UNIVERSITY OF PUERTO RICO
MAYAGÜEZ CAMPUS

COMPUTER SCIENCE AND ENGINEERING
DEPARTMENT

Computer Networks

CIIC – 4070

Final Report:

A Survey for the Fifth Generation Cellular System

Raúl A. Ortiz Rivera ID: 802-18-7733

Professor: Kejie Lu

March 12, 2023

Table of Contents

Introduction.....3

The History and the Current Status of Cellular Networks.....4-6

Market Trends of 5G Systems…….....7

Applications of 5G Systems.....7-8

Key Technologies...….....8-12

Other Major Issues...….....12-14

The Future of Cellular Systems...….....15-16

Conclusion.....17

References.....18-21

List of figures

Figure 3.1.1…….....9

Figure 3.1.2...….....10

Introduction

This final report of *A Survey for the Fifth Generation Cellular System* will investigate everything about mobile networks. It will begin by exploring the history of the different generations from 1G to 4G LTE. The status of each of these networks will also be verified. Then we will move on to the current 5G generation looking for its market trends and the applications of this generation. After knowing each of its characteristics we will move on to some key technologies such as Massive MIMO, mmWave, NOMA and that represent for today. In the same line of key technologies, the network layer will be investigated specifically in Software-defined networking, Network function virtualization and Network slicing. After the research of the networks will be investigated on some technologies such as Network densification, Edge computing, Internet of Things and Cellular vehicular to everything (C-V2X). Lastly, it will be seen that awaits us in the future studying B5G, the sixth generation or 6G and that they will represent artificial intelligences for the cellular system.

The History and the Current Status of Cellular Networks

1. 1G

    - The 1G or the first generation of wireless technology for cell phones was first seen in the 1980s. The first time it was seen was in 1979 in a Japanese commercial for NTT (Nippon Telegraph and Telephone). The first cell phone capable of using this network was Panasonic's TZ-801. After this it was spreading through the Nordic countries giving way to international roaming with the NMT standard and the first mobile device developed in Switzerland in 1983. The 1G network came to the United States in 1983 in the Chicago area using the Motorola DynaTAC mobile phone. In the 1990s the 1G network was replaced by 2G with technologies such as GSM and cdmaOne.
    - Currently the 1G network is totally obsolete. Countries have opted for more recent and efficient technologies. Most countries discontinued 1G in the 2000s having as record the last operational 1G network in Russia in 2017.

2. 2G

    - The second generation of mobile telephony or 2G was commercially launched in Finland in 1991 by Radiolinja. The 2G network uses GSM standards and unlike the 1G network this technology uses digital radio signals. In the North American area, different standards such as Digital Amps were used and cdmaOne was the most dominant although GSM was also used. The biggest improvements offered by 2G were encrypted conversations between the mobile phone and the telephone database,

efficient use of the radio frequency spectrum allowing more users and added multi-meter services such as text messages (SMS) and multimedia (MMS). There were small in-network evaluations such as 2.5G and 2.75G(EDGE). These updates improved encoding and data rates.

- As for its use today, it can be said that it is still used in countries of Europe, Africa, and Central America. Some places have predicted its use until 2030 so it is still a technology used in 2023. You can see this technology in North America although its use is not so common since it is considered unsafe.

3. 3G

- 3G was the substitute for 2G technologies with all its variants. It was mainly introduced in 2001 offering better call quality and data rates. This technology was 15 years in development by ITU (International Telecommunication Union). The communication spectrum ranged from 400MHz to 3GHz where the name comes from. Its test phase was in 2001 and its commercial launch was in 2002 by SK Telecom in South Korea. This technology had its adaptation in different times such as in the United Kingdom and Australia that arrived in 2003 which is a small period after its departure unlike other countries such as India that was launched in 2008. This technology in addition to bringing more than 200 million subscribers brought the feasibility to access the internet on a mobile device, medical devices, fire alarms, ankle monitors use this network for

accomplishing their designated tasks. This technology gave way to 4G leading 3G to a state of obsolescence.

- As for its use at present there are still countries that use it although most countries no longer use this technology to the point that the 2G network continues to operate while the 3G was turned off. Its replacement has reached the point that some mobile devices will become inoperative. The United States is one of the countries that will completely turn off 3G after 2023.

4. 4G

- 4G technology began to be announced in 2009 but the first cell phones were not available until 2010. Work began in 2004 where it was proposed by NTT DoCoMo in Japan. Then the development continued where the first Japanese prototype was tested in 2007 by the same company. After this, it passed a process of approval by federal entities and organizations until in 2008 it was launched to be commercialized. The predominant and accepted standard was LTE (Long Term Evolution). This technology brought improvements to replace 3G bringing greater speed and efficiency reaching up to 1Gbps. This improvement brought greater speed when searching the internet, quality video calls and online games.
- Today still the 4G and 4G LTE network is considered a network that is not obsolete. It is widely used in the world and although 5G has arrived and provides improvements in speed and efficiency, there is still time for mobiles that use this technology to be inoperable.

Market Trends of 5G Systems

- The market trends for 5G technology have very promising valuations in the coming years. This technology was valued at $5.13 billion in 2020 and is expected to be worth approximately $800 billion by 2030.
- One of the biggest improvements will be incredible speeds at mega low latency levels.
- 5G technology is expected to revolutionize the market bringing advancements to the area of communications, hardware, entertainment, Internet of things, autonomous vehicles, and others.
- A reach of 130 billion is projected in 2021 and so consecutively in the 5G market.

Applications of 5G Systems

- IoT (Internet of Things) - 5G will be a very big advance for the technology of things. Smart homes with light bulbs, refrigerators and virtual assistants are some of the improvements we will see in the coming years. In addition, all this will be in real time thanks to 5G.
- Autonomous Vehicles - Thanks to 5G technology which has such low latency allows the use of navigation, collision avoidance and communication with other autonomous vehicles in real time. In the future cars like Tesla will use functions to communicate through sensors and thus make autonomous driving safer than the current one.

- Smart cities and Healthcare - For smart cities it will help create improvements in traffic management, energy, security while for health there will be updated patient data remotely such as telemedicine and patient monitoring.
- Streaming, Broad band and Industrial improvements - These 3 services will benefit from 5G technology. Starting with the use of streaming and broad band services where the loading of these videos and the resolution will be much more efficient. As for the industrial area, the use of automation will be more reliable and accurate.

Key Technologies

- **Physical Layer**

1. Massive MIMO
    - Massive MIMO (Multiple Input Multiple Output) is a technology that uses a greater number of antennas to overcome the interference and propagation of a wireless network. There are MIMOs which use only a few more antennas but in Massive MIMO dozens or in some cases hundreds of antennas are used in a single array. This technology, in addition to increasing the capacity of users, focuses on reaching each device more precisely. The technology has millimeter waves above 24GHz which reinforce the signal even more. This technology is key to the development of 5G networks as it allows faster data speeds and higher capacity.

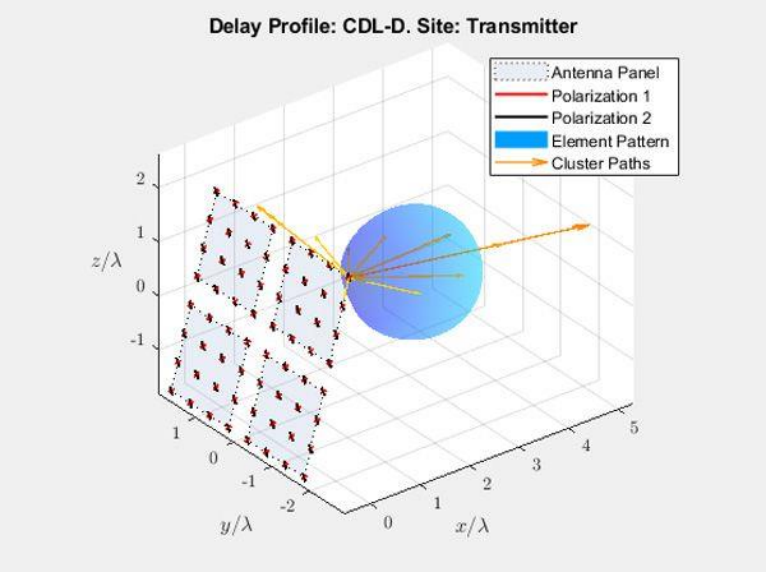

Fig. 3.1.1 MATLAB Massive MIMO Example

2. mmWave

   - Millimeter Wave Spectrum is a type of spectrum band between 30 GHz (can be above 24GHz) up to 300 GHz. This technology is generally used in standard 802.11ad Wi-Fi networks to bring 5G and expand it through the population. mmWave brings benefits such as lower energy costs, greater bandwidth, and distribution of higher quality multimedia. They also have uses such as radars and satellites. This technology faces some challenges such as the range since it is very easy to lose the frequency when the distance is far. The distance problem is being reduced with the implementation of Massive MIMO.

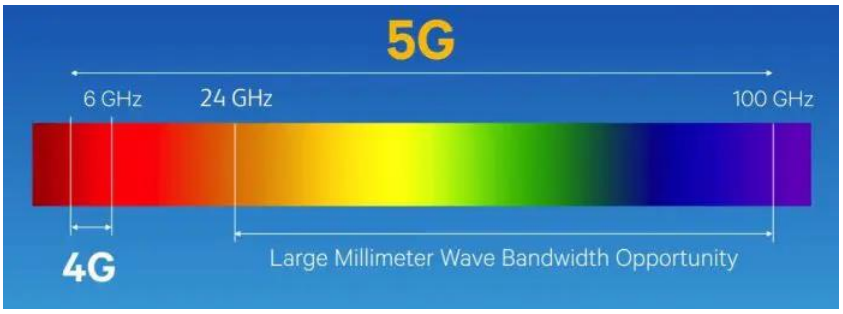

Fig. 3.1.2 Millimeter Wave Spectrum Band

- Data Link Layer and MAC Sub-Layer
    1. Non-Orthogonal Multiple Access (NOMA)
        - The NOMA technique is a technique that basically allows several users to occupy the same transmission channel at the same time. The purpose of this technology is to be implemented in the 5G network so that through a technique that emits differences between the signals of the different users who are connected to the same channel. In the end, improvements in capacity and spectral efficiency are obtained, which in turn makes the 5G network more stable and efficient. The opposite of this technology would be to divide the frequency, time and efficiency between users as is done in a 4G LTE network which uses an OFDMA (Orthogonal Frequency-Division Multiple Access) frequency.
- Network Layer
    1. Software-Defined Networking
        - The SDN is a type of network that is responsible for maintaining centralized control using software-based controllers or application

programming interfaces (APIs) to communicate with underlying hardware to simplify a network, streamline processes and improve its management. This model allows a new path to control data packets on a centralized server. Some of the important points to highlight are the increase in the control of a network, the speed of the network, creating a customized infrastructure model for the network and a considerable increase in network security. The biggest difference between the traditional method and SDN is the infrastructure. The SDN method is based on software while the traditional one on hardware. This allows the SDN to be functional in all compatible models, so it is not tied to a hardware, it is allowed the automation and programming of how the network behaves. In addition, one of the biggest differences is that it separates the control plane from the data handling plane.

2. Network Function Virtualization

    - NFVs are the replacement of hardware appliances with virtual machines. This allows the separation of routers, VPNs and firewalls which need specific hardware and would run from servers. This change would represent advantages in terms of Scalability since they can respond to changes in the demand for these services. It would also represent a reduction in costs so organizations would use general hardware instead of specific ones. Finally, it would add an innovation phase where new functions and network services can be developed without the need for new investments.

3. Network Slicing
    - Network Slicing is a technology that allows you to create specific virtual networks in the same network infrastructure. Each network created or "slice" allows optimization for that specific network. This architecture allows multiplexing capable of meeting the requirements of a particular application. An example of this would be a smart car or some IoT device since with this architecture networks could be created that allow low latency and are less expensive and more efficient. In addition to this, it uses security functions since if any attack occurs to the network, they would only be attacking the custom network and not the entire network system. As for 5G, it is an important factor as it seeks to reduce costs, improve efficiency, provide a high-quality service, and offer greater flexibility.

- **Other Major Issues**

1. Network Densification
    - The Network densification is a term used in the field of communications to refer to the improvement of capacity, coverage, and efficiency of some communication system. This term is mostly used in urban cities since the flow of users tends to lower the quality of the networks. Some of the technologies used to improve the densification of networks are the use of Massive MIMO, mmWaves and HetNets. As for the current 5G network, densification is needed

since this technology uses a millimeter wave spectrum, so it is needed to be as efficient as possible. Some of the problems that can arise are the cost since it increases drastically, the interference that can be created, energy consumption since more equipment means an additional expenditure of energy and finally the necessary regulations since there are laws that limit the number of devices and frequencies that can be emitted.

2. Edge Computing
    - Edge computing is a framework that accelerates the processing of data at the edge of the network. It basically removes a lot of latency by processing the data on the device and sending the most important thing to the data center. This type of technology is useful in autonomous vehicle services, security, IoT devices and augmented reality applications. An example of this would be a camera in a local, the camera instead of recording 24 hours a day only activates the recording when it detects a suspicious movement or object. In addition, edge computing improves security since part of the data is handled locally and that is a huge step in the infrastructure of the network.
3. Internet of Things (IoT)
    - The internet of things refers to any device that connects to the network and can execute tasks through that communication. Some objects are vehicles, sensors, appliances, sensors, and many others. These devices

are said to be the future in homes and daily tasks with the ability to improve homes by making them smart. You could monitor cameras, open doors, and even control the fridge of a house. In addition, cities are expected to become smart through sensors that can improve efficiency in time, energy, traffic management and lighting. These devices can interact with others like Amazon's Alexa does with light bulbs and smart devices. More IoT is expected to use the network. The only problem that has arisen with this technology is the security and privacy of users. This problem is being minimized with greater data encryption.

4. Cellular Vehicular to Everything (C-V2X)
    - The C-V2X is a mobility platform that allows vehicles to communicate with other vehicles, pedestrians, cyclists, road infrastructure and other mobile networks. Essentially, it is the communication of vehicles wirelessly with their environment. This communication can be direct using the 5.9GHz network to interact with other vehicles (V2V), with pedestrians (V2P), infrastructure (V2I) without the need for a network. It can also communicate via mobile network (V2N) to access the cloud and use real-time traffic information and mapping services. The advantage of if this technology were to be used would be greater road safety, less traffic and support of autonomous vehicles. If this technology is standardized, the boost to the 5G network would be enormous.

The Future of Cellular Systems

- **Beyond 5G (B5G)**

  B5G is the given term that is being used to predict what is expected after 5G. Now it is considered a theoretical concept that continues in research and is expected to be published in 2030. Some of the improvements predicted for this generation will be higher speed (100 times more than 5G) and lower latency to the point of being in real time. Also, the density will be expanded in conjunction with new services such as the internet of the senses. A current advancement that is expected to advance in the future with B5G is the development of advanced artificial intelligences. Finally, frequencies and sustainability will be expanded.

- **6G**

  The sixth generation of mobile or 6G systems is expected to be the successor to the current 5G. Its approximate launch will be in 2030 and it is expected to use technologies like 5G which is service area that is divided into small geographical areas called cells. Terahertz radiation (300 to 3000 GHz) is expected with a sensitivity greater than 5G in terms of propagation. The advantages of this technology are ultrafast data speed, higher capacity and density, higher frequency usage, advances in applications such as C-V2X.

- **AI for Cellular System**

  In the coming years, artificial intelligence is expected to revolutionize all areas including cellular systems. At this moment it is already beginning to be used in some services to improve the efficiency and performance of mobile networks. Some of the futures for the network in cellular systems are as follows:

- Network Management - Improve network efficiency by predicting and redirecting traffic to optimize.
- Fault Correction - AI can be used to prevent and even minimize network failures.
- Security - AI can be employed to execute security methods in the event of an attack.
- Spectrum management - The spectrum of the network can be managed dynamically and efficiently using the bands that are unoccupied.
- Optimization - Can be used in energy and resource optimization.

Conclusion

This final report on *A Survey for the Fifth Generation Cellular System* provides an analysis of the evolution and current state of mobile networks. It presents a journey through the history of cellular generations from 1G to 4G LTE, discussing their respective statuses. The 5G generation was explored, focused on its market trends and applications, its key technologies were studied, such as Massive MIMO, mmWave and NOMA. In addition, network layer technologies such as software-defined networking, network function virtualization and network slicing were explored. In addition, we analyze the implications of network densification, edge computing, the Internet of Things, and Vehicular Cellular to Everything (C-V2X) for current and future network infrastructures. Looking to the future, B5G and 6G were studied, and the transformative potential of artificial intelligence for the cellular system. The evolution of networks is drastic over the years. At a point where the last generation is hundreds of times faster than when the first one was launched and seeks to continue improving the efficiency of these technologies.

References

D. T. AG, “5G network as foundation for autonomous driving,” www.telekom.com. https://www.telekom.com/en/company/details/5g-network-as-foundation-for-autonomous-driving-561986

“1G,” Wikipedia, Jul. 18, 2021. https://en.wikipedia.org/wiki/1G#:~:text=In%201983%2C%20the%20first%201G

“5G Technology Market Size, Share | Industry Analysis & Overview-2026,” Allied Market Research. https://www.alliedmarketresearch.com/5g-technology-market#:~:text=The%20global%205g%20technology%20market

“The global economic impact of 5G. Powering your tomorrow ATM 2 PwC The global economic impact of 5G.” Available: https://www.pwc.com/gx/en/tmt/5g/global-economic-impact-5g.pdf

“5G and Its Impact on The Internet of Things,” www2.stardust-testing.com. https://www2.stardust-testing.com/en/5g-and-impact-on-iots#:~:text=With%205G%2C%20data-transfer%20speeds

“What Does 5G Mean for IoT?,” Telenor IoT. https://iot.telenor.com/technologies/connectivity/5g/

“10 5G Healthcare use cases,” STL Partners. https://stlpartners.com/articles/digital-health/10-5g-healthcare-use-cases/

“Industrial 5G is coming,” siemens.com Global Website. https://www.siemens.com/global/en/products/automation/industrial-communication/industrial-5g.html (accessed May 13, 2023).

“What Is Massive MIMO?,” www.mathworks.com. https://www.mathworks.com/discovery/massive-mimo.html#:~:text=Massive%20MIMO%20(massive%20multiple-input

“What is mm wave and how does it fit into 5G?,” RCR Wireless News, Aug. 15, 2016. https://www.rcrwireless.com/20160815/featured/mmwave-5g-tag31-tag99

“5G mmWave | Ultra-high throughput and ultra-low latency | Qualcomm,” www.qualcomm.com. https://www.qualcomm.com/research/5g/5g-nr/mmwave (accessed May 13, 2023).

“Non-Orthogonal Multiple Access - an overview | ScienceDirect Topics,” www.sciencedirect.com. https://www.sciencedirect.com/topics/computer-science/non-orthogonal-multiple-access#:~:text=6.1%20Non-orthogonal%20multiple%20access%20(NOMA)&text=The%20capacity%20of%20NOMA%20to (accessed May 13, 2023).

VMWARE, “What is Network Functions Virtualization (NFV)? | VMware Glossary,” VMware, Feb. 24, 2022. https://www.vmware.com/topics/glossary/content/network-functions-virtualization-nfv.html

“Small Cell Densification,” CommScope. https://www.commscope.com/solutions/5g-mobile/small-cell-densification/ (accessed May 13, 2023).

Microsoft, “What Is Edge Computing? | Microsoft Azure,” azure.microsoft.com. https://azure.microsoft.com/en-us/resources/cloud-computing-dictionary/what-is-edge-computing/#:~:text=Edge%20cloud%20computing%20explained

“What is the Internet of Things (IoT)?,” www.oracle.com. https://www.oracle.com/internet-of-things/what-is-

iot/#:~:text=The%20Internet%20of%20Things%20(IoT)%20describes%20the%20network%20of%20physical

5gaa, “C-V2X explained,” 5GAA. https://5gaa.org/c-v2x-explained/#:~:text=Cellular%20Vehicle-to-Everything%2C

“What is Cellular Vehicle to Everything (C-V2X)? - Definition from WhatIs.com,” IoT Agenda. https://www.techtarget.com/iotagenda/definition/Cellular-Vehicle-to-Everything-C-V2X

“Beyond 5G Promotion Consortium,” b5g.jp. https://b5g.jp/en/

“6G (network),” Wikipedia, Oct. 26, 2020. https://en.wikipedia.org/wiki/6G_(network)

mathlab, “AI for Wireless,” www.mathworks.com. https://www.mathworks.com/solutions/wireless-communications/ai.html (accessed May 13, 2023).

“AI for Wireless - IEEE Spectrum,” spectrum.ieee.org. https://spectrum.ieee.org/ai-for-wireless

A. Benjebbour, K. Saito, A. Li, Y. Kishiyama, and T. Nakamura, “Non-orthogonal multiple access (NOMA): Concept, performance evaluation and experimental trials,” IEEE Xplore, Oct. 01, 2015. https://ieeexplore.ieee.org/document/7381343 (accessed May 13, 2023).

T. Fautier, “How 5G Could Evolve Mobile Streaming and Video Delivery,” www.harmonicinc.com. https://www.harmonicinc.com/insights/blog/mobile-streaming/

R. Galazzo, “Timeline from 1G to 5G: A Brief History on Cell Phones,” CENGN, Sep. 21, 2020. https://www.cengn.ca/information-centre/innovation/timeline-from-1g-to-5g-a-brief-history-on-cell-phones/

S. Hakak et al., “Autonomous vehicles in 5G and beyond: A survey,” Vehicular Communications, vol. 39, p. 100551, Feb. 2023, doi: https://doi.org/10.1016/j.vehcom.2022.100551.

Hindawi, “State-of-the-Art Wireless Emerging Technologies for Beyond 5G/B5G Communication,” Hindawi. https://www.hindawi.com/journals/misy/si/259895/

T. Reply, “The importance of 5G for Smart City and the its impact,” Reply. https://www.reply.com/en/telco-and-media/5g-smart-cities

P. Tracy, “What is network densification and why is it needed for 5G?,” RCR Wireless News, Nov. 09, 2016. https://www.rcrwireless.com/20161109/featured/network-densification-5g-tag31-tag99

VMware, “What is Software-Defined Networking (SDN)? | VMware Glossary,” VMware, Dec. 17, 2021. https://www.vmware.com/topics/glossary/content/software-defined-networking.html

D. Varma, “The Impact of 5G Technology on IoT & Smart Cities,” Medium, Mar. 08, 2023. https://pub.towardsai.net/the-impact-of-5g-technology-on-iot-smart-cities-6694d7eb9cf5#:~:text=In%20smart%20cities%2C%205G%20technology (accessed May 13, 2023).

Wikipedia Contributors, “2G,” Wikipedia, Jul. 15, 2019. https://en.wikipedia.org/wiki/2G

Wikipedia Contributors, “3G,” Wikipedia, Sep. 01, 2019. https://en.wikipedia.org/wiki/3G

Wikipedia Contributors, “4G,” Wikipedia, Aug. 28, 2019. https://en.wikipedia.org/wiki/4G

Wikipedia Contributors, “5G network slicing,” Wikipedia, Oct. 12, 2019. https://en.wikipedia.org/wiki/5G_network_slicing

Wikipedia Contributors, “Internet of things,” Wikipedia, Mar. 16, 2019.

https://en.wikipedia.org/wiki/Internet_of_Things