Rethinking the Mobile and Wireless Network Architecture

The METIS Research into 5G

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Abstract— The METIS project is laying the foundation of 5G mobile and wireless communication systems putting together the point of view of vendors, operators, third party players and academia. In particular, METIS is developing and evaluating the key technology components of 5G systems. In this framework, a new mobile and wireless network architecture is required to accommodate those technical enablers and communication paradigms while taking into account existing and emerging architectural trends. This article provides an overview of the METIS system and architecture research into this future mobile and wireless network, discussing various alternatives and perspectives.

Keywords—5G; Architecture; Beyond 2020; METIS

I. INTRODUCTION

For best user experience, improved flexibility and scalability as well as lower energy consumption and cost reduction, the scientific community and the standardization bodies are working together to accommodate current mobile networks to the new needs posed by the society of the future. Prospective studies suggest that in the next decade, that is, beyond 2020, it will be necessary to support 1000 times higher mobile data volume per area [1] together with new wireless broadband communication services coming from a plethora of different market segments. These requirements will go beyond the natural evolution of IMT-Advanced technologies, which shows the need for a new mobile generation, with certain disruptive features with respect to legacy technologies. Although there is no unanimous agreement so far, this seems to be the birth of the Fifth Generation (5G) technologies.

METIS (Mobile and wireless communications Enablers for the Twenty-twenty Information Society) is an integrated research project partly funded by the European Commission under the FP7 research framework [2]. METIS aims at providing the foundation for the beyond 2020 wireless communication systems by providing the technical enablers needed to address the very challenging requirements foreseen for this time frame. Within this research for the foundations of 5G mobile communication systems, new network architecture design is of paramount importance, especially taking into account the structural limitations of current Internet [3].

To make the Internet more content-centric, Information Centric Networking (ICN) appeared one decade ago based on the use of publish/subscribe primitives, name-based routing and universal caching. Several projects all over the world (such as NDN in the USA, 4WARD, PSIRP, SAIL in the EU, or AKARI in Asia [4]) have investigated ICN as a clean-slate solution to many of the problems of the Internet. A good survey on ICN can be found in [5].

With the same objective to take full advantage of caching, the Mobile Content Delivery Network (MCDN) concept is gaining increasing attention [6]. The idea is to introduce caching at the network edge, i.e. base station or even end-user devices, in such a way that the buffered video can be delivered to the user thus reducing latency and transport network traffic load. Content Providers might even upload contents to special caches in the mobile network to improve the user Quality of Experience (QoE). Operators’ routers would become cooperative nodes of the content distribution network.

Finally, among other architecture trends, Software Defined Network (SDN) architecture [7] in combination with Network Function Virtualization (NFV) [8] is a promising candidate to enable on-demand creation of customized Virtual Networks (VN) using a shared resource pool. VNs based on SDN architecture allow effective decoupling of control and data plane in order to optimize routing and mobility management.

This paper discusses a number of design choices and features that could change the way we understand mobile and wireless network architecture. This article provides an initial overview of the vision of the set of operators, vendors and academic partners that work together in the METIS project. It does not provide the final solution, but highlights the most promising research lines, which may be useful to combine efforts in the same direction.

II. METIS’ VISION ON BEYOND 2020 TECHNOLOGIES

All mobile generation changes so far have been provoked by new radio link concepts. In this sense, new flexible air interfaces, possible new waveforms, as well as new multiple access, Medium Access Control (MAC) and Radio Resource Management (RRM) solutions and signaling schemes must be investigated to dispute the idea that physical layer improvements are already close to their upper limit.

However, the foreseen evolutionary steps towards the ubiquitous high bit-rate service promised by beyond 2020 systems passes mainly by managing multi-cell and multi-user MIMO together with new paradigms of network deployment
with multiple Radio Access Technologies (RATs) coexisting or multi-layer networks (Heterogeneous Networks, HetNets). Despite these improvements, there is an agreement that future data rate demands will require a higher density of base stations. Ultra Dense Networks (UDN) refers to this new paradigm of wireless communication network, which includes network cooperation and ultra-dense availability of radio nodes. However, conventional cellular system nodes are too expensive for UDN deployment, and new radio node types are necessary, e.g., User Equipments (UEs) could become network nodes, and Device-to-Device (D2D) communications be used to guarantee the ubiquity of high quality services and offload the transport network.

Of course, new spectrum bands must be identified in the ITU-R Radio Regulations to support the increase of traffic demand. Despite the fact that the current practice of predominantly using dedicated licensed spectrum will remain the main stream, new regulatory tools and approaches of sharing the spectrum and optimizing its use must be devised.

In addition to the above-mentioned UDN and D2D enablers, the 5G architecture should also integrate additional complementary concepts that have been identified as fundamental to build the next generation mobile and wireless system:

- Massive Machine Communications (MMC) will provide up- and down-scalable connectivity solutions for tens of billions of network-enabled devices, which is vital to the future mobile and wireless communications system.
- Moving Networks (MN) will enhance and extend our current concept of communication. One or several MN nodes, such as a car, bus or train, will communicate with other nodes, fixed or mobile, that are inside or even outside the moving entity.
- Ultra-Reliable Communications (URC) will enable high degrees of availability. In this context, METIS aims at providing scalable and cost-efficient solutions for networks supporting services with extreme requirements on availability and reliability.

From the perspective of the end-to-end flow, even the protocol stacks could be optimized and customized via software according to the required services or the network topology. Protocol stack becomes more and more a set of functional building blocks flexibly combined on demand to fulfill the very specific task of a certain service.

Flexible combination and reload of functional building blocks will also overcome the separation of radio access and radio core networks. Software-Defined Content delivery (SDC) allows the distribution of certain functions across the network nodes depending on the requirements.

The realization of NFV [9] via centralized software applications on general purpose cloud-based hardware will happen in medium term primarily for core network elements. This can be partly in combination with integration of fixed-mobile network components. The extension to the Radio Access Network (RAN) is also expected, which is referred to as Cloud RAN (C-RAN) [10]-[11]. NFV can be seen as highly complementary to SDN, as it is relying on techniques currently in use in many data centers. However, applying NFV together with the SDN approach of separation of control and data planes can enhance the final performance and reduce the CapEx and OpEx of the networks.

As a summary, Figure 1 shows how the 5G mobile and wireless network architecture must accommodate a number of technical enablers and communication paradigms while taking into account existing and emerging architectural trends as previously presented.

Moreover, 5G network architecture will most likely be scenario and use-case specific, e.g., it may be different in areas with low cell density compared to deployments in ultra-dense areas, such as Mega-Cities. In this sense, METIS scenarios will be used to provide specific and realistic design approaches [12].

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**III. FIRST APPROACH TO 5G ARCHITECTURE**

**A. Analysis of Scenarios**

In Figure 2, a first high-level view on 5G architecture is sketched. The scenario *Amazingly Fast* [12], which deals with high data rates and provisioning of high network capacities, will require UDN enablers for including radio node densities down to about 10 m outdoors as well as one or more radio nodes per room indoors. Radio nodes will comprise traditional access nodes as well as virtual access nodes based on emerging user-centric concepts. The flash behavior of the Internet content will be a key factor. Hence, local break out and accelerated content delivery by distributed mobile core functions are needed. Densification of networks must be accompanied by constantly improving spectral efficiency, which may be attained by novel physical layer, multi-antenna, multi-node, network-level and spectrum usage concepts. For sure, some of these schemes may demand decentralized functionalities, which may cause additional costs and, hence, may hamper needed cost reductions.
Local C-RAN in these cases will be mandatory in order to enable enhanced interference management and multi-antenna solutions keeping CapEx and OpEx sufficiently low. Most significant advantages of C-RAN introduction in combination with SDN and NFV are:

- Extension of cloud service offerings (noted as IaaS or PaaS) from mobile core to RAN area (RANaaS).
- Flexibility with respect to integration of decentralized core functions in C-RAN processing units like joint scheduling as well as MCDNs with caching capabilities.
- Increased flexibility in end-to-end (E2E) service offerings by on-demand adaptation of data transport on radio and back-/fronthaul layers according to service content and available resources (content and resource awareness).
- Simplified clustering of cells for joint RRM (including carrier aggregation), interference coordination (including coordinated multi-point (CoMP) procedures) and mobility management due to centralized processing and minimum delay among baseband processing units.
- Multi-operator network infrastructure and resource sharing (as well as Fixed Network Operators with respect to back-/fronthaul usage) realizable in an optimal manner.
- Flexible integration and adaptation of Operation, Accounting and Maintenance (OAM) and Self-Organizing Networks (SON) functionalities, also to implement green network operation (e.g., on-demand switch on/off of radio nodes).

The provisioning of suitable backhaul and, in case of C-RANs fronthaul stands for a very important aspect for UDN. Even in the medium-term future, it cannot be expected that wired solutions will be available everywhere. Hence, wireless backhaul and fronthaul solutions will play a key role in future mobile network.

There can also be local communication contexts, wherein information is relevant only for the devices in a limited area. This can potentially be supported by direct D2D communication, but the network can provide a role here in helping the devices to find each other, provide security mechanisms, and potentially providing reliability in licensed spectrum.

Great Service in a Crowd [12] aims at provisioning of mobile broadband services under crowded conditions. In these cases scalability and versatility of network configuration is foreseen to be a big challenge. At locations where crowded conditions could be predicted UDN and D2D could be possible solutions. Mobile broadband in unexpected situations like traffic jams may be enabled by applying MN with Vehicular-to-Vehicular (V2V) or Vehicular-to-Device (V2D) communication. Similar to improvement of coverage in blind spots, in these cases mobile relays can enable robust mobile backhauling to the infrastructure.

Mobile networks will face completely different requirements in the scenario Ubiquitous Things Communicating [12]. In the case of MMC, the number of devices to be served in a cell will be 10 to 100 times higher compared to today. Most challenges that have to be met are related to the air interface, i.e., enabling MMC devices to share spectrum with broadband devices and to be robust in challenging environments (i.e., very high path loss) while at the same time being low cost devices that are extremely energy efficient. From the mobile network perspective, one main objective is to provide 99.9% coverage which may be achieved by utilization of multi-RAT technologies.

The scenario Best Experience Follows You [12] will also require almost full coverage. At the same time, high data rates of up to 100 Mbps should be transmitted reliably to fast...
moving receivers on highways. To fulfill these needs, robust and reliable mobile backhauling including redundant links as well as multi-operator feasibility is demanded.

Finally, the developer of the overall system architecture has to consider that in the future there will be a strong relation between fixed and mobile network evolution. Especially for operators with fixed and mobile network infrastructure, cost reduction in future deployment stages is of great importance when common network infrastructure is reused.

B. Relation to Fixed Network Evolution

C-RAN infrastructure is implemented in Central Offices of required resulting in higher cost compared to approaches where Fixed Network Operators covering many radio nodes.

Especially for UDNs with short transmission intervals on the fronthaul length and the achievable performance in the cells. Coordination schemes: There might be a tradeoff between the transmission link plays an important role for dimensioning of the network.

Whereas for cooper-based access networks the Local EXchange (LEX) is less than 6 km apart from the customer end point. FTTH lines will have an average length of 15 km between ONT and OLT.

C-RAN functions or direct communication between base station sites set limits to the maximum allowed delay for backhaul/fronthaul links. The length and technology of backhaul and fronthaul (wired/wireless) links will have strong impact on signal delays. In combination with transmission schemes and protocol implementations the delays often determine the final performance of e.g. interference coordination schemes. There might be a tradeoff between fronthaul length and the achievable performance in the cells. Especially for UDNs with short transmission intervals on the radio link, the realization of local C-RAN sites might be required resulting in higher cost compared to approaches where C-RAN infrastructure is implemented in Central Offices of Fixed Network Operators covering many radio nodes.

IV. DISCUSSION AND PERSPECTIVES

A. Evolution or Revolution

From the point of view of METIS, a complete redesign of the Internet is discarded. Since the current Internet has become so large, the implementation of new architectural principles is impossible due to the commercial and operational difficulties it poses. Some concepts such as ICN are considered unrealistic, although some of its fundamentals, as the universal caching, have to be taken into account in order to offload the network. If 5G includes a revolution, it will come from the radio interface, where some new paradigms under discussion represent a radical change in the current form we have on mobile networks in addition to some fundamental changes in the mobile core functions, e.g., driven by new concepts of mobility.

B. Virtualization

Having said that, it is worth noting that virtualization allows the coexistence of independent networks built over the same infrastructure. In this sense, METIS supports the network virtualization in all its planes with a twofold objective, that is, flexible adaptation to the dynamic nature of the traffic and to be ready for running new protocols on top of the network in case of necessity of drastic changes in the Internet operation. The 5G mobile network infrastructure should support much more diverse types of services with sometimes fully contradicting requirements. To cope with all of the various challenges, the 5G mobile network architecture must enable on-demand setup of specific virtual networks. This has a significant impact on the network control functionalities and the scalability of the architecture. Detailed analysis of the technical solution proposals and the requirements with respect to the level of the real time processing will show how much of the radio protocol stack can support virtualization techniques.

C. Several Radio Technologies or a Single One

Currently, the coexistence of multiple radio technologies introduces many problems for users and operators, including higher management complexity, and increased delay and power consumption, among others. However, METIS considers that the 5G network will consist of evolved versions of existing RATs complemented by a set of new wireless technologies especially suited for the different scenarios. Still the new architecture must optimize the Multi-RATs coordination and interworking, being more flexible in RRM and traffic allocation. Moreover, new signaling procedures must be
designed to increase efficiency and reduce mobility management complexity in some scenarios.

D. Interfaces Among Players

The specification of new management interfaces among players aims at improving network management, binding the requirements of service providers (SPs) and Over-the-Top providers (OTTs) to the Mobile Network Operators (MNOs), as well as enabling cooperation among the Operators for the better exploitation of network resources.

Depending on the agreement between the SPs, the OTTs and the MNOs, different physical and logical parts of the network should be modified. For example, some OTTs may request access to some functions or nodes close to a special event whilst other OTTs would request access throughout a larger part or even the entire network. Of special relevance is the case of content delivery, since including base stations or even UEs as cooperative nodes of the content distribution network would reduce incredibly the current load of the Internet. This new paradigm requires new agreements between MNOs and SPs, which could result in alliances or even acquisition of complete business as we have seen recently.

E. D2D Communications and the Control from Operators

D2D communications as direct D2D and network-controlled D2D has recently received major interest. Network-controlled D2D communication and device discovery aspects are currently being discussed in 3GPP, with study items on system architecture and radio access network. There are two main drivers for D2D: a) public safety scenarios including disaster mode requirements and b) commercial use cases such as open-air festival, commercial shopping streets, and indoor office. The main benefit for enabling a direct D2D is the desired offloading of network-routed communication.

The role of one or more network operators would be to enhance D2D experience by enabling the following management elements in the system architecture: a) dynamic spectrum management entity, possibly with multi-operator sharing, b) mobility management, c) authorization and security architecture, d) accommodate for charging by operators.

Figure 4 shows the system architecture that 3GPP foresees for D2D communications (referred to as Proximity services), where the control plane is managed by the network. We note that the architecture depicted in Figure 4 can only be the starting point; 5G architecture will be different in future networks because of the support of substantially diverse requirements of, e.g., human- and machine-based communications, resulting in native implementation of D2D features in the 5G air interface.

For the future 5G systems, D2D proximity-based services as D2D communication on the user-plane.

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**REFERENCES**


