5G: A Layman's Digest

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Abstract**—*****The 5G wireless communication system will be the next generation of mobile communications beyond 2020. 5G now is still in the exploration stage. There are some shortcomings in LTE and LTE-Advanced, such as strict synchronism, high latency with increasing number of connections, high energy consumption, and thus provides great challenges for its implementation in Internet of Things. The deployment of ultra-dense small cell networks or 5th gen networks provides unmatched opportunities to create an advanced system that meets the demands of future services, consumers, industries and paves way for further innovations. In this paper is discussed the architecture, standards and researches which would shape up the 5G wireless communication networks of the 2020s.***

I. INTRODUCTION

The development of mobile communications and electronic element technologies, better user experience for these technologies and lower prices of devices have greatly accelerated the growth of wireless telecommunication industry. It is estimated that the number of global subscriptions of smart phone could be 10 billion in 2025 and 12 billion in 2030. And the number of global subscriptions of tablet and other smart devices could be 3 billion in 2025 and 5 billion in 2030**[1].** However, the number of feature phone subscriptions will decrease rapidly beyond year 2020. 4G system has been deployed and reaching maturity in most developed countries, and even in prominent developing countries vast 4G networks have been deployed. So what could be the future of wireless networks?

Network equipment giant Cisco predicted in 2010 about, what they called, the wireless data explosion **[2].**The rate at which data traffic is growing today is about 2.4 times faster than fixed broadband data traffic around the world. Video streams take up on an average 66% of all the data usage on mobile devices across the world. Incremental changes in wireless networks, like the 4th generation networks which are current trends, will fail to meet consumer demands by 2020**[3]**. Thus, greater changes in the wireless network architectures are needed and 5th generation of wireless systems or mobile networks are the proposed solution.

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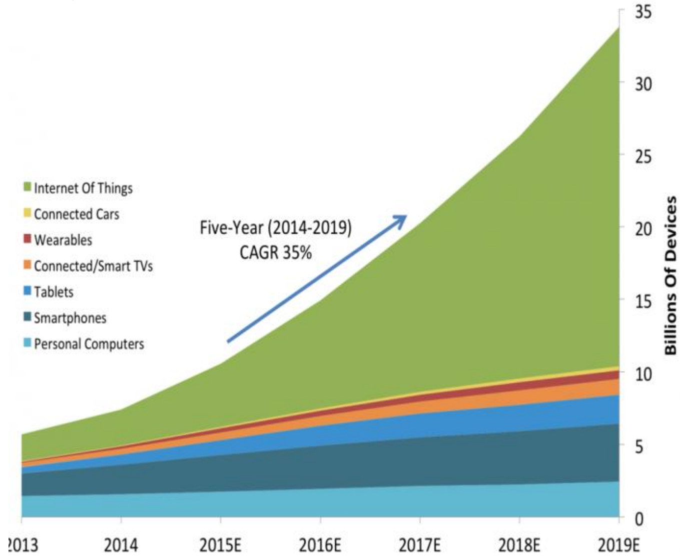
"The key technologies in 5G networks are not only physical layer transmission technologies and channel encoding but also considering more extensive breakthroughs such as multi-points, multi-users, massive MIMO (Multiple Inputs Multiple Outputs), multi-cells cooperation, and higher-level spectral efficiency. The 5G enhancement architecture will greatly improve the system performances. Compared to the 4G network, it is estimated that it should achieve more than 10 times the spectral efficiency, 25 times the average cell throughput by introducing new architecture, and achieve 1000 times the system capacity" **[17]** . 5G research and development, apart from data rates up to 10 Gigabits per second, also aims at lower latency than 4G equipment and lower battery consumption, for better implementation of the Internet of things.By 2018, the global mobile traffic is expected to increase from 2.6 to 15.8 exabytes. Estimations indicate 5G will support 1000 times the current aggregate data rate and 100 times the user data rate, while enabling 100 times increase in the number of currently connected devices, 5 times decrease of the end-to-end latency, as well as 10 times increase in the battery lifetime**[27].**



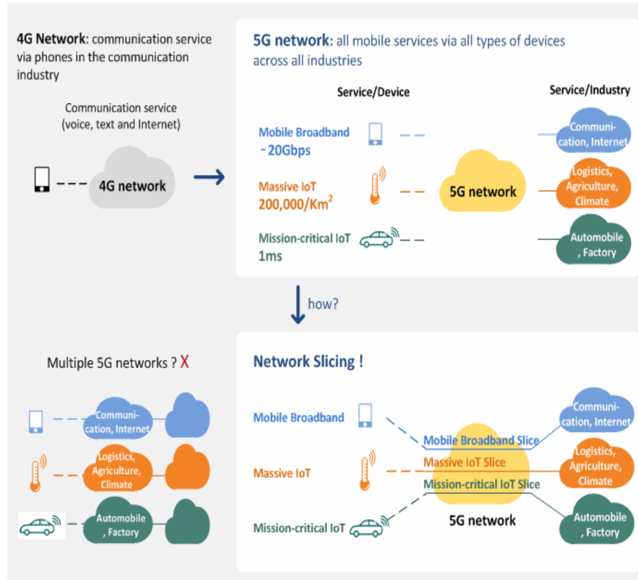
[E: Estimated]
Fig.: A representation of the number of devices connected to the internet. Source:**[26].**

II. ARCHITECTURE [9]:

The service architecture of 5G networks aims at meeting several mobile service requirements. With the use of Software Defined Networks (SDN's) and Network Virtualization Functions (NFV's) supporting the underlying physical infrastructure, 5G comprehensively cloudifies access, transport and core networks. This cloud adoption enables better support for diversified 5G services and key technologies of End to End (E2E) network slicing, along with on-demand deployment of service anchors.

The cloud RAN (Radio Access Network) consists of sites and mobile cloud engines. This coordinates multiple services operating on different standards in various site types for RAN real time resources that require a number of computing resources. Multi-connectivity is introduced to allow on-demand network deployment for RAN non-real time resources.

The transport network consists of Software Defined Network (SDN) controllers and underlying forwarding nodes. SDN controllers generate a series of specific data forwarding paths based on network topology and service requirements. The enabling plane abstracts and analyses network capabilities to implement network optimization or open network capabilities in the form of API. The top layer of the network architecture implements End to End automatic slicing and network resource management. The foundation for diversified 5G services is the End to End network slicing.Three layer cloud DC (Direct Connect, a peer to peer communication protocol) consists of computing and storage resources. The bottom layer is the central office DC, which is closest in relative proximity to the base station side. The second layer is the local DC, and the upper layer is the regional DC, with each layer of arranged DCs connected through transport networks. Network slices feature a logical arrangement and separated as individual structures.



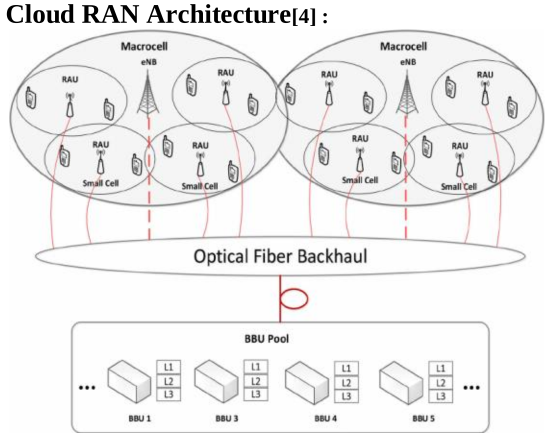
Network Slicing in 5G Systems **[19]**

III. CLOUD RAN [18] AND MULTI-CONNECTIVITY

In order to implement Radio Access Networks' (RAN) real time functions, network slicing and on-demand deployment of non-real time (NRT) resources, Cloud Ran Architecture is used. "With Mobile Cloud Engine (MCE), Cloud RAN can implement orchestration for Real time functions based on various service requirements to perform cloudification of the RAN. Cloud core functions are pushed out into the network and RAN is centralized to some degree, or with RAN and core executing in a centralized data center environment. This enables substantially lower latencies for the interconnection between RAN and core."

BBU: Base Band Unit
RAU: Radio Access Unit
eNB: Evolved Node B

Cloud RAN Architecture[4] **:**



Reliable high-speed data transfer cannot depend on a single frequency band or a single standard connection. In heterogeneous networks,**"Multi-Connectivity[9]**helps provide a better user experience based on LTE and 5G capabilities, such as high bandwidth and rates of high frequency, network coverage and reliable mobility of low frequency, and accessible Wi-Fi resources. In scenarios that require high bandwidth or continuity, a user requires multiple concurrent connections. For example, data aggregation from multiple subscriptions to 5G, LTE, and Wi-Fi is required to produce high bandwidth.In the Cloud RAN architecture, non-real time processing function modules in access points of different modes are integrated into the Mobile Cloud Engine (MCE) , which serves as an anchor for data connection. Data flows are transmitted to each access point over the MCE, which prevents alternative transmission and reduces transmission investment by 15%, and latency, by 10 ms."

IV. Software Defined Networks:

SDN has emerged as a new intelligent architecture for network programmability. Device controller (DCON) in a 5G network is a unit responsible for the device's physical layer connectivity to the 5G network. In a 5G scenario where devices are expected to have a number of radio access capabilities, the DCON handles AS (Access Stratum) functions such as access selection and network selection **[20]**. The primary idea behind SDN is to move the C-plane or control plane for the networks outside the switches and enable external control of information through a virtual entity called controller."SDN provides simple abstractions to identify the components, the functions they provide, and the protocol to manage the forwarding plane from a remote controller via a secure channel. This abstraction captures the common requirements of forwarding tables for a majority of switches and their flow tables.."**[21]**This centralized real time updated view enables the controller to perform network management functions, while allowing easy modifications in the network behavior through a software supported control plane.

SDN makes it possible to control the entire network through intelligent orchestration and provisioning systems, allowing real time resource allocation, completely virtualized networks, and secure cloud services. Thus, a static network transforms into an independent service delivery platform capable of continuously changing end user, market and even vendor demands. This results in simplification for devices, as they no longer need to accept and compute thousands of protocols, but just receive instructions from the SDN. The value of SDN in 5G networks is specifically highlighted through the capabilities it adds to the network, including network virtualization, creating new services on top of virtualized resource layers in a secure service delivery format. Furthermore, SDN separates the control logic from vendor specific hardware ecosystems creating vendor neutral C-planes.

V. **Beam Division Multiple Access (BDMA)** [24]

In the BDMA (Beam Division Multiple Access) allocation .technique, an orthogonal beam is allocated to each mobile station. Capacity of the system is increased as an antenna beam will get divided and allocated into the locations of mobile base stations thus providing the multiple accesses. As the mobile and base stations are in LOS (Line Of Sight) state, they can transmit beams directed to each other's position for proper communication, refraining from any interference from cell edge mobile stations. In case of mobile stations being positioned at different angles respective to the base station, the base station will transmit the beams in such a way that different angles will be covered, taking care of multiple mobile stations at the same time. One mobile station does not use one beam exclusively, but communication with the base station will occur with the same beam shared by mobile stations at similar angles. Mobile stations sharing the same beam will use the orthogonal resources, dividing frequency or time resources.

In order to maximize spatial reuse of frequency or time resources, three dimensional divisions happen in case of beams.The BDMA technology is applicable for cellular wireless communication systems for the next generation mobile communication. Further BDMA can act as a radio interface for 5G.

VI. **Network Function Virtualization (NFV)[29]**

In order to connect a massive number of devices and terminals, the development of scalable and versatile network functions is necessary, functions that could cope with a wider range of service requirements including low power, low data rate machine type communication, high data rate multimedia and latency sensitive services. 5G network functions face critical architectural challenges despite their superiority performance-wise. CoMP (Co Ordinated Multipoint Transmission Reception) can improve the user experience by using coordinated and combined transmission of signals from multiple transmission units, cells, terminals, or sites to improve the Downlink (DL) and Uplink (UL) performance, but these gains are achieved on the cost of increased computational requirements, signal overhead and higher equipment costs. These challenges will be tackled with the Implementation of network functions as software components using the NFV paradigms.

In NFV, vendors implement network functions in software components called Virtual Network Functions (VNFs). VNFs are deployed on cloud serversinstead of specialized hardware, which in case of 5G networks will be the Cloud RAN. NFV can overcome some challenges of 5G by:
(i) Optimizing provisioning of resources for cost and energy efficiency,
(ii) Mobilizing VNFs from one hardware resource to the other,
(iii) Ensuring performance promises of VNFs operations, including maximum failure rate and latency, and
(iv) Enabling VNFs to co-exist with network functions that are non-virtualized [28].

Network Functions that can be virtualized include:
(i) Evolved core packet functions like service gateway and packet data network gateway,
(ii) Baseband processing unit functions like Media Access Control (MAC) and Radio Link Control (RLC), **[30]**
(iii) Switching functions, and
(iv) Traffic load balancing.

VII. MAJOR CURRENT R&D PROJECTS [5]

The first of research and development project on 5[th] generation of wireless networks began in South Korea **[10]**, based on "Beam-Division multiple access and relays with group cooperation." NYU Wireless, a research center at New York University in 2012 was also set up as a multidisciplinary research center for 5G wireless researches, as well as its use in medical and computer science fields. The center is funded by the National Science Foundation and a board of 10 major wireless companies that serve on the Industrial Affiliates board of the center. The current projects of NYU wireless research center under the 5G networks development domain include **[15]**:

- Power Consumption of A/D Converters in Millimeter-Wave Systems
- Millimeter Wave Radiation and Biological Health effects on Humans
- Millimeter Wave MAC Layer Design
- Millimeter Wave 5G Prototype and Channel Sounder
- 3D 28 GHz and 73 GHz measurements and models
- Spatial Channel Estimation and Tracking
- Stochastic Congestion Control Protocols for High End-to-End Throughput in Next Generation Cellular Networks
- mm Wave Propagation Database

In 2012, the European Commission, committed 50 million euros for research to deliver 5G mobile technology by 2020. **[6]** In particular, The METIS **[11]** 2020(*Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society*) Project was the flagship project that allowed reaching a worldwide consensus on the requirements and key technology components of the 5G. Driven by several telecommunication companies, the METIS overall technical goal is to provide a system concept that supports 1,000 times higher mobile system spectral efficiency, compared to current LTE deployments. In addition, in 2013, another project has started, called 5GrEEn **[12]**, linked to project METIS and focusing on the design of green 5G mobile networks. The goal of 5GrEEn project is to emphasize energy efficiency and sustainability.

Moreover, in July 2015, the European research project mmMAGIC **[12]***(Millimeter-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications)* was launched to develop new concepts for mobile radio access technology (RAT) for mm wave band deployment. This project aims at paving way for a European head start in 5G. It brings together major infrastructure vendors, European operators, research institutes and universities, measurement equipment vendors and one Small and Medium sized Enterprise. mmMAGIC is led and coordinated by Samsung. Ericsson acts as technical manager with Intel, Fraunhofer HHI, Nokia, Huawei and Samsung leading one of technical work packages.

VIII. PROPOSED FREQUENCY SPECTRUM

In order to support increased traffic handling capacity and to enable the enhanced mobile transmission bandwidths to support very high data transfer rates, 5G networks will extend the range of frequencies used for mobile communications. This includes new spectrum below 6GHz, as well as spectrum in higher frequency bands.

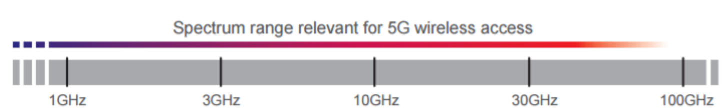


Figure: Spectrum relevant for 5G wireless access **[22]**.

Thus the spectrum for 5G communications can hypothetically range from 1 to 100 GHz. "It is important to understand that high frequencies, especially those above 10GHz, can only serve as a complement to lower frequency bands, and will mainly provide additional system capacity and very wide transmission bandwidths for extreme data rates in dense deployments."**[22]**

Although the backbone for mobile communications in the 5G era, with wide area connectivity in sight, will continue to be the spectrum allocations in the lower frequency range bands.

Lower 5G bands for early deployments[23]

Europe	3400 – 3800 MHz (awarding trial licenses)
China	3300 – 3600 MHz (ongoing trial), 4400 – 4500 M 4990 MHz
Japan	3600 – 4200 MHz and 4400-4900 MHz
Korea	3400 – 3700 MHz
USA	3100 – 3550 MHz (and 3700 – 4200 MHz)

Potential first deployments of higher 5G bands[23]

USA: 27.5 – 28.35 GHz and 37 – 40 GHz pre-commercial deploymer

Korea: 26.5 – 29.5 GHz trials in 2018 and commercial deployments ir

Japan: 27.5 – 28.28 GHz trials planned from 2017 and potentially con deployments in 2020

China: Focusing on 24.25 – 27.5 GHz and 37 – 43.5 GHz studies

Sweden: 26.5 – 27.5 GHz awarding trial licenses for use in 2018 and o

EU: 24.25 – 27.5 GHz for commercial deployments from 2020

IX. Currently Available Solution

The NOKIA 5G **[7]**First is the first industry standard solution considering its advancements over the LTE and LTE-A networks. It is an end to end solution incorporating NOKIA's Airscale, Airframe technologies, along with their 5G acceleration services. This solution is based on industry specifications as defined by the Verizon 5G Technology Forum ecosystems. It is aimed at providing Mobile Telecommunications Operators a first-to-market advantage for setting up future Radio Access Networks, with the current framework being based on early specifications.

NOKIA's Airscale Radio Solution comprises of AirScale Base Stations including new Radio Frequency elements, system modules, AirScale Active Antennas for lean site solutions & massive MIMO and AirScale Cloud RAN with Management solutions for it.

AirScale Cloud RAN**[8]** is NOKIA's solution for a multi-layered one-cloud Radio Access Network with a functional split between real-time (RT) and non-real-time (NRT) traffic, enabling much longer backhaul latency to be tolerated and permitting the use of Ethernet-based backhaul transport.

X. Use Cases

The International Telecommunication Union (ITU) [13] has categorized 5G mobile network services into three types:

- Enhanced Mobile Broadband (eMBB)
- Ultra-reliable and Low-latency Communications (uRLLC)
- Massive Machine Type Communications (mMTC)

Enhanced Mobile Broadband aims to meet people's demands for an increasingly digital lifestyle, with focus on services demanding high bandwidth, like

- High Definition Video Streaming
- HD Video calls and video conferencing
- Implementations of Online Architecture as a service
- Augmented Reality (AR)
- Virtual Reality (VR) etc.

Ultra-reliable and low Latency Communications aims to meet expectations for an ever demanding digital industry with main focus on providing solutions for latency-sensitive services, which include

- Assisted Driving Systems
- Automation in vehicles like self-driven concept cars
- Mission Critical Applications
- Remotely Managed or automated Life Support systems etc.

Massive machine type Communications services demands for a further developed digital society with services facing issues of high connection densities, such as

- Smart City
- Smart Agriculture
- Smaller implementations of the Internet of Things (IoT) like smarter homes.
- Big Data Network Architecture and Monitoring [16]

Deployment scenarios with Spectrum divisions [25]:

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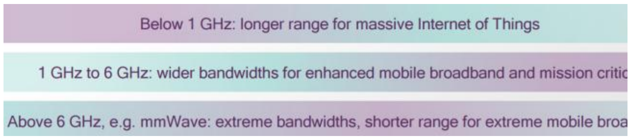

XI. CONCLUSION

The pace of change and upgrades in digital technologies has been accelerating ever since the birth of computing, and is expected to further accelerate with upcoming overhauls in the field of mobile communication networks. Mobile terminals are progressing each quarter, accumulating more processing power, on board memories, advanced sensors, artificially intelligent software components as well as longer battery lives to support all this. With use of technologies like Cloud RAN, MCEs, Beam Division Multiple Access and Software Defined Networks, 5G networks, although still in early development stages, and the ever progressing smart phones promise huge advancements in fields of communication.

It is now concluded that this paper intends to provide its readers with a fundamental knowledge in the current trends, technologies implemented in, and the status of development of fifth generation of mobile communication networks, or 5G.

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