

5G and Relevant Enabling Technologies

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1 Introduction

The mobile industry has passed many big milestones over the last twenty years, which have led to fundamental changes to our behaviors and society. When mobile data traffic surpassed mobile voice traffic in 2009, it was difficult to know what today's use of mobile technology would look like. However, all the previous mobile technology generations were basically developed to address only consumer predominantly: for voice and SMS in 2G, for basic internet browsing in 3G, and higher speed data and video in 4G).

5G and the Internet of Things (IoT) promise new capabilities and use cases, which are set to impact not only consumer services but also many industries embarking on their digital transformations. In fact, 5G will serve consumers and multiple industries and open new business models across industries. 2018 will be the

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year for the first rollouts of 5G networks as well as large-scale deployments of cellular IoT.

This change will require the combined effort of industry players, operators, and regulators to align on technology, new services and use cases, spectrum, and standards.

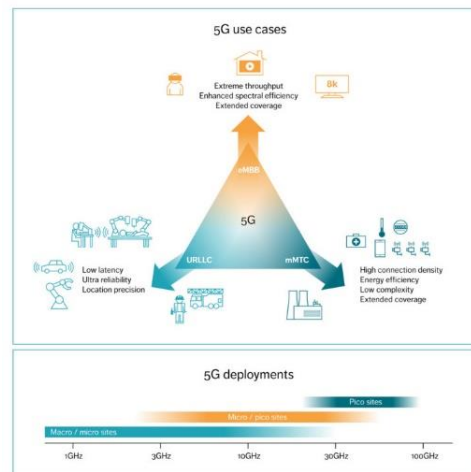
2 5G Use Cases

5G wireless access is being developed with three broad **use case families** in mind [1]: enhanced mobile broadband (**eMBB**), massive machine-type communications (**mMTC**) and ultra-reliable low-latency communications (**URLLC**).

5G will kick off with **eMBB** as its **first use case**. With the continued growth in mobile traffic, there is a need for a more efficient technology, higher data rates, and **spectrum** utilization. In terms of consumer digitalization and richer user experience, new applications based on virtual and augmented reality will require higher bandwidths and lower latency. Key elements of eMBB are: i) **massive mobile connectivity** as demand for mobile broadband will continue to increase; ii) **high data rates, connection density** and mobility; iii) **Human-centric use cases** for access to multi-media content, e.g. 4k streaming on mobile or on-site live experiences.

mMTC means multiple sensors pinging low volume data from machines, wearables and infrastructure. Examples are logistics trackers, temperature control, Narrow Band IoT (NB-IoT) to enable sensors with ten times longer battery life. Key elements: i) usage scenarios which need **connectivity for millions of devices**; ii) each device typically transmitting a relatively **low volume** of **non-delay-sensitive** data (low BW & not-latency critical); iii) Devices are required to be **low cost** and have a **very long battery life**.

cMTC means supporting remote control of robots and big excavators in mines, traffic and safety control in increasingly mobile factories with automated



guided vehicles for material handling and drones for infrastructure support, remote medical surgery, distribution automation in a smart grid, transportation safety, etc. It requires real time data and actions and ultra-low latency (at millisecond level). Key elements: i) usage scenarios which need ultra-reliable **resilient, instantaneous connectivity**; ii) stringent requirements for capabilities such as **latency, availability, and reliability**.

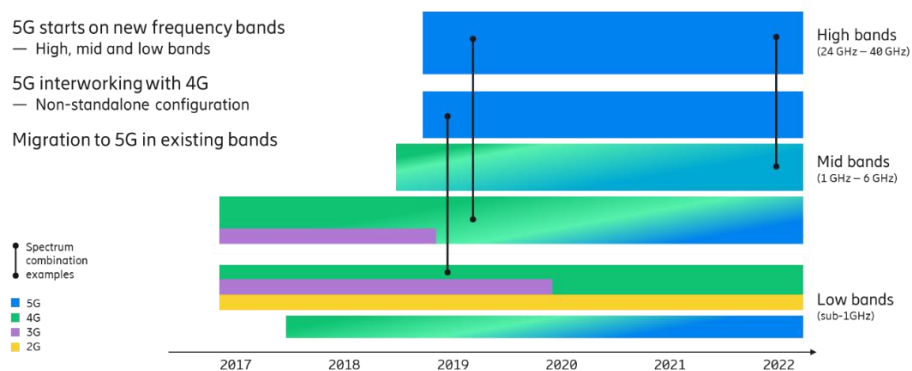
3 5G Spectrum and Enabling Technologies

To meet the complex and sometimes contradictory requirements of these diverse use cases, 5G will encompass both an evolution of today's 4G (LTE) networks and the addition of a new, globally standardized radio access technology known as **New Radio (NR)**. **5G NR** [2]-[3] will operate in the frequency range from below 1 GHz to 100 GHz with different deployments. There will typically be more coverage per base station (macro sites) at lower carrier frequencies, and a limited coverage area per base station (micro and pico sites) at higher carrier frequencies.

Spectrum. Spectrum is fundamental for wireless communication and there is a never-ending quest for more spectrum to meet the demands of increased capacity and higher data rates. This is one of the major reasons why NR needs to exploit also frequencies in the mm-wave range, as well as aggregation of multiple wide-band carriers. However, the amount of licensed spectrum an operator has access to may not be sufficient and there is typically a cost associated with obtaining a spectrum license. Despite the less controlled interference situation, unlicensed spectrum is of interest, primarily as a complement to licensed spectrum but also on its own in local deployments. So, to provide high service quality and optimal reliability, licensed spectrum will continue to be the backbone of the wireless network in 5G, and transmission in unlicensed spectrum will be used as a complement to provide even higher data rates and boost capacity.

The spectrum situation for 5G is far from similar around the world. Large differences exist between countries when it comes to spectrum allocations and availability dates. This makes every operator's starting position for 5G unique and tailored solutions are needed to fit all the needs. In general terms, we can expect that initial 5G deployments will be non-standalone in low, mid and high bands,

interworking with 4G. 3.5GHz is one interesting option that is being considered widely, while also high-band millimeter wave implementations can be expected. As traffic increases and markets mature, we can expect to see more and more combinations of bands. Existing spectrum, in which 4G is currently deployed, will be gradually migrated to 5G, when the increased penetration of 5G devices is high enough to offload the load on 4G spectrum. Functionalities for both spectrum migration and combinations (both bands and technologies) are crucial for operators to be able to make a smooth 5G evolution plan.



5G Spectrum and deployments

Multi-antenna transmission, including MIMO and **beamforming**, is a key part of NR and will evolve further in release 16 of the standard. Joint transmission from multiple, geographically separated antenna panels can bring additional capacity and improve data rates. Multi-antenna transmission already plays an important role in current generations of mobile communication and will be even more central in the 5G era. Massive MIMO (multiple-input and multiple-output) uses a combination of advanced antennas with many steerable ports to significantly increase the number of transmission points, spectral efficiency, and network capacity and delivers faster data throughput.

Beamforming utilizes the Massive MIMO advanced antenna array to increase the capacity and effectiveness of radio transmissions. Beamforming achieves this

by shaping the radio signals into highly focused, steerable beams which deliver a stronger radio signal a greater distance and with less energy. As a result, Beamforming and Beam steering enable higher data throughput throughout the cell, and higher data rates at the cell edge. With Beamforming, the radio data transmission is sent directly to the device instead of broadcasting across the entire cell which also reduces intercell interference further improving system performance. The number and shape of the beams is controlled dynamically to meet the application needs.

Enhanced feedback from the terminals about the radio conditions can allow more extensive usage of advanced multi-antenna schemes and bring gains.

Dual connectivity enhancements, for example support of asynchronous dual connectivity, is another example of an enhancement relevant for geographically separated cells.

With the need for higher data rates and higher capacity, the networks are likely to become more and more dense, stressing the need for efficient backhaul from all these base stations. **Integrated access and backhaul (IAB)** refers to the work in 3GPP on using NR not only for the access link but also for the backhaul link connecting the base stations to the core network. For example, smaller base stations may be deployed and connect wirelessly using NR to macro base stations with fixed backhaul.

Fronthaul for 5G: eCPRI. To meet the needs for 5G, the new industry standard 5G fronthaul—eCPRI—will improve bandwidth efficiency, increase capacities and lower latencies. Ericsson has implemented the market's first commercial eCPRI interface in Ericsson Radio System. Its bandwidth scales flexibly with user traffic and allows for a 10x reduction of bandwidth on the interface. eCPRI will use standard Ethernet connections over dedicated fiber. By using the eCPRI interface, Ericsson has moved beamforming processing from the baseband to the radio. This allows for a much simpler Massive MIMO deployment and provides the flexibility needed in real-life site environments.

Ultra-lean radio-access design is important to achieve high efficiency in 5G networks. The basic principle of ultra-lean design can be expressed as: minimize any transmissions not directly related to the delivery of user data. Such transmissions include signals for synchronization, network acquisition and channel estimation, as well as the broadcast of different types of system and control information. Ultra-lean design is especially important for dense deployments with

many network nodes and highly variable traffic conditions. However, lean transmission is beneficial for all kinds of deployments, including macro deployments.

Virtualized RAN for 5G. Some of the RAN functions that are less sensitive to time delay which are hosted within the baseband units can become virtualized to increase network flexibility., For example, the multipath-handling function that is the anchor point for dual connectivity in 5G can be further optimized. By moving this function higher up in the network, “tromboning” traffic delays and inefficiencies can be avoided.

The **5G standardization** has been accelerated with first 5G NR standard finalized in Dec 2017 and completed in June 2018. First commercial 5G networks and devices based on the 3GPP standards are expected in 2018. The first very few 5G devices will likely be introduced towards the end of 2018. Ericsson estimates the number of subscriptions reaching one billion by the end of 2023.

In early 2018 **Ericsson** has launched the **industry’s first 5G NR-capable radio**, called Ericsson AIR 6468. It features 64 transmit and 64 receive antennas enabling it to support our 5G plug-ins for both Massive MIMO and Multi-User MIMO. The high-performance beamforming, required for Massive MIMO, is enabled through the use of a split Cloud RAN architecture, which brings the required intelligence and scalability to this new radio. And, the AIR 6468 is designed for compatibility with the 5G NR standard while also supporting LTE.

In September 2018 Ericsson has announced **the first 3GPP-compliant 5G New Radio** (5G NR) millimetre-wave (mmWave) over-the-air call using a smartphone form-factor mobile device in partnership with Qualcomm. The call was made in Ericsson's Kista, Sweden, lab, utilising the 39GHz mmWave spectrum band and Ericsson's commercial 5G NR Air 5331 radio and baseband products, as well as a mobile test device packing a Qualcomm Snapdragon X50 5G modem and RF subsystem.

4 Ericsson 5G Application Scenarios

Ericsson has identified six industrial social and industrial applications [4] in which 5G will bring substantial revolutions. The following sections illustrate such

applications detailing the beneficial impact of 5G and the relevant main technology enablers.

4.1 Broadband and Media Everywhere

This scenario shows how it will be possible to communicate in crowded or remote areas at high speed, thanks to a decrease in latency and the increase in data rates. Thanks to 5G, every mobile user will experience high-quality broadband service both upload and download.

With 5G, users will experience broadband access in crowded areas like concerts, sporting events and festivals, alleviating issues with capacity, interference and reliability. 5G customers will also enjoy 4K movies downloaded in just seconds without a Wi-Fi connection. While live TV broadcasts and sporting events will become immersive viewing experiences, as if you were at the event in real-life. For customers, 5G will also maximize their experience in both indoor and outdoor connectivity and offer high QoS broadband even in challenging network conditions.

Technology enablers	
5G radio access	<ul style="list-style-type: none">• Capacity and full mobility• Improved beam forming• Massive MIMO• Broadcast• Carrier aggregation• New high frequency spectrum
5G core network	<ul style="list-style-type: none">• QoS support for e.g. emergency/safety related communication• Roundtrip latency in 1 ms range• Cloud based flexible deployment of media services

	<ul style="list-style-type: none"> • Network slices all optimized for mobile broadband and media delivery
5G management & orchestration	<ul style="list-style-type: none"> • Congestion handling per subscriber/service or based on usage • Dynamic allocation of resources according to traffic variation • Reduce load on transport links and central processing units

4.2 - Smart vehicles and transport

Sensors embedded in roads, railways, airfields and vehicles will communicate with each other through the 5G network. Ericsson is fully aware that this use case is focused on massive machine type communication and is working to ensure that the 5G network has the necessary high coverage and low power consumption.

When transportation and vehicles are equipped with 5G connectivity, it will revolutionize the way we travel. Vehicle-to-vehicle and vehicle-to-infrastructure communication will make roads safer and more environmentally friendly, while allowing buses and public transportation to run more efficiently. New services and business models can be supported considering sensors embedded in roads, railways and airfields to communicate to each other and/or with smart vehicles.

Technology enablers	
5G radio access	<ul style="list-style-type: none"> • Massive density • Device cost Mobility & latency • Significantly reduced signaling overhead – device energy consumption • Soft-SIM or no-SIM operation for sensor type devices
5G core network	<ul style="list-style-type: none"> • Integrate public infrastructure network within network slices • Support for pub/sub message-oriented communication • Roundtrip latency in 1 ms range

5G management & orchestration	<ul style="list-style-type: none">• Orchestration of a big amount of data and input interfaces• Common view for all the utility/infrastructure suppliers• Different user profiles to access the same network
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4.3 - Critical services and infrastructure control

5G brings high reliability and low latency required to control critical services and infrastructure. This unlocks new opportunities for public safety, government, city management and utility companies.

5G will be a key enabler of the future digital world. It will bring about new service capabilities for industrial stakeholders thanks to the unprecedented on-demand performance and real-time reactivity. For example, energy and water utilities will can connect to millions of networked devices, taking real-time, intelligent and autonomous decisions.

Technology enablers	
5G radio access	<ul style="list-style-type: none">• Massive density• Device cost• Significantly reduced signaling - device energy consumption• Soft-SIM or no-SIM operation for (at least) sensor type devices.• Always available and basic services e.g. emergency calls

5G core network	<ul style="list-style-type: none"> ● Integrate infrastructure network within network slices ● Reliability ● Roundtrip latency in 1 ms range
5G management & orchestration	<ul style="list-style-type: none"> ● Orchestration of a big amount of data and input interfaces ● Common view for all the utility/infrastructure suppliers ● Co-relate and process different inputs for fast response

4.4 - Critical control of remote devices

5G introduces the ability to remotely control devices and heavy machinery, thus unlocking the potential for improved medical services and surgeries that would otherwise be unavailable to rural communities. 5G would also allow for heavy machinery to be controlled from a distance, making hazardous situations safer for humans.

Amongst other benefits, 5G will allow for heavy machinery to be controlled remotely. This lowers the risk of injury in hazardous environments and means that work can be completed in a more effective way. Similarly, industries like manufacturing and mining will experience better efficiency and reduced costs.

5G radio access	<ul style="list-style-type: none">• High node/service availability at least 99.999% node availability• Uplink capacity for high quality video• Mobility & latency• Best use of licensed and unlicensed technologies
5G core network	<ul style="list-style-type: none">• QoS functions and network slices• 99.9% accessibility and retain ability• Roundtrip latency in 1 ms range
5G management & orchestration	<ul style="list-style-type: none">• Improve response time for diagnostic• Meet real-time constraints• Estimate and report about the achieved reliability of a connection (per user, per service)

4.5 – Human-Machine Interaction

The high performance of 5G networks will make IoT more accessible by humans, to enhance the awareness of the context in which people live. Ericsson 5G system allows for the context awareness that allows you to fill the gap between people and IoT.

5G will become the backbone of IoT, connecting devices in ways we never thought possible. Users will experience smart cars that are capable of communicating with traffic lights; augmented reality and 360 degree immersive gaming and movies; and transmitting touch and texture to realize the tactile internet. The IoT applications that 5G will help enable is truly limitless.

5G radio access	<ul style="list-style-type: none"> • High node/service availability at least 99.999% node availability • Uplink capacity for high quality video • Extremely low latency • Best use of licensed and unlicensed technologies
5G core network	<ul style="list-style-type: none"> • QoS functions and network slices 99.9% accessibility and retain ability for comm. services • Roundtrip latency in 1 ms range
5G management & orchestration	<ul style="list-style-type: none"> • Improve response time for diagnostic questions • Meet real-time constraints • Estimate and report about the achieved reliability of a connection (per user, per service)

4.6 – Sensor Networks

5G technology will expand business opportunities through monitoring, tracking and automation capabilities on a large scale - from connected farms and agriculture to smart cities and buildings.

5G will allow the IoT (Internet of Things) era to become a reality by breaking constraints and capturing information in new ways. For instance, sensors will be able to be implemented throughout farms allowing for crops to communicate moisture and fertilization needs. While utility companies will be able to monitor and report on energy useage. Thus, improving the reliability and sustainability of energy production and distribution.

5G radio access	<ul style="list-style-type: none">• Device cost• Significantly reduced signalling overhead – device energy consumption• Soft-SIM or no-SIM operation• Reliability• Coverage & spectrum efficiency
5G core network	<ul style="list-style-type: none">• QoS functions• Network slices
5G management & orchestration	<ul style="list-style-type: none">• Orchestration of a big amount of data and input interfaces• Common view for all the utility/infrastructure suppliers• Co-relate and process different inputs for fast response• Data analytics – business intelligence

5 The 5G for Italy program

TIM and Ericsson announced in June 2016 [5] the launch of the "5G for Italy" program aimed at creating an open ecosystem for research and implementation of innovative projects enabled by 5G networks - the next generation of mobile technology - to accelerate digitization of the country.

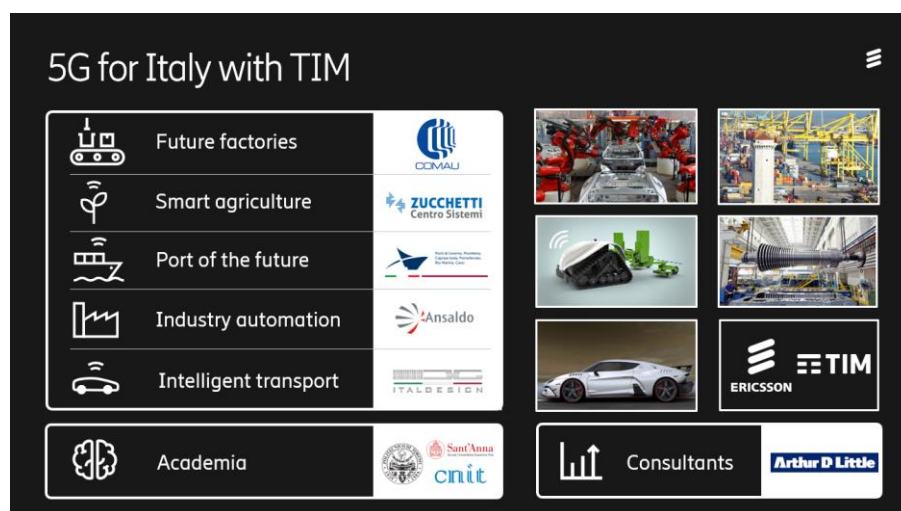
The initiative brings together industries, institutions, universities, research centers, local administrations and small and medium-sized businesses to develop and test new services and pilot projects using 5G technology. The main areas of

analysis are the Smart City, the Internet of Things, Industry 4.0, Transport and Smart Agriculture.

The "5G for Italy" program is an opportunity to develop applications that can be used by both citizens and industries in the Networked Society.

In a broader scenario, the collaboration of the companies participating in the project envisage monitoring and identifying emerging trends in the Italian and international scenario and analyzing and studying the new technological and business opportunities that 5G technology will introduce in the market starting from 2020.

As global standardization will be a crucial element for the success and rapid deployment of the new 5G technology, it will also be the program's objective to increase the companies' competences on the evolution of current mobile networks towards 5G, to address and support the development of a unique "5G" standard.



Comau and the factory of the future

TIM, Ericsson and Comau partnership is aimed to build the factory of the future within the Industry 4.0 paradigm with specific applications in the areas of Cloud Robotics for Smart Manufacturing. This specific use case is detailed in the next section.

The Port of the future in Livorno

One of the first projects in the 5G for Italy program is based on the collaboration between TIM, Ericsson, CNIT (National Inter-University Consortium for Telecommunications) and the Port of Livorno. The main scope is to implement the first ‘Connected Port’ where Augmented and Virtual reality technology, supported by the 5G mobile infrastructure will be used to optimize the transportation logistics with the aim to improve the port efficiency and throughput.

Italdesign and Smart Transportation

TIM, Ericsson e Italdesign are working to extend 5G capabilities to V2x applications such as Assisted Driving support with holographic call, Autonomous Driving, Infotainment.

Seikey: drones for Public Safety

TIM, Ericsson and Seikey are collaborating on 5G network support for drone remote flight control. Main use cases are related to drone owner tracking, irregular flight detection, safety in public parks and business delivery operations.

6 5G for Industry 4.0: the Comau Case

Since 2016, Ericsson has partnered with Comau, a world leader in industrial automation to experiment the factory of the future paradigm in a real industrial context. More specifically, Partners have explored low-latency network and edge cloud for manufacturing plants. Details about these experiments, including the results, were published in Ericsson Technology Review [6].

The joint research with Comau addresses the evolution towards **Industry 4.0**. The critical requirements of wireless networking in a plant have been the main challenge, as industrial protocols demand tight radio performances with high reliability, availability, and security. Wireless connected sensors (pressure, temperature, vibrations, cameras) feed expert systems to determine what is happening, to predict future issues, and to prevent failures. Adaptability is addressed by enabling and implementing the centralization and virtualization of controllers, at all levels: plant, production lines, working robotic cells, single robots, actuators. Having a central, global control entity facilitates a fast reaction and an autonomous response to any event and, when needed, to invoke the action and decision of the human supervisor.

The trend for “personal” product customization is growing, along with a preference for online purchasing. Therefore, current processes need to be adapted to be more flexible and customizable, while still protecting initial investments into the production line. High speed wireless infrastructure, such as **5G networks**, can help modification, required by customized products, of an original equipment manufacturer (OEM) machine with minimal impact.

The digitization of factory operations enabled by IoT technologies promises to make that happen. Digital tools will be able to monitor and control all tools of production, collecting data from thousands of sensors to create a digital image of the product being realized, usually referred to as a “digital shadow.” Once a digital shadow has been created for a physical product and bears its specific DNA, it is possible to manufacture that product more efficiently and with higher quality in the digitized production facility. In this way, it is possible to optimize the manufacturing process, detect quality issues early to prevent defects at the end of the production line and make continuous improvements. It is also possible to carry out predictive and preventive maintenance.

A mature **plant** has up to **1000 moving parts** plus many more devices and sensor. Data traffic is no longer supportable by existing wired internal networks, largely based on legacy Ethernet networks. Current plant networks start to have bottlenecks.

There are three alternative options to solve the problem:

1. Add a second wired network in support of the legacy network: possible but not easy to integrate both the networks together
2. Complete re-cabling of the plant, for example using optical fibers
3. Going wireless, using a **4G/5G cellular technology** in licensed spectrum

The third option is preferred by Comau because:

- It reduces the cost for connection of various elements of the line, reducing the commissioning cost for plant construction/upgrade.
- It facilitates using a plethora of new wireless sensors, easy to attach on robots even in legacy plants: sensors with long lasting batteries and communicating few data in real time. Example of sensors are: pressure, temperature, vibration (IMU). Correlating data from these sensors would enhance monitoring and prevention.
- It facilitates connecting new robots and moving objects without complex and inflexible cabling. Cabling are easily subject to attrition especially in fast moving robots.
- It enables connecting AGVs that will replace conveyor belts in future.

- It is more scalable with the number of “objects” that are and will be connected in a plant.
Wi-Fi is not viable in a factory environment for various motivations:
- It is a “best effort” communication technology on a shared spectrum, not robust to the co-channel interference due to the presence of multiple access points competing for bandwidth. The phenomenon is well controlled in cellular technologies operating on a licensed spectrum.
- The scalability required in a factory (e.g. for adding new sensors and devices) cannot be ensured by Wi-Fi because performances degrade with the number of connected objects. In fact, too many clients, converging on a single access point, bring to a detrimental contention loss.
- It’s not easy to make a stable Wi-Fi coverage planning of the plant because a “signal strength mapping” is quite inaccurate and can be dynamically affected by “objects” moving around.

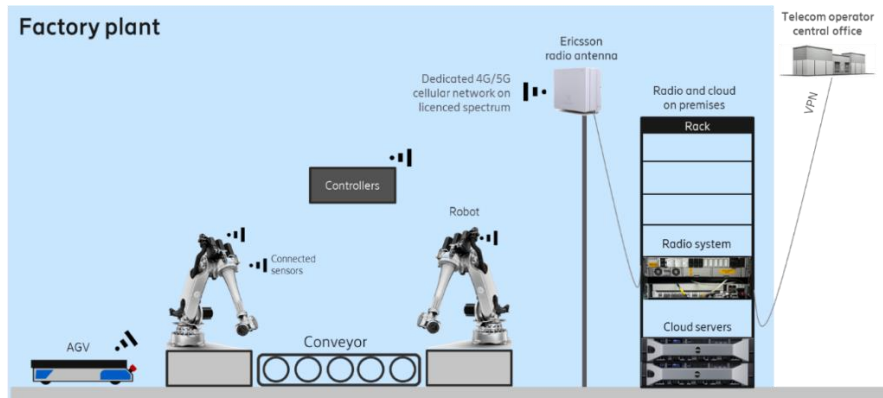
Communications among all the factory elements must work in a **challenging environment** characterized by **electromagnetic interferences** and distributed over a large area that could span several buildings. While LTE connectivity is robust and capable enough to cope with that environment today, stringent latency requirements will soon demand 5G connectivity. In particular, 5G is the target technology truly capable of delivering the performance needed to complete moving and virtualizing robot controller functionalities in cloud, with the required security and stability.

5G, with dedicated cellular radio coverage, will ensure:

- an almost immediate response from the network (= very low latency, up to 1 millisecond)
- slicing to serve different needs in the plant with same radio installation: e.g. critical machine type communication for robot control, NB-IoT for capturing data from sensors, broadband for HD cameras used to detect parts alignment before robot pick up and AGVs...
- maximum security and stability in wireless data transmission
- a standard communication technology

The combination of wireless sensors and high-capacity communication networks such as 4G and 5G plays a key role in this context, by enabling data collection from shop-floor level (production lines) and data transfer to cloud systems for continuous monitoring and control.

The following scheme illustrates the main components of the proof-of-concept. Both radio core and cloud servers are located on premises. A VPN connect the demo area with the TIM central office to enable the use of the licensed spectrum (dedicated to the experiment).



High level sketch of the Comau setup, including link to operator central office

Virtual controllers that combine control, data logging and alarms into a cloud platform also help the process of digitization and save cost, panel space and maintenance activities compared with traditional control systems. They can control a wide variety of production tools and are also a solution for remotely located machines and portable systems that can run standalone.

References

- 1 ITU-R M.2083-0, “IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond”, September 2015.
- 2 Stefan Parkvall “5G NR release 16 – start of the 5G Evolution”, Ericsson Research Blog, <https://www.ericsson.com/research-blog/5g-nr-release-16-start-5g-evolution/>
- 3 Ali A. Zaidi, Robert Baldemair, Mattias Andersson, Sebastian Faxér, Vicent Molés-Cases, Zhao Wang, “Designing for the future: the 5G NR physical layer”, Ericsson Technology Review

- 4 Ericsson 5G Use Cases, <https://www.ericsson.com/en/5g/use-cases>
- 5 5G for Italy press release, <https://www.ericsson.com/en/news/2016/6/tim-and-ericsson-launch-5g-for-italy-program-to-accelerate-the-countrys-digitalization>
- 6 R. Sabella, A. Thuelig, M. C. Carrozza , Massimo Ippolito,“Industrial automation enabled by robotics, machine intelligence and 5G”, Ericsson Technology Review

5G-MoNArch

Mauro Renato Boldi and the Project Partners

1 Description and objectives of the project

The overall concept of *5G-MoNArch* and its implementation are illustrated in

. The ultimate goal is the full design, implementation and evaluation of the 5G architecture. The concepts are complemented with five key innovations required to achieve the *5G-MoNArch* objectives; these include three *enabling innovations* contributing to the baseline architecture, and two *functional innovations* which correspond to specific network slices.

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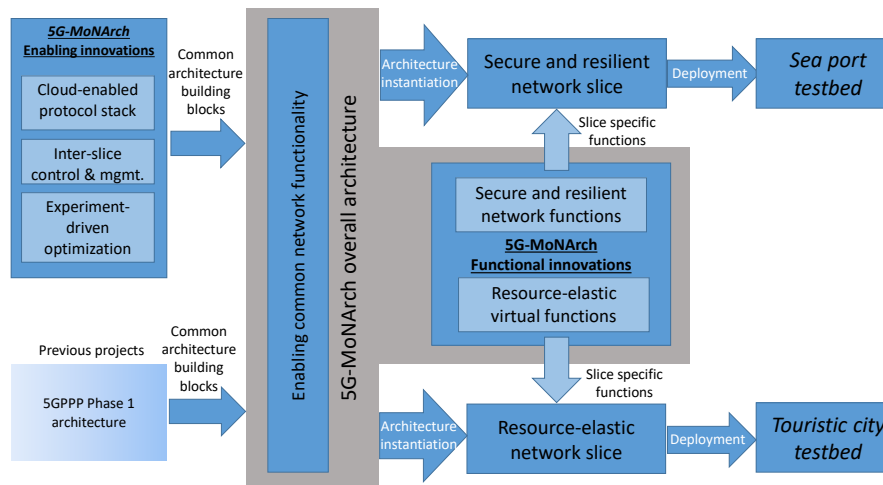


Figure 1-1: 5G-MoNArch concept.

As shown in Figure 1-1, combining 5G-PPP Phase 1 architecture concepts with the **three enabling innovations** results in the *5G-MoNArch* “enabling common network functionality”. This enabling functionality includes the common architectural functions needed to dynamically instantiate network slices that meet specific use case requirements. To deploy slices that provide specialised functionality, the common network functionality are complemented with **two functional innovations**: (i) secure and resilient functions, and (ii) resource-elastic functions. The combination of the enabling common functions with the functional innovations forms the *5G-MoNArch* overall architecture. This architecture is designed to enable the integration of external novel functions (in addition to our functional innovations), such as, e.g., that provided by other 5G-PPP projects) that may target specific requirements different from the ones in *5G-MoNArch*, providing thus extensibility and future-proofness.

Building on the above *two functional innovations*, *5G-MoNArch* develops specific NFs for *two representative use cases* requiring security and resilience on the one hand, and network elasticity on the other hand. These NFs is deployed in two dedicated network slices, one for each use case. These network slices are implemented in *two testbeds*: the first one is a sea port testbed, which focuses on security and resilience, and the second one is a touristic city testbed in an urban downtown environment, which applies the resource elasticity concepts.

In the context of the project concept outlined above, the individual objectives of *5G-MoNArch* are detailed next.

Objective 1: Detailed specification and extension of the 5G architecture.

5G-MoNArch fully *specifies* the 5G architecture complemented with key concepts and innovations derived within the project. Indeed, while 5G-PPP Phase 1 projects have developed the key concepts of the 5G architecture, they have not provided a full architecture specification. The specification of *5G-MoNArch* includes the functional control and user plane architecture as well as the management and orchestration plane. Furthermore, attention is put to the specification of all aspects of network slices, including their implementation in access and core, their management, orchestration, and control. The architecture specification includes the three enabling and two functional innovations of *5G-MoNArch*, which are detailed in the following objectives.

Objective 2: Extend the architecture design with three key enabling innovations that enable the operation of sliced 5G networks and specific functional extensions. To provide the desired functionality, the architecture concepts developed by 5G-PPP Phase 1 projects need to be complemented by **three architecture enablers** that are in the focus of *5G-MoNArch*:

- **Inter-slice control and cross-domain management**, which enables the interworking of different network domains operated and used by different tenants while providing cross-domain service guarantees.
- **Experiment-driven modelling and optimisation** of a virtualised environment, which builds on specific processing models of the deployed communication platforms. This innovation leverages the implementation of *5G-MoNArch* architecture to gain experimental insights into the architecture and use these insights to design optimised algorithms and functions.
- Native **cloud-enabled protocol stack**, which reduces dependencies within the NFs in the protocol stack in order to enable a more flexible placement of such functions within the network.
- The above three architecture enablers, as well as two functional innovations described in the next objective, complement the 5G-PPP Phase 1 architecture concepts (more details are provided in Section 1.3).

Objective 3: Develop novel functional innovations required for two key technologies required for the use cases identified.

In addition to the general enabling architecture targeted by the two objectives above, more specific functions may be required when deploying network slices with particular requirements. In this context, two main technology gaps have been identified to address the performance requirements pinpointed in 5G-PPP Phase 1 and not addressed by ongoing SDO initiatives or previous projects: (i) “resilience and security”, and (ii) “resource elasticity.” The *novel functional innovations* required by both technologies is in the focus of *5G-MoNArch*:

- The key technology **resilience and security** addresses the following two issues: (i) the need to provide a *failsafe mobile network operation* which can be maintained even under difficult circumstances such as outage of parts of the infrastructure (long-term outage) or due to changes of the radio propagation environment (short-term outage); and (ii) the need for guaranteed *security and privacy* even in the case of shared infrastructure and resources, including non-exclusively used spectrum, e.g., provided by public MNOs. For the latter, we need to take into account that IoT devices may be subject to stringent power efficiency requirements, and thus efficient lightweight security mechanisms may be required.
- **Resource elasticity** addresses the need for managing information processing and communication resources in a flexible and efficient way. For instance, in the case of a typical urban downtown scenario, the required services may range from augmented reality to video chats and instant messaging, each imposing different requirements over a certain period of time at a specific location. To address this problem in a cost-efficient manner, (i) the mobile network has to be able to *assign, scale and cluster resources* to those parts of the networks where they are needed; and (ii) the *NFs* need to be *elastic* so as to adapt to the available resources without impacting performance significantly.

Objective 4: Deployment and experimental implementation of the architecture in two use cases.

5G-MoNArch experimentally validates the introduced key concepts and innovations. The experimental validation is based on prototypes provided by the manufacturers of the project consortium, deployed in testbeds managed by the operators along with vertical industries. The implementation of the 5G architecture is used to provide “closed-loop” feedback for the specification and refinement of the 5G architecture. To achieve this objective, the following two use cases are deployed by *5G-MoNArch* (see Section 1.3.3 for a description of the detailed testbed setups):

- **Sea port use case:** the first testbed is deployed at the Hamburg sea port to showcase typical applications in an industrial enterprise environment. For this use case, the “resilience and security” functional innovation described in the previous objective is of utmost importance.
- **Touristic city use case:** the second testbed is deployed in the city of Venice to showcase typical public 5G services, with a special focus on the high demanding applications resulting from a touristic environment (such as haptic Internet, virtual or augmented reality). For this use case, the “resource elasticity” functional innovation is of primary interest.

The above two use cases are representative of a much wider variety of scenarios that cover most of the performance requirements, features and technologies discussed in 5G-PPP Phase 1 [5GAWP]: (i) the sea port use case is representative for a *private deployment* where a customer requires a solution within its own premises that provides guaranteed and secure performance and solves a specific need; and (ii) the touristic city use case is representative for *public deployments* where customers use very high resource demanding applications but may accept that occasionally quality degrades slightly.

Objective 5: Evaluation, validation, and verification of the architecture performance

5G-MoNArch defines a methodology and framework to evaluate, validate, and verify the architecture based on the two testbeds deployed by the project. Building on this framework, 5G-MoNArch quantitatively evaluates the performance of the proposed innovations, and it validates and verify the overall architecture based on functional, operational, and performance KPIs. This framework considers techno-economic aspects as well, to verify the economic advantages of the proposed architecture.

2 Italian contribution to the project

TIM is the only Italian partner in 5G-MoNArch. The research areas of TIM (belonging to the Wireless Access Department) involved in 5G-MoNArch will use the results of the project as an input to the Technology Plan, a document (internal

to Telecom Italia Group) that lists the available technologies and that is the basis to develop the investment plan together with the strategy plan. Therefore, this will have a direct impact on future investments and network operating costs, and could be exploited to develop prototypes of new services. Moreover, the project will be exploited by TIM by influencing the industry with requirements; the same applies with the standardisation activity within the bodies participated by TIM. The overall activity within the project will be exploited as an opportunity to show to the investor community the sensitivity of Telecom Italia towards innovation and fore-runner research.

More specifically, TIM leads the demonstration activity in the Turin testbed in Palazzo Madama, coordinating the partners' involvement in the deployment of the elasticity feature in network slicing. This activity has also an important aspect related on the relationships established with the Municipality of Turin and the "Fondazione Torino Musei" that were able, even if not partners in the consortium, to exchange their requirements on the 5G deployment in the testbed.

METIS

Mauro Renato Boldi and the Project Partners

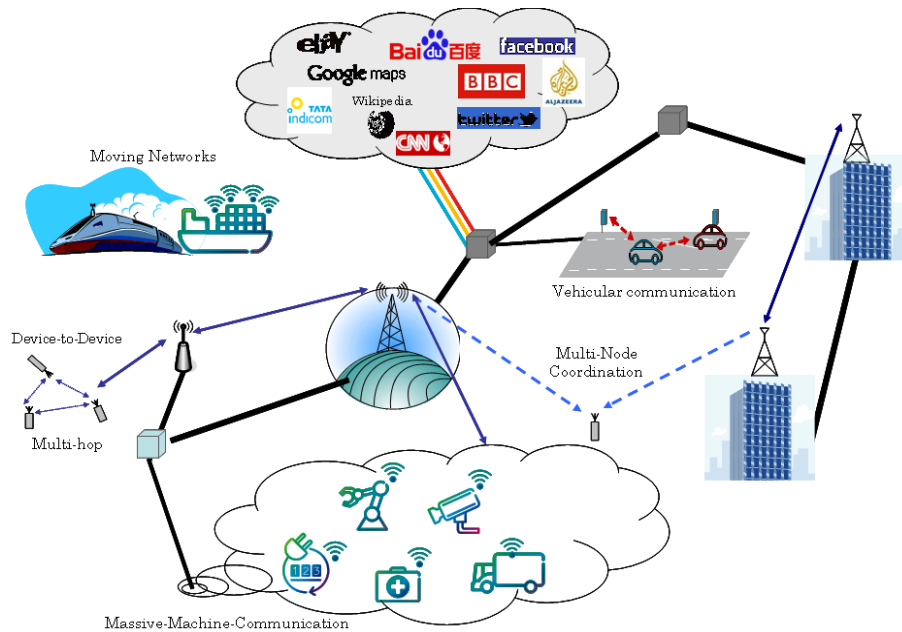
1 Description and objectives of the project

METIS provided the basis for the all-communicating world envisioned beyond 2020 by proving a first investigation of technology concepts addressing the efficiency, versatility and scalability of future communication systems. METIS was able to determine which technology components in wireless communication systems may pursue an evolutionary path, and where complete paradigm changes and revolutionary approaches were needed to meet the ambitious targets.

Through its strong consortium and the right timing, METIS was expected to achieve a European-lead global consensus on fundamental questions connected to the further development of wireless communication systems. In order to achieve this, METIS pursued a **two-fold research approach: Horizontal Topics** which enabled the future wireless communication system; and **Technology Components** as being the foundations of the Horizontal Topics.

On one hand, METIS developed and enhanced the most promising **technology solutions/scenarios and use cases** (called as **Horizontal Topics**) for beyond 2020 communications, such as: Direct Device-to-device Communication, Massive Machine Communication, Ultra-dense Networks, Moving Networks, and Ultra-reliable Communication. These technology scenarios and use cases are illustrated in the figure and explained in the sequel.

Mauro Renato Boldi
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Promising technology solutions and use cases for beyond 2020 communication

- **Direct Device-to-device (D2D) Communication** implies user-plane communication directly between mobile devices, without going via any network infra-structure. D2D communication offers the possibility for enhanced efficiency and improved service quality in densely populated networks by reducing the radio-link distances. The objective of METIS was to integrate D2D as part of the overall communication network. Therefore, METIS studied adequate resource allocation and interference management solutions, allowing the integration of D2D communications in the multi-dimensional networks.
- **Massive Machine Communication** will be vital ingredients in future wireless communication networks. Communicating machines are predicted to be an important source of traffic in the future all-communicating world. The corresponding machine-related communication will be associated with a wide range of characteristics and requirements that will in many cases deviate substantially from the characteristics and requirements of the currently dominating human-centric communication. The technologies researched and

developed within the METIS project addressed these characteristics and requirements and provided enablers for efficient support of massive machine communication within the future all-communicating world.

- The concept of **Moving Networks** enabled an efficient support of large populations of jointly moving communication devices. The term “Moving Networks” refers to a number of novel concepts that focus on moving and/or nomadic network nodes (e.g. vehicles, busses, trains, ferries, airplanes, etc.). Note that a moving network node goes beyond the classical definition of a moving relay as being discussed for LTE-A: a moving network node (e.g. vehicles or busses with advanced communication and networking capabilities) or a group of such nodes can form a “moving network” that communicates with its environment i.e. other fixed or mobile nodes that are inside or even outside the moving entity. The concept of moving and nomadic⁴ network nodes relates to most of the technology components. The METIS objective for moving networks was to design wireless backhaul communication, mobility management such as interference and handover management, as well as models for spectrum and network sharing.
- **Ultra-dense Networks** enables capacity, cost and energy efficiency: Infrastructure densification is a path that has already been taken within e.g. existing cellular radio-access technologies, with inter-site densities as small as in the order of 200 m in currently existing deployments. However, METIS planned to take network densification even further, considering network-infra-structure densities being order of magnitudes higher than today and where at some point one may even have scenarios with, locally, a higher infra-structure than device density. The aim was to enable extreme traffic capacity and service level. Ultra-dense deployments raise many new challenges e.g. related to mobility and backhauling. METIS provided/designed the physical layer and network-layers functionally e.g. related to interference management and mobility management for this enabler. Moreover, METIS investigated the performance of ultra-dense networks in terms of cost, energy and spectral efficiency.
- **Ultra-reliable Communication** enabled availability and scalability: METIS aimed at providing scalable and cost-efficient solutions for networks

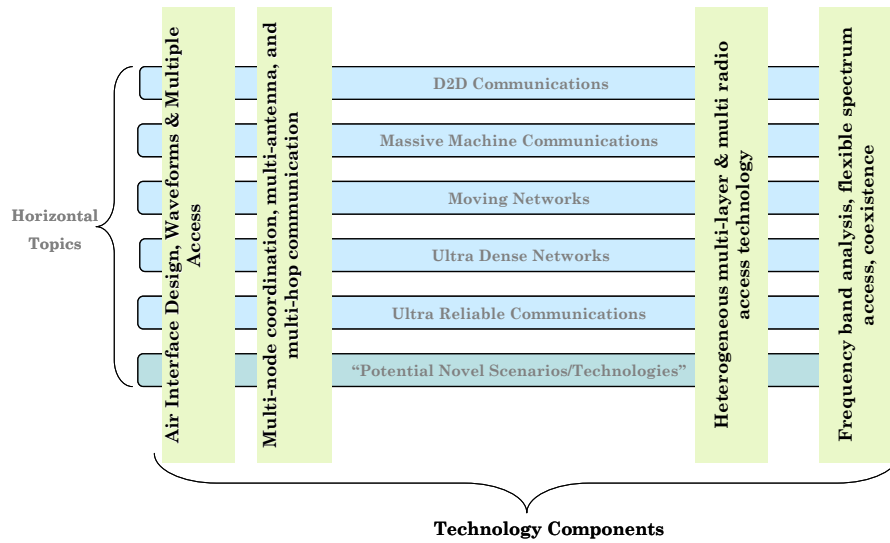
⁴ The concept of nomadic network nodes defines a base station-like network node that can be activated and deactivated and change its location in a flexible manner depending on traffic, service and coverage demands.

supporting services with extreme requirements on availability and reliability. Herewith, METIS met the upcoming demand in domains such as Internet of Things, telematics, automatization requiring wireless support. METIS also aimed at providing concepts and solutions for the evolutions and migration of existing dependable and secure networks allowing the respected market domains to benefit from the economy-of-scale of the public wireless communication market.

On the other hand, METIS conducted research on the **technology components** needed to support the technology solutions and use cases stated before. These technology components were

- Air Interface Design, Waveforms and Multiple Access
- Multi-node coordination, multi-antenna, and multi-hop communications
- Heterogeneous multi-layer and multi radio access technology
- Frequency band analysis, scenarios, flexible spectrum access, coexistence

The two-fold research approach pursued in METIS led to a matrix structure of the project. METIS integrated the horizontal topics as the project driving topics. These enablers rely on the technology components (i.e. vertical dimension) e.g. link, multiple access, multi-node, multiple-dimensional network and spectrum aspects. The vertical dimension is crucial since this is how technology is dissected and evolves, and how standardisations activities are classically organised. While the vertical dimension allowed technology-driven innovation and more efficient technical dissemination, the horizontal dimension ensured to capture emerging market, societal and economical needs through the topic “Potential Novel Scenarios”. In summary technology components were integrated as whole and tightened together by emphasizing on the horizontal topics such as Direct Device-2-Device Communication, Massive Machine Communication, Moving Networks, Ultra-dense Network, Ultra-reliable Communication, and any new promising enablers identified during the course of the project time life. As such the technology components pushed for achieving the needs of the HTs. In return new HT will pull the technology toward new directions.



The two-fold research approach pursued in METIS

Consequently, METIS addressed the 2020 information society needs and requirements, and was able to attract new stakeholder segments and existing telecom industry. As stated, the technology components may provide the basis for completely new wireless communication systems or may be integrated as part of a long-term evolution of current wireless communication systems, with a target market impact around year 2020 and beyond. The project outcome was to find the modus operandi between potential new wireless communication solutions, based on a preliminary assessment and a common understanding of the gain of various potential concepts; and technology components for the evolution of IMT-Advanced, which can be considered as retro-fit concepts to legacy standards.

2 Italian contribution to the project

TIM was the only Italian partner in METIS and this gave to the company a competitive advantage in the race towards 5G, that was started practically from the scratch by METIS project. The activity performed in the project was the basis

for all the future developments in 5G research in Europe and beyond. The NGMN white paper on 5G, that many consider as the kick-off of the 5G era, was largely inspired by METIS, and many partners were working in METIS and NGMN. Also in the standardization process, the findings of METIS were of paramount importance; as an example, all the ITU categorization of use cases for 5G is based on METIS deliverables. The three well known families of use cases (eMBB, mMTC, URLLC) are directly derived from the pioneering activity performed in METIS.

METIS II

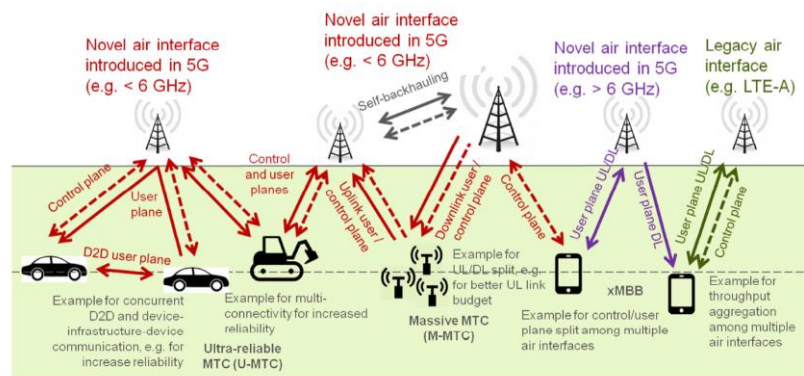
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1 Description and objectives of the project

METIS-II is the project of 5G-PPP call for Phase 1 that is considered a direct derivation of the project FP7 METIS (2012-2015) that laid the foundation of 5G system in Europe.

METIS-II provided a 5G RAN design for an optimized support of wireless communication services for industrial, public and private businesses. It is expected that the support of the variety of 5G use cases requires the existence of multiple 5G air interfaces (or variants of them) that have different characteristics in terms of coverage, latency, capacity, frequency bands, mobility, complexity, deployments (indoor/outdoor) etc. In addition to this, it is also assumed that an overall 5G system may benefit from these multiple air interfaces being more closely integrated than in the case of 2G/3G/4G in order to fulfil novel requirements such as ultra-reliability, very high peak data rates, seamless mobility, etc. Also, an important aspect will be the investigation on how other legacy air interfaces (e.g. LTE evolution and Wi-Fi) can be more efficiently integrated in the 5G domain. The most suitable tightness of integration among novel air interface variants introduced in the 5G timeframe and legacy air interfaces will be determined during the project.

Mauro Renato Boldi
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The METIS-II project built upon METIS and other projects related to 5G, but went significantly beyond the achievements in these projects. In particular, the METIS-II project pursued the following ambitious objectives:

- 1) **Develop the overall 5G radio access network (RAN) design** (where 5G refers to the overall wireless communications system including evolved legacy and novel radio access technologies), in a level of detail in between “Technology Readiness Level 2” and “Technology Readiness Level 3”, and focusing particularly on **designing the technology for an efficient integration of legacy and novel radio access network concepts** into one holistic 5G system.
- 2) **Provide the 5G collaboration framework within 5G-PPP for a common evaluation of 5G radio access network concepts** from both a performance and techno-economical perspective. More specifically, METIS-II further refined 5G scenarios, requirements and KPIs, developed a performance and techno-economical evaluation framework, and **provided consolidation and guidance to other 5G-PPP projects** on spectrum and overall 5G radio access network design aspects. Further, METIS-II developed an **open-source 5G evaluation and visualisation tool** for illustrating the key use cases of a 5G system as such, and the benefit of the key radio access network design elements developed.
- 3) **Prepare concerted action towards regulatory and standardisation bodies** for an efficient standardisation, development and economically attractive roll-out of 5G with a strong European footprint and head start.

METIS-II had to overcome many unsolved technical problems by the following **key innovation pillars**. These pillars are essential in the context of integrating

legacy and novel air interface technologies into a holistic 5G radio access network, and these inherit potential paradigm changes in cellular system design, which are especially important to be addressed in wide industry consensus:

- **Holistic spectrum management architecture.** METIS-II defined, in collaboration with other projects and related forums, a framework and architecture for flexible spectrum management and multi-operator collaboration in 5G. The key difference to METIS activities is significantly more focus on the integration of spectrum beyond 6 GHz, consideration of “new 5G user groups” and vertical industries as well as the increased flexibility needed to make best use of different kinds of spectrum access mechanisms available. In contrast to the past, not only the overall quantity of the available spectrum but the different qualities of spectrum (bandwidth, propagation conditions etc.) will define its potential usage and drive the work in METIS-II. The initial acceptance of spectrum sharing concepts like Licensed Shared Access (LSA, such as in CEPT FM 52 and 53) opens the door for a broader adoption of spectrum sharing concepts dynamic spectrum sharing, for other bands as well. The outcome of WRC-15 and the preparation for WRC-18/19 opened new possibilities for spectrum usage to be exploited in 5G. Integrating different spectrum usage options (covering licensed and licence-exempted bands) has been considered for network offloading but for vertical industries using these bands.
- **Holistic air interface harmonisation framework.** METIS-II developed a framework to harmonize similar protocol functionalities in the different protocol layers of air interface variants to be used in 5G, including both legacy and new air interfaces, with the aim to keep device and infrastructure complexity tractable and ensure a lean standard. This harmonisation can for instance be performed by simply introducing common air interface characteristics, such as frame structures, or functionalities, for instance on the PHY or MAC layer, across multiple air interface variants. Alternatively, generic air interface functionalities can be designed that can be parameterized to suit the needs for different air interface variants. It is of course essential that harmonisation is only applied to the extent that does not sacrifice the performance of individual air interfaces too much. While there had already been previous work on, e.g., developing novel air interfaces scalable to some extent of 5G scenarios, there had yet been no work on a holistic air interface harmonisation framework considering all air interfaces, including novel and legacy ones, needed to respond to the overall 5G requirement space.

- **Agile Resource Management (RM) framework.** The METIS-II project defined a new complex multi-link, multi-layer network ecosystem. There, new flavours of control and user plane integration and protocol adaptation were present, which provided novel opportunities to re-design several functions (e.g. interference management, power control, RAN moderation etc.) to meet the 5G requirements. To achieve this, the project made additional abstractions to the established concept of radio resource management (RRM) and designed a holistic multi-air-interface framework for assigning services to the most suitable resource not only in terms of time, frequency and space, but also in terms of air interface variant and network processing resources (i.e. real and virtual network elements). A key aspect of this framework is that it enabled an easy integration of existing and novel air interface variants, and facilitated the introduction of potential novel air interface variants. In this context, METIS-II investigated different design options, such as a split of RRM functionality into an air-interface-dependent and air-interface-agnostic part.
- **Cross-layer and cross-air-interface system access and mobility framework.** The METIS-II project extended the cross-layer optimization concept to another dimension, enabling a higher interaction of functionalities from the multiple air interfaces in order to improve the overall resource usage. New procedures were designed in such a way that functionalities of one air interface could be used in a flexible way by another air interface, where this coordination is dictated by a control plane framework which is common for these air interfaces. To give an example, one of the concepts that were studied was a *Unified System Access*, where unified system information for all the air interfaces is made available to the mobile terminals and possibly coordinated random access actions may occur across the multiple air interfaces. Within this context, it was also investigated how the 5G system can benefit from the existing infrastructure of legacy systems (e.g. LTE).
- **Common control and user plane framework.** METIS-II designed a common control/user plane framework for multiple 5G air interface variants, including the evolution of legacy standards such as LTE-A. This will allow the further development of multi-connectivity features such as fast link switching, control/user plane diversity, throughput aggregation, etc. in order to fulfil the different 5G requirements. To achieve this goal, integration alternatives over the multiple protocol layers (RRC/PDCP/RLC/MAC/PHY)

were investigated and a recommendation was issued in terms of which layers should be common to the different air interfaces based on different criteria such as the required synchronicity between the different layers, end-to-end delays, potential benefits from coordination, etc. Control/user plane functions were evaluated as candidates for virtualization.

2 Italian contribution to the project

TIM was the only Italian partner in METIS-II, as a follow up of the participation of TIM to the “parent” project METIS, that run from 2012 to 2015 in the context of the call FP7 and laid the foundation to the research activity about 5G all over Europe and beyond. METIS-II was based on a sub-set of partners that were also partners of METIS and was intended as the “Target Action 1” in the 5G-PPP pre-structuring model for Phase 1 projects. In this role, METIS-II concentrated its activity on the overall end-to-end implementation of the 5G architecture and most of the findings of the projects were the basis for the standardization activities leading to 3GPP Release 15 and partially also Release 16.

In the project, TIM, as well as contributing actively on many topics (spectrum, overall architecture definition, ...), oversaw the standardization and dissemination Work Package. In this role, TIM promoted the activities of the project, finalised in 2018 with the preparation of the book “5G System Design – Architectural and Functional considerations and long term research” edited by Wiley (Mauro Boldi main TIM author) and presenting a broad view on all the most challenging topics in the implementation of 5G systems.

5G-CORAL

Mauro Renato Boldi and the Project Partners

1 Description and objectives of the project

The 5G-PPP Phase 2 project termed “5G-CORAL: A 5G Convergent Virtualized Radio Access Network Living at the Edge” aims at identifying and experimentally proofing – through trials on large-scale testbeds – which are the key technology innovations enabling the development of a virtualized Edge and Fog architecture with convergence of multiple Radio Access Technologies (RATs) which is also scalable, flexible and interoperable with other network domains including transport, core network and distant Clouds. It is well known, in fact, that the 5G system is expected to provide a wide range of services not limited to mobile broadband. These services, especially the ones which are bandwidth-intensive (e.g. massive IoT) and/or delay-sensitive (e.g. V2X communications), require networking, computing and storage capabilities to be provided closer to the end-users, i.e. in the Edge of the mobile network. It is here where users’ data originates and needs to be collected, processed and possibly sent to other nearby users, hence leading to the concept of the Intelligent Edge. Techniques allowing for the above-mentioned capabilities to be moved out of remote centralized Data Centres (i.e. the Cloud) have been defined in the context of ETSI Multi-access Edge Computing (MEC) in order to meet 5G services’ stringent requirements. This approach, however, cannot be implemented without considering the Network Functions Virtualization (NFV) framework, also developed by ETSI, which allows both fixed

Mauro Renato Boldi
TIM

and mobile network functions to be software-implemented and then instantiated by the operator on commodity off-the-shelf (COTS) servers by exploiting virtualization technologies. The Edge computing approach is also needed for IoT applications due to the fact that there is the need to properly handle the significant amount of data originated by “things” at the Edge, which negatively impacts mobile network performance in terms of both required bandwidth and latency. This issue can be solved by allowing data processing and applications to be concentrated locally in smart devices rather than being performed in the Cloud, leading to the so-called Fog computing architectural paradigm. Actually Edge and Fog approaches can allow not only (virtualized) RAN but also transport and core network functions to be executed in the Edge and Fog tiers of the network so as to save bandwidth in their respective domains and offer local breakout when needed. Furthermore, in order to continuously offer wireless connectivity to various types of devices and services in a given local area, a variety of RATs having different characteristics in terms of capacity, spectral efficiency, mobility support, complexity and costs needs to be integrated into a common framework, realizing the so-called multi-RAT convergence. Integration of RAN functions belonging to various RATs (e.g., LTE, WiFi, Narrow Band IoT, Bluetooth Low Energy, ZigBee and so on) within an Edge and Fog virtualized architecture enables simpler and cheaper networks to be realized via re-use of common functionalities and infrastructure, also extending the service coverage of one RAT to areas where other RATs are available without the need to deploy additional network equipment. In addition, the possibility to dynamically select the best-suited RAT for the service(s) the user is requesting helps in continuously ensuring the user’s Quality-of-Experience (QoE). Another important aspect addressed in the Project is the need to consider computing, storage and network resources being provided by any Edge/Fog node or device on the move and regardless of the respective owners. This goes beyond the ETSI MEC, where a fixed and centralized location for the Edge platforms owned by only one stakeholder (i.e., the operator) is considered.

The 5G-CORAL concept is illustrated in Figure 1. It sets root in a hierarchical multi-tier computing infrastructure, from Clouds and central Data Centres (DCs) on top, down to Edge Data Centres (Edge DCs), and further distributed down into Fog Computing Devices (Fog CDs) available locally in the access area. The focus of the Project is on the Edge and Fog tiers of the distributed computing infrastructure, along with their interaction with the distant tiers. The concept comprises of two major systems:

- the Edge and Fog computing System (EFS), as the host environment for the virtualized functions, services, and applications
- the Orchestration and Control System (OCS) for managing and controlling the EFS, including its interworking with other, external (i.e. non-EFS) domains (e.g., transport network, core network, distant Clouds and DCs, etc.).

The 5G-CORAL solution will be validated in three real and large-scale testbeds, identified and characterized according to the mobility requirement, i.e. low, medium and high mobility. The testbeds, namely (i) Shopping Mall (low mobility scenario), (ii) Connected Cars (medium mobility scenario) and (iii) High-Speed Train (high mobility scenario) are located in Taiwan and, for the Connected Cars only, also in Italy.

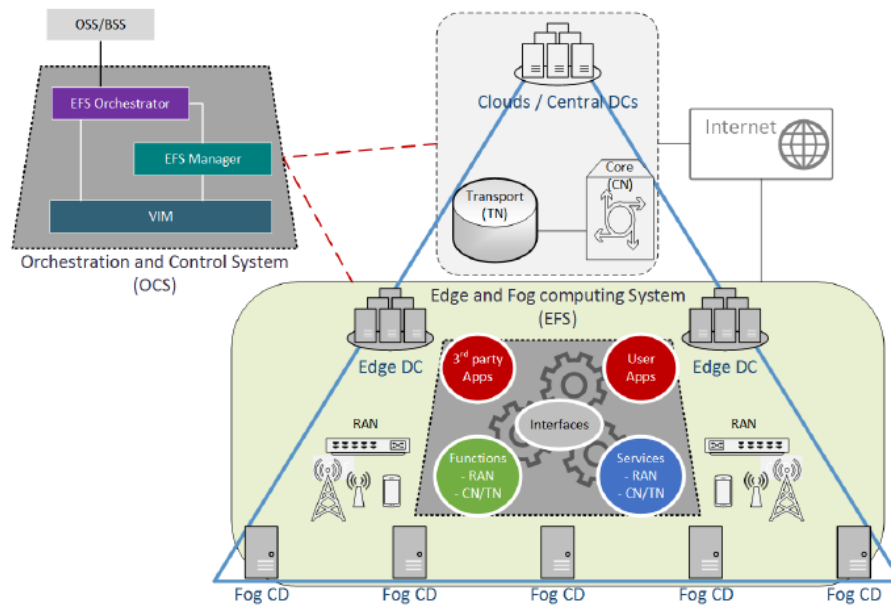


Figure 1 - 5G-CORAL concept.

The main objectives targeted by 5G-CORAL are the following:

Objective 1: Develop a system model that includes use cases, requirements, architecture and business models to design and validate the 5G-CORAL solution.

This objective aims at identifying (and prioritizing) use cases, deployment scenarios and requirements for the design and demonstration of the 5G-CORAL solution which leverages existing industrial frameworks for NFV, SDN, MEC and

Fog computing. The 5G-CORAL system framework also needs to support convergence of multiple RATs. The business perspectives of the 5G-CORAL solution will also be identified by considering all the stakeholders of the 5G-CORAL value chain, e.g. operators, vendors, service/application/Cloud providers, facility owners, end-users. Finally, step-based procedures and techniques for enabling incremental deployment of the 5G-CORAL solution into existing networks will be defined.

Objective 2: Design virtualised RAN functions, services, and applications for hosting in the 5G-CORAL Edge and Fog computing System (EFS).

The virtualization of RAN functions on the EFS is explored for multiple RATs, by developing their requirements and assessing their merits from an access convergence viewpoint. In addition, EFS services will be specified for collection, aggregation, publishing and use of radio and network context information by applications and possibly virtualised functions. EFS functions will be developed by using EFS services from multiple RATs and the transport and core networks in support of access convergence, e.g. multi-RAT convergence function to optimise the traffic delivery across the multiple RATs. Finally, EFS applications will be developed by using EFS services from multiple RATs and the transport and core networks to improve network Key Performance Indicator (KPIs) and user QoE.

A proof of concept for the EFS will also be developed in order to demonstrate EFS functions, services, and applications, with at least two coordinated RATs. Selected EFS components will also be validated through a system verification in the integration testbeds.

Objective 3: Design an Orchestration and Control system (OCS) for dynamic federation and optimised allocation of 5G-CORAL EFS resources.

Existing industrial frameworks for NFV, MEC, and Fog will be extended to best suit dynamic environments where EFS resources are volatile. In addition, federation mechanisms for EFS resources belonging to multiple owners and subject to different technical, business, and administrative requirements will be developed. Also interfaces for automated deployment of EFS functions and applications will be specified. Finally the integration of the EFS with central Clouds to enable instantiation and migration of virtual functions and applications between the EFS and central Clouds, together with the development of orchestration and control algorithms for elastic placement and migration of EFS functions and optimised allocation of EFS resources, are also other important parts of this objective.

A proof of concept for the OCS will be developed to prove and demonstrate: (1) Federation mechanisms in static and dynamic scenarios; (2) Orchestration algorithms aimed at reducing latency for EFS functions and applications; and (3) Aggregation and offloading mechanisms for the best use of multiple RATs in the EFS. Selected OCS components will also be validated through a system verification in the integration testbeds.

Objective 4: Integrate and demonstrate 5G-CORAL technologies in large-scale testbeds making use of facilities offered by Taiwan, and measure their Key Performance Indicators (KPIs).

Existing testbeds in Taiwan will be customized in order to meet the needs of the 5G-CORAL proof-of-concept in large-scale deployments. This requires integration and validation of both EFS and OCS in large-scale testbeds (i.e. Shopping Mall, High-Speed Train, and Connected Cars). Multi-RAT access convergence as well as low latency applications (e.g. augmented reality and car safety) will be demonstrated in real-world scenarios involving real users. The performance of the 5G-CORAL solution will be evaluated on-field via measurement of relevant KPIs on data rates and latency in low and high mobility environments.

Objective 5: Disseminate and contribute 5G-CORAL results into international research and innovation venues to pave the way for their successful exploitation.

This objective relates to the communication and dissemination of the 5G-CORAL technical findings: the specification of a proactive standardisation plan (including roadmaps, intellectual property creation, and contribution to relevant standards) as well as an exploitation plan of the 5G-CORAL results into value creation for all stakeholders during the project lifetime and beyond are parts of this objective.

2 Italian contribution to the project

Two Italian partners contributed to the Project: Telecom Italia (TI) and Azcom Technology (Azcom).

TI had the role of Work Package 1 leader (and also task T1.1 leader) and was focused on driving the use cases' definition aligned with the envisioned network evolution and business perspectives from a European operator's point of view. TI also collaborated with Azcom for the definition, setup and integration of the Connected Cars testbed as well as to the experimentation and evaluation of the car safety communication proof of concept. Initial experimental activities related to the safety use case, in fact, have been conducted in TI premises in Torino (TILab). Finally TI also contributed to disseminate the Project findings in public events such as the IEEE 5G Summit held in Trento (Italy) in March 2018.

Azcom actively participated in WP1 for the definition of use cases, requirements, and business perspectives related to the 5G-CORAL car communications. Furthermore, Azcom contributed to the specification of the EFS by focusing on the Connected Cars' functions and applications. In the context of the experimental activities, Azcom lead task T4.1 and defined the Connected Cars testbed and trialled the related use cases, such as the delivery of safety-related messages leveraging the low-latency of 5G-CORAL solution. Finally, Azcom also contributed to dissemination activities addressing the area of the vehicular communications.

5G-MiEdge

Mauro Renato Boldi and the Project Partners

1 Description and objectives of the project

Current research efforts on 5G Radio Access Networks (RAN) strongly focus on millimeter-wave (mmWave) access for addressing a critical weakness of deployed cellular systems, i.e. the capacity to realize enhanced mobile broadband (eMBB) services, as discussed at the World Radio-communication Conference 2015 (WRC-2015). Recently, mmWave technologies have reached a significant degree of maturity and their state-of-the-art products, operated in the 60GHz unlicensed band, are already in the market. However, there are many unsolved issues for an effective deployment of mmWave 5G RAN. The most critical issue is the impossibility of providing 10 Gigabit Ethernet backhaul everywhere. Meanwhile, Network Function Virtualization (NFV) and Mobile Edge Computing (MEC) have obtained much attention in 5G networks. Especially MEC is considered as a key technology to enable mission-critical (low latency) applications by allocating storage and computation resources at the edge of the network, so to circumvent the backhaul networks' limited capacity. However, in the case of mobile networks, it is not easy to reallocate computational resources on demand, while meeting the strict latency constraints foreseen in 5G networks. In this project, mmWave access and MEC are firstly combined as a perfect couple of technologies compensating each other's weaknesses, and the resulting new system is called mmWave edge cloud (MiEdge) henceforth. To facilitate MiEdge, the second main goal of this project is to develop a new cellular network control plane in which context

Mauro Renato Boldi
TIM

information (location, traffic, classes of applications, etc.) of users are collected and processed to forecast traffic and users' requests, in order to enable a proactive resource allocation. This novel control plane is called liquid RAN C-plane, since the services and connections can follow and adapt to users' need like a liquid to the form of its container. Lastly, the users or application providers orchestrate MiEdge to create a user/application centric 5G network that supports both eMBB and mission-critical applications. In summary, the 5G MiEdge project develops a feasible 5G ecosystem by combining MiEdge, liquid RAN C-plane, and user/application centric orchestration. The project contributes to the standardization of mmWave access and liquid RAN C-plane in both 3GPP and IEEE. At end, the project demonstrates a joint 5G test-bed in the cities of Berlin and 2020 Tokyo Olympic Stadium.

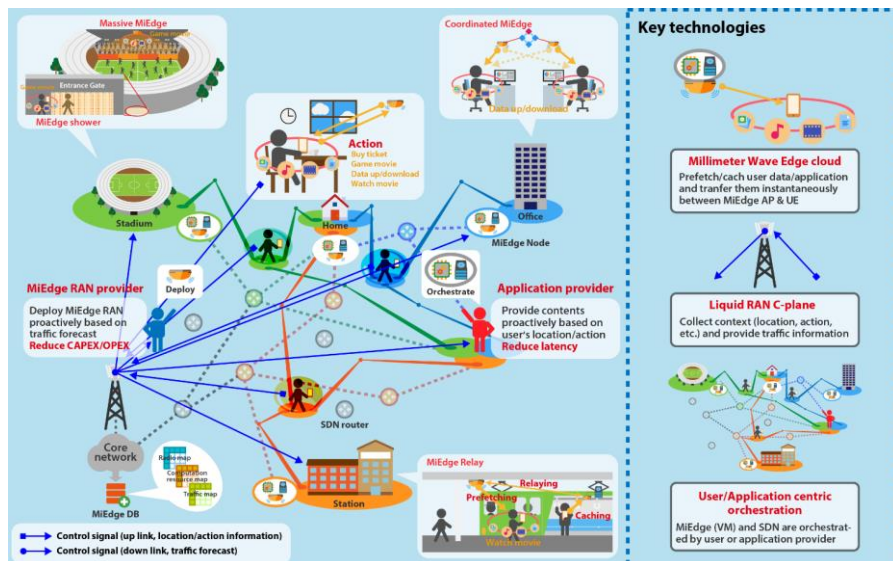


Figure 1-1: 5G MiEdge concept, use cases (left side) and key technologies (right side).

Objective 1: Research, develop, and prove the 5G based MiEdge concept

The project has the objective to research, develop and prove the 5G based MiEdge concept whose viability is evaluated by detailed theoretical and numerical analysis and prototyped for proof-of-concept.

Objective 2: Develop transmission schemes and protocols of mmWave access/backhauling

The project develops transmission schemes and protocols of mmWave access/backhauling aimed to assist the mobile edge cloud with caching/prefetching so as to realize ultra-high speed and low latency service delivery, resilient to network bottlenecks, such as e.g. backhaul congestion, users' density, mission-critical service deployment, assuming three target scenarios: stadium, office, and train/station.

Objective 3: Develop novel ultra-lean and inter-operable control signaling over 3GPP LTE

The project develops novel ultra-lean and inter-operable control signaling over 3GPP LTE to provide liquid ubiquitous coverage in 5G networks based on acquisition of context information and forecasting of traffic requirements, in order to enable a proactive orchestration of communication/computation resources of the mmWave edge cloud.

Objective 4: Develop user/application centric orchestration algorithms and protocols to adapt radio and computation resources of mmWave edge cloud in 5G networks

The project develops user/application centric orchestration algorithms and protocols to adapt radio and computation resources of mmWave edge cloud in 5G networks by utilizing traffic forecast provided by liquid RAN C-plane to enable self-organized and proactive reservation of the resources and satisfy low-latency service requirements.

Objective 5: Develop a joint 5G test-bed integrating mmWave edge cloud, liquid RAN C-plane, and user/application centric orchestration

The project develops a joint 5G test-bed integrating mmWave edge cloud, liquid RAN C-plane, and user/application centric orchestration to foster an effective impact of 5G MiEdge in both Europe and Japan, particularly in preparation of 2020 Tokyo Olympic Games. The 5G MiEdge test-bed will liaise actively with the other EU/JP consortium focusing on the network side as well as to leverage synergies between alternative 5G concepts.

Objective 6: Contribute to the definition of 5G mobile communications standards in 3GPP and IEEE

The project contributes to the definition of 5G mobile communications standards in 3GPP and IEEE as well as in open fora such as NGMN, Small Cell Forum, and the International Telecommunication Union (ITU) Industry Specification Group MEC, in terms of mmWave access, liquid RAN C-plane, and protocols for user/application centric orchestration by coordination across European and Japanese partners.

2 Italian contribution to the project

TIM, together with the University of Rome “La Sapienza” are the two Italian partners in the 5G_MiEdge project consortium. Both TIM and University of Rome “La Sapienza” are involved in the definition of use cases and reference scenarios for the project activities. Concerning the research areas the University of Rome “La Sapienza” is mainly involved in theoretical/simulative analysis concerning dynamic resource allocation as well as more MEC focused investigations like procedures for joint optimization of radio computations resources under latency constraints. The acquired knowledge is disseminated to industry and society through major international peer-reviewed conferences, workshops and journals and the latest topics research results can be introduced in the education courses of students at the university. At the same time, PhD and master students whose research topics are related to 5G-MiEdge are involved in the project.

TIM, as industrial partner, has addressed its investigations toward more experimental activities in order to exploit the advanced 5G testing infrastructures available in its Labs. TIM owns an Antenna lab designed for mmWave antenna testing. The lab is based on a Compact Antenna Test Range (CATR) installed in a shielded anechoic chamber designed to cover frequency range from 3 GHz to 110 GHz. Within 5G-MiEdge

TIM tests some of the mmWave antenna prototypes designed and developed by the partners.

The project results on an extremely innovative subject like the synergic usage of both mmWave access and MEC are very important to better understand how to design and operate a network in the mmWave band able to provide eMBB services with a very low latency constraint like, e.g., immersive reality applications.

5G Picture

Mauro Renato Boldi and the Project Partners

1 Description and objectives of the project

5G-PICTURE proposes a paradigm shift, from the traditional RAN and recent C-RAN to the “Dis-Aggregated RAN” (DA-RAN) approach. DA-RAN is a novel concept adopting the notion of “disaggregation” of HW and SW components across the wireless, optical and compute/storage domains. “Resource disaggregation” allows decoupling of HW and SW components creating a common “pool of resources” that can be independently selected and allocated on demand. These HW and SW components form the basic set of building blocks that, in principle, can be independently combined to compose any infrastructure service. Apart from increased flexibility, disaggregation, due to its modular approach, offers enhanced scalability, upgradability and sustainability potential that are particularly relevant to 5G environments supporting enormous and continuously growing number of end-devices and services. To exploit the concept of disaggregation in RAN environments, novel 5G technology solutions are needed to increase the density and power efficiency of the “pool of resources”, supporting at the same time high bandwidth connectivity between them. These will rely on

- hardware programmability: allowing HW repurposing to enable dynamic on demand sharing of resources and

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TIM

- network softwarisation: enabling migration from the traditional closed networking model, focusing on network entities, to an open reference platform instantiating a variety of network functions.

Such novel networking approaches can facilitate increased functionality and flexibility infrastructures, offering simplified management and advanced capabilities including slicing and virtualisation that allow the

disaggregated resource pool to be shared and accessed remotely. On-demand selection and allocation of these resources (flexible mix-and-match) will enable provisioning of any service without the prerequisite of owning and installing any specific HW or SW, adopting novel approaches such as the notion of service chaining (SC).

Network slicing and service chaining will be facilitated adopting architectural models such as the SDN reference architecture and the ETSI NFV standard.

Objective 1: Design and prototype an open 5G infrastructure capable of instantiating and co-hosting different vertical sectors. This will be based on leading industry and open source technologies supporting very diverse service requirements.

The 5G-PICTURE SW/HW disaggregated network approach is key for the creation of a 5G infrastructure able to support a large variety of 5G ICT and "vertical" services. According to the proposed solution, vertical service providers, currently relying on closed and proprietary infrastructures, is able to deploy any service without having to own and install any HW or SW component. The 5GPICTURE solution allows end-users and third parties to access real or virtual equipment, services, systems and tools on demand regardless of their geographical location. This solution is expected to support any type of service ranging from delay sensitive video, to infotainment services, and from best effort applications to ultrareliable ones such as M2M communications. This will enable transformation of vertical sectors from closed inflexible environments into a pool of modular HW and SW components that can be combined on demand.

Objective 2: enable a common, flexible and open underlying network infrastructure that can unleash market innovation and support wide adoption and new business models and opportunities to a wider ecosystem (ICT and verticals) 5G-PICTURE will adopt and develop HW technology innovations.

5G-PICTURE designs, develops and prototypes advanced and highly configurable optical/radio infrastructure technologies and interfaces at the data plane, integrated in a single transport solution supporting both 5G ICT and vertical operational and end-user services. In addition, 5G-PICTURE will develop advanced solutions for programmability of data plane functionalities offering HW acceleration for high performance and low latency processing, HW programmable network interfaces, and platform independent programming abstractions. FH and BH processing, together with the relevant exposed interfaces and programming models, including abstractions of existing HW, will be also supported. The upper layers will be provided with a stack of open SW and Application Programming Interfaces (APIs) coupled with the necessary metadata definition. These will enable the abstraction and exploitation of the underlying HW platform taking into account specific requirements for closed platforms.

Objective 3: the integration of the SDN and NFV approaches and adopting the concept of network functions that are functional building blocks with well-defined external interfaces and behaviour.

The implementation of 5G RAN functional splits is determined by the underlying platforms.

Given the heterogeneous compute and network infrastructure envisioned in future 5G networks, 5GPICTURE investigates and experimentally demonstrate optimal 5G functional splits for different types of infrastructure (compute and network). It will also demonstrate the concept of flexible RAN functional splits that are “adaptive” RAN implementations requiring platforms able to instantiate more than one functional split. Flexible RAN functional splits are an enabler for slicing.

Furthermore, realizing that nowadays synchronisation protocols are based on packet round trip time measurements that are subject to congestion, especially in the wireless BH, 5G-PICTURE investigates novel approaches, including the PHY layer, to deliver high accuracy synchronisation to heterogeneous wireless/optical/packet domains.

Objective 4: provide an operating system able to simplify the infrastructure management and the provisioning of a large variety of services that are complex constructs of a diverse set of functions, supported by the heterogeneous physical infrastructure and technologies.

The core value proposition of 5G-PICTURE is “HW programmability”: HW can be configured to execute given functions exceeding the speed of SW running on

commodity hardware blurring the boundary between SDN (configurable packet handling) and NFV (deploy functions into the network). 5GPICTURE extends the concepts of SDN control and NFV orchestration and merge or, at least, tightly integrate them. In addition, the role of a “slicing system” and its integration with SDN/NFV is not obvious and has to be solved. A core contribution of this first objective will be a set of interfaces between these system components as well as advanced interfaces (e.g., one to feed predictions into the system).

Objective 5: Demonstrate converged FH and BH services in: a smart city environment, the first 5G railway experimental testbed showcasing seamless service provisioning and high speed mobility management, and a stadium supporting media services for ultra-high density users

The 5G-PICTURE solution enables the overall 5G vision, supporting any service, including operational and end-user services for both ICT and “vertical” industries. Proof of concept demonstrators will be showcased in realistic environments including:

- (a) 5G-railway testbed located in Barcelona, Spain comprising three tracks covering scenarios with the rolling stock. This will be the first 5G railway experimental testbed to showcase support of seamless service provisioning and mobility management in high speed moving environments,
- (b) 5G-stadium testbed located in Bristol, UK to address scenarios with increased density and static-to-low mobility. In this environment media services associated with large venues will be demonstrated
- (c) 5G-smart city testbed to experimentally validate the DA-RAN concept through the support of joint BH and FH services. This test-bed will be supported and hosted by the state-of-the-art 5G “City of Bristol” network infrastructure (BIO).

2 Italian contribution to the project

TIM and CNIT are the only Italian partner in 5G-PICTURE.

In the project, CNIT, involved with the University of Rome Tor Vergata research unit, leverages, and significantly extends, data plane programmability know how acquired (and technologies developed) in two previous projects: the

5G H2020 project SUPERFLUIDITY on network programmability, and the ICT-05 BEBA on stateful network processing. CNIT will bring from SUPERFLUIDITY the work done in terms of functional decomposition of flow/packet-processing tasks, including fine-grained decomposition of selected functions into very elementary events/actions. From this decomposition a preliminary processor architecture for packet manipulation has been identified. From the BEBA project CNIT will leverage the stateful forwarding switch architectures including a first small-scale OpenState-FPGA prototype (Mealy Machine execution on FPGA), its corresponding software open-source implementation in OFsoftswitch13 with the relevant Ryu controller extensions.

Within the project, TIM works on the definition of vertical systems and consequent requirements and the architecture of integrated fronthauling and back-hauling network. Also some details within the control umbrella will be touched. Due to experience in managing EU projects and technical skills, Telecom Italia has been appointed for the management and coordination of a workpackage devoted to the definition of the global architecture.

Fantastic-5G

Mauro Renato Boldi and the Project Partners

1 Description and objectives of the project

FANTASTIC-5G (Flexible Air iNterfAce for Scalable service delivery wiThin wIreless Communication networks of the 5th Generation) targets to design a single modular Air Interface (AI) allowing the concurrent support of this wide range of use cases. This is deemed as essential because future communication systems are not only to deliver Mobile BroadBand (MBB) services but also to support Massive Machine Communications (MMC) and Mission Critical Communications (MCC) efficiently, therefore it is expected operators to be able to capitalize on new revenue streams. Similarly, supporting Broad- and Multicasting Services (BMS) in 5G will help widen the market and potentially free parts of the spectrum. Finally, Vehicle-to-Vehicle and Vehicle-to-Infrastructure communications (V2X) will also play a crucial role in future mobile networks, to more efficiently support mobile services while on the move and to enable new use cases such as traffic safety.

These above-mentioned five services, i.e. MBB, MMC, MCC, BMS and V2X – also labelled by FANTASTIC-5G as “core services” in the 5G ecosystem – are each linked to different sets of Key Performance Indicators (KPIs) to be optimized, in terms of which the service requirements are defined. A simple and straightforward solution to provide each service type is the design of a dedicated, service-specific AI, which however represents an uncompetitive and unprofitable

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approach when compared to the design of a single AI being able to be parameterized in different ways to concurrently accommodate all use cases on a per-need basis. According to this FANTASTIC-5G targets a single modular AI concurrently supporting a wide range of use cases: this cannot be achieved by following a “one-fits-all” approach but, instead, by designing the AI in such a way that different parts of the AI and related functionalities can be properly parameterized in order to satisfy the needs of the respective service being targeted.

FANTASTIC-5G is set out to design the 5G AI and proposes inputs for standardization, whose timeframe is expected to start during the project lifetime. Five trends which are pushing the limits of 4G have been identified, pointing towards a need for the 5th generation cellular technology:

- *Trend 1 – Increase in capacity:* the demand for wireless data is predicted to increase significantly, resulting in 1000x higher mobile data volumes and 10-100x higher end-user data rates
- *Trend 2 – Increase in the number of connected devices:* the number of connected devices is predicted to increase by a factor of 10-100, which means that up to 300.000 devices need to be served per access point
- *Trend 3 – Increase in reliability:* wireless connectivity will be applied to new use cases that require extremely reliable connections (typically 99.999% availability) and mission-critical communications, such as Vehicle-to-Vehicle coordination, critical control of the power grid, etc
- *Trend 4 – Decrease in latency:* remote presence and tactile Internet that impose stringent latency constraints on the end-to-end connection, including the wireless part. Forecasts indicate that the latency should be decreased by a factor of 5 in order to enable such services
- *Trend 5 – Increase in efficiency:* efficiency in terms of resource utilization (e.g. energy, spectrum) is becoming more and more pronounced. It is seen as an indispensable ingredient for a healthy/sustainable ICT market/business and environment.

FANTASTIC-5G sets out a vision on a new 5G AI below 6GHz with the following Key Characteristics:

- *flexibility* to support a broad class of services with their associated (broad class) of KPIs
- *scalability* to support a high number of devices being connected
- *versatility* to support the diverse device types and traffic/transmission characteristics

- *efficiency* to support the requirements on energy consumption and resource utilisation
- *future-proofness* to support easy integration of new features.

In order to make this vision a reality, FANTASTIC-5G is committed to conduct work towards the achievement of the following high-level measurable objectives:

- *Objective 1*: to develop a highly flexible, versatile and scalable AI to enable the in-band coexistence of highly differing services, device types and traffic/transmission characteristics
- *Objective 2*: to design an AI enabling ubiquitous coverage and high capacity where and when required
- *Objective 3*: to develop an AI being highly efficient in terms of energy and resource consumption
- *Objective 4*: to render 5G more future-proof than former generations through easier introduction of new features
- *Objective 5*: to evaluate and validate the developed concepts by means of system level simulations and hardware proof of concepts for selected components
- *Objective 6*: to build up consensus on reasonable options for 5G standardization among the major industrial partners of the project that are also voting members in 3GPP (Alcatel Lucent, Orange, Huawei, Nokia, Intel, Samsung Electronics, Telecom Italia) and to push the innovations of the project for standardization (through study items).

Figure 1 depicts how the first four (technical) objectives of FANTASTIC-5G are linked to its vision and to the trends presented above. Note that in this figure there is not a one-to-one correspondence between the trends, the key characteristics and the objectives, e.g. *Objective 1* is not an outcome of only the *Key Characteristic 1* (Flexibility), which itself is not an outcome of only *Trend 1*. All objectives are derived from the combinations of the Key Characteristics, which are the outcomes of the ensemble of the Trends.

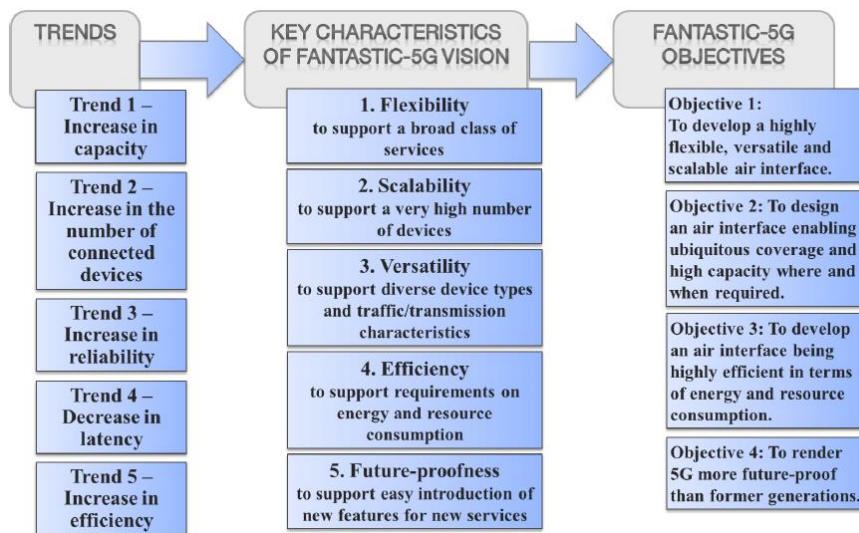


Figure 1: From trends to the FANTASTIC-5G objectives.

Essentially the FANTASTIC-5G research project is targeting at pre-standardization development of a new 5G AI to influence future 3GPP 5G standardization. By fulfilling the project objectives represents an interesting set of research challenges on how to most efficiently adapt the design of AI components (e.g. waveform, frame structure, channel coding, modulation, etc.) and related physical layer procedures (e.g. support of MIMO, HARQ retransmissions, channel estimation, synchronization, etc.) to the requirements of the multiple sources of heterogeneity. The FANTASTIC-5G hypothesis is that this is possible through re-configuration of flexible solutions for the AI components and related procedures.

2 Italian contribution to the project

Two important Italian partners contributed to the project: Telecom Italia (TI) and the research group belonging to the Telematics Lab - Politecnico di Bari (POLIBA).

TI, being a key player in the mobile industry, was essential for the objective of building up consensus on reasonable options for 5G standardization. As an operator, TI was crucial for the selection of relevant scenarios, the identification of requirements to be taken into account by the AI design and for the overall AI design itself. Telecom Italia was involved in Work Package 2 (WP2), where it was leading the task responsible for requirements definition in the Project (T2.1–KPIs, requirements, and air interface framework). In addition, within WP2, TI also contributed to Task 2.2 (System Design) and Task 2.3 (System Evaluation, in conjunction with POLIBA). TI also had an effort in both WP6 tasks for Project's dissemination and exploitation.

TI used the results from FANTASTIC-5G as an input to the Group Technology Plan, an internal document that lists the available technologies and that is the basis to develop the Investment Plan together with the Strategy Plan. Moreover, the project has been exploited by TI for influencing the industry with requirements, mainly focusing on:

- enhancing service quality for mobile broadband (in particular by increasing UE throughput in hotspots, such as stadiums, where large concentrations of people for short periods of time are expected), directly impacting customer satisfaction, revenues and customer retention
- improving energy efficiency and general sustainability indicators
- exploiting Internet-of-Things (IoT) and, more in general, Machine-to-Machine communications as well.

All the above-mentioned areas of activity have a direct impact on future investments and network operating costs. The standardization activity within the project has also been exploited by TI by ensuring that standards do take into account the requirements of TI itself, in particular related to user throughput and to ensure a proper Quality of Experience to the customer. The overall activity within the Project also represented an opportunity to show to the investor community the sensitivity of TI towards innovation and forerunner research. TI disseminated the Project's results via publication of articles in the TI magazines distributed within the Group and available for experts in Telecommunication field but also by organizing workshops with national and international scope (including South America subsidiaries).

The research group belonging to the Telematics Lab - POLIBA has a long tradition of research on Quality-of-Service/Quality-of-Experience (QoS/QoE) management in wireless systems, congestion control, wireless sensor network,

IoT, industrial protocol stacks, information centric networking, smart city and smart grid, eco-sustainable heterogeneous networks, and system-level simulators in wireless and cellular networks. In addition, it founded (and it is maintaining) the open source project LTE-Sim, which is an open source network simulator tool able to model a very large number of aspects belonging to both LTE and LTE-A specifications. The network simulator tool was of high relevance for the Project: promising technical component conceived in the context of the FANTASTIC-5G project, in fact, have been implemented into the simulator for assessing system-level gains.

Specifically, POLIBA was involved in WP2, contributing to both tasks T2.2 (System Design) and T2.3 (System Evaluation). In this context, POLIBA developed a flexible simulation tool being able to support the system-level evaluation of WP2 technical findings. The LTE-Sim simulator was properly extended to integrate 5G environmental models (scenarios and services), abstraction of PHY and MAC layers, and tools for the evaluation of KPIs. Moreover, to ensure right and repeatable results, an accurate calibration of both channel and network models, that were available within the simulator, was carefully executed.

Moreover, POLIBA was involved in dissemination and exploitation activities envisaged for the WP6. Besides disseminating research findings in conferences with recognized international level and journals with high impact factor in the field of communication networks, POLIBA included activities related to the FANTASTIC-5G project within Masters and Doctoral courses, also promoting the diffusion of the simulation platform in both academia and industry environments being interested in 5G technologies (distributing it as an open source tool). In this manner, several aspects of the project have been disseminated in a very broad fashion.

METRO HAUL

Mauro Renato Boldi and the Project Partners

1 Description and objectives of the project

METRO-HAUL involves the design and development of a novel, spectrally efficient and adaptive network solution, using dynamic elastic optical networking, including both transparent and flexible optical switching and adaptive transmission. METRO-HAUL will address the granularity mismatch between the wireless access and the optical metro domain via a new edge node design (Figure 1), and achieved through dynamic optical bandwidth allocation. This will provide metro support for increased volume of services with reduced cost and energy consumption.

To support the required dynamicity and flexibility, the METRO-HAUL architecture will be developed to integrate a wide range of optical technologies. These will be controlled using automation schemes and programmability features that will enable concepts such as HW disaggregation and virtualization, the coordination of which will be supported by a purposely designed control plane. Optical nodes will be dynamically adapted to the needs of specific services, optimally exploiting the data plane through use of relevant data monitoring and analysis schemes.

The control plane will be also responsible for the provisioning of 5G and vertical industry services that require the allocation of heterogeneous compute, storage and networking resources and ensure the required end-to-end QoS and QoE

Mauro Renato Boldi
TIM

levels for each application. The METRO-HAUL control plane will leverage on the well-established SDN and NFV paradigms and exploit the benefits of a unified system, coordinating networking, computing, storage, transmission, and switching aspects, enabling abstraction at different levels.

Through the combination of improved, elastic-based optical techniques and intelligent, dynamic management of 5G applications, METRO-HAUL will support more than 100 times the capacity of current metro networks.

METRO-HAUL will perform PoC demonstrations to illustrate its network solution, metro node prototypes, novel optical transmission technologies and associated control plane / orchestration software. Detailed performance evaluation of both data and control planes will be carried out. The final project demonstrations will also involve the demonstration of real 5G and vertical services across the METRO-HAUL test-bed. Finally, the project will actively participate in the relevant standardization bodies to promote METRO-HAUL solutions to the wider community.

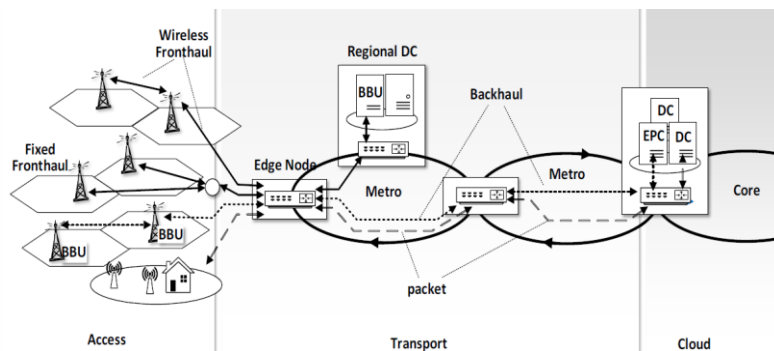


Figure 1: Metro Network Supporting RANs, with distributed DC and virtualized / pooled BBUs and EPC

Objective 1: To architect and design cost-effective, energy-efficient, agile and programmable metro networks that are scalable for 5G access and future requirements, encompassing the design of all-optical metro nodes (including full compute and storage capabilities), which interface effectively with both 5G access and multi-Tbit/s elastic core networks.

The main objective is to improve metropolitan networks by defining an architecture that supports 5G access requirements, notably in terms of low latency, mobility, increased bandwidth and also dynamic storage and compute functions,

implying highly energy efficient operation. Given the scale of targeted deployments, metro networks must be cost-effective, including both CAPEX and OPEX. This involves new node and transmission technologies, but also introduces commoditization of multi-vendor hardware leading to new business models

Objective 2: Establish the most cost and energy-efficient, high bandwidth, flexible optical metro transport technologies to support continued exponential consumer and business data demands together with the backhaul (or 'METRO-HAUL') of 5G traffic.

METRO-HAUL will explore a wide range of transport options that provide flexible and cost effective high bandwidth, ranging from fully filterless to optical filter based solutions

Objective 3: To explore and identify pros/cons of different multi-technology, multi-vendor or disaggregated "whiteboxes" ecosystems for metro nodes and optical metro-wide networks, and the impact on Operators' O&M processes and System Vendors' business models.

The metro network's reduced geographical range relaxes the optical performance parameters, making it easier to integrate components from multiple vendors. O3 will find the aspects of METRO-HAUL that can be disaggregated, utilizing whitebox components without compromising overall network performance, but radically reducing cost. Several possible scenarios will be examined from both the Operators' and system Vendors' points of view.

Objective 4: To design, implement and evaluate prototype Optical Infrastructure Elements (OIE) to enable METRO-HAUL concept demonstrations..

The project will explore a range of optical components, including ROADMs and other low-cost optical switching technologies, flexible transceivers and digital switches. O4 will explore how to obtain high-capacity and flexibility in the economically challenged metro environment.

Objective 5: To design and implement an SDN/NFV control framework and architecture for heterogeneous metro-haul networks supporting 5G operational and both end-user and vertical oriented services, including slicing

The objective targets the design and implementation of an augmented SDN/NFV control framework and architecture specially adapted for METRO-HAUL and enabling the dynamic deployment of 5G services (i.e. the operation of both end-user

and corporate-oriented services). These services have requirements for resources (processing, storage and networking) that change over time considering aspects of the service life-cycle and variations in usage; the architecture will inherently support multi-tenancy, network virtualization, and slicing

Objective 6: To build integrated prototype metro network demonstrators to show the improvements to the performance of vertical 5G applications

The project intends to bring together the multiple innovations in the form of demonstrators – integrated Proof of Concepts designed to show key data plane and control plane features and also designed to show how METRO-HAUL supports 5G Vertical applications

Objective 7: To design algorithms to improve efficient resource usage for the overall METRO-HAUL solution

This objective targets the design and validation of algorithms to analyse and control different network aspects, focusing on optimization of the wide range of heterogeneous (network and IT) resources. Algorithms will cover computation across the infrastructure, for the supported services, including dynamic metro resource activation, spectrum management, data analytics for Knowledge Discovery from Data (KDD), network re-optimization and function placement.

2 Italian contribution to the project

Several partners are involved in Metro-Haul: TIM, CNIT, Coritel, Ericsson and Nokia (former Alcatel Lucent) .

As an incumbent carrier TIM contributes with the definition of service requirements including KPI and SLA, techno-economic feasibility studies and potential migration roadmap identification. Furthermore, it will contribute to the definition of Metro Node architecture to virtualize at once services and network functionalities; to the separation of control and management planes from data planes; and to the disaggregation of complex optical network elements in elementary bricks to arrange as needed in a multivendor environment; to the development of agents for optical white box control and management; and to the definition of final demonstrators of project proposed solutions.

TIM feeds the Standardization bodies with Metro Haul outcomes.

CNIT contributes to METRO-HAUL through two distinct aspects. The first aspect concerns the data plane, with particular focuses on: i) investigating solutions for disaggregation of optical functions in a multi-vendor environment (optical white boxes), including both filtered and filterless scenarios, ii) the use of photonic integrated components (e.g. mini-ROADMs) as switching elements in optical white boxes, iii) flexible and programmable transceivers for high capacity metro segment, providing advanced software-defined features and addressing both coherent and direct detection.

CNIT also intensely works on the control plane for the METRO-HAUL architecture. In particular, it will contribute to: i) the study, design and implementation of a Common Optical Node Control (CONC) SW for optical white boxes as well as interfaces towards monitoring systems for optical resources and transmission QoT, ii) the definition of functional requirements for control and programmability of the underlying metro-haul infrastructure, also focusing on monitoring and recovery aspects, iii) the definition of data models of the elements and devices and the control of photonic-integrated components and node solutions for enhanced filterless/semi-filterless scenarios, iv) to Service Function Chaining (SFC), including algorithmic aspects for function placement and network virtualization.

Ericsson Telecomunicazioni contributes to the project analysing the Metro Access network segment and its evolution influenced by the evolving Fronthaul and Backhaul networks for 5G Wireless Radio Mobile and Wireline access, by defining the flexible deployment and the reconfiguration of network elements and networking functions. The metro network segment may evolve to operate as the functional backhaul for 5G network: Metrohaul. The network connectivity will be designed with a unified network model, supporting different underlying data planes and protocol schemes in order to better serve/recognize the end user applications/demands. Analysis is performed on the sustainability of a possible data-com-telecom convergence solution in metro-access network enabling 5G: Work is done on the design of an updated metro-access network with the lowest possible impact in terms of cost, power dissipation and system complexity, enabling software driven dataplane, network function virtualization, network automation and improving technical performance. Interoperability issue based on white box context will be addressed for instance by ensuring high quality of service and reliable fault management. Contribution is given in the definition and demonstration of

relevant use cases supported by datacom-telecom converged network in 5G scenario.

CoRiTel is involved in the design and evaluation of the proposed architecture and it works on the control plane requirements, in the identification of data models and the implementation of algorithms for traffic-based resource activation, and on VNF placement algorithms. CoRiTel is also involved in WP1 in project organization and management, and in WP6 will contribute in dissemination aspects, mostly related to scientific publication.

Finally, Nokia Italy contributes to METRO-HAUL with its expertise on software architecture to design and provide a new SDN app for the management of optical defragmentation in a multilayer network.

5G XCAST

Mauro Renato Boldi and the Project Partners

1 Description and objectives of the project

5G-Xcast devises, assesses and demonstrates large scale immersive media delivery by means of conceptually novel wireless technologies, contributing to the further definition of 5G and its standardisation. 5G-Xcast is focussing on large scale media distribution, as this use case is one of the most demanding requirements in terms of data rate (capacity), scalability (cost-effectiveness) and ubiquity (coverage). The 5G-Xcast media delivery solution will have built-in unicast/multicast/broadcast modes and caching capabilities, holistically approaching media delivery harmonisation across the three communication modes with seamless user experience, as well as common Application Programming Interfaces (APIs) to content service providers. The project covers multiple disciplines from the radio interface to the transport and application layers, including protocols and APIs, as well as network and system architecture aspects. The development of the 5G-Xcast media delivery solution is focused on the Media and Entertainment (M&E) vertical. The automotive, Internet of Things and public safety verticals will be considered to ensure that their respective technical requirements are also identified and suitably addressed. Proof-of-concept prototypes and technology demonstrators are pivotal tasks of the project. Special emphasis is being given to emerging new immersive media services that cannot be efficiently delivered by existing technologies and networks. 5G-Xcast will enable progressive convergence in the media delivery sector while optimising the resources of the available infrastructures, enabling new business models over fixed, mobile and broadcast networks that will be also investigated in the project. The consortium is a balanced combination of telecom and media entities, covering the complete M&E value chain,

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with a very strong presence in 5G-PPP phase-1 and 3GPP standardization of 4G Broadcast.

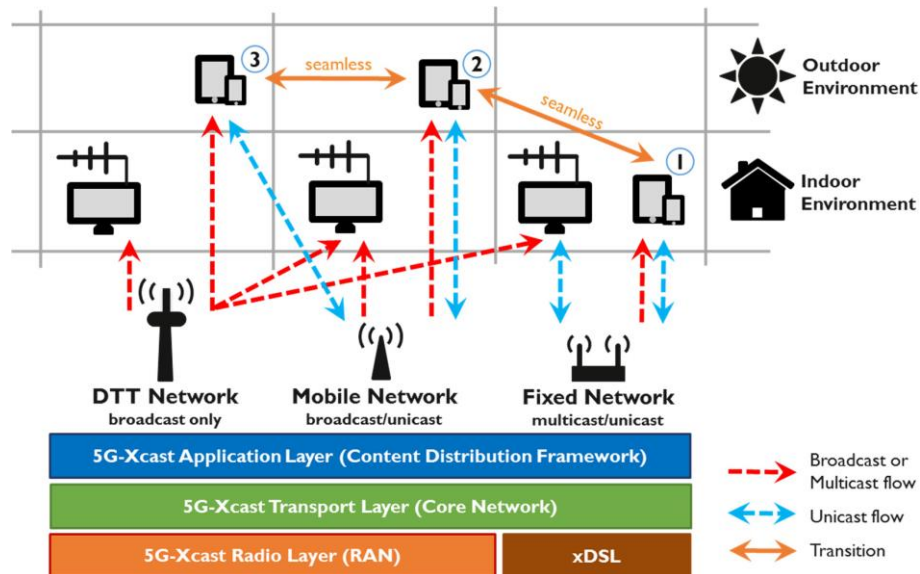


Figure 1-1: An example of one user moving between three different environments (identified by the labels 1,2 and 3) each of which has different combinations of networks available. The converged media delivery architecture of 5G-Xcast over fixed broadband, mobile broadband and terrestrial broadcast networks allows a seamless, uninterrupted service to be offered to the users as they move.

Objective 1: To develop broadcast and multicast point to multipoint (PTM) capabilities for 5G and evaluate 5G spectrum allocation options for PTM network deployment

Broadcast is considered as an integral part of the 5G system from the beginning. Multicast and broadcast appear as part of the 5G vision of many stakeholders, including the 5G-PPP (see e.g. its vision, M&E whitepaper, and 5G vertical sectors whitepapers). 3GPP has also identified broadcast transmissions as a critical technical requirement for eight 5G use cases including, connected vehicles, in-network and device caching, and broadcast/multicast services using a dedicated radio carrier. The broadcast/multicast use case was also identified by the Next-Generation Mobile Network (NGMN) alliance in, where the possibility that 5G

could complement or even act as a substitute for the legacy radio/TV broadcast networks was considered. However, this topic has received very little attention by the 5G research community during phase-1 of 5G-PPP. Furthermore, 3GPP decided to prioritize the work in other areas for Release (Rel)'15 and hence 5G broadcast would only be addressed starting from Rel'16. This creates an opportunity for 5G-Xcast to develop novel solutions and contribute to the standardisation work in time for Rel'16 whose stage III will be frozen in Dec. 2019 allowing for a maximum impact by the project.

5G-Xcast will provide '**5G Broadcast**', an innovative evolution of MBMS (Multimedia Broadcast Multicast Services). Both 3GPP RAN (Radio Access Network) and SA (Service and System Aspects) aspects will be covered. 5G-Xcast will operate a paradigm shift from 3G and 4G LTE (Long Term Evolution) networks, where the broadcast transmissions have been built as an add-on service. The 5G-Xcast design will integrate 5G Broadcast as a built-in feature for delivery optimisation. The proposed 5G broadcast air interface will outperform existing wireless multicast/broadcast technologies in terms of spectral efficiency, throughput, power consumption, latency and interactivity, enhancing the 5G Key Performance Indicators (KPIs) relevant and applicable to the specific 5G-Xcast use cases and scenarios, as described, for example, in Rec. ITU-R M.2083. 5G-Xcast will also evaluate conceivable spectrum options with regards to their suitability for 5G Broadcast².

The project aims at making results available to e.g., CEPT (European Conference of Postal and Telecommunications Administrations), RSPG (Radio Spectrum Policy Group), and ITU (International Telecommunication Union) either directly or through 5G-PPP and initiatives contributing to international technical work also contributing to the ITU-R IMT-2020 evaluation process.

Objective 2: To design a dynamically adaptable 5G network architecture with layer-independent network interfaces capable of dynamically and seamlessly switching between unicast, multicast and broadcast modes or use them in parallel and exploiting built-in caching capabilities

Future 5G networks must support many very different use cases within one common technical framework. Clearly structured and transparent interfaces between content service providers and network operators, as well as between different network layers (**radio, transport and application layers**) are crucial to fulfil the required tasks. The 5G-Xcast project will introduce and develop the concepts of **radio network-related elements (Radio Access Network, RAN), network-**

aware elements (core network) and network-agnostic elements (content distribution framework). This will enable progressive convergence of media delivery system allowing soft switchover between technologies and infrastructure whilst also enabling optimised resource utilisation of all available infrastructures. 5G-Xcast will enable the **full integration of unicast, multicast and broadcast modes under one common framework**. Dynamical seamless switching between different modes of operations, as well as their parallel usage, are essential to exploit network and spectrum resources in an efficient and economic manner. In combination with **advanced caching technologies**, this approach will open a door to completely new levels of network management and **delivery cost-efficiency**. 5G-Xcast will provide the necessary mechanisms.

Objective 3: To experimentally demonstrate the 5G key innovations developed in the project for the M&E and PWS verticals

The 5G-Xcast consortium will experimentally test and validate the technical solutions developed in the project for the **M&E vertical**. For that purpose, the project will utilize **three test-beds**, including two urban city test-beds in Munich (Germany) and Turku (Finland) from the two most relevant national research projects in Europe about 4G Broadcast, and a university campus test-bed of the 5G Innovation Centre (5GIC) in Surrey (UK). The project aims to demonstrate the key innovations at the **International Broadcasting Convention (IBC) in 2018** and at the **Mobile World Congress (MWC) in 2019**. In order to demonstrate feasibility of the developed solutions in operational conditions, 5G-Xcast also aims to participate in a 5G large scale trial around the **European Championships in summer 2018**. Furthermore, the project will demonstrate 5G-Xcast technologies for the **PWS vertical**⁴ in at least one of the urban city test-beds.

2 Italian contribution to the project

TIM, as an operator, is involved together with the other consortium partners in the use case and scenario definition to be used as a reference for the overall project investigations and experimentations. TIM is contributing to both the radio access aspects and core network aspects. Concerning the Radio Access Network TIM's contribution is focused on radio electric coverage analysis and RRM. Regarding

the Core Network TIM is involved in the investigations on architectural aspects. Up to now, in general, mobile broadcasting has not been successful as expected. In any case, in the light of the introduction of 5G that, through eMBB, enables the provision of multimedia contents with a high quality level not possible with previous mobile systems generations, even the multicast/broadcast could gain a higher interest. And, also for PWS (Public Warning Systems), an efficient multicast/broadcast 5G solution can represent an important way to provide such a kind of services. The project results can then be very useful for TIM in order to better exploit the cellular resources when designing and operating the future 5G network. Also the new and innovative concepts studied in the project with a view to achieving a coordinated usage of currently “isolated” networks to deliver multicast/broadcast services will provide TIM with guidelines for optimized network design and operation based on usage scenarios and related requirements with positive impacts on both the customer experience and consequent business return.

5G-CROSSHAUL project

D. Siracusa, E. Salvadori, G. Landi, N. Ciulli, C. Casetti, A. Di Giglio, P. Iovanna

Abstract The aim of 5G-CROSSHAUL project is to develop an adaptive, shareable, cost-efficient 5G transport network solution integrating the fronthaul and backhaul segments of the network whilst supporting existing and new radio access protocol functional splits envisioned in 5G. This transport network will flexibly interconnect distributed 5G radio access and core network functions, hosted on in-network cloud nodes, through a unified data plane encompassing innovative high-capacity transmission technologies and a control infrastructure facilitating the set up of end-to-end services.

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1 Project summary

5G-PPP Phase	1
H2020 Call	H2020-ICT-2014-2
Project duration:	1 July 2015 – 30 December 2017
Project budget:	€ 8.352.273,00
Requested EC budget:	€ 7.942.523,00
Project coordinator:	Universidad Carlos III (Spain)

The key idea of the 5G-Crosshaul proposal is to move from a traditional transport network perspective to a novel architecture integrating both fronthaul and backhaul into the 5G-Crosshaul transport network. Figure 1 shows the physical infrastructure that 5G-Crosshaul is composed of, categorized into three differentiated layers. The bottom layer corresponds to the “Interconnection Plane” and shows the networking infrastructure, formed by heterogeneous links connecting the different elements of the planes located above.

The “Interconnection Plane” makes use of **5G-Crosshaul Packet Forwarding Elements (XFE)** to **interconnect a broad set of novel technologies to create a packet-based network** that can meet the demands of 5G networks. The technologies, which have already been identified as relevant for the future of the backhauling, are represented in the figure too. They span from fibre optics to novel CPRI-over-packet technologies, also considering wireless links such as mmWave. The second plane (depicted in green in Figure 1) has been named “5G-Crosshaul General Processing Plane” and shows the different **5G-Crosshaul Processing Units (XPUs)** that carry out the bulk of the operations in the 5G-Crosshaul. The functionality provided by these XPUs is multi-faceted. It highly depends on the actual interconnection and must encompass functionality expected from the different elements in the 5G network (depicted in the uppermost layer of **Fig**). As an example, in (partially) centralized RAN implementations, the XPUs will host BBUs or MAC processors (thus enabling true Cloud RAN). Further, they might serve as end-points for services or even caches. The different functional distributions between 5GPoA and XPU relation and the different services that can be hosted in the XPUs are one of the pillars of the flexibility provided by the 5G-Crosshaul architecture.

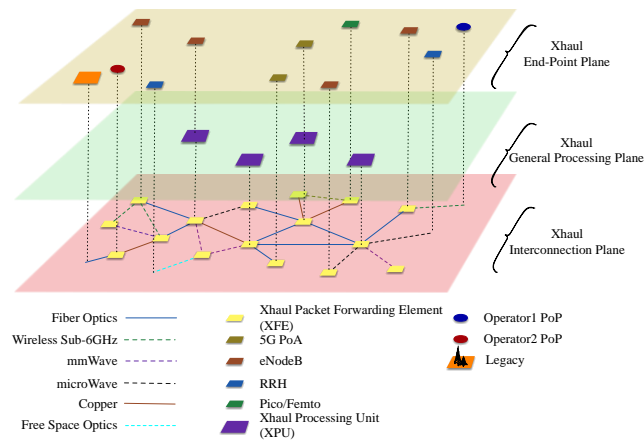


Figure 1: Physical Infrastructure of 5G-Crosshaul

This is represented by the different connection options between the uppermost (“End-Point Plane”) and the middle layer of Figure 1.

1 Project Objectives

The 5G-Crosshaul project is a very ambitious initiative aiming at designing the transport network that will serve the 5G deployments. The next generation transport network needs to unify the way it manages the different traffic sources, with really diverse, and potentially extreme, requirements in terms of bandwidth, latency or number of users. Specifically, the project pursues the following eight key objectives:

- Design of the 5G-Crosshaul Control Infrastructure (XCI): Develop XCI by extending existing Software Defined Network (SDN) controllers to provide the services for novel Northbound (NBI) and Southbound (SBI) Interfaces and enable multi-tenancy support in trusted environments.

- Specification of the XCI's northbound (NBI) and southbound (SBI) interfaces: Define interfaces to accelerate the integration of new data plane technologies (SBI) and the introduction of new services (NBI) via novel or extended interfaces. In more details the work consists of:
 - Specify an abstract network information model for 5G-Crosshaul technologies, including abstracted control parameters and system status metrics.
 - Collect contextual information about traffic, congestion, interference of radio resources, and energy savings to provide applications (WP4) with a media-independent system status report of the heterogeneous network.
 - Specify the set of southbound XCI actions (e.g., control the forwarding behaviour, configure radio parameters, deploy/migrate 5G-Crosshaul functions).
 - Specify the set of northbound XCI actions (e.g., provisioning of new VPNs) to enable Service Level Agreement (SLA)-level reports, create new virtual 5G-Crosshaul slices for multi-tenancy support.
- Unification of the 5G-Crosshaul data plane: Develop a flexible frame format to allow carrying fronthaul and backhaul on the same physical link to replace different technologies with a uniform transport technology for both fronthaul and backhaul.
- Development of physical and link-layer technologies to support 5G requirements: Exploit advanced physical layer technologies, not currently used in the 5G-Crosshaul network segment, as well as novel technologies, such as wireless optics, silicon photonics for miniROADM, flexi-PON, etc. to increase coverage and aggregated capacity of integrated backhaul and fronthaul networks. Increase cost-effectiveness of transport technologies for ultra-dense access networks.
- Design of scalable algorithms for efficient 5G-Crosshaul resource orchestration: Develop and evaluate management and control algorithms on top of the XCI NBI that ensure top-notch service delivery and optimal 5G-Crosshaul resource utilization.
- Design of essential 5G-Crosshaul-integrated (control/planning) applications: Develop an ecosystem of most essential XCI NBI applications, both to support (prediction, planning, monitoring) and to exploit (media distribution, energy management) the 5G-Crosshaul resource orchestration functions.

- 5G-Crosshaul key concept validation and proof of concept: Demonstration and validation of 5G-Crosshaul technology components which will be integrated into a set of 5G testbeds in Madrid, Berlin, Barcelona and Taiwan.

2 Contributions from Italian partners

In this Section we provide a short overview of the major contributions from the Italian partners to the project.

TIM has been leading the task on the architecture requirements and contributed to the definition of the stakeholders. It has also developed a dimensioning tool and performed an analysis of cost and energy consumption in a cross-haul metropolitan realistic network, demonstrating the impressive Capex and Opex savings due to the novel Crosshaul architecture and the introduction of miniROADM in the optical stratum.

Furthermore TIM has also validated some experiments set-up and provided a transmission demo in a real link.

Ericsson Telecomunicazioni SpA has provided the system requirements and the definition of use cases, mapping them onto transport requirements. On this basis, it has realized an innovative C-RAN solution that guarantees low and deterministic latency at lower cost compared to the solutions used in current aggregation and metro networks. The solution includes novel framing protocol, deterministic circuit-based switching and a cost effective silicon photonics reconfigurable optical add-drop multiplexer (miniROADM). To assess the solution, both simulations and experimentation in a proof of concept demo have been provided, integrating the system in the 5G-Crosshaul demonstrator in the 5Tonic testbed.

Ericsson Telecomunicazioni SpA has also acted as leader of WP2, regarding the specification of the data-plane, and as Innovation Manager of the project, contributing to an ETSI White paper and submitting two approved contributions at ITU-T IMT-2020.

Networks has performed the design of the XCI components, with focus on the internal components of the XCI SDN controller and the XCI NFV MANO stack. In particular, Nextworks has implemented extensions to the OpenDaylight SDN controller for the monitoring and control of the power-sates and the flow

switching with QoS in XPFE-based network domains. Moreover, the team has also developed with Politecnico di Torino an energy-efficient algorithm for joint resource orchestration of XPFEs and XPU, and has evaluated its performance in both emulated and real testbed (5TONIC in Madrid) environments. Networks has integrated the SDN controller with the XPFEs network domain in 5TONIC testbed and implemented an NFV orchestrator and VNF Manager compliant to the ETSI IFA standard specifications, which has been validated in the lifecycle management of an OpenAirInterface vEPC network service. Public demonstrations of the various developments on NFV MANO and integrated SDN controllers have been executed in international conferences (EUCNC 2017) and in the context of 5TONIC.

FBK CREATE-NET has contributed to the finalization of models for mm-Wave radio and Ethernet links interconnecting 5G-Crosshaul switching elements in a random topology network. It has also defined the REST APIs for service request, provisioning and flow actions of the Resource Management Application (RMA) in the 5G-Crosshaul architecture. It performed the design and development of the Resource Management application (RMA) and its integration with other building blocks (i.e., TVBA, CDNMA and MMA applications) in one of the final project demo.

Politecnico di Torino has developed experimental-based models of the energy consumption due to different virtualization approaches and designed optimization algorithms for on/off switching of network nodes, leading to energy saving. It has also performed the design and development (on top of an ONOS-based SDN controller) of the EMMA application, which efficiently routes traffic flows over the network in order to minimize energy consumption.

References

1. D1.2 Final 5G-Crosshaul system design and economic analysis - http://5g-crosshaul.eu/wp-content/uploads/2018/01/5G-CROSSHAUL_D1.2.pdf
2. D4.2 Final design of 5G-Crosshaul Applications and Algorithms - http://5g-crosshaul.eu/wp-content/uploads/2018/01/5G-CROSSHAUL_D4.2.pdf
3. D7.3 Final Project Report - http://5g-crosshaul.eu/wp-content/uploads/2018/01/5G-CROSSHAUL_D7.3.pdf

COHERENT project

R. Riggio, E. Salvadori

Abstract The exponential growth of mobile traffic, drastically increasing of network complexity, and the strong need for inter-network coordination of wireless network resources call for breakthroughs in control, coordination and flexible spectrum management in 5G heterogeneous radio access networks. The COHERENT project aims to address these problems by researching, developing and validating a novel control framework for future mobile networks. The key innovation of COHERENT is to develop a unified programmable control framework to coordinate the underlying heterogeneous mobile networks as a whole.

1 Project summary

5G-PPP Phase	1
H2020 Call	H2020-ICT-2014-2
Project duration:	1 July 2015 – 30 December 2017
Project budget:	€ 6.024.299,00
Requested EC budget:	€ 6.024.299,00
Project coordinator:	VTT Technical Research Centre of Finland Ltd

Roberto Riggio, Elio Salvadori
FBK CREATE-NET

2 Objectives

The innovative impact of the COHERENT project is in enabling a unified control and coordination framework for heterogeneous mobile networks by combining innovative approaches on abstraction of low layers in underlying mobile networks, software defined networking, and flexible spectrum management. The COHERENT control framework has two unique features to deal with the insufficiency of current control solutions for inter-network coordination. First, theories and methods to abstract the low layer network states and behaviors of different underlying mobile networks are developed, which provides a simplified but sufficient abstracted network view for network-wide control and resource coordination. Network abstraction will significantly reduce the signaling overhead, making scalable network-wide control solutions feasible, and enable more flexible spectrum management, which are key for the success of 5G networks. Second, based on the abstracted network view, common interfaces and software-development kits will be developed to enable programmability in controlling and coordinating heterogeneous mobile networks. The programmable control will provide operators a flexible and cost efficient way to implement new control functions and thus to support new services. Specifically, the project pursues the following eight key objectives:

- Lay theoretical foundation and develop practical implementation on the abstraction of physical and MAC layer states, behaviours and functions of various radio access networks to enable simple, unified, scalable control and coordination solutions for HMN (Heterogeneous Mobile Networks).
- Build flexible spectrum management upon the awareness of network conditions through properly developed network abstraction. We aim to significantly improve spectrum reuse in 5G networks by applying fine-grade, real-time, adaptive and network-aware spectrum management in LSA and inter/intra- operator spectrum sharing.
- Design and develop SDK based low-layer abstractions to enable programmable control and coordination in HMN. The SDK will define as set of RAN Application Programming Interface (API) and communication protocols, allowing network application to configure and modify the behaviour of the underlying RANs.

- Propose traffic steering and resource allocation algorithms based on the COHERENT control framework to realize network-wide resource optimization, and especially network energy saving by taking advantage of awareness of network topology and states from the COHERENT control framework.
- Leverage physical and MAC layer abstraction to improve user cooperation like D2D communications in HMN, develop related protocols and control methods based on the proposed COHERENT control framework, and showcase its ability to significantly improve D2D communications in HMN.
- Explore the low-layer abstraction and COHERENT control framework to significantly improve mobility management and coverage extension in HMN with particular attention to the moving relay/cell scenarios.
- Provide practical programmable solutions by carefully applying the CAP theorem in the COHERENT control framework. Leverage the SDK to enable programmable control for radio resource provisioning in HMN.
- Investigate, design and implement different strategies to enable RAN sharing between multiple virtual operators. Virtualization is an integral part of SDN and must be taken into account at the early stages of abstractions design in different settings including cellular, cloud and D2D. Performance and logic isolation of concurrent slices of networking resources will be investigated and adapted to COHERENT through the use of the SDK.
- Demonstrate the benefits of the COHERENT concept by validating the project use cases in realistic conditions. Showcase the technical and business impact of the project results using rich infrastructure and simulators/Emulators platforms from partners' and FIRE facilities. Provide solid standard contribution to 3GPP RAN1, RAN3 and ECC PT1.

3 Contributions from Italian partners

In this Section we provide a short overview of the major contributions from the Italian partners to the project.

FBK CREATE-NET has contributed to the project by providing support to its 5G-EmPOWER platform [4] which was used in one of the project demo platforms implementing the COHERENT SDK. The demo showcased the first prototype of the COHERENT integrated control plane for heterogeneous networks. It has also

implemented probabilistic monitoring, channel busyness module, and channel quality map for WiFi networks. FBK CREATE-NET has also extended its 5G-EmPOWER by adding support to the LTE open source platform srsLTE. It has also proposed new methods for spectrum sharing in the multi-tenant use case, and provided system level simulation model to analyse multi-tenant RAN and spectrum sharing. As WP leader on the workpackage about the Programmable RAN, FBK CREATE-NET contributed to several algorithms for end-to-end Wi-Fi RAN slicing, for channel-aware user association in software-defined Wi-Fi networks, for traffic-aware user association in heterogeneous RANs, and for flexible functional splits in 5G network. It has also implemented a RAN slicing in WiFi and LTE networks.

References

1. D2.4 Final release of the SDK - http://www.ict-coherent.eu/coherent/wp-content/uploads/2018/05/COHERENT_D2_4_v1.0.pdf
2. D5.2 Final specification and implementation of the algorithms for programmable radio access networks - http://www.ict-coherent.eu/coherent/wp-content/uploads/2018/03/COHERENT_D5.2_v1.0.pdf
3. D6.2 Final report on technical validation - http://www.ict-coherent.eu/coherent/wp-content/uploads/2018/08/COHERENT_D6_2_final.pdf
4. 5G-EmPOWER - <http://5g-empower.io/>

SESAME project

R. Riggio, E. Salvadori, D. Munaretto, A. Albanese

Abstract The project proposes the Cloud-Enabled Small Cell (CESC) concept, a new multi-operator enabled Small Cell that integrates a virtualised execution platform (i.e., the Light DC) for deploying Virtual Network Functions (NVFs), supporting powerful self-x management and executing novel applications and services inside the access network infrastructure. The Light DC will feature low-power processors and hardware accelerators for time critical operations and will build a high manageable clustered edge computing infrastructure. This approach will allow new stakeholders to dynamically enter the value chain by acting as ‘host-neutral’ providers in high traffic areas where densification of multiple networks is not practical.

1 Project summary

Roberto Riggio, Elio Salvadori
FBK CREATE-NET

Daniele Munaretto
ATHONET

Antonino Albanese
Italtel

5G-PPP Phase	1
H2020 Call	H2020-ICT-2014-2
Project duration:	1 July 2015 – 30 December 2017
Project budget:	€ 8.206.935,00
Requested EC budget:	€ 7.488.434,00
Project coordinator:	OTE AE (Greece)

2 Objectives

SESAME project targets innovations around three central elements in 5G: the placement of network intelligence and applications in the network edge through Network Functions Virtualisation (NFV) and Edge Cloud Computing; the substantial evolution of the Small Cell concept, already mainstream in 4G but expected to deliver its full potential in the challenging high dense 5G scenarios; and the consolidation of multi-tenancy in communications infrastructures, allowing several operators/service providers to engage in new sharing models of both access capacity and edge computing capabilities. In order to “address” this need and building upon the pillars of network functions virtualisation, mobile-edge computing (MEC) and cognitive management, SESAME’s main goal is the development and demonstration of an innovative architecture, capable of providing Small Cell coverage to multiple operators “as-a-Service”. SESAME envisages the logical partitioning of the localised Small Cell network to multiple isolated slices as well as their provision to several tenants. Moreover, in addition to virtualizing and partitioning Small Cell capacity, SESAME supports enhanced multi-tenant edge cloud services by enriching Small Cells with micro-servers. Specifically, the project pursues the following nine key objectives:

- Definition and specification of the system architecture and interfaces for the provisioning of multi-operator Small Cell networks, optimised for the most promising scenarios and use cases.

- Specification, design and implementation of a multi-operator CESC prototype, supporting Self-x features enabling multi-tenant and multi-service access infrastructure.
- Specification, design and implementation of a low-cost Light DC prototype as NFV Point-of-Presence (PoP), providing support for intensive low latency applications, secure connections and high quality of experience, while minimising space, infrastructure costs and energy consumption.
- Launching of at least three high-impact sample VNFs for demonstration and assessment of SESAME CESC platform – Small Cell virtualisation through providing MOCN as a VNF.
- Design and development of a framework for efficient resource planning and coherent management of the multi-operator Small Cells as light NFV distributed infrastructure.
- Design and implementation of CESC-M, capable of chaining and orchestrating the different VNFs required to cope with the dynamic SLAs between the CESC provider and the network operators.
- Integration into one Pre-Commercial Prototype of Small Cells, Light DC and management and orchestration functionalities - The prototype will be used to perform testing and evaluation, against solidly defined use cases.
- Conduct of Market Analysis, Road-mapping, as well as establishment of new Business Models - Detailed Techno-economic Analysis towards exploitation and commercialisation by industrial partners is also a priority.
- Communication/dissemination of project results raising awareness and impact on stakeholders and the wider community, as well as assessment of received feedback - Creation and exploitation of synergies with the rest 5G-PPP projects and the Association towards building a consistent 5G view.

3 Contributions from Italian partners

In this Section, we provide a short overview of the major contributions from the Italian partners to the project.

Italtel has contributed to the definition and specification of the SESAME overall system architecture, especially focusing on the HW and SW design of the Light

DC. As WP leader of the work package 4 “Light DC Design and Implementation”, Italtel has supervised all the contributions from the partners. Furthermore, Italtel has designed and developed the computing and networking extension related to the micro server virtualization SW platform, the video Transcoding service VNF on both Intel and Arm platforms (including support for HW acceleration, Service Function Chain, Monitoring and Scaling). Lastly, Italtel has provided the testbed for the integration of the Light DC prototype used for one of the SESAME final demo (benefits and performances of GPU HW acceleration in the video transcoding VNF).

FBK CREATE-NET has contributed to the project by contributing to the overall SESAME architecture definition. It has also contributed to define and consolidate the small cell functions virtualised within the architecture as well as to demonstrate several CESC functions within the SESAME platform (caching of multimedia content within the CESC, functional split and RAN sharing). As a contribution toward the virtualised architecture, FBK CREATE-NET has also developed a software agent that allows the ClickOS virtual machines to communicate with its own 5G-EmPOWER Virtualised Infrastructure Manager (VIM) platform [3]. It has also consolidated the software-agent that enabled the communication between the Open Air Interface open source software, which implemented the protocol stack of the SESAME small cell, and the 5G-EmPOWER VIM. Finally, FBK CREATE-NET has developed a theoretical work on optimal dynamic placement of small cell functions for multi-tenancy trying to minimize aggregate interference.

ATHONET has contributed to the design of the SESAME use cases, as well as on the definition of the SESAME network architecture. It has also participated to the design and implementation of virtualized small cell systems by studying and identifying the edge modules and components for MOCN from the core network point of view. It has also been evaluating the feasibility (3GPP compliancy) to implement the demonstrator designed and built in the work package and review the interfacing proposed with the core network. ATHONET has integrated multiple vEPCs with partners’ small cells from IPA and SISTEL, remotely and locally with different RAN sharing and MOCN configurations, to deploy and test the MOCN feature which enabled the use cases envisioned in SESAME.

References

1. D2.5 SESAME Final Integrated Architecture and PoC Assessment KPIs - http://www.sesame-h2020-5g-ppp.eu/Portals/0/Deliverables/SESAME_Deliverable%202.5_v1.0_Final.pdf?ver=2018-10-29-153359-757
2. D7.5 Overall Assessment and Roadmap - http://www.sesame-h2020-5g-ppp.eu/Portals/0/Deliverables/SESAME_Deliverable%207.5_v1.0_Final.pdf?ver=2018-11-08-142833-237
3. 5G-EmPOWER - <http://5g-empower.io/>

5G-ESSENCE project

R. Riggio, E. Salvadori, D. Munaretto, A. Albanese, M.R. Spada

Abstract The project addresses the paradigms of Edge Cloud computing and Small Cell as a Service by fuelling the drivers and removing the barriers in the Small Cell market, forecasted to grow at an impressive pace up to 2020 and beyond and to play a key-role in the 5G ecosystem. 5G ESSENCE provides a highly flexible and scalable platform, able to support new business models and revenue streams by creating a neutral host market and reducing operational costs by providing new opportunities for ownership, deployment, operation and amortization. 5G ESSENCE leverages knowledge, SW modules and prototypes from various 5G-PPP Phase-1 projects, SESAME being particularly relevant. Building on these foundations, very ambitious objectives are targeted, culminating with the prototyping and demonstration of 5G ESSENCE system in three real-life use cases associated to vertical industries.

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1 Project summary

5G-PPP Phase	2
H2020 Call	H2020-ICT-2016-2
Project duration:	1 June 2017 – 30 November 2019
Project budget:	€ 7.978.272,50
Requested EC budget:	€ 7.978.272,50
Project coordinator:	OTE AE (Greece)

2 Objectives

The technical approach envisioned by 5G ESSENCE project exploits the benefits of the centralisation of Small Cell functions as scale grows through an edge cloud environment based on a two-tier architecture: a first distributed tier for providing low latency services and a second centralised tier for providing high processing power for computing-intensive network applications. This allows decoupling the control and user planes of the Radio Access Network (RAN) and achieving the benefits of Cloud- RAN without the enormous front-haul latency restrictions. The use of end-to-end network slicing mechanisms will allow sharing the 5G ESSENCE infrastructure among multiple operators/vertical industries and customising its capabilities on a per-tenant basis. The versatility of the architecture is enhanced by high-performance virtualisation techniques for data isolation, latency reduction and resource efficiency, and by orchestrating lightweight virtual resources enabling efficient Virtualised Network Function placement and live migration. Specifically, the project pursues the following eight key objectives:

- To specify the critical architectural enhancements from 5G-PPP Phase-1 that are needed to fully enable cloud-integrated multi-tenant small cell networking.

- To define the baseline system architecture and interfaces for the provisioning of a cloud-integrated multi-tenant small cell network and a programmable RRM controller, both customisable on a per vertical basis.
- To develop the centralised SD-RAN controller that will program the radio resources usage in a unified way for all CESC (Cloud-Enabled Small Cells).
- To exploit high-performance and efficient virtualisation techniques for better resource utilisation, higher throughput and less delay at Network Services creation time.
- To develop the orchestrator enhancements for distributed service management. The 5G ESSENCE orchestrator will jointly consider the decentralised data centre environment with the operation of cSD-RAN controller for multi-tenancy.
- To demonstrate and evaluate the cloud-integrated multi-tenant small cell network in three real-life use cases associated to vertical industries, i.e., edge network acceleration in a crowded event, mission critical applications, and in-flight communications.
- To conduct a market analysis and to establish new business models. Detailed techno-economic analysis and roadmapping towards exploitation and commercialisation by industrial partners is also a priority.
- To ensure maximisation of 5G ESSENCE impact to the realisation of the 5G vision by establishing close liaison and synergies with 5G-PPP Phase-1 & 2 projects and the Association. To pursue extensive dissemination and communication activities, as well to assess the perceived impact from the stakeholders and the wider community.

3 Contributions from Italian partners

In this Section, we provide a short overview of the major contributions from the Italian partners to the project.

Italtel is participating in the elaboration of Use Cases and Requirements as well as in the definition of the overall architecture that will specify how the SES-AME Light DC will evolve towards the two-tier “Edge DC”. It is also participating in the design, development and testbed implementation of the Network

Embedded Edge Cloud that includes the Edge DC (Light DC plus Main DC). Italtel is involved also in the development of efficient, high performance virtualised edge nodes on single-board computers (SBCs) based on both x86 and ARM processors, supporting ultra-low latency virtualization platform. Lastly, Italtel is contributing in the project Use Cases integration, demonstration and validation, especially for the In-Flight Entertainment and Connectivity (IFEC) one, providing the “i-EVS” (Enhanced Video Service) virtualized application used for the wireless in-flight streaming.

FBK CREATE-NET is involved in the design of the 5G-ESSENCE overall architecture, and is contributing to the technical specification of the system, in particular for the 5G cSD-RAN controller. FBK CREATE-NET will develop a CESC slicing mechanism based on ClickOS and Docker approaches, and algorithms to service-oriented resource assignment to the slices (both network and licensed/unlicensed spectrum) and for scheduling the slices over the common CESC infrastructure relying on different functional splits between virtual and physical small cell. FBK CREATE-NET will contribute with a test-bed including programmable small cells based on Open Air Interface (OAI), Wi-Fi and the 5G-EmPower RAN controller [4] to perform preliminary tests in lab testing of slicing and SON features.

Athonet is contributing to the use case definition and requirements. Athonet mainly provides the core network functionalities (vEPC, vMBMS) to enable broadcast video services during a live event in a stadium. Moreover, Athonet contributes to the project by providing MEC functionalities at the edge of the network, which represent a first bridge to the 5G technology across the use cases of the project. Athonet also contributes to the standardisation efforts with a particular focus on ETSI MEC and ETSI MCPTT.

Wind Tre is contributing to the requirements specifications and the definition of the 5G ESSENCE architecture and in the elaboration of the Use Cases. Wind Tre is guaranteeing also a part of the evaluation of 5G ESSENCE project in the telecommunications domain; all the activities are performed through an investigation of the new evolutions proposals for all the technological and procedural aspects and the new possible interaction models, implemented by the project. Finally, Wind Tre is leading the workpackage (WP8) on “Dissemination, Communication & Exploitation of Results”, and is participating in the formulation of preliminary business cases. Together the other industrial partners, Wind Tre is involved in getting the best out of the project’s outcomes.

References

1. D2.1 System Use Cases and Requirements - http://www.5g-essence-h2020.eu/Portals/0/5G%20ESSENCE_%20Deliverable%202.1_v1.0_Final.pdf?ver=2018-10-04-143227-963
2. D3.1 Techniques for advanced radio resource centralised management and 5G network coordination - http://www.5g-essence-h2020.eu/Portals/0/5G%20ESSENCE_%20Deliverable%203.1_v1.0_Final.pdf?ver=2018-10-04-144118-413
3. D4.1 Optimisation of virtualisation, orchestration, and resource allocation - http://www.5g-essence-h2020.eu/Portals/0/5G%20ESSENCE_%20Deliverable%204.1_v1.0_Final.pdf?ver=2018-10-04-144621-157
4. 5G-EmPOWER - <http://5g-empower.io/>

5G-CARMEN project

R. Riggio, E. Salvadori, C. Casetti, M. Dell'Amico, L. D'Orazio, L. Andreone, M. Cecchi, L. Pulcinelli, I. De Biasi, G. F. Cordella, S. Capato, B. Ferraioli, C. Pahl

Abstract The project will build a 5G-enabled corridor from Bologna to Munich to conduct cross-border trials of 5G technologies in three major use cases: vehicle manoeuvre negotiation (at various levels of automation), infotainment, and emission control. The 5G New Radio will be used to support latency sensitive and/or bandwidth hungry services and applications. The project will leverage on a distributed mobile edge cloud spanning from the vehicle itself to the centralised cloud. Multi-tenancy and neutral host concepts will be leveraged upon to deliver a final platform capable of enabling new business models. 5G-CARMEN will complement C-V2X with LTE and C-ITS technologies, targeting interoperability and harnessing a hybrid network.

1 Project summary

R. Riggio, E. Salvadori (FBK)
C. Casetti, M. dell'Amico (CNIT)
L. D'Orazio, L. Andreone (CRF)
M. Cecchi (TIM)
L. Pulcinelli (INWIT)

I. De Biasi (AutoBrennero)
G. F. Cordella (DriveSec)
S. Capato (SWARCO)
B. Ferraioli (PIIU)
C. Pahl (UNIBZ)

5G-PPP Phase	3
H2020 Call	H2020-ICT-18-2018
Project duration:	1 November 2018 – 31 October 2021
Project budget:	€ 18.566.123,75
Requested EC budget:	€ 14.960.887,26
Project coordinator:	Fondazione Bruno Kessler (FBK)

2 Objectives

European mobility is drastically changing: growing urbanisation, environmental aspects, and safety are only a few of the key indicators pointing in this direction. Road infrastructures and vehicles are blending with the digital world, becoming always-connected, automated and intelligent, delivering optimal experience to passengers, and addressing societal goals (e.g., emission and accident reduction) and economic needs (e.g., vehicles as smart-living environments). In this respect, the European Union pushes for large-scale collaborative cross-border validation activities on cooperative, connected and automated mobility.

5G-CARMEN addresses these challenges harnessing the concept of “Mobility Corridors”. In 5G-CARMEN important European industries, academics and innovative SMEs commit to achieve world-wide impact by conducting extensive trials across an important corridor (by people/goods traffic volumes), from Bologna to Munich, spanning 600 km of roads, connecting three European regions (Bavaria, Tirol and Trentino/South-Tyrol) across three countries. 5G-CARMEN will realise a 5G-enabled corridor to validate a set of innovative Cooperative, Connected, and Automated Mobility (CCAM) use cases from both business and technical perspectives. To achieve this, 5G-CARMEN will leverage on the most recent 5G technology enablers, including 5G NR, C-V2X interfaces, Mobile Edge Computing (MEC), end-to-end network slicing, highly accurate positioning and timing, and predictive quality of service. The neutral host model will be used in order to enable this vision. Mobile Virtual Network Operators (MVNOs), Over-

the-Top (OTT) providers, and service providers will have access to a multi-tenant platform that supports the automotive sector transformation towards delivering safer, greener, and more intelligent transportation with the ultimate goal of enabling self-driving cars.

Specifically, the project pursues the following seven key objectives:

- Specify the technical and business requirements for the planned use cases in order to enable an extended 5G CCAM corridor between Bologna-Munich.
- Design a federated 5G system architecture and deployment model that can effectively support the CCAM use cases.
- Advance the enabling technologies for a 5G corridor including the network-embedded cloud, the NR, and the new frequency planning to conform with the CCAM KPIs.
- Design, implement, and validate a service-oriented, federated, and secure platform for CCAM.
- Validate, evaluate and demonstrate the 5G-CARMEN concepts via single-country and cross border pilots.
- Conduct a market analysis and to devise new business models based on the 5G-CARMEN platform. To provide a detailed techno-economic analysis and road-mapping towards exploitation and commercialisation by industrial partners.
- Ensure the long-term success of the project through standardisation and dissemination in commercial, industrial and scientific fora and by exploiting synergies with other 5G-PPP initiatives and projects.

3 Contributions from Italian partners

In this Section we provide a short overview of the major contributions from the Italian partners to the project.

Fondazione Bruno Kessler will act as project manager of 5G-CARMEN and will involve two of its research centers: CREATE-NET and ICT. FBK will contribute to the definition of the requirements of 5G-CARMEN use-cases and to the detailed specification of system level architecture. FBK will also develop MEC applications with special emphasis on low resource utilization and lightweight

virtualization using containers and container orchestration solutions, and it will work towards network driven integration of C-V2X and ITS-G5 technology components. FBK will develop mobile identity management solutions striking a good balance between security, privacy, and user experience while checking the compliance of the security and privacy policies with existing legal provisions in the EU about processing personal data. FBK will also investigate centralized, distributed and hybrid realizations for resource control and orchestration across the heterogeneous physical and virtual infrastructure and contribute to the development of required multi-domain service orchestration solution. Finally, FBK will contribute in the validation of test results by collecting the required data from the pilots and validate them using statistical analysis and simulations.

FCA-CRF will contribute to the use case definition and use cases requirements analysis, and provide requirements for the integration of a 5G connected system on-board the vehicle; it will also participate in the system level technical specifications. FCA-CRF will develop the on-board applications to enable selected 5G-CARMEN use cases on its vehicle prototypes, adapting in-vehicle functionalities according to the 5G-CARMEN requirements. FCA-CRF will integrate the on-board system and the developed applications with the in-vehicle network, and set-up 2 vehicle prototypes for the demonstration of the 5G-CARMEN system for connected vehicles and automated driving. It will also contribute to the testing and validation methodology, planning and preparation. FCA-CRF will be involved in exemption procedures and safety issues activities, mainly regarding the regulation aspects and authorization procedures for automated driving, and will also support partners for the 5G connectivity part. It will also be involved in IPR and data management issues, considering the aspects related to in-vehicle data when dealing with connected driving and vehicle-infrastructure communication. FCA-CRF will finally contribute to the market analysis and business modelling as OEM, and will evaluate possible exploitation opportunities of the 5G-CARMEN results within FCA.

TIM will contribute to the definition and analysis of the 5G-CARMEN selected use cases with the connectivity requirements analysis for the implementation in the automotive corridor. TIM will study the main technologies enabling the deployment of the 5G-CARMEN use cases, by considering the evolution in the standardization of the V2X systems and MEC-based vehicular communications system. TIM will investigate network options to allow interworking for vehicles equipped with ITS-G5 and LTE-V2X. As the partner with direct

involvement in the Italian sector of the 5G-CARMEN corridor, TIM will operate the mobile network infrastructure deployed along the motorway A22 and will contribute in the definition and set-up of the experimental tests in the Italian segment of the vehicular corridor selected by 5G-CARMEN. TIM will act as workpackage leader of “Dissemination, Partnerships and Cooperation models, and standardization” activities, ensuring the participation of the project to global leading events in the 5G and automotive sector and a proper impact of 5G-CARMEN outcomes towards the relevant SDOs (3GPP and ITU) and 5G-PPP groups (i.e. 5G Automotive Working Group).

CNIT will contribute to the detailed definition of use-cases, focusing on aspects related to virtualization, slicing and orchestration, and interworking between 5G, ITS-G5, and LTE C-V2X technologies. From the analysis of those use cases, it will contribute to identifying detailed requirements and their impact on the functional and system architecture. CNIT will collaborate to the evaluation of the critical components in both C-V2X and ITS-G5-based network elements at the physical and access layers that guarantee low-latency communication, and will design solutions capable of ensuring smooth migration from existing or upcoming technologies (ITS-G5, LTE, and LTE C-V2X) to vehicular 5G. CNIT will also work on the definition of new slicing models toward the novel paradigm of “Vehicle as Infrastructure” and contribute with a software stack for predictably exploiting next-generation embedded computing devices to seamlessly integrate the 5G communication stack with the autopilot software. CNIT will contribute to the design of the required multi-domain service orchestration solution, focusing on cross-border interoperation of MEC entities. It will contribute to the planning activity of test sessions for the different pilots with the aim of validating the KPIs associated to different use cases. CNIT will support the design of the analytics needed to compare the data communication and execution latency with benchmarks collected. CNIT will support the development of a market analysis and the development of novel business models proposing the canvas methods used in other projects.

Autostrada del Brennero will be end-user of the project and will make the infrastructure available for the deployment of the project, also contributing with its experience in terms of large-scale demonstration and issues related to the implementation of on-site tests. It will contribute in the definition of the use cases and the analysis of their requirements and work on the integration of the notifications messages originating from cellular base stations into the C-ITS server

installed at the TCC, so as to enable it to broadcast the message also on the ITS-G5 network.

INWIT will investigate a viable "neutral hosting" approach in collaboration with MNOs which is applicable to both the traditional and new components of the network architecture. INWIT will identify suitable sites for tests, define MNO lease space requirements and possible ancillary service they might require (e.g., FO backhauling) coupling those requirements with inherent Service Level standards. It will also contribute to the business analysis and modelling and KPI definition respectively according to a "neutral hosting " approach.

SWARCO will provide solutions that enable the deployment of C-ITS services, through the 5G technology. It will contribute to the definition of the use cases requirements and specifications and of the functional architecture of the project. It will also contribute to the integration of 5G technologies into the existing solutions for connected vehicles, while providing 5G-CARMEN with its infrastructure, products and knowledge to reach the successful integration and testing at pilot level.

DSEC will provide to 5G-CARMEN the competence and resources needed to provide to the solutions the needed and appropriate cybersecurity protection, considering regulation and functional safety. DSEC will provide guidelines to be considered in the development of future CCAM applications, in order to properly address cybersecurity protection and a methodology to assess the level of cybersecurity, as a validation tool, of components or systems. DSEC will also participate to 5G-CARMEN pilots execution, to validate the methodology and to assess the cybersecurity of the developed applications.

PIIU will elaborate specific licensing models regarding the part of the results of the project that will be exploited under open sources schemes. It will also focus on the social-economical analysis aspects of the 5G-CARMEN project. PIIU will be the responsible for the creation and maintenance of the concrete plan for the dissemination and use of knowledge of the project, by coordinating the dissemination actions of the project in scientific and business events and being responsible for the project's visibility through online channels, such as the online social media channels. PIIU will also manage the activities related to the involvement of external SMEs to unlock the commercial potential of high-value solutions offered by 5G-CARMEN.

UNIBZ will bring its expertise in the management of virtual resources in edge computing environments. More specifically, the contribution is to address cross

domain orchestration, i.e. orchestration of resource between different clouds. The 5G-CARMEN project will involve clouds in different countries and owned by different entities and workloads must be migrated from one cloud to the other ensuring SLA aspects including security and performance related concerns.

References

1. 5G-CARMEN Internal documentation
2. 5G-PPP homepage: <https://5g-ppp.eu/5g-carmen/>
3. 5G-CARMEN official press-release on FBK website: <https://magazine.fbk.eu/en/news/5g-carmen-a-digital-corridor-for-the-mobility-of-the-future/>

5GCity

Gino Carrozzo, Paolo Cruschelli, Maria Rita Spada, Mauro Di Bugno, Luca Vignaroli, Antonino Albanese, Andrea Michelozzi¹⁷

Abstract 5GCity is a H2020 Innovation Action funded by the European Commission as part of the 5G PPP Phase 2 programme. The project is designing, developing and deploying a distributed cloud and radio platform for municipalities and infrastructure owners who can act as 5G Neutral Hosts. The main goal of 5GCity is to build and deploy a common, multi-tenant, open platform that extends the centralized cloud model to the extreme edge of the network, with a live demonstration and trials to be run in three different cities: Barcelona (ES), Bristol (UK) and Lucca (IT). In these cities, three main categories of use case scenarios are going to be tested and validated: Neutral Host, Media and Entertainment and City Monitoring.

1 Project background and architecture

The value creation in the telecommunications market which is preparing to 5G roll-out is no longer the case of a closed market limited to a few players: new roles and relationships are emerging to become essential part of the new 5G-powered ecosystem. As depicted in Fig. 1, the traditional roles of Hardware

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Andrea Michelozzi, Comunicare Digitale

(Equipment) manufacturers/vendors and Network Operators are being complemented by Infrastructure owners, who own the necessary infrastructure that can be used for hosting the computing, storage and networking infrastructure of the 5G network (e.g. space in street cabinets, lampposts or buildings along with power supply and connectivity).

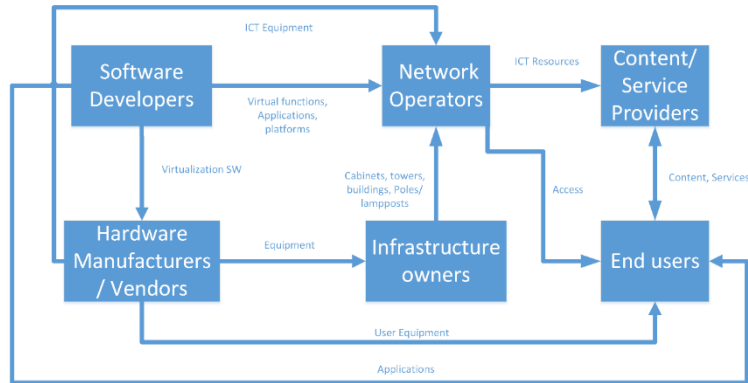


Fig.1 Relationships between actors in the new 5G ecosystem

A new role is taken by the Software Developers who develop the necessary software as well as the Virtual Network Functions (VNFs) that are necessary to the delivery of the 5G network services and to the specific requirements of the vertical applications running on the 5G infrastructure (e.g. video analytics or augmented reality software). Finally, Content/Service Providers are heavily entering the 5G value creation chain, being them among the primary actors who realize the vertical industry and who develop services and contents to be offered to End users, i.e. the citizens.

5GCity has its main stakeholder in the municipalities who quite often own and manage the best urban spaces to host 5G Small Cells and are undergoing a digital transformation towards becoming Smart Cities. Here 5GCity generates most of its impact, unleashing the power of new value-added services through the support of a Neutral Host model (see Fig. 2).

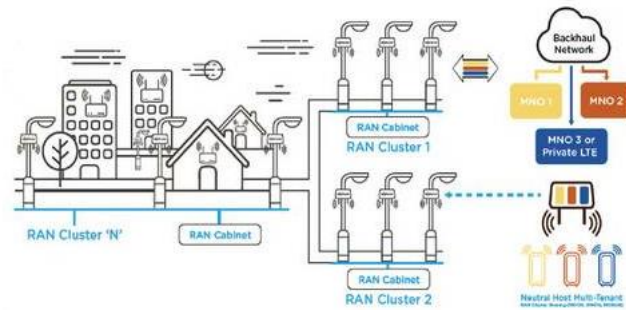


Fig. 1 5GCity Neutral Host concept

5GCity is designing a completely de-centralised, 3-tier architecture where compute, storage and networking are allocated between core and edge segments of the 5G network infrastructure capable to offer tight-loop interactions between applications and enabling connectivity services. The 5GCity functional architecture is depicted in Fig. 2, which provides a view of the different functional blocks necessary to adapt city infrastructure to the cloud and virtualized edge network. This architecture is composed by three layers:

- Service/Application Layer
- Orchestration & Control layer
- Infrastructure layer

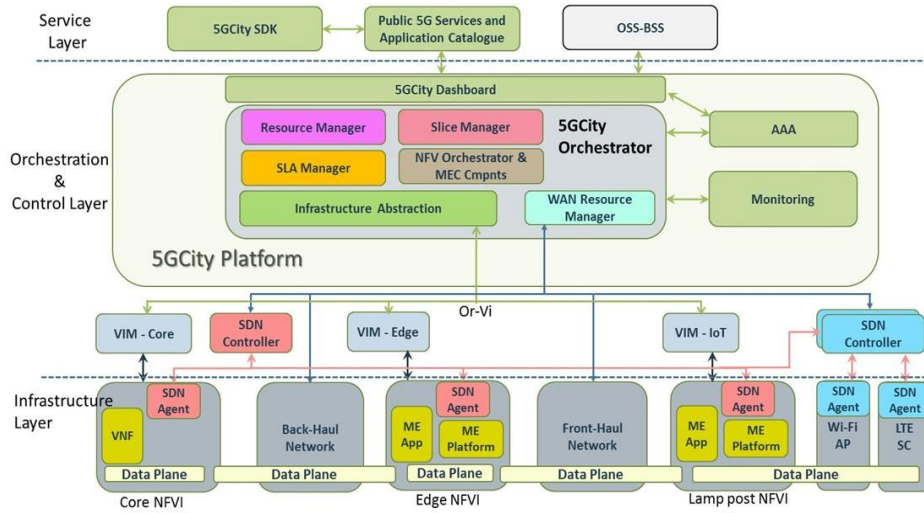


Fig. 2 5GCity Functional Architecture

The 5GCity architecture adapts distributed cloud technologies in order to build its combined edge and network infrastructure providing a multi-tenant, cost-effective platform for deploying virtualized heterogeneous services. Through this architecture it is possible to realise the **5G Neutral Host model**, i.e. the network slicing mechanisms developed in 5GCity which allows to manage a network infrastructure to host any entity that uses it to provide its services to its end users. In this model, the “Neutral Host” (infrastructure owner) is able to operate a partition of its resources and to arrange them in a set of homogeneous tenants (or slices). Following this business model, future operators will interact with the following actors in order to monetize 5G investments and increase their revenues from MNOs and vertical industries.

The 5GCITY platform is the core engine to implement the Neutral Host functionalities. It is a software suite which allows complete lifecycle management of end-to-end network services dynamically created over heterogeneous city infrastructures. The 5GCITY platform is composed of the following main elements:

- **5GCity /Orchestrator** is the core entity of the platform, which handles the complete life-cycle management of the network services, providing the suitable degree of abstraction between resources as exposed by hardware layer and services as intended by end-users.

- **5GCity Dashboard** is the main operational interface allowing 5GCity users (vertical or service providers) to deploy network services over on owned set of network slices.
- **5GCity VIMs** are the entities which acts as intermediary between the orchestrator and the physical resources located at various levels (Core VIM for data center level, Edge VIM for network edge level, and Extended Edge for devices level).
- **5GCity NFVIs** are thin layers deployed over the pool of hardware resources and acting as agent for the configuration of the physical resource management (on the three levels, similarly to the VIMs).
- **SDN controllers** are the functional entities which provide suitable control plane operations.

To ease the design and development of applications and services on this orchestration layer it is essential to

- Expose powerful APIs through which it is possible to access, define and program the different edge services and the orchestrator functionalities.
- Grant access via APIs and via a service Software Development Kit to a rich set of primitive functions for network and vertical application layer services (e.g. programmable connectivity with QoS, media acquisition, transcoding, traffic monitoring, security, etc.). These primitive functions can be composed to form the various service flows the vertical applications requires.

Service development kits are a fundamental component to open-up the virtualisation advantages to third party enterprises or individuals, also in terms of commercial relationships. Different SDK toolkits are just available within the NFV research (e.g. the COHERENT SDK, the SONATA SDK, etc.). However, most of these SDKs adopt a network-centric approach, aiming at defining and testing Network Services and VNFs before their instantiation in runtime MANO environments. 5GCity advocates for a more data-centric programming model based on Flow Based Programming (FBP), in which functional components can be assembled into applications by connecting them using pipes. Under this model, applications can adapt by rewiring components, adding/removing functions or changing their implementation. 5GCity is extending the FBP model by using smart-pipes, i.e. allowing in-network functions such as aggregation and filtering. This can allow edge services to adapt to resource availability, handle failures, and network configuration changes (for example, node migration).

In 5GCity, SDN/NFV network solutions, multi-access edge computing (MEC), and optimized lightweight virtualization platforms are all integrated to manage and orchestrate the distributed 5G platform deployed in the city. In fact, other important features offered by the 5GCity architecture include:

- The ability to allocate or deallocate resources (Network slices and MEC nodes) to the Service Providers according to their own SLA (QoS, etc.)
- The ability to dynamically reallocate resources to the Service Providers to align with the changing needs of different users and applications
- The ability to reduce per-VM memory footprint (down to MBs or even KBs);
- The ability to shorten creation times to support just-in-time deployment of virtualized applications (e.g., in 100 of ms or less) and migration times (down to 100 ms or less).

5GCity is working on these optimizations to allow to run a much larger number of VMs than currently possible on resource constrained devices (e.g., in the order of tens or more depending on the device). 5GCity will further provide a tool for generating minimalistic, specialized VMs (a.k.a. unikernels) in order to provide low overhead, virtualized edge applications in an automated way.

2 Pilots in 5GCities and use cases

5GCity is building city-wide pilots implementing three different types of use cases, which simultaneously take place in dense environments such as the cities and that need to co-exist and share the ICT infrastructure with different requirements: (i) neutral host; (ii) media industry use cases; and (iii) waste management through video analytics.

The **5GCity Neutral host use case** implements the category of telecom operator driven use cases. It will leverage on orchestrated core/edge virtualization platforms in order to enable the cities to create dynamic end-to-end slices containing both virtualized edge and network resources and lease it to third-party operators. For example, a 5G radio operator can become a service provider in cities where it does not have infrastructure, with full management and control capabilities over the slice, further than the typical MVNO use case.

The second scenario (**Industry vertical**) is strictly related to different aspects of the media and entertainment industry and encompass all the Use Cases pivoting around video acquisition, editing and delivery. Three different media Use Cases are taken into account in 5GCity:

- Mobile real-time transmission
- UHD video distribution
- Real-time video acquisition and production in edge cloud.

Instead the third scenario (**City Services**) is tailored to the specific needs about security and surveillance of the territory in Smart Cities. 5GCity exploits the cities' surveillance cameras and Video Analytics based applications that can process video streams close to the acquisition cameras to rapidly identify illegal waste dumping, violation of accesses, etc.

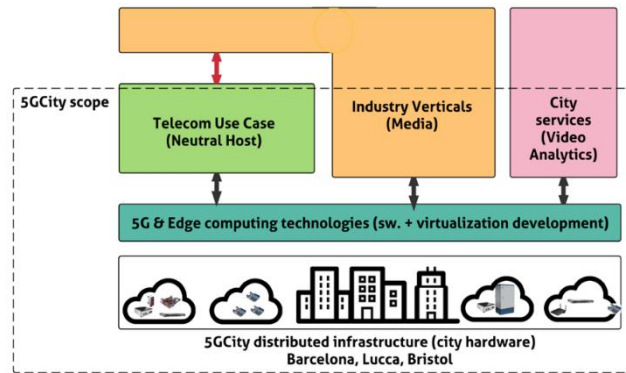


Fig. 3: 5GCity Use Cases Overview

Fig. 3 below depicts the logical perspective of the different use cases in 5GCity which are being implemented and deployed in the cities of Barcelona, Bristol and Lucca as pilot demonstrators. Six Use Cases have been identified corresponding to the three vertical categories covered by 5GCity. Pilots for these use cases will be developed in the three cities involved in the project as summarized in TABLE I.

TABLE I. 5GCITY USE CASES AND SELECETED CITIES FOR PILOTS

ID	Use Case Name	City
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		Barce- lona	Bris- tol	Lucca
UC1	Unauthorized Waste Dumping Prevention	-	-	Yes
UC2	Neutral Host	Yes	Yes	Yes
UC3	Video Acquisition and Production Community media engagement in live events	Yes	Yes	-
UC4	UHD Video Distribution Immersive Services	-	Yes	Yes
UC5	Mobile Backpack Unit for Real-time Transmis- sion	Yes	-	-
UC6	Cooperative, Connected and Automated Mobil- ity (CCAM)	Yes	-	-

3 Contributions from Italian partners

In 5GCity, a solid group of Italian partners is leading the pilot validation activities in Lucca and the supporting 5GCity platform development activities.

Nextworks is the Technical Manager of the project from Nov. 2018 and has an active role in the 5GCity architecture design, in the specification of the various NFV MANO interfaces, and is leading the activities related to the design and development of the 5GCity SDK. Nextworks also participates in the configuration of the 5GCity infrastructure in Lucca and in the development of the video surveillance elements for the Unauthorized Waste Dumping Prevention Use Case.

Comune di Lucca, is the owner and maintainer of one of the three main pilot sites of the project, directly involved in the activities of specification of the use case and infrastructure requirements, classification and prioritization. Comune di Lucca has the particular role of validator of the Unauthorized Waste Dumping Prevention Use Case.

Italtel, coordinates the definition and specification of the 5GCity use cases and architecture, as well as system high-level interfaces, workflows and business models. Moreover, Italtel contributes to the Virtualization and VNF data models on MEC nodes, to the orchestration platform, including the related SDK, and to the usage of machine learning techniques for improving service deployment. Italtel is involved in the integration and validation activities of the 5GCity pilots, particularly in Lucca. Moreover, Italtel is leader of the 5GCity Innovation Board.

RAI, as broadcaster, operator of terrestrial and satellite networks, and media content provider in Italy, is developing the use case on UHD video distribution and immersive services. RAI is using advanced video acquisition devices (e.g. 360 degree cameras) and a set of services for 4K/HDR video distribution to allow the end-user to move in a city to obtain and immersive experiences in cultural places like the City of Lucca.

Wind Tre, contributes to define 5GCity solutions requirements and use cases. In Lucca Wind Tre is offering the spectrum for use case tests and contributes to the verification, and testing of the 5GCity components over the city-wide infrastructure.

Comunicare Digitale, contributes to the definition of the innovative UHD/4K offering as digital services in the 5GCity pilot in Lucca, engaging 5G smart user groups and evaluating results, reactions, and feedbacks. CODI is also the leader of the 5GCity communication activities.

References

- [1] H2020 5GCity Project web site, [Online]. Available: <http://www.5gcity.eu/>, Accessed on: Oct. 2018
- [2] 5GCity Deliverable 2.1 - 5GCity System Requirements and Use Cases, December 2017
- [3] 5GCity Deliverable 2.2 - 5GCity Architecture & Interfaces Definition, June 2018

5G-MEDIA: Programmable edge-to-cloud virtualization fabric for the 5G Media industry

Francesca Moscatelli, Giacomo Bernini, Pasquale Andriani and Giuseppa Caruso

Abstract The 5G PPP Phase 2 5G-MEDIA project innovates media applications to exploit the capabilities of the underlying 5G networks and develops an integrated SDN/NFV-based Service Virtualization Platform for the lifecycle management and monitoring of media services in 5G networks.

1 Project objectives and architecture

Media applications are amongst the most de-manding services in terms of resources, requiring huge quantities of network capacity for high bandwidth audio-visual and other mobile sensory streams. 5G-MEDIA (<http://www.5gmedia.eu/>) aims at innovating media-related applications by investigating how these applications and the underlying 5G network should be coupled and interwork to the benefit of both. The 5G-MEDIA framework leverages on SDN/NFV tools and concepts for offering an integrated Service Virtualization Platform (SVP) capable of handling the lifecycle management (LCM) and monitoring of media services and

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applications in 5G networks. In particular, the project's main goal is to deliver an integrated programmable platform solution for the development, design and operations of media applications in 5G networks by providing mechanisms to flexibly adapt service operations to dynamic conditions and react upon events (e.g. to transparently accommodate auto-scaling of services, VNF re-placement, etc...). The whole 5G-MEDIA framework, as depicted in Fig. 1 includes:

- an SDK tool for developing, validating and testing media-oriented services,
- a generalized 5G Apps and Services Catalogue capable of validating and storing heterogeneous 5G application and service descriptors and translating them in NFVO-specific descriptors,
- an SVP including an ETSI MANO framework integrated with a Monitor Adapt Plan and Execute (MAPE) component for an automated LCM of media services based on collected and aggregated monitoring data,
- different Network Function Virtualization Infrastructures (NFVIs) comprising the "Physical Layer" that provide computing resources by different operators and supporting different cloud technologies to allow the instantiation of generic and media-specific VNFs, depicted at the "Virtualized Resource Layer", closer to the user (edge computing paradigm) host.

Furthermore, the 5G-MEDIA platform enables the application of Function-as-a-Service (FaaS) to VNF management, complementing traditional VM based VNFs with FaaS based media specific functions, aiming at dramatically reducing development cycles and slashing operational costs to 5G-MEDIA users. The combination of the FaaS approach with the VNF packaging and the enablement of inserting FaaS VNFs in a typical VNF forwarding graph is one of the main innovation aspects of the proposed 5G-MEDIA approach. Another specific innovation of the 5G-MEDIA project is the integration of the 5G-MEDIA MAPE and the related monitoring components able to gather NFVIs, VNFs and applications metrics within the SVP. The Cognitive Network Optimiser (CNO) within the MAPE is able to respond on dynamic changes of the environment (e.g., location change of end users, varying QoS demands) and to adapt the deployment of VNF forwarding graphs seamlessly to continuously meet expected QoS requirements.

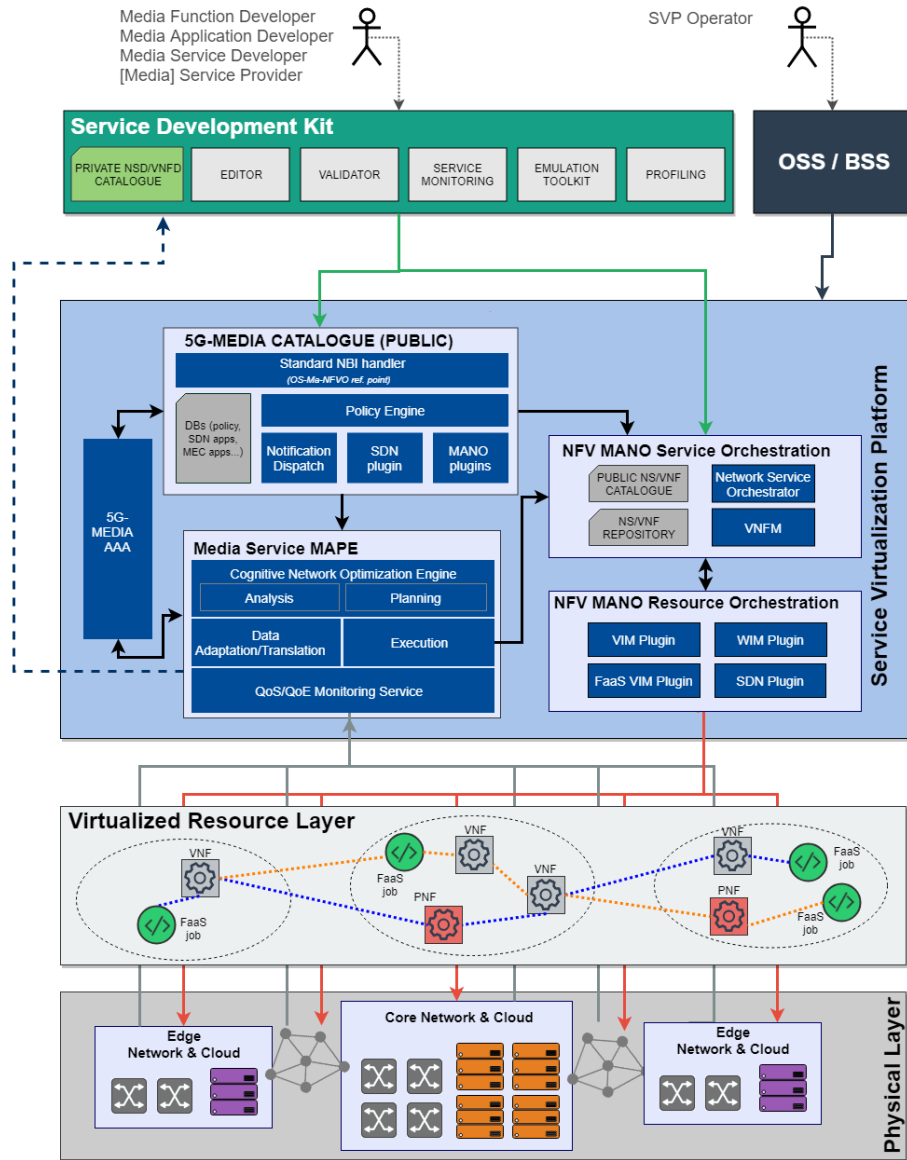


Fig. 1 5G-MEDIA Architecture

The 5G-MEDIA DevOps framework will be demonstrated through three media industry-oriented use cases.

Use case 1 - Immersive media and Virtual Reality

GOAL: Ensure the Quality of Experience of users in real-time, interactive multi-party 3D immersive media applications.

MAIN BENEFITS: Tele-Immersive applications can elevate the feeling of presence and enhance remote interaction, collaboration and communications.

Use case 2 - Smart Production and User-generated Content

GOAL: Provide broadcasters with ad-hoc, scalable, flexible and time-saving production mechanisms for remote media content.

MAIN BENEFITS: Reduction in costs, time and complexity for content production, enabling exploitation of user generated media content.

Use case 3 - Ultra High Definition over Content Delivery Network

GOAL: Deliver new capabilities to distribute UHD content (4K and 8K) with an optimal consumption of resources.

MAIN BENEFITS: Enhanced security, better experience for end users and new market opportunities in content delivery.

2 Contribution of Italian partners

Two Italian partners are involved in 5G-MEDIA: Engineering Ingegneria Informatica and Nextworks.

Engineering - Engineering is the 5G-MEDIA project coordinator leading WP1 and will lead the definition of the 5G-MEDIA business models.

5G-MEDIA: Programmable
edge-to-cloud virtualization
fabric for the 5G Media industry

427

Nextworks - In 5G-MEDIA, Nextworks will work on micro-Cloud platforms and the NFV MANO components for media service delivery, with focus on the Open Repository and the generic Network Apps for 5G-MEDIA. Nextworks will also lead the validation activities related to the High Demanding UHD over Open CDNs Pilot.second section.

blueSPACE

Giada Landi, Marco Capitani

Abstract The blueSPACE project is a H2020 5G-PPP Phase 2 project that aims to develop novel technologies and architectures for the 5G fronthaul network, able to guarantee high capacity and flexibility in scalable infrastructures. blueSPACE exploits the optical Space Division Multiplexing (SDM) technology, proposing an SDM-based infrastructure with multi-core fiber, optical beamforming and analogue Radio-over-Fiber fronthaul, orchestrated through an SDN/NFV platform for service provisioning.

1 Project objectives, technical challenges and architecture

The blueSPACE project (<http://5g-transformer.eu/>) aims to exploit photonics technologies to address the increasing bandwidth demands expected in 5G fronthaul networks, while guaranteeing the flexibility, programmability and scalability required by 5G communication networks. The final goal is to develop an efficient 5G infrastructure supporting a 1000-fold increase in capacity compared to 4G, ultra-low latency and reliable connectivity for over 1 billion users and a deeper network programmability for automated adaptation and resources sharing.

blueSPACE proposes a fronthaul solution that combines the adoption of Spatial Division Multiplexing (SDM) and flexi-grid DWDM to exploit both spatial

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Nextworks

and spectral resources, integrating Analog and Digital Radio-over-Fiber (A-RoF and D-RoF) techniques. blueSPACE technologies can be integrated into optical access networks for 5G infrastructures using massive beam steering capabilities. On top of this novel fronthaul infrastructure, blueSPACE integrates an SDN/NFV-based management and orchestration platform that adopts Multi-Access Edge Computing (MEC) and Network Slicing concepts to deliver end-to-end services across radio, fronthaul/backhaul and core network segments.

blueSPACE addresses several technical and research challenges, as follows:

- Adaptation of DRoF schemes and ARoF techniques into SDM networks, with increased degree of integration and full compatibility between the two schemes.
- Development of advanced hardware components for (i) cost efficient ARoF transceivers; (ii) remote power distribution over SDM networks for efficient Remote Radio Units (RRUs) powering; (iii) spatial optical beam forming schemes, compatible with ARoF transceivers at the RRU; and (iv) compact SDM splitters and Multi-Core Fiber (MCF) adapters for advanced SDM-based Optical Distribution Network (ODN) designs.
- Implementation of algorithms and procedures for optimum allocation of the Baseband Unit (BBU) pools and edge applications (e.g. video analytics, data caching) at the Central Office (CO), with joint configuration of switching and interconnection in fronthaul and backhaul networks.
- Design of optimized interfacing elements between SDM technology and radiating elements in the RRU sites to enable massive MIMO and beam steering solutions for both DRoF and ARoF.
- Design and implementation of an SDN/NFV/MEC-based control and orchestration platform to support the deployment of virtual BBUs and edge functions in the CO, with integrated configuration of the SDM/WDM-enabled fronthaul and packet-based backhaul.
- Design and development of network slicing and multi-tenancy solutions, integrated with the virtualization of fronthaul/backhaul network resources, for deployment of services from different verticals over a shared infrastructure.

The solution proposed by blueSPACE for the fronthaul network architecture is depicted in Fig 1. Multiple cell sites are connected to a CO through an SDM/WDM-based ODN with ARoF and DRoF transceivers and Power over Fiber (PoF) devices to power the cell sites. The CO includes a pool of BBUs or Distributed Units (DU) connected to an array of ARoF and DRoF transceivers,

and an optical switch connecting the ARoF/DRoF transceivers to an array of Spectrum Selective Switches (SSS) for spectral multiplexing. Mixing SDM and flexi-grid DWDM, this architecture exploits the spectral and spatial dimensions in the fronthaul segment. The cell site deploys a spatial multiplexer/demultiplexer with some ports connected to several ARoF/DRoF transceivers (spatial channels) or one ARoF/DRoF transceiver (spectral channels).

At the CO, a small Data Center acting as an NFV infrastructure point of presence (NFVI-PoP) is adopted to deploy VNFs and edge applications (e.g. video analytics, data caching, location services.), exploiting the concept of Multi-Access Edge Computing. A packet network is adopted at the backhaul segment for the connectivity among the BBU/DUs, the small DC, and the optical metro/core network.

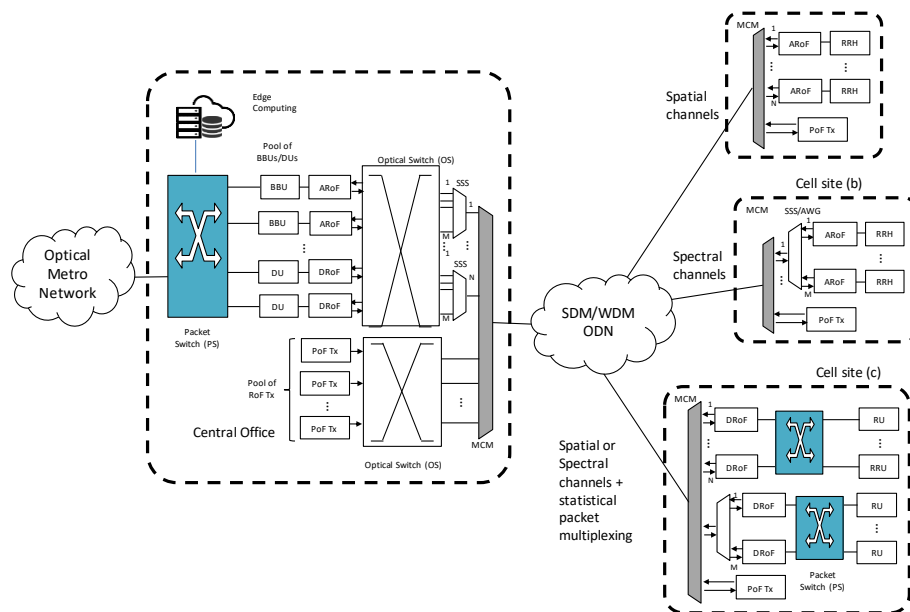


Fig 1. blueSPACE fronthaul network architecture

On top of this infrastructure, blueSPACE adopts an SDN/NFV platform which extends the concept of the ETSI NFV Management and Orchestration (MANO) framework to implement network service management and resource orchestration functions. In particular, the mechanisms for resource orchestration are extended

to support the integrated configuration of the 5G SDM/WDM-enabled fronthaul through a dedicated SDN controller.

2 Contributions from Italian partners

In blueSPACE, **Nextworks** (NXW) is leading the design and the development of the NFV Platform and Network Slicing solution. In particular, Nextworks has developed an NFV Orchestrator (NFVO) which integrates mechanisms for the configuration of the transport network via SDN controllers and for the orchestration of MEC hosts' resources to deploy MEC applications. In blueSPACE context, this NFVO interacts with an SDN controller operating over the SDM/WDM-based fronthaul and manages the MEC resources made available at the Central Office. On top of the NFVO, Nextworks is also developing a tool for management of network slices in a multi-tenant environment.

5G-CroCo

Gino Carrozzo, Giada Landi

Abstract The 5G-CroCo project is a H2020 5G-PPP Phase 3 Innovation Action project, started in November 2018, that will trial 5G technologies in the cross-border corridor connecting the cities of Metz-Merzig-Luxembourg, traversing the borders between France, Germany and Luxembourg to validate advanced 5G features such as 5G New Radio, MEC-enabled distributed computing, Predictive QoS, Network Slicing, and improved positioning systems, all combined together, to enable innovative use cases for connected, cooperative and autonomous mobility (CCAM).

1 Project objectives

5GCroCo will trial 5G technologies in the cross-border corridor along France, Germany and Luxembourg. In addition, 5GCroCo also aims at defining new business models that can be built on top of this unprecedented connectivity and service provisioning capacity. Ultimately, 5GCroCo will impact relevant standardization bodies from the telco and automotive industries.

The possibility of providing connected, cooperative and autonomous mobility (CCAM) services along different countries when vehicles traverse various

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national borders has a huge innovative business potential. However, the seamless provision of connectivity and the uninterrupted delivery of services along borders also poses interesting technical challenges. The situation is particularly challenging given the multi-country, multi-operator, multi-telco-vendor, and multi-vehicle-OEM scenario of any cross-border layout. Motivated by this, 5GCroCo brings together a strong consortium from both, European automotive and mobile communications industries, with the explicit support of road traffic authorities and the respective national governments (through letters of support), to develop innovation at the intersection of these two industrial sectors. The aim is to define a successful path towards the provision of CCAM services along cross-border scenarios and reduce the uncertainties of a real 5G cross-border deployment. 5GCroCo aims at trialling 5G technologies in the cross-border corridor connecting the cities of Metz-Merzig-Luxembourg, traversing the borders between France, Germany and Luxembourg.

The objective is to validate advanced 5G features, such as New Radio, MEC-enabled distributed computing, Predictive QoS, Network Slicing, and improved positioning systems, all combined together, to enable innovative use cases for CCAM. 5GCroCo aims at defining new business models that can be built on top of this unprecedented connectivity and service provisioning capacity, also ensuring that relevant standardization bodies from the two involved industries are impacted.

2 Contributions from Italian partners

In 5G-Croco **Nextworks** is working on core services for Network Slicing, multi-domain resource orchestration, configurable monitoring and edge computing orchestration, adaptations/developments on MEC related network services for tele-driving.

SELFNET

Giacomo Bernini, Pietro G. Giardina

Abstract SELFNET proposes an autonomic network management framework to meet the requirements of advanced self-organizing network (SON) capabilities for the 5G network infrastructure. In particular, a combined architecture that integrates SDN and NFV and network intelligence is provided.

1 Project objectives and architecture

SELFNET (<https://selfnet-5g.eu/>) provides an autonomic management framework based mainly on the combination of Software-Defined Networking (SDN), Network Function Virtualization (NFV) and network intelligence to provide self-organizing enhanced capacities to 5G networks. Following a use case driven design approach, SELFNET provides smart autonomic management of NFV and SDN functions in order to automatically resolve or mitigate network problems and improve the QoS/QoE.

The development of the SELFNET framework has been driven by the specification of three independent, ambitious use cases that have played crucial roles in realizing the highly autonomic network management capabilities required by 5G networks:

- Self-Protection Use Case: to detect and mitigate effects of cyber-attacks and restore 5G network traffic to steady state of security by means of dedicated SDN and VNF sensors and actuators (e.g. virtual DPIs, virtual honeynets, virtual IPSs) deployed and chained at different locations of the network

- Self-Healing Use Case: to detect and predict common failures and malfunctioning in 5G network infrastructures (at both hardware and software level, including infrastructure and operational issues) to apply reactive or proactive recovery measures by means of dedicated actuators
- Self-Optimization Use Case: to deliver high-quality video streams from a network media server to end users in a hotspot covered by a 5G network with guaranteed QoE, by detecting and mitigating network congestion effects through dedicated QoE video sensors and actuators

The SELFNET framework architecture enhances the ETSI NFV architecture approach and principles towards enabling self-organizing capabilities in 5G networks management, and is built around five differentiated layers with the following logical scopes (as shown in Figure 1):

- Infrastructure Layer: This layer provides the resources required for the instantiation of virtual functions (Compute, Network and Storage) and supports the mechanisms for that instantiation. It represents the NFVI (Network Functions Virtualization Infrastructure) as defined by the ETSI NFV terminology.
- Virtualized Network Layer: This layer represents the instantiation of the Virtual Networking Infrastructures created by the users of the infrastructure as part of their normal operational plan and those created by the SELFNET framework as part of the SON capabilities. The layer is composed by a number of network functions and applications interconnected in a designed topology in order to provide the functionalities required by the user
- SON Control Layer: This layer contains the applications that enables the collection of data from sensors deployed through the entire system (SON Sensors) and the applications that are responsible for enforcing actions into the network (SON Actuators) as part of the enabling mechanisms to provide network intelligence in 5G networks.
- SON Autonomic Layer: This layer provides the mechanisms to provide network intelligence. The layer collects from the network pertinent information about the network behaviour, uses that information to diagnose the network condition, and decides what must be done to accomplish the system goals. It then guarantees the organized enforcement of the actions that are determined. A Service Orchestrator plays a key role to glue the different monitoring, analysis, decision and action enforcing functions together and close the SON

control loop. Specific Onboarding features are also provided to equip the SELFNET framework with SON sensors and actuators network functions and applications.

- **NFV Orchestration & Management Layer:** This layer corresponds to the ETSI NFV Management and Orchestration layer, and provides its basic functions: NFV Orchestration, VNF Management, and Virtualised Infrastructure Management. The aim is to manage the lifecycle of SON sensors and actuators in a common and unified way.

In terms of applications, SELFNET accommodates a heterogeneous set of sensors and actuators network functions in support of the envisioned use cases (self-protection, self-healing, self-optimization). Several types of applications are supported in SELFNET, all grouped under the concept of “APP”, which is the SELFNET terminology used to represent all the network functions that can be onboarded to the SELFNET platform. An APP can be a Virtualized Network Function (VNF, or more generally NFV application) or an SDN application, according to the following definition:

- **NFV applications:** they implement in software either control or data plane network functions on top of a virtualized environment. Therefore, they are control plane VNFs or data plane VNFs managed by a cloud management system, like OpenStack;
- **SDN applications:** they are software applications implementing control plane functions that are not virtualized network functions, and can even possibly run directly on top of a physical infrastructure. When these applications are deployed within the same runtime environment of an SDN controller, they are referred as SDN Controller Apps; on the other hand, when they are deployed and instantiated outside the runtime environment of an SDN controller they are referred as SDN-Apps.

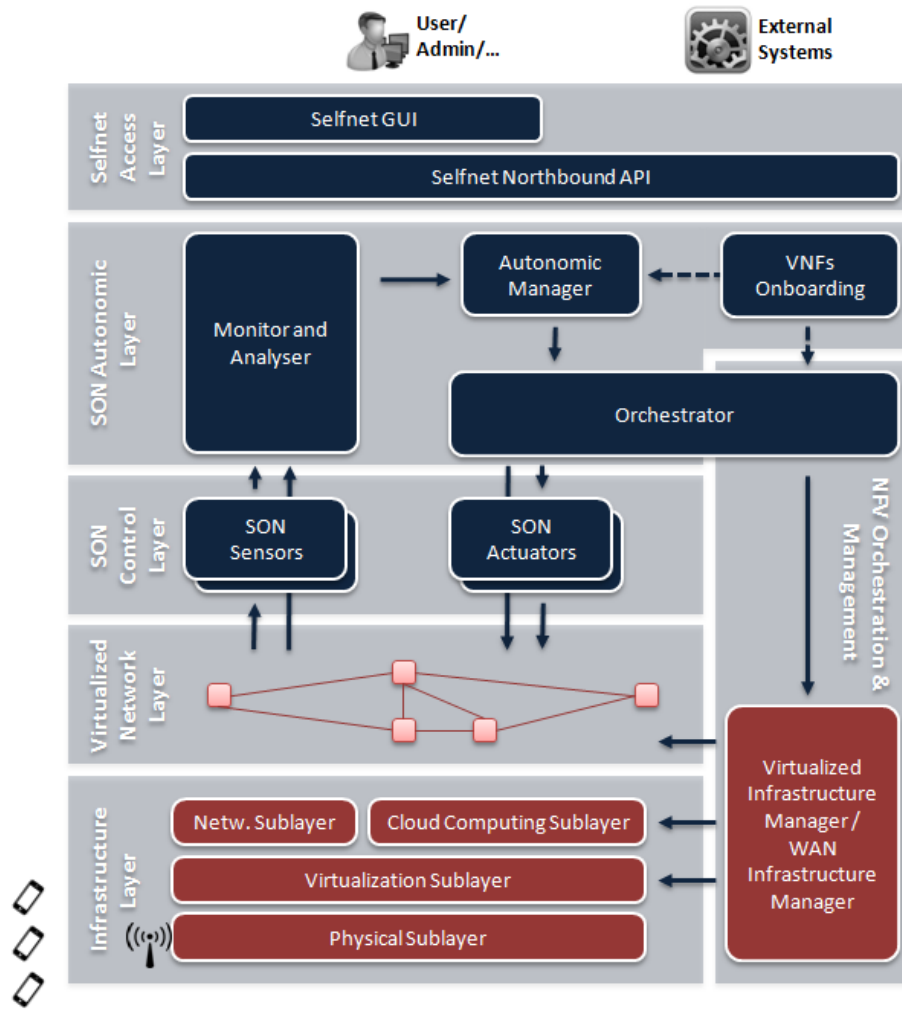


Figure 2 SELFNET reference architecture

2 Contribution of Italian partners

One Italian SME was involved in SELFNET, Nextworks.

Nextworks actively contributed to the definition and implementation of the self-protection use case, with main focus on development of the related VNFs and SDN applications. In particular, Nextworks provided the full NFV packaging of a virtual IDS based on Snort, and a virtual Honeynet function including embedded lifecycle management agents for Day1 and Day2 configuration of the VNFs. Moreover, Nextworks developed an SDN application for selective network flow control to be used in the context of the self-protection use case to support selective mirroring, diversion and drop features. In addition, Nextworks developed the Selfnet App Catalogue, that maps to the onboarding component in the figure and provide a full catalogue service for one-click and automated onboarding of VNFs, SDN applications and PNFs in the Selfnet platform, with a common model and approach following the ETSI NFV principles.

SliceNet

Giacomo Bernini, Pietro G. Giardina, Ciriaco Angelo, Cosimo Zotti

Abstract SliceNet implements a modular framework for the management and control of network slices in multi-domain 5G infrastructures, allowing verticals to easily customize, configure and monitor their slice services.

1 Project objectives and architecture

SliceNet (<https://slicenet.eu/>) aims at defining a vertical-oriented, Quality of Experience (QoE)-driven network slicing framework that focuses on cognitive network management and control of end-to-end network slicing operation and slice-based (and slice-enabled) services in 5G networks. An effective and efficient orchestration, management and control of 5G network slices is crucial for delivering a wide plethora of services customized for heterogeneous vertical businesses with often diverging requirements for Quality of Service (QoS), QoE and Service Level Agreement (SLA) at large. As a further challenge, SliceNet also tackle network slicing in multi-domain and cross-provider environments, therefore requiring additional and dedicated composition logics (at orchestration, management and control levels) for slice providers to offer and deliver to verticals end-to-end slices while abstracting the details of different providers involved.

While network slicing is being recognised as a fundamental technology in the emerging softwarised and virtualised 5G mobile networks to enable independent

Giacomo Bernini, Pietro G. Giardina - Nextworks
Ciriaco Angelo, Cosimo Zotti - Ericsson Telecomunicazioni

end-to-end logical networks on a shared physical infrastructure, still verticals and slice consumers role and involvement in the runtime control and management of their slices is very limited. In this context, SliceNet aims at going beyond this current practice by targeting a high involvement of verticals and slice consumers in all the phases of the end-to-end slice lifecycle, from slice/service definition, to provisioning and runtime control and management. The main SliceNet idea refers to the “Vertical-in-the-Loop” concept, that can be considered as one of the main innovative principles proposed. With SliceNet, verticals and slice consumers are able to have access to their slices and have the possibility to play on top of them through a set of tailored control operations.

SliceNet lays its foundation on a set of key innovations: Network Slicing, One-Stop API, Plug & Play control, Cognition and Cross-Plane Orchestration. The overall architecture is highly based on based on Software-Defined Networking (SDN) and Network Function Virtualization (NFV) technologies, and it is built around three main logical planes (as depicted in Figure 1):

- Management Plane: encompasses all the mechanisms related with the design, deployment, provisioning, configuration, supervision and decommissioning of network resources, slices and services;
- Control Plane: includes the mechanisms required to guarantee that the configurations applied by the management plane are respected and executed during the slice and service delivery/run-time;
- Data Plane: responsible for processing and forwarding packets between network elements.

One of the most important concepts of SLICENET is the capability to apply cognitive management through enhancing an autonomous, policy-based, closed loop with machine learning capabilities. Two main policy-based autonomous closed loops are foreseen within the SLICENET system architecture:

- Cognition Closed Loop & Autonomous Management Closed Loop:
 - a) this policy-based closed loop involves the Monitoring, Cognition and the Orchestration Sub-Planes and is used for longer term proactive management procedures, such as QoE/performance scenarios;
 - b) besides implementing the autonomous management closed loop described in a), this loop also includes the intelligent, e.g. machine-learning, procedures which, as a result, can update or create new policies for both the autonomous management closed loop (described in a)) and for the autonomous control closed-loop;

- Autonomous Control Closed Loop:
 - this policy-based closed loop involves the Monitoring, Control and Orchestration Sub-Planes and is used mostly for real-time sensing and actuation on the network. It is based on policies and models fed by the Cognition Sub-Plane.

SliceNet will demonstrate its verticals-oriented, QoE-driven network slicing framework through three vertical use cases:

- SmartGrid: it implements an advanced self-healing solution for electric power grids for protection coordination, automatic reconfiguration and differential protection;
- SmartCity: it implements a smart lighting service in a Smart City, over a 5G infrastructure, with slicing support, from IoT devices to the smart lighting cloud application
- eHealth: where a connected ambulance acts as a connection hub for the emergency medical equipment and wearables, enabling storing and real-time streaming of video and scanned data to the awaiting diagnostic team at the destination hospital.

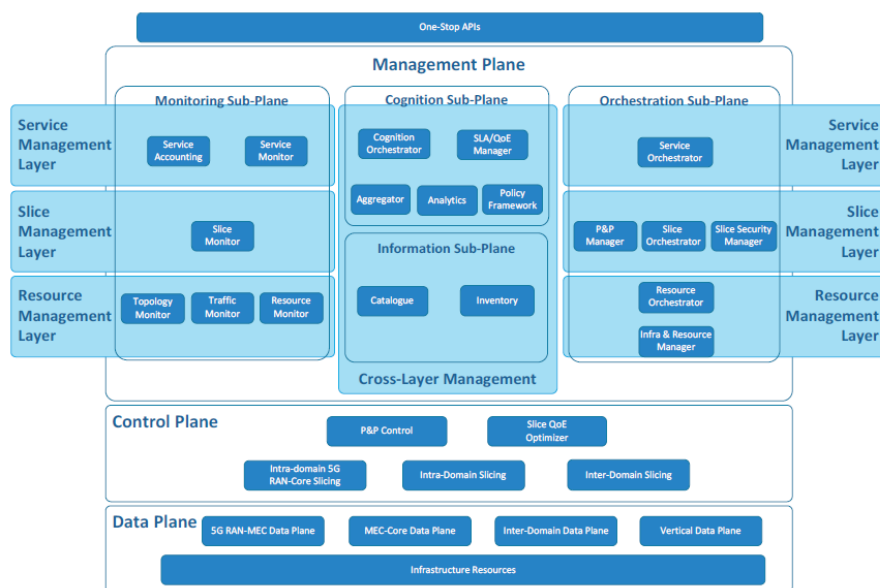


Figure 1 SliceNet logical architecture

2 Contribution of Italian partners

Two Italian partners are involved in SliceNet: Ericsson Telecomunicazioni and Nextworks.

Ericsson Telecomunicazioni as part of Ericsson Company, world leader providing communications technology and services to enable 5G Networks, is contributing to SliceNet with its strong background on SDN, NFV and telecommunication networks. Focus is on overall system architecture with specific effort on design, implementation and integration of the: i) control mechanisms of 5G Radio and Core Networks in order to achieve dynamic network slicing configuration in a virtualised multi-tenant mobile edge computing environment, ii) functionalities and modules to constantly monitor failures and to perform automatic re-configuration of the resources for each slice. Microservices and Containers technology are used for all produced SW modules.

Nextworks is bringing in SliceNet its long-term experience and proven background on SDN and NFV, focusing its contribution towards all the aspects related to network slice orchestration and vertical slices customisation. In practical terms, Nextworks is developing the Plug & Play control framework, following a micro-service and containerized applications approach implemented with Kubernetes, to offer vertical-tailored slice control instances to verticals, as isolated control environments where customized control functions and logics are plugged to build a truly tailored slice view with tailored runtime control features. Nextworks is also actively contributing in the design and implementation of the Service and Slice orchestration tools for combined coordination of end-to-end network slices and NFV Network Services in support of the SmartCity, SmartGrid and eHealth vertical use cases.

5G Research in Nextworks

Nicola Ciulli

Abstract The deployment and availability of 5G technologies are going to have an impact on the way we develop and market our current product lines in the area of Building Management Systems, Smart Buildings, and on the future ones in Smart Factory.

1 5G impact on our products and business

During its lifetime, Nextworks has developed and commercialized a range of innovative products and solutions in the domain of facility control and automation, from luxury yachting to residential / office building. The current focus of Nextworks' product lines is in *Building Management Systems*, and solutions for *Smart Buildings* and *Smart Neighborhoods* at large. These encompass diverse systems for comfort, entertainment, network, security, remote management, energy management, works management and communications.

The advent and spreading of 5G technologies will have a strong impact on our production activity in at least two major ways: in the way we conceive and develop our technology solutions, and in the way we bring them to the market (i.e. business models and go-to-market strategies).

Nicola Ciulli
Nextworks

Concerning the technology aspects, 5G and its architectural enablers (e.g. SDN, NFV, MEC) are expected to have an impact on several subsystems in our Smart Building solution.

Virtualization of Smart Building functions. Some years ago we have started an R&D thread on the virtualization of some of the BMS functions, to run them outside the technical facilities located in the building (e.g. in the cloud), with the goal to maximize the utilization of IT resources and streamline building management operations in those cases where several buildings are under the same ownership or control. However, some of these functions (e.g. those related to lighting or other subsystems with hard real-time requirements) cannot deliver the right performance behaviors when running in the cloud. A mixed cloud/local virtualization approach provides the necessary architectural fix, and the adoption of Mobile Edge Computing principles are helping us implement it.

Indoor communication infrastructure. Small cell 5G solution can provide the next generation of building networking solutions, which are specifically important for the refitting of existing buildings (e.g. historical buildings, where a wired network cannot be deployed). Thanks to the availability of a mini C-RAN fully fledged radio architecture with the related benefits (e.g. MEC), 5G for indoor communication has the chance to surpass the solutions that are currently adopted, which are based on proprietary wireless automation solutions and/or Wi-Fi.

A second line of impact from the adoption of 5G on our business is our development of smart factory product lines. The technologies behind our current BMS / Smart Building products can be naturally and easily evolved towards solutions for some of the use cases in the factory of the future, in particular, those related to overall facility automation (lighting, HVAC), shopfloor automation and logistics in general. Our current plans already include this evolution, and the knowledge that we have developed in 5G control plane enabling architectures and technologies (SDN, NFV and MEC) can be instrumental in two ways: allow us to develop/integrate the necessary technologies, and help build our image in a brand new market domain.