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Καθηγητής: Α.Α Οικονομίδης | **Professor: A.A Economides**

Η ΕΞΕΛΙΞΗ ΤΩΝ ΚΥΨΕΛΟΕΙΔΩΝ ΔΙΚΤΥΩΝ

EVOLUTION OF CELLULAR NETWORKS

Αλέξανδρος Τσαρουχίδης mis18021

Γιάννης Κιρπίτσας mis18019

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Περίληψη

Η παρούσα εργασία εκπονήθηκε για να μελετήσει την διαδρομή των δικτύων κινητής τηλεφωνίας από την απαρχή τους μέχρι και τον μέλλον τους. Τόσο σε τεχνολογικό επίπεδο όσο και σε επίπεδο αναγκών που εξυπηρετούν. Σε κάθε κεφάλαιο αναλύεται κάθε δίκτυο κινητής τηλεφωνίας που έχει εφευρεθεί. Ακολουθεί μία SWOT ανάλυση των πιο πρόσφατων υλοποιήσεων τους και στο τέλος γίνεται αναφορά στην μελλοντική εξέλιξη τους, καθώς και των λύσεων που αυτές θα προσφέρουν.

Abstract

This assignment was devised to investigate the evolution of cellular networks and their impact to our everyday lives. In the following chapters, each evolution of cellular networks is analyzed. Then a SWOT analysis follows, in which the most recent implementations are evaluated. Finally, the future of mobile networks is examined.

1.Introduction

Cellular networks nowadays are part of our everyday life. We use them not only to conduct voice calls, but also for messaging, video conferences, entertainment and various other tasks where in the past they would take a computer and a landline to do them. All these began in 1979 in Japan by Nippon Telephone and Telegraph (NTT), which invented the first-generation cellular system (1G) (Pankaj Sharma, 2013). By the early 90's the second-generation cellular system (2G) was launched in Finland to give us more capabilities, such as digital voice and messaging (Mohammad Meraj ud in Mir & Dr. Sumit Kumar, 2015). Even though the 2G system was updated to offer faster data speeds, the increasing demand for more bandwidth to mobile devices led to the invention of the third-generation cellular system (3G) (3G (n.d) In Wikipedia. Retrieved May 11, 2018, from https://en.wikipedia.org/wiki/3G). But in a fast paced and ever-changing world this was not enough and in 2005 in Tokyo, Japan the first successful field trial of the fourth-generation cellular system (4G), took place (Pankaj Sharma, 2013).

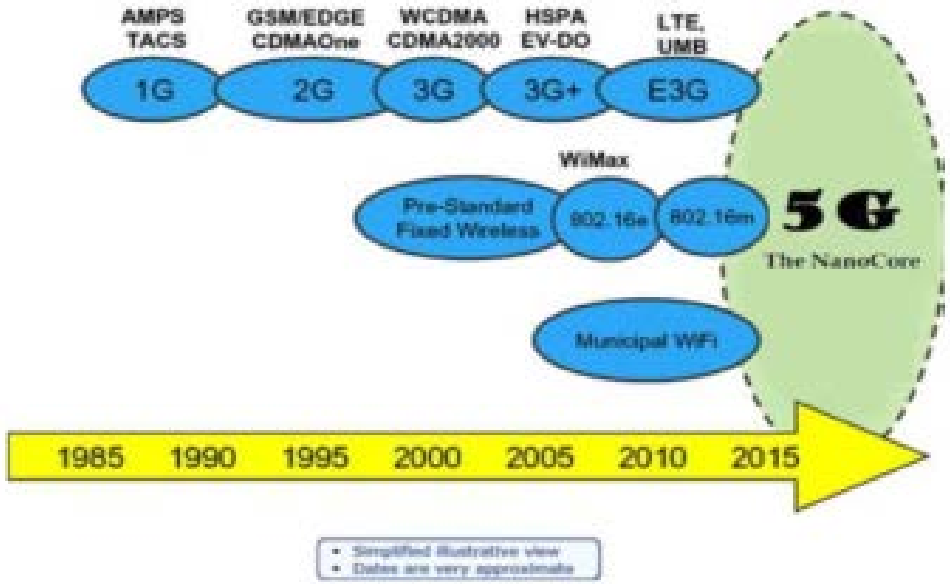

Figure 1 - Evolution of cellular networks (Mohammad Meraj ud in Mir & Dr. Sumit Kumar, 2015, p. 2546)

2.First generation cellular system (1G)

The first-generation mobile system was used only for speech services. As we have already mentioned, it was first implemented in the late 70's in Japan and it was using circuit-switched systems and analogue transmission to carry low quality voice calls (Panagiota D. Giotopoulou, 2015). Due to its analogue nature the voice quality was poor and the calls susceptible to eavesdropping, because the signal transmission was carried out by radio towers. Another major drawback, compare to its successors, were that even though it had roaming capabilities, due to the fragmentation of its implementations it didn't materialized (Mohammad Meraj ud in Mir & Dr. Sumit Kumar, 2015). Also, it could at any time support only one user per channel and the devices were huge (2G, 3G, Next-G, 4G - What's the difference? (n.d) In Telcoantennas. Retrieved May 11, 2018, from https://www.telcoantennas.com.au/site/guide-to-mobile-networks).

2.1 Network standards

First generation cellular networks were using different standards across the globe. In Europe the most popular were Nordic Mobile Telephones (NMT) and Total Access Communication Systems (TACS) and in USA was AMPS (Mohammad Meraj ud in Mir & Dr. Sumit Kumar, 2015). All the systems above were based on FM radio transmissions using the FDMA principle, where every user uses their own frequency to separate user's channels within the assigned spectrum.

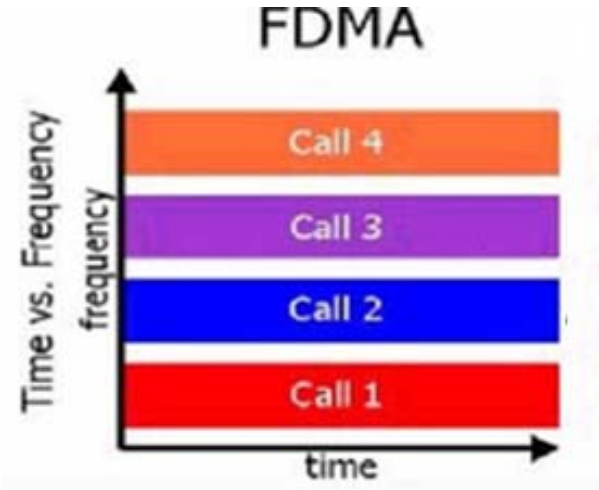

Figure 2 - Frequency Division Multiple Access (Kyle Bryson & Alison Chen & Allen Wan, (n.d). Retrieved May 12, 2018 from https://www.clear.rice.edu/elec301/Projects01/cdma/FDMA.jpg)

The speed of the first-generation networks was usually from 4.8 Kbps to 14.4 Kbps, depended on the signal strength. They also used full duplex transmission, allowing simultaneous reception and transmission. Both TACS and AMPS systems, which were operated at 800 MHz and 900 MHz frequencies, were ideal for urban areas. In contrast the NMT system was at first designed to be used in rural environments, with low population density and it was operated at 450 MHz frequency (Alex Shneyderman & Alessio Casati, (n.d). Retrieved May 11, 2018, from etutorials.org/Mobile+devices/mobile+vpn/Part+I+Wireless+Data+Fundamentals/Chapter+3+Wireless+Systems+Overview+A+Radio+Interface+Perspective/1G+Cellular+Systems/).

It wasn't until 1986 when NMT adopted the 900 MHz range, which made it acceptable to use in urban areas (Nordic Mobile Telephone (n.d) In Wikipedia. Retrieved May 11, 2018, from https://en.wikipedia.org/wiki/Nordic_Mobile_Telephone).

3. Second generation cellular system (2G)

The shortcomings of 1G led to the invention of the second-generation cellular system (2G), at the beginning of the 90's in Finland. 2G is digital and additional to voice it can provide text messaging, picture messaging, MMS, and basic internet functionality (WAP). Compared to 1G it provides more secure communications, by using encryption. One more advantage was that in 2G era most countries used the same protocol, leading to the successful implantation of roaming for users travelling between them (Mohammad Meraj ud in Mir & Dr. Sumit Kumar, 2015). Also, it can support more than one user per channel and it can operate in smaller devices. Another thing that 2G era introduced, due to digitalization, was the SIM card (2G, 3G, Next-G, 4G - What's the difference? (n.d) In Telcoantennas. Retrieved May 11, 2018, from https://www.telcoantennas.com.au/site/guide-to-mobile-networks).

3.1 Network standards

Four were the main standards of the second-generation cellular systems. The GSM, D-AMPS, cdmaOne and PDC. GSM is the most popular of them all and was developed by European Telecommunications Standards Institute (ETSI), D-AMPS was developed in USA and was mainly used in North America, CDMA was developed by Qualcomm (cdmaOne (n.d) In Wikipedia. Retrieved May 12, 2018, from https://en.wikipedia.org/wiki/CdmaOne) and is adopted in many parts of the world and PDC was developed and used in Japan (Panagiota D. Giotopoulou, 2015).

3.1.2 GSM

As we mentioned GSM is by far the most popular of the 2G implantations. Because of this it lowered the costs of the adoption of the new technology, due to mass production (Alex

Shneyderman & Alessio Casati, (n,d). Retrieved May 12, 2018, from http://etutorials.org/Mobile+devices/mobile+vpn/Part+I+Wireless+Data+Fundamentals/Chapter+3+Wireless+Systems+Overview+A+Radio+Interface+Perspective/2G+Cellular+Systems/).

To support more than one user per channel, it uses the TDMA transmission scheme. TDMA resources are shared in time, by dividing the signal into different time slots. Each user is allocated in a time slot for a small amount of time and moves to another one after that time is ended. The result is that the frequency can be shared among users, through taking turns in the time slots (Panagiota D. Giotopoulou, 2015).

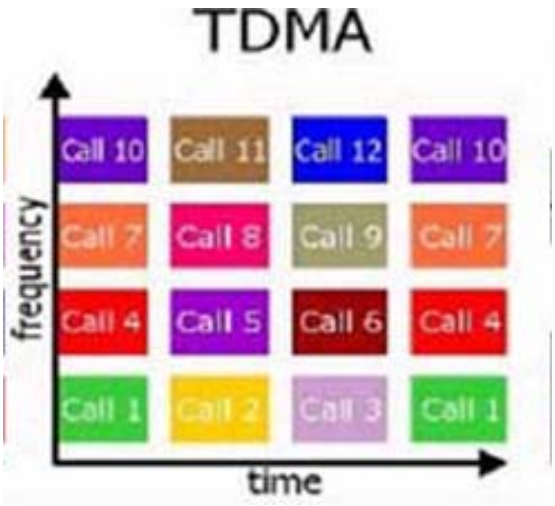

Figure 3 - Time division multiple access (Kyle Bryson & Alison Chen & Allen Wan, (n.d). Retrieved May 12, 2018 from https://www.clear.rice.edu/elec301/Projects01/cdma/TDMA.jpg)

At first GSM was operating only at 900 MHz. Which in turn it was divided into 124 channels of 200 KHz. This channel in turn it was divided into eight timeslots one for each user, using the TDMA access technology we mentioned before. Later the GSM could also operate at 1800MHz (Panagiota D. Giotopoulou, 2015). GSM is also capable of QoS in order to provide better services, and features such as call waiting, call forwarding, call barring and conference calling. (Alex Shneyderman & Alessio Casati, (n.d). Retrieved May 12, 2018, from

http://etutorials.org/Mobile+devices/mobile+vpn/Part+I+Wireless+Data+Fundamentals/Chapter+3+Wireless+Systems+Overview+A+Radio+Interface+Perspective/2G+Cellular+Systems/).

3.1.3 D-AMPS

D-AMPS or North American TDMA it was the second-generation system used mainly in USA, Canada and South America. As GSM it uses the TDMA access method to allocate more than one user in each channel. But it divides the channel to three-time slots, in contrast to eight slots of the GSM. It can operate at both 800 MHz and 1900 MHz frequency bands. Also, many D-AMPS devices can work in both AMPS (analog) and D-AMPS (digital) mode, in order to offer their users, the ability to use their phones in both digital and analog infrastructures (Alex Shneyderman & Alessio Casati, (n.d). Retrieved May 12, 2018, from http://etutorials.org/Mobile+devices/mobile+vpn/Part+I+Wireless+Data+Fundamentals/Chapter+3+Wireless+Systems+Overview+A+Radio+Interface+Perspective/2G+Cellular+Systems/).

3.1.4 CdmaOne

One of the drawbacks of the TDMA, compare to 1G systems, is its limited range. This is a result of the slow speed of D-AMPS and GSM systems and the time slot access mode. What happens is that the further you move from the phone tower, the slower your speed will be and it will take more time for your signal to reach the tower. This in turns could result in a lost call, if your phone cannot respond to its given timeslot and the tower drop your signal and begin to handle another call (2G, 3G, Next-G, 4G - What's the difference? (n.d) In Telcoantennas. Retrieved May 11, 2018, from https://www.telcoantennas.com.au/site/guide-to-mobile-networks).

In order to resolve this CDMA, also called CdmaOne, was invented. CDMA doesn’t use time slots as TDMA, but increases the spectrum capacity by allowing all users to occupy all

channels at the same time. Then to avoid packet coalition, it assigns a unique code to its user (Panagiota D. Giotopoulou, 2015). CDMA broadcasts at a lower frequency (800 MHz) than D-AMPS and GSM, which also helps to maximize its range (2G, 3G, Next-G, 4G - What's the difference? (n.d) In Telcoantennas. Retrieved May 11, 2018, from https://www.telcoantennas.com.au/site/guide-to-mobile-networks).

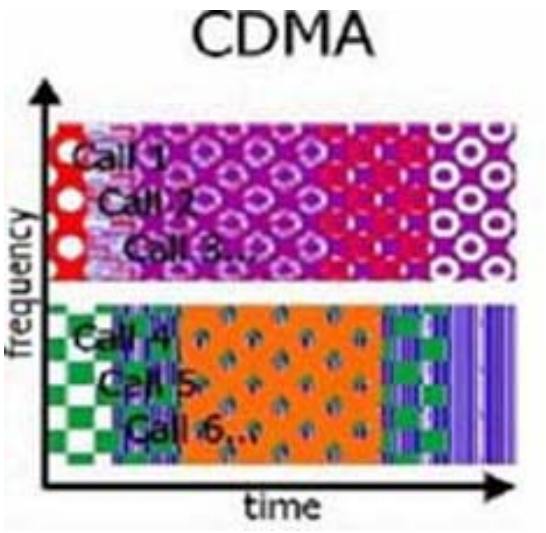

Figure 4 - Time division multiple access (Kyle Bryson & Alison Chen & Allen Wan, (n.d). Retrieved May 12, 2018 from https://www.clear.rice.edu/elec301/Projects01/cdma/CDMA.jpg)

3.2 Evolution of 2G systems (2.5G)

The problem of limited range can also be solved, by update the already installed GSM infrastructure to 2.5G systems. 2.5 Generation systems are still use the TDMA system, but with higher speeds, in order to reduce drop signals (2G, 3G, Next-G, 4G - What's the difference? (n.d) In Telcoantennas. Retrieved May 11, 2018, from https://www.telcoantennas.com.au/site/guide-to-mobile-networks). Faster speeds resulted in more usable mobile internet. The changes that 2.5G brought, are covered below:

- GPRS or General Packet Radio Service combines several time slots into a single bearer to achieve better speeds. In theory it can achieve speeds up to 115Kbit/s, but in practice it can only reach 56Kbit/s. The maximum speed depends on the carrier's implementation and on user's device.

- Enhanced Data Rates for Global Evolution or EDGE it's an update of GPRS. It can achieve speeds up to 384Kbit/s
- High-Speed Circuit-Switched Data or HSDC can achieve speed up to 57Kbps by using up to four GSM channels. HSDC can implemented with minimum changes in the existing network architecture (Panagiota D. Giotopoulou, 2015).

4. Third generation systems (3G)

Soon a time came when the bandwidth of 2G systems wasn't enough to fulfill the ever-growing needs. Concepts such as remote access to intranet systems, internet multimedia services, and teleworking, where beginning to emerge and the need for faster mobile networks was apparent. Another problem was that even though 2G systems were less fragmented than 1G, due to GSM's dominance, still roaming couldn't implemented by all users globally.

So, a plan was implemented by International Telecommunication Union (ITU), in which the standards of the third-generation systems where decided. 3G systems will provide backward compatibility to its regional 2G system, but at the same time they will provide seamless coverage across the globe as well speeds from 144Kbps to 2Mbps (Mohammad Meraj ud in Mir & Dr. Sumit Kumar, 2015).

Third generations systems were developed mainly on two technologies The UMTS and CDMA 2000 systems. The first one is the evolution of GSM systems and the latter the evolution of CDMA ones (Panagiota D. Giotopoulou, 2015).

4.1 W-CDMA

W-CDMA or wideband-CDMA is the technology which drives the radio access network part of UMTS. It's a CDMA based standard which can provide higher data transmission rates in GSM systems. W-CDMA can achieve speeds up to 2.4Mbps and it operates at 1885MHz – 2025MHz and 2110MHz – 2200MHz bands according to ITU specifications (UMTS

frequency bands (n.d) In Wikipedia. Retrieved May 12, 2018, from https://en.wikipedia.org/wiki/UMTS_frequency_bands).

But it depends on the mobility of its user, as it is described below:

- High mobility, such as while the user is driving car, can result to a speed up to 144Kbps
- Low mobility, such as while the user is walking, can result to a speed up to 384Kbps
- Indoor mobility, such as when the user is sitting in its home, can results to a speed up to 2.4Mbps (Alex Shneyderman & Alessio Casati, (n.d). Retrieved May 12, 2018, from http://etutorials.org/Mobile+devices/mobile+vpn/Part+I+Wireless+Data+Fundamentals/Chapter+3+Wireless+Systems+Overview+A+Radio+Interface+Perspective/3G+Cellular+Systems/).

4.2 CDMA 2000

CDMA 2000 or CDMA 3G, as its often called, is the successor of CDMA and it can provide speeds up to 144Kbps. The carriers can use this new system by simply upgrade their CDMA infrastructure, without the need to buy new spectrums to operate, as opposed to UTMS (Alex Shneyderman & Alessio Casati, (n.d). Retrieved May 12, 2018, from http://etutorials.org/Mobile+devices/mobile+vpn/Part+I+Wireless+Data+Fundamentals/Chapter+3+Wireless+Systems+Overview+A+Radio+Interface+Perspective/3G+Cellular+Systems/).

4.3 Evolution of 3G systems (3.5)

The need of greater speeds came and the industry found ways to update the already installed infrastructure to meet the new user's demands. So, the HSPA and 1xEV-DO systems came, to update W-CDMA and CDMA 2000 respectively.

HSPA consists of two standards the HDSPA or High Speed Downlink Packet Access and HSUPA or High Speed Uplink Packet Access. The first can give download speeds up to 14Mbit/s and the second one can offer upload speeds from 2Mbit/s to 5.76Mbit/s

On the other hand, the update of the CDMA system, 1xEV-DO, can offer speeds up to 2.4 Mbit/s (Panagiota D. Giotopoulou, 2015).

5.1 Fourth generation systems (4G)

As years passed by, the need for online gaming, live video conferencing and other high bandwidth usage scenarios came forth in the mobile environment. So, the fourth generation-systems were invented to fulfil those needs.

4G are IP-based systems and a packet switching evolution of 3g systems. With them the broadband mobile internet access is actualized. The fourth-generation systems consists of the following standards:

- LTE or Long Term Evolution was developed by 3GPP and it belong to the same family as GSM. It can reach speeds over 100MB/s and in case of bad reception it can safely fall back onto legacy networks
- IEEE 802.16 or WiMAX can provide speeds up to 40Mbit/s. But it’s not suitable for voice services. Also, due to its limited adoption can’t support many services and roaming
- UMB or Ultra-Mobile Broadband it belongs to the CDMA family. It didn’t deployed, even though it was promising, due to lack of interests (Panagiota D. Giotopoulou, 2015).

5.2 Fourth generation systems disadvantages

As with every technology 4g systems also have their disadvantages. Those are the following:

- They require large infrastructure investments

- They tend to be more power hungry than 3g systems. So, they require mobiles with larger batteries.
- In some parts of the world 4g network plans are priced higher than the 3g ones. (Heba Soffar, 2017. In Online Sciences. Retrieved May 13, 2018, from https://www.online-sciences.com/technology/4g-technology-uses-features-advantages-and-disadvantages/)
- Since 4G is IP based is more vulnerable to mobile-to-mobile attacks (Tyson Macaulay, 2013).

5.3 Evolution of 4G systems

The evolution of LTE is called LTE Advanced and it was standardized by 3GPP, in March 2011. It features several new techniques, like heterogenous networks (HetNet), coordinated Multi-Point operation (CoMP), in order to provide better quality of service for users on cell edges. It also introduces another new feature called In-device Co-existence (IDC), which can eliminate the interferences between LTE/LTE-A components with other radio subsystems of a device. LTE advanced is backward compatible with LTE (Wifi, Bluetooth etc.) (LTE Advanced (n.d) In Wikipedia. Retrieved May 12, 2018, from https://en.wikipedia.org/wiki/LTE_Advanced).

6. SWOT analysis

Following the changing needs for enhanced communication and collaboration in the recent years, cellular networks have established universal use. For the past decade, 4G networks have certain technologically advantages. However, our needs are ever-growing and there is always room for improvement. That is what drives nowadays the 5G evolution.

Focusing in the core Strengths, Weaknesses, Opportunities and Threats, we can plot the following SWOT diagram, for the current cellular networks:

A) 4G Network strengths, weaknesses, opportunities and threats	
Strengths	Weaknesses
- Can use part of existing infrastructure/investments - Significantly faster data transfer - Higher bit-rate - Higher bandwidth - Boost consumer base applications use	- Covered limited yet to certain geographical areas - High cost for carrier's equipment to supply 4G services - Multiple 4G antennas & transmitters require advanced capacity batteries for devices
Opportunities	Threats
- Consumers continue driving a fast pace adaption/ expansion of the mobile devices market. - Worldwide economy anticipates growing factors - Technological advancements led by focus in heterogeneous networks - Need for high data transfer speeds constantly increases - Need for M2M connectivity advances	- Security vulnerability, with mobile-to-mobile attacks, since 4G is IP based - The 3G technology still plays a significant role in the market - National regulations, creating obligations to carriers to intercept many different types of traffic (Edge, Voice, Internet)

7. Conclusion and the rise of 5G

We have come a long way since the days of 1G. But even though 4G is fast and reliable, still it lacks the capabilities to fulfil the requirements of the future services. That leads to the 5G network appearance as the latest update for a faster and more flexible cellular network. For the next decade, scientists are promising the rise of a network with larger volumes of data transport, in combination with intense development of smart cities, smart grids, machine learning and artificial intelligence, unmanned vehicle driving and many more technological

advancements (Project Foresight: 5G (n.d). In 451Research. Retrieved May 13, 2018, from https://451research.com/project-foresight-5g)

As stated by the Groupe Speciale Mobile Association, 5G networks will have the following characteristics, in principal:

- 1-10Gbps connections to end points in the field (i.e. not theoretical maximum)
- 1 millisecond end-to-end round trip delay (latency)
- 1000x bandwidth per unit area
- 10-100x number of connected devices
- (Perception of) 99.999% availability
- (Perception of) 100% coverage
- 90% reduction in network energy usage
- Up to ten year battery life for low power, machine-type devices. (Dan Warren & Calum Dewar, 2014. In GSMA Intelligence. Retrieved May 13, 2018, from https://www.gsmaintelligence.com/research/?file=141208-5g.pdf&download)

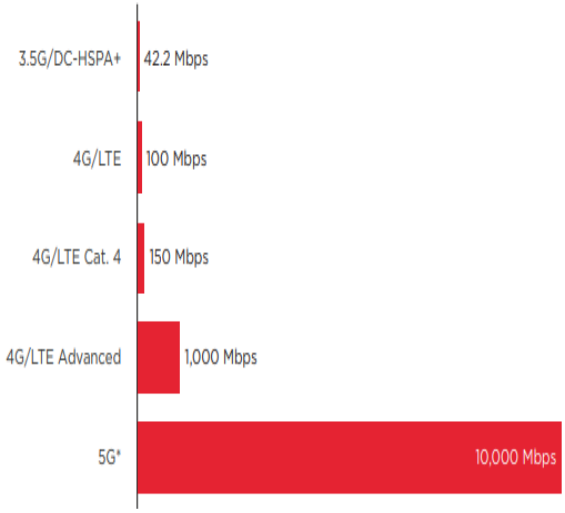

Figure 5 - Maximum Downlink speed by technology generations (Dan Warren & Calum Dewar, 2014, In GSMA Intelligence. Retrieved from https://www.gsmaintelligence.com/research/?file=141208-5g.pdf&download)

While network speed is a key advancement and characteristic of 5G, another major differentiation from previous technology is the lower latency. In simple words, the latter will lead to unforeseen responsiveness, when we will access mobile services in the future. Such services could be 4K streaming, high definition gaming, clustering, car parking sensors and A.I systems. (Gary Marshall, 2016. In Techradar. Retrieved May 13, 2018, from https://www.techradar.com/news/world-of-tech/why-5g-will-be-far-more-life-changing-than-you-think-1320066).

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