Technology Digest

Bulletin of telecom technology

Issue, May 2018

Telecom Regulatory Authority of India

This is the second part of the series of Technology Digest on the topic **"Evolution of Mobile Communications".**

Evolution of Mobile Communications (4G and 5G)

In this issue

In first part of this series we introduced initial three generations of mobile communication 1G, 2G and 3G. Mankind was getting services, opportunities, entertainment, education and much more at the click of a button or touch of the screen. As a result demand expanded and so did the mobile consumers. In the field of automation, Internet of Things (IoT) also started gaining limelight. With connectivity and IoT technologies it became possible for a doctor to perform surgery sitting miles away, through a robot, by using internet. Hence the need for faster speed and better connectivity aroused. To meet these needs fourth generation of mobile technology was introduced in 2010. With the entry of new operator(s) in the mobile services using 4G technology, these services expanded quickly particularly in India. Now focus is shifted to 5G (Fifth Generation) technologies. Operators in countries like South Korea, Japan and China are making efforts to start 5G commercial services soon.

This paper is focussed on discussion of 4G and 5G technologies.

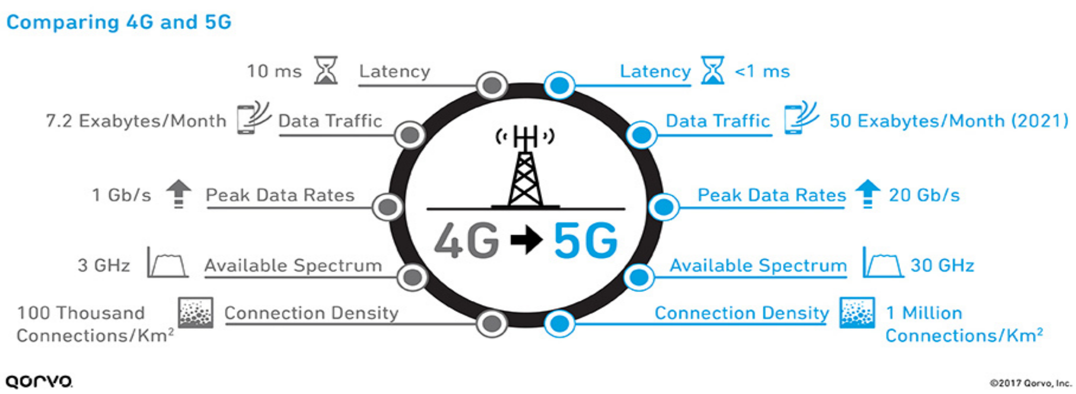


Figure 1: Transition from 4G to 5G (Src – Qorvo[1])

Fourth Generation

Fourth Generation (4G) of broadband cellular network technology is based on the capabilities defined by the ITU(International Telecommunication Union) in IMT Advanced (International Mobile Telecommunications Advanced) which supersede the 3G. It is popularly referred to as MAGIC[2] which is the acronym for "*Mobile multimedia, Any-where, Global mobility solutions over, Integrated wireless and Customized services*."According to the ITU, a 4G network requires a mobile device to be able to exchange data at 100 Mbps for high mobility communication and 1 Gbps for low mobility communication.

[1] Qorvo(2015) is an American semiconductor company that designs, manufactures, and supplies radio-frequency systems and solutions for applications that drive wireless and broadband communications, as well as foundry services.

[2] Noorus Sabah; 4G Technology and its Applications; International Journal of Research in Engineering, Technology and Science, Volume VI, Special Issue, July 2016

Network Standards

There are multiple 4G mobile technology standards used by different cellular providers that conform to 4G requirements, namely, LTE (pre - 4G), LTE-Advanced, WiMAX, and Ultra Mobile Broadband (UMB).

LTE: The UMTS (Universal Mobile Telecommunications Service) cellular technology upgrade termed as Long Term Evolution (LTE), which is also sometimes called 3.9G or Super 3G,is to accomplish higher speeds along with lower packet latency. A number of new technologies were introduced by LTE as compared to the previous cellular systems. For example the OFDMA (Orthogonal Frequency Division Multiple Access) technology and the SC-FDMA (Single- Carrier FDMA) technology. The UMTS architecture that was used in 3G (Third Generation) consisted of the Radio Network Controller (RNC) controls the Node Bs and performs resource management and connects to the Serving GPRS Support Node (SGSN)[3]. In LTE both the function of NodeB and RNC is performed by ENodeB – Evolved NodeB.

LTE-Advanced: For LTE Advanced / IMT Advanced, the number of key requirements and key features has been specified[4]; some of them are as follows:

a. To have maximum downlink speed of 1Gbps
b. To have maximum uplink speed of 500 Mbps
c. To have latency less than or equal to 10ms
d. To have peak spectrum efficiency of downlink as 30bps/Hz and uplink as 15bps/Hz
e. Should possess the ability to support scalable bandwidth upto 100MHz

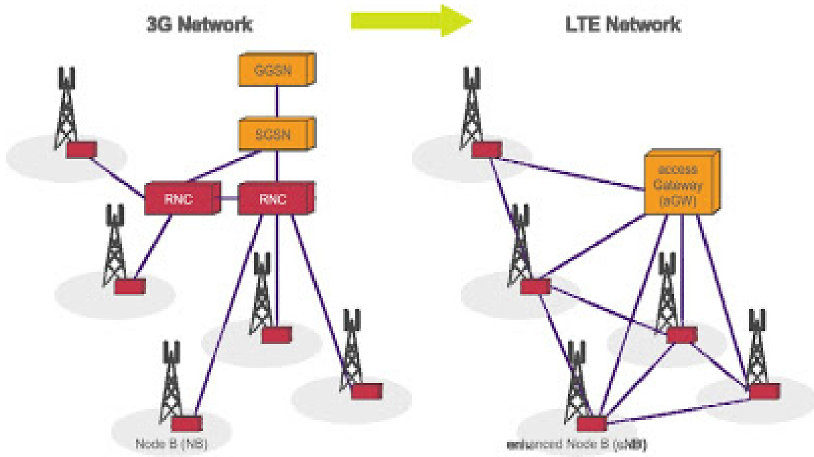


Figure 2: Evolution from UMTS technology used in 3G to LTE used in 4G

MIMO (Multiple Input Multiple Output) and OFDM are two of the base technologies that will facilitate LTE Advanced to achieve the high data throughput rates. Along with these, there are a number of other technologies that will be employed to achieve requirements specified for LTE-advanced. These are:

Carrier Aggregation (CA): Carrier Aggregation utilises multiple channels either in the same bands or in different bands of the spectrum. This solves the problem of insufficient contiguous spectrum to provide the required bandwidths for the very high data rates.

Coordinated Multipoint: Poor performance at the cell edges remains one of the key issues with many cellular systems. The data rates reduce due to interference from adjacent cells. A solution to this problem can be joint scheduling and transmissions as well as joint processing of the received signals. For LTE-Advanced this scheme known as coordinated multipoint. In this way, a UE (User Equipment) at the edge of a cell can be served by two or more eNodeBs (LTE Base Station Component). This will allow improvement in received and transmitted signals which in turn will increase the throughput at the cell edge.

LTE Relaying: LTE relaying is a scheme that enables signals to be forwarded by remote stations from the main base station to improve coverage.

As mentioned earlier there are two access technologies used in Fourth Generation telecom

OFDMA: In Frequency Division Multiplexing, the total bandwidth is divided into several non-overlapping frequency bands. Each band is used to carry a separate signal. This way a single bandwidth can be utilised to send a number of signals without any interference amongst them. When modulation of any type - voice, data, etc. is applied to a carrier, then the sidebands spread out on either side of frequency range.For successful demodulation of the data, it is necessary for a receiver to receive the whole signal to successfully demodulate

[3] **SGSN:** Serving GPRS Support Node - the SGSN forms a gateway to the services within the network.
GGSN: Gateway GPRS Support Node, GGSN, forms the gateway to the outside world.

[4] These features are specified by 3GPP (Third Generation Partnership Project); March 2009

the data. This requires spacing between the transmitted signals so that they can be effectively filtered. This space is known as the guard band (fig.3). But such is not the case with OFDMA (Orthogonal Frequency Division Multiple Access). Even though the sidebands from each carrier fold over each other, the signals can still be received without the expected interference because the carrier signals are orthogonal (statistically independent) to each other.

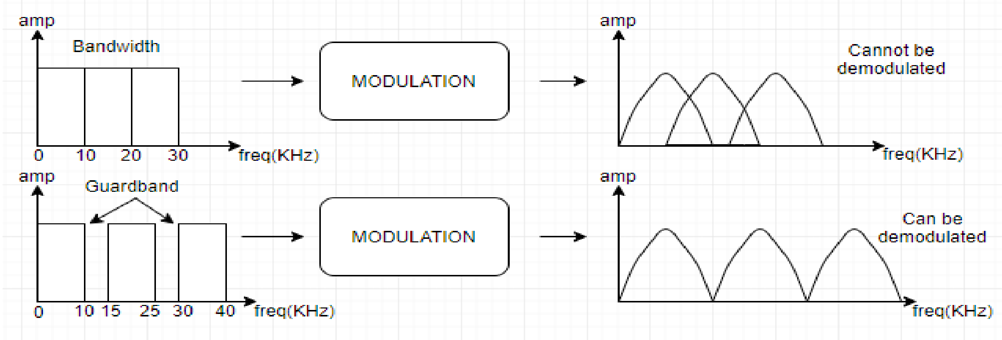


Figure 3: Importance of guard bands in FDM

SC-FDMA: Due to the superposition of all the orthogonal signals, OFDMA has a high Peak to Average Power Ratio (PAPR). Signals with high PAPR require higher energy to be transmitted to long distances. Since base station acquires a definite land area in each circle which is big enough to provide high energy sources, therefore OFDMA is suitable for downlinks. But there is a limited battery life of each mobile and it cannot render such high power signals to the base station for significant time period. As a result, LTE uses a modulation scheme for uplink communication known as SC-FDMA (Single Carrier FDMA), which is a hybrid format that combines the low peak to average ratio offered by single-carrier systems with the multipath interference resilient and flexible subcarrier frequency allocation that OFDMA provides.

Fifth Generation

The forecast for future 10 years' traffic demand illustrates an increase in 1000 scales and more than 100 billion connections of Internet of Things.[5] This foists a big challenge for future mobile communication technology beyond year 2020. The consumers demand a high speed data at low prices. 5G is targeted to resolve these contradictory demands towards year 2020. 5G was labelled as 'ultra-fast, ultra-reliable, ultra-high capacity transmitting at super low latency' by the National Infrastructure Commission in the report "5G Infrastructure Requirements in the UK" (2016). Facilities that might be seen with 5G technology include far better levels of connectivity and coverage. The term World Wide Wireless Web or WWWW is being coined for this.[6]

Set of 5G requirements

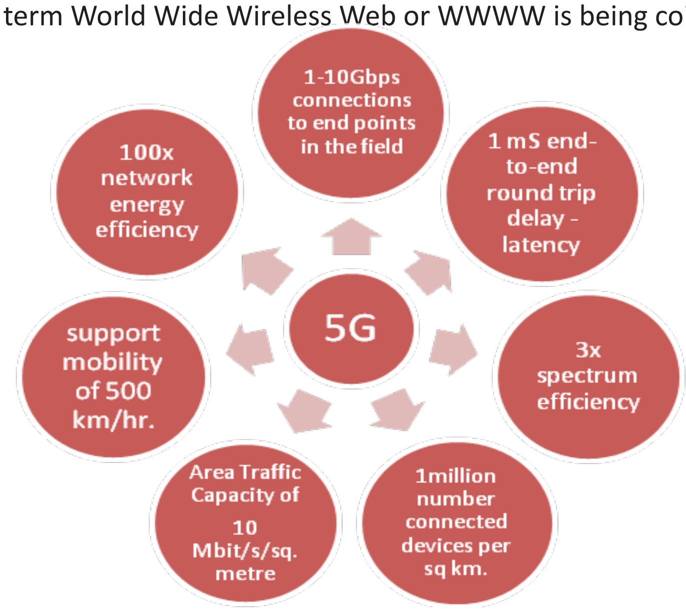
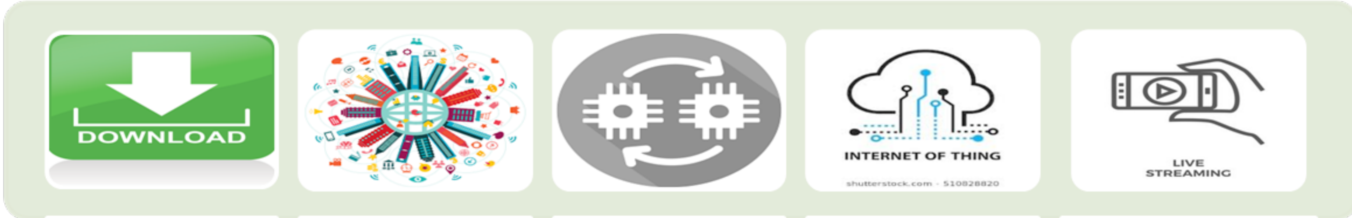


Figure 4: Visions for the Fifth Generation of Mobile Communications (Src - ITU)

[5] Guangyi Liu and Dajie Jiang; 5G: Vision and Requirements for Mobile Communication System towards Year 2020;Chinese Journal of Engineering Volume 2016, Article ID 5974586

[6] Swaroop Gandewar et al: 5G:wwww; International journal of advanced Engineering, Management and Science; 2017

Why do we need 5G?



Ultra HD movies can be downloaded in seconds.

5G will enable an interconnection of 20.8 billion devices from door locks to cars to refrigerators.

Machine to Machine Communi-cation will be enabled.

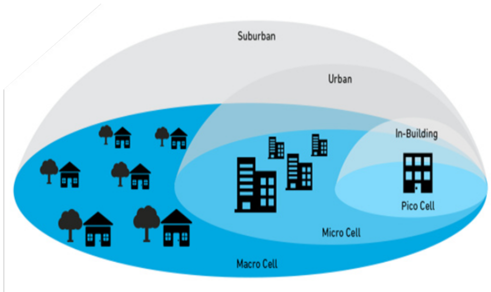
Backbone in buiding up Smart Cities with an IoT infrastructure.

5G will promote ulta low latency which means that a spectator in a cricket stadium can watch a live stream of an alternate camera angle of the action that matches what is going in the pitch ahead with no perceivable delay.

5G Technology

Millimeter Waves: Telecom Service Providers (TSPs) make use of radio frequency spectrum to send and receive data. With increasing number of consumers, more data is being consumed. But this data remains crammed on the same frequency bands. That means less bandwidth for everyone, causing slower service and more dropped connections. To avoid these problems, TSPs are experimenting with transmission of signals on a whole new swath of spectrum of 20~50 GHz. This band, acknowledged as the mmWave band, makes use of higher frequencies than the radio waves that have long been used for mobile phones. The mmWave band from 20~50 GHz alone accounts for 10 times more available bandwidth than the entire 4G cellular band.[7]Many manufacturers are fostering components that can be operated in the range of millimeter waves and semiconductor technologies that are suitable to operate at frequencies up to 90 GHz, especially in V-band (57 to 66 GHz) and E-band (71 to 86 GHz) applications. There is one disadvantage to the use of mmWaves, i.e. due to such high frequencies of mmWaves, they are not able to travel through buildings or obstacles and can be absorbed by foliage and rain.

Small Cells: Small cells can be placed throughout the cities after every 250 meters or so. They are portable miniature base stations that require minimal power to operate. Thousands of small cells installed in the city, due to the short range of mmWave signals, form a dense network called the HetNet (Heterogeneous Network) that receives signals from other base stations and send them to the users at different locations, like a relay. This largely prevents signals from being dropped. The term 'small cell' encompasses pico cells, micro cells, femtocells and can comprise of indoor/outdoor systems. Small cells can be as small as the size of a shoe-box. Such small cells can be bolted to light poles and the sides of buildings, hence do not require separate towers.



Cell Type	Output Power (W)	Cell Radius (km)	Users	Locations
Femtocell	0.001 to 0.25	0.010 to 0.1	1 to 30	Indoor
Pico Cell	0.25 to 1	0.1 to 0.2	30 to 100	Indoor/Outdoor
Micro Cell	1 to 10	0.2 to 2.0	100 to 2000	Indoor/Outdoor
Macro Cell	10 to >50	8 to 30	>2000	Outdoor

Figure 5: The output power, cell radius sizes and other features of different base station types, from small cells to macro cells. (Src – Qorvo)

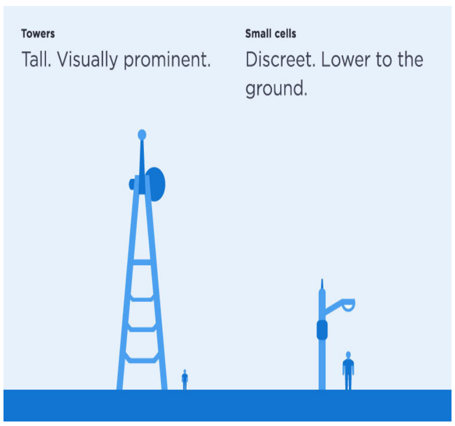


Figure 6: Difference between towers of cells and the transceiver of the small cells.

7 5G Key Enabling Technologies; Mobile tech Insights; Program; Samsung Developers

Massive MIMO: MIMO is the acronym for Multiple Input Multiple Output. MIMO refers to a wireless system that uses two or more transmitters and receivers to send and receive more data at once. Presently, 4G base stations possess a dozen ports for antennas to handle all cellular traffic. But 5G base stations can support about a hundred ports, which mean that a single array can accommodate many more antennas and hence can send to and receive signals from bountiful users at once. This leads to an increase in capacity of mobile networks by a factor of 22 or more.[8] Below is a list of key technological characteristics of massive MIMO.

1. **Fully digital processing**: every antenna bear its own RF (Radio Frequency) and digital baseband chain. The signals emitted from all the antennas at each base station (due to MIMO) are processed coherently together. Fully digital processing allows to measure complete channel response on the uplink as well as quickly responds to such changes in the channel.

2. **Computationally inexpensive precoding/decoding** : As there are more than one transmitter and receiver in a MIMO network, there exists one LOS path from every transmitter to every receiver ideally(fig 7a). However there may be reflection or diffraction from the surrounding atmosphere and the signals could interfere causing a low SNR (Signal to Noise Ratio) at the receiver. Hence the data streams cannot be decoded effectively. To avoid this precoding is used on the transmission side with the goal of equalising the signal reception across multiple receiver antennas.

3. **Channel hardening**: Due to microscopic changes in environment, the channel gain tends to fluctuate randomly. This is known as channel fading. The channel is said to have hardened when the fluctuations in gain do not impact the transmitted data. Channel Hardening effectively removes the effects of channel fading. Operationally, each terminal-base station link forms a scalar channel whose gain stabilizes to a deterministic and frequency-independent constant.

4. The reliance on **reciprocity of propagation and TDD (Time division Duplex) operation** reciprocates the need for prior or structural knowledge of the downlink propagation channel since the downlink channels can be estimated from uplink pilots.

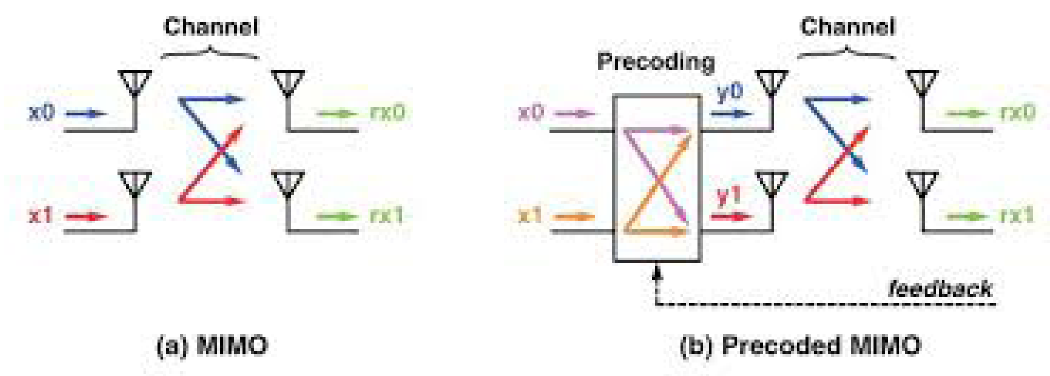


Figure 7: Difference between MIMO and Precoded MIMO

5. The array gain offers the link budget improvement and the spatial resolution of the array results in interference suppression. This facilitates the provision of **uniformly good quality of service to all terminals in a cell.**

Beamforming: Beamforming reduces the interference for nearby users by recognising the most efficient data delivery route from cellular base station to a particular user. Beamforming can help massive MIMO arrays for more skilled use of the spectrum around them. Massive MIMO faces a challenge to reduce interference while transmitting information from many antennas at once. At massive MIMO base stations, the best transmission route is plotted using signal-processing algorithms to send individual data packets in many different directions, bouncing them off buildings and other objects in a precisely coordinated pattern. Beamforming allows exchange

[8] Shaunak Roy; Companies; BBN Times

Figure 8: Visual representation of beamforming technology.

of al lot of information between the users and antennas on a massive MIMO arrays by choreographing the packets' movements and arrival time. Beamforming and the devices that support beamforming work under the IEEE 802.11ac specification.

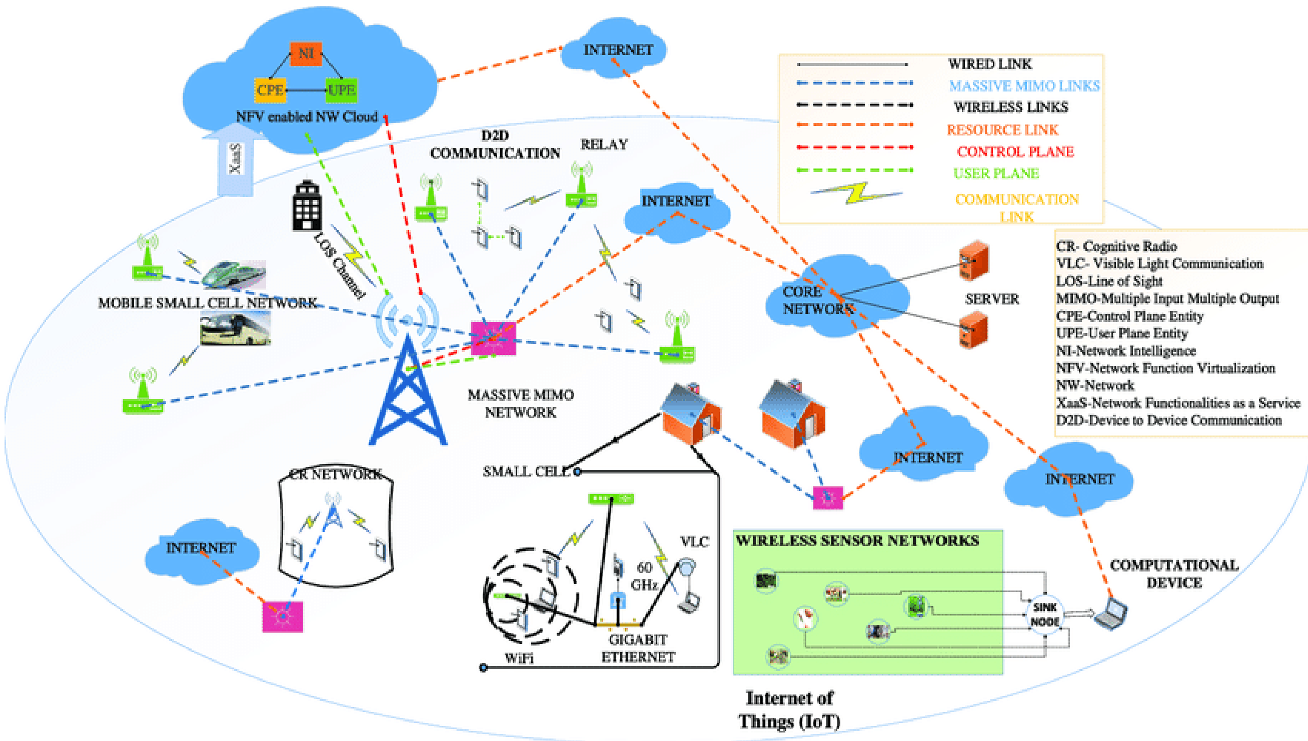


Figure 9: A general 5G cellular network architecture.[9]

Comparison chart of Generation in Telecommunication[10]

GENERATION	1G	2G	3G	4G	5G
DEPLOYMENT	1970/1984	1980/1989	1990/2002	2000/2010	2017/2020
DATA BANDWIDTH	2Kbps	14-64 Kbps	2Mbps	200Mbps	1Gbps
STANDARDS	AMPS	TDMA, CDMA, GPS, GPRS	WCDMA	Single unified standard	Single unified standard

[9] Akhil Gupta, Dr.Rakesh Kumar Jha; A Survey of 5G Network: Architecture and Emerging Technologies; IEEE Access 3:1206-1232; Aug 2015

[10] Src- Hanamanta NB;5G wireless technology; CITECH; 2015)

GENERATION	1G	2G	3G	4G	5G
TECHNOLOGY	Analog cellular	Digital cellular	Broadband with CDMA, IP technology	Unified IP and seamless combination of broadband of LAN, WAN and WLAN	Unified IP and seamless combination of broadband, LAN, WAN, WLAN and WWWW
SERVICES	Mobile technology (voice)	Digital Voice, SMS, Higher capacity packetized	Integrated high quality audio and video	Dynamic information Access, Wearable devices	Dynamic information Access, Wearable devices with AI capabilities
MULTIPLEXING	FDMA	TDMA, CDMA	CDMA	CDMA	CDMA
SWITCHING	Circuit	Circuit and packet	packet	All packet	All packet
CORE NETWORK	PSTN	PSTN	Packet network	Internet	Internet
HANDOFF	Horizontal	Horizontal	Horizontal	Horizontal and Vertical	Horizontal and Vertical

Conclusion

Rapid growth in data traffic suggests the need of the integration of existing network technologies that permits dynamic switching amongst the available Radio Access Technologies (RATs) and the efficient utilization of bandwidth. For radio resource allocation, the concept of super core needs to be implemented that can coordinate between RATs. The network management modules ought to be more dynamic, cost-effective, and adaptable, making it ideal for the high-bandwidth and dynamic nature of today's applications, e.g. Software Defined Networks (SDNs).

The evolution path of telecommunication from the first generation to the fifth generation provides different aspects and approaches towards the current state of telecom. The onset of 4G has already revolutionized the field of telecommunication by bringing the wireless experience to a new level altogether. Further, 5G is expected to be a milestone development for the success of IoT and M2M communications.

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