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Special theme: 5G

KEYNOTE

SPECIAL THEME

The special theme "5G" has been coordinated by Thomas Zemen (AIT Austrian Institute of Technology) and Toon Norp (TNO)

Introduction to the special theme

RESEARCH AND INNOVATION

This section features news about research activities and innovative developments from European research institutes

ANNOUCEMENTS, IN BRIEF

European 5G Research and Beyond

As part of the Digital Single Market (DSM) initiative launched by the Juncker Commission, 5G has been recognised as a key technology for Europe. 5G has indeed been identified as the connectivity platform to support the wider DSM policy objectives of large scale digitisation of the industry, thanks to the native 5G capability to support agile and intelligent connectivity for very diverse use case requirements originating from automotive, healthcare, factories, energy or media sectors. The more systematic adoption of technologies derived from the cloud computing environments such as Virtual Network Functions, micro-service and containers have enabled the design of networks with cloud native architectures supporting a very high flexibility and versatility of connectivity platforms. Beyond the introduction of new radio waveforms, access networks and spectrum uses, "virtualisation and cloudification" is a key innovation of 5G, enabling communication to be flexibly integrated into a complete digital business value chain.

Bernard Barani,
Deputy Head of Unit "Future Connectivity Systems"
European Commission, DG CONNECT

As a consequence, 5G has the potential to open new B2B markets. Revenues from traditional broadband markets are currently stagnating in spite of a traffic increase of at least 50 % per year. Market estimates point, however, to a potential of € 550 billion extra revenues in 2025 from vertical industries. In September 2016 the European Commission adopted a 5G Action Plan to put in place the right framework conditions for the launch of 5G in Europe by 2020, notably fostering licensing and spectrum availability across member states.

European efforts are needed to keep abreast of fierce global competition. The USA and Asia are already moving ahead with the first 5G deployment. They primarily target the "enhanced mobile broadband" use case based on the first version of the standard made available by 3GPP in June 2018 (Release 15). Under the ongoing Release 16 work, the standard will be complemented with essential features needed to fully address the requirements of multiple vertical sectors, notably automotive and factories. European 5G deployments are expected in 2019 in a few cities and larger scale deployments from 2020 onwards. 5G readiness of EU Member States is also progressing fast. About 140 5G trials have been identified for multiple use cases. Six member states have assigned 5G spectrum at C-band and a significant number of auctions are planned in 2019. Nine member states have also published their 5G roadmap and another eight are expected in 2019. These initiatives support the emergence of a European critical mass for 5G which is key to avoid the patchy deployment scenarios of 4G.

Europe also supports 5G trials through the 5G Public Private partnership (5GPPP), a research initiative launched in 2013 to federate 5G R&I in Europe. This 5GPPP has received € 700 million from the European Horizon 2020 research programme, matched by an industrial investment of three to five times that amount. The 5G PPP has delivered key results in a multiplicity of domains as diverse as new radio access technologies, network architectures with co-operation of a multiplicity of fixed or mobile access networks including satellites, operation of new spectrum in the millimetre wave ranges, network virtualisation, redesign of the core network, applications of software techniques to network management . Currently, the 5G PPP is in its third phase that supports 5G validation across a large number of use cases and vertical industries. To that end, a European 5G end to end platform comprising more than 20 nodes has been launched and opened to vertical industries. This platform is unique in the world.

For the next multi annual financial framework covering the 2021-2027 period, the Commission adopted its proposal to support research and innovation in June 2018. Following the 5G PPP, a new partnership to cover "Beyond 5G " research in Europe with an enlarged scope is under consideration. The target is to address a complete value chain covering connectivity, the device aspects in an IoT context and the service aspects in the context of distributed computing moving at the network edge. Several technologies such a THz or LiFi communication in ultra dense networks, move towards cloud native architectures, edge computing and networking have been identified as future research and innovation topics, including artificial intelligence and blockchain supporting both network management or user applications. Both energy efficiency and cybersecurity and trust should receive particular attention.

We count on the European research community to mobilise its strength to make Europe a leader in future connectivity infrastructures, which are increasingly considered as critical infrastructures.

Bernard Barani

The views expressed herein are those of the author and shall not be considered as official statements of the European Commission.

Introduction to the Special Theme

5th Generation Telecommunication Standard

by Thomas Zemen (AIT Austrian Institute of Technology) and Toon Norp (TNO)

5G standardisation and first system trials have generated significant interest in the new system capabilities and use cases of 5G. 5G aims to increase the peak data rate to 10Gbit/s, and focuses strongly on business applications where a latency (transmission delay from transmitter (TX) to receiver (RX)) of 1 ms and a battery lifetime of up to 10 years are key performance parameters. Clearly, a 5G system will not provide all the performance targets simultaneously for a single communication link. In fact, 5G provides a combination of three different use case categories, within one system. These three use cases are: (a) enhanced mobile broad band (eMBB) for data rates up to 10 Gbit/s, (b) massive machine type communication (mMTC) with low energy consumption for a battery life of 10 years, optimised for low data rates of 10 bit/s; and (c) ultra-reliable low latency communication (URLLC) providing 1ms latency at low frame error rates of 10^{-5}.

URLLC has the biggest consequences for the existing eco-system of service providers, network operators and network vendors. Due to the required short latencies, a change in the overall system architecture is required, in addition to the new wireless technology (5G). Application processing cannot be carried out by central cloud services but must be carried out very close to the terminal. This leads to "edge cloud" architectures, which must be developed in connection with the actual radio technology.

To support different applications with different requirements on a single network infrastructure, 5G supports the concept of slicing. With slicing a 5G network can support multiple "slices", or virtual networks, each optimised for a particular application and with a different service level agreement. The goal of slicing is that 5G should support the wide range of applications envisaged in the digital society without requiring a multitude of dedicated infrastructures. On the other hand, for applications that have such specific requirements that implementation on a general network infrastructure is not feasible, it is also possible to implement non-public networks using 5G technology. Non-public networks can, for instance, be used for factory networks that have to support automation control, with very low latency requirements.

This special theme on 5G outlines a wide range of ongoing research activities within Europe. In the keynote from B. Barani, the future 5G eco system is described from a political point of view as well as ongoing trials and future research directions in the upcoming Horizon Europe funding scheme.

G. Dürrenberger's contribution describes the special regulatory situation in Switzerland with respect to maximum electromagnetic ffield strength and the effects on the future 5G rollout.

In the article from M. Corici et al., the Open5GCore is described, which is used in multiple European 5G research projects. The 5G Playground in Berlin and its experiments with network slicing are presented. An end-to-end facility in Greece that is based on the Open5GCore is characterised by the contribution from C. Tranoris et al. The project 5G-Vinni aims to validate key performance indicators for end-to-end connections in different vertical industries. O. Apilo and his colleagues report on the project 5G Test Network (5GTN), that focuses on sport wearable devices and media broadcasting. Real-life use cases with cellular internet of things technologies (CIoT) were investigated empirically to shape the future development of CIoT in 5G systems.

A special deployment method for 5G network in light poles is presented by J. Varis from the LucTurrim5G project for establishing 5G mmWave networks. In the article by H. van den Berg et al. ultra dense 5G networks are envisioned that have a “self-planning” function using data driven machine learning concepts.

S. Faye et al. investigate methods to simulate connected automated vehicles and compare several wireless access methods ranging from IEEE 802.11p up to 5G. 5G can also be used to improve road safety, as discussed by T. Ojanperä in their article about the 5G-Safe project, which investigated crowd sourcing information for road maintenance inspection as well as improving the safety of autonomous vehicles. In the work of D. Loeschenbrand and T. Zemen, a new distributed 5G massive MIMO software defined radio (SDR) testbed is presented that enables the investigation of signal processing algorithms for vehicular URLLC links. The focus of the project MARCONI is on time-variant propagation conditions in massive MIMO systems.

M. Elshatshat et al. discuss device-to-device intercell interference coordination (ICIC) in 5G networks. The ICIC is optimised by utilising small base stations that operate as relays.

Factory communication is the focus of the contribution of H. Zhang. The project Clear5G and its approach to investigating non-orthogonal multiple access (NOMA) for machine-type communication with high node densities is presented.

Application scenarios for the integration of 5G aerospace networks are described by M. Bacco et al. A special focus is given to new techniques such as software defined networks (SDN) as well as network function virtualisation (NFV).

The security of the 5G standard is investigated in the contribution from L. Hirschi et al. They describe formal methods to verify the security of the 5G authentication and key agreement (AKA) protocol. Their found vulnerabilities led to a new and improved 5G AKA protocol version.

D. Hazael-Massieux presents the project Web5G. Their work investigated cross layer methods to reduce latency and allows for adaptive congestion control. With these improvements, applications such as augmented reality and 8K video streaming over 5G will become a reality.

Finally, E. Vlachos et al. discusses methods to realise tele-immersion (TI) for real-time interaction using 5G network and their edge computing infrastructure.

The articles in this special theme give a good overview of the diverse research required to realise the goals of 5G. With work on Release 16 currently ongoing and the targets outlined in the keynote of B. Barani, we can expect many interesting research questions into the future, even after the first 5G networks become operational.

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5G: A View from Switzerland

by Gregor Dürrenberger (ETH Zürich) and Harry Rudin

Switzerland projects a rural, pastoral image with beautiful countryside and mountains, but it is also a highly industrialised country that is recognised for its precision manufacturing and innovative services. It is the industrialised side of Switzerland that is vitally interested in 5G, the most advanced generation of mobile communication. Currently the country faces social, political and legal challenges that make the 5G roll-out both difficult and costly.

In October 2018 the highest level of government in Switzerland, the Bundesrat, acknowledged that a solid, efficient and reliable IT network infrastructure is the backbone of a successfully functioning economy and society. New digital technologies promise huge improvements in education, vehicle safety, manufacturing, financial transactions, and inter-personal communication.

For Switzerland to take advantage of these improvements it needs more wireless capacity. Switzerland has strict regulations regarding non-ionising radiation - in fact, Switzerland's field-strength limits are ten times more restrictive than those in the European Union. These non-ionising radiation limits are exhausted in most urban locations, meaning that 5G cannot be added on top of the already installed services at these locations. Furthermore, with its dynamic, "smart" antennas, 5G challenges the regulatory framework that governs static antennas.

"Smart" antennas have many names that often stress different characteristics: massive MIMO (massive Multiple Input Multiple Output), switched-beam antennas, dynamic phased-array antennas, or adaptive antenna arrays. We can no longer afford to blanket a large area with communication energy. One key characteristic of 5G is that smart antennas permit transmitted energy to be focussed on a small area where there is an active user. The dynamic aspects of these antennas even allow the system to follow an active user in motion. In addition, the antenna can simultaneously serve multiple users. Such beam-steering implies that non-active, potential users would receive little radiation, in contrast to the current static antennas that cover large areas with communication energy.

Given the importance of 5G to wireless communication in Switzerland, the Swiss Research Foundation for Electricity and Mobile Communication organised a conference in December, 2018, focusing on smart antennas. Professor Jürg Leuthold from the Swiss Federal Institute of Technology in Zurich summarised the technical fundamentals of 5G, stressing the capabilities of smart antennas.

A talk by Hugo Lehman from Swisscom, Switzerland's largest communication service provider, discussed the difficulties faced by providers in installing the new technology: to stay within radiation limits per cell site, additional cell sites are needed. For the general public, this is a contradiction; more cell sites to protect against non-ionizing radiation.

The problem is exacerbated in 5G due to the dynamic control of the antenna beam. Worst-case radiation summation leads to an overestimation of the average peak radiation by factor of 5-10. This calls for either a change of the current practice of assessing maximum exposure, or an increase in allowed radiated power, or both. Lehmann also reported that preliminary 5G systems are running in six cities in Switzerland to test equipment and coverage. These experimental systems operate under the existing, maximum average transmitted power regulation, even though propagation at 5G's higher frequencies face increased atmospheric attenuation.

Switzerland's federal government organisation BAFU (Federal Office for the Environment) implements national laws and ordinances relating to environmental protection. Within BAFU is a section devoted to non-ionising radiation.

Urs Walker from BAFU discussed the political dilemmas faced by the Office: First, the Telecommunications Act and the Environmental Protection Act follow goals that are not easy to harmonise in the field of radiation protection. Second, customers of mobile services and citizens living close to base stations generally have opposing interests. Third, the Swiss Parliament is in disagreement on the issue: the two houses of Parliament are divided: one house was in favour of allowing an increase in the radiated power - by only a few votes; the other was in favour of preserving the present regulation - also by only a few votes.

5G smart antennas deliver energy where it is needed rather than blanketing a large area. Illustration courtesy of Romain Bonjour, IEF, ETH Zurich.

BAFU is currently investigating the political options as to how to proceed. These options should address: (i) current and future network capacities, including bottlenecks and topologies, (ii) current and future exposure levels of the population in relation to potential roll-out scenarios of 5G networks, and (iii) the current state of evidence on potential health impacts of cell phone radiation from both handsets and base-stations. The report, prepared by a group of experts, should be available in mid-2019 and is eagerly awaited.

The last presentation was given by Andy Fitze from the consultancy Swiss Cognitive. He explored the necessity of 5G for taking advantage of recent developments in blockchain technology, big data, data analytics and artificial intelligence widely accessible to the Swiss economy. His talk was clearly focused on innovation and economic opportunities, not on health risks. The most important risk he identified was missing out on the current development of the digitalisation of society.

An overview and charts from the presentations is available on the web page below, written mostly in German.

Link:
https://kwz.me/hcb

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Paving the Way for Local and Industrial 5G Networks and Testbeds

by Marius Corici, Marc Emmelmann, Manfred Hauswirth, Thomas Magedanz (Fraunhofer FOKUS, TU Berlin)

Local 5G networks are a major area of 5G innovation and offer vital insights into practical 5G deployment. Local 5G networks can give us important information because in these environments 5G technologies must be tightly integrated with different access network technologies and with the end-to-end software stacks of different vertical application domains, such as manufacturing and energy. To achieve this in an efficient and economical way, the Open5GCore.net software toolkit of Fraunhofer FOKUS provides the first 3GPP Release 15 5G core network implementation facilitating the rapid deployment of local 5G use-case-oriented testbeds. We have also developed the FOKUS "5G Playground", a reference live deployment, with multiple customised network slices based on the Open5GCore and use case applications. The "5G Playground" has served as a blueprint for many other 5G testbeds deployed across Europe and around the world in the context of 5GPPP.

After many years of international research and standardisation [1] the 5th Generation of Mobile Communications (5G) is on the verge of being deployed. The first 5G network deployments will start this year after the first 5G frequency auctions. Like previous generations of mobile communication systems, 5G will evolve functionally over time by means of new 3GPP releases and from practical experience obtained during the deployments of previous releases. However, the 5G system architecture is probably the most complex one so far, representing a radical change from previous generations due to its incorporation of various technology innovations, such as software-defined networks (SDN), network function virtualization (NFV), and edge computing, which make 5G a distributed, dynamically programmable software platform. Another reason for the complexity of 5G is its multi-access network support, including the novel 5G New Radio (NR) system, which adds a lot of flexibility, but also complexity to interworking in the migration to 5G. In addition, concepts like network slicing and local networking enable completely new levels of network customisation and new business models within different vertical domains. This means that the scope, the degree and the dimensions of flexibility are quite different from previous versions.

Thus, current 5G technology is still in its infancy and still requires a wide range of validation and optimisation by means of proof-of concepts and real-world trials in different application contexts in order to be fully applicable and gain acceptance in the different vertical domains. In this context the notions of campus networks and local/regional networks are gaining strong momentum. In contrast to public trials focussing on enhanced multimedia broadband use cases, requiring significant infrastructure investments with unpredictable returns, 5G deployments in a local context will be more affordable and can focus on very specific industrial requirements in the field of ultra-reliable, low-latency communication for complex business processes, such as automation in manufacturing. Also, business model exploration is going to happen in this area, as new deployment and operation models may evolve. In these local network environments, scalability and interoperability become key issues because local networks vary in size. Their access network and backhaul technologies, and their applications also vary, often demanding dedicated networks or different network slices. These emerging considerations have moved to the centre of discussions in the latest German plans for local/regional 5G spectrum assignments in the 3,7-3,8 GHz frequency range.

This is the environment for the Open5GCore, a scalable 5G core network; highly customisable to different application needs (mMTC vs. eMMB) for building 5G testbeds, developed by Fraunhofer FOKUS. Fraunhofer FOKUS has a long track record of building reference software toolkits for testbeds since 3G.

Open5GCore provides a solution for most of the requirements currently under discussion as it adequately reflects the 3GPP Release 15 for the core network functionality and its integration with 5G New Radio along with legacy off-the-shelf LTE-based access and non-3GPP accesses. As such, Open5GCore enables the immediate demonstration of different features and applications and supports the current requirement to support a genuine 5G Core Network in addition to an evolved EPC one.

Figure 1 depicts the current components of the Open5GCore implementation, in particular the integration with 5G New Radio, the implementation of the control-user-plane split, service-based architecture features, and data path diversity, supporting local offloading and backhaul control (see [L1] for more details). Open5GCore runs on top of available hardware platforms and can be deployed with containers or virtual machines on top of a large number of virtualisation environments, ranging from Raspberry PI to a complete rack of servers. As such, Open5GCore – being a highly customisable and scalable 5G core adjustable to the needs of specific use cases – is a unparalleled candidate for building 5G testbeds on-premises and for deploying local campus and industrial networks.

In the current implementation version, the Open5GCore concentrates on three major innovation areas proving the feasibility of the 5G system: (1) It includes the functionality required for access and mobility control, session management and authentication and authorisation to enable the carrier-grade connectivity of the 5G devices in both standalone and non-standalone mode. (2) For the highest flexibility, the control plane is implemented using the 3GPP service-based architecture and it integrates dynamically with the data path using the 3GPP session and data path management. (3) With these features, Open5GCore represents the first available prototype implementation of the 5G core network, enabling the immediate demonstration of the use cases in a similar and vendor-independent environment to the real deployments.

For enabling customised deployments at the edge, the Open5GCore additionally includes the interoperability with the backhaul management for networks deployed for use cases at multiple locations interconnected with best-effort third-party internet connections. Additionally, Open5GCore can be deployed using a set of edge-central models which enable the appropriate interaction according to the use case requirements and the available computing, storage and networking resources at the edge location. Through this, the current implementation facilitates customisation of connectivity for the specific needs of local networks.

To address all of these requirements in an appropriate fashion, Open5GCore was implemented in the C programming language on Linux OS platforms, using our own software platform which is able to manage the different threads, inter-thread communication and memory requirements specifically tailored to systems in which delay and reliability are more important than the fine-granular management of resources. At the moment, Open5GCore represents a large software system with multiple components and interactions between the components as specified by 3GPP and extended with our own innovations in the area of data path and subscriber management. Table 1 provides an informal overview of the complexity of the overall Open5GCore system.

Some interesting experiences and findings from the implementation of the Open5GCore are: The most complex part of the overall system is the interaction between the different components. The large number of interfaces and exchanged messages can result in a very large number of side effects. On the plus side, the independence of the subscriber-related state information on each of the network functions enables a very good parallelisation of the different operations. Thus a highly scalable system can be achieved with limited cost, enabling the local network to scale according to the requirements. Because of these properties, a 5G packet core can be installed on different types of hardware supporting different numbers of subscribers, making a software-only implementation combined with off-the-shelf hardware an ideal solution for initial deployments.

The Berlin 5G Playground [L2] hosted by Fraunhofer FOKUS is an instantiation of such a testbed designed to enable innovative product prototyping in a realistic, comprehensive 5G end-to-end environment, including calibration,

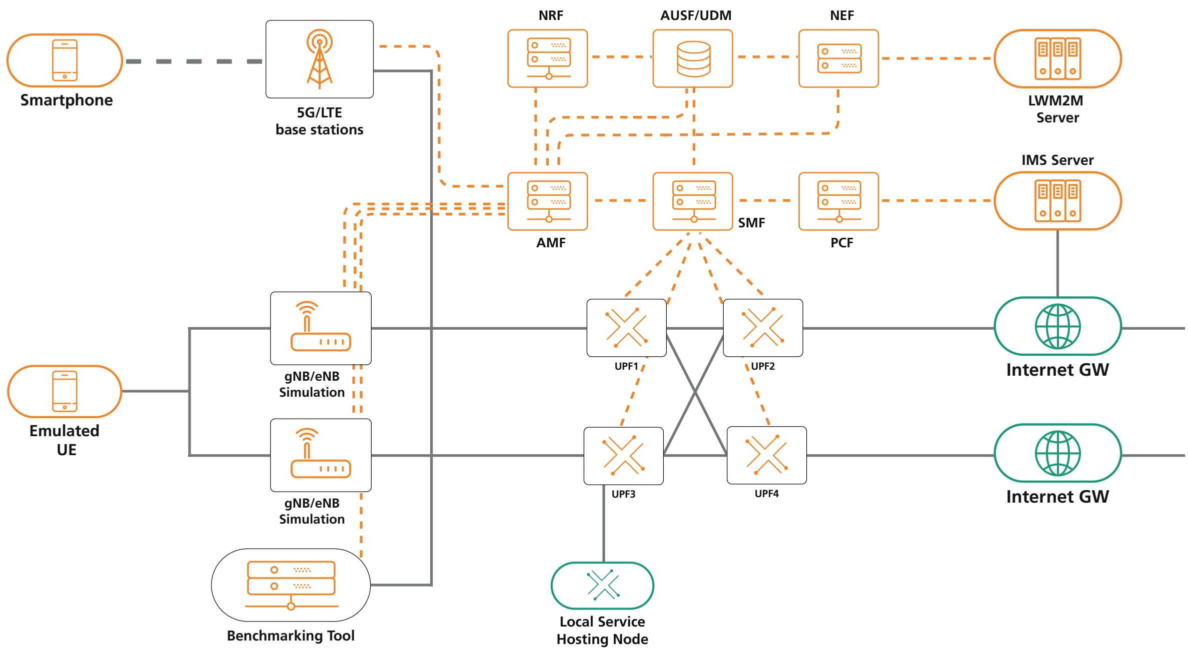

Figure 1: Architecture of the Open5GCore.

Feature	Amount	Description
Modules	112	The 112 Open5GCore modules span from protocol modules, interface modules and component modules.
Files	5860	Each of the modules includes a large number of files. From these, 2600 files are C code modules.
Commits	15000	A large team of developers are extending the software to address the latest requirements and standards.
Components	16	Components are considered independent network functions having a specific functionality. Multiple of these software components may be instantiated within the same testbed as to enable more complex scenarios.

Table 1: Overview of the over all Open5GCore system.

benchmarking and interoperability testing among new prototypes and products. For that, the 5G Playground can be flexibly augmented by infrastructure, software network functions and service components from third parties.

Employing local and experimental spectrum licenses in conjunction with spectrum provided by telecommunication providers, the 5G Playground offers outdoor radio coverage of the Berlin city around the Fraunhofer FOKUS campus. By combining 5G, 4G and non-3GPP access technologies, the 5G Playground allows the user to perform and validate experiments in a diverse outdoor-indoor environment previously only feasible in laboratories (see Figure 2). As such, it also enables the creation of dedicated, specialised networks via "slicing" as required for general, highly-reliable networks, automotive verticals, as well as for networks for security and safety use cases.

In conjunction with the Open5GCore, the Berlin 5G Playground acts as a blueprint for planning and installing remote testbeds at the use case locations. Fraunhofer FOKUS contributes the 5G Playground to several European research projects, e.g., 5GENESIS [L3] and 5G-VINNI [L4], providing the only German-based 5G testbed which is part of two of the three existing EU-funded 5G infrastructure initiatives. In addition, the Open5GCore provides the basis for the SATis5 testbed of the European Space Agency (ESA) [L5] to showcase the advantages of satellite-terrestrial convergence as part of the 5G environment, especially underpinning the benefits provided for a large number of multimedia delivery and dedicated IoT deployments. The participation in these projects allows Fraunhofer FOKUS to further advance its Open5GCore towards 3GPP Release 16 capabilities and to evaluate current 5G KPIs related to the network core via end-to-end, large-scale trials. Until now, the testbed has been replicated 12 times at customer premises, addressing the needs of various use cases.

The full availability of an integrated 5G testbed and its underlying software components with all services and functionalities currently under standardisation enables telecommunication companies, equipment manufacturers and companies from any vertical segment to test business models and functionalities in a realistic environment. On the research side, such environments and software are essential in finding new approaches and evaluating them according to highest scientific standards.

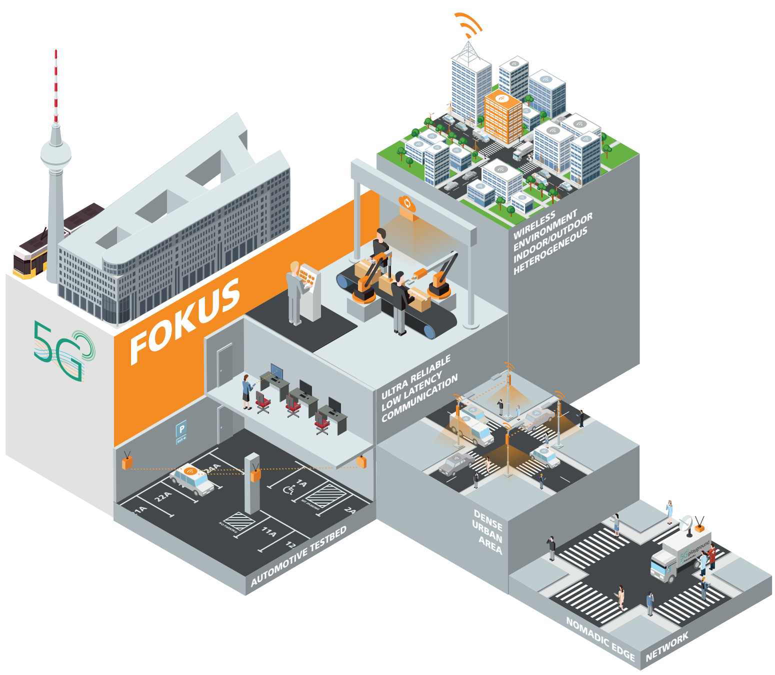

Figure 2: Components of the Berlin 5G Playground.

Links:

[L1] Fraunhofer FOKUS Open5GCore: http://open5gcore.org/

[L2] Fraunhofer FOKUS 5G Playground: https://kwz.me/hcx

[L3] EC H2020 5G-PPP 5Genesis: https://5genesis.eu/

[L4] EC H2020 5G-PPP 5G-VINNI: https://www.5g-vinni.eu/

[L5] ESA SATis5: https://satis5.eurescom.eu/

Reference:

[1] M. Shafi et al., "5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment, and Practice," in IEEE Journal on Selected Areas in Communications, vol. 35, no. 6, pp. 1201-1221, 2017. doi: 10.1109/JSAC.2017.2692307

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Patras 5G: An Open Source Based End-to-End Facility for 5G Trials

by Christos Tranoris and Spyros Denazis (Univesrity of Patras)

5G-VINNI, a European H2020 funded project, focuses on the third phase of the 5G PPP by deploying an end-to-end facility which demonstrates that the key 5G network KPIs can be met. The 5G-VINNI facility in Patras/Greece is an exemplary open source 5G facility, which can be accessed and used by various vertical industries.

5G aims to significantly improve the capabilities of network infrastructure in terms of the supported key performance indicators (KPI). The telecommunications industry has aligned itself to a number of KPIs, including “1000 times higher mobile data volume per geographical area”, “10 to 100 times more connected devices”, “10 times lower energy consumption” and “end-to-end latency of less than 1ms” [1]. The 5G network will be a key asset to support societal transformation, societal cohesion and sustainable development by empowering the vertical industries. In a number of white papers and publications the 5G PPP has described use cases and requirements of several vertical industry sectors, such as automotive, e–Health, energy, entertainment, manufacturing and others [1].

5G-VINNI [L1] follows certain guidelines to implement a 5G E2E facility that is composed of several interworking 5G sites. We use the term 5G end-to-end (E2E) facility to denote a unified set of network, compute and storage resources providing E2E services modelled according to 5G architecture [2]. Currently VINNI facilities around Europe have started deploying 5G New Radio and 5G Core solutions with novel ETSI compliant Network Function Virtualization Orchestrators (NFVOs) based on either commercial (e.g. NOKIA’s FlowOne) or open source (ETSI’s Open Source MANO) while an End-to-End solution is implemented for Network Connectivity as well as Service Orchestration.

The 5G-VINNI facility in Patras/Greece is an exemplary open source 5G-IoT facility. This means that most of the installed components are offered as open source but there are also dedicated components and services to support 5G-IoT scenarios. Various solutions are deployed in the Patras/Greece facility, thus creating a unique 5G playground for KPI validation and support for future verticals. In Greece/Patras 5G facility site the following tasks are performed with the 5G-VINNI project:
- Providing 5G standard-conformant components and core network infrastructure;
- Provide mmWave backhaul to link the access to the core network, and Fixed Wireless Access to provide broadband services to the facility;
- Integration of Next GenOpen5GCore (from Fraunhofer FOKUS) together with an SDR platform and UEs and g/eNB (based on Limemicro SDR and SRS LTE open source solutions);
- Enabling the E2E deployment of multiple customised-slices over the whole network – access, transport and core. This includes the slicing of the IoT devices at the edge of the network;
- Supporting Multiaccess Edge orchestration and mobility management features for the support of interactive mobile streaming edge services.

Figure 1 displays a high-level view of the Patras facility site end-to-end design including all the necessary components. The facility will be interconnected with GRNET NRN in Athens that will allow high speed connectivity to public internet but also to dedicated GEANT links or VPN connections with other 5G-VINNI sites or other universities or research institutes across Europe.

Detailed radio planning studies (see Figure 2) have been performed by Intracom Telecom (a Greek company/partner of 5G-VINNI) to identify the optimum locations, the appropriate equipment and its configuration, in order to provide high-speed

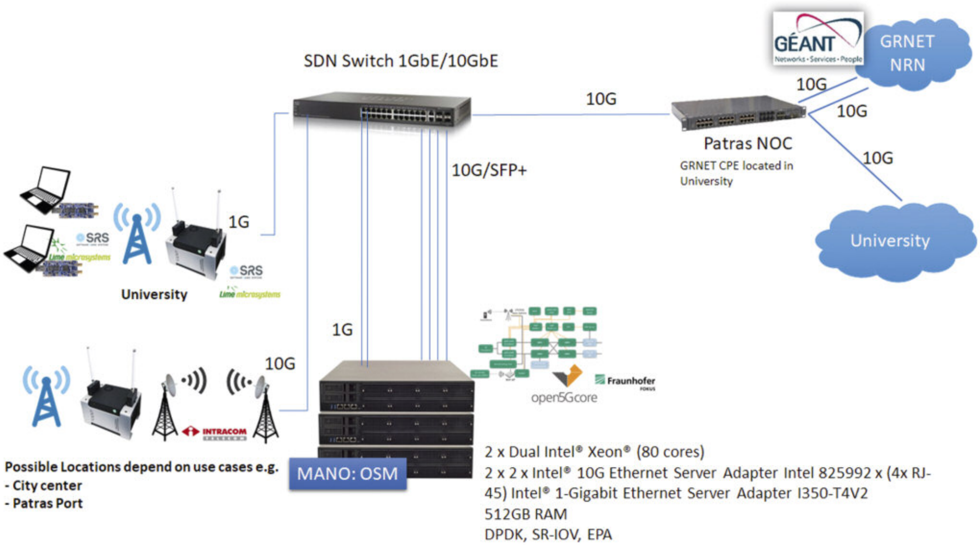

Figure 1: Patras facility site end-to-end design.

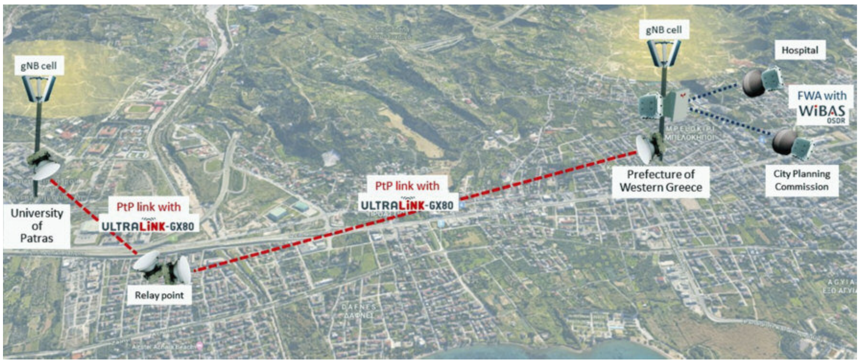

Figure 2: FWA and Backhaul Networks at Patras Facility Site.

Figure 3: Equipment used.

fixed wireless access to two public service establishments, and to cover this, along with a collocated gNB, with high capacity, low latency, long range backhaul. Point-to-Point mmWave wireless links, operating at 71-76/81-86 GHz and delivering up to 10 Gbps, will interconnect the university campus with selected sites several kilometres away, backhauling the gNBs . Fixed wireless access (FWA) links at 26/28 GHz bands, providing up to 1 Gigabit Ethernet to the subscriber and up to 1.6 Gbps aggregate capacity per sector, will interconnect two buildings of public interest in the Patras sub-urban area, providing access to 5G-VINNI core network services.

The RAN section of the Patras facility will comprise both an indoor and outdoor testbed. The indoor testbed will be primarily utilised for short-distance RF link experiments using low power SDRs. This more controlled environment is ideal for prototyping and more preliminary experimentation, before placing the radio nodes in the field. The outdoor testbed will, in turn, be mainly focused on long-distance experiments with network topologies that better match those observed in real-world RANs. The equipment is based (see Figure 3) on Limemicro's SDR products. The 5G mobile core is realised by the deployment of Fraunhofer FOKUS' Open5GCore. Finally, the cloud/network function virtualisation infrastructure (NFVI) is based on Openstack and Kubernetes and utilises generic off-the-shelve switches.

Currently, the Patras facility has already met the challenge of delivering a 5G facility based mostly on Open Source components. Due to lack of 5G NR UEs SDRs cards attached on laptops have been used to initiate testing of 5G KPIs. The facility implements network slicing and slice templates utilizing open source components thus the facility delivers isolated logical networks, running on common infrastructure, mutually isolated and created on demand. The performed tests so far involve both Virtual and Physical Network Functions (VNFs/PNFs), various PoCs have been performed or scheduled in near term (like concurrent execution of different slice types eMBB and URLLC) while the facility prototypes the automated orchestration and delivery of an end-to-end isolated 5G network for every tenant, allowing multiple experiments to be deployed, depending however on the available resources.

The following use case is performed in the facility and will help to measure various 5G key performance indicators:
- First person view remote-controlled vehicle/drone, which can provide real time video streaming from an on-board camera allowing the user to control and move the vehicle/drone. This use case includes elements from both enhanced mobile broadband (eMBB) and ultra-reliable and low latency communications (URLLC). Here the facility's E2E solution creates two slices involving both VNFs and PNFs. The drone is based on Intel's Aero platform where we have attached an SDR solution that allows to test interconnectivity with the 5G Core and investigate 5G NR KPIs. Still the research is heavily involved in the area of optimizing the latency for controlling the drone and delivering on demand a URLLC slice type. Next use cases are planned to be performed in near future as well as from new ICT-19 EU funded projects:
- 360O video broadcast (eMBB): video streaming from a person equipped with a 360o camera to a viewer;
- Coverage study and slicing in NB-IoT;
- Augmented reality (eMBB/URLLC): delivery of annotations on top of a video stream captured by an end user of the service.

Link:
[L1] https://www.5g-vinni.eu/

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5G Test Network: Testing the Mobile Communications for Sports Wearables and Media Broadcasting

by Olli Apilo, Mikko Uitto and Jukka Mäkelä. (VTT)

Controlled test environments enable testing and development of next generation use cases. VTT Technical Research Centre of Finland Ltd is testing 5G use cases covering several vertical industry domains for improved living quality, including solutions for sports wearables and media broadcasting.

One of the goals of 5G is to fulfil the needs of future applications that require even higher data rates or low latency wireless connectivity. However, with the current LTE-A Pro it is already possible to create similar network conditions to the impending 5G technology by allocating most of the network resources to a single dedicated test. VTT has piloted and tested several use cases in different vertical industry domains including smart grids, connected and autonomous vehicle communications, mobile TV, and IoT applications such as wearables. Before widespread deployment of the emerging applications, it is important to test their performance in real live networks without disturbance to existing services.

5G Test Network Finland (5GTNF) is a joint effort between Finnish academic and industrial partners [L1]. It combines several local test network environments such as 5GTN [L2] equipped with latest wireless and wired technologies, see Figure 1. Live parts of 5GTN use the latest LTE-A Pro technologies with operator-grade evolved packet core. 5G links can be tested in the private laboratories with non-commercial prototypes. In 2019, 5GTN will be upgraded with available commercial 5G new radio (NR) base stations and a 5G service core.

Test cases “IoT for sports wearables” and “Broadcast for efficient media delivery”, described below, are examples of 5G use cases, which were conducted in a 5GTN environment located in Oulu, Finland. The complete 5G test system – from infrastructure to applications and services – allows unique testing possibilities from prototype devices to complete solutions in a controlled environment. The use cases and associated test scenarios from our industry partners and research projects guide the evolution of 5GTN.

Testing Cellular IoT for Sports Wearables

To meet the growing demand for widespread and reliable IoT connectivity, 3GPP developed narrowband IoT (NB-IoT) and LTE for machine-type communications (LTE-M) that can be deployed to existing LTE network infrastructure with software updates. These cellular IoT (CIoT) technologies support extended coverage, low device cost, and minimised power consumption [1]. Sports wearables are predicted to be one of the new application domains of CIoT. Sports wearables measure various parameters, such as heart rate and location, during an exercise. Currently, the measured data is uploaded after exercise using USB or a short-range wireless link. CIoT enables bi-directional, long-range and real-time connectivity during exercise. This opens up new service possibilities for device users and other interest groups, such as coaches, personal trainers, and sport fans.

The feasibility of CIoT for sport applications was evaluated by field measurements with CIoT evaluation boards connected to LTE-A Pro base stations and core network. Throughput, latency, CIoT modem power consumption, mobility support, and coverage were measured during extensive testing. Both NB-IoT and LTE-M were able to support the transfer of periodic heart rate and location updates as well as the reception of text messages in normal conditions. The CIoT coverage enhancements were not suitable for sport application traffic as the delays become very large due to repetitive transmissions. Although NB-IoT is not primarily designed for wearables, it can also support the basic sport application traffic. The higher data rates and better mobility support of LTE-M enable more advanced use scenarios, such as

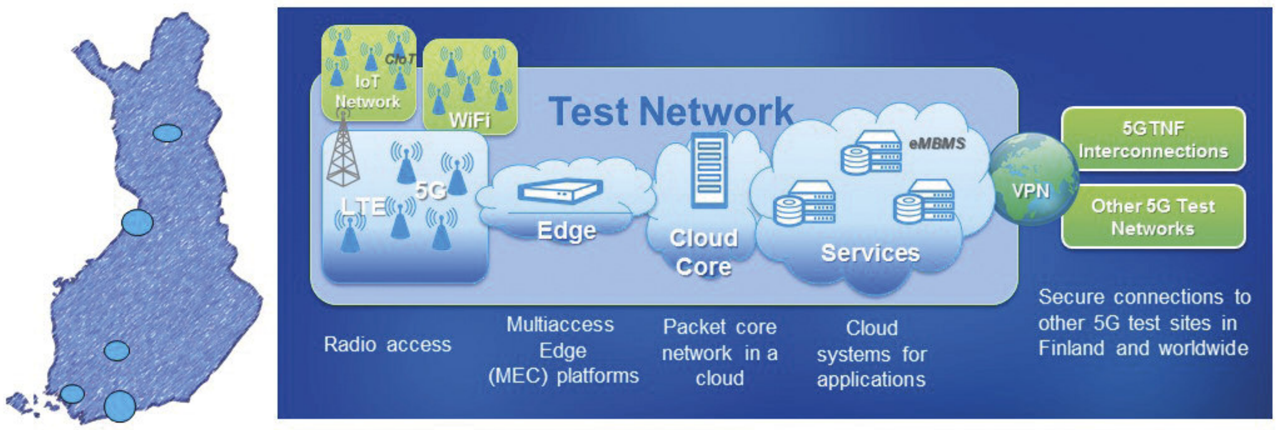

Figure 1: Locations and typical setup of different 5G test sites in Finland.

voice calls, at the price of higher power consumption.

Broadcasting for Efficient Media Delivery

Current mobile media distribution suffers not only from waste of network resources and spectrum, but also due to its inability to adjust peak times for popular content. 5G enables high throughput data transmission, but a large number of simultaneous media users in the same area can result in a lower quality experience for end users. Therefore, 5GTN acquired evolved multimedia broadcast multicast service (eMBMS) from Expway to distribute popular content more efficiently with high quality whilst saving core transmission capacity and spectrum. eMBMS has already been introduced in 4G LTE [2], but it still lacks a business model, especially for operators. However, the increasing number of mobile video users should give the needed boost to eMBMS usage in Finland during the era of 5G. One of the use cases "Broadband and media everywhere" by Ericsson [L3] emphasises the importance of efficient video streaming techniques in 5G. eMBMS service was in the air for the first time in Finland, distributing live content from the Finnish broadcasting company, Yle. The successful eMBMS demonstrations and an extensive set of lab experiments revealed that multicast/broadcast based techniques outperform the traditional unicasting, especially in terms of network bandwidth load and spectrum usage, thereby freeing up precious network capacity for other tasks. Where unicast streaming requires as many streams as there are users, eMBMS requires only a single stream delivered to everyone. Thus, this is also a step in the right direction towards green networking.

Conclusions

The vertical use cases realised and tested in the 5GTN environment have shown the emerging needs of 5G actualisation in real life scenarios where high data rates, transmission efficiency, energy efficiency and reliability are needed. The demonstrations and results carried out during the project provide important information regarding future developments in CIoT and eMBMS deployment and resolve possible bottlenecks in their utilisation. These form an excellent basis for the evolution of 5GTNF and trigger for future developments where more adaptation against fluctuations and dynamic intelligence is needed from the network.

Links:
[L1] https://5gtnf.fi
[L2] https://5gtn.fi
[L3] https://kwz.me/hct

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LuxTurrim5G: Smart 5G Light Pole Infrastructure for Digital Service Ecosystems in Cities

by Jussi Varis (VTT)

LuxTurrim5G is developing and demonstrating a fast 5G network based on smart light poles with integrated antennas, base stations, sensors, screens, and other devices. This joint project with research institutes and companies opens new digital services and business opportunities for a real smart city.

Our societies and cities are faced with the challenges of improving security, energy efficiency, effectiveness of transportation and quality of living. There is a growing need for a new generation service infrastructure that provides a digital ecosystem in smart cities and enables the development of smart city infrastructure and services, thereby opening novel service and business opportunities for companies and new micro-operators.

Current mobile networks will soon be insufficient to serve the increasing number of users of bandwidth-intensive digital services. This bottleneck threatens the realisation of important smart city digital services, which will require an effective and reliable telecommunications network for connection and distribution. This problem can only be solved with the use of small cell radio technology and higher frequencies. It is also of utmost importance that the networks work well indoors, a salient problem with modern energy-efficient buildings. The propagation conditions are particularly challenging at frequencies above 6 GHz, which will play a significant role in 5G networks.

LuxTurrim5G's Approach

LuxTurrim5G project [L1] is formed by a consortium of selected forerunner companies (Nokia, Teleste, Vaisala, Sitowise, Indagon, Lammin Windows and Doors, Premix, Ensto, and Rumble Tools) and research organisations (VTT, Aalto University, and Tampere University). The project has been investigating the technological opportunities and economic feasibility of the digital ecosystem, by developing proof-of-concept prototypes and demonstrating concrete technical solutions for the smart light pole-based 5G infrastructure. The project will make big data capacity available and provide an open access platform for new digital services – both for technology and business.

One of our goals is to integrate the high capacity and low latency 5G radio tech-

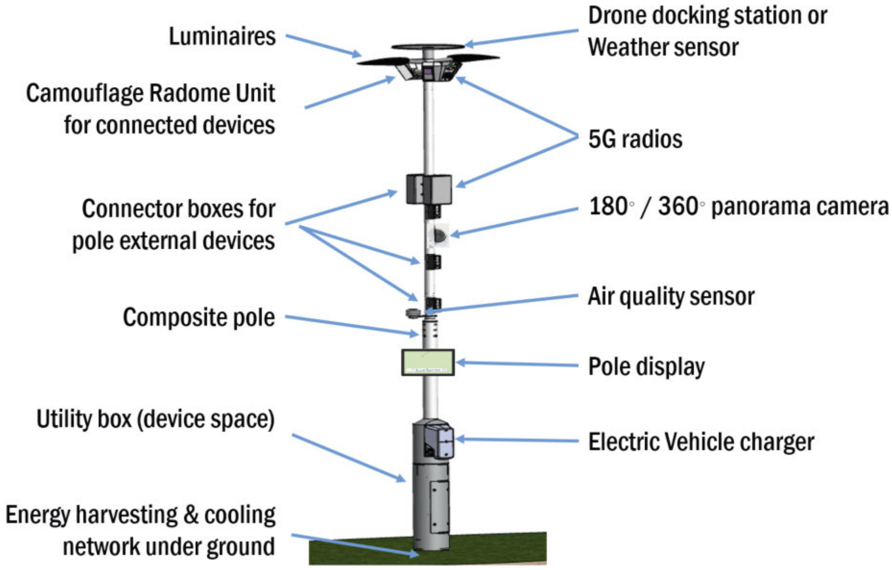

Figure 1: LuxTurrim5G light pole with integrated 5G mmW base station and a set of sensors and cameras.

nology and other equipment to a novel composite light pole, which acts as a mechanical structure for the antennas. The antennas will be designed in such a way as to be invisible and guarantee transparent signal propagation through the radome [1]. Miniaturised antenna solutions, small cells, and the novel smart lamp post infrastructure form a disruptive concept, which could enable online digital services for a smart city. The high integration level connected with thermal management challenges [2] requires robust structures and the highly-automated network installation and management is a challenge that is yet to be solved.

LuxTurrim5G small cell technology will also enable accurate positioning and navigation services in challenging environments. Modern buildings fit this description; the coverage from the 5G lamp posts must reach indoors by penetrating new selective window glass. The project has been verifying the technology's effectiveness in this regard through radio propagation measurement campaigns with the aid of drones, automated cars, and robots.

The solutions, based on 5G small cells integrated to smart light poles together with selected sensors and related services, have been demonstrated in field trials. Currently, Nokia campus in Espoo has a test network of four smart poles in operation. The poles carry millimetre wave radios, air quality sensors, cameras, displays, etc. (see schematic in Figure 1) supported by a service platform with edge computing capabilities. Service prototypes developed for testing the platform enable early market opportunities for participating companies. Examples of the services implemented in the project include sensor device monitoring and management, video analytics (person anonymisation and pose estimation in video feeds from surveillance cameras), climate and air quality analysis and visualisation, seamless positioning for machines and humans, info sharing (active screens aware of human presence), and smart lighting control. Of course, many other services and their combinations can be built on top of the platform, for instance, control of autonomous vehicles to enable effective and sustainable modern urban transport.

Searching for Business Opportunities

Although the project focuses on technical innovations, business opportunities are the key underlying driver for the innovations [3]. The business environment in the digital smart city ecosystem is complex, with a range of public and private stakeholders. Companies need to identify their role in the business context and in the LuxTurrim5G platform ecosystem. Ultimately, the main concern is, how do individual companies create value to the ecosystem and make a successful business case? From a scientific perspective the question is twofold: how to understand the individual technology value proposition and its relation to other technologies in the platform, and what kind of business model is viable when competing in global markets.

Links:

[L1] LuxTurrim5G project: https://www.luxturrim5g.com/

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Design of Robust Ultra-Dense 5G Networks for Smart Cities

by Hans van den Berg (UT, TNO and CWI), Rob van der Mei (CWI, VU) and Peter van de Ven (CWI)

5G mobile communication is commonly seen as a key enabler for smart cities. It will deliver huge improvements in speed, throughput, device deployment, traffic capacity and latency needed by the smart city ecosystem. A major challenge, however, is how to roll-out the highly-dense 5G network infrastructure in urban environments, with highly complex planning constraints, in a cost efficient way.

Recent years have seen the emergence of the smart city concept, which aims to use countless sensors and ubiquitous computational power to enable applications such as smart road traffic control, improved surveillance, and virtual/augmented reality. In 2017, an inter-disciplinary team comprising representatives of big Dutch cities and the national government as well as researchers and representatives from Dutch industry, presented the "NL smart city strategy" [L1]. This strategy document describes how smart city-type applications rely heavily on a robust, low-latency, high-capacity mobile communication network that is able to connect numerous devices, and emphasises the need for an enhanced mobile communication infrastructure, such as emerging 5G networks, in order to realise the smart city concept.

5G networks are currently being developed, with the initial roll-out taking place in 2020, and more features to be added over the next decade. They are expected to provide significantly higher data rates and lower latency than the current generation of cellular networks, enable the interconnection of millions of IoT devices, and provide fast and scalable access to computational power. First 5G field trials are currently set up in many major cities in Europe and beyond, including a planned trial with 5G in Amsterdam during the 2020 European soccer championship. While these trials are promising and show the significant potential of smart city applications supported by 5G, they also reveal that the design and planning of 5G networks is a critical issue that arises when trying to scale up these pilot projects to a full-edged smart city [L2].

In order to realise its potential, 5G includes a range of novel technologies and concepts, such as ultra-small cells/ultra-density, mmWave communication, extreme beamforming and mobile edge computing, where "cloudlets" are distributed throughout the network to allow for quick access to computational power.

Significant attention is devoted in research literature on how to control

5G will deliver huge improvements in speed, throughput, device deployment, traffic capacity and latency needed by the smart city ecosystem. Picture: Shutterstock.

these resources in order to ensure service quality. However, our research is concerned with how to deploy the infrastructure in a cost efficient way, given the demands of the smart city environment. Here we are faced with various crucial decisions, such as where to place the antennas and mobile edge computing (MEC) servers, how to connect the small cells to the network core (fibre or wireless fronthaul/backhaul), and how to exploit existing infrastructure [1], [2]. These decisions involve constraints on the placement of the physical infrastructure, strongly heterogeneous, unpredictable and variable communication and computation demands, and very strict requirements on network performance and robustness. One consequence of these constraints and requirements may also be that cities will require network operators to cooperate and share communication infrastructure, further complicating the design process. Another complicating aspect is the intermittent nature of mmWave wireless channels to be used in 5G. In particular, the capacity of these high frequency channels (possibly also used for fronthaul/backhaul) may strongly fluctuate in the crowded and dynamic environment of a city.

We propose new heuristics to solve the corresponding huge, intrinsically difficult (NP-hard) optimisation problems arising in this context, as well as evolutionary algorithms for network "self-planning". In particular, we will develop methods that exploit and combine model-based and data-driven (e.g., machine learning) techniques for timely prediction of bottlenecks in the network as well as appropriate (cost-efficient, sustainable) modifications to avoid these bottlenecks (cf. [3]). Special emphasis will be put on important requirements regarding robustness of the solutions, i.e., the resulting network designs should be (up to a certain extent) resistant against unpredictably strong traffic fluctuations or failures of network elements due to e.g. extreme weather conditions, vandalism, attacks or just breakdowns due to usage and aging. Related to this, we are also interested in questions like: "How sensitive are the network costs and resulting network performance to the specific network design/planning choices made?" Or: "To what extent are real-time 5G network management approaches able to deal with sub-optimal network design choices?" Insights into these questions are particularly relevant for the development of practically useful guidelines and heuristic approaches for 5G network planning. The ultimate goal of this project is to combine these results into a proof-of-concept network planning tool designed to assist network operators and cities in the roll-out of their 5G network.

Links:

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Announcement

IEEE 5G World Forum

Dresden, Germany, 30 September – 2 October 2019

IEEE, the world's largest professional organization advancing technology for humanity, is hosting the second Annual IEEE 5G World Forum (5GWF'18) 30 September – 2 October 2019 in Dresden, Germany. This unique event is designed to examine key critical 5G innovations across technologies that will alter the research and application space of the future.

5G is not only evolutionary, providing higher bandwidth and lower latency than current-generation technology; more importantly, 5G is revolutionary, in that it is expected to enable fundamentally new applications with much more stringent requirements in latency and bandwidth. 5G should help solve the last-mile/last-kilometer problem and provide broadband access to the next billion users on earth at much lower cost because of its use of new spectrum and its improvements in spectral efficiency.

The World Forum will attract industry practitioners, researchers and academia, government regulators, and public sector executives to hear industry experts and peers share best practices and lessons learned, latest research, new standards development initiatives, innovations, and first-hand experiences regarding prototyping and initial service offerings. It offers an outstanding opportunity to showcase your products and applications to a vibrant and engaged audience and provides an ideal platform for you to reach hundreds of key decision makers involved in 5G.

More information:
http://ieee-wf-5g.org/

Simulating Cooperative, Connected and Automated Mobility in Luxembourg

by Sébastien Faye, Gérald Arnould, Francesco Ferrero, Imen Mahjri and Djamel Khadraoui (LIST)

In recent years, mobility challenges have led to a massive expansion of Intelligent Transport Systems (ITS), which are benefiting from the rapid technological advances in communication networks. In addition, the increasing complexity of new emerging applications, particularly associated with Cooperative, Connected and Automated Mobility (CCAM), is promising. New scientific approaches are continuously being incorporated into these applications, and it is vital that they are evaluated under realistic conditions, especially in the context of 5G communication networks. Luxembourg has recently experienced considerable changes in its traffic conditions, as shown by concrete examples of the use of simulation scenarios to advance the knowledge of complex CCAM and 5G applications in a simple, cost-effective way.

Almost 200,000 cross-border commuters come to Luxembourg every day. With a few highly populated areas and several mid-sized cities, this country faces several mobility challenges, which the authorities are trying to mitigate with strong initiatives such as free public transport for all (from 2020) and the deployment of several ITS. As such, Luxembourg is a perfect place for experimenting and validating innovative solutions with high impact, such as 5G – the emerging fifth generation of cellular networks. Nevertheless, deploying and testing solutions is not an easy task, often requiring many participants, hardware and a test site large enough to reflect a realistic situation. This is further amplified by evidence that new cooperative ITS (C-ITS) rely predominantly on communication networks, which are also facing their own challenges. Simulation-based approaches are seen as a key solution.

The Luxembourg Institute of Science and Technology (LIST) – the Research and Technology Organisation of the Government of Luxembourg, through its background in the mobility sector, has, over the years, taken full advantage of communication technologies to offer new services that meet existing challenges [1].

A large number of initiatives have demonstrated the value of using distributed communication technologies based on the 802.11p protocol for vehicle-to-vehicle and vehicle-to-infrastructure interactions, especially for safety applications and traffic management (e.g. collision warning, traffic light management). However, these models no longer correspond to reality. Experience has shown that one communication technology alone rarely addresses all the requirements that are specific to a mobility model [2], such as the high speed of vehicles, low latency requirements, or the increasingly larger number of devices that can result in network congestion. This has been verified by eCoBus [L1], a national project funded by the Luxembourg National Research Fund (FNR), which revealed that a territory like Luxembourg had to deal with various means of communication to ensure sufficient service quality and to ease C-ITS deployment. This can be done through setting up control layers to switch between cellular networks and direct communication in order to identify the best physical transport layer enabling vehicles, city infrastructure and other sensors to communicate seamlessly.

A key strength of eCoBus is the use of realistic simulation tools and scenarios, able to accurately reproduce mobility in Luxembourg and network connections that meet the constraints of a road environment (e.g. poor signal quality), based on the SUMO road traffic simulator [3]. LIST has notably exploited these simulation tools by developing components that consider electro-mobility issues and manage bus fleets and their passengers in the best possible way, both over an entire city and locally at intersections (see Figure 1). These components have, for instance, recently proven that it is possible and realistic to use exclusively bus-to-bus communication in some of the most concentrated areas of the city as a basis for C-ITS applications – thus reducing deployment costs. By the end of the project, these tools will make it possible to validate complex multi-objective optimisation models, considering the entire city of Luxembourg, more than 500 bus stops and realistic traffic conditions over 24 hours.

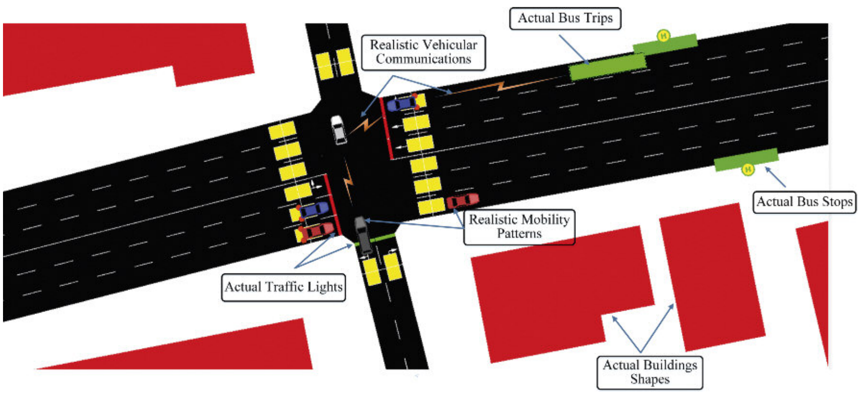

Figure 1: ECOBUS simulation environment.

In parallel with the possibilities offered by well-established communication network technologies, an interesting perspective is provided by 5G, which appears as a key enabler for implementing meaningful mobility applications in urban and cross-border areas, such as Luxembourg. However, 5G will face many deployment challenges, and the use-cases that could benefit from it still need to be matured and their adequacy validated.

How can mobility applications, such as Connected and Automated Driving, benefit from 5G? This is exactly the question that 5G-MOBIX [L2], a Horizon 2020-funded project in which LIST is involved, aims to answer. This initiative is part of a series of other projects aimed at validating the technical and commercial interest of 5G in a CCAM context all around Europe. In these cases, again, simulations represent an excellent means of testing new applications at low cost and in a timely way, with the ability to reconfigure the vast majority of communication and road traffic parameters. One of LIST's tasks will be to study strategies for deploying antennas on a citywide and countrywide scale, considering criteria that would be impossible to include with a vision limited to streets and intersections.

These simulation-based approaches also make it possible to study how 5G can contribute to existing communication technologies. Safety services, already widely prototyped using 802.11p, would for instance benefit from the ultra-reliable low-latency communications offered by 5G and 5G would drastically reduce the cost of embedding such services in commercial cars (e.g. e-call). Moreover, as demonstrated in eCoBus, the efficient management of urban traffic requires communication capabilities among vehicles, road infrastructure (e.g. traffic lights) and a plethora of other sensors in order to ensure the smooth circulation of a rapidly increasing number of vehicles. Nowadays, several proprietary communication technologies are used to that extent and are often very difficult to maintain or to adapt to evolving requirements. 5G would allow deployment of cheaper sensors with a longer battery life and unify the communication protocols in a smart city scenario. Ultimately, using LIST's simulation scenarios, which are the result of several years of research in Luxembourg in its various research centres, has the potential to lead to efficient, targeted and realistic recommendations to local authorities and companies to justify the deployment of new mobility solutions and their compatibility with existing communication technologies.

Links:

[L1] https://ecobus.lu/
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5G Network to Improve Road Safety

by Tiia Ojanperä (VTT)

The 5G mobile network and fast data transmission solutions can be used to collect a huge amount of data from vehicles on the road. The information can be used for various purposes, such as providing road weather services, carrying out road maintenance and controlling self-driving cars. Ultimately the aim is to reduce accidents.

The two-year 5G-Safe project [L1] explored the possibilities of using 5G to improve road safety. Thanks to the fast 5G network and distributed data processing solutions, including multi-access edge computing (MEC), vast amounts of sensor, video and radar data can be collected from vehicles. The information can be transmitted automatically in real-time, without the need for drivers to do anything themselves. The data can also be processed, and warnings can be sent to road users, road maintenance and third parties by means of intelligent systems.

The 5G-Safe project developed and piloted novel 5G road safety solutions [1] in real vehicle and test network environments. The final piloting event took place at the Sod5G winter vehicle test track [L2] in Sodankylä, Finnish Lapland in November 2018. At the final event, the project demonstrated to the public advanced road weather services enabled by 5G, vehicle-to-vehicle video for improving road safety, road maintenance optimisation through crowdsourcing and 5G-assisted automated driving.

The VTT-led project was completed at the end of 2018. Participants included the Finnish Meteorological Institute, Destia, Unikie, Sitowise and Kaltiot. The project was part of the Challenge Finland competition and financed by Business Finland.

Icy Corner Ahead – Please Slow Down!

Local road weather services are one of the key applications for the data collected from vehicles. In the future, real-time weather information and warnings can be sent directly to drivers' satellite navigation devices, for example. The new solutions give drivers access to highly localised data, such as warnings about icy conditions around the corner. Drivers can use the information to choose a different route or change the way they drive.

In the final pilot, the 5G-Safe project demonstrated three weather and safety related services delivered to vehicles via the 5G test network on the test track. The services included the road weather forecast, traffic safety alert and weather alert [2]. The services relied on the robust and extensive data exchange between vehicles and cloud enabled by 5G.

Figure 1: The 5G-assisted automated driving scenario demonstrated on the Sod5G winter vehicle test track. The front vehicle transmits LiDAR data to an obstacle detection algorithm running on a MEC server. The self-driving car Martti, behind, receives a warning and manages to go around the obstacle.

Some automated weather warnings can already be transmitted via the current 4G and ITS-G5 networks, and solutions are being introduced gradually. However, transmitting real-time video footage or 3D LiDAR views reliably between vehicles requires considerably more network capacity and very low latency. The fast 5G network can support both.

One way to use vehicle videos and 3D views is a 'see-through' application [2] demonstrated at the final event. It can be used, for example, to share the dashboard camera footage of a lorry holding up a long queue of cars with the drivers stuck behind the lorry. This increases safety especially in poor weather conditions such as when visibility is obstructed by drifting snow.

Crowdsourcing Information for Road Maintenance Purposes

5G technology also opens up new possibilities from the perspective of road maintenance. The new technology provides an extremely efficient way to collect information on the condition of roads. The 5G-Safe project demonstrated how the data can be used to alert road maintenance providers to a range of issues requiring their attention, such as snow build-up on the roads, snowy traffic signs or potholes.

This is a big improvement on the current approach, in which road maintenance contractors are responsible for collecting this information themselves and therefore need to drive around to inspect roads visually. If monitoring could be crowdsourced to all road users, road maintenance contractors could work considerably more efficiently and cut their costs.

Having access to comprehensive and reliable data would allow road maintenance contractors to prioritise the most urgent jobs. More efficient maintenance could improve the entire road network and therefore increase road safety.

Self-Driving Cars Expand Their Territory

5G technology helps human drivers behind the wheel, but its impact on self-driving cars could be even more revolutionary. Real-time data can be used to better control self-driving cars and change their behaviour based on observations. VTT's self-driving car Martti [3] has already trialled these possibilities.

In the final pilot, VTT's self-driving car Martti drove in automated mode on the test track utilising its own sensors and warnings received through the 5G test network [2]. Martti received warnings from a MEC service that was detecting obstacles on the road in real-time based on LiDAR data transmitted by another vehicle. A snapshot of the scenario is shown in Figure 1. In addition, Martti received slippery road alerts from the road weather service. Based on the warnings, the robot car was able to plan its route to avoid dangerous stretches of the road and go around obstacles.

Precise information can be vital in challenging conditions and even expand the potential uses of self-driving cars. Self-driving cars are currently mostly used in areas where weather conditions are not a problem. Controlling self-driving cars in Nordic climate requires accurate information on road conditions in real-time. The new technology makes it possible to collect data from areas beyond the cars' own sensors [L3]. These kinds of services are extremely important for future self-driving cars.

Towards Global Markets

Services developed during the 5G-Safe project have been piloted in real-life environments. The next step is to commercialise the results. In addition, the partners are currently planning a follow-up project involving further development of road safety solutions based on 5G technology. The new project will include partners elsewhere in Europe, since there is clearly a lot of interest in solutions and services that improve road safety on the global market as well.

Links:

[L1] 5G-SAFE project website: http://5gsafe.fmi.fi

[L2] Sod5G project website: http://sod5g.fmi.fi/

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Distributed Massive MIMO Measurement Framework for 5G Vehicular Scenarios

by David Löschenbrand and Thomas Zemen (AIT)

Massive multiple input multiple output (MIMO) is widely considered as a key enabling technology for 5G. It promises increased spectral efficiency and the mitigation of small-scale fading in rapidly time-varying communication channels through channel hardening due to the large amount of base station antennas. Spectral efficiency is of utmost importance for data-heavy applications. Channel hardening, however, is a key feature for ultra-reliable low latency communication (URLLC) because large fading dips causing loss of possibly safety-critical messages can be avoided. In the project MARCONI we investigate a measurement framework for rapidly time-varying distributed massive MIMO communication channels typically found in vehicular scenarios. With this empirical data we will work on massive MIMO channel models and new transceiver algorithms enabling a constant transmission quality from the base station to the mobile station. We will explore algorithms to enable these properties for the first time for highly time-variant and non-stationary V2I scenarios in both time-division duplex (TDD) and frequency division duplex (FDD) systems. We analyse the measured channel characteristics over time for collocated and distributed receive antenna setups to evaluate the fundamental limits of communication systems in such scenarios. Our results show that antenna placement plays a crucial role for establishing ultra-reliable communication links between cars and infrastructure.

The performance of wireless communication systems is limited on a physical level by the characteristics of the wireless propagation channel. Vehicular scenarios pose a great challenge to communication systems due to the large (relative) velocities, many moving metallic reflectors and low flexibility in antenna placement [1]. The utilisation of massive MIMO communication links for vehicle to infrastructure (V2I) applications in safety-critical scenarios promises reliability and robustness against harsh propagation conditions of vehicular settings through channel hardening [2].

The characterisation of these propagation conditions via measurements lays the foundation for future ultra-reliable low latency communication (URLLC) systems. Due to the rapidly time-varying and non-stationarity behaviour of the channel, common measurement that rely on slowly changing or constant propagation conditions are not applicable for V2I scenarios. To this end, we are developing a fully parallel distributed massive MIMO channel measurement framework capable of characterising numerous vehicular channels with high speed. A custom-built calibration unit facilitates the calibration of the measurement framework in the field. A flexible long distance synchronisation solution allows great variability of the antenna placement under test. Below is an overview of our measurement framework and obtained results.

Channel Measurement Framework

The transmitter node of the presented massive MIMO channel measurement framework consists of a software-defined radio (SDR) covering the anticipated 5G frequency ranges below 6GHz. The highly adaptable SDR is programmed to act as two mobile stations (i.e. Smartphones) with one antenna each transmitting data to a base station. A GPS-enabled Rubidium clock is used for nanosecond precision synchronization to the base station and for localization in space. The setup is powered by an uninterruptible power supply which allows for more than four hours of measurement time without the need of a power outlet. The transmitter node is placed in a small van and transmit antennas as well as GPS antennas for position tracking are mounted on the roof of the van. The transmitter node is thus mobile and can be operated at various speeds and in different propagation scenarios.

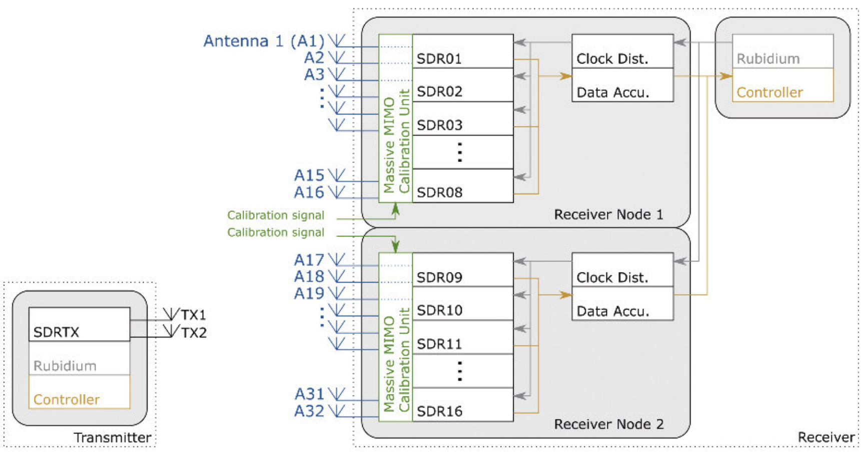

Figure 1: Base station with 32 receive antennas in two nodes (left and right).

The receiver features 32 antennas which operate fully parallel and act as a base station. We group the receive antennas into two nodes with 16 antennas each. These nodes can be arbitrarily positioned in space with a separation of up to 60m to analyse different antenna geometries and their performance. The receiver also uses a Rubidium clock for nanosecond precision synchronization. Figure 1 shows the 32 receive antennas of the measurement framework as well as the SDRs (that sample the received signal), the calibration unit and the control computer.

A custom built massive MIMO calibration unit is integrated in the measure-

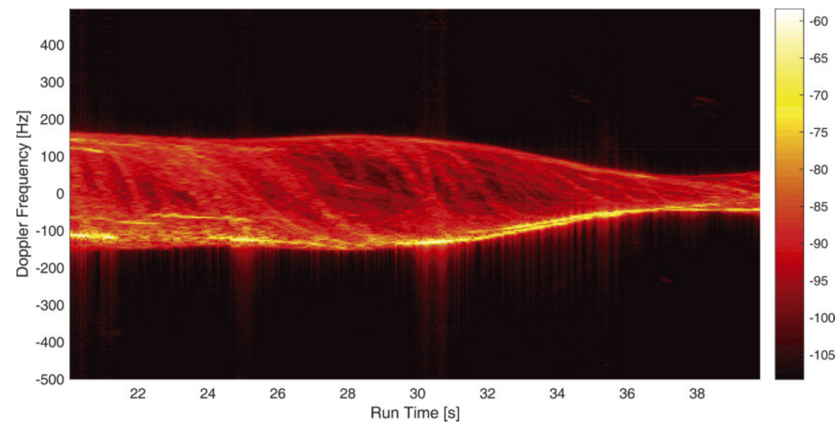

Figure 2: Power delay profile (PDP) for one transmitter-receiver pair for a duration of 20s. The PDP shows a rich scattering environment with a strong line of sight (LOS) path, a second strong path with a delay of 120ns from 32s-40s and various additional multipath components.

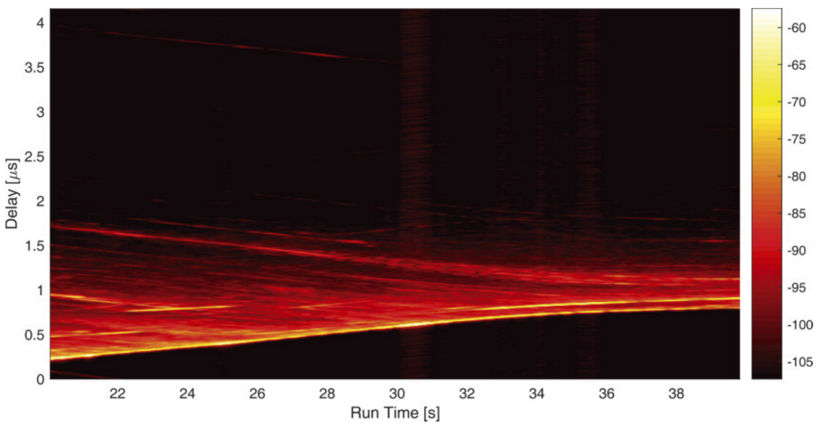

Figure 3: Doppler spectral density (DSD) of one transmitter-receiver pair for a duration of 20s. The DSD shows a strong component with increasing negative Doppler shift. The transmitter is moving away from the receiver, approaching a crossing with ~ 40km/h and decelerating before turning right.

ment framework to ensure fast and reliable calibration. By doing so, the effects of the measurement equipment is factored out and only the effects of the wireless propagation channel remain.

Channel Measurement, Analysis and Results

Vehicular wireless channels exhibit rapidly time-varying behaviour and non-stationary statistics [3]. It is thus crucial to measure the channel repeatedly in time to capture even the slightest variations. We use a broadband signal similar to the ones used in current wireless standards at a carrier frequency of 3. 5GHz (reserved for 5G usage) to capture the channel characteristic over time. The broadband signal is transmitted and received 1,000 times per second to capture the time-varying wireless propagation channel sufficiently often for further analysis.

To analyse the time-variant characteristics of vehicular channels for a given transmitter and receiver, we revert to the time-variant power delay profile (PDP) and the time-variant Doppler spectral density (DSD). The PDP indicates the signal strength arriving at the receiver with a given delay (or, accordingly, with a given distance). The DSD indicates the relative velocities of scattering objects and how much signal strenght is contributed by a scatterer at a given velocity. Since the transmitter and the surroundings move over time, the PDP and DSD also change over time, hence the fading process is non-stationary.

Figure 2 shows the PDP for the transmitter moving away from the receiver, thus increasing their distance and therefore the delay of the transmission. There is a strong line of sight (LOS) component present and the urban environment creates rich scattering with various delay values. Well reflecting and large scattering objects create continuous traces in the PDP plot with changing delay over time. Figure 3 shows the DSD for the same scenario. The departing transmitter creates a strong negative Doppler component. It passes numerous scattering objects, which appear as traces from positive to negative Doppler values.

Further analysis, considering all 32 base station receivers and two mobile station transmitters, show the large influence of base station antenna placement on the potential performance of 5G massive MIMO communication systems [4]. Obtaining those results is only possible with a highly flexible distributed measurement framework as presented above. It sparks numerous exiting research questions which are to be addressed for fully leveraging the potential of URLLC systems in 5G.

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Device-to-Device Based Inter-Cell Interference Coordination for Delay-Sensitive 5G Networks

by Mohamed Elshatshat and Stefanos Papadakis (ICS-FORTH) and Vangelis Angelakis (Linköping University)

Heterogeneous 5G networks that consist of dense deployment of macro base stations, small base stations and device-to-device communications play a central role in improving the spectral efficiency and the delay performance of real-time applications. Enhanced inter-cell interference coordination based on time-domain coordination mitigates the downlink interference at the small base station users' equipment but degrades the delay performance of the macro base station users' equipment. In this work we exploit the inactive users' equipment to serve as relays between the small base station and the macro base station users' equipment which ensures that the delay requirements of real time users are achieved.

Device-to-device (D2D) communications sharing the spectral resources with the cellular users is one of the enabling technologies for the 5th generation (5G) of wireless networks. Among the major 5G use cases that can benefit from D2D communications are the massive machine type communication (mMTC) in the internet-of-things (IoT) networks, vehicle-to-vehicle (V2V) communications and ultra-reliable and low latency communications (uRLLC). D2D communications exploit the proximity of devices to achieve low latency, higher spectral efficiency and less energy consumption [1]. In addition, the heterogeneous deployment of macro base stations (BSs) and small BSs is seen as one of the main technology drives that could boost the spectrum efficiency if frequency reuse over the different tiers of the wireless network is applied.

One major issue with frequency reuse is that users' equipment (UE) is normally associated with the BS that has the highest received signal strength which results in the small BSs being underutilised owing to their low transmission power. For this reason, 3GPP introduced a virtual expansion of the coverage area of the small BSs by adding a bias value to their received signal at the UEs [2]. This is known as the cell range expansion (CRE) and is shown in Figure 1. On one hand, CRE helps by offloading UEs from the macro BS to the small BS. But on the other hand, it creates a vulnerable region at the edge of the small BSs where UEs are prone to high interference from the macro BS. One of the interesting approaches to protect those UEs at the edge between the small BS and the macro BS, called here edge UEs, is the enhanced time-domain inter-cell interference coordination scheme (eICIC) [2]. In eICIC, the macro BSs mute their downlink transmission during certain sub-frames so the small BSs can serve the edge UEs. Those sub-frames are known as the almost blank sub-frames (ABS) and their value is related to the expanded region of the small BS. However, the main drawback of eICIC is that the transmission rate and the delay performance of the UEs associated with the macro BS, called macro UEs, is reduced during the ABS sub-frames [3].

In our previous work [3], we proposed to improve the performance of the macro UEs during ABS sub-frames by integrating D2D communications with eICIC. We considered using the inactive UEs as relays, called here relay UEs, to the macro UEs to avoid the service degradation due to eICIC. This work is based on the assumption that there is a set of relay UEs at each small BS that can operate in D2D mode and serve as relays between the small BS and the macro UEs during ABS sub-frames. Relay UEs are associated with the edge region of the small BS to guarantee

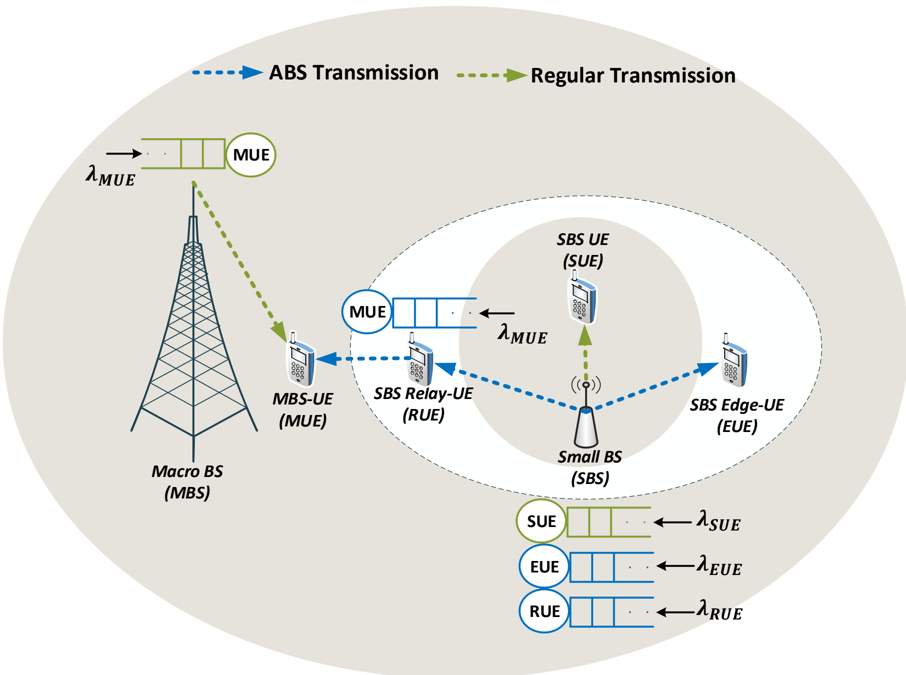

Figure 1: Heterogeneous 5G network system model with cell range expansion. D2D communication ensures that macro base station UEs receive downlink transmission during almost blank sub-frames.

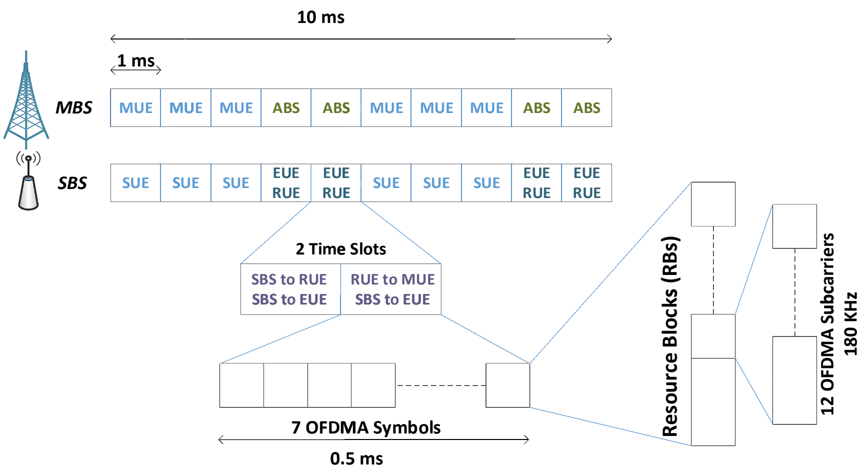

Figure 2: Downlink resource grid based on using device-to-device communication during the almost blank sub-frames.

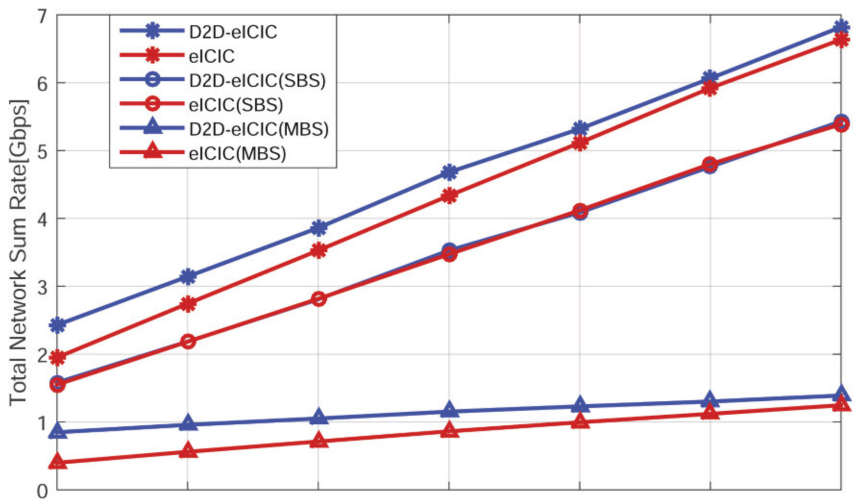

Figure 3: Sum-rate vs. traffic load at the small base stations.

good channel conditions with the macro UEs. In Figure 1, we show that this approach could also improve the delay performance of the macro UEs with real time applications.

Figure 2 shows the structure of the proposed downlink resource grid. BSs can allocate multiple resource blocks to the UEs depending on the required data rates. The fundamental idea of our approach is to exploit the frame structure to relay the downlink packets from the small BS to the macro UEs through the relay UEs during ABS sub-frames. We assume that a central controller at the core network, which is connected to the BSs via optical fibre back-haul links, is responsible for allocating the resource blocks to the UEs. We also assume that BSs have global knowledge of the channel state information to facilitate the allocation of resource blocks. We assume that macro UEs have dual connectivity and their downlink data packets are delivered through both the macro BSs and the small BSs. During ABS sub-frames, the macro BS does not transmit to the macro UEs and ABS sub-frames are divided into two time slots. In the first slot, the small BSs transmit to the relay UEs. While in the second slot, the relay UEs forward the packets to the macro UEs using decode and forward protocol. Note that during ABS sub-frames, the small BS is able to transmit to the edge UEs as well since orthogonal OFDMA subcarriers in the frequency domain can be used during the same time slot.

In this work we are considering a resource allocation approach that gives higher priority to the edge UEs during ABS sub-frames, which means that increasing the traffic load at the small BSs leaves fewer resources for serving the macro UEs in the proposed D2D-eICIC. The reason for this priority-based resource allocation is to guarantee that small UEs' performance does not degrade with D2D-eICIC. In Figure 3 we show the sum-rate performance of the proposed approach in comparison to the traditional eICIC (without D2D communications) at varying percentage of the traffic load at the small BSs. The upper two lines show the total sum-rate of the network and it shows that D2D-eICIC performance is always higher. We can also observe from bottom two lines that the sum-rate of the macro UEs is higher for D2D-eICIC at low traffic conditions at the small BS. However, this gain in the macro UEs' sum-rate decreases when the traffic load at the small BSs increases. Finally, the middle two lines show that the small UEs maintain the same sum-rate in D2D-eICIC compared to the traditional eICIC, which is a result of the priority-based resource allocation at the small BS.

This work has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No 642743 [L1].

Link:
[L1] http://wivi-2020.eu

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Clear5G: 5G Empowers the Factories of the Future

by Haibin Zhang (TNO)

The Horizon 2020 EU-Taiwan collaboration Clear5G project focuses on 5G wireless solutions to empower the factories of the future. Some intermediate results of the project are also presented.

Wired networks are still dominating the industrial automation market today. However, wireless communication has advantages in some factory environments [1] [L1], for example, where chemical or metal particles are harmful to wire connectors, costing hundreds of thousands of Euros per year to maintain in a medium-to-large-sized factory. In addition, wireless communication is the most convenient (or even only) means to transmit information to or receive information from mobile robots or moving objects such as AGVs or forklift trucks.

The Horizon 2020 EU-Taiwan collaboration project Clear5G [L2] addresses how 5G wireless networks may empower the Factories of the Future (FoF). “Clear5G” stands for “Converged wireless access for reliable 5G Machine-Type Communications for factories of the future”. The project was launched in September 2017 and will run until February 2020. Clear5G’s objective is to design, develop, validate, and demonstrate an integrated convergent wireless network for Machine Type and Mission Critical Communication (MTC/MCC) services for FoF. Clear5G aims to deliver technical solutions in the radio network domain, which can support massive deployment of connected devices, security, ultra-low latency and ultra-high reliability in FoF applications.

Various use cases in FoF pose different technical requirements on 5G, which cannot be met by any single available wireless technology. Technological versatility improves service provisioning capabilities, but meanwhile increases challenges on how to effectively manage convergence among co-existing technologies (short- and long-range, private and public, infrastructure- and ad-hoc based, etc.) at a large scale. The challenges are further increased by peak interference due to the operation of heavy machinery (e.g., switches) in typical FoF environments. With this in mind, Clear5G focuses on providing physical (PHY) layer, medium access (MAC) layer, and architectural and management enhancements to meet the strict requirements of FoF applications, thus contributing to the ITU-R objectives for the next generation mobile networks.

At the PHY layer, Clear5G studies solutions for reliable MTC that can support massive numbers of devices, achieving extreme low latency and reduced signalling and control overhead. Key technical components include adaptive frame structure and waveform, non-coherent modulation, non-orthogonal multiple access (NOMA), and physical-layer security. At the MAC layer, Clear5G focuses on solutions for integrated convergent access supporting low latency, high reliability, massive connection density, and high energy and spectrum efficiency. Both contention-based and contention-free mechanisms are considered, in potentially heterogeneous networking scenarios. Clear5G also addresses joint PHY and MAC optimisation, in particular in the context

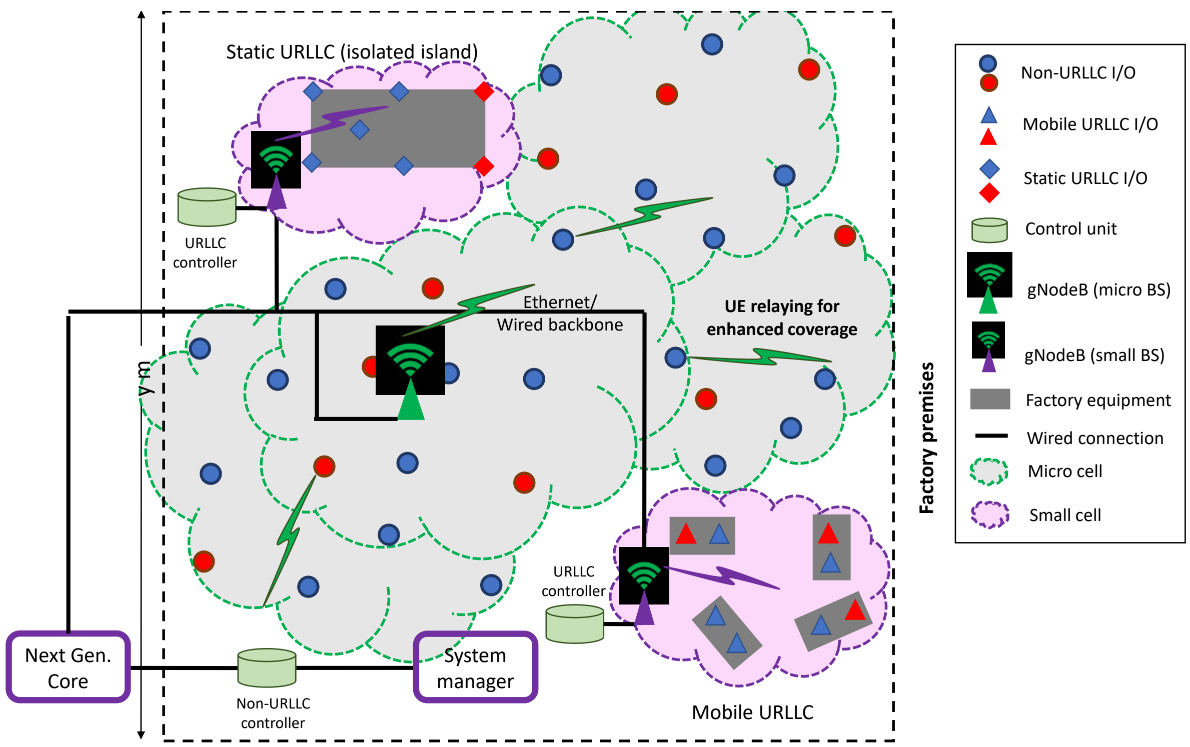

Figure 1: Multi-tier 5G factory network enhanced by UE relaying and D2D communication [2].

of NOMA (for high connection density). At the architectural and management level, Clear5G designs radio network architecture and management mechanisms (with potential coexistence of public and private infrastructures) to fulfil the needs of FoF applications in terms of latency, heterogeneity, reliability, scalability and manageability. Further, energy efficiency (especially at the device side) will be among the major performance targets in the design of network architecture and management strategies. Key technical components include inter-slice management, multiple connectivity, UE relaying, SDN and data analytics tooling for network management.

Figure 1 illustrates a multi-tier 5G factory network, proposed by Clear5G [2], providing wireless connectivity among different types of input/output (I/O) devices: URLLC and non-URLLC ones, mobile and static ones. Different network slices may be configured to support URLLC and non-URLLC services, respectively. For a slice of URLLC services, a controller may be deployed locally as close as possible to the application area (edge computing). On the other hand, for a slice of non-URLCC services a controller may be deployed in a private or public cloud for central management. When blocking occurs, due to the presence of heavy metals and/or electro-magnetic interferences, (dynamic) UE relaying could be used to provide better coverage and higher reliability. Faster data exchange between URLLC devices could also be facilitated through device to device (D2D) communication where possible.

In the context of low latency, Clear5G addresses latency in both user plane (i.e. data transmission in RRC connected mode) and control plane (i.e. the transition from the idle/inactive mode to the connected mode). Data transmission via the control plane is enabled and (for URLLC services) as early as possible. Figure 2 exemplifies the performance of URLLC services using a proposed two-step random access procedure with data repetitions (noted as '5G repeat') in the form of the 50th, 99.9th and 99.99th percentile latency, in comparison with the state-of-the-arts (SoTA) solutions: LTE Cat-M1, Early Data Transmission – EDT (available since 3GPP Release 15). The achievable minimum latency of the '5G repeat' solution is 5 ms, in comparison with 37 ms of LEE Cat-M1 and 14 ms of EDT. Note that 3GPP has requirement of < 10 ms for control plane latency. Further note that these example results and comparison are based on a Transmission Time Interval (TTI) of 1 ms. For 5G NR, with a lower TTI length (e.g. 0.25 ms), the minimum control plane latency could be further lowered (e.g. to 1.25 ms).

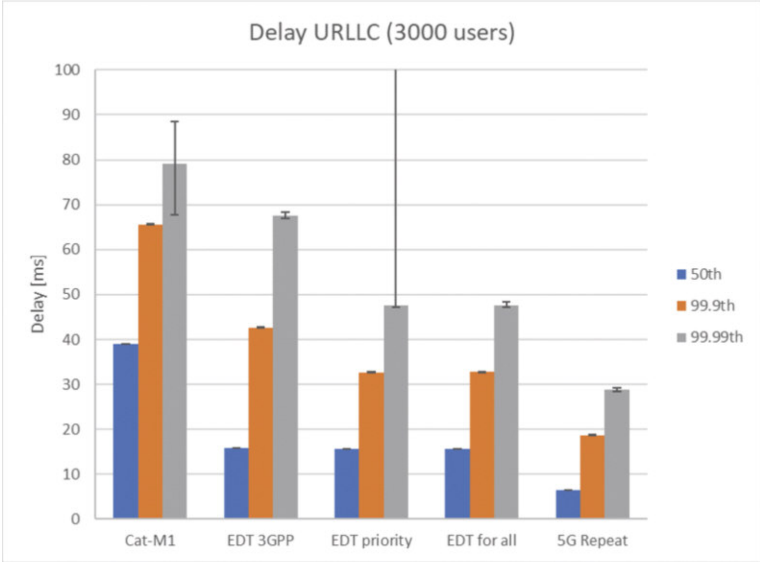

Figure 2 Random access latency of URLLC services using the two-step procedure in comparison with SoTA solutions [3].

Interested readers may refer to the deliverables of Clear5G [L2] for more (intermediate and detailed) results of the project.

The Clear5G consortium consists of seven European partners and four Taiwanese partners, with a combination of major corporations (FFG-Fair Friend Group, Toshiba, Turk Telekom, ADLINK), SMEs (WINGS), as well as research and academic institutions (University of Surrey-coordinator, TNO, CEA, ARGELA, III, National Taiwan University). ERCIM member TNO is technical manager of the project, with the responsibility to ensure that the scientific content of the project is of a high-standard, adhering to the objective of overcoming the technical challenges envisioned, while staying up to date with the scientific progress in areas relevant to the project.

The overall project results will be demonstrated using the facilities provided by both Taiwanese and European parties. The Taiwanese and European facilities will be coordinated to serve the same project goal. For example, the 5GIC testbed at University of Surrey will be mainly used for proof of concept demonstration and to further validate the project results in a scenario that shows and allows investigation of the coexistence of physically private and public infrastructure. A mini-PC based relaying testbed at TNO will be used to showcase the potential of UE relaying to improve coverage and communication reliability in factory scenarios where radio propagation is subject to large shadowing or blockage effects from metal objects. The final project demonstration is planned in the factory floor of ANEST IWATA Taiwan Corporation, a joint venture of FFG, for validation of project results in a near-to-real factory environment.

Links:
[L1] https://kwz.me/hc7
[L2] http://www.clear5g.eu/

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Integration of 5G and Aerospace Networks by SDN and NFV Techniques

by Manlio Bacco, Pietro Cassarà and Alberto Gotta (ISTI-CNR)

5G trials are beginning in several parts of the world. The smarter core capabilities, along with increased network capacity, very low delays and native support for machine-to-machine communications, open up several new application scenarios, while reinforcing existing ones. This work focuses on the joint use of aerospace platforms and 5G networks, surveying the huge advantages that their seamless integration can bring to the market, enabling ever more use cases and potentially providing coverage in low-population and low-income areas.

In the past, the main role of satellite networks has generally been perceived to be to provide backhauling solutions in remote or hard-to-reach locations. This assumption is based on the technical complexities of integrating satellite and terrestrial networks, due to the lack of prevalent standards and the proliferation of vendor-specific solutions. With the advent of 5G networks and the adoption of software defined radio (SDN) and network function virtualization (NFV) paradigms, the role of satellite networks can change due to the ease with which they can be integrated with existing network infrastructures.

In fact, such an integration will create significant new opportunities for both terrestrial and aerospace networks, thanks to a greater flexibility in the operation and evolution of end-to-end network services.

While the SDN approach is well consolidated on wired networks, thanks to the match/action abstraction characterising the operation of heterogeneous network nodes, in the wireless domain there is not a clear programming model for access nodes.

Indeed, unlike wired networks, node configurations at the physical layer (such as the transmission bandwidth, power, modulation format, etc.) have a direct impact on link reliability, coverage and capacity, thus introducing a further level of flexibility on the data plane. In order to provide the “southbound interface” for the network controller, it is therefore necessary to abstract the behaviour of terrestrial and aerial base stations in terms of a common model and a set of programmable network functions, decoupled from proprietary hardware.

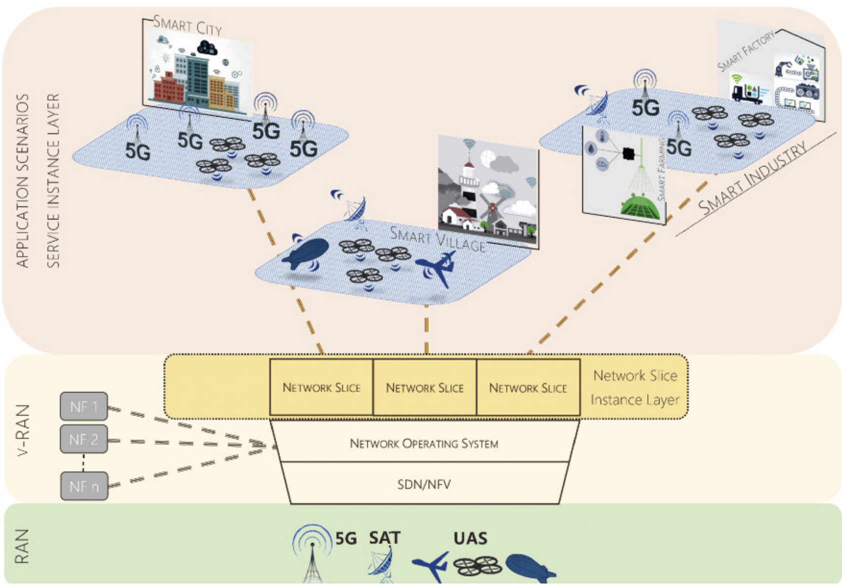

Figure 1: SDN and NFV techniques can provide an easy integration between 5G and aerospace networks in the considered application scenarios thanks to the virtual RAN (v-RAN), the virtualised network functions, and 5G network slicing. All network resources and network functions are coordinated by distributed network intelligence.

Base Station Abstractions

Although terrestrial and aerial base stations have different peculiarities in terms of cell breathing opportunities, available transmission power, link configuration capabilities, multi-user management, and so on, we can easily recognise some common sub-systems: an outdoor unit, including the antenna and the remote radio head, responsible for acquiring signal samples; a baseband unit, responsible for mapping bits into symbols and samples and vice versa; one or more forwarding units, responsible for opportunistically accessing wireless resources and managing traffic queues with multiple priorities; one switching unit, responsible for steering traffic flows between the core network and the wireless access network or from one wireless forwarding unit to another (as in the case of relay nodes). Each sub-system will expose a parametric configuration interface (as in the case of the remote radio heads), an application programming interface for defining specific behaviours (for example, for configuring the switching rules following OpenFlow that is a communication protocol enabling SDN operations), and the possibility of executing software-defined network functions, including baseband, framing and scheduling functions. A set of additional network functions can be defined at higher levels in the access network, including proxy functions, TCP (Transport Control Protocol) optimisations, HTTP and content caching.

Controller Operations

The abstraction of wireless access nodes into subsystems, with internal parameters, states, and application programming interfaces will allow the definition of control logics completely decoupled from the node capabilities, which can also benefit from global and dynamic views of the network.

Examples of reconfigurations of the access nodes can include activating/deactivating a satellite interface, loading a new switching rule sending machine-to-machine (M2M) traffic to a link toward an aerial base station or loading a new baseband function. The aggregation of network data and configurations into global views will be provided by the wireless network operating system, while the logic for enforcing a specific configuration of the access network will be specified by a network control program. Different control programs could also be defined for managing independent network slices, pursuing different application requirements and optimisation goals.

SDN and NFV are and will continue to be the main drivers of the integration between 5G [L1,R1] and aerospace networks [1, 2], by taking advantage of softwarisation. Figure 1 shows how the virtualisation of the physical layer can be used to abstract from a specific radio access network (RAN), in order to provide customisable and scalable solutions to enable the application scenarios under consideration. NFV is expected to provide a significant reduction in capital expenditure and operating costs, thus permitting more flexible and economical installations compared with to the previous cellular generations.

One way that this can be achieved is through network slicing, a concept that was introduced in 3GPP release 15. Such a tool can be used to meet communication requirements in a variety of application scenarios, by allowing flexible and tailored use and configuration of both network resources and network functions (NFs). In fact, each network slice can exploit shared resources, which are orchestrated by centralised coordinators.

In Figure 1, we show how network slicing (by means of the network slice instance layer) can be achieved by exploiting SDN and NFV, in order to provide a perfectly tailored service to the service instance layer. This allows match application demands to be matched to the available network resources in an adaptive way, in order to satisfy both operators' revenues and scenario requirements. It is worth highlighting how network functionalities, for instance, a subset of RAN, can be used by multiple slices in a shared way, in order to minimise operating costs.

Link:

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Security Issues in the 5G Standard and How Formal Methods Come to the Rescue

by Lucca Hirschi (Inria & LORIA), Ralf Sasse (ETH Zurich) and Jannik Dreier (Université de Lorraine & LORIA)

Our recent academic research has identified several serious security and privacy issues in the 5G standard. These issues were discovered with the help of security protocol verification tools based on formal methods, which are now mature enough to meet industry-level standards. We thus advocate for their systematic use in critical standardisation processes, such as mobile communication and e-voting.

Our intensive daily use of cell phones and other mobile devices relies on the capacity of our devices to connect to carriers which serve us internet data, calls, and SMSs. When sending/receiving calls/texts or browsing the web, phones and corresponding networks need authentication (whom to bill?) and confidentiality (privacy) mechanisms for securely exchanging user data over-the-air. Since the advent of 3G, this has been achieved worldwide through a protocol called Authentication and Key Agreement (AKA), standardised by 3GPP [L8]. 3GPP claims that the 5G version of AKA (5G AKA) provides better security and privacy guarantees than previous iterations, but there exists very little evidence to support this claim. Two of our recent works [1, 2] have identified critical security and privacy shortcomings in 5G AKA and indicate that use of formal methods and verification tools could have avoided this situation and should be used early in the design process in the future. This effort is the outcome of past and ongoing collaborations [L2, L5, L6] with different research teams.

5G AKA does not meet its Security Goals

A comprehensive, formal security evaluation of the 5G AKA protocol [1], reveals that 5G AKA does not meet two critical security goals: an attacker can either impersonate a serving network towards a mobile, or a mobile towards a network.

Our methodology is as follows [L1] (see Figure 1):
- We extract precise requirements from the 3GPP standards defining 5G and we identify key missing security goals as well as flaws in the stated goals.
- Using the security protocol verification tool Tamarin, we conduct a full, systematic, security evaluation of the protocol with respect to the 5G security goals.
- Our evaluation automatically identifies the minimal security assumptions required for each security goal and

we automatically find that the aforementioned security goals are not met, except under additional assumptions missing from the standard.
- Finally, we make explicit recommendations with provably secure fixes for the attacks and weaknesses we found.

A new vulnerability has been identified in all generations of AKA, including 5G AKA; in fact, 5G AKA can be leveraged to breach subscriber privacy more severely than known location privacy attacks, e.g., IMSI catchers [2]. Namely, [2] shows for the first time how an attacker can learn 3G, 4G, and 5G subscribers' typical activity patterns including number of calls and SMSs sent in a timeframe. We stress that these activity patterns can be monitored long-time and remotely even if subscribers are outside attacked areas most of the time. Moreover, IMSI-catcher attacks have been mitigated in 5G through the use of randomised encryption for protecting subscribers' identities. [2] shows that other attack vectors will be at the disposal of attackers to locate and monitor subscribers.

Impact

Our research reveals that the specification, serving as deployment basis, of 5G networks does not meet critical security goals. This can lead to a flawed deployment of 5G networks that may suffer from attacks. It is very likely that all 5G subscribers will be subject to the aforementioned attacks, a situation that has already drawn the attention of news media [L3, L4]. It turns out that it is also possible for a poor standard-conform implementation to result in users being charged for the mobile phone usage of a third party, due to a lack of authentication. We proposed an improvement that removes this flaw. It is now advisable for 3GPP to integrate our recommendations in order to reduce the risk of flawed deployments and to mitigate the privacy threats for future generations. We have communicated our findings to 3GPP and GSM Association (GSMA) (see the acknowledgments [L1]), and we are in communication regarding possible fixes and improvements.

We stress that potential remedies must be standardised. Having them only deployed by some network providers does not meet our expectations of a global standard.

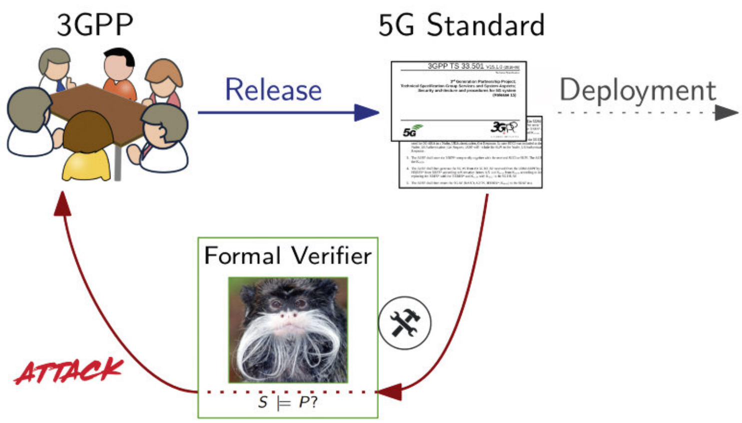

Figure 1: Formal verification workflow. The Tamarin picture refers to a state-of-the-art verifier.

Mandating the Use of Formal Methods and Verifiers

Our security evaluation is made possible by improvements in automated tools based on mathematical principles, such as the Tamarin or ProVerif verifiers for security protocol analysis. Our resulting security guarantees are machine-checked and based on a solid mathematical foundation. From different lines of research in the area numerous verification tools are now capable of analysing various security properties. This has led to numerous large-scale formal analyses of standard properties on real-life protocols recently, e.g., TLS 1.3 and the Signal instant messaging protocol. Some of those analyses have led designers and standardisation bodies to correct flawed protocols. It is safe to say that existing techniques for automated security verification have now reached maturity to guide design, analysis, and standardisation. We have the encouraging example of the TLS Working Group adopting an "analysis-prior-to-deployment" paradigm for drafting TLS 1.3 with notable efforts from the academic community, and the example of the Swiss government mandating the use of such techniques for e-voting systems [L7].

We intend to continue to bring mathematical reasoning to the security protocol design process. We hope that 3GPP and other standardisation bodies also plan to bring verification tools to their decision process. Possible future targets are the new wireless standard WPA3, as well as e-voting schemes being prepared in different countries.

[1] is a joint work with: David Basin (ETH Zurich), Jannik Dreier (Université de Lorraine & LORIA), Lucca Hirschi (Inria & LORIA), Saša Radomirović (University of Dundee), Ralf Sasse (ETH Zurich), Vincent Stettler (ETH Zurich).

[2] is a joint work with: Ravishankar Borgaonkar (SINTEF Digital), Lucca Hirschi (Inria & LORIA), Shinjo Park (TU Berlin), and Altaf Shaik (TU Berlin).

Links:
[L1] https://kwz.me/hcS
[L2] https://kwz.me/hc4
[L3] https://kwz.me/hc0
[L4] https://kwz.me/hc1
[L5] https://kwz.me/hc2
[L6] https://kwz.me/hc3
[L7] https://kwz.me/hc5
[L8] http://www.3gpp.org/

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Web5G: Making Web and 5G Networks Work Together

by Dominique Hazaël-Massieux (W3C)

Just like its predecessors 3G and 4G, 5G's success will depend on the degree to which it benefits the users of the applications and services it will transport. Making 5G and its concomitant network improvements work for the Open Web Platform will be key to the widespread adoption of this technology across as many industries as possible. The World Wide Web Consortium (W3C) is planning to launch a multi-year initiative bringing telecommunications operators, OS and browser vendors and cloud providers together to take full advantage of 5G on the Web.

In conjunction with the deployment of 5G, networking technologies are going through a series of transformations aiming to improve their performance and make them more programmable and adaptable, namely:
- virtualisation and softwarisation of network components,
- improved and configurable latency,
- aggregated network paths,
- adaptive congestion control.

The major network investments needed to achieve these are hard to justify if they cannot be clearly identified as perceivable improvements to networked applications. Historically, many network improvements have been severely undermined by accidental or intentional lack of collaboration between applications and network (e.g. lack of widespread adoption of QoS capabilities).

Many developments on the application side point toward a need for better control of network behaviour, either as improvements to the overall user experience (for instance, an additional delay in responding to user interactions can be directly translated in terms of loss of business), or in a growing number of cases, as critical aspects of deployment of these new applications (streamed augmented reality (AR) and virtual reality (VR), 8K / higher-colour video streaming, immersive real-time communications, telepresence, real-time distributed machine learning, etc.).

Meanwhile, increasing volumes of network traffic is encrypted end-to-end to match the increased stakes on end users' security and privacy of a networked society. This positive development also means that it is increasingly difficult for network operators to know what kind of traffic they're transporting, making it hard or impossible to make use of these latest evolutions without explicit collaboration from flow endpoints.

Why is the Web Critical to 5G Deployment?

Fifth generation networks (5G) are intended to provide higher bandwidth, lower latency and better coverage than today's 4G networks. Improvements to both the physical network and its control plane are expected to make the network more reactive, flexible, and with better performance, and enable better cooperation among its end points. But it is not just network capabilities that matter; the application layer must also be up to the task.

The Open Web Platform is the most ubiquitous and scalable platform to deploy applications and services. Ensuring 5G technologies can be properly exploited on the Web is thus a key component to the long term success of 5G. This need is all the more timely as the Web is rapidly growing its capabilities in a range of areas, including AR and VR [L1], in real-time communications and streaming [L2], machine learning [L3], and internet of things [L4].

Bringing Web & 5G together is key to many innovative usage of the network, such as enabling streamed virtual and augmented reality.

What are W3C's Plans for Web5G?

W3C, as the steward of the Web, convened its community in May 2018 in a dedicated workshop [L5] to evaluate how to make Web and 5G technologies work together. Based on the discussions at this event and further conversation among its members, W3C is now preparing to launch a dedicated interest group, the Web & Networks Interest Group [L6], to ensure the harmonious development of technologies at the network and application layers, in coordination with the relevant consortia and standard organisations in this space (e.g. 3GPP and IETF).

Based on the input gathered so far, cross-layers approaches that benefit both application developers and network operators feel like a promising direction to support. For instance, making it easy for application developers to indicate which if their network flows are latency-sensitive or bandwidth-hungry open the way for OSes to decide when to enable multi-path TCP, and for networks when to provide carrier aggregation.

With a focus on such cross-layer approaches, this interest group aims to identify the key technical standards that need to be developed or better integrated to ensure that network operators, cloud providers, OS and browser vendors and application developers can derive direct advantages from the enormous opportunities provided by the next generation of network technologies.

Longer term, the group is expected to chart how network technologies may re-architect online services: with ultra-low latency and edge computing, the distinction between client and server, and between local and remote are expected to get blurrier, which is made all the more enticing with the deployment of Web Assembly [L7] as a lingua franca on both clients and servers.

Links:
[L1] https://www.w3.org/immersive-web/
[L2] https://www.w3.org/TR/webrtc-nv-use-cases/
[L3] https://kwz.me/hcw
[L4] https://www.w3.org/WoT/
[L5] https://w3c.github.io/web5g-workshop/
[L6] https://w3c.github.io/web-networks-charter/
[L7] https://www.w3.org/wasm/

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Enabling Extended Reality Applications over 5G Mobile Networks

by Evangelos Vlachos (University of Edinburgh) and Aris S. Lalos (ISI/ATHENA R.C.)

5G mobile networks are expected to support applications with very high-bandwidth and ultra-low latency requirements. Augmented reality (AR) and virtual reality (VR) are among the most attractive use cases. Of course, processing and communication of the huge amount of the four dimensional (4D) data introduce challenging requirements to the network design. To meet these requirements a novel framework that optimizes jointly multiple objectives is required. In this article we provide a paradigm where the reconstruction quality and the transmission efficiency of 4D data are jointly optimized.

The augmented reality (AR) and virtual reality (VR) revolution is still in its early phase. These technologies have the potential to revolutionise multiple industries over the next five to ten years. They will transform the way we interact with the surrounding world, unlock new experiences and increase productivity. However, the real-time interactivity of the extended reality (AR/VR) applications requires very high bandwidth and ultra-low latency supported by the 5G networks. Indeed, the scale of acquired data in real-time operation is growing very quickly, making the communication and processing a very challenging task. To meet these requirements a multi-objective framework for the network design is required. Specifically, objectives from different layers of the network stack should to be optimized jointly. As such, reconstruction quality, transmission efficiency, energy efficiency of the mobile device, and communication bandwidth are some indicative objectives.

Low latency is a critical requirement for delivering the best AR and VR experience because even small delays can have a disorientating effect. For instance, when a user turns and the landscape does not move simultaneously, the user may experience motion sickness. VR requires less than 1ms latency and currently the global average latency is 36ms on fixed and 81ms on mobile. Coincidentally, these requirements comprise some of the main targets to be addressed by modern 5G networks. To achieve the low-latency requirement, efficient and low-complexity processing is necessary. AR and VR applications require the acquisition and processing of complex and highly deformable 3D objects represented by four dimensional (4D) data. Modern signal processing and mathematical optimisation tools play a crucial role for the acquisition and the reconstruction of this massive amount of data [1].

One crucial processing step for increasing quality of experience in extended reality applications is 4D models enhancement. The acquired 4D models are represented by a sequence of time varying and unstructured point clouds. These data are usually corrupted by several forms of imperfections, like scanning noise, outliers and missing parts of surfaces. Hence, enhancement techniques are an essential pre-processing step before rendering the models to AR and VR headsets. The exploitation of the spatial and temporal coherence of the generated time varying point-clouds (TVPC) may provide low-complexity techniques for real-time operation. For instance, in [2] modern mathematical optimization tools (matrix completion theory) have been used for enhance-

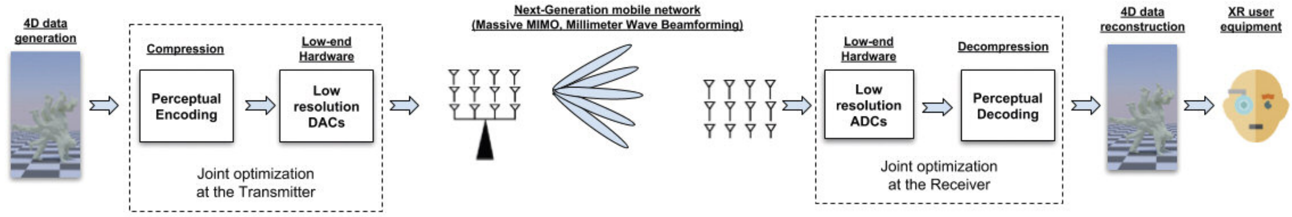

Figure 1: Simple paradigm of the proposed design. Next-generation network technologies (i.e.,massive MIMO) can compensate the losses due to low-end hardware (i.e., analog-to-digital and digital-to-analog components (ADC/DAC). To achive real-time high-quality reconstruction at the user's XR equipment, the parameters which define the perceptual quality and the transmission efficiency have to be optimized jointly.

ment and reconstruction of the 4D data from a reduced number of points.

Compression is another important process for streaming the 4D data. Compression of th 4D acquired geometry represented by TVPCs is very resource demanding operation. This is attributed to the fact that the raw geometry data are usually represented using floating point precision. As a result, the compression of geometry information introduces tough challenges to enable aggressive compression ratios, without significantly reducing the visual quality. To overcome these issues, compression of the 4D models should also exploit the spatio-temporal correlations of the data. In [3], a sparse coding technique is proposed, to generate compact representations of static geometries.

Ultra-low latency requirement also poses demanding specifications for the wireless communication processing. Mobile devices with low-end hardware and strict power constraints have to communicate and process the 4D data in real-time. To this end, promising designs for energy efficient receivers have been proposed recently. These designs exploit the benefits of 5G, where a large number of antennas (massive MIMO) could be employed at the mobile terminals. Specifically, massive MIMO designs can compensate the losses due to low-end hardware. For instance, since analog-to-digital components (ADC) have exponential power consumption, lowering their specifications significantly reduces the overall system power consumption. However this is at the expense of the introduced distortion to the transmitted/received signal. Therefore, novel techniques which will optimise overall user experiences through a distortions aware design are required [4]. These examples call for novel designs of operations and architectures for 5G mobile networks.

From our perspective, the successful realisation of the real-time extended reality applications over 5G mobile networks, must address several challenges (e.g., quality-of user-experience, energy-efficiency, limited hardware resources) in a joint and combined manner. The development of novel multi-objective mathematical optimization tools is a key enabler to accomplish this challenging endeavour.

Link:
[L1] https://kwz.me/hcK

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Real-Time Wireless Channel Emulation for Autonomous Vehicles

by Markus Hofer and Thomas Zemen (AIT)

The properties of wireless vehicular communication channels do not remain constant during a vehicle's trip. Both the transmitter and the receiver are moving, which generates not only time and frequency (doubly) selective channels but also channel statistics that are non-stationary, i.e., they change over time. To function properly, new wireless vehicular communication systems for connected autonomous vehicles require validation and verification in vehicular environments. To avoid time intensive, costly and difficult to repeat real-world measurements on the road, real-time channel emulators that emulate the wireless vehicular channel as accurately as possible are needed. We present a real-time channel emulator based on a software defined radio platform that is able to emulate real-world propagation scenarios.

Connected autonomous vehicles exchange information using wireless vehicle-to-everything (V2X) communication to improve road safety and travelling convenience, reducing traffic congestion, minimising fuel consumption and enhancing the overall driving experience. In fully automated driving systems real-time control algorithms integrated into the automated vehicle's control unit will use this information to adapt the driving route and velocity to the current situation.

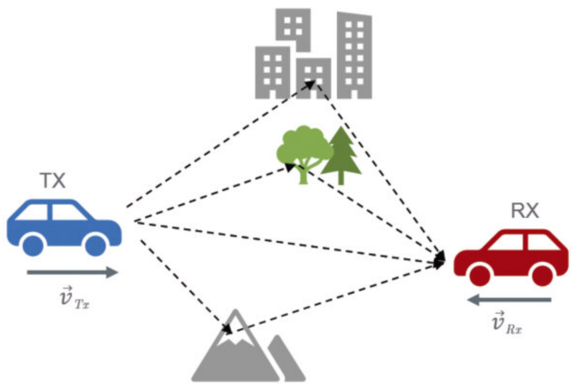


Figure 1: Influence of environment on wireless communication.

The performance of wireless communication systems is fundamentally determined by wireless communication channel properties. Due to moving transmitter, receiver and scatterer objects, wireless vehicular communication channels exhibit multipath propagation and non-stationary channel statistics, i.e., channel statistics that change over time. A schematic representation is shown in Figure 1.

For the development of reliable low-latency communication links, the wireless communication system together with the real-time control algorithm have to be tested in a repeatable fashion in vehicular environments.

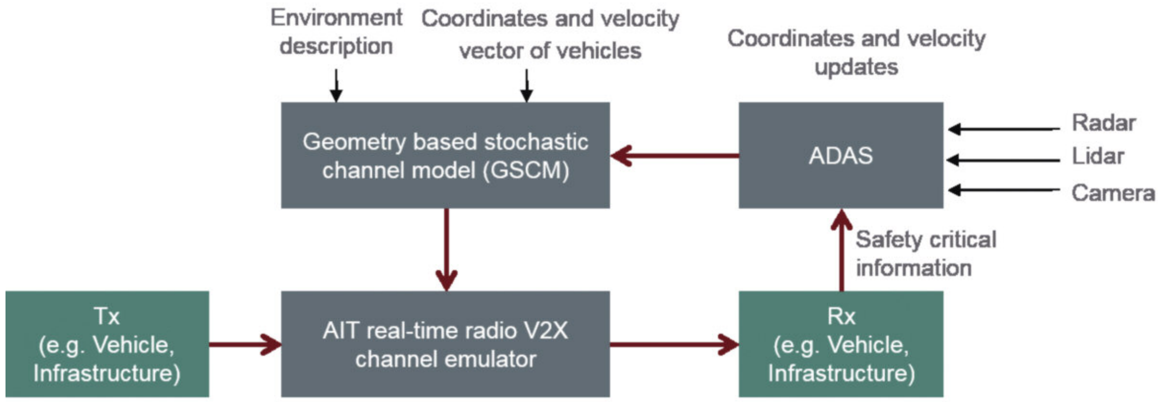


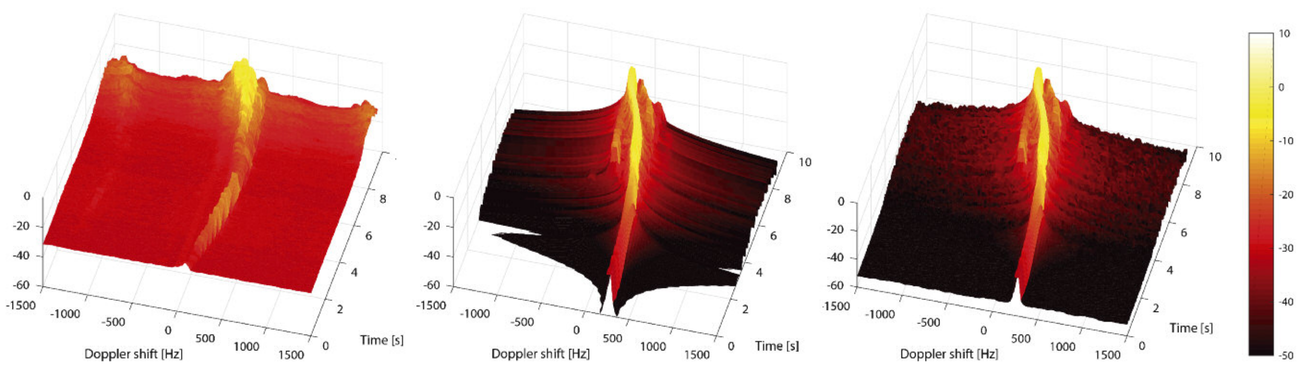
Figure 2: Real-Time Channel Emulation.

Tests in the laboratory have the benefit of easy repeatability, while tests on the road are typically costly, labour intensive and difficult to repeat. To conduct laboratory tests, the wireless communication channel has to be mimicked, which is done by wireless channel emulators. These channel emulators need to reflect the real word propagation channels as accurately as possible. Specifically, the testing of real-time control algorithms requires updating the position and speed of the transmitter (TX) and receiver (RX) according to the laws of kinematics, and correspondingly, the wireless propagation characteristics in real-time with continuous variations in delay and Doppler shift. With this approach the real-time wireless data communication between the controller and the sensors as well as between the controller and the actuators will reflect the properties of a realistic environment. Current channel emulators, however, use very simple channel models such as a basic path-loss or delay and stationary statistics.

We present real-time channel emulation for non-stationary propagation scenarios based on a geometry-based stochastic channel model (GSCM) that was developed within the Security and Communication Technologies group of the Centre for Digital Safety and Security of the Austrian Institute of Technology (AIT) in Vienna. A schematic representation is shown in Figure 2. The GSCM utilises the environment description, such as the positions of buildings, road signs, traffic lights, etc. as well as the coordinates and velocities of moving objects to calculate all possible propagation paths including their attenuations, Doppler shifts and path delays. Variations of the model, like the number of moving cars on the street or the diffuse scattering caused by vegetation or wall clutter, for instance, are taken care of by statistical models.

The high complexity of the GSCM prohibits a direct real-time implementation. Hence, we use a low-complexity subspace projection model which allows for an emulation complexity that is independent of the number of propagation paths [1, 2]. With this technique it is possible to emulate real world propagation environments, like road crossings, highways, merging lanes, etc. with a large number of paths in real time. Due to the real-time capability of our emulator we are able to test communication systems in connection with advanced driver assistance systems (ADAS) in a virtual environment, see Figure 2. The ADAS uses information from Radar, Lidar and camera sensors as well as safety critical information that is obtained from other vehicles, to update the trajectories (coordinates and velocities) of the vehicles. These changes are directly reflected in the channel propagation properties, i.e., in the change of path attenuation, Doppler shift and delay which are emulated by our real-time channel emulator. The utilisation of modern software defined radio equipment allows for flexible frequency bands e.g., 3.5 GHz or 5.9 GHz.

To test the proper functionality of the channel emulator we measured the emulated channel with a special measurement device in collaboration with the Department of Electrical and



(a) Measured propagation channel *(b) Numerical GSCM evaluation* *(c) Measured channel emulator*

Figure 3: Comparison of the time-varying Doppler spectral density for a road intersection.

Information Technology of University of Lund. In Figure 3 we show the comparison of the Doppler spectral density of a road intersection for (a) a real-world measurement, (b) numerical co-simulation and (c) measurement of our real-time channel emulator [3]. We clearly observe that our emulation method captures the non-stationary properties of the communication channel very well. This allows for a repeatable test of communication devices in the laboratory

The developed methods are not limited to vehicular scenarios like road intersections, urban scenarios or highways. They can also be applied to mimic the wireless communication channel in industrial or railroad environments, for example, where robots have to communicate with each other.

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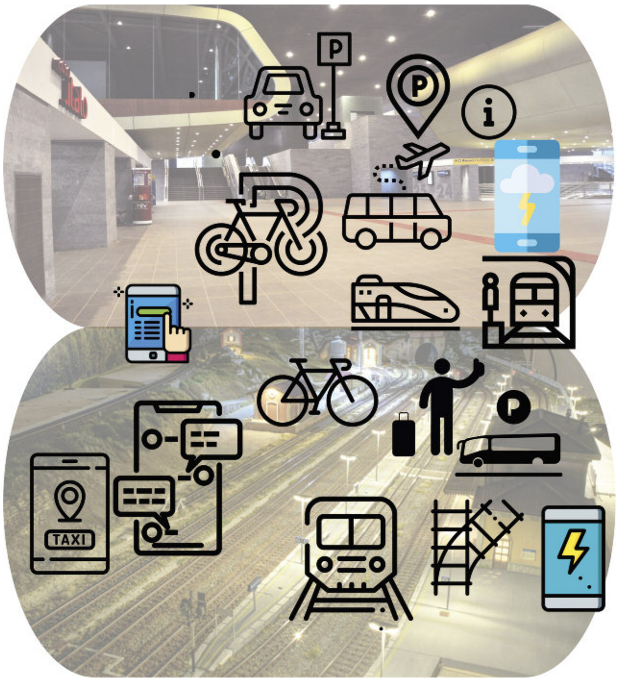

STINGRAY is developing an intelligent train station infrastructure.

Smart Services for Railways

by Felicita Di Giandomenico, Stefania Gnesi, and Giorgio O. Spagnolo (ISTI-CNR) and Alessandro Fantechi (ISTI-CNR and University of Florence)

The project STINGRAY (SmarT station INtelliGent RAilwaY) addresses the role of the railway station, traditionally seen as a meeting point for a city, in order to enhance its importance and integration into the smart city of the future.

Although railway stations are central hub of the city, a primary point of aggregation in the urban environment, they traditionally have a private energy distribution and communication system. The main reasons for this are to ensure uninterrupted power supply and security, but this isolation has two main drawbacks. First, it prohibits integration with "smart cities", in which, ideally, information between different transport systems (i.e. bike sharing, car-sharing, urban transport) is synergically exploited. Second, the station system fails to benefit from modern energy saving techniques.

In the project STINGRAY, researchers from the Formal Methods and Tools and the Software Engineering and Dependable Computing groups of ISTI-CNR are designing and developing a station communication infrastructure, integrating powerline and wireless technologies, which:
- realises a LAN network over the station plants using power line and wireless technologies;
- allows the control and monitoring of station equipment (supervisory control and data acquisition (SCADA));
- creates value-added services for both customers and railway staff, such as connectivity, monitoring, energy man-

agement service (EMS), fault prediction service (FPS), video surveillance, environmental surveying and integration and access to smart city infomobility services.

STINGRAY will utilise powerlines to enable more efficient management of machinery and energetic resources; an innovation that will be far more cost effective and less environmentally damaging than building new infrastructure.

We are currently defining the requirements for the “smart station” and the design of the system architecture. We are also optimising existing strategies for managing energy consumption within the station to avoid wasting energy; for example, we are considering station lighting and the heating of the railroad switches in ice conditions.

STINGRAY is being conducted in the context of the POR FESR 2014-2020 Tuscany Region project will run until July 2020. The project is coordinated by Letizia Bellini from ECM spa (Italy).

Link: https://stingray.isti.cnr.it/

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ProvQL: Understanding the Provenance of your Data

by Giorgos Flouris, Argyro Avgoustaki, Irini Fundulaki and Dimitris Plexousakis (ICS-FORTH)

ProvQL is a high-level structured query language, suitable for seeking information related to data provenance. It is especially suitable for tracking the sources that contributed to data generation, and for helping data experts assess the trustworthiness and reliability of data.

The proliferation of (open) data on the Web, in the form of linked open data, has made it possible to publish structured data so that it can be interlinked and become more useful through semantic queries. This way, web pages are not only useful for human readers, but are also able to include data and information that can be read automatically by computers (metadata).

In this setting, data is being recorded in the form of RDF quadruples, e.g., (Donald_Trump, president_of, USA, DBpedia), where the subject (Donald_Trump) is associated with the object (USA) with a property (president_of), and this information is recorded in a specific dataset (DBpedia). Note that all elements of the quadruple (e.g., Donald_Trump) identify a specific resolvable entity or relation, corresponding to an actual person, role, object, or concept (e.g., the person Donald Trump, the role of being a president etc.). This way, all references to “Donald_Trump”, in any dataset, are automatically associated to each other.

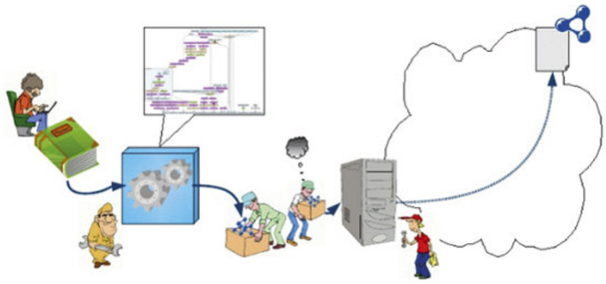

Figure 1: Data Provenance (source: O. Hartig, J. Zhao, “Using Web Data Provenance for Quality Assessment”, SWPM-09).

This constitutes one of the main advantages of linking different datasets, namely the ability to combine data and information from different sources in order to produce new data or knowledge on a domain of interest. However, this advantage comes with a price. For example, if a certain quadruple is later identified to be erroneous or inaccurate, how can one track down its dependencies and identify the (derived) quadruples that should be retracted? And how can one assess the trustworthiness, credibility, authenticity, reliability or accuracy of his/her data, when part of it was the result of some form of reasoning over data coming from other, external, sources? And what about the problem of data accountability?

To address these questions, there is a great need to record the provenance of published data, i.e., their history, their origins and the process through which data records (quadruples) were “copied” from one source to another, modified and transformed in the process and/or reasoned upon to produce new data records (see Figure 1).

In recent years, provenance has been widely studied in several contexts, e.g., databases, workflows, distributed systems, Semantic Web, etc., and with respect to different aspects and applications. These studies have resulted in various theoretical provenance models, each with a different level of complexity and detail, such as the “why, where and how” prove-

Figure 2: Excerpt from the W3C PROV model (Source: Provenance Analysis and RDF Query Processing, Satya Sahoo, Praveen Rao, ISWC2015).

nance models, as well as hybrid ones [1]. Also, various representation models (such as CIDOC CRMdig or W3C PROV) have been developed to support the representation of different types of provenance information (see Figure 2).

Although these works have addressed the problem of determining how provenance should be recorded and represented, the issue of querying data provenance information has not yet been adequately considered. Although answering provenance queries over existing models (such as W3C PROV) is possible using standard (adequate) query languages (such as SPARQL), this would require familiarity with the specific representation model, and would be suitable only for this specific representation model. Therefore, applications using this approach would break if the representation model changes.

The objective of our work is to define a structured high-level query language for provenance, called ProvQL, which will allow a user to express provenance queries. The language should be implementation-agnostic and representation-agnostic, i.e., unrelated to the specific representation model used to represent provenance. In addition, one should be able to filter the required data both on the basis of its provenance, and on the basis of the actual data itself. In particular, ProvQL should be able to answer queries such as:
- Which data records or sources contributed in deriving this data record?
- Identify all data records whose provenance includes a specific data source (or data item).
- Identify all quadruples referring to "Donald_Trump" that originate from a specific source.

ProvQL is currently under development. We have already defined the syntax of the language, which follows an SQL-like format, as well as its semantics, based on the well-known approach of mappings [2] that associate variables with data or provenance. The next step is to provide a suitable implementation of the language, efficient enough to tackle complex provenance queries over large datasets.

References:

[1] J. Cheney, L. Chiticariu, and W.C. Tan: "Provenance in databases: Why, how, and where", Foundations and Trends in Databases, 1(4), 2009.
[2] J. Pérez,M. Arenas, and C. Gutierrez: "Semantics and complexity of SPARQL", ACM TODS, 34(3), p.16., 2009.

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Innovation in Security Education – You have been hacked!

by Harry Rudin

As members of an emergency response team for a bank, you have been summoned together to handle an emergency situation: some of your data has been hacked and highly sensitive information is already on the Web; word of the situation is already in the news and a television crew is in front of your bank wanting an interview; some of your automatic teller machines do not work and complaints are pouring in. In this simulated scenario in IBM's C-TOC centre, it is time to act!

IT security experts say the question is not if an organisation will be hacked, but when. A year ago ransomware was the preferred method of attack. Apparently the returns to hackers were limited and so they have moved on to hunt bigger game, namely large corporations. Ransomware attacks have diminished by 45 percent over the last year. On the other hand, crypto jacking has increased by some 450 percent. In crypto jacking, the target's operating system is infiltrated by the hacker and used for the generation of cryptocurrency; much of the hacked system's capacity is drained. Phishing attacks are also on the rise. Here the preferred method is compromised business emails wherein the hackers plant malware in the system software to gain the desired access to sensitive data.

Given this rapidly growing threat to IT systems, IBM put together its Cybersecurity Operations Centre. This was first available only in the US and was extremely popular among clients. To satisfy European needs, IBM built a second centre on wheels. The result is an eighteen-wheel, 23-ton semi-trailer packed with IT gear and even its own electrical power generating unit. Inside are twenty fully-outfitted workstations, backed by substantial computing power, complete with telephones. C-TOC has its own secure satellite communication capabilities. The "C-TOC" (Cyber Tactical Operations Centre) is patterned after military command centres and organised to respond to a cybersecurity crisis. There are three main objectives.

The first is education of business clients, especially the staff responsible for cybersecurity. C-TOC participants are taxed with a rapid-fire barrage of cleverly forged internal business emails, reports of data leaks, phone calls, notices of system failures and requests by the press for clarification of the situation. Even staff members trained for handling such situations often become unnerved and quickly forget that they are taking part in a simulation; there is a lot of adrenalin flowing. Clients can put their own cybersecurity crisis-response plans to the test in a simulated crisis and observe how their plans handle the situation. C-TOC's security experts are available to help improve the plan.

The second objective is providing cybersecurity backup for large public events such as congresses or sporting events. With its knowledgeable security experts, mobility, back-up

Figure 1: IBM's 22-ton C-TOC underway (photo courtesy IBM).

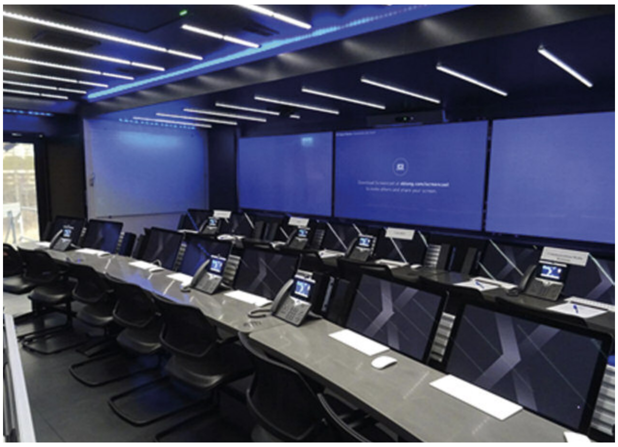

Figure 2: Some of the C-TOC's 20 workstations ready for a security crisis (photo courtesy L. Rudin).

satellite communication links and self-contained power-generating capacity the C-TOC is well suited to this purpose.

Finally, since cybersecurity threats are rapidly growing, there is a raging demand for security professionals. The third goal of the C-TOC is security education and encouraging people to work in the field - particularly young people. Hopefully many of the young visitors will be enticed into exploring a career in cybersecurity. The C-TOC certainly presents a strong case for the importance of cybersecurity.

Links:
Security intelligence
https://securityintelligence.com/cryptojacking-rises-450-percent-as-cybercriminals-pivot-from-ransomware-to-stealthier-attacks/

C-TOC
https://www.ibm.com/security/services/managed-security-services/security-operations-centers

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Harry Rudin, Swiss Editor ERCIM News
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"Being an ERCIM fellow has surely helped me expand my previous knowledge in the field of Information Security, by applying state-of-the-art techniques and consolidated theories in this interdisciplinary field. After the successful research experience at the IIK department in NTNU Gjovik, Norway, I was further able to apply for upcoming research and teaching positions, with the final outcome being hired as an Assistant Professor in the same department at NTNU.

Erjon ZOTO
Former ERCIM Fellow

ERCIM "Alain Bensoussan" Fellowship Programme

The ERCIM PhD Fellowship Programme has been established as one of the premier activities of ERCIM. The programme is open to young researchers from all over the world. It focuses on a broad range of fields in Computer Science and Applied Mathematics.

The fellowship scheme also helps young scientists to improve their knowledge of European research structures and networks and to gain more insight into the working conditions of leading European research institutions.

The fellowships are of 12 months duration (with a possible extension), spent in one of the ERCIM member institutes. Fellows can apply for second year in a different institute.

Why to apply for an ERCIM Fellowship?

The Fellowship Programme enables bright young scientists from all over the world to work on a challenging problem as fellows of leading European research centers. An ERCIM Fellowship helps widen the network of personal relations and understanding among scientists. The programme offers the opportunity to ERCIM fellows:
- to work with internationally recognized experts;
- to improve their knowledge about European research structures and networks;
- to become familiarized with working conditions in leading European research centres;
- to promote cross-fertilization and cooperation, through the fellowships, between research groups working in similar areas in different laboratories.

Deadlines for applications are currently 30 April and 30 September each year.

Since its inception in 1991, over 500 fellows have passed through the programme. In 2018, 30 young scientists commenced an ERCIM PhD fellowship and 56 fellows have been hosted during the year. In 2005 the Fellowship Programme was named in honour of Alain Bensoussan, former president of Inria, one of the three ERCIM founding institutes.

https://fellowship.ercim.eu

Editorial Information

ERCIM News is the magazine of ERCIM. Published quarterly, it reports on joint actions of the ERCIM partners, and aims to reflect the contribution made by ERCIM to the European Community in Information Technology and Applied Mathematics. Through short articles and news items, it provides a forum for the exchange of information between the institutes and also with the wider scientific community. This issue has a circulation of about 6,000 printed copies and is also available online.

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13th International Workshop on Information Search, Integration, and Personalization

Heraklion, Crete, 9-10 May, 2019

Special Topic: Information Search, Integration, and Personalization for Health

With increasingly sophisticated research in science and technology, and the proliferation of Web content, there is a growing need for interdisciplinary and international availability, distribution and exchange of the latest research results, in organic forms, including not only research papers and multimedia documents, but also various tools for measurement, analysis, inference, design, planning, simulation, and production as well as the related data sets. We need new theories and technologies for the advanced information search, integration through interoperation, and personalization of such content. This workshop offers a forum for presenting original work and stimulating discussions and exchanges of ideas around these themes.

Topics of interest include but are not limited to:
- Data Quality
- Social Cyber-Physical Systems
- Information search in large data sets (databases, digital libraries, data warehouses)
- Comparison of different information search technologies, approaches, and algorithms
- Novel approaches to information search
- Personalized information retrieval and personalized web search
- (Big) Data Analytics
- Integration of Web-services, Knowledge bases, Digital libraries
- Federation of Smart Objects
- Machine learning and AI
- Visual and sensory information processing and analysis
- Ontology-based Data Access, Integration, and Management
- Provenance Tracking in the Context of Data Integration
- Ontology Alignment, Instance Matching, Ontology Mapping
- Data Mining
- Privacy in the context of data integration

More information:
https://isip2019.ics.forth.gr/

HORIZON 2020 Project Management

A European project can be a richly rewarding tool for pushing your research or innovation activities to the state-of-the-art and beyond. Through ERCIM, our member institutes have participated in more than 90 projects funded by the European Commission in the ICT domain, by carrying out joint research activities while the ERCIM Office successfully manages the complexity of the project administration, finances and outreach. The ERCIM Office has recognized expertise in a full range of services, including identification of funding opportunities, recruitment of project partners, proposal writing and project negotiation, contractual and consortium management, communications and systems support, organization of events, from team meetings to large-scale workshops and conferences, support for the dissemination of results.

How does it work in practice?

Contact the ERCIM Office to present your project idea and a panel of experts will review your idea and provide recommendations. If the ERCIM Office expresses its interest to participate, it will assist the project consortium either as project coordinator or project partner.

Please contact:
Peter Kunz, ERCIM Office, peter.kunz@ercim.eu

Announcement and Call for Papers

AITA 2019 – International Workshop on Advanced Infrared Technology and Applications

Florence, Italy, 16-19 September 2019

AITA 2019 is the 15th in a series of workshops organised by the Giorgio Ronchi Foundation, in collaboration with the Institute of Information Science and Technologies "Alessandro Faedo" (ISTI), the Institute of Applied Physics "Nello Carrara" (IFAC) and the Construction Technologies Institute (ITC) of the National Research Council of Italy.

The primary purpose of AITA is to provide an international forum to present and discuss current trends and future directions in Infrared Technology, mainly for civilian applications. The workshop also aims at fostering the creation of a permanent network of scientists and practitioners for easy and immediate access to people, technologies and ideas. So far, the events were successful not only for the qualified presence of international attendees and for the high quality of the scientific communications, but also for the friendly atmosphere that characterizes AITA workshops.

Submission and publication

Paper submission deadline:
31 May 2019

All the contributions should then be submitted in PDF format by using the Easychair submission system:
http://www.easychair.org/conferences/?conf=aita2019

In the 15th AITA edition, particular emphasis will be given to the following topics:
- Advanced technology and materials;
- Smart and fiber-optic sensors;
- Thermo-fluid dynamics;
- Biomedical applications;
- Environmental monitoring;
- Aerospace and industrial applications;
- Nanophotonics and Nanotechnologies;
- Astronomy and Earth observation;
- Non-destructive tests and evaluation;
- Systems and applications for the cultural heritage;
- Image processing and data analysis;
- Near-, mid-, and far infrared systems;
- Vibrational spectroscopies and biomedical applications.

Selected papers will be published in a Special Issue of Applied Optics, OSA, which has already published selected papers during the last three editions of the workshop.

The Proceedings of the Workshop will consist of the abstracts of all the papers, including those selected for the Special Issue, and will be published electronically in a dedicated issue of MDPI Proceedings.

4th Under 35 Paper Award

A best paper award will be assigned by the chairpersons in honor of Ermanno Grinzato, AITA cochair for a long time and known scientist in the thermography community.

The award aims at encouraging innovative studies of young researchers in some of the topics of interest for the workshop.

Workshop chairs

L. Ronchi Abbozzo (Fondazione Ronchi, General Chair, Italy), P. Bison (CNR-ITC, Italy), M. D'Acunto (CNR-IBF, Italy), X. Maldague (Laval University, Canada), D. Moroni (CNR-ISTI, Italy), V. Raimondi (CNR-IFAC, Italy), A Rogalski (MUT, Poland), T. Sakagami (Kobe University, Japan), M. Strojnik (CIO, Mexico).

More information:
http://ronchi.isti.cnr.it/AITA2019

SCHLOSS DAGSTUHL
Leibniz-Zentrum für Informatik

Call for Proposals

Dagstuhl Seminars and Perspectives Workshops

Schloss Dagstuhl – Leibniz-Zentrum für Informatik is accepting proposals for scientific seminars/workshops in all areas of computer science, in particular also in connection with other fields.

If accepted the event will be hosted in the seclusion of Dagstuhl's well known, own, dedicated facilities in Wadern on the western fringe of Germany. Moreover, the Dagstuhl office will assume most of the organisational/administrative work, and the Dagstuhl scientific staff will support the organizers in preparing, running, and documenting the event. Thanks to subsidies the costs are very low for participants.

Dagstuhl events are typically proposed by a group of three to four outstanding researchers of different affiliations. This organizer team should represent a range of research communities and reflect Dagstuhl's international orientation. More information, in particular, details about event form and setup as well as the proposal form and the proposing process can be found on

https://www.dagstuhl.de/dsproposal

Schloss Dagstuhl – Leibniz-Zentrum für Informatik is funded by the German federal and state government. It pursues a mission of furthering world class research in computer science by facilitating communication and interaction between researchers.

Important Dates

- Proposal submission: October 15 to November 1, 2019
- Notification: February 2020
- Seminar dates: Between September 2020 and August 2021 (tentative).

ERCIM – the European Research Consortium for Informatics and Mathematics is an organisation dedicated to the advancement of European research and development in information technology and applied mathematics. Its member institutions aim to foster collaborative work within the European research community and to increase co-operation with European industry.

ERCIM is the European Host of the World Wide Web Consortium.

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www.cwi.nl

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