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The METIS 5G System Concept – Meeting the 5G Requirements

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***Abstract*—The development of every new generation of wireless communication systems starts with bold, high-level requirements and predictions of its capabilities. 5G system will not only have to surpass previous generations with respect to rate and capacity, but also address new usage scenarios with very diverse requirements, including various kinds of machine-type communication. Following this, the METIS project has developed a 5G system concept consisting of three generic 5G services: extreme Mobile BroadBand (xMBB), massive Machine-Type Communication (mMTC), and ultra-reliable MTC (uMTC), supported by four main enablers: Lean System Control Plane, Dynamic Radio Access Network (DyRAN), Localized Contents and Traffic Flows, and Spectrum Toolbox. This article describes the most important system-level 5G features, enabled by the concept, necessary to meet the very diverse 5G requirements. System-level evaluation results of the METIS 5G system concept are presented, and we conclude that the 5G requirements can be met with the proposed system concept.**

***Index Terms*—5G, 5G Features, 5G System Concept, METIS, Extreme Mobile Broadband, Massive Machine-Type Communication, Ultra-reliable Machine-Type Communication, Lean System Control Plane, Dynamic RAN, Localized Contents and Traffic Flows, Spectrum Toolbox, System-level Evaluation**

I. INTRODUCTION

EVERY new generation of wireless cellular systems starts with bold, high-level requirements and predictions of its capabilities. These requirements are often detached from the concurrent research work on detailed technological innovations and solutions to specific problems. The development of 5G follows the same pattern. 5G systems will not only have to surpass previous generations in requirements related to rate and capacity [1], but also address new usage scenarios, including various kinds of machine-type communication, with very diverse requirements on reliability and latency. The process of building a new wireless generation can be seen as a synergy among three different levels of abstraction:

Level 1. Objectives and requirements, often very bold, posed on 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 Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS) project has concretized the 5G requirements into the following technical objectives[1] [2]: **(1)** 1000 times higher mobile data volume per area; **(2)** 10 to 100 times higher typical user data rate; **(3)** 10 to 100 times higher number of connected devices; **(4)** 10 times longer battery life for low power devices; **(5)** 5 times reduced E2E latency. These objectives belong to Level 1, as described above. However, at Level 3, METIS also worked on a large number of innovative wireless technologies, covering the physical, MAC/link, and network layers. Detailed descriptions of the technology components developed in METIS are out of the scope of this paper, since the focus here is on the overall design of the 5G system.

The METIS 5G system concept, placed at Level 2, bridges the gap between the bold numbers and detailed research, and provides a framework for continued 5G research agenda. For example, one requirement identified at Level 1 is to use the wireless connections to improve traffic safety and efficiency. The system concept identifies and combines Technology Components (TeCs) that are instrumental to fulfill this requirement and achieve low latency; here to use reliable Device-to-Device (D2D) communication in combination with the usual cellular communication. This concept at Level 2 creates a context for positioning and optimizing various Level 3 TeCs in order to meet the end-user requirements.

METIS envisions a user-centric multi-RAT 5G system concept that provides improved Quality of Experience (QoE) and

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[1] The performance numbers are compared to the LTE Release 8 networks deployed when the METIS project started.

reliability to both consumers and devices/machines. The METIS 5G system concept consists of both new solutions and evolved versions of existing systems. The essence of the METIS 5G system concept is three generic services: extreme Mobile BroadBand (xMBB), massive Machine-Type Communication (mMTC), and ultra-reliable MTC (uMTC). We note that the METIS project was a pioneering effort that identified these three generic services, which in the fast-paced development of 5G have since been widely adopted, e.g. [3][4], which is the best possible acknowledgement of the METIS concept[2]. We advocate four main enablers of the generic services: Lean System Control Plane (LSCP), Dynamic Radio Access Network (DyRAN), Localized Contents and Traffic Flows, and the Spectrum Toolbox. Details on preliminary versions of the concept, focusing on the Horizontal Topics (HTs) are presented in [5][6], and details on the final version are presented in [7].

The proposed concept presented in this paper supports a set of system-level features that make 5G system meet very diverse user requirements. In order to further elaborate on the proposed concept, system-level evaluations of the METIS 5G system, the first ones to the best of authors' knowledge, are also presented in this paper.

The concept has been evaluated with respect to overall technical objectives, and the requirements and Key Performance Indicators (KPIs) set forth in [2]. We use these outstanding results to conclude that the proposed concept meets the 5G requirements. However, further refinements are necessary before standardization.

This paper gives the reader a clearer view of the fundamentals of the 5G and how it is technologically possible to reach the demanding requirements of the 5G. In Section 2, we briefly describe the METIS 5G system concept and its three generic 5G services and four main enablers. This description shows the realization of the vision presented in [2], where a set of use cases characterizing the 5G are presented. Then, Section 3 presents several features that we expect to be present in the 5G wireless systems, and some enabling TeCs. This is followed by the assessment of the METIS 5G system concept in Section 4, where we show that the 5G goals are met. Our conclusions are presented in Section 5.

II. THE METIS 5G SYSTEM CONCEPT

The METIS 5G system concept is highly flexible and configurable in order to adapt to the large variation in 5G requirements (rate, latency, number of devices, etc.) that occur in different scenarios. The proposed 5G system concept generalizes key characteristics of the use cases and aligns the requirements, and combines various TeCs into three generic 5G communication services, supported by four main enablers. The generic 5G communication services include functions that are service-specific, and the main enablers include functions that are common to more than one generic 5G service.

A. The Three Generic Services

Each of the generic 5G services xMBB, mMTC, and uMTC emphasizes a different subset of the 5G requirements, but all requirements are relevant to some degree to all generic services. The generic 5G services can be seen as the corners of a requirements triangle, and all 5G use cases as combinations thereof, as illustrated in Fig. 1.

- **Extreme Mobile BroadBand** 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. xMBB stretches from peak rates in the order of Gbps to moderate rates, in the order of tens of Mbps with very high reliability.
- **Massive Machine-Type Communication** 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.
- **Ultra-reliable Machine-Type Communication** addresses the needs for ultra-reliable, time-critical services, e.g., V2X (Vehicle-to-Vehicle/Infrastructure) applications and industrial control applications. The main attribute is high-reliability, while the number of devices and the required data rates are relatively low compared to mMTC.

The generic 5G services have very different requirements concerning minimum data rates, latency, battery life, coverage, data packet size, etc. Therefore, they will not necessarily have the same air interface. The preferred waveform depends on design decisions, relationship between the control data and the user data, and service mixing of the generic 5G services. The generic 5G services will still dynamically share the same time-frequency resources, achieving efficient spectrum utilization.

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[2] The names adopted by ITU-R and 3GPP are enhanced Mobile BroadBand (eMBB), massive Machine Type Communications (mMTC) and Ultra-Reliable and Low Latency Communications (URLLC), but the services are the same as envisioned by METIS.

B. The Four Main Enablers

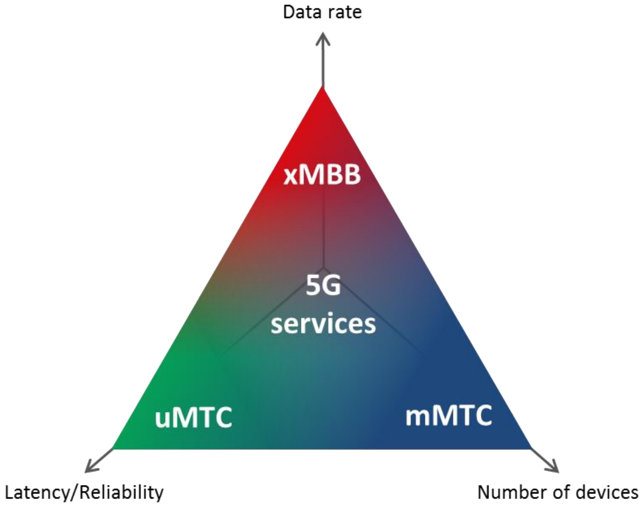

Fig. 1. The three generic 5G services emphasize different 5G requirements. The generic services should be considered as basis functions spanning the 5G use case space.

Today's networks integrate loosely different wireless generations and other, unlicensed, wireless technologies at the higher layers of the protocol stack. The four main enablers providing a versatile 5G platform that supports the three generic 5G services are:

- **Lean System Control Plane** providing new lean signaling/control information is necessary to guarantee latency and reliability, support spectrum flexibility, allow separation of data and control information, support large number and variety of devices with very different capabilities and ensure energy efficiency.
- **Dynamic RAN** providing a new paradigm in Radio Access Networks (RANs). In Dynamic RAN, the wireless device exhibits a duality, being able to act both as a regular terminal node and as an infrastructure node. Dynamic RAN incorporates Ultra-Dense Networks (UDN), nomadic access nodes, antenna beams and supports D2D communication both for local traffic (off-loading) and backhaul.
- **Localized Contents and Traffic Flows** allow offloading, aggregation and distribution of real-time and cached content. Localization reduces the load on the backhaul and/or provides aggregation of e.g. sensor information.
- **Spectrum Toolbox** contains a set of enablers (tools) to allow 5G systems to operate under different regulatory frameworks and spectrum usage/sharing scenarios. These spectrum sharing enablers are fundamental to design a flexible radio interface that is frequency agile, coexistence/sharing capable, and applicable to the developments in spectrum regulation.

The main enablers are closely related to the 5G system architecture that is flexible enough to emphasize different characteristics of the system, e.g. coverage, capacity, and low-latency [8].

III. THE 5G FEATURES

The METIS 5G system concept enables a set of 5G features, i.e., system properties that are different compared to previous generations, and allow novel services and new ways of communication. The 5G features are instrumental in providing the necessary versatility to support the large variety of foreseen 5G use cases. The 5G landscape in which the METIS system concept and the 5G feature reside is shown in Fig 2. The 5G features and a selection of the enabling TeCs are described in the following.

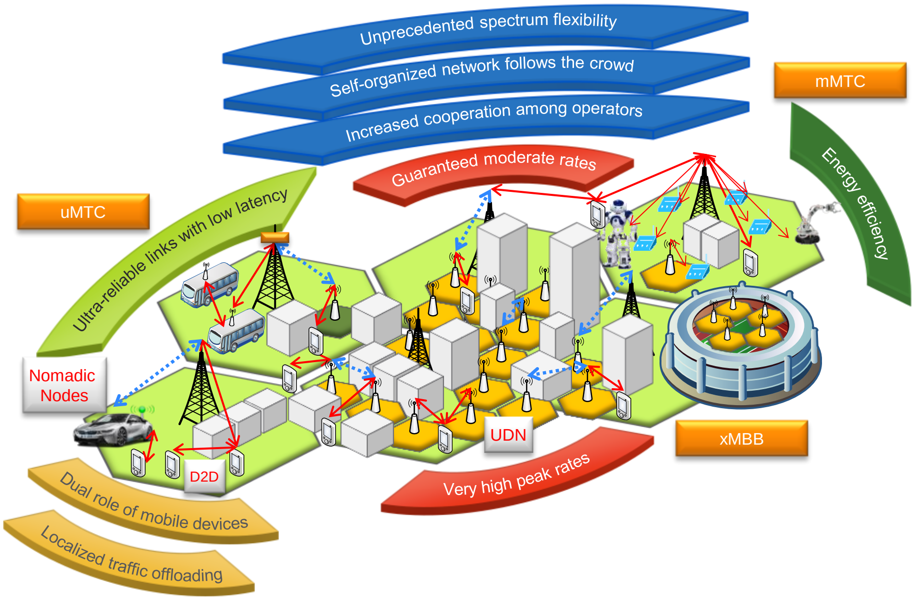

Fig. 2. The 5G landscape, features, and generic 5G services.

The reader may argue that some of the features are already present in 4G or even the earlier generations, e.g., D2D connections or MTC. However, we expect such existing features to mature within 5G and support the ambitious objectives set at Level 1 described in the introduction. In fact, it is expected that 5G systems will be realized by combining TeCs of three different types:

- Mature TeCs from previous generations with suitable adaptation, e.g. wide-area coverage, efficient mobility support and energy-efficient terminal operation.
- Emerging TeCs expected to mature in order to fit the 5G requirements, e.g. cloud RAN, D2D for relaying and offloading through local connections.
- Novel 5G-specific TeCs, e.g. nomadic nodes, ultra-reliable connections for critical control, and aggregation of machine-type traffic.

A. *Dual role of the mobile wireless devices*

Traditionally, mobile wireless networks feature two node types: infrastructure nodes (base stations, access points) and terminal nodes (mobile devices). As network densification leads to less complex network nodes and the processing capability of advanced wireless devices increases, the difference between a terminal and a network node will diminish. A device equipped with D2D capability can have a dual role, either act as a terminal or as an infrastructure node, 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 local-area traffic.
- 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.

Taken together, 5G networks are expected to feature nodes that float in the region between pure infrastructure nodes and pure terminal nodes. In this framework, new paradigms and tools for network deployment will be needed in order to cost-effectively deploy and manage such dense networks. As an example, nomadic nodes allow a temporary increase of network densification.

In vehicles equipped with two access points, one for outside transmission/reception and another for inside users, their best reception chain improves the link budget for the end user by up to 9 dB, in cases where the user is outside the car, and up to 24 dB, when the user is within the car [9]. This results in better coverage or higher user throughput, mostly at the cell edge.

It is noted, though, that D2D requires network control to support some important capabilities, such as interference management (hidden node problem), security, and service announcement overhead.

B. *Ultra-reliable links with low latency*

5G systems will have to satisfy novel requirements on reliability and availability, and enable applications such as traffic safety, automatic train control systems, industrial automation, and e-health services [10]. Traffic safety applications require information packets to be successfully delivered with very high probability, within a certain deadline. Enabling technologies include D2D/V2X communication and deadline-driven Hybrid Automatic Retransmission request (HARQ), but it is also necessary to carefully co-design the application layer and wireless link to guarantee safety while keeping the costs acceptable. Industrial control requires Ultra-Reliable MTC (uMTC) that is capable to handle different traffic types featuring periodic data, sporadic data and configuration messages. Reliable and low-latency (<10 ms) connections within a relatively short range are necessary.

D2D communication is one enabler in the reduction of the average latency. Since the network infrastructure is not involved in the data plane, latencies in the order of 1 – 2 ms can be achieved. Half of the traffic can be offloaded from the cellular system, which results in reduced average E2E latency. With a dedicated bandwidth of 80 MHz used for D2D link, the end-to-end latency is reduced to 60%, as compared with current LTE Release 8 system and using the same Transmission Time Interval (TTI) and assumptions detailed in [9]. Additional latency reductions are achieved through localized caching, see Section III.F.

C. Very high peak rates and guaranteed moderate rates

The feature that is most commonly associated with 5G is the provision of extremely high rates to each user. Under good conditions, data-rates in the order of Gbps should be provided in high-demand scenarios. The target on 10 – 100 times higher typical user data rate is linked to a corresponding target on 1000 times higher mobile data volume per area.

From the end-user perspective, provisioning of moderate rates – 50 to 100 Mbps – with high availability everywhere is at least as important as maximizing the peak rates. High reliability means that moderate rates should be sustained even in crowded conditions, in rural areas, or at high mobility. This allows a new class of disruptive services, designed under the assumption that the wireless connection is "always available". 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 seen as a technology optimized for high peak rates.

The key enablers to meet the target on very high peak rates include network densification, massive MIMO, and spectrum access and utilization. Massive MIMO and appropriate spectrum are also enablers of guaranteed moderate rates. For indoor deployments with ISD of 10 m, the capacity scales as 0.73 times the number of nodes, provided that centralized interference coordination [9]. Between 1 and 2.5 nodes per 100 m^2 are needed, depending on the available bandwidth and carrier frequency. For outdoor deployments, a single node for each 400 m^2 suffices. The capacity can be increased by a factor of 10 as compared with LTE Release 8, when increasing the available bandwidth with additional 100 MHz and using three times more nodes [9]. We foresee a network densification of 3 to 5 times compared to the baseline deployment.

To meet the requirements on very high data rates, additional spectrum is necessary in the range from 2350 MHz up to 8600 MHz. The 2350 MHz figure assumes maximal trunking efficiency (i.e., a single block of spectrum is available to all operators), no cost constraints on the level of possible densification, and the presence and utilization of additional technology components that improve spectral efficiency. The 8600 MHz figure assumes the same level of densification as today. Therefore, access to additional spectrum will be necessary, most likely above 6 GHz in order to find wider contiguous bandwidths. On the other hand, access to spectrum in lower frequency bands is essential to provide ubiquitous coverage in outdoor environments.

Massive MIMO can be used to reach both the very high data rate and the guaranteed moderate rate requirements. To satisfy the very high data rate requirement, massive MIMO must reach the 256x256 scheme [9]. Spectral efficiency can be increased by a factor of 20 with this setup as compared with 4x4 antenna systems. Of course, we do not foresee 256 antenna elements in the handheld terminal. In suburban and rural environments massive MIMO beamforming can increase the average SINR in an area.

D. Increased cooperation among operators

5G services will require novel and more complex way of interaction and collaboration among the operators. Compared to a normal cellular operation, the new services associated with V2X communication supported by network-controlled D2D, requires changes in operating procedures. 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. Another example for inter-operator cooperation is spectrum sharing for improved interference management and coexistence. Spectrum sharing is one example of increased cooperation among operators, cf. Section III.G.

E. 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 adaptability that even goes beyond SON. The 5G network will consist of traditional and new network node types that will be activated as needed to provide coverage and rate, e.g., of nomadic nodes [6][11]. Although nomadic nodes are stationary when serving users, there is an inherent uncertainty with regards to its temporal and/or spatial availability.

When not needed, any network node should be deactivated to reduce energy consumption and interference. Since the location of traffic hot-spots will change over time, this large number of candidate nodes gives the network the opportunity to flexibly adapt to the current requirements, and in that sense 5G networks will "follow" the crowd. Solutions for wireless self-backhaul are needed to support a self-organized network that follows the crowd. The benefits of wireless self-backhaul depend on the environment and the traffic profile of the intended use case. In indoor environments, wireless backhaul always provides capacity benefits in the uplink direction of the access link, but on the contrary reduces the downlink capacity [9]. However, this is a good solution for outdoor environments in which line of sight conditions apply by using frequency bands above 6 GHz.

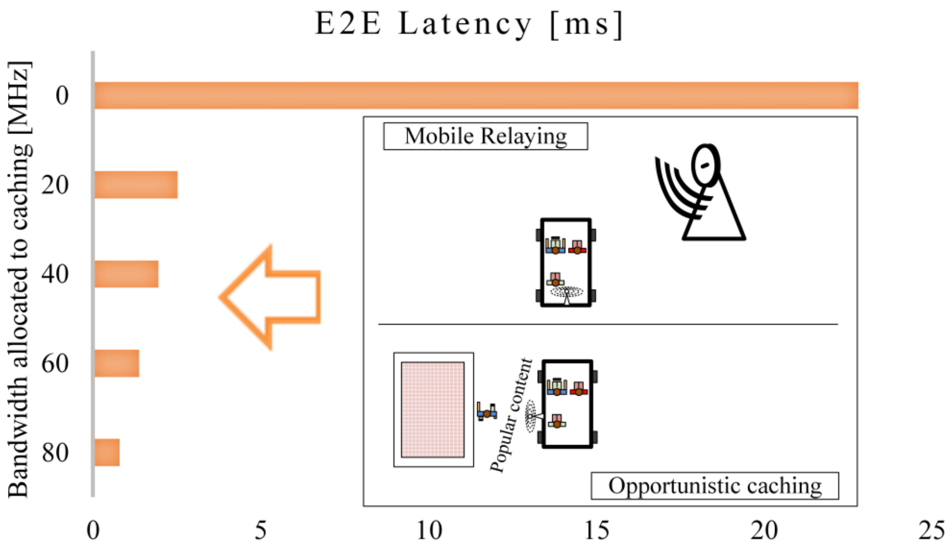

Fig. 3. Opportunistic caching and mobile relaying concept and its impact on E2E latency reduction.

F. *Localized traffic offloading*

Offloading from cellular to e.g. Wi-Fi and localized caching of popular contents both reduces the latency and the load of the transport network. Mobile data offloading from cellular to Wi-Fi has been discussed for several years, and 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 provides the ultimate offloading since the user data does not even enter the network. 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.

Simulation results demonstrate that caching reduces the E2E latencies experienced by users using cached contents. In Fig. 3 it is shown a significant reduction of E2E latency for real time traffic with just 20 MHz allocated to opportunistic caching transmission. With 80 MHz, E2E latency is reduced to around 1 ms. An additional positive effect of caching is the offloading of traffic in the transport network. With the current traffic type distribution and caching probabilities, about one half of the traffic load may be offloaded.

G. *Unprecedented spectrum flexibility*

The use of exclusively licensed spectrum builds the basis for mobile network operators to deliver good quality of service for their subscribers. This type of spectrum usage should be prioritized, especially for applications requiring high reliability of data transmissions. However, as we are facing an exponential increase in the volume of wireless data traffic, we need to be prepared for supplementary solutions to serve the mobile users demand in space and time.

The required spectrum flexibility can be achieved by use of a Spectrum Toolbox, see Fig. 4, which enables flexible use of all available frequency resources aiming at best serving the user under the given regulatory frameworks; Primary user mode, Unlicensed mode, or License Shared Access (LSA)/Spectrum Access System (SAS) mode [7]. In Fig. 4 we see different options for spectrum sharing, ranging from mutual renting, to unlicensed use of spectrum. The spectrum sharing enablers include e.g., spectrum opportunities detection and Dynamic Frequency Selection (DFS)/Dynamic Channel Selection (DCS), and use of a Geo-Location DataBase (DLDB).

Given the limited availability of contiguous bandwidths of spectrum in the lower frequency bands [7], additional bands at higher frequencies will be needed and used to provide additional capacity where required, e.g., outdoor hotspots (e.g. squares, campus, stadium, business districts, etc.), indoors (e.g. airports, fairs, malls, enterprise, home, etc.), or fixed wireless links between buildings and backhaul.

Form factor considerations make massive MIMO more attractive for centimeter wave (cmW) and millimeter wave (mmW) bands. This is in line with our proposal of using higher frequencies above 6 GHz due to the reduced antenna size.

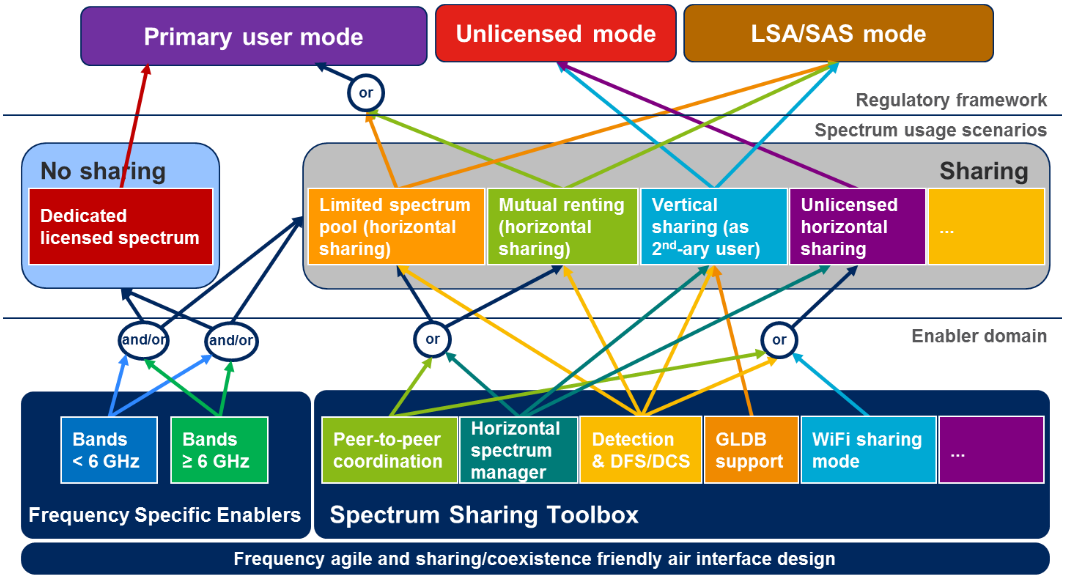

Fig. 4. The illustration of the spectrum toolbox spans three domains; the Regulatory framework, Spectrum usage scenarios, and the Enabler domain. The enabler domain contains different technical "tools" to allow operation under different regulatory frameworks and usage scenarios. The best solution in each situation, i.e., in each regulative framework, can be found by taking the most appropriate enabling tools from the toolbox. A certain regulative framework can be addressed with one or a combination of different spectrum usage scenarios and enabling tools. This all needs to be taken into account in air interface design.

H. *Energy efficiency*

The energy efficiency can be considered at a device side or a network side, though the distinction will be blurred by the dual role of the mobile wireless devices in 5G. The energy consumption in today's networks is dominated by transmission of pilots, when no user data traffic is transmitted [12]. As networks densification continues to meet the capacity demands, it becomes increasingly important to implement new lean signaling procedures, to be able to activate and deactivate network nodes depending on the traffic load, or, to switch off some of the node functionality in low-load modes [12].

Narrowband IoT (NB-IoT) with the massive MTC requirements, e.g., long device battery life in mind, has been specified in LTE Release 13 [13]. NB-IoT supports both Power-Saving Mode (PSM) and extended discontinuous reception (eDRX) sleep cycles but in challenging coverage it is instead the long transmission and reception times that will limit the device battery life. Providing long battery life and extended coverage simultaneously is therefore very challenging. Multi-hop solutions changing the topology of the problem, e.g., in the form of UE relaying, could therefore be a necessary component to reach 10-years device battery life also in challenging locations [9].

The use of machine UE relaying, where devices with good coverage forward messages to and from devices in extended coverage, can increase battery life by a factor of 5 for the devices which are routed via a relay (for a 4% drop rate capacity target as found in [9]). For a particular deployment scenario, the capacity in terms of system throughput, is approximately x5 higher using relaying as compared to using direct links, since for direct links a higher amount of time repetition is required. As shown in Fig. 5, with a system throughput of 5 Mbps the battery life can be improved from 1 to more than 25 years for the devices served by relays, and for loads higher than that, the baseline case cannot provide sufficient capacity. In this direction, clustering and cluster head identification affects a lot the performance of the system, which motivates the interest for further study.

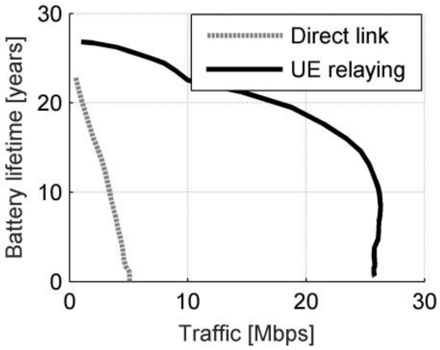

Fig. 5. Battery lifetime improvements as a function of system throughput for a system using a UE relay compared to the case with direct transmission.

IV. TOWARDS MEETING THE 5G TECHNICAL OBJECTIVES

The METIS 5G system concept has been evaluated to see to which extent it meets the technical objectives stated in the introduction. The evaluation has been conducted on the five scenarios and twelve test cases of METIS [2]. The specific setup and simulation assumptions are given in [9]. In test cases where a cellular-based technology is applicable, the assumed baseline is a 3GPP LTE Release 8 system with 20 MHz bandwidth at 2.6 GHz, 4x2 MIMO, and conventional macro/micro deployment. Since 5G systems are currently being standardized, it is not possible to do full system-level simulations. However, an estimate of the overall system performance has been established by assessing the performance of combinations of the techniques introduced in Section III, and detailed in [7]. In this evaluation, we have chosen a system level simulator used in the official ITU-R evaluation of the IMT-Advanced technologies, and calibrated for the baseline LTE system described above.

Table I quantifies the foreseen improvement realized through the use of the techniques under the METIS evaluation framework and assumptions. The improvement factors are obtained comparing the performance of the technique under study with respect to the LTE Release 8 baseline. Techniques are gradually added to the 5G solution following the row ordering, in the sense that each impact factor represents the improvement with respect to the previous setup. The table shows that the METIS 5G objectives are met and in some cases significantly exceeded.

TABLE I

SUMMARY OF THE IMPACT OF THE MOST PROMISING TECHNIQUES CONTRIBUTING TO THE FULFILLMENT OF THE METIS GOALS.

METIS Goal	Most promising techniques	Impact
1000x throughput	Sufficient spectrum, including additional bandwidth from new spectrum bands. This spectrum needs range from 2350 MHz, assuming no cost constraints on the level of densification, up to 8600 MHz, assuming the same level of densification as today.	x 3.40 (assuming 693 MHz of spectrum availability today)
	Densification of the system and use of distributed radio heads. Number of nodes 3-5 times the number of nodes we have today.	x 3.65
	More prominent use of TDD mode in a dynamic manner	x 1.67
	Coordination among cells with reduced TTI	x 1.21
	Massive MIMO with 256x256 antenna elements	x 20
	D2D and localized traffic flows	x 2
		≈ 1000 times achieved
10 to 100x end typical user data rate	Sufficient spectrum, including additional bandwidth from new spectrum bands. This spectrum needs are higher than 2150 MHz	x 3.10 (assuming 693 MHz of spectrum availability today)
	Shorter transmission distances with D2D and denser deployments, reducing the transmission distance down to 10 m	x 4
	More prominent use of TDD mode in a dynamic manner	x 1.67
	Massive MIMO, with 32 antenna elements in each UE	x 2.50
		≈ 50 times achieved
10 to 100x higher number of connected devices	Flexible use of different radio interfaces. Implementation of specific transmission schemes in dedicated carriers for MTC	Enabler
	Filter-Bank Multi-Carrier (FBMC) or similar narrowband transmission	x 12 (DL)
	Sparse Code Multiple Access (SCMA) multiple access scheme	x 10 (UL)
	Traffic concentration	x 200
	Sufficient spectrum, including additional bandwidth from new spectrum bands. At least 200 MHz required.	Enabler
	Efficient signaling to reduce the overhead of mMTC	Enabler
		≈ 2000 times achieved
10x longer battery life for low power mMTC devices	Efficient signaling	x 20
	FBMC	x 1.20
	SCMA	x 1.50
	Shorter transmission distance with traffic concentrators	x 2
		≈ 70 times achieved
5x reduced E2E latency	D2D communication with localized traffic flows	x 3
	Reduced TTI and retransmission processes	x 1.80
	Better QoS differentiation	Enabler
	Optimized architecture	Enabler
	New waveforms, e.g. FBMC and/or SCMA	Enabler
		≈ 5 times achieved

V. CONCLUSIONS

This paper has presented the METIS 5G system concept and given insights into the features, required flexibility, and initial performance evaluation. The development of 5G wireless systems is in its early stages but we note that the METIS concept with three generic services was a pioneering effort that has gained traction in ITU-R and 3GPP. In this early stage, it is difficult to state precisely what the final system design will look like. Yet, it is already possible to identify important services, enablers and features that will be present in any conceivable solution for a 5G system. Themes that pervade multiple features are network-controlled D2D communication that will lead to improvements in reliability, spectrum utilization and reduced latency; massive MIMO that will provide improved rates and coverage; and the dynamicity of the RAN.

Finally, the system-level evaluations of the METIS 5G system concept has shown that the 5G requirements are met and even exceeded. 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.

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