The journey from 5G towards 6G

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***Abstract*— This paper gives an overview of the journey from 5G towards 6G evolution. The 5G has been built across three main application verticals as defined by ITU, namely: Enhanced Mobile Broadband, Massive Machine Type Communications and Ultra-reliable Low Latency Communications (URRLC). To support these verticals, 5G has defined the following enablers: Massive MIMO, cloudification of network infrastructure, network automation, network slicing and edge cloud computing. It is expected that 5G will provide flexibility in terms of openness, mobility, programmability and agility and robustness in a standardized manner. The journey towards 6G will describe the limitations of 5G technologies and outlines the technology enablers for 6G. These enablers include smooth integration and interworking of Non-Terrestrial Networking technologies (NTN), use of Reconfigurable Intelligent Surfaces (RIS) and use of AI to orchestrate network and cloud resources. Additionally, the paper will give an overview of 6G research initiatives at both regional and international level.**

Keywords—5G, 6G, NFV, Edge Cloud, Network Automation, TN/NTN

I. Introduction

5G technologies have evolved after several years of R&D. Leading companies and Non-Governmental Organisations (NGOs) are focused on the evolution of 5G in terms of capabilities, providing a unique technology to systems beyond 5G (B5G) [1]. It is expected that the 6G market will also focus on filling 5G capability gaps. R&D considerations are driven by ICT ecosystem economics, such as new B5G market-driven business models and opportunities, as well as societal factors, such as the United Nations Sustainable Development Goals (SDGs).

It is expected that the number of generated data will grow exponentially over the next years. In this context, edge cloud computing has been introduced to provide offload and caching capabilities to devices that are connected to co-located access points. To reduce Total Cost of Ownership (TCO), there is a need to push AI on the edge, allowing innovation and open edge services to partners and developers to create applications that support consumer, enterprise and multiple verticals while adding significant value to their business. Therefore, distributed intelligence at the edge network can be a real differentiation. The introduction of softwarisation and automation can drive innovation in smart-grids, manufacturing and smart cities to provide intelligence resilience, flexibility and control. As an effect, there is a need for cross-sectoral and cross-disciplinary challenges for the evolution, adaptation and smart control.

This paper aims to describe the 5G characteristics as defined by the ITU and outlines key 5G technology enablers such as SDN/SD-WAN, NFV, network slicing, 5G RAN, edge cloud computing, and network automation. The rationale for 6G is described afterwards, providing key enablers such as TN/NTN integration, cell free mMIMO and AI network automation through the use of Intent Based Networking. Finally, initiatives on 6G at international level are outlined.

The paper is organised as follows: Section II describes 5G characteristics and the technological enablers, Section III outlines the needs towards 6G evolution along with the technology enablers. Finally, section IV presents the 6G initiatives at international and regional level.

II. 5G Characteristics

A. 5G Characteristics

ITU has defined the following use cases for 5G, under three main pillars [2], [3]:

- Enhanced Mobile Broadband (eMBB) to support services such as 4K/8K video streaming, AR/VR, Cloud gaming etc.
- Ultra-reliable (URLLC) to facilitate industrial manufacturing and automation.
- Massive Machine type Communications (mMTC) to support the deployment of IoT to support use cases related to smart building, logistics, utilities etc.

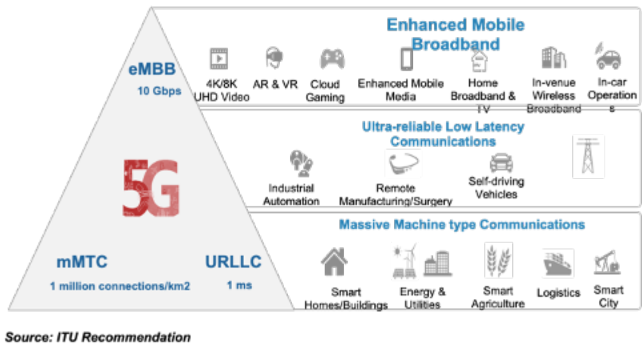

Figure 1: 5G Use cases

The next section outlines the technology enablers to facilitate the 5G ecosystem supporting various applications in different verticals.

B. 5G Technology Enablers

1) SDN

Recent evolution in topology and network routing agility regards the use of Software-Defined Networking (SDN), where the Control-Plane (CP) is kept into a logically centralized location and it is decoupled from the Data Plane (DP). SDN has gained popularity, where increased agility, flexibility, central control, dynamic policy definition and security are of paramount importance in data networking [4].

Although SDN offers a wide range of benefits over traditional network models, it has received limited interest on commercial deployment. Telecommunication Giant-sized network infrastructure owners such as service providers, data Centers, and telcos are reluctant to replace existing IP-based hardware with SDN devices.

Enterprise networks' inter-site data volume traffic has risen rapidly. Additionally, the increased complexity of mobile and application-centric networks is pushing traditional WAN architectures to their limit. Furthermore, enterprises tend to integrate several communication technologies such as Broadband, LTE, MPLS, etc., for a high-available dynamic WAN connectivity. As an effect, there is an interest to adopt a distributed computing model in the WAN environment. Software-Defined WAN (SD-WAN) is a generation shift that adapts the centralized model of SDN to WAN that fills the bottlenecks of its predecessor [5]. It provides over twice the bandwidth having the same backhaul with more manageability, autonomy, and network security.

2) Network Function Virtualisation (NFV)

NFV, aims to replace physical network appliances (e.g. router, switch, firewall etc) with software-based virtual appliances running on commodity IT servers [6]. The Virtual Appliances can be installed on IT servers using orchestration software. Orchestrator aims to manage in automated fashion the VNF associated with optimal placement, resource allocation, and provisioning.

3) Network Slicing

Network slice is considered as an End-to-end logically isolated infrastructure (5G device, access, transport and core network functions) [7]. The network slices can support different use case scenarios, as shown in the Figure 2. The market drivers include but not limited to: Cost saving, flexibility and innovation speed.

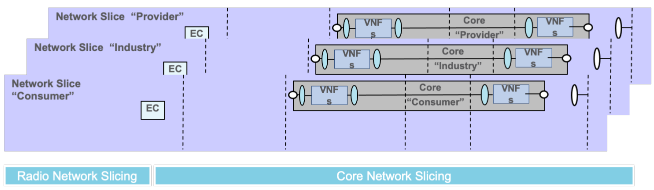

Figure 2: Network Slicing

4) 5G RAN

5G RAN has been designed to be interoperable with the previous generations of wireless communications equipment, such as 4G LTE [8]. When evolving from 4G to 5G, the biggest improvement is not only the enhanced user experience; but also, more business possibilities and reduced CapEx and OpEx through network softwarisation and automation. Moreover, 5G network-slicing at the RAN level gives operators the ability to monetize different service experiences as per the user requirements.

5G consists of three frequency bands (low, mid, and high). Each band has different capabilities: the low band (less than 1GHz) has greater coverage but lower speeds, the mid band (1GHz–6GHz) offers a balance of both, and the high band (24GHz–40GHz) offers higher speeds but a smaller coverage radius, as shown in Figure 3.

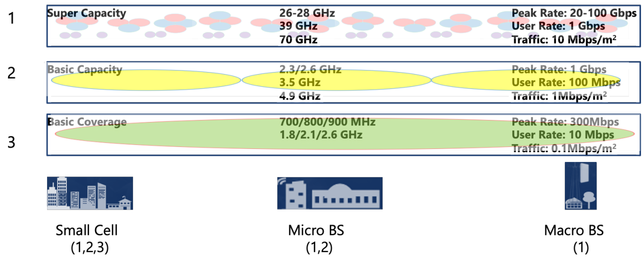

Figure 3: 5G Frequency Bands

5G Non-Standalone (NSA), has been introduced in 3GPP Release 15. It is considered as the first stage of 5G deployment over existing 4G networks. However, 5G NSA does not support low latency and it requires a higher level of energy [9].

The 5G NR architecture comprises next-generation RAN (NG-RAN) and 5G Core Network, as defined in 3GPP Releases 16 and 17. The NG-RAN offers the following new functions: network slicing, communication with UEs in inactive mode, handover between 4G and NR either through direct interface between eNB and gNB or via core network (CN), and dual connectivity.

Open RAN (ORAN) architecture provides an open-interface protocol stack that disaggregates the RU (Radio Unit) from the DU (Distributed Unit) to provide the deployment and runtime flexibility for robust value-delivery services [10]. Additionally, ORAN provides closed loop intelligent control and management of Radio resources in RAN, which makes it more agile for future functional and model-driven developments (e.g. AI/ML augmentation).

5) Edge Cloud Computing

Edge Cloud computing refers to the adaptation of cloud computing resources closed to the users in anywhere and anytime manner, where data are stored and processed outside mobile devices [11]. Fog computing a term coined by Cisco Systems is also referred to as multi-access edge cloud computing (MEC) by ETSI. Fog computing is mainly driven by the IoT industry, whereas MEC is supported by three telecommunication industry. The following figure illustrates the deployment differences among fog, MEC and cloud computing.

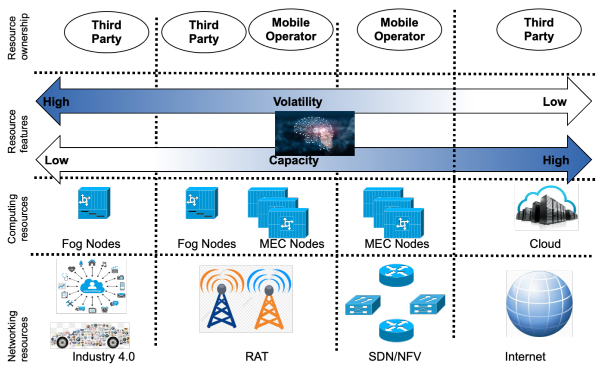

Figure 4: Fog vs MEC vs Cloud Computing

6) Telemetry

All existing telemetry protocols such as SNMP, NetFlow, NETCONF, and RESTCONF are pull-based [12]. In a Pull model, a collector maintains a list of agent endpoints (e.g., IP address, Socket ID, or URL) and connects to a Database. Within the context of 5G ecosystem, cloud computing parameters (e.g. CPU, RAM) are quite important. Additionally, besides pull-based methods, push-based methods are important where the agent initiates the telemetry to an intermediate message broker. The message broker may decouple the Collector and agent bond and introduces autonomy in scale and replication without informing each other for enhancing high availability, security, and load-balancing. Challenges in network telemetry include the following:

- **Custom data modeling**: In Classic SNMP, the Management Information Base (MIB) is a vendor-specific hierarchical data structure. Current protocols such as NETCONF and its RESTful extension RESTCONF provide model-driven programmability using the YANG data modeling language. However, YANG poses several challenges for establishing telemetry in a multi-vendor scalable environment. First, the YANG uses XML based model descriptor, which does not support native data structures like Dictionary and List. The evolution towards JSON-based data descriptor that is far more human-readable than XML; also, the user does not have to follow the strict YANG formatting while composing the model. As most programming languages natively understand JSON documents, no additional translation is needed.
- **Transport mode**: Standard APIs such as SNMP and NetFlow use raw sockets for transporting the data over a negotiated port number. Additionally, RESTCONF (available only in high-end network devices) provides the transport using HTTP-based RESTFul API, which every firewall allows by default. The HTTP body encapsulates the RPC operations, which are exposed as API endpoints.

C. *Network Automation and Softwarisation*

The orchestration challenges must take into consideration the cloud-to-edge continuum along with network virtualization [13]. This implies that the highly heterogeneous nature of the devices in terms of cloud capabilities, heterogeneous link-layer technologies and constraints in latency, resilience and security. The orchestrator must ensure the complexity of this environment, by considering the physical and virtual network devices that must interact to meet the below 1ms latency requirement.

D. *Knowledge-Defined Networking (KDN)*

KDN can take decisions based on information collected from a distributed cognitive framework. The primary objective of Knowledge Defined Networking (KDN) in 5G is to accumulate holistic information from a supervising CP of an underlying network to offer SON capabilities: Self-Optimization, Self-Configuration, and Self-Healing [14].

A typical of example of KDN protocol stack is illustrated in the Figure 5. The combination of AI and an optimized edge architecture can reduce cloud data and backhauling costs. Different AI frameworks such as federated, transfer and split learning can be deployed in the edge.

The Overlay-plane virtualizes, manages and orchestrates a physical network. It aims to provide a transport-agnostic model deploying dynamic end-to-end Tunnelling technologies (e.g., IPSec3 over DMVPN4 and OMP5). It allows Enterprise and service providers to use different transport modes (e.g., MPLS, LTE, 5G, etc). Additionally, it abstracts the data-plane infrastructure to the control plane and presents a unified interface to automate and configure policies on it.

The Knowledge Plane (KP) leverages the KDN paradigm. This component takes care of all data pre-processing, and offline and online training. It returns a trained model initially as an outcome of offline training. However, the model gets updates during online training whenever the trend changes.

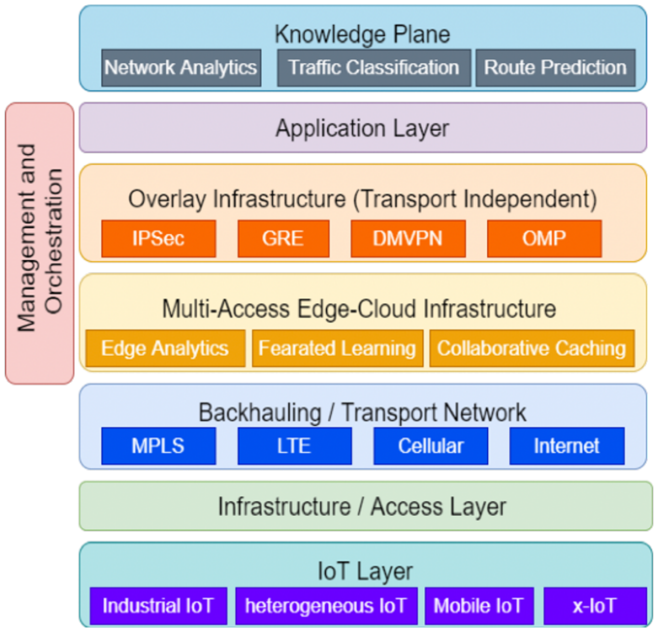

Figure 5: KDN

III. The Need Towards 6G

A. *6G requirements*

6G aims to alleviate the limitation of 5G technologies [15]. This includes:

- Global coverage using TN, NTN and underwater communication systems.
- Novel applications integrating of communications, sensing, immersive media, autonomous systems, AI and big data.
- Improving sensing using holographic communications and XR
- Use of digital twin providing interactions between physical and virtual words.
- Strong security facilitating reliable communications.

B. *Technology Enablers*

1) *TN/NTN Integration*

Demand for broadband service continuity is expected to further drive the network evolution and expansion into areas with broadband coverage for direct connectivity and IoT services [16]. Integration of Terrestrial and Non-Terrestrial Networks as a unified network will be able to provide the global coverage and connectivity everywhere and anytime.

3GPP and satellite stakeholders are capitalizing on ongoing trends to include satellite connectivity, in other words NTN, as an additional networking service. In fact, satellites have already been playing a pivotal role in standardisation. These service requirements have been captured initially in 3GPP Release14, highlighting the added value that satellite coverage brings, as a complementary network forming part of the 5G paradigm, especially for mission critical and industrial applications where ubiquitous coverage is crucial. Moreover, major international research initiatives such as 5GSAT (Horizon 202012), and European Space Agency funded (ESA) OSMOSIS and SATis5 are targeting integration of satellite connectivity as part of the 3GPP 5G NR architecture, where satellite is used as a backhaul service for demonstrating so far complementary use-cases targeting nomadic nodes.

C. Cell-Free MIMO

Cell-free massive MIMO networking can potentially resolve many of the interference issues that appear in current cellular networks [17]. In cell-free mMIMO networks, cooperative signal processing is usually very costly due to the extremely large amount of data, which may involve prohibitively high computational cost of joint processing. A full-scale cooperation also requires the estimation of channel coefficients from all devices to all radio units (RUs), or access points (APs), resulting in significant channel estimation overhead, and thus fundamentally limiting the gain achieved through cooperation. In addition, fronthaul networks are often capacity limited, which prohibits excessive information exchange among RUs. In general, one of the main challenges is to achieve the benefits of cell-free operation in a practically feasible way, with computational complexity and fronthaul requirements that are scalable to large networks with many users.

D. Reconfigurable Intelligent Surface (RIS)

RIS is a 6G technology enabler allowing to manipulate phase, amplitude and polarization to create a virtual line-of-sight (LoS) propagation path between a source and a destination [18]. RIS could be deployed in large surfaces such as rooftops, ceilings and walls. As an effect, RIS can be capable of managing blocking and coverage for both mmWave and THz communications. RIS can be either antenna-array-based or metasurface-based structures.

E. AI-based IBN

It is expected that AI will play an important role in 6G. Intent Based Networking (IBN) is a technology of intelligently and autonomously managing the network operations and resource allocation without human intervention [19]. IBN uses the following building blocks to realise intent: translation and validation, automation, state update, dynamic optimization and security. In a full deployment of IBN, the ultimate goal is to provide assurance and monitoring and have a full life-cycle management intentions from administration level into the infrastructure. The vision of fully automated network management cannot be achieved without implementation of high-level intention and policy translation and configuration. There is recent evolution on IBN, where Natural Language Processing (NLP) through Large Language Models have the potential to provide an automated IBN workflow [20].

IV. 6G Initiatives

This section outlines 6G research initiatives at both international and regional level.

A. Horizon Europe SNS

The Smart Network and Service (SNS) is part of the Horizon Europe. It aims to foster innovation and challenges for Systems beyond 5G [22]. The SNS aims to accomplish two missions: Fostering Europe's technology sovereignty in 6G by implementing a research and innovation (R&I) programme and accelerating the 5G deployment within the Europe market.

B. One-6G

One-6G aims to promote research and standardisation in 6G technologies, speed the development of new services across different verticals and promote standardisation [23]. One-6G consists of the following working groups: Use cases, KPIs and future market and business scenarios (WG1), Enabling technologies and system architecture (WG2), Communication and dissemination (WG3) and Evaluation, testbeds and pilots (WG4).

C. 6G Flagship

This is an 6G initiative that has been established by the Finish government [24]. It aims to design and develop different technology enablers to support different vertical applications through 6G experimental testbeds. The programme has already defined three goals: technology enablers, 6G Test Network Development, 6G Vertical Applications and 6G vision leadership.

D. UKTIN

This is an initiative by the UK government [25]. It aims to identify and respond to gaps in UK telecoms R&D to 2030 and beyond. UKTIN aims to gather insights from different working groups into the future evolution of the telecommunications ecosystem. UKTIN aims to align findings and build new bridges between the academia and industry in order to establish priority areas for future R&D&I.

V. Conclusions

This paper presents the of 5G characteristics and the key technologies of 5G ecosystem including the following technologies: SDN, NFV, network slicing, 5G RAN, edge cloud computing, network automation and use of AI to facilitate Knowledge Defined Networking. Limitations of the 5G and evolution towards 6G have been highlighted and the enablers for 6G presented, include the following: TN/NTN integration, cell free MIMO, RIS and AI-based network automation. Finally, 6G research initiatives at both international and regional level are presented.

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