Towards the METIS 5G Concept

First view on Horizontal Topics Concepts

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***Abstract*—METIS is developing a 5G system concept that meets the requirements of the beyond-2020 connected information society and supports new usage scenarios. To meet the objectives METIS uses Horizontal Topics (HT) that addresses a key new challenge, identifies necessary new functionalities and proposes HT-specific concepts. This paper presents an initial view of the HT-specific concepts for each of the METIS HTs: Direct Device-to-Device Communication, Massive Machine Communication, Moving Networks, Ultra-Dense Networks, and Ultra-Reliable Communication. It also describes how the HT-specific concepts will be integrated into one overall METIS 5G concept.**

Keywords—5G; Direct Device-to-Device Communication (D2D); Massive Machine Communication (MMC); Moving Networks (MN); Ultra-Dense Networks (UDN); and Ultra-Reliable Communication (URC); System concept; METIS

I. INTRODUCTION

The overall purpose of METIS is to develop a system concept that meets the requirements of the beyond-2020 connected information society and broadens the use of today's cellular communication systems to support new usage scenarios [1]. The developed concept should support the following METIS overall technical goals:

- 1000 times higher mobile data volume per area
- 10—100 times higher number of connected devices
- 10—100 times higher typical user data rate
- 10 times longer battery life for low power MMC, and
- 5 times reduced End-to-End latency,

and achieve these at a similar cost and energy consumption as today's networks (though not all goals are relevant to all applications and may not necessarily be realized simultaneously). The requirements of the connected information society are captured in five METIS scenarios [1].

METIS uses Horizontal Topics (HTs) to facilitate the concept development process and meet its objectives. The METIS HTs are Direct Device-to-Device Communication (D2D), Massive Machine Communication (MMC), Moving Networks (MN), Ultra-Dense Networks (UDN), and Ultra-Reliable Communication (URC), cf. Section 2. For each HT, a HT-specific concept is developed that addresses a key new challenge, identifies necessary new functionalities and integrates the Technology Components (TeCs) researched in METIS into new solutions that adequately address the different use-cases of future wireless systems.

The HT-specific solutions will be integrated into an overall METIS concept. The final METIS concept will be a flexible system that can be configured to provide different services. For instance, the system should provide native support for extreme Mobile Broadband (MBB) communication, MMC and URC, and the underlying system architecture must support UDN, D2D and MN.

The rest of the paper is organized as follows. In Section 2 we give an overview of the HTs and in Section 3 we present an initial view of the corresponding HT-specific concepts. Section 4 describes some of the identified commonalities and the integration towards an overall concept.

II. OVERVIEW OF THE METIS HORIZONTAL TOPICS

We here give a short overview of the METIS HTs. A thorough description is available in [2].

A. HT D2D

Direct Device-to-Device Communication (D2D) refers to network-controlled direct communication between devices without user-plane traffic going through any network infrastructure; the network controls radio resource usage of the direct D2D links and the resulting interference effects. The aims of the HT D2D are to increase coverage (availability and reliability), to offload backhaul (cost efficiency), and to provide an alternative communication mode (reliability), to improve spectrum usage (spectrum efficiency), to increase capacity per area (capacity), and to enable new services and applications (e.g., through reduced latency).

B. HT MMC

Machine-Type Communication (MTC) is associated with a wide range of traffic characteristics and requirements (e.g. data rate, latency, cost, availability and reliability) that will often deviate substantially from those of human-centric communication in current use. Massive Machine Communication (MMC) refers to connecting tens of billions of network-enabled devices with stringent requirements on low energy consumption and cost. The aims of the HT are to provide up- and down-scaling connectivity solutions for tens of billions of network-enabled devices (scalability).

C. HT MN

Moving Networks (MN) integrates moving and nomadic nodes into a dynamic RAN of the proposed system concept to provide improved coverage, capacity and safety. By setting technical requirements and solution guidelines, it will provide a basis for developing novel solutions (such as mobile and

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reliable D2D communications or dynamic network deployments based on nomadic network nodes) that allow for ubiquitous services for end-users on the move.

D. HT UDN

Ultra-Dense Networks (UDN) refers to an access node densification far beyond today's networks, and is one of the main enablers to address the predicted traffic demands and high data rates targeted in the METIS goals. A further network densification of existing standards cannot be easily achieved due to increasing problems related to e.g., inter-cell interference, pilot and mobility signaling overhead. The goals of UDN are therefore to increase capacity while enabling a better exploitation of under-utilized spectrum and keeping a tight limit on the cost and energy dissipation per area.

E. HT URC

Ultra-Reliable Communication (URC) refers to solutions that will enable high degrees of reliability and availability. HT URC aims at providing scalable and cost-efficient solutions for networks supporting services with very high requirements on availability and reliability, not met by today's systems The resulting system concept will meet the demands of the Internet of Things in areas that could benefit from wireless connectivity, but at present are not using it due to insufficient reliability guarantees, e.g., telematics and automation.

III. HT-Specific Concepts

This section gives a short overview of the HT-specific concepts. For a detailed description, see [2].

A. D2D Concept

Direct D2D communication between wireless devices (mobile as well as stationary) can improve the overall system performance and support new services. It is a cornerstone in the METIS 5G concept and will be integrated from the very beginning. The initial METIS D2D concept is illustrated in Fig. 1.In the following we describe some of the key building blocks.

A **Flexible TDD air interface** with a set of different modes of operation and appropriate selection metrics allows the air interface to be individually configured according to actual system conditions and service requests. For low-mobility devices, TDD with a dynamic partitioning of UL/DL periods and a scalable frame structure enables cost-efficient local D2D communication. For high-speed devices, the air interface designed for moving networks and V2X communications is used to support local V2X direct communication. An optimized signaling structure meeting MMC requirements on low cost and power consumption supports extended MMC coverage [3].

A unified **D2D discovery framework** is under investigation by taking into account the benefits from both User Equipment (UE)-based and network-based schemes.

After device discovery, the **D2D Communication Mode Selection** mechanism decides whether a D2D candidate pair should communicate via regular cellular mode or D2D mode. Both distributed Channel State Information (CSI)-based and location based mode selection schemes are proposed [4].

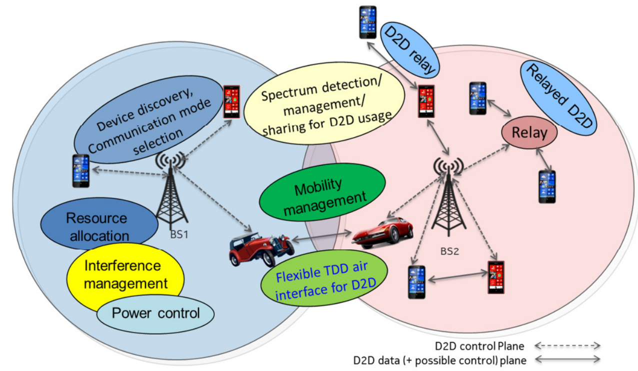

Fig. 1. Initial METIS D2D concept.

Interference management both between D2D pairs and between the D2D link and the cellular link. METIS is researching centralized resource allocation for both single-cell and multi-cell approaches, and joint mode selection and resource allocation. Distributed resource allocation, e.g., decentralized interference-aware scheduling, is studied as well [5]. Power control is considered, e.g., distributed iterative power control exploiting covariance measurement [2].

Other important building blocks include e.g., optimized **mobility management** procedure, including a new D2D handover criterion [4], and new forms of D2D relaying [5]. **Spectrum detection/management/sharing** based on D2D requirements can identify suitable spectrum for D2D usage [6].

Compared to the currently ongoing 3GPP work [7]— [10], the METIS D2D concept brings significant improvements, e.g., considering not only broadcast, a configurable air interface and scalable frame structure, and new multi-hop modes.

B. MMC Concept

HT MMC is an example of how fundamentally different communication applications are integrated into the METIS concept. To achieve the METIS goals concerning MMC, three types of MMC communication are considered; direct access, accumulation/aggregation point access, and direct M2M communication, see Fig. 2.

In the direct access mode, Fig. 2a) devices transmit directly to the access node. The benefit of this scheme is that it requires no planning when deploying devices, given that access nodes provide full macro coverage. Another advantage is the provided flexibility in terms of mobility management for non-static devices. The drawback is the coverage aspect; for low-complexity devices with low output power constraints extra attention is needed to reach the coverage KPI in the uplink.

In the accumulation/aggregation point access, Fig. 2b), traffic from the devices in the proximity is accumulated in a local node before being sent to the macro access node. The accumulation point can either be a relay, a service-dedicated gateway, a smart phone connecting personal electronic devices, or a dynamically selected device acting temporarily as the group/cluster head. For this scheme, a varying range of data processing could be applied; From forwarding the data as it is, as a relay, to accumulating data in order to have few but larger transmissions to the access node, and even all the way to doing processing in the accumulation point in which case only the relevant and processed data is forwarded to the macro access node. With the use of accumulation point access, deep indoor penetration can be more easily obtained.

The direct M2M communication mode between devices is depicted in Fig. 2c). Although the focus is on very low bit rates and delay tolerant traffic rather than very high bit rates and short delay, this case naturally inherits most technical solutions from HT D2D. One key difference of M2M communication relative to D2D is the requirement for very high protocol efficiency (i.e., very low signaling overhead) and the requirement for long device battery life. Direct M2M transmission is beneficial when the device has reached the maximum transmit power level. In most other cases, the major factor affecting the device battery life is the required on-time and the base power consumption of the power amplifier. Therefore, more long term and static setup would be required for M2M communication compared to D2D communication.

Note that the three access schemes are not mutually exclusive and can be applied together in hybrid scenarios.

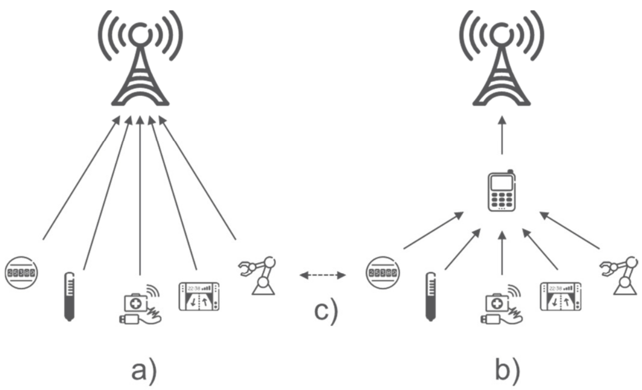

Fig. 2. HT MMC illustrated in the case of a) direct access, b) accumulation point access, and c) M2M access.

C. MN Concept

HT MN introduces nomadic and moving radio nodes that can provide connectivity to users in their proximity, and increased data rates by shortening the distance to the nearest access node. HT MN addresses a broad and diverse range of applications and is therefore divided into three clusters:

- MN-M: Mobility-robust high-data rate communication links for mobile terminals and moving relays to enable broadband as well as real-time services.
- MN-N: Flexible and demand-driven network deployment based on nomadic network nodes.
- MN-V: V2X communications to enable reliable and low-latency services for traffic safety and efficiency.

The concept for MN-M relies on reliable, high capacity communication links in the physical layer, combined with efficient management mechanisms in the higher network layers. Reliable links are provided by novel waveforms, advanced modulation and coding schemes, and exploitation of diversity to enable high mobility robustness and reduced coding/decoding latency. The URC framework [2] enables QoS control over the communication links and constitutes an interface to the radio resource management and medium access control schemes.

Other important components are optimized handover mechanisms to enable seamless and optimal connectivity, and interference management [4]. Moreover, context information and trajectory prediction can be used to select the appropriate access node and provide QoS control.

The core part of the solution for MN-N focuses on management algorithms that identify coverage and capacity demands of UEs, which trigger the activation and de-activation of nomadic nodes. The activation/deactivation of nomadic nodes impacts the interference situation and hence dynamic interference management algorithms coordinating fixed and nomadic nodes are key components, see Fig. 3.

Smart mobility management techniques are required that ensure seamless connectivity since the non-stationarity of nomadic networks can cause handover of stationary users. Wireless backhaul links are essential to leverage the gains of nomadic networks. Such schemes significantly improve the capacity and reliability of the whole network, since backhaul is often the bottleneck.

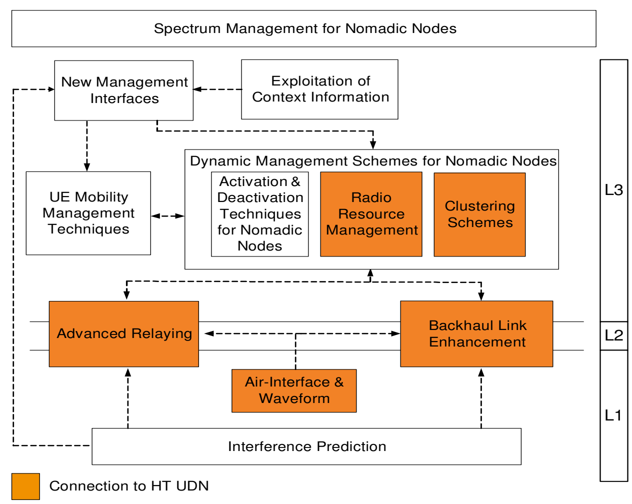

Fig. 3. Concept for HT MN MN-N

The MN-V concept is based on D2D communication for the exchange of information between traffic participants using unicast and broadcasting transmissions. Compared to HT D2D, V2X communications pose additional challenges in terms of resource allocation, e.g., to provide any QoS guarantees for the D2D links [11]. The MN-V concept integrates the use of both network-controlled and pure ad-hoc D2D communication in a complementary manner to provide reliable service also outside network coverage.

The MN-V concept incorporates new advanced waveforms, channel coding, link adaptation and HARQ techniques into the physical and MAC layers in order to achieve a very high robustness against Doppler shifts and better performance at link level by means of improved time diversity, while taking the stringent deadlines of road safety and traffic efficiency applications into account. At the same time, handover optimization mechanisms based on the exploitation of context information and interference identification are incorporated into the system concept in order to improve the radio resource management, avoid handover failures and minimize the signaling information related to handover.

Spectrum management and availability is important for all MN clusters. In particular, for MN-N and MN-V, multi-operator support is necessary.

D. UDN Concept

The UDN concept consists of a core part and an extended part, as depicted in Fig. 4. The core part is related to the METIS goals regarding the expected increase of mobile data volume and user data rates. The extended part addresses coexistence of the new UDN and other networks, especially macro/base layer networks, and the potential benefits that can be achieved from closer collaboration.

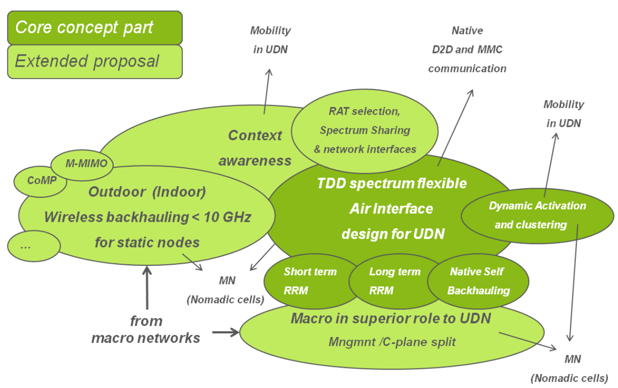

Fig. 4. Concept proposal for UDN.

The core part of the UDN concept proposes a new stand-alone system optimized for ultra-dense deployments and addresses most of the METIS goals, see [2].

At the center of the UDN system concept is the new **TDD spectrum-flexible air interface** optimized for UDN. The key building blocks for the air interface includes flexible frequency use including bands from few GHz up to the mmW, access to wider bandwidths, high flexibility in use of UL/DL resources based on TDD access, and physical layer waveform based on the modified OFDM METIS proposals. Latency is decreased by reduction of round trip time to ≈1 ms and single TTI reduced to 0.25 ms or less for high frequencies (mmW).

The UDN concepts also include solutions contributing to following system aspects; Short-term and long-term radio resource and interference management, native support of dynamic activation/deactivation of nodes and sleep mode reducing the energy consumption, native support of wireless self-backhauling reducing cost and increasing capacity without major increases in receiver complexity.

In UDNs, tens or hundreds of nodes can be deployed at random locations making detailed location planning and provision of sufficient backhaul unfeasible. Even if the mobility of users is low, reliable handover procedures will be challenging due to the short Inter-Site Distance (ISD). Integration of the UDN with macro networks and possible reuse of their resources is challenging but can provide benefits. The extended part of the UDN concept is focused on the novel functionalities related with coexistence of UDN and other networks, in particular base-layer cellular networks.

The extended UDN concept includes e.g., Multi-layer, multi-connectivity networks separating the control and data planes between macro and UDN and activation/deactivation of UDN network nodes; Efficient provisioning of backhaul using self-organizing networks (SON) functionality; Context awareness for improved QoS; and Inter-RAT selection and inter-operator spectrum sharing.

E. URC Concept

The URC problems have been divided into long-term (URC-L), short-term (URC-S), and emergency (URC-E) problems. The goal of URC-L is to provide certain rate guarantees to the served users. URC-L targets moderate-to-high data rates for providing an ordinary, rather than emergency, connectivity. URC-S also targets providing certain rate guarantees but with a stricter latency requirement, e.g., <2 ms latency with 99.999% guarantee. URC-E provides a basic communication when the infrastructure becomes partially damaged or dysfunctional due to, e.g., an earthquake. The most important parameters for URC-E are the time it takes to establish a connection at a certain data rate R as a function of the percentage of the damaged infrastructure in the area, and the probability that a device will be able to send a message of a given size within a certain time-frame.

Different sets of TeCs are suited for a particular type of URC problem. For URC-L and URC-S there is a generic set of relevant TeCs for achieving very high reliability.

Spectrum allocation and management, e.g., offloading to another frequency band and operation in less-interfered spectrum to ensure/improve reliability, and operation in dedicated spectrum to attain e.g., low-latency D2D operation.

Robust PHY mechanisms to improve the reliability for a given spectrum allocation through one or more of: Robust waveforms (robustness towards imperfect channel estimation or non-coherent operation); Interference identification using multi-layer inputs and Interference mitigation/cancelation; Large-scale spatial diversity of Massive MIMO (improving SINR through energy collection); and Additional infrastructure nodes and/or inter-node cooperation, such as CoMP or relays.

The **signaling structure** is able to adapt to low-latency requirements (URC-S) and to offer minimal rate within the desired radio coverage (URC-L). The signaling structure should also be able to support flexible spectrum allocation.

Improved RAT integration and cooperation among multiple RATs, introducing diversity on top of layer 2, improves the reliability and availability, especially in URC-E.

Reliable service composition which can be seen as information propagated from the lower layers to the higher layers, such that the latter decrease their demand. For example, if the lower layer signals inability to support the normal operation, the higher layer goes to a mode in which only critical data is transmitted. This is well exemplified by the URC framework URC, and applied by e.g., HT MN.

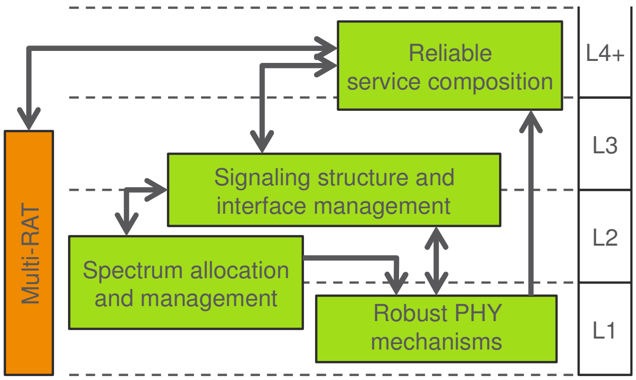

Fig. 5. Toolbox of generic mechanisms for URC and their interactions.

Fig. 5 depicts the relationship among the four generic mechanisms for achieving ultra-reliable communication, applicable both to URC-L and URC-S.

Additional enabling TeCs for URC-E include D2D communication, including network assisted discovery and network assisted communications; Multi-hop and relaying techniques, such as cooperative D2D communications; and Nomadic nodes to establish an ad-hoc wireless infrastructure.

IV. Towards an Overall METIS 5G Concept

The final METIS concept is developed by integrating the HT-specific concepts into a concept that meets the METIS goals. The HTs have significant synergies which are exploited in the integration. Two examples of synergies are given below.

An example of an application with strong synergy between HT concepts is METIS Test Case 12 Traffic Efficiency and Safety [1]. It is addressed by MN-V, while in terms of performance requirements it belongs to URC-S. High reliability in V2V communication is achieved through network-controlled D2D, which is a specific form of HT D2D. Resolving resource conflicts among multiple uncoordinated vehicles requires efficient algorithms MMC.

Flexible and demand-driven deployment of nomadic network nodes is addressed by MN-N and is clearly related to UDN in terms of activation/deactivation of network nodes and wireless backhaul. Additionally, nomadic nodes are instrumental as ad hoc infrastructure in emergencies, making them highly relevant to URC-E. A technology that can complement the ad hoc infrastructure of nomadic nodes is direct D2D connectivity, making also D2D highly relevant for the emergency scenarios.

Fig. 4 shows how the components selected for UDN also supports D2D and MMC, and how the MN "Nomadic nodes" concept is related to UDN concerning dynamic nodes activation/deactivation, nodes clustering and macro wireless backhaul service for static nodes.

By assessing which aspects of the HTs can be grouped, we can identify a minimum set of new air interfaces and network functions that need to be developed to meet the METIS goals. Other aspects of the HTs have implications on the system architecture and how the integration of air interfaces should be done to meet the overall requirements on efficiency, versatility and scalability.

The final METIS 5G system concept, outlined in Fig. 6, will be flexible and configurable to provide different services. For instance, the system should provide native support for extreme MBB communication, MMC and URC, and the system architecture must support D2D, MN and UDN.

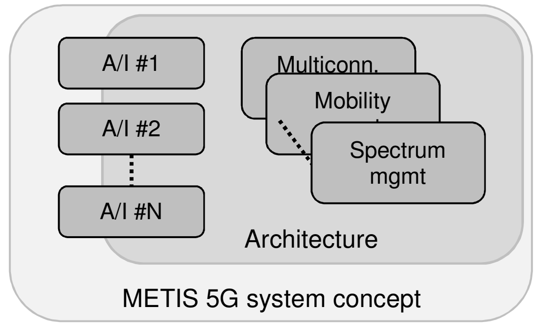

Fig. 6. Illustration of the METIS 5G system comcept.

V. Conclusions

We have briefly described the METIS HT-specific concepts and some of the most relevant enabling technology components. The way towards an overall METIS 5G concept has been outlined.

Acknowledgment

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