5G Network - General

Daniela Tomás
up202004946@edu.fc.up.pt

Diogo Nunes
up202007895@edu.fc.up.pt

João Veloso
up202005801@edu.fc.up.pt

***Abstract*—Humanity has reached a place where every person needs a fast way to cruise through the internet. 4G was the solution in the plane until 5G came along and delivered new heights of speed, efficiency, and capacity. However, even at these new heights, the internet still feels "slow." Why? Because even with these heights and advantages that 5G presents, we still use 4G and the old top speeds. This means that 5G is not always being used. In this paper, we are providing an overview of the history of cellular communication technology, the current general state of 5G networks, including how they work, advancements compared to 4G, possible and potential applications, and challenges of 5G.**

***Index Terms*—5G networks, heights, applications, deployment, overview**

I. Introduction

The digital world is evolving more with each passing day, driven by an unending hunger for data consumption and on-the-go connectivity. As we are starting to approach the limits of current 4G deployments, the new 5G of cellular connectivity stands ready to take on this monumental task of ever-increasing perpetual online connectivity. Unlike some of its predecessors, 5G isn't just an iterative improvement, as it brings to the table new technologies that have never been utilized by its predecessors while also improving on existing technologies to help deal with the impressive amount of devices and data of current days. This paper will dive into all of this, explaining some of the core functionalities that make all of this possible. This paper will also provide a top-level overview of the previous generations of the technology, with a special focus on comparing it to its predecessor, 4G.

II. Past cellular technologies overview

A. 1G

First deployed in Tokyo, Japan, in 1979, this mostly analog technology had many different standards deployed all throughout the world in the 1980s and was largely superseded in the 1990s by its digital evolution, 2G. This generation supported only audio communications, was limited to a maximum speed of 2.4 kbps and had no security. The name 1G was added retroactively with the launch of 2G.

B. 2G

Introduced in Finland in 1991, 2G switched to all digital and TDMA or CDMA, depending on the specific standard, allowing higher speeds of up to 10 kbps and making more efficient use of the radio frequency, which enabled more users per frequency band, while also implementing new features that would survive until today, like SMS and even e-mail access. 2G also provided some security by having encrypted communications between a mobile device and the cellular base station it connected to, but not necessarily on the remaining infrastructure. There were some different standards, with the most common one being GSM.

C. 2.5G

2.5G is more commonly known as General Packet Radio Service (GPRS), which is an improved 2G system that has a packet switched domain in addition to the normal circuit switched domain. This allowed the data rate to increase to a maximum of 50 kbps.

D. 2.75G

Enhanced Data Rates for GSM Evolution (EDGE) is another evolution of 2G that brought with it higher data rates per radio channel by utilizing 8PSK, which increases gross output threefold, although it is not guaranteed to use this scheme all the time.

E. 3G

Arriving in 2001, this new generation brought with it, once again, a faster data rate of up to 384 kbps but also higher quality audio calls, internet access, and video calling, which would be later improved by subsequent 3.5G and 3.75G technologies. This generation operated under two different standards: UMTS, which was the most widely deployed of the 2, and CDMA2000, which was most notably used in North America. This is also the generation that introduced roaming.

F. 3.5G

High Speed Packet Access (HSPA) was the first iterative evolution of 3G, UMTS in this particular case, that aimed to bring data rates of up to 30 mbits that were possible with the use of QPSK and 16QAM, as well as reduced latency by adding improvements to other areas. HSPA and its contemporary, EV-DO, also mark the switch to a packet-based network, leaving behind the circuit switching technology.

G. 3.75G

Evolved High Speed Packet Access (HSPA+) achieves yet again higher data rates, this time by utilizing 64QAM, as well as adding novelties that are still employed to this day, like beamforming and multiple-input multiple-output (MIMO).

H. LTE

Long-Term Evolution is based on both 2G (GSM) and 3G (UMTS) standards, improves on their capacity and speed, and is presented as an upgrade and replacement for both of these standards. LTE features a maximum data rate of 200 mbps and so falls short of the 4g requirement of at least 1 gbps on the downlink while also respecting a given spectral efficiency, of which it does neither. LTE and its iterations, LTE-Advanced and LTE-Advanced Pro, are fully backwards compatible with each other, which was one of the big focuses of this technology.

I. 4G

LTE-A can be considered the first fully conforming 4G network, featuring a maximum downlink rate of up to 3 gbps and also respecting the defined minimum spectral efficiency.

III. 5G USAGE IN CURRENT TIMES

5G, which started rolling out worldwide in 2019, is projected to serve a quarter of global mobile connections. 5G networks promise to download things faster, have lower latency, provide a better experience for services that depend on them, and better serve densely populated areas. Thanks to these promises, 5G presents interesting applications when it's used:

A. Autonomous vehicles

Previously, fully autonomous vehicles were unattainable due to limited 3G and 4G data transmission capabilities. 5G technology enables speedier transportation systems for vehicles and trains compared to previous generations.

B. Smart factories

5G connections, AI, and ML enable machines to perform routine jobs. 5G technology has the potential to significantly impact how products are delivered to our homes.

C. Smart cities

Cities that are super-connected using 5G network speeds to innovate in areas like law enforcement are becoming real. There are cities that are using 5G-enabled sensors to identify traffic patterns in real time, so the signals are properly adjusted, helping reduce congestion and improve traffic flow.

D. Smart healthcare

Having a 5G network is beneficial as it can save more lives. 5G technology enables a speedier response to crisis calls, perhaps saving more lives, as previously stated. Robotic surgery and high-definition live streams over 5G networks provide further benefits.

All these usages are enhanced by 5G. However, a study case [1] shows that during a download, the set of serving cells switches between 5G cells and 4G cells. Even with the presence of 5G and its clearly better performance over 4G, it is still not used all the time. This just goes to show that all that speed and power that 5G has are not being properly used. But why is this happening?

IV. HOW DOES 5G WORK

Like in previous cellular networks, 5G technology uses cell towers that transmit data via radio waves. Cell towers connect to networks using wireless technology or a wired connection. 5G technology works by modifying the way data is encoded, considerably increasing the number of radio waves usable for operators. To achieve the high speeds that were promised, 5G takes advantage of a whole new band of radio spectrum from 4G in addition to the conventional cellular radio spectrum. These frequencies are broadcast between 30 and 300 GHz, versus the bands below 6 GHz that were used in the past. This frequency range is then divided into three subcategories:

A. Sub-6GHz (Low Band)

5G will operate on the same low frequencies used in 3G/4G because low-band frequencies travel much farther and go through walls, trees, and other obstacles easily. Also, with the use of the old frequencies, carriers did not have to build new towers to blanket areas with 5G coverage. While deployment was easier because the groundwork was already there, it eventually proved to be a disadvantage because the 5G performance was not a lot faster than 4G/LTE (sometimes lower). These lower bands are better suited for higher coverage, making them perfect for areas with a lower population.

B. Sub-6GHz (midband/C-band)

The two last subcategories are extreme opposites of one another. The medium between the ultra-fast but extremely short-range mmWave and the lower-band frequencies offered expansive range but no meaningful improvement in speed over the 4G/LTE networks that 5G is supposed to replace. This mid-band range of frequencies, between 2.5 GHz and 4.7 GHz, has become the sweet spot for 5G. This frequency gives better range than mmWave while delivering near-gigabit performance levels. Middle bands are more suited for cities, leaving room for the creation of smart cities, as shown in Chapter III.

C. mmWave

In order to reduce reliance on the so-called ”beachfront spectrum”, that is, the traditionally used frequency range by 5G´s predecessors, used for its reliable propagation characteristics, 5G adopts the use of the mmWave, a spectrum ranging from 30 GHz to 300 GHz. While some parts of this spectrum can´t be used due to their properties or are already reserved for other uses, 5G will still be able to tap into a considerable chunk of new bandwidth, which will serve to help it fulfill its requirements.

V. Advancements compared to 4G

5G has better speed, coverage, lower latency, and a bigger bandwidth than 4G. 5G also has better capacity and spectral efficiency thanks to the use of improved or new techniques.

A. MU-MIMO

Multi-User MIMO, an improvement on MIMO already used in 4G, allows for multiple users to be allocated to a resource that would previously be only allocated to one, increasing density.

B. Beamforming

Beamforming reduces interference and increases the effectiveness of the transmission by directing the wireless signal towards the target user.

C. Security

In terms of security, when a person connects to a station in 4G, the user identification is verified without encrypting the data, whereas in 5G, the encryption is made for the user identification and position [2]. Network slicing is also an important advancement because of the isolation and protection it gives to sensitive data, which means that even if some slice is compromised, it doesn't affect the other slices.

VI. Possible and Potential Application

The possible and potential applications of 5G technology are vast and diverse. The three main usage scenarios are the following [3], [4]:

A. Enhanced Mobile Broadband (eMBB)

One of the most noticeable and expected effects of 5G technology is in eMBB. 5G provides faster data rates, more bandwidth, and consequently improved performance compared to previous generations, allowing continuous high-resolution multimedia streaming, faster downloads, smoother online gaming experiences, etc. This not only improves the user experience but also opens up opportunities for innovative services and applications that require high data rates, such as virtual reality (VR) and augmented reality (AR).

B. Ultra-Reliable and Low Latency Communications (URLLC)

5G URLLC capabilities are crucial for applications that require ultra-fast real-time responsiveness and high reliability, benefiting applications in a variety of areas such as assisted driving, remote medical, industrial automation, and so on. In contrast to eMBB, URLLC focuses on applications with high mobility and moderate data rates.

C. Massive Machine Type Communications (mMTC)

The concept of mMTC refers to the ability of 5G mobile communication networks to support a large number of Internet of Things (IoT) devices, allowing them to communicate moderate amounts of data over long periods. This has repercussions in various sectors, such as smart cities, healthcare, and manufacturing, among others.

VII. Challenges of 5G

There are numerous challenges that 5G has faced, some of which are broader and apply to 5G as a whole, while others only apply to a subset of its components.

A. Spectrum Availability

The frequency spectrum is an inherently finite resource, one that is also currently saturated. To overcome this particular challenge, 5G will not only use the traditionally used bands, located between 300 MHz and 3 GHz [5], but will also be deployed on higher frequencies that are currently not saturated.

B. Security

As is paramount in any sort of modern communication technology, security will always be a major concern, and as such, 5G will face challenges in order to mitigate attacks such as eavesdropping in order to preserve customer security and privacy.

C. Access Mode

5G presents 2 major deployment modes, StandAlone (SA) and Not-StandAlone (NSA), each with a different subset of options with varying capacities, features, and costs [6], and it will be up to each operator to choose what they think is best for each scenario.

D. Device-to-Device communication

This particular part of 5G will allow multiple devices to talk directly with each other with minimal or no involvement from the network infrastructure. A major concern with this type of communication is security, and from the operator's perspective, pricing is also a major concern due to the very fact that there is almost no supervision [7].

VIII. Conclusion

Mobile communications technology has evolved and will continue to do so in the foreseeable future. 5G represents a big evolution in mobile communications technology, enabling more use cases, higher data rates, higher efficiency, and a better perceived quality of service.

In this paper, we went over some of the improvements of 5G in comparison to previous iterations, how it works, exploring its advancements, some of its new features, and design and implementation challenges.

References

[1] Y. Liu and C. Peng. A close look at 5g in the wild: Unrealized potentials and implications. In *IEEE INFOCOM 2023 - IEEE Conference on Computer Communications*, pages 1–10, 2023.

[2] Vaishnavi Bande, Sukanya Dhavle, and Shubhalaxmi Joshi. Comparative study of security architecture of 5g with 4g. *Vidhyayana-An International Multidisciplinary Peer-Reviewed E-Journal-ISSN 2454-8596*, 8(si7):361–377, 2023.

[3] Olaonipekun Oluwafemi Erunkulu, Adamu Murtala Zungeru, Caspar K Lebekwe, Modisa Mosalaosi, and Joseph M Chuma. 5g mobile communication applications: A survey and comparison of use cases. *IEEE Access*, 9:97251–97295, 2021.

[4] Mansoor Shafi, Andreas F. Molisch, Peter J. Smith, Thomas Haustein, Peiying Zhu, Prasan De Silva, Fredrik Tufvesson, Anass Benjebbour, and Gerhard Wunder. 5g: A tutorial overview of standards, trials, challenges, deployment, and practice. *IEEE Journal on Selected Areas in Communications*, 35(6):1201–1221, 2017.

[5] Zhouyue Pi and Farooq Khan. An introduction to millimeter-wave mobile broadband systems. *IEEE Communications Magazine*, 49(6):101–107, 2011.

[6] Hind Fehmi, Meryem Fakhouri Amr, Ayoub Bahnasse, and Mohamed Talea. 5g network: Analysis and compare 5g nsa /5g sa. *Procedia Computer Science*, 203:594–598, 2022. 17th International Conference on Future Networks and Communications / 19th International Conference on Mobile Systems and Pervasive Computing / 12th International Conference on Sustainable Energy Information Technology (FNC/MobiSPC/SEIT 2022), August 9-11, 2022, Niagara Falls, Ontario, Canada.

[7] Mohsen Nader Tehrani, Murat Uysal, and Halim Yanikomeroglu. Device-to-device communication in 5g cellular networks: challenges, solutions, and future directions. *IEEE Communications Magazine*, 52(5):86–92, 2014.