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An Overview of the Development of Mobile Wireless Communication Technologies

Mohammed Alnaas[1], Elmabruk Laias[2], Saleh Alghol[3], Hosian Akeel[4]

[1]Faculty of Information Technology, Azzaytuna University, Tarhuna, Libya
[2]Computer Department, Omar Al-Mukhtar University, Darna, Libya
[3]Faculty of Information Technology, Tripoli University, Tripoli, Libya
[4]Director of International Relation and Corporation, Libya Post Company, Tripoli, Libya

Email address
m.alnaas@gmail.com (M. Alnaas), emlaias@yahoo.com (E. Laias), salehalghul@yahoo.com (S. Alghol), h.akeel@libyapost.ly (H. Akeel)

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Abstract

Mobile wireless technologies have followed different evolutionary (generation) paths aimed at unified target related to the performance and efficiency in high mobile environment, which provides access to wide range of telecommunication services including advanced mobile services supported by mobile and fixed networks. This paper illustrate the developments of the mobile wireless communication, focus on the specification and capability for each technology to make an idea about the future technology what will offer.

Keywords

ITU-R, 3GPP, WiMAX, LTE, 5G, IMT-Advanced

1. Introduction

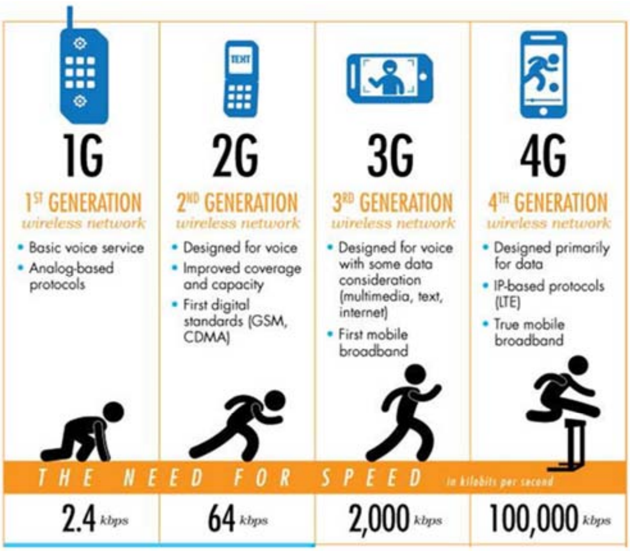

Figure 1. *Upgrade from 1G to 4G Technology.*

In the last few years, mobile wireless communication networks have experienced a great change, the mobile wireless generation (G) generally refers to a change in the nature of the system, speed, technology and frequency. Each generation have some standards, capacities, techniques and new features which differentiate it from the previous one [1, 10].

Since the first move from an analog (1G) to analog (2G) network. After that there was (3G) multimedia support, spread spectrum transmission and 2011 all Internet Protocol (IP) switched networks (4G) comes. The last few years have witnessed a phenomenal growth in the wireless industry, both in terms of mobile technology and its subscribers [2, 3].

Both the network operators and vendors have felt the importance of efficient networks with equally efficient design [5, 14]. This resulted in network planning and optimization related services coming in to sharp focus.

Next generation mobile networks, commonly referred to as 4G, and are envisaged as a multitude of heterogeneous systems interacting through a horizontal IP centric architecture [2, 8, 11]. The 5G core is to be a re-configurable, multi-technology core. The core could be a convergence of new technologies such as nanotechnology, cloud computing and cognitive radio, and based on All IP platform. These new technologies requirements pose the several challenges toward 5G development [3, 7, 14].

2. Third-Generation (3G)

3G refers to the third generation of mobile telephony (cellular) technology. The 3G, as the name suggests, follows two earlier generations. When 3G networks started rolling out, they replaced the second generation (2G) system, a network protocol that only allowed the most basic of what we would now call smartphone functionality.

Most 2G networks handled phone calls, basic text messaging, and small amounts of data over a protocol called Multimedia Messages (MMS). With the introduction of 3G connectivity, a number of larger data formats became much more accessible, including standard Hyper Text Markup Language (HTML) pages, videos, and music. The speeds were still pretty slow, and mostly required pages and data specially formatted for these slower wireless connections. By 2G standards, the new protocol was speedy, but still didn't come anywhere close to replacing a home broadband connection [4, 5].

The first generation (1G) began in the early 80's with commercial deployment of Advanced Mobile Phone Service (AMPS) cellular networks. Early AMPS networks used Frequency Division Multiplexing Access (FDMA) to carry analog voice over channels in the 800 MHz frequency band [8, 13].

Figure 2. *Steps from 2G To 3G Technology.*

The 2G emerged in the 90's when mobile operators deployed two competing digital voice standards. In North America, some operators adopted IS-95, which used Code Division Multiple Access (CDMA) to multiplex up to 64 calls per channel in the 800 MHz band.

Across the world, many operators adopted the Global System for Mobile Communication (GSM) standard, which used Time Division Multiple Access (TDMA) to multiplex up to 8 calls per channel in the 900 and 1800 MHz bands [9 11].

Figure 3. *Second Generation (2G).*

The International Telecommunications Union (ITU) defined the 3G of mobile telephony standards to facilitate growth, increase bandwidth, and support more diverse applications. For example, GSM could deliver not only voice, but also circuit-switched data at speeds up to 14.4 Kilobit per second (kbps).

To support mobile multimedia applications, 3G had to deliver packet-switched data with better spectral efficiency, at far greater speeds.

However, to get from 2G to 3G, mobile operators had make evolutionary upgrades to existing networks while simultaneously planning their (revolutionary) new mobile broadband networks. This lead to the establishment of two distinct 3G families 3GPP and 3GPP2 [6, 7].

The 3rd Generation Partnership Project (3GPP) was formed in 1998 to foster deployment of 3G networks that descended from GSM. 3GPP technologies evolved as follows.

1. General Packet Radio Service (GPRS) offered speeds up to 114kbps.
2. Enhanced Data Rates for Global Evolution (EDGE) reached up to 384kbps.
3. UMTS Wideband CDMA (WCDMA) offered downlink speeds up to 1.92Megabit per second (Mbps).
4. High Speed Downlink Packet Access (HSDPA) boosted the downlink to 14Mbps.
5. LTE Changed UMTS Terrestrial Radio Access (E-UTRA) is aiming for 100Mbps.

GPRS deployments began in 2000, followed by EDGE in 2003. While these technologies are defined by IMT-2000, they are sometimes called (2.5G), because they did not offer multi-megabit data rates. EDGE has now been outdated by HSDPA and its uplink partner High-Speed Uplink Packet Access (HSUPA) [10, 12, 13]. According to the 3GPP, there were 166 HSDPA networks in 75 countries at the end of 2007

A second organization, the 3rd Generation Partnership Project 2 (3GPP2) was formed to help North American and Asian operators using CDMA2000 transition to 3G. 3GPP2 technologies changed as follows:

1. One Times Radio Transmission Technology (1xRTT) offered speeds up to 144Kbps.
2. Evolution Data Optimized (EV-DO) increased downlink speeds up to 2.4Mbps.
3. EV-DO Rev. A boosted downlink peak speed to 3.1Mbps and reduced latency.

4. EV-DO Rev. B can use 2 to 15 channels, with each downlink peaking at 4.9Mbps.
5. Ultra Mobile Broadband (UMB) was slated to reach 288Mbps on the downlink.

1xRTT became available in 2002, followed by commercial EV-DO Rev. 0 in 2004. Here again, 1xRTT is referred to as (2.5G), because it served as a transitional step to EV-DO [13].

EV-DO standards were extended twice Revision A services emerged in 2006 and are now being succeeded by products that use Revision B to increase data rates by transmitting over multiple channels [14].

3. Fourth-Generation (4G)

4G is the short name for fourth-generation wireless, the stage of broadband mobile communications that will overcome the 3G. The International Telecommunications Union-Radio (ITU-R) is the United Nations (UN) official agency for all manner of information and communication technologies, which decided on the specifications for the 4G standard in March 2008.

Carriers that use Orthogonal Frequency-Division Multiplexing (OFDM) instead of TDMA or CDMA are increasingly marketing their services as being 4G, even when their data speeds are not as fast as the ITU specifies.

According to the ITU, a 4G network requires a mobile device to be able to exchange data at 100Mbps. A 3G network, on the other hand, can offer data speeds as slow as 3.84Mbps. Unfortunately the ITU-R doesn't have control over the implementation of the standard, which led to 1G technologies being criticized for not being up to scratch with true 4G [7. 8].

The reason for this is that other groups (3GPP being an example) that work with the technology companies who develop the hardware had already decided upon next generation technologies, leaving us with sub-standard 4G capabilities.

Figure 4. *Different Technology of the Fourth Generation (4G).*

From the consumer's point of view, 4G is more a marketing term than a technical specification, but carriers feel justified in using the 4G label, because it lets the consumer know that (he/she) can expect significantly faster data speeds.

4G technology is meant to provide what is known as (Ultra-Broadband) access for mobile devices, and ITU-R created a set of standards that networks must meet in order to be considered 4G, known as the International Mobile Telecommunications Advanced (IMT-Advanced) specification.

According to the IMT-Advanced specification, two requirements for the 4G service are:

1. 100 Mbps for high mobility communication like cars and trains
2. 1 gigabit per second (Gbps) for low mobility communication like pedestrians and stationary mobile users

This isn't an error, the wireless data transfer of 1Gbps of 4G service. On the other hand the mobile operators are using the name 4G for the speeds in most cases well below 10Mbps for downlink. So, the real 4G technology with the real 4G speeds is still Science fiction for all. The actual speeds are even 100 times below 1G, the speed specified by the responsible organization for the mobile communications [9, 11].

3.1. Standards of 4G

4G networks must be based on an all Internet Protocol (IP) packet switching instead of circuit-switched technology, and use OFMDA multi-carrier transmission methods or other Frequency Domain Equalization (FDE) methods instead of current spread spectrum radio technology [1. 12].

In addition, peak data rates for 4G networks must be close to 100Mbps for a user on a highly mobile network and 1Gbps for a user with local wireless access or a nomadic connection. It must also be able to offer smooth handovers across differing networks without data loss and provide high quality of service for next generation media.

One of the most important aspects of 4G technology is the elimination of parallel circuit switched and packet switched network nodes using Internet Protocol version 6 (IPv6). The currently used standard, IPv4, has a finite limitation on the number of IP addresses that can be assigned to devices, meaning duplicate addresses must be created and reused using Network Address Translation (NAT), a solution that only masks the problem instead of definitively solving it. IPv6 provides a much larger number of available addresses, and will be instrumental in providing a streamlined experience for users [14].

3.2. Worldwide Interoperability for Microwave Access (WiMAX)

WiMAX is a technology standard for long-range wireless networking, it is a broadband (for both mobile and fixed connections) access standard developed and maintained by the IEEE under the 802.16 designation. As its name suggest, WiMAX can be thought of as an extension of Wi-Fi designed to enable pervasive, high-speed mobile Internet access on a wide range of devices, from laptops to smartphones [1, 3].

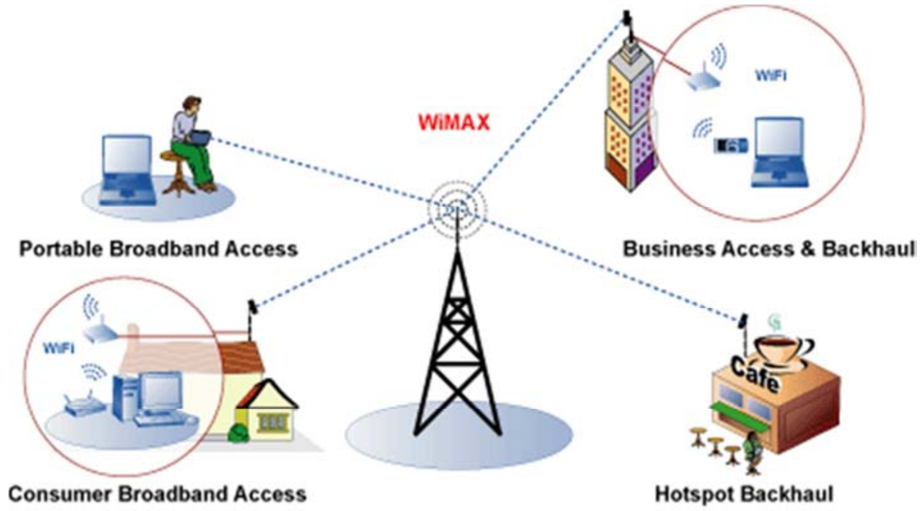

Figure 5. *Commercial WiMAX Deployments.*

The architecture of WiMAX includes a Base Station (BS) and two or more Subscriber Stations (SS). Clients are connected to SS's or the SS itself can be a client. The current implementation is based on the IEEE802.16e specification which offers theoretical downlink rates upwards of 70Mbps and up to 30-mile ranges, also it supports Multi-In-Multi-Out (MIMO) technology, which means that additional antennas can increase the potential throughput [4].

Data transmission in uplink channels (from SS to BS) and/or downlink channel (from BS to SS) is done through TDMA method. Time is divided between frames and there is a guard time between each frame. Each frame is then divided into two sub-frames as uplink and downlink sub-frames.

Uplink sub-frame is divided into 3 time intervals, ranging period, bandwidth contention period, and uplink data period. Therefore, BS should specify the time, the period, and the condition in which SS should transmit [14].

Key specifications such as delay, different flows, least reserved bandwidth, bandwidth request methods and bandwidth dedication are defined in the standard, but when and where we can use them for having the maximum quality of service (QoS) is not stated in the standard

Once again, (theoretical) is the keyword here as WiMAX, like all wireless technologies can either operate at higher bitrates or over longer distances, but not both. Production networks being operated in the United States are seeing average speeds go from 3 to 6Mbps, with bursts up to 10Mbps.

3.2.1. WiMAX Benefits

WiMAX has some great benefits when it comes to mobility, but that is precisely where its limitations are seen.

WiMAX is popular due to its low cost and flexible nature. It can be installed faster than other internet technologies, because it can use shorter towers and less cabling, supporting even non-line-of-sight (NLOS) coverage across an entire city or country.

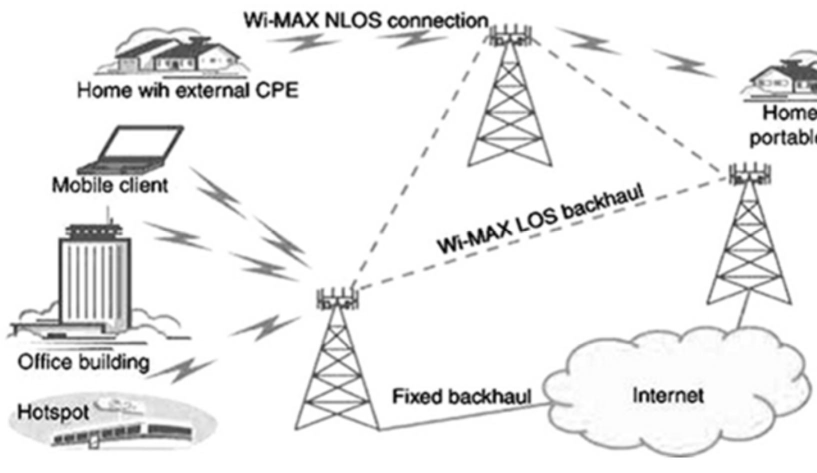

Figure 6. *WiMAX (NLOS/LOS) Connection.*

WiMAX isn't just for fixed connections either, like at home. User can also subscribe to a WiMAX service for their mobile devices since USB dongles, laptops and phones can have the technology built-in [7, 8].

In addition to internet access, WiMAX can provide voice and video transferring capabilities as well as telephone access.

Since WiMAX transmitters can span a distance of several miles with data rates reaching up to 30-40Mbps (1Gbps for fixed stations), it's easy to see its advantage, especially in areas where wired internet is impossible or too costly to implement [7, 12].

WiMAX supports several networking usage models:

1. A means to transfer data across an Internet Service Provider (ISP) network, commonly called backhaul
2. A form of fixed wireless broadband internet access, replacing satellite internet service
3. Internet access for users in extremely remote locations where laying cable would be too expensive

3.2.2. WiMAX Disadvantages

Because WiMAX is wireless by nature, the further away from the source that the client gets, the slower their connection becomes. This means that while a user might pull down 30Mbps in one location, moving away from the cell site can reduce that speed to 1Mbps or next to nothing.

Similar to when several devices suck away at the bandwidth when connected to a single router, multiple users on one WiMAX radio sector will reduce performance for the others.

Wi-Fi is much more popular than WiMAX, so more devices have Wi-Fi capabilities built in than they do with WiMAX. However, most WiMAX implementations include hardware that allow a whole household, for example, to use the service via Wi-Fi, much like how a wireless router provides internet for multiple devices [8].

3.3. Long Term Evolution (LTE)

LTE isn't as much a technology as it is the path followed to achieve 4G speeds, LTE is considered by many to be the natural successor to current-generation 3G technologies, in part because it updates UMTS networks to provide significantly faster data rates for both uploading and downloading. The specification calls for downlink peak rates of at least 100Mb/s and an uplink of 50Mb/s, but going by real world tests its transfer speeds will more likely range from 5-12Mbps for downloads and 2-5Mbps for uploads [2, 8, 10].

Figure 7. *Long Term Evolution (LTE).*

There are two fundamental aspects of LTE. The first is that the technology finally leaves behind the circuit switched network of its GSM roots and moves to an all-IP flat networking architecture. This is a significant shift which in very simple terms means that LTE will treat everything it transmits, even voice, as data.

The other big change relates to the use of MIMO technology, or multiple antennas at both the transmitter and receiver end to improve communication performance. This setup can either be used to increase the throughput data rates or to reduce interference [11, 14].

In the U.S., Verizon Wireless has said it is going commercial with its LTE network in the fourth quarter, with 25 to 30 markets up and ready at launch. AT&T and T-Mobile claim they will begin to deploy LTE in 2011, but in the meantime both networks have moved to HSPA 7.2 and the latter plans to roll out HSPA+ beginning this year. Theoretically these can support speeds of up to 7.2 and 21 Mbps, respectively, but in real world scenarios they are only marginally faster than most 3G data services.

Parameter	WiMAX IEEE 802.16e	LTE
Standard body	IEEE & WiMAX	3GPP
Legacy	IEEE802.16 a to d	GSM,GPRS,UMTS,HSPA
Network Architecture	IP based, Flat	IP based, Flat
Access Technology	DL:OFDMA(for mobile WiMAX) UL:OFDMA(for mobile WiMAX)	DL:OFDMA UL:SC-FDMA
Channel Bandwidth	1.25,3.5,5,10 MHz	1.4,1.6,3.5,5,10,15,20 MHz
Duplexing Mode	TDD,FDD: Focused on TDD	TDD/FDD Focused on FDD
Spectrum (MHz)	2300,2500,3500,3700	700,850,1700,2500,2600
Peak data rate	DL:75Mbps,UL:25Mbps	DL:100Mbps,UL:50Mbps
Spectral Efficiency (bits/sec/Hz)	3.75	5
Mobility	120Kmph	350Kmph
Handovers	Optimized Hard Hand over.	Inter frequency Soft hand Over
Modulation	QPSK,16-QAM,64-QAM	QPSK,16-QAM,64-QAM
Framing	Variable2-20msec	Fixed 1msec(2 slots in 0.5ms)
Subcarrier Spacing	10KHz for mobile WiMAX	15kHz.
Cell Radius	2-7Km	5Km
Cell Capacity	100-200users	>200users (at 5MHz) >400 users (at 20 MHz)
Roaming Framework	In Progress	Through existing GSM/UMTS network

Figure 8. *Comparison of WiMAX IEEE 802.16e and LTE.*

The reason behind LTE's strong industry support lies in the relative ease of upgrading from current 3G networks worldwide over to LTE mobile broadband, compared to the significant infrastructure build out that WiMAX has taken thus far. Fewer cell sites have to be built and penetration into buildings is better at the 700 MHz spectrum LTE uses. However, WiMAX deployments are already up and running while LTE's formal debut is still a few months out [5, 6].

3.3.1. LTE Benefits

Peak download rates up to 299.6Mbits and upload rates up to 75.4Mbits, because LTE supports MIMO, which mean higher data rate can be achieved

Improved support for mobility, exemplified by support for terminals moving at up to 350 km/h or 500 km/h depending on the frequency band [7].

Support for cell sizes from tens of metres radius up to 100 km radius macro-cells. In the lower frequency bands to be used in rural areas, 5 km is the optimal cell size, 30 km having reasonable performance, and up to 100 km cell sizes supported with acceptable performance.

LTE network uses all IP network architecture, it is dedicated for packet switched operations. It supports data as well voice. The voice can be transported using voice over LTE protocols (i.e. VOIP) and fall-back to legacy networks (i.e. 2G/3G) [1, 14].

LTE does not take much time for user to open the browser and download high bandwidth movie, which result in:

1. Latency is very low.
2. Smooth data streaming without any interruption of on-going data transfer.

3.3.2. LTE Disadvantage

Voice calls, the LTE standard only supports packet switching with its all-IP network. Voice calls in GSM, UMTS and CDMA2000 are circuit switched, so with the adoption of LTE, carriers will have to re-engineer their voice call network.

Frequency band, the LTE standard can be used with many different frequency bands. In North America, 700/ 800 and 1700/ 1900 MHz are planned to be used; 800, 1800, 2600 MHz in Europe; 1800 and 2600 MHz in Asia; and 1800 MHz in Australia. As a result, phones from one country may not work in other countries. Users will need a multi-band capable phone for roaming internationally [14].

LTE has adopted MIMO technology. As a result, cell BS may need additional transmit and receive antennae. Mobile phones may have one transmit antenna and up to two receive antennae. Service providers may have to upgrade BS, and consumers will need to buy new phones to utilize these upgraded networks [11].

4. Fifth-Generation (5G)

5G is an upcoming standard in wireless communication that will soon become available to the public. This technology dramatically improves on the speed and consistency of 4G connections, allowing it to sustain more precise functions. It will allow machines to communicate and pretty much anything else that will benefit from being connected [2, 6].

Figure 9. *Beginning of the Fifth Generation (5G).*

To qualify as 5G, a connection must have:

1. A data rate of at least 100Mbps when in metropolitan areas, and in the tens of megabits when there are tens of thousands of people using it
2. 1 millisecond end-to-end round trip delay (latency)
3. Peak download data rate of 20Gbps
4. Peak upload data rate of 10Gbps
5. 1000x bandwidth per unit area
6. (Perception of) 99.999% availability
7. Superior spectral efficiency, signaling efficiency, and coverage compared to 4G
8. Less than one millisecond of latency
9. Hundreds of thousands of wireless sensing connections, operating simultaneously

5G will be faster than 4G, but, how much faster is the question. The details are a bit sketchy at this point, but the speeds are supposed to be upwards of 1 to 20Gbps compare to the 4G standards which are 100Mbps up to 1Gbps [9].

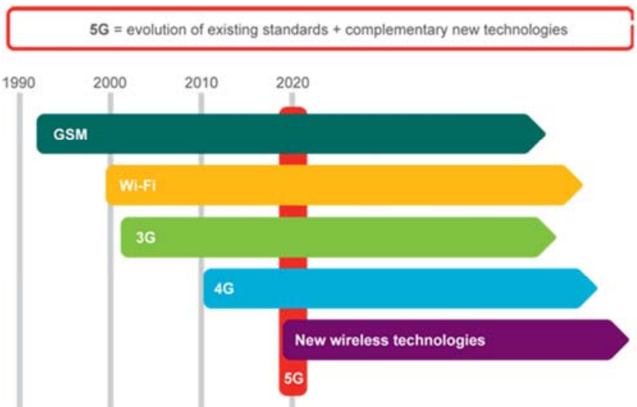

Figure 10. *Evaluation of a Different Standards.*

A lot faster, but will those speeds ever be realized is another question that we will find out sometime around the year 2020. According to a report from Next Generation Mobile Network, 5G should be commercially available on a global scale by the year 2020 [12]. Consumers and businesses will thus soon be able to take advantage of these advances. It could very well change the smartphone industry entirely.

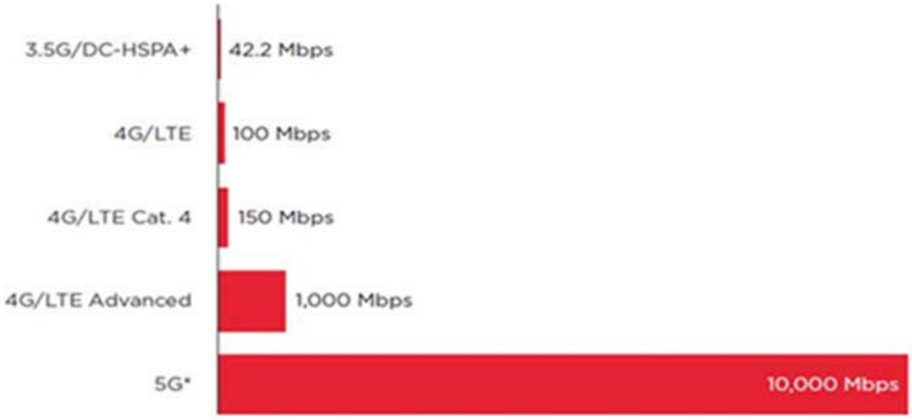

Figure 11. *Maximum Theoretical Downlink Speed by Technology Generation.*

The Global System Mobile Association (GSMA) has two views of the technology. One is the hyper-connected vision which basically incorporates all of the existing technologies and puts them on steroids, not a true generation shift. The other is Next-generation radio access technology with the latency and data rates being strictly defined. That is a true generation shift, 5G will probably be a combination of the two views [10, 11].

Technology	1G	2G/2.5G	3G	4G	5G
Deployment	1970/1984	1980/1999	1990/2002	2000/2010	2014/2015
Bandwidth	2kbps	14-64kbps	2mbps	200mbps	>1gbps
Technology	Analog cellular	Digital cellular	Broadbandwidth/ cdma/ip technology	Unified ip & seamless combo of LAN/WAN/WLAN/PAN	4G+WWWW
Service	Mobile telephony	Digital voice,short messaging	Integrated high quality audio, video & data	Dynamic information access, variable devices	Dynamic information access, variable devices with AI capabilities
Multiplexing	FDMA	TDMA/CDMA	CDMA	CDMA	CDMA
Switching	Circuit	Circuit/circuit for access network&air interface	Packet except for air interface	All packet	All packet
Core network	PSTN	PSTN	Packet network	Internet	Internet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal&Vertical	Horizontal&Vertical

Figure 12. *Comparison of 1G To 5G Technologies.*

Somehow, there will be advantages like an increased bandwidth for all users (more bandwidth means faster speed), and new technology options may become available on a 5G network [12, 14].

On the other hand, disadvantage will be an increased bandwidth will mean less coverage and the radio frequency may become a problem, but hopefully, the advantages will make it all worth it.

5. Conclusion

This paper presented an overview about a different mobile wireless networks technologies, Users should not be surprised if also find other technologies mentioned as 4G technology, even in 2010 Sprint used the 4G for their WiMAX network, not to mention the first WiMAX network in the world launched in 2006 by South Korean KT. AT&T and T-Mobile have used the term 4G technology for their HSPA+ network.

Neither WiMAX nor LTE are truly considered a 4G technology by the ITU. As defined in their IMT-Advanced family of standards, these technologies must have target peak data rates of approximately 100Mbps on high mobility devices and approximately 1Gbps for stationary devices, but in the most cases the more appropriate would be LTE to be considered as 4G technology.

Also, as we know, the most fundamental advantage of 5G is going to be its speed, but connection limitations (latency issues), can challenge the reality of the experience

References

[1] A. Aryaputra and N. Bhuvaneshwari, “5G- The Future of Mobile Network”, Proceedings of the World Congress on Engineering, Vol 2, October 19-21, 2011.

[2] A. Kumar and P. “5G Technology-Redefining wireless Communication in upcoming years”, International Journal of Computer Science and Management Research, Vol 1 Issue 1 ISSN 2278-733X, 2012.

[3] M. Kachhavay and A. Thakare, "5G Technology-Evolution and Revolution", International Journal of Computer Science and Mobile Computing, 2014.

[4] G. Naik, V. Aigal, P. Sehgal and J. Poojary, “Challenges in the implementation of Fourth Generation Wireless Systems”, International Journal of Engineering Research and Applications (IJERA), Vol 2, Issue 2, 2012.

[5] T. Arunkumar and L. Kalaiselvi, “Latest Technology of mobile Communication and Future Scope of 7.5G”, International Journal of Engineering and Technology Research, Vol 2, Issue 4, 2014.

[6] S. Singh and P. Singh, "Key Concepts and Network Architecture for 5G Mobile Technology", International Journal of Scientific Research Engineering & Technology (IJSRET), Vol 1 Issue 5, 2012.

[7] V. Krishna and T. Poornima, "A Study of Wireless Mobile Technology", International Journal of Advance Research in Computer Science and Software Engineering, Vol 4 Issue 1, 2014.

[8] Anju Uttam Gawas, “An Overview on Evolution of Mobile Wireless Communication Networks: 1G-6G”, International Journal on Recent and Innovation Trends in Computing and Communication ISSN: 2321-8169 Vol 3, Issue 5, 2015.

[9] Fidaim Vllasaliu, “The Evolution of Mobile Networks: 1G 2G 3G 4G and 5G”, Kosbit. net, 2017.

[10] C. Beard and W. Stallings, “Wireless Communication Networks and Systems”, Pearson Education Limited, ISBN: 978-1292108711, 2015.

[11] E. Ezhilarasan; M. Dinakaran, “A Review on Mobile Technologies: 3G, 4G and 5G”, Recent Trends and Challenges in Computational Models (ICRTCCM), IEEE, 2017.

[12] Pankaj Sharma, “Evolution of Mobile Wireless Communication Networks-1G to 5G as well as Future Prospective of Next Generation Communication Network”, International Journal of Computer Science and Mobile Computing, ISSN 2320–088X IJCSMC, Vol. 2, pg. 47-53, 2013.

[13] Williams. C, Strusani. D and Kovo. D, “The Economic Impact of Next-Generation Mobile Services: How 3G Connections and the Use of Mobile Data Impact GDP Growth”, The Global Information Technology Report: 77-80, 2013.

[14] P. Sharma, D. Sharma and R. Singh, “Evolution of mobile wireless communication networks (0G-8G)”, Article in International Journal of Applied Engineering Research, 10 (6): 14765-14778, 2015.