communicate with other facilities through a phone cable. Also, the development of a novel cluster algorithm is discussed in [14] for an Arduino-based WSN which determines the status of parking places by using ultrasound sensors. Moreover, in [15] a WSN and a parking algorithm based on finite state machine logic and magnetic sensors are utilized to decide whether a parking place is occupied or not. Finally, in [16] vehicles are equipped with communication devices in order to be guided towards a parking place. An intelligent antitheft algorithm is used so as for every vehicle to be guarded but it is not clear how the status of parking places is determined.

As far as the related research projects are concerned, the SmartSantander [17], the ExpressPark [18], and the SFpark [19] seem to be the most remarkable ones. The first one aims at applying in the city of Santander and its environment a platform composed of sensors, WSNs, actuators, and cameras to offer useful information to citizens. As a result, environmental parameters can be monitored for study while citizens can be informed about available parking places. The ExpressPark and the SFpark have approximately the same goal but the environmental monitoring is not a primary concern.

As it is evident from the above mentioned works and studies, no effort exist for estimating the free size of parking places. To the best of the authors knowledge, our previous work presented in [1] introduces for the first time a method which supports the following features: *1)* A FIS is implemented on each WSM whose output is the estimation of the free size of a specific parking place taking into account that a car may be placed in many positions, *2)* the estimation error of the output of the FIS has been modeled by using real numerical data which was utilized in order to solve a data fitting problem, *3)* the energy consumption of the battery of the WSMs has been modeled by using simulation results which was utilized in order to solve a data fitting problem, and *4)* an optimization problem was solved in order to find the optimal values for the distance d between the WSMs and the sampling period (SP) based on which the output of the FIS should be re-computed so as to simultaneously minimize the error of the FIS estimation and the WSM energy consumption. In what follows, the implementation and contribution of the aforementioned approach are discussed.

3. A fuzzy rule-based method

Our study in [1] is based on the fact that the earth's magnetic field changes dependently of the various positions that the cars may be placed. I.e., there exist different variations of the magnetic field for different car positions while the mathematical model for this variation is difficult to be formed. Therefore, the usage of a FIS seems to be a remarkable solution. More specifically, the Waspmote WSMs version 1.1 were utilized which support magnetic field sensors. These WSMs were randomly placed along the centre line under the parking spaces at equal distances apart (d). Furthermore, the fuzzy rules of each WSM's FIS were developed by using the real numerical data obtained from the aforementioned magnetic sensors. To this end, the learning algorithm, introduced in [20] was used. In each run, 50% real data instances were randomly selected for training and the remaining 50% were used for validation and error computation. The mean percentage error of the FIS predictions for all the possible values of d is depicted in Figure 1. One observes that the aforementioned percentage grows as d increases. This is attributed to the fact that as d increases, less real numerical data is available for studying the variation of the magnetic field of a specific parking place as the number of WSMs whose magnetic sensor's range coincides with the space of a specific parking place decreases.

As far as the computation cost is concerned, the generation of the fuzzy IF/THEN rules of the FIS from the real numerical data was performed by a personal computer, as there is no need for this generation to be performed by the WSMs. Then, the constructed FIS based on the selected d was embedded in each one of the Waspmote WSMs. This FIS requires 8.9 Kbytes of flash program memory independently of the selected d. On the contrary, the static RAM consumption and the computation time for estimating the free size highly depend on this value. This is attributed to the fact that d determines the amount of real numerical data that the FIS must process (as it was mentioned before) in order to estimate the free size of a specific parking place. For example, in cases where $d = 5$ metres, and

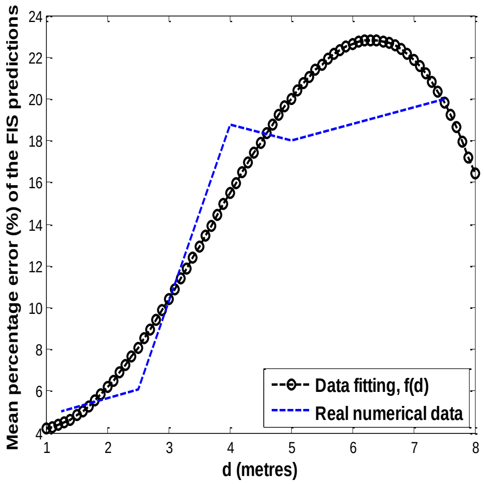


Figure 1 Mean percentage error (%) of the FIS predictions for various values of d

where $d = 2.5$ metres, the static RAM consumptions are 5 Kbytes and 7 Kbytes respectively. Moreover, the computation times required for computing the output are 55 milliseconds and 76 milliseconds, again respectively.

4. Energy consumption

The NS-2 was used for obtaining simulation results related to the mean energy consumption due to communication packet exchanges at each WSM at each sampling instant of the study in [1]. This simulator supports the IEEE 802.15.4 set of standards utilized by the Waspmote WSMs, a variety of routing protocols, and an energy consumption model. The results are illustrated in Figure 2 for various values of d and SP.

5. Cost function and optimal values for d and SP

The following cubic polynomials were fitted to the real numerical data of Figures 1 and 2 respectively:

$$f(d) = c_0 + c_1 d + c_2 d^2 + c_3 d^3 \tag{1}$$

$$\left.\begin{aligned} \mathrm{g}(d,SP) &= r_0 + r_1 d + r_2 SP + r_3 d^2 + r_4 SP^2 + r_5 dSP \\ &\quad + r_6 d^2 SP + r_7 dSP^2 + r_8 d^3 + r_9 SP^3 \end{aligned}\right\} \tag{2}$$

The coefficients c_0, c_1, c_2, c_3 and $r_0, r_1, r_2, r_3, r_4, r_5, r_6, r_7, r_8, r_9$ have been calculated and the graphs of the $f(d)$ and $\mathrm{g}(d,SP)$ are depicted in Figures 1 and 2 respectively. Lastly, real-valued cost function is defined as

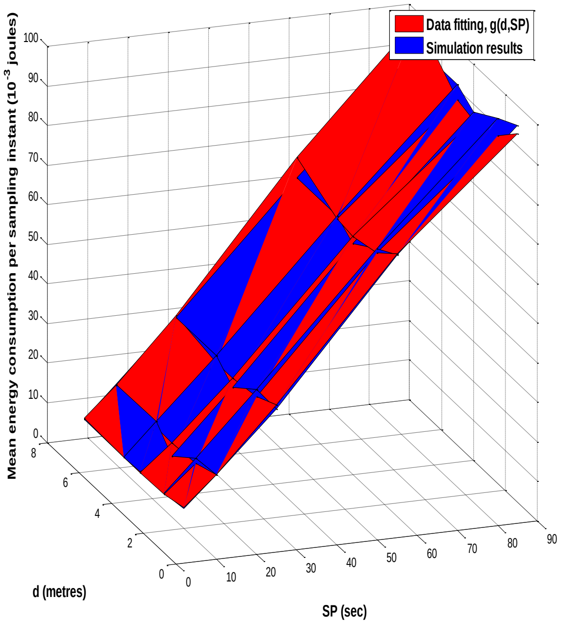


Figure 2 Mean energy consumption at each sampling instant

$$\Omega(d,SP) = \left[f(d) \quad \mathrm{g}(d,SP) \right] \tag{3}$$

The following constrained nonlinear optimization problem was solved:

$$\left.\begin{aligned} &\min imize \quad \Omega(d,SP) \\ &subject \quad to \quad 0 < d < 7.5 \\ &\qquad\qquad\qquad SP > 0 \end{aligned}\right\} \tag{4}$$

The optimal values of d and SP was computed to be 3.16 metres and 1.08 μsec respectively.

6. Conclusion

This paper examines available solutions regarding the estimation of the free size of parking places in smart cities by using wireless senor networks. The implementation of the most promising such study and its computation cost were discussed in detail while simulation results related to its energy consumption were presented.

The work presented in this paper has been partially supported by the General Secretariat for Research and Technology (GSRT) [21] of the Hellenic Ministry of Development in the framework of project KATHODIGOS - contract # 09SYN-52-768 which runs under the “Cooperation” 2009 Call.

References

[1] I. Samaras, A. Arvanitopoulos, N. Evangeliou, John Gialelis, Stavros Koubias, “A fuzzy rule-based and energy-efficient method for estimating the free size of parking places in smart cities by using wireless sensor networks,” in *Proc. IEEE ETFA '14*, Sep. 16-19, 2014.

[2] T.-P. Wu, and S.-M. Chen, “A new method for constructing membership functions and fuzzy rules from training examples,” *IEEE Trans. Syst., Man, and Cybern., Part B: Cybern.*, vol. 29, no.1, Feb. 1999, pp. 25-40.

[3] L. A. Zadeh, “Fuzzy sets,” *Inf. Contr.*, vol. 8, no. 3, Jun. 1965, pp. 338–353.

[4] S. N. Sivanandam, S. Sumathi, and S. N. Deepa, *Introduction to fuzzy logic using MATLAB*, Berlin Heidelberg: Springer-Verlag, 2007.

[5] D. Teodorovic, and P. Lucic, “Intelligent parking systems,” *European J. Operational Research*, vol. 175, no. 3, Dec. 2006, pp. 1666-1681.

[6] E. Kokolaki, M. Karaliopoulos, and I. Stavrakakis, “Opportunistically assisted parking service discovery: Now it helps, now it does not,” *Pervasive and Mobile Computing*, vol.8, no. 2, Apr. 2012, pp. 210-227.

[7] I. Benenson, K. Martens, and S. Birfir, “PARKAGENT: An agent-based model of parking in the city,” *Computers, Environment and Urban Syst.*, vol. 32, no. 6, Nov. 2008, pp. 431-439.

[8] S. - Y. Chou, S. - W. Lin, and C. - C. Li, “Dynamic parking negotiation and guidance using an agent-based platform,” *Expert Syst. with Applicat.* ,vol. 35, no. 3, Oct. 2008, pp. 805-817.

[9] T. B. Hodel, and S. Cong, “PSOS, parking space optimization service,” in *4th Swiss Transport Research Conf.*, Mar. 25-26, 2004, pp. 1-22.

[10] P. Benson, T. O’Donovan, P. O’Sullivan, U. Roedig, and C. Screenan, “Car-park management using wireless sensor networks,” in *31st IEEE LCN ‘06,* Nov. 14-16, 2006, pp. 588-595.

[11] P. V. Kumar, and T. S. Siddarth, “A prototype parking system using wireless sensor networks,” *Int. J. Comput. Commun. Inf. Syst.*, vol. 2, no. 1, Jul. - Dec. 2010, pp. 276-280.

[12] J. Jeffrey, R. G. Patil, S. K. K. Narahari, Y. Didagi, J. Bapat, and D. Dias, “Smart parking system using wireless sensor networks,” in *6th SENSORCOMM ‘12,* Aug. 19-24, 2012, pp. 306-311.

[13] A. Kianpisheh, N. Mustaffa, P. Limtrairut and P. Keikhosrokiani, “Smart parking system (SPS) architecture using ultrasonic detector,” *Int. J. Software Engineering and Its Applicat.*, vol.6, no. 3, Jul. 2012, pp. 51-58.

[14] L. O. Urdiain, C. P. Romero, J. Doggen, T. Dams and P. Van Houtven, “Wireless sensor network protocol for smart parking application experimental study on the arduino platform,” in *2nd AMBIENT ’12,* Sep. 23-28, 2012, pp. 45-48.

[15] J. Gu, Z. Zhang, F. Yu, and Q. Liu, “Design and implementation of a street parking system using wireless sensor networks,” in *10th IEEE INDIN ‘12*, Jul. 25-27, 2012, pp. 1212-1217.

[16] R. Lu, X. Lin, H. Zhu, and X. S. Shen, “SPARK: a new VANET-based smart parking scheme for large parking lots,” in 2*8th IEEE INFOCOM ’09,* Apr. 19-25, 2009, pp. 1413-1421.

[17] SmartSantander. [Online]. Available: http://www.smartsantander.eu/.

[18] ExpressPark. [Online]. Available: http://www.laexpresspark.org.

[19] SFpark. [Online]. Available: http://sfpark.org/.

[20] S. L. Chiu, “Fuzzy model identification based on cluster estimation,” *J. Intelligent and Fuzzy Syst.*, vol. 2, no. 3, 1994, pp. 267-278.

[21] General Secretariat for Research and Technology. [Online]. Available: http://www.gsrt.gr.

Ioakeim Samaras received the Diploma and the Ph.D. degrees from the University of Patras, Patras, Greece and the Aristotle University of Thessaloniki, Thessaloniki, Greece, respectively, both of them in electrical and computer engineering.

He has authored or coauthored nine articles in refereed journals and conference proceedings. His main current scientific interests include enterprise integration, service oriented architecture (SOA) at the device level, Internet of Things (IoT), MAC-layer protocols, ad-hoc wireless networks, stochastic processes, and fuzzy inference systems.

Dr. Samaras is serving as a reviewer for the IEEE Transactions on Industrial Informatics, the IEEE Communications Letters, the Wireless Networks and the Journal of Communications and Networks, as an editorial board member for the International Journal on Advances in Networks and Services and as a technical program committee member for the International Conference on Sensor Technologies and Applications (SENSORCOMM). He served as an organizer of a special session and as a reviewer for the 19th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2014). He is a member of the Industrial Systems Institute/ATHENA RC, the Intracom-Telecom, the IEEE Industrial Electronics Society, and the Technical Chamber of Greece.

John Gialelis received the Ph.D degree in electrical engineering from the University of Patras, the M.Sc degree in electrical engineering from the Polytechnic Institute of New York University (NYU Poly) and the B.Sc in electrical engineering from Fairleigh Dickinson University (FDU). Since 1996 he has been a research fellow and a tenured teaching staff in the Engineering School at the University of Patras, Greece and he is a member of the Industrial Systems Institute / ATHENA RC. He has authored or co-authored more than 60 articles in refereed journals, conference proceedings and book chapters and supervised many research projects funded by the European Union and Greek organizations. His main research interests include Modeling Engineering, Artificial Intelligence and Security in Networked Embedded Systems. He is a regular reviewer in many scientific journals. He is a member of the IEEE Industrial Electronics Society.

Call for Papers

IEEE Workshop on Quality of Experience-based Management for Future Internet Applications and Services (QoE-FI)

Sponsored by the IEEE ComSoc Technical Committee on Multimedia Communications

http://qoe-fi.diee.unica.it

Organized in conjunction with
IEEE International Conference on Communications (IEEE ICC 2015)
8-12 June 2015, London, UK

Recent technological advances have enabled a constant proliferation of novel immersive and interactive services that pose ever-increasing demands to our communication networks and add to their load. Examples are: social TV, immersive environments, mobile gaming, HDTV over mobile, 3D virtual world, book/newspaper consumption, social networking, IPTV applications, just to cite a few. Some of these services have already reached a major market success especially because a *user-centered* approach has been followed to design the whole process of content production, service activation, content consumption, and service (and network) management.

In addition, we witness the trend of migrating end-to-end multimedia communication systems/platforms to the cloud. Media processing and consumption in the cloud requires attention from two main perspectives: maintenance of processing-related cloud operations over the execution time considering the end-user and application-related QoS/QoE requirements via dynamic resource provisioning; and the parallelization and abstraction of media processing tasks for the optimization of limited and shared cloud resources. Furthermore, the domain of Smart Cities offers new opportunities and use cases, but at the same time poses new challenges for keeping users engaged and interested in those services. This also includes other aspects such as quality of life as well as critical considerations such as user safety, particularly when it comes to urban transport and emergency scenarios.

In this dynamically evolving context, network operators and service providers are struggling to keep their increasingly sophisticated customers content while remaining profitable at the same time. Consequently, optimization and management of QoE has become crucial issue in the deployment of successful services and products. However, even if the concept itself may seem straightforward to understand, it requires rather complex implementation processes for efficient performances in real end-to-end systems/networks. The complexity of QoE is mainly due to the difficulties in its modeling, evaluation, and mapping to objective Quality of Service (QoS) parameters, which, for more than a decade, has been used as a partial substitution to QoE, and due to its multi-dimensional end-to-end nature covering a wide range of networks, applications, systems, devices, contexts and expertise.

On this background, the workshop is aimed 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:

- QoE evaluation methodologies and metrics
- Frameworks and testbeds for QoE evaluation (crowd-sourcing, field testing, etc.)
- QoE studies & trials in the context of Smart Cities
- QoE models, their applications and use cases
- QoE for immersive audio-video and interactive multimedia communication environments
- QoE-aware cross-layer design
- QoE-driven media processing and transmission over the cloud and over the top (OTT)
- QoE control, monitoring and management strategies
- QoE in community-focused interactive systems
- KPI and KQI definition for QoE optimization in different environments
- Integration of QoE in infrastructure and service quality monitoring solutions
- Media analytics from QoE Big Data
- Standards for media coding (HEVC, HEVC for 3D, etc.) and transport (DASH, MMT, XMPP, etc.)
- Future Media Internet architectures

General Chairs:
Ahmet Kondoz, Loughborough Univ. London, UK
Luigi Atzori, University of Cagliari, Italy
Raimund Schatz, FTW, Austria

Panel Chairs:
Weisi Lin, Nanyang Technological University, Singapore
Periklis Chatzimisios, Alexander TEI of Thessaloniki, Greece

Technical Program Chairs:
Markus Fiedler, BTH, Sweden
Pedro Assuncao, Institute of Telecommunications/IPL, Portugal
Tasos Dagiuklas, Hellenic Open University, Greece

Publicity Chairs:
Adlen Ksentini, University of Rennes, France
Nabil J. Sarhan, Wayne State University, USA
Evangelos Pallis, TEI of Crete, Greece

Important Dates
Submission deadline: **January 10, 2015** Author notification: **February 14, 2015** Camera ready due: **February 28, 2015**

Call for Papers

IEEE Workshop on LTE in Unlicensed Bands: Potentials and Challenges

http://www.lte-u.com

Organized in conjunction with

IEEE International Conference on Communications (IEEE ICC 2015)

8-12 June 2015, London, UK

The exponential growth of mobile data traffic and the scarcity and costliness of licensed spectrum are driving mobile network operators (MNOs) to consider offloading at least part of their traffic onto the unlicensed spectrum. Most recently, the 3GPP is considering extending the use of LTE into the unlicensed spectrum as a seamless approach to enable traffic offload. This new approach is dubbed LTE Unlicensed (LTE-U). Compared to Wi-Fi, LTE-U offers MNOs a way to offload traffic onto the unlicensed spectrum with a technology that seamlessly integrates into their existing LTE evolved packet core (EPC) architecture. Furthermore, LTE-U promises higher throughout and spectral efficiency than Wi-Fi, with estimates ranging from 2x to 5x improvement over Wi-Fi. Currently two operating modes are under discussion: 1) unlicensed spectrum is aggregated with existing licensed channels and 2) unlicensed spectrum acts as the only carrier for LTE-U where both data and control channels reside. The liberal non-exclusive use of unlicensed spectrum has spurred innovation on the one hand, but has also created the need for coexistence measures when various uncoordinated wireless networks operate on the same frequency. In this case, LTE-U introduces new coexistence challenges for other technologies operating in the same unlicensed bands particularly for legacy Wi-Fi. Wi-Fi is designed to coexist with other technologies through channel sensing and random backoff, while LTE is designed with the assumption that one operator has exclusive control of a given spectrum. Furthermore, LTE traffic channels are designed to continuously transmit with minimum time gap even in the absence of data traffic. Consequently, Wi-Fi users will have little chance to sense a clear channel and deem it suitable for transmission. The goal of this full-day workshop is to bring together academics, researchers, and practitioners to discuss the opportunities, challenges and potential solutions for operation of LTE in the unlicensed bands. The topics of interest include, but are not limited to:

- Coexistence of schedule-based and contention-based networks in unlicensed bands
- Fairness considerations for coexistence of LTE and Wi-Fi
- Performance impact of LTE on networks operating in the unlicensed band
- Radio resource management, dynamic channel selection and band steering for LTE/WiFi coexistence
- Traffic demand-aware coexistence
- Distributed and centralized techniques for coexistence of heterogeneous networks
- Technical challenges and solutions of operating LTE solely on the unlicensed bands
- QoS model for standalone LTE-U access model

Paper submission link: https://edas.info/newPaper.php?c=18693&track=66309

Information for Authors: Prospective authors are invited to submit original technical papers by the deadline January 10, 2015. All submissions should be written in English with a maximum paper length of Six (6) printed pages (10-point font) including figures without incurring additional page charges (maximum 1 additional page with over length page charge if accepted). Please also see the Section in the main ICC 2015 website for Authors Guidelines.

Registration: Please see the Section in the main ICC 2015 website on Registration.

Workshop Organizers
Dr. Andrea Goldsmith, Stanford University, USA (andrea@wsl.stanford.edu)
Dr. Alireza Babaei, CableLabs, USA (a.babaei@cablelabs.com)
Dr. Jennifer Andreoli-Fang, CableLabs, USA (j.fang@cablelabs.com)
Dr. Klaus Doppler, Nokia Research Center, USA (klaus.doppler@nokia.com)

TPC Chairs
Dr. Shiwen Mao, Auburn University, USA (smao@ieee.org)
Dr. Karthik Sundaresan, NEC Laboratories America, (karthiks@nec-labs.com)
Dr. Sayantan Choudhury, Nokia Research Center, USA (sayantan.choudhury@nokia.com)

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: February 1, 2015
First Round Decisions: May 15, 2015
Major Revisions Due: June 15, 2015
Final Decisions: August 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).

Editor-in-Chief

Rajkumar Buyya, the University of Melbourne, Australia

Guest Editors

- Chuan Heng Foh, University of Surrey, UK
- Satish Narayana Srirama, University of Tartu, Estonia
- Elhadj Benkhelifa, Staffordshire University, UK
- Burak Kantarci, Clarkson University, USA
- Periklis Chatzimisios, Alexander TEI of Thessaloniki, Greece
- Jinsong Wu, Alcatel Lucent, China

MMTC OFFICERS (term 2014—2016)

E-LETTER BOARD MEMBERS (Term 2014—2016)