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A Survey on Current Repertoire for 5G

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***Abstract*—**Cellular technology progressed miraculously in the last decade. It has redefined communication paradigm. Statistics provided by Ericson and Cisco show the number of mobile connected devices will reach figures of 9.2 billion and 11.6 billion respectively by 2020. Overall connected devices will surpass 50 billion then. Extremely higher data rates, zero latency, massively scalable, connecting everything anywhere is what that 5G promises. To meet such ambitious goals which apparently seems challenging, the tools and technologies that mobile communication has in its repertoire and what it needs more either enhancement in existing solutions or new solution or joint venture of both, is a question that demands an answer. To realize 5G, evolution and revolution both approaches are being employed. Evolution seeks enhancements in existing technologies while revolution looks for new innovations and technologies. Extension in frequency spectrum, network densification, MIMO, carrier aggregation, Centralized-RAN, HetNets, and Network Functionality Virtualization are the key enablers. This paper disseminates information about ongoing research and development of 5G.

Index Terms—Fifth Generation (5G), Heterogeneous Networks (HetNet), Multiple Input Multiple Output (MIMO), Carrier Aggregation, millimeter Wave.

I. INTRODUCTION

Societal development and Machine type communication are the two key forces shaping the communication. Emerging applications like e-health, e-business, e-banking, e-learning and their proliferation into daily life around the world is going to put tremendous load on mobile and wireless communication. Internet of things (IoT), smart cities, traffic controls, smart grids and industrial automation and controls are examples of future communicating machines paradigm. Internet is influencing all aspects of life; from daily life, to academic activities, and business in all industries. Mobile access to internet has become a fundamental requirement in modern business. It is needed not only to increase productivity but also to expand business operations across the continents thus leading to remarkable growths. Growth in demand and use of internet, cloud services, data services and data analytic services have made possible for everyone to benefit from globally connected and shared knowledge base everywhere. The infrastructure of modern information communication technologies' (ICT) networks and their transformation are key elements behind innovations and growth in modern business. ICT appeared as an effective tool to enhance efficiency and is one among important drivers of economic and societal growth.

According to [1] and [2], the number of mobile connected devices will reach figures of 9.2 billion and 11.6 billion respectively by 2020. Overall connected devices will surpass 50 billion then.

Development of Fifth Generation (5G) technology will be another leap to realize a major breakthrough in evolution and transformation ICT networks. ICT has transformed the way people make communication and access data and information. Mobile wireless networks have done a lot in this regard, and it continues to redefine communication infrastructure and services. The goal is to make mobile services equipped with potential to connect any user any device any time. 5G internet is implementation of ubiquitous ultra-broadband network infrastructure and integration of mass cloud with the wireless networks. Thus it would make mobile networks capable of flexibly providing services at extremely higher unprecedented rates and to meet the growing demand of data traffic, IoT and security.

To meet such ambitious goals which apparently seems challenging, what tools and technologies that mobile communication has in its repertoire, and what it needs more, either enhancement in existing solutions or new solution or joint venture of both, is a question that demands an answer typically in the mind of individuals having little awareness of wireless communication technologies.

This paper in section II gives a summary of evolution of mobile communication technology, section III identifies the requirements and challenges of 5G, section IV states a little explanation of some of the enabling technologies, section V gives glimpses of ongoing research and development to realize 5G and highlight issues, and section VI concludes the discussion.

II. Evolution of Cellular Communication

1G system used analogue encoding, circuit switching, 30 KHz channel bandwidth (BW) and Frequency Division Multiple Access (FDMA). These were specifically for voice transmission. These systems included NMT, AMPS, TACS, RTMI, C-450, and TZ801 to 803. Only NMT provided non-commercial DMS mode at 380 bps with external hardware support [3].

2G systems used digital encoding. Here we found two approaches as shown in Fig. 1; first Time Division Multiple Access (TDMA) and other is Code Division Multiple Access (CDMA). TDMA based Global System for Mobile Communication (GSM) was initially designed as Circuit Switched network with 200 KHz channel BW. It was mainly to transport voice traffic and a little capacity of data transmission at 9.6 Kbps. By relaxing algorithms for error control, encoding and 4 time slots enabled it to provide data rate of 57.6 Kbps. Later it was enhanced to support packet switched functionality to deliver internet services on mobile handsets. This enhancement was named General Packet Radio Service (GPRS). According to GSM Edge Radio Access Network (GERAN), GPRS Release 97 (R97) promised transmission at 40 Kbps Downlink (DL) and 14 Kbps Uplink (UL). To achieve this, GSM time-slots were aggregated into single bearer. In R98 and R99 DL data rate was achievable up to 171 Kbps theoretically. Another step in advancement of GSM was Enhanced Date Rates for Global Evolution (EDGE) sometime termed as Enhanced GPRS. In EDGE, modulation technique 8PSK replaced GMSK; it resulted in three fold increase in transmission speed. It increased spectral efficiency by employing new channel coding. EDGE offered data rate of 384 Kbps. Later EDGE Evolution that is complement to HSPA technology brought down the latencies to 100 ms and improved spectral efficiency.

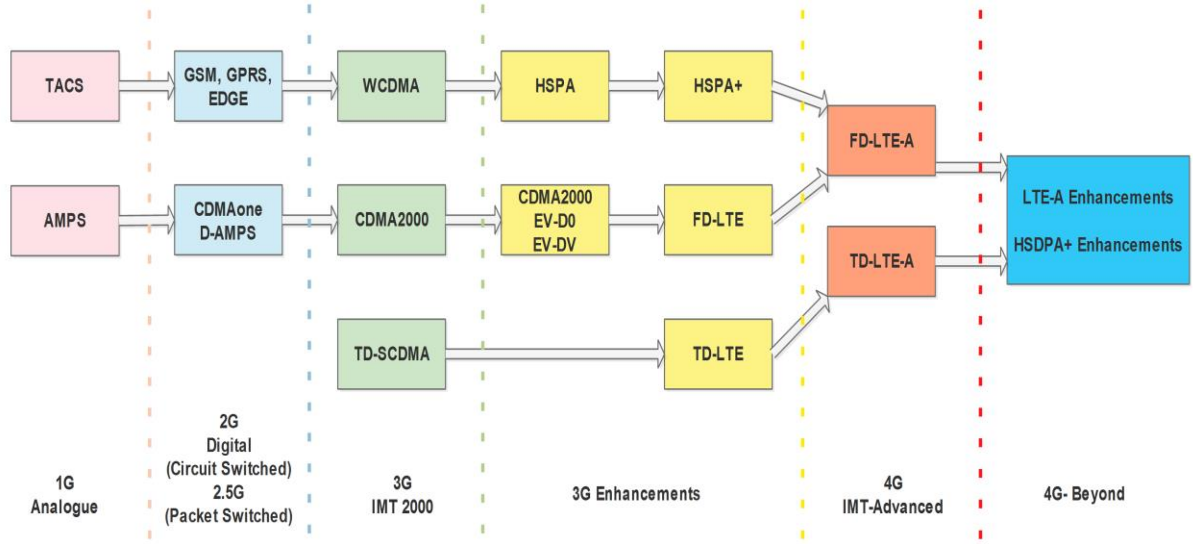

Fig.1. Evolution of Mobile Network Technology [42]

CDMA based systems feature anti-jamming and higher quality. IS-95 with 1.25 MHz channel BW offered data rate of 9.6 Kbps. Later IS-95A provided 14.4 Kbps and it was improved to 115.2 Kbps in IS-95B by allowing maximum 8 Walsh Codes to a single user.

Under the umbrella of ITU-IMT2000 family of 3G standards; 3GPP-II developed upgrade for IS-95B, by only software upgrade and addition of network channel cards, following path of CDMA2000 1xRTT with 144 Kbps and further upgraded to CDMA2000 1xEV with 2.4 Mbps and CDMA2000 3xRTT with 2 Mbps.

3GPP Universal Mobile Telecommunication System (UMTS) developed Wideband CDMA (W-CDMA) radio access technology (RAT). W-CDMA uses Spread Spectrum (SS) modulation technique. Unlike other techniques, its channels use whole BW of 5 MHz and provide data rate of 2 Mbps. It supports Frequency Division Duplex (FDD) and Time Division Duplex TDD. Its channel encoding scheme makes transmitted signals intelligible to decoder if it knew the code, otherwise it is noise. UMTS derives core network from GSM to support backward compatibility and seamless handover of user between GSM and W-CDMA. Further its specifications allow Universal Terrestrial Radio Access (UTRA) to utilize wide band allocated to it and coexist with other prevalent Random Access Technologies (RAT). 3GPP has vision behind UMTS that seeks to expand capabilities to ensure delivery of most of the services either over GERAN or UTRAN [4]. Fig. 2 shows simplified architecture of 3GPP technologies.

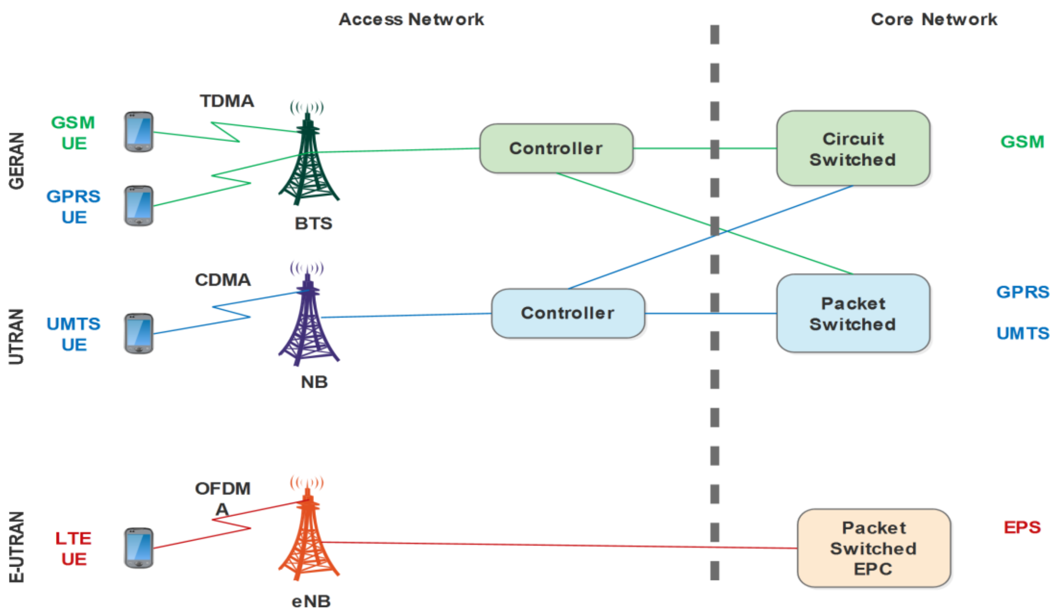

Fig.2. Simplified Architectures of GERAN, UTRAN, E-UTRAN [5]

Deployment of UMTS created an increasing demand for further higher data rates with lower delays. This lead to an upgrade in WCDMA named High Speed Packet Access (HSPA). HSPA was introduced incrementally, in Release 5 High Speed Down-Link Packet Data Access (HSDPA) and, in R6 High Speed Up-Link Packet Data Access (HSUPA) was incorporated. Combining both, it is commonly termed as HSPA Evolution. To reduce amount of delays in channel allocation and keep with varying channel qualities, HSPA added some function in NodeB. These functions include; scheduling that is selection of UEs going to use radio resource after each 2 millisecond Transmission Time Interval (TTI) in R99 TTI was 10 milliseconds, and Link Adaptation meant to effectively utilization of resources by setting coding rate of channel and selection of modulation technique either QPSK or 16QAM. Further metrics used in making decision are channel quality information, type of service and UE category. For carrying HSDPA user data, a new shared transport channel named HS-DSCH is used which maps to one or more Physical HS-PDSCH. It also featured sharing of channelization code via time multiplexing besides code multiplexing in R99. The enhancement made in HSUPA provides dedicated transport channels named Enhanced Dedicated Channel (EDCH) to each User Equipment (UE) that maps to Enhanced Dedicated Physical Data Channel (E-DPDCH) on Physical Layer. To carry higher UL data rates, more E-DPDCH can be used. HSDPA provides maximum channel rate of 14.4 Mbps, and HSUPA provides 5.8 Mbps.

Enhancement of HSPA, termed as HSPA+ using higher order modulation techniques i.e. 64-QAM for DL and 16-QAM for UL, and MIMO with spatial multiplexing for DL, further increases data rates. It offers data rate of 21 Mbps for downlink using 64QAM, 15 codes (R8 specifies 42 Mbps with 64QAM) and 11 Mbps for uplink using 16QAM.

Long Term Evolution (LTE) is advancement in mobile communication. It introduced a pure IP based system named Evolved Packet System (EPS), and developed over the top of UMTS technologies. 3GPP R8 introduced E-UTRAN that describes access side of EPS. The key features of E-UTRAN include higher spectral efficiencies, larger bitrates, small round trip time, and flexibility in use of Frequency Spectrum (FS) and BW. It does not place any centralized intelligent controller instead intelligence is distributed amongst base stations. This makes connection set up faster and reduces the handover time. TTI is set to 1ms. In each TTI, eNB scheduler makes scheduling and decisions considering physical characteristics of radio environment and QoS requirements etc. 3GPP adopted Orthogonal FDMA (OFDMA) for DL and Single Carrier - FDMA (SC-FDMA) for UL. OFDMA using higher order modulation techniques up to 64-QAM, bandwidth up to 20MHs, and spatial multiplexing technique provides data rate of 300 Mbps in DL and 75 Mbps in UL.

Evolved Packet Core (EPC) introduced in R8 by 3GPP. It forms the core of LTE technology. EPC is a flat architecture as shown in Fig. 3. It is envisioned to cater higher data rates with higher performance at lower cost. Taking into account the different functionalities and characteristics; it separates user data (User-Plan) from signaling (Control-Plan) to make scalability independent and flexibility for the operators. UE connects to Evolved UTRAN (E-UTRAN) through Evolved NodeB (eNB). The main components of EPC include Serving Gateway (SGW), Packet Data Network Gateway (PDN-GW), Mobile Management Entity (MME) and Home Subscriber Server (HSS). eNB serves as Base Station (BS) of LTE radio. PDN-GW connects external IP networks with the EPC. Its functionality includes IP address allocation, charging etc. SGW together with PDN-GW transports packet data traffic between UE and external network. SGW functionalities include routing of IP packets, intra-network mobility and inter-network mobility. MME takes care of signaling needed for mobility management and security. HSS is database which contains subscriber related information for authentication, authorization and support for MME.

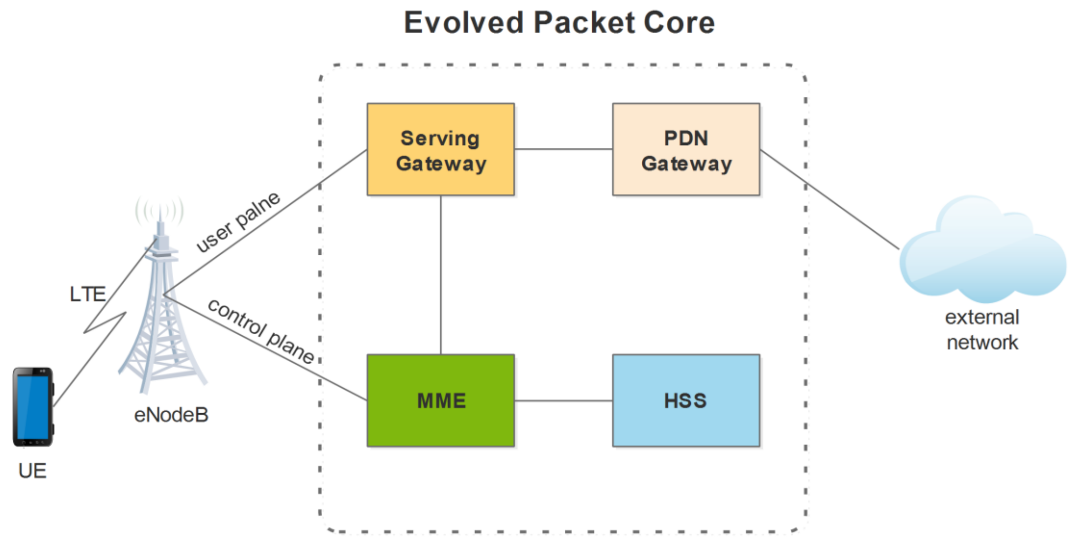

Fig.3. EPC Architecture [6]

LTE-Advanced (commonly termed as 4G) is another step in advancement made by 3GPP. It is meant to achieve higher capacity. LTE-Advanced promises data rate of 3 Gbps for DL and 1.5 Gbps for UL. It also aims at increasing spectral efficiency to 30 bps/Hz, delivering services to large number of subscribers at same time and delivery of services at cell edges efficiently. To achieve these objectives LTE-Advanced introduced new techniques like CA, multiple antenna systems, and support for Relay Nodes (RN) [7].

III. 5G Requirements and Challenges

Societal development and Machine type communication are the two key forces shaping the communication. Emerging applications like e-health, e-business, e-banking, e-learning and their proliferation into daily life around the world is going to put tremendous load on mobile and wireless communication. Internet of things (IoT), smart cities, traffic controls, smart grids and industrial automation and controls are examples of future communicating machines paradigm.

Growth trends so far predict that there will be increase in mobile connected devices from 7.1 billion in 2014 to 9.2 billion devices by 2020. This includes in total 26 billion connected devices by 2020 including 15 billion phones, tablets, desktops and laptops. Evolution of existing and emergence of innovative technologies would create new use cases which would increase the connected devices to 50 billion. Global mobile data traffic would increase from 3.4 Exabyte per month in 2014 to 32.8 Exabyte per month in 2020 with tenfold increase. Smart phones will be having share of 80% of this data traffic. One can imagine future communication requirements by looking into workloads. For example 1.5 Terabyte of traffic was generated by 75000 spectators during final of football world championship 2014 which was five times greater than average busiest hour traffic [1].

According to [2] there will be 11.6 billion mobile connected devices by 2020 from 7.9 billion in 2015 with 8% compound annual growth rate (CAGR). Global mobile data traffic will increase from 3.7 Exabyte per month in 2015 to 30.6 Exabyte per month in 2020. Smart phone will be having share of 81% of this total with 8% CAGR. M2M devices will increase from 604 million in 2015 to 3.1 billion by 2020 with 38% CAGR. Wearable devices from 97 million in 2015 to 601 million by 2020 with 44% CAGR and their data traffic will increase from 15 PetaByte in 2015 to 335 PetaByte by 2020 with 87% CAGR.

So, future mobile communication will pose challenges of extremely higher data rates, much lower latencies, and massive numbers of connected devices, connectivity, mobility, and cost and energy efficiency. 5G networks will meet these challenges. METIS envision 5G challenges and requirement and portrayed them into five scenarios and 12 test cases. They cover most of the application and user requirement in 2020. METIS identified technical goals paving the way for system concepts that as compared to today networks will support 1000 fold higher mobile traffic per area, 10 to 100 folds connected devices, 10 to 100 folds higher data rates, 10 folds longer battery life, and 5 times decrease in end-to-end latency. The scenario of “amazingly fast” deals with the challenge of extremely higher data rates, ‘Great service in crowd’ deals with dense crowd of users, ‘Ubiquitous things communicating’ deals with massive scalability and cost and energy efficiency, ‘Best experience follows you’ deals with mobility, and ‘Super real-time and reliable connection’ deals with constraints of reliability and latency. Test cases are provided to capture problem description and requirements, and to determine key performance indicators (KPI) from the perspective of end user. The insight in test cases reveals the possible challenges which are also reflected in scenarios [8].

IV. The Repertoire for 5G

These are the key techniques and technologies that have potential, and their application enable meeting 5G challenges and requirements. They may be called ‘enablers’.

A. Frequency Spectrum

Frequency is a limited resource. The underutilized and unutilized bands in spectrum have a great deal of opportunity in meeting the demands of 5G. Cellular networks, deployed so far, use carrier frequency spectrum from 700MHz to 2.6GHz. Higher frequency spectra are key enabler for provisioning of 5G data rates.

B. HetNets

The increasing rate of subscribers of mobile broadband and BW intensive services forced operators to find new ways for effective network planning. They responded to this challenge by raising network capacity with addition of new spectrum, implementation of efficient modulation techniques, coding and multi-antenna systems. But these measures were unable to cope typically in crowded environments like a football stadium and at cell edges where degradation of performance is severe. Integration of homogeneous small cells into macro network greatly helped in distributing the load while maintaining performance and efficient reuse of spectrum. Increasing sectors in a single eNB is also employed to resolve such issues. All these solutions were homogeneous. Another alternative approach is also employed in which, to an existing macro eNB, number of Small Cells (SC) are added through low per base stations. These SCs are termed as heterogeneous NodeBs, or Remote Radio Head (RRH) or Relay Nodes (RN). These SCs provide capacity increase in hotspots, fill coverage gaps of macro cells in both indoor and outdoor, and increase network performance by offloading macro cells. After incorporating these SCs, the resultant network is Heterogeneous Network (HetNet) [9]. In HetNet cells are categorized into macro, micro, pico, and femto on basis of BS power. LTE Release 9 specified Home eNB (HeNB) which may be privately owned for indoor coverage, and femto cells in offices for closed subscriber groups. Introduction of these heterogeneous cells makes network planning complex. However to resolve the issues in HetNets; LTE introduced Inter-Cell Interference Coordination (ICIC) in Release 9, Carrier Aggregation (CA) in Release 10,and Coordinated MultiPoint (CoMP) in Release 11.

C. Carrier Aggregation

What is simplest idea to increase capacity? The answer is increase bandwidth. CA employs this same idea but after crafting it. It can be employed in DL also in UL, and supports FDD and TDD. By aggregating different carriers up to 100 MHz bandwidth is achievable. In LTE R8, R9 network resources allocation to UE can be made on one Component Carrier (CC). However in R10, if UE is capable of CA, resources allocation is made on all CCs. Further cross carrier scheduling using mapping of PDCCH on different CCs of smaller and larger cells. CA results in even higher bitrates.

D. MIMO

Multiple Input Multiple Output (MIMO), also termed as Spatial Multiplexing uses different reference signals for transmission of multiple data streams using multiple antennas or arrays of antennas (Distributed Antenna Systems) on same frequency and at same time. LTE-Advanced introduced 8x8 MIMO in DL and 4x4 MIMO in UL. This technique can be utilized if S/N ratio is high. R10 specifies different transmission modes for different MIMO configurations [10].

E. CoMP

In Co-ordinated Multi Point (CoMP) multiple transmission/ reception points coordinate with each other to deliver services to UE. The idea is multiple transmission points (eNB, RNs, and RRHs) transmit data to UE at same time in same Physical Resource Block (PRB). For UL data is received from different transmission points in sub frames. CoMP increases utilization of resources and provides higher DL, UL data rates.

F. Cognitive Radio/Software Defined Radio

Cognitive Radio (CR) improves spectrum utilization. It exploits the idea that primary system in licensed bands can utilize underutilized secondary spectrum. There are two approaches for this communication either it can be interference free or interference tolerant [11]. For it, CR needs to be aware of its surrounding radio environment.

In place of hardware radio that contains filters, modulator/demodulator and converter; Software Defined Radio (SDR) provides an easy interface for band selection. Complexities of bands like encodings and protocols are built in thus user can select Wi-Fi, WiMAX, GSM, LTE signals and utilize their services. Together with CR, SDR can improve spectrum utilization. Combing CR with SDR network performance can be enhanced for 5G systems [12].

G. Software Defined Network (SDN)

Software Defined Network (SDN) separates the network control and forwarding functionality thus provides more flexibility to program and control functionality dynamically. For applications and making forwarding decisions, it abstracts the underlying hardware and provides a single interface [13].

The Open Network Foundation also set up Mobile and wireless Working Group for identification of use cases applicable in mobile and wireless domain which can be implemented using Software Defined Networks (SDN) built on the foundation of OpenFlow.

H. Centralized-RAN

Centralized Radio Access Network (C-RAN), is introduced by China Mobile Research Institute in April 2010. It separates the Base Band Units (BBU) from access units, thus enables to migrate BBU processing at central clouds. It offers a great deal of scalability and flexibility [13].

In Distributed RAN, backhaul links base stations with their peer entity in the core network. In LTE Serving Gateway (SGW) and Mobility Management Entity (MME) serve as backhaul links and provide a transmission pipe for user-plane, control-plane and management data between base stations and core network using logical interface S1-u/c.

In Centralized RAN, baseband processing is not performed at base station; instead baseband units (BBU) are moved to centralize location. Thus base stations needs to be equipped only with RF electronics components. Such base stations with no BBU are termed as Remote Radio Heads (RRH); these are connected to C-RAN-BBU by front-haul using optical or wired high speed links for transmission of digitized IQ sample. The C-RAN architecture may be implemented in various schemes like dedicated-BBU, pooling-BBU, or more flexible and configurable cloud-BBU [14].

I. Network Function Virtualization (NFV)

Instead of deployment of network functionalities on dedicated hardware, it implements these on general purpose computers or data centers in software environment.

Virtual networks formed by combining SDN and NFV provides, a more flexible mechanism that can adapt modifications and can be easily managed by operators. Software defined RATs with integration of C-RAN and D-RAN for front-haul and back-haul will be a solution to requirements of future networks [15]. European Telecommunication Standard Institute (ETSI) has set up an Information Service Group (ISG) to define requirements and standardize the architecture for network functionality virtualization (NFV) and resolve the challenges.

J. mmWAVE (mmW)

Millimeter Wave (mmW) band (30 GHz to 300GHz) encompasses 90% of the allocated spectrum. Cellular networks are operating below 3GHz. traditionally it is not considered suitable for cellular transmission due to path loss and attenuation. However it is observed that using CMOS RF circuits and miniaturized multi-antennas transmission over a distance of 100-200 m, it is viable with multi Giga bit rate. Typically at identified spectrum around 80GHz band and 230GHz band where oxygen attenuation is only fraction of a decibel greater than free space attenuation [16].

K. Fiber Optic

Utilization of fiber optic at fronthaul and backhaul can increase the data rate of 5G up to the scale. In backhaul, besides with microwave and copper wire, it is already in use. As it is a guided media so its deployment forces to incur costs. Radio over Fiber (ROF) already gained attention of researchers and results show that it can provide multi-giga data rates [10].

L. Direct D2D wireless

This technique does not use network resources like BS, BSC etc. Instead of these communication takes place directly between the devices. It depends on proximity of devices and their capabilities. Network can be used for connection set up, if devices are closer to each other, Direct D2D mode take over the communication. Thus it offloads the network, and network capacity and spectrum usage can be employed efficiently [17].

M. FD Wireless

Full Duplex (FD) Wireless enables data transmission /reception simultaneously on same frequency band. The problem that restricts FD mode is Self Interference. Techniques are available for Self Interference cancellation up to 120 dB for analogue and digital wireless communication. It results in doubling the capacity of physical layer, improvement in feedback latency, and physical layer security [18].

N. Energy Efficiency and Energy Harvesting

One of the major challenges posed in envisioned 5G system is energy efficiency and prolonged life in the case of battery powered devices. Besides other techniques aiming at processing efficiencies and optimization to reduce energy consumption, and innovations in electrochemical design of batteries, energy harvesting from the environmental resources (like solar, wind) offers optimistic opportunities. However due to variation in the energy levels of these sources, they may not be suitable for such wireless applications those enforce constraints of QoS and reliability. RF energy harvesting resolves such issues and can provide sustained energy typically suitable for wireless cellular networks. RF energy harvesting networks (RF-EHN) and Simultaneous Wireless Information and Transfer of Power (SWIPT) featuring FD and energy harvesting with sensitivities of UE for information -10 dB, and for power -60 dB are discussed in [10].

V. RESEARCH AND DEVELOPMENT OF 5G AND ISSUES

5G is in research phase, it is not standardized yet. Many organizations and research community are looking into prospects, challenges and opportunities of the technologies to realize 5G, these include METIS in Europe, ARIB 2020 and Beyond Ad hoc (20B AH), FANTASTIC-5G, and NGMN. Besides these Ericson, Nokia, NEC, SAMSUNG, HUAWEI, NTT DOCOMO, QUALCOMM, 3GPP and many others are leading the research and development.

The evolutionary path for 5G is led by 3GPP; it looks for enhancements in existing standards and deployments. By incorporation of technological innovations into existing standards, 3GPP is in fact setting up the foundation for the future wireless communication. It has introduced features like offloading of network to WiFi or LTE-Unlicensed, CA, MIMO, MTC and D2D in Release 13.

5G should be built on the top of 4G i.e. LTE-A to be viably accepted by operators. So, apart from other innovations and technologies needed to be developed, we can think LTE-A as the foundation of 5G. 4G technology is basically seamless integration of existing and upcoming technologies to meet user demands and to ensure mobility and roaming. In it, a core network is integrated with several RANs. They communicate through core interface. Multiple radio interfaces enable mobile device to communicate with RANs [19]. There are 64 LTE-A commercial deployments in 39 countries, in these deployments over 80% support category 6 (150 Mbps to 300 Mbps maximum DL throughput theoretically). Around 393 LTE networks are running commercially in 138 countries and by the end of 2015 this count reached to 460. LTE subscribers reached 497 million till the end of December2014, in which 290 million subscribed in that year that reflects a growth of 140% annually [20].

METIS follows push/pull methodology for innovative solutions. Bottom-up approach focuses on new Radio Access Technologies (RAT) which are optimized to meet 5G implications. In top-down approach use cases are evaluated to determine their application and service needs. It typically proceeds with the perspective of end user. Technology components used for provisioning of viable solutions to METIS test cases are integrated into a system concept under the name of Horizontal Topics (HT).

METIS HTs [21] include

- Direct Device to Device (D2D) communication that enables direct communication between user devices. It offloads network because user-plan traffic does not pass through network infrastructure. However network controls radio resource usage to mitigate issues of interference due to D2D communication. It provides increased coverage and spectrum utilization. Besides these, it offloads network backhaul, supports fallback connectivity and raise in capacity per area.
- Massive Machine Communication (MMC) looks for provisioning of scalable connectivity to unlimited number of devices; one example of such paradigm is IoT. It also caters the varying needs of these communicating machines in terms of reliability, latency, cost and data rates.
- Moving Networks (MN) are meant to extend and enhance the coverage for devices that jointly move. A single or many node part of MN are connected to the bigger network. Wireless sensors inside and outside of moving vehicle is an example of such network.
- Ultra Dense Networks (UDN) is network densification that simply means large number of networks; it resolves the issues of provisioning capacity, energy efficiency of radio links. It increases the utilization of spectra.
- Ultra Reliable Communication (URC) ensures provisioning of availability for the network supported services, which are reliability and availability critical, in cost effective and scalable manners.
- Architecture (Arch) HT provides a consisting framework for integration novel architectural approaches for implied challenges of 5G while ensuring scalability.

The technology components, which are essentially the enablers of 5G, that fit into HTs include following.

For Radio links, Connectivity solution to 5G scenarios and test cases requires an air interface that is flexible enough to cater wide range of devices. For UDN, it should be flexible enough to support wider spectra utilized by UDNs in a cost effective solution that adapts signal conditions, by devising a scalable frame structure.

For MMC, it needs an optimized signaling mechanism that reduces signaling overhead while maintaining reliability. In some applications it requires assurance of high reliability and support for mobility at higher speeds.

For physical layer; as it has to cater wide range of services and application; wave forms, encoding, and modulation techniques are being investigated. A few approaches are as follows; Faster than Nyquest provides transmission of higher data rates at expense of more complex receiver design. New waveform technologies include Filtered and Filter-bank-based multi-carrier techniques that efficiently utilize fragmented spectrum, and sharing of spectrum. Full Duplex transmission supported transceiver design is another avenue promising solution for the upcoming challenges by provisioning of simultaneous transmission and reception thus increasing the overall spectral efficiency.

In the aspect of Multiple Access, to overcome the limitation of orthogonality, non orthogonal and quasi-orthogonal techniques are being investigated. These will enable serving much more number of devices, and better spectrum utilization. For Medium Access Control (MAC), contention based schemes are being investigated that could support MMC and distributed mechanism for synchronization. Hybrid Automatic Repeat Request (HARQ) caters the requirements of URC by delivering packets with in defined deadline constraints.

3G, 4G systems are devised with the perspective of requirements of macro-cell. Here the focus is consistent coverage with same services for indoor and outdoor environments, and backward compatibility. In contrast to this; 5G, to provide different services in terms of data rates, capacity, and delay for indoor and outdoor environments; would have to employ a heterogeneous framework. It has to incorporate both IMT-A macro-based and IMT local-based solutions exhibiting coexistence and coordination. Higher data rates are required by applications and devices in indoor and hot spot scenarios. This can be provisioned using higher frequency spectrums which are also suitable for small cells due to their propagation properties. The indoor and the hotspot scenarios exhibit properties of low mobility that is 0~30 Km/h and 150 meters radius cell size. While the macro-cell scenarios can handle higher mobility i.e. >350 Km/h and cells of size 30 Km. Propagation properties of higher frequency spectrum used in small cells together with utilization of multi-antenna design enabled for even higher performance gains. Small cells base stations need less power and can be put out at idle time as compared to macro cells, it results in more power efficient solution [22].

Tailoring of 3GPP-LTE can also support some of the 5G requirements. Subcarrier spacing Δf and cyclic prefix (CP) length which are used to determine cell size and mobility support. Normally cell size is few tens of kilometers and up to 350 Km speeds are supported. Here reduction in CP and increase in Δf can be exercised for optimization and performance gains for indoor scenarios. [22].

MIMO technology is thought to be specifically suitable for provisioning of higher data rates, capacity and coverage. However it requires special consideration for the distance between elements of antenna arrays because it affects the mutual correlation between radio channels, and fading of signals on each antenna element. Another issue is feedback of channel information; it impacts performance of MIMO technology.

Available options to address the challenges of data rate and capacity include extension in spectrum, higher degree of spectrum efficiency, network densification and network traffic offloading. Extension in spectrum encompasses exploitation of higher frequency bands for mmW, unlicensed band, and aggregation of fragmented spectrum using carrier aggregation. Connectivity of user equipments to multiple base stations is another form of aggregation of spectrum usage.

Antenna arrays of small form factor, contrast to conventional single antenna system, are able to deliver 10 time increase in capacity [23]. These can be used both for the now available spectrum and future extensions. Beam-forming gains can mitigate the issues of path loss attenuation typically at higher frequencies resulting in extension of coverage.

Higher order modulation and coding schemes, like 256-QAM along with MIMO, further increase the spectral efficiency and system capacity [24]. Multiple Access techniques like Non-Orthogonal Multiple Access (NOMA), Sparse Coded Multiple Access (SCMA), and Filter Bank MultiCarrier (FBMC) can be used to enhance spectral efficiencies. NOMA with receivers featuring successive interference cancellation demonstrated 30% improvement in throughput in macro-cells as compared to orthogonal scheme [25].

Splitting the user-plane and control-plane provide more flexibility and scalability, as capacity can be provided to user-plan without scaling up the control-plane. Even Control-plane can be moved upwards to macro-cells and user-plane caters the deployed small cells. [22]

Shorter transmission time interval (TTI) can decrease air interface latency to few hundred microseconds; however it requires more bandwidth available that can be provisioned in higher spectrum. Enhancement in higher layer protocols like network admission and congestion control, and deploying some intelligence at edge can help in meeting latency challenges. Crafting Non-Access Stratum (NAS) also can help in decreasing latency by reducing signaling overhead during set up of connection.

Besides higher bandwidth and lower latency, addition of caches and computing resources at the edge of network can provision enhanced QoE.

5G era will witness coexistence of legacy and innovative Radio Access Technologies (RAT), and multi layered network. The key challenges that RATs has to overcome are mobility, interference, and scalability. Challenges put forth by dense deployment of connected devices, call for novel solutions to mobility and interference management. UDNs will reduce the cell size; hence there will be few users per cell. Thus traffic will be bursty which can be best handled by TDD. MNs like Vehicle to X will introduce very different interference constellations. In such cases the Radio Resource Management (RRM) has to make tradeoff between system performance, infrastructure size both in terms of equipments and cost, signaling overhead and scalability.

Inter-node coordination is thought to increase spectral efficiency and throughput typically in the radio environments which are non-favoring. The work in this direction proceed in three paths, first improvement in classical inter-node coordination but now considering it as core characteristic not as an add-on feature as provided in LTE Release 10, second interference alignment, third looks for newer techniques based on innovations and enhancements in network and in user equipments.

UDNs and MNs raise concerns for relaying techniques. Wireless network coding, processing mechanism of interfering flows joint processing is preferred, and buffer aided relaying techniques are viable solutions for backhaul.

Extension in spectrum is definitely promising technique for provisioning of higher data rates. However it seems to be rigid, for some scenario a more flexible mechanism is needed like Cognitive Radio. UE having support for CR is more benefited by the network services due to its adaptive nature. CR is more suitable for small cells or indoor scenarios.

The revolutionary path for 5G looks for new techniques and technologies. Extension of Frequency Spectrum is off course an appealing option. ITU is working on IMT spectrum requirements in 2020 and beyond. New IMT spectrum hopefully will be decided in world radio communication conference WRC 2019. Frequency spectrum from 6GHz to 100 GHz is a focus of attention for realizing 5G. The revolutionary technologies include orbital angular momentum encoding [26], full duplex [27], and non-orthogonal wave form. Remaining part of this section highlights some of the development activities related to 5G.

In [10] they proposed a 5G architecture based on separation of indoor and outdoor scenarios to avoid weakening of signal due to building walls. Together with Massive-MIMO, distributed antenna arrays techniques, it will increase capacity gain due antenna arrays. Outdoor BSs with their larger antenna arrays and some antenna elements distributed in the cell linked via optical fiber to their BS. These distributed antenna arrays will be installed outside of buildings. For outdoor user it will make possibly LoS communication and for the indoor users distributed antenna array elements will be wired connected to an indoor wireless access point. Indoor users will access the network through this access point. Inside the building Wi-Fi, mmW, femtocell, ultra wide band, or Visible Light Communication (VLC) can be used to cater indoor users. For high mobility users they used MFemtocell that is based on this same idea.

The challenges put forth by 5G necessitates to efficient utilization of radio spectrum. If there is some portion of spectrum which is found underutilized then it must exploit. This notion leads to integration of such underutilized bands with the crowded bands. Wi-Fi spectrum typically 5 GHz is underutilized. 3GPP R13 provides LTE-U that let integrate and utilize unlicensed band. Using Listen-before-talk feature Non-coordinated Coexistence for LTE-U and Wi-Fi and coordinated Coexistence for LTE-U and Wi-Fi experimented resulting in increased throughput [28].

WiMax along with others is candidate for traffic offloading. It is based on IEEE 802.16 standards. It is meant to provide wireless broadband services to fixed and mobile usage models. WiMax provides Non Line Of Sight (NLOS) connectivity between subscriber station and base station. Release 2 specifies peak data rates as, of DL 365Mbps using 2x20 MHz FDD with 4x4 MIMO, and UL 376Mbps using 2x20 MHz FDD with 2x4 MIMO [29].

Integration of LTE and Wi-Fi or WiGig put forth some challenges during handovers that must be met to provide seamless transmission. Wi-Fi access point even if it is co-located with LTE base station during handovers mobile IP is used for flow switching may causes packets losses. For this integration PDNGW is acting as home agent. In situations where IPv6 is not supported between access point and PDNGW, VPN tunneling is needed to use prior employing mobile IP procedures. In [30] described, treating access point as an eNB with its physical layer based on LTE enables to run LTE adaptation protocols on top of Wi-Fi MAC layer

Mass multimedia services are not being provided up to the scale, convergence of mobile and broadcast TV is still awaited. In 5G, multimedia services like mobile TV will be one among the major data traffic source. Digital Video Broadcast standards DVB-T2 and DVB-NGH are widely used. Based on these a universal standard is being developed named ATSC 3.0. Using the concepts of Future Extension Frame (FEF) and CA of LTE-A, it is proposed that integrating eMBMS with DBS-T2 data streams transmitted by high power high tower system can be used for fixed and mobile TV [31].

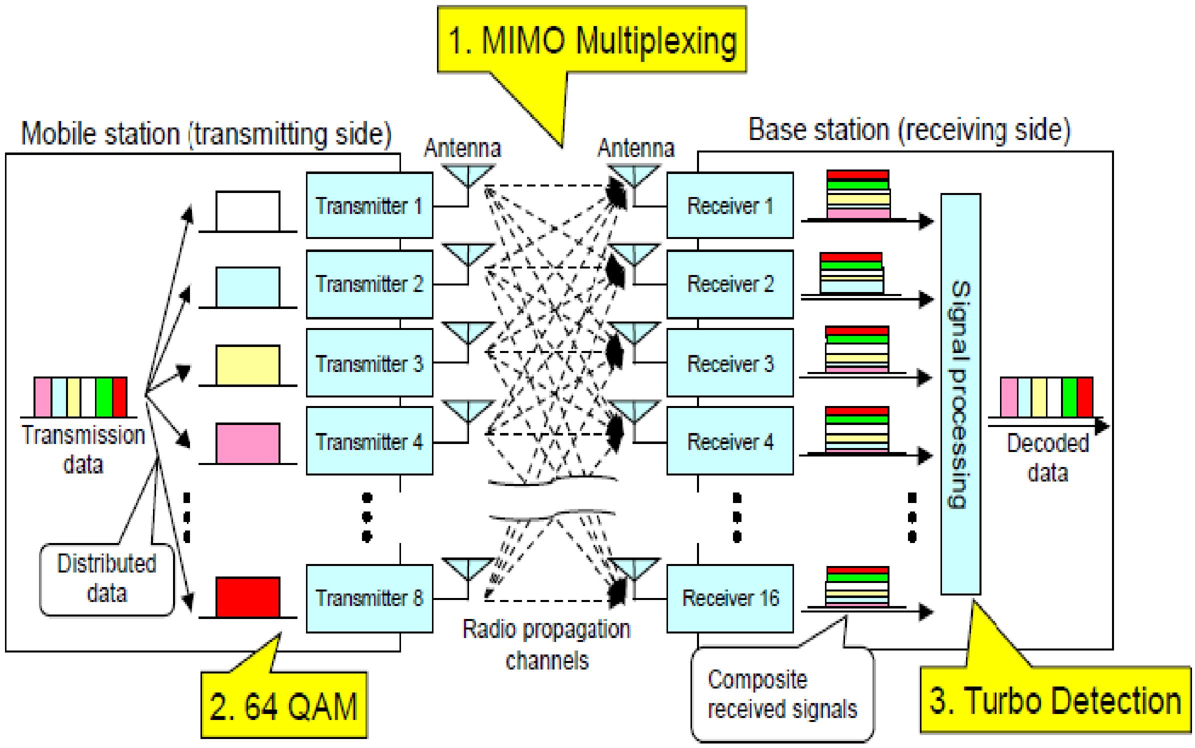

Fig.4. Key Technologies of 10 Gbps Packet Transmission Experiment [39]

Centimetre Wave (cmW) and mmW communication is being experimented resulting in success and promising 5G to be a reality sooner.

Cellular networks deployed use carrier frequency spectrum from 700MHz to 2.6GHz. Higher frequencies are considered to be not suitable for cellular transmission due to their inherent high susceptibility for transmission impairments. However mmWaves typically 28GHz and 38GHz bands suffer attenuation of 1.4dB per 200 m (mostly cell radius is around 200m), and these can be allocated for cellular networks with 1GHz channel bandwidth and for backhauls. The larger available bandwidth results in higher data rates. So, mmWave communication is a promising candidate technology for implementation and achieving 5G data rates [32]. In-band mmW backhaul can be an attempt to solve the issues of handover latencies [33].

A demonstration of date rate of more than 1GBps over 2km distance has been made at Samsung lab [34].

DOCOMO and Nokia successfully trialled 2Gbps at 70 GHz band in December 2014. At 17 GHz frequency band, DOCOMO and Ericson successfully experimented transmission speed of 4.5 Gbps in February 2015[35]. At 4.63 GHz frequency spectrum with channel bandwidth of 100 MHz, transmission speed of 5 Gbps is successfully experimented using 64-QAM, 12-MIMO, and VSF-Spread OFDM [36]. Tokyo institute of technology developed a system for super high bit transmission in mobile outdoor environment (Fig. 4). It was tested along with DOCOMO [37]. It used 8x16 MIMO with OFDM at 11 GHz frequency spectrum with 400 MHz bandwidth for transmission above 10 Gbps [38].

Nokia Networks and National Instruments demonstrated 10 Gbps on April, 8, 2015 in Brooklyn 5G Summit, using mmW. The experiment was conducted at 73GHz with 2 GHz bandwidth. It employed 16-QAM modulation with 2x2 MIMO. [40].

In cmW band, SK-Telecom and Nokia successfully demonstrated data rate of 19.1 Gbps on October 30, 2015 in Seoul. The experiment employed 256-QAM, 8x8 MIMO and 400 MHz bandwidth [41].

VI. Conclusion

The techniques and technologies discussed in section IV are mostly integrated in LTE-A, however mmW is still awaited. MIMO, CA, CoMP, C-RAN, HetNets are deployed, and enabled operators to achieve better throughput, and resource utilization. Moreover these techniques resulted in increased spectrum efficiency and reduction in cost per bit. They also meant to increase data rates to meet the promised limit of LTE-A.

Extension in IMT frequency spectrum is the key enabler of 5G; it can definitely provide targeted data rate of 5G. Successful experiments of cmW and mmW conducted by various vendors clearly show that 5G is reality about to happen. mmW has limitation of coverage due to its inherent characteristics.

VII. Futurework

To determine buffering requirements and queue management for 5G networks, we are conducting simulations to draw statistical results. Transmission impairments in mmW technology are a major hurdle. These instigate scientific community to come up with such solution that mitigates these problems. Microwave and wire is already in use in backhauls, it is thought that fiber optic and mmW can be used for both fronthaul and backhaul. Future wireless networks might witness a total guided backhaul using fiber optic. The other promising areas for realization of 5G include orbital angular momentum encoding, full duplex, and non-orthogonal wave form seeks attention of research community.

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