METIS System Concept: The Shape of 5G to Come

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Abstract

Every new generation of wireless cellular systems starts with bold, high-level requirements and predictions of its capabilities, often detached from the concurrent work on detailed technological innovations and solutions to specific problems. To bridge this gap, and the framework for a 5G research agenda, the METIS project has developed a system concept. The essence of the concept is three generic services: extreme Mobile BroadBand (xMBB), ultra-reliable Machine-Type Communication (uMTC), and massive MTC (mMTC), as well as four main enablers: lean system control plane, dynamic Radio Access Network (RAN), localized contents/traffic flows, and a spectrum toolbox. The paper describes the most important system-level features that a 5G system must have to meet very diverse user requirements. Finally, it introduces the elements of new flexible architecture, based on Software Defined Networking (SDN) and Network Function Virtualization (NFV) that will serve as a basis to integrate the 5G technology components and protocols.

1 Introduction

The process of building a new wireless generation requires a synergy among three different abstractions:

Level 1. Objectives and requirements, often very bold, posed to the wireless systems over mid- and long term;

Level 2. System concepts that are aligned to meet the requirements and at the same time create the context for technical innovation;

Level 3. The detailed technology components of the new wireless system.

The project METIS is among the largest coordinated research efforts worldwide dedicated to 5G wireless technologies. At Level 1, METIS starts by specifying five 5G scenarios [1]: “Amazingly fast”, “Great service in a crowd”, “Ubiquitous things communicating”, “Best experience follows you”, “Super real-time and reliable connections”. METIS provides a further input to Level 1 by outlining the following 5G objectives [1]:

- 1000 times higher mobile data volume per area,
- 10 to 100 times higher typical user data rate,
- 10 to 100 times higher number of connected devices,

- 10 times longer battery life for low power devices,
- 5 times reduced E2E latency.

At Level 3, METIS works on a large number of innovative technology components, covering the physical, MAC/link and the network layers. The technology components are: frame structure, retransmission protocols, channel estimation, etc. that are optimized to meet various requirements, such as average rate, latency, reliability for a fixed rate, etc.

This paper presents the contribution of METIS to the 5G system concept, placed at Level 2. The system concept is converting the bold numbers of the technical objectives into operational requirements posed to the detailed wireless technology components. In addition, it indicates how the technology components can be combined to reach Level 1 objectives. For example, one requirement identified at Level 1 is to use the wireless connections to improve traffic safety and efficiency. The system concept that is instrumental to achieve reliable low latency connection is to use device-to-device (D2D) communication in combination with the cellular communication. This Level-2 concept creates a context for integrating and optimizing various Level 3 technology components and thus operationalizes the scenario "Super real-time and reliable connections". Similarly, the technology components are combined to reach the requirements of the other scenarios.

The paper is organized as follows. In the next section, we start our discussion on the system concept by identifying three generic 5G services and four main enablers. Section 3 presents several features that we expect to be present in the 5G wireless systems. This is followed by description of an open and service-oriented architecture in Section 4. Our conclusions are presented in Section 5.

2 The METIS System Concept

The 5G services will have very different requirements in terms of minimum data rates, latency, battery life, coverage, data volume, etc. The 5G METIS system concept is highly flexible and configurable in order to adapt to the large variation in requirements (rate, latency, number of devices) that occur in different scenarios. METIS envisions a user-centric 5G system concept based on multi-RAT (Radio Access Technologies) that provides improved Quality of user Experience (QoE) and reliability to both consumers and devices/machines.

2.1 The Three Generic 5G Services

The METIS concept envisions three generic services: *extreme Mobile BroadBand (xMBB)*, *ultra-reliable MTC (uMTC)*, and *massive MTC (mMTC)*. These services are depicted in Figure 1. For xMBB we emphasize the high rates and the increase of reliability as the rate goes to moderate; for mMTC we emphasize the massive number of devices; and for uMTC we emphasize the importance of very high reliability.

- **xMBB** provides increased data rates, but also improved QoE through reliable provisioning of moderate rates. Larger data rates are requested by high-demand applications, such as augmented reality or remote presence. Improved QoE is instantiated through the requirement to reliably provide moderate rates almost (>99%) anywhere/anytime and degrade the performance gracefully in terms of data rate and latency as the number of users increases. As seen from Figure 1, xMBB stretches from peak rates in the order of Gbps to moderate rates – in the order of tens of Mbps, where the latter are offered with very high reliability.

- **mMTC** provides connectivity for a large number of cost and energy-constrained devices. Sensor and actuator deployments can be in a wide-area for surveillance and area-covering measurements, but also co-located with human users, as in body-area networks. The main attribute of this service is the massive number of connected devices, as emphasized on Figure 1, where the required rates decrease as the number of devices grows significantly.
- **uMTC** addresses the needs for ultra-reliable, time-critical services, e.g., V2X (Vehicle-to-Vehicle/Infrastructure) applications and industrial control applications. Both examples require reliable communication and V2X additionally require fast discovery and communication establishment. The main attribute is high-reliability, while the number of devices and the required data rates are relatively low.

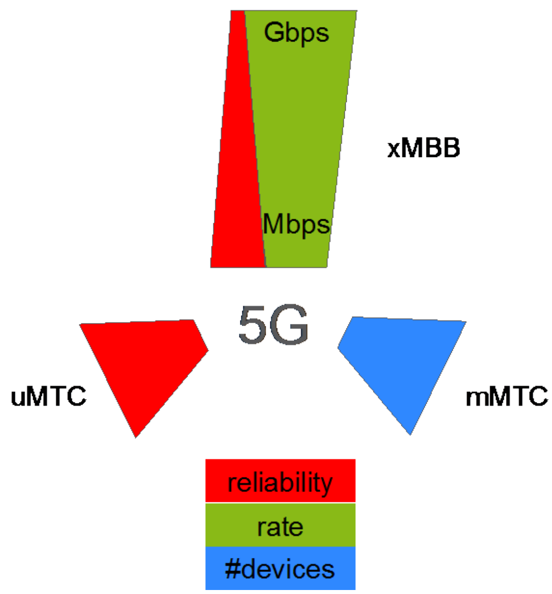

Figure 1. The three generic 5G services.

These services have very different requirements with regards to minimum data rates, latency, battery life, coverage, data packet size, etc. Different air interfaces would be suitable for the different services, which will be reflected in the relationship between the control data and the user data. Examples where the air interfaces will differ include the design of HARQ, scheduling, random access, paging, etc. These services would still dynamically share the same time-frequency resources, achieving efficient spectrum utilization. When introducing a new service an operator would not have to buy a new spectrum band and deploy a specific radio access technology for this purpose. Instead, in the 5G concept a new service could be introduced reusing the common components, for example mobility management functionality and upper layers, and dynamically expand radio resources over time as the service is becoming increasingly popular.

2.2 The Four Main Enablers

Today's networks integrate loosely different wireless generations and other, unlicensed, wireless technologies at the higher layers of the protocol stack. On the other hand, the heterogeneity across the three generic services implies 5G systems will tightly integrate diverse services closer to the terminal, which requires the following:

- Common control functions that enable integration among different variants of the interface;
- Control functions and metadata that is specifically optimized for xMBB, mMTC, or uMTC.
- Unified radio interface from which the interfaces of xMBB, mMTC, and uMTC appear as instances.

The key enablers towards creating a versatile 5G system that can support the three services are:

- *Lean System Control Plane.* It efficiently provides new signaling/control information that is necessary to guarantee latency and reliability, support spectrum flexibility, support large variety of devices with very different capabilities and ensure energy efficiency.
- *Dynamic RAN (Radio Access Network).* A revision of the traditional radio access infrastructure in order to include dynamic elements, such as rapid dense deployment of access points or nomadic access points. As the first 5G feature indicates, in dynamic RAN a wireless device may exhibit duality, being able to act both as terminal and as an infrastructure node. Dynamic RAN incorporates ultra-dense networks (UDN) and nomadic access nodes (mobile relaying does not exist up to now in 3GPP networks), and supports Device-to-Device (D2D) communication for local traffic offloading and backhaul.
- *Localized Contents/Traffic Flows.* Allows offloading, aggregation and distribution of real-time and cached content. Localization reduces the load on the backhaul and provides aggregation of e.g. sensor information.
- *Spectrum Toolbox.* This is a set of enablers (tools) to allow 5G systems to operate with unprecedented spectrum flexibility in existing and new bands, under different regulatory and spectrum sharing scenarios.

3 The 5G Features

This section describes a set of *5G features* as envisioned by the METIS 5G system concept. Some of the features are already present in 4G or even the earlier generations, such as e.g. the ongoing standardization of D2D connections [2][3] or Machine-Type Communication (MTC) [4]. However, we expect these features to mature within 5G and support the ambitious objectives set at Level 1. In fact, 5G wireless systems will contain three types of features:

- *Mature elements of the system concepts transferred from the previous generations*. These features will be carried into the 5G systems, with suitable adaptation. Examples include: wide-area coverage, efficient mobility support and energy-efficient terminal operation.
- *Emerging system concepts.* Some of those concepts are already deployed and operational, but are expected to mature in order to fit the 5G requirements and architecture. Examples include cloud RAN, offloading through local connections, etc.
- *Novel 5G-specific concepts.* These concepts include nomadic cells, ultra-reliable connections for critical control, D2D for relaying and aggregation of machine-type traffic, massive machine-type communications, flexibility and configurability across a large range of rate and latency requirements, etc.

3.1 Dual role of the mobile wireless devices

Traditionally, mobile wireless networks feature two node types: infrastructure nodes (access points, base stations) and terminal nodes (mobile devices). There has been a clear, predefined hierarchy of master nodes (infrastructure) and slave nodes (terminals) that is underlying any protocol pertaining to the establishment, usage and maintenance of a wireless link. As the processing/computing capability of the wireless devices increases, 5G networks will feature mobile wireless devices that float in the region between pure infrastructure and pure terminal nodes. The key enabler is the direct D2D communication, where certain radio network control functions are transferred to the device. A D2D-equipped device can have a *dual* role, illustrated in Figure 2, either act as an infrastructure node or as a terminal, such as:

- Vehicle acting as a terminal, but also as an access node of a nomadic cell.
- D2D relaying for range extension, improved capacity, longer battery life and confinement of the traffic to the local area instead of using resources over a wide area.
- Caching of popular contents in mobile devices, which puts them later on in a position to act as access node for wireless distribution of contents.

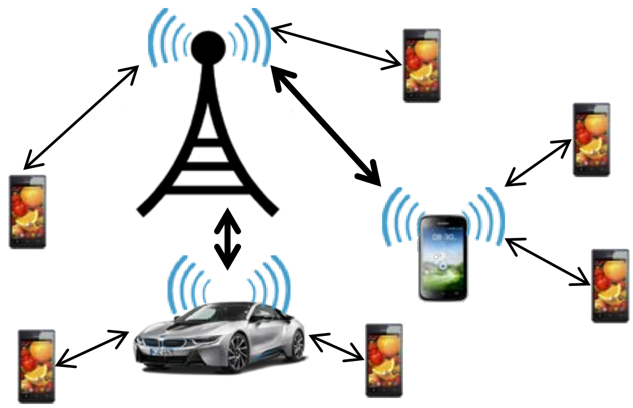

Figure 2. Examples of a dual role for a 5G device.

The dual role of a wireless device parallels the emerging concept of *prosumer* in smart energy grids, where a user can act both as a consumer and producer of energy. The dual role is primarily assigned to devices supporting very large or very reliable moderate rates, as in xMBB, as they will be similar in size and complexity to the infrastructure nodes. On the other hand, the MTC devices will be significantly simpler and cheaper from the high-rate devices. Hence, in 5G the difference between some infrastructure nodes and some device types will be much smaller than the difference across various device types.

3.2 Ultra-reliable links with low latency

5G systems will have to satisfy requirements, not supported currently, in terms of reliability and availability and enable applications such as traffic safety, automatic train control systems, industrial automation, and e-health services [5]. Two examples are illustrated in Figure 3.

For example, some traffic safety applications require information packets to be successfully delivered with very high probability, within a certain deadline. The failure to achieve this can seriously affect the well-being of the users relying on the traffic safety service. Achieving high reliability at all locations and all times would result in an overdesigned system and air interface that is inefficient in terms of data rate and power consumption. It is therefore necessary to carefully co-design the application layer and wireless link to guarantee safety while keeping the costs acceptable.

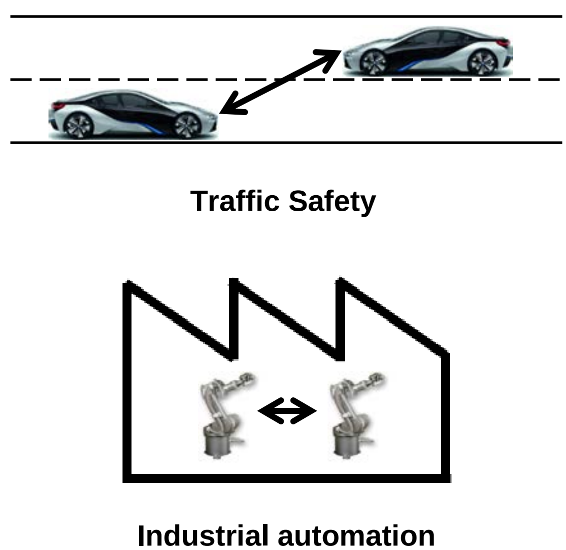

Figure 3. Two example scenarios that require ultra-reliable links with low latency.

As another example, industrial control requires Ultra-Reliable MTC (uMTC) that is capable to handle different kinds of traffic featuring periodic data, sporadic data and configuration messages. Periodic data is associated with inputs and outputs of control algorithms and must be delivered, with a high reliability, within a deadline. In general, the typical data packet is short and the bandwidth per node is low. Sporadic data, e.g. associated with alarms, must be delivered with a bounded latency, which may differ depending on the alarm criticality. Configuration messages are typically non-real-time, but require extremely high reliability of delivery.

In order to support reliable and low-latency (<10ms) connections within a relatively short range, 5G wireless systems will feature network-controlled D2D communication. The network assistance will enable efficient discovery, link-establishment, as well as optimized management of interference among the proximate interfering links. The use of wide-area networks connection makes this D2D communication mode fundamentally different from the other modes for short-range connectivity, such as D2D connection in unlicensed bands.

3.3 Guaranteed moderate rates and very high peak rates

The feature that is most commonly associated with 5G is the provision of extremely high rates to each user, ranging in the order of Gbps. However, from the user perspective, reliable provisioning of moderate rates (50-100 Mbps) is at least as important as maximizing the peak rates. This is often expressed as providing a certain minimum data rate "everywhere". Such a feature has the potential to introduce a new class of disruptive services, which are designed under the assumption that the wireless connection is "always there".

The reliable support for moderate rates is fundamentally different than extrapolating today's air interfaces to higher data rates, since e.g. 4G can be regarded as a technology optimized for high peak rates. The new transmission technologies, such as Massive MIMO, and the concept of ultra-dense deployments are instrumental for providing robust radio signal and maintain the desired Signal-to-Interference-and-Noise Ratio (SINR). High reliability means that moderate rates should be sustained when the wireless network is challenged, such as in crowded scenarios or under high mobility. For example, in crowded scenarios, the reliable moderate rates means that the system is capable to gracefully degrade the performance of each user instead of refusing service to some of the users. An important enabler of reliable moderate rates is the tight integration of multiple RATs, using optimized signaling/control information.

3.4 Wireless resilient to the lack of infrastructure support

The lack of infrastructure support in general occurs due to: (1) user mobility towards places with worsened or nonexistent network coverage; (2) equipment failure or infrastructure damages due to reasons like natural disasters. 5G systems should integrate the complementary use of network-controlled and pure ad-hoc D2D communications in order to offer minimal connectivity in emergency/disaster scenarios, and to satisfy the availability and reliability requirements for mission-critical applications (uMTC), such as road safety and public safety, in an efficient manner. Network-controlled D2D communication provides a significantly better performance than pure ad-hoc D2D communication as result of the superior resource allocation and interference management that can be achieved by the involvement of a central entity (i.e. base station). Nevertheless, critical applications must operate at some degree along the entire service area (e.g. the road network in the case of road safety applications), and not only in the presence of network coverage. The use of ad-hoc D2D communication is therefore essential to enable the communication between devices even in out-of-coverage circumstances. 5G networks are expected to feature mode selection schemes that manage the switching between different communication modes, such as ad hoc and network-controlled D2D mode.

The future 5G network shall also work in case of partial network failure caused, for instance, by a natural disaster. In this manner, the base stations or even the devices can adopt the role of a cluster head to form ad-hoc networks, and thus, enable local communication even if the connection to the core network is broken. To this purpose, limited core network functions could be preconfigured in the radio access network.

3.5 Increased cooperation among operators

5G services will require novel and more complex way of interaction and collaboration among the operators. Let us consider, as an example, the new services associated with V2X communication, supported by network-controlled D2D communication. Compared to a normal cellular operation, D2D requires changes in operating procedures especially considering communication among devices from different operators. Only when operators can cooperate more closely, and the devices or vehicle terminals from different operators can establish direct communication link among themselves, the D2D based solution can provide satisfactory performance, as show in Figure 4. Another example for inter-operator cooperation is spectrum sharing for improved interference management and coexistence.

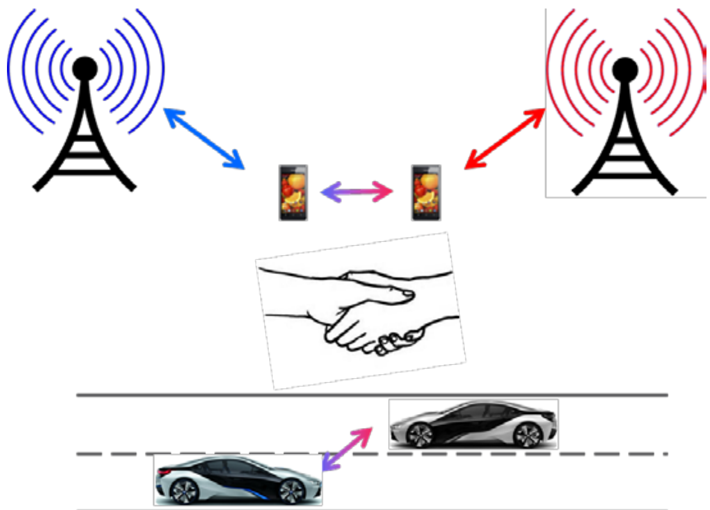

Figure 4. Situations where increased cooperation between operators is beneficial or even necessary to provide the desired service level.

There are different ways to increase cooperation among operators. One way to solve the problem is to have one network unit which is running independently to handle inter-operator issues including authentication, inter-operator service authorization etc. while another way is operator can exchange certain information via devices. Taking co-existence as one example, one operator can make decision based on the device measurement report where the measurement is done in the other operator’s NW.

3.6 Self-organized network follows the crowd

Self-organizing networks (SON) have been specified and defined in 3GPP featuring self-configuration, self-optimization, and self-healing functions. However, next-generation networks will show a new level of adaptivity that even goes beyond SON. One clear instance is the introduction of nomadic nodes [6], which will provide a very flexible tool for dynamic network deployment in order to respond to the user demand. In particular, a nomadic node describes a network node that provides relay-like communication capabilities. However, in contrast to a

traditional fixed or moving relay (as defined in 3GPP), there is an inherent uncertainty with regards to its temporal and/or spatial availability, i.e., a nomadic node may shut-down its service, change its geographical position and then become available again (hence, the term “nomadic”). For example, the on-board communications infrastructure deployed in future vehicles may serve for such purposes while the vehicle is parked since the density of cars is strongly correlated to the density of people i.e. follows the crowd. Although nomadic nodes are stationary, the inherent uncertainty with regards to their availability resembles a network that is “moving” or “movable”. While the location of operator-deployed relay nodes is optimized by means of network planning, nomadic nodes are randomly distributed and operate in a self-organized fashion. Furthermore, nomadic nodes are likely to cluster (e.g., parked vehicles) which allows for activating only those nodes that best serve the current capacity, coverage, load balancing or energy efficiency demands while causing least additional interference [7]. The dynamic deployment and activation of nomadic nodes requires a flexible backhaul. Wireless backhaul, either inband or outband, utilizing massive-MIMO in cmW/mmW and network coding are promising.
In this sense, future networks will “follow” the crowd (i.e., end users) as well as the demands of novel and revolutionary services.

3.7 Localized traffic offloading

Mobile data offloading from cellular to WiFi has been discussed for several years in order to cope with the exponentially increasing data traffic volume. 3GPP has been specifying mechanisms for WLAN and cellular interworking. Another technique that brings offloading gain is local opportunistic caching on clients rather than on servers and sharing.

Direct D2D communication is the key enabler for seamless and local traffic offloading in 5G networks. Network-controlled D2D communication offers the opportunity for local management of short-distance communication links, which allows separating local traffic from the global network. This will not only significantly unburden the load on the backhaul and core network caused by data transfer and signaling, but also reduce the effort necessary for traffic management at the central network nodes. Based on D2D communication, local data sharing zones can be easily set up, allowing real-time and cached content sharing by a large number of users without overloading the global network. This setup extends the idea of distributed network management by incorporating the end devices into the network management concept. The short distance transmission enables high-rate links with reduced power consumption, even if D2D is operated on the same carrier as the cellular network.

Another enabler for localized traffic handling is the establishment of local data sharing by means of wireless access points in dense deployments, which can coordinate the sharing process. For example, the local content interesting for the target crowd may be stored at nomadic nodes on-a-need basis. The use nomadic nodes, which follow the crowd, allows for operating local data sharing hotspots in an ad-hoc manner.

3.8 Unprecedented spectrum flexibility

Licensed exclusive use of spectrum builds the most important basis for good quality of service for end users and businesses. 3GPP is currently discussing to supplement the licensed spectrum for LTE with an unlicensed spectrum. However, as we are facing an exponential increase in the amount of wireless traffic, there is a need for novel approaches to the spectrum use, demanding unprecedented flexibility in allocating and using the spectrum in order to adapt to the opportunities and demands in space and time.

One approach is to build a set of tools to address the expected needs in the expected situations. Figure 5 shows the possible tools, i.e., technical enablers, and how they can be combined to address the right spectrum usage scenarios under the possible regulatory frameworks.

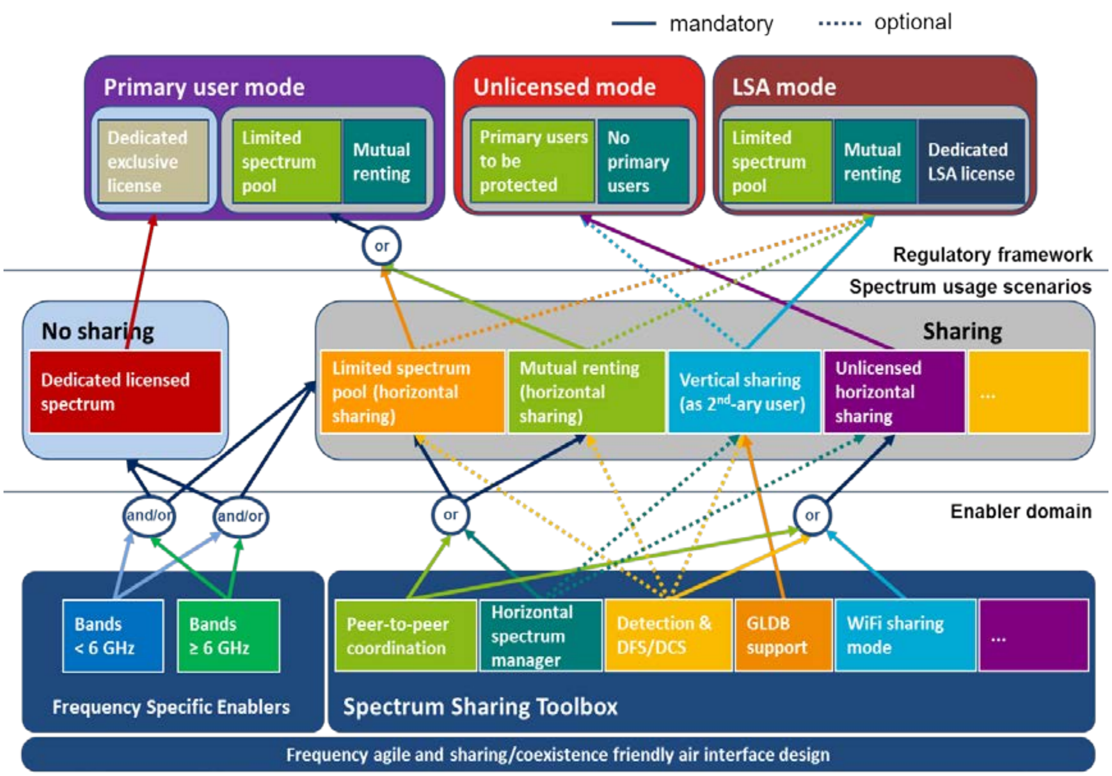

Figure 5. Illustration of the spectrum toolbox.

Use of radio spectrum can be authorized in two ways: *individual authorization (licensed)* and *general authorization (unlicensed).* The difference with the current notion of licensed/unlicensed use is much more refined rules for sharing, leading to complex spectrum usage patterns. Four main spectrum usage/sharing scenarios can be identified for these authorization modes (see Figure 5), spanning the region relevant for any future spectrum regulation:

- *Limited spectrum pool.* A limited number of known operators obtain authorizations to access a spectrum band on a shared basis
- *Mutual renting*. An operator rents at least part of its licensed spectrum to another operator, but has preemptive priority to its own licensed spectrum resources
- *Vertical sharing.* 5G systems are expected to be operating with lower spectrum access priority than primary users.
- *Unlicensed horizontal sharing.* This is similar to a classical unlicensed access with restrictions in power, time usage, use of Listen-Before-Talk, etc.

A number of enablers can be identified that, sometimes in combination, will address the expected technical requirements derived from the scenarios. The set of those enablers constitute the Spectrum Toolbox. Example enablers include: peer-to-peer coordination (spectrum negotiation and sharing between resource-compatible networks that implement the same coordination protocol), horizontal spectrum manager (resource usage between equal-priority networks), spectrum sensing, frequency-specific enablers above 6GHz (taking advantage of the specific physical properties of these higher frequencies), flexible usage of fragmented and dynamically changing spectrum opportunities.

3.9 Energy efficiency

The energy efficiency can be considered at a device side or a network side. However, with the dual role of the mobile wireless devices in 5G, the distinction between the two cases above will be blurred. As networks densification continues to meet the capacity demands, it becomes increasingly important to be able to activate and deactivate network nodes depending on the traffic load, or alternatively, to switch off some of the node functionality in low-load modes [8][9].

The energy consumption in today's networks is dominated by transmission of overhead signals, such as pilots, when no user data traffic is transmitted [8]. Improvements in network energy efficiency can be achieved by e.g., new lean signaling procedures, novel air interface designs, and network node activation/deactivation. A 5G system will integrate nodes with large and small coverage areas operating in different frequencies, e.g., macro cells below 6GHz and fixed and/or nomadic nodes in mmWs. This leads to a different split of the control and user planes. For xMBB it makes sense to split the C and U planes, to have control at a lower frequency and user traffic at higher frequencies for higher data rates [10]. For other services, e.g. mMTC a C/U plane split may not be desirable and it will therefore be a challenge to have xMBB and mMTC on the same carrier and hardware.

4 Open and Service-oriented flexible radio access network

The envisioned flexible architecture will provide the necessary means to realize efficient integration and cooperation of many technology components to fulfill the different requirements of the target services. The most important features of an open and service-oriented flexible architecture are:

- Focus on network functions (NFs) and their interfaces rather than on network nodes.
- Service-oriented flexible network configuration utilizing adapted NF Virtualization (NFV) and Software Defined Networking (SDN) approaches [11].
- Integration of any connected or connectable network element (NE) including device networks.

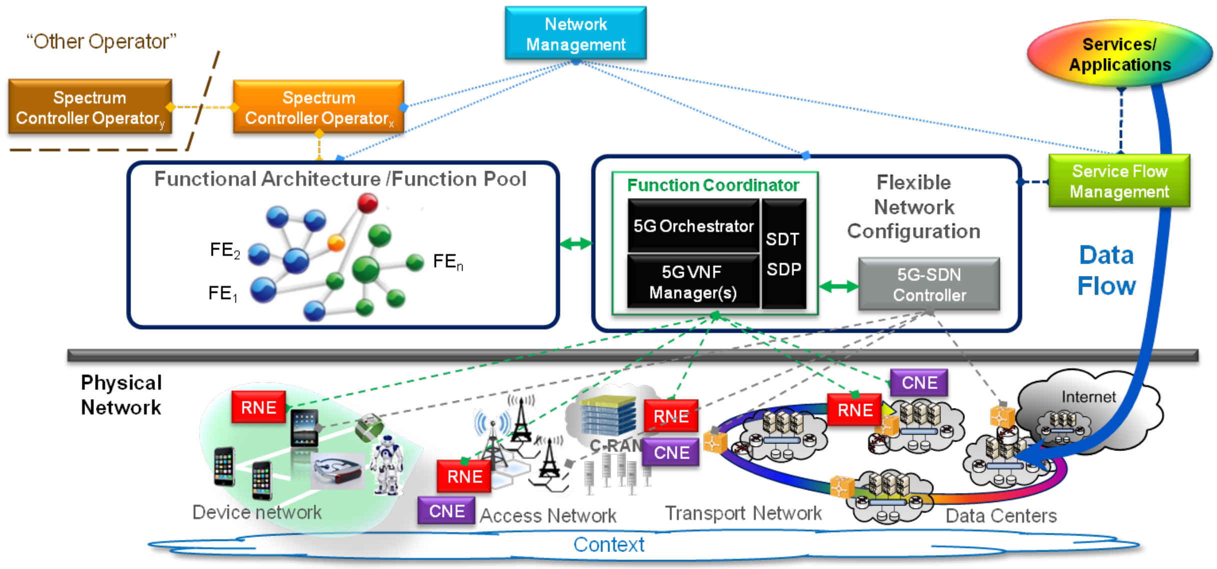

Figure 6. High-level logical view of open and service-oriented flexible architecture.

The 5G function pool (Figure 6) is a collection of data processing and control functions that are derived by functional decomposition of promising technologies, such as network-assisted D2D, massive MIMO, low-latency HARQ, etc.. Service-flow management analyzes the requested services and outlines the requirements for data flows of the target services through network. Instead of static assignment of NFs to NEs the function configuration is managed by a Function Coordinator comprising orchestrator and Virtual NF (VNF) managers. NF descriptions of the Function Pool as well as context information collected from the whole network are taken into account. In particular, there are NFs that comprise a set of Functional Elements (FEs) and operate synchronized to radio slots and frames, whereas others have more relaxed time constraints.

The time constraints will influence the flexibility of function placement within the network topology. NFs with tight timing constraints will have to be placed in the vicinity of antennas or at medium layers within the network topology (Cloud RANs, C-RAN) where Radio NEs (RNEs) can be flexibly configured to host NFs. NFs with relaxed time constraints may be operated in a centralized or distributed manner, according to service or operator needs. Similar to RNE, logical Core NEs (CNEs) will host mainly VNFs related to classical core responsibilities. Depending on the service needs, CNEs will not only be operated centrally but also at network edge (e.g., local break outs for latency reduction).

This architecture enables on-demand creation of customized virtual networks in a complex heterogeneous deployment. Software Defined Topology (SDT) manager is used to set up service-oriented logical control and data-plane topologies, while Software Defined Processing manager (SDP) configures RNEs and CNEs based on these logical topologies. Extended 5G SDN controllers for RNE will handle radio specific peculiarities, such as piggy backing of control and data streams in case of MTC, mobility management, etc.

The METIS system concept enables integration of any connected or connectable NE considering the network as a whole. As a consequence, certain functionalities of the user devices may be partially controlled by the operator, e.g. in case of D2D relaying. In addition to the current NFV and SDN concepts, novel 5G Function Coordinator needs to support NEs for virtualization, but also a mix of optimized components with accelerators, and simple software and hardware platforms, e.g., hardware-limited sensors that may not be updated with new functionalities and cluster heads that can employ device duality within dynamic RAN.

5 Conclusions

The development of 5G wireless systems is in its infancy and it is difficult to state precisely how the final system design options will look like. Yet, it is already possible to identify important services, enablers and features that will be present in, practically, any conceivable solution for a 5G system. The main objective of this paper is to give insights into the features, required flexibility, and the general architectural approach to the design of a 5G system. A theme that pervades multiple features is direct D2D communication, as its combination with the cellular network communication will lead to improvements in reliability and/or spectrum usage. The overall architecture follows the trend of SDN and NFV, adding functions and procedures specific to wireless mobile communication, such as resource allocation and mobility. We believe that this paper is shaping the 5G research agenda by setting a useful framework for innovation and optimization of specific wireless transmission techniques and protocols.

Acknowledgments

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