The Evolution of 5G into 5G Advanced

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Abstract

The fifth generation (5G) network is making its presence known globally as it is emerging rapidly to become the mobile telecommunications network for a growing number of devices. The full 5G system is still young and developing, but technology and digitization are constantly charging ahead, introducing new use cases and applications in addition to having mroe and more devices within a single network. These new use cases require a network that can handle heavy traffic loads and maintain ultra-low latency. 5G Advanced is underway as part of the evolution of 5G. 5G Advanced is set to enhance all existing features of the current 5G network which includes the ability to control network congestion, accurate positioning, and low latency maintenance. 5G Advanced will use artificial intelligence and machine learning (AI/ML) techniques to improve the accuracy and precision of the network by using existing 5G data to create models and train them with real-time, accurate data. Applying AI/ML is a step in the direction of the future, as AI/ML are being grounded within the digital revolution of gearing the world toward different realities such as extended reality (XR), virtual reality (VR), and cloud gaming. These applications are fine-tuned and require networks with close to optimal performance. This is where 5G Advanced as a directed path toward the sixth generation (6G) of mobile telecommunications networks, by providing performance metrics that satisfy the ever-growing and increasingly demanding use cases.

Keywords: 5G Advanced, 5G evolution, 3GPP Release 18, 5G New Radio, MIMO, artificial intelligence, machine learning, IoT, extended reality

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1 Introduction

Wireless communication technologies are in the fifth generation (5G) with futuristic thinking toward what the sixth generation (6G) will look like. The development of wireless communication technology has been underway since the 1980s, starting with the first generation (1G) of mobile networks and now approaching 6G. The 5G network was first deployed in 2019 and it has rapidly become more prominent in a very short amount of time. The development and use of 5G networks globally have introduced areas in which the mobile communication standard can be enhanced, which brings the concept of 5G Advanced. While 5G brought better performance, efficient technology, and a smoother user experience that surpassed that of the generations before it, 5G Advanced aims to augment these features. With the use of technology such as massive MIMO, massive Machine-Type Communication (MTC), and Ultra-Reliable Low-Latency Communication (URLLC), the existing 5G network that is proliferating globally will be even further enhanced. This will allow for more advanced and involved applications such as extended reality (XR) and IoT communication. The existing 5G network provides a foundation for 5G Advanced, both of which will provide the infrastructure for 6G. Research into the next generation is already heavily underway and the improvements made in 5G Advanced will be important to building a depdendable and well-performing network for global use.

1.1 5G Overview

Work on 5G commenced in the late 2000s and was later deployed in 2019, transforming the wireless telecommunications industry today. 5G has far better performance than its predecessor and has kickstarted the eventual influence on the "Big Data" industry through the Internet of Things (IoT) while touching areas related to AI/ML. The goal of the 5G network is to support the enormous amount of mobile network traffic that the fourth generation (4G) is not scaled to handle. Every year, there are more and more devices that need a mobile wireless connection which causes traffic in the network, requiring it to be largely scalable. 5G brings new capabilities such as lower latency, introducing Gigabit speeds, and performance improvements are also made to lower network congestion. 5G is still relatively young and emerging to become ever-more present in the lives and smartphones of people globally. Even though it is still largely being researched and developed, discoveries are being made to contribute to the next level of 5G, which is 5G Advanced.

1.2 5G to 5G Advanced

5G Advanced is an enhancement of the 5G network. Nokia, one of the leading telecommunications companies, claims that 5G Advanced will be the culmination of the rich capabilities existing in the current 5G network [Nokia2022]. Additionally, the 5G Advanced network will be able to support demanding applications and a broad range of use cases [Nokia2022]. One application that has string network performance requirements is extended reality (XR) which 5G Advanced aims to support. 5G Advanced is also geared toward IoT devices as well as AI/ML applications. Research and development on 5G Advanced is currently underway and is predicted to start rolling out in 2025 [HSST2021]. Overall, 5G Advanced incorporates more intelligence, better performance, and efficiency into the current 5G network.

1.3 3GPP Standards for 5G and Beyond

The 3rd Generation Partnership Project (3GPP) is an organization that develops standards for mobile telecommunications. These standardizations come in the form of "Releases" where new features, upgrades, or technology are introduced and iterated on in subsequent releases. As defined by the 3GPP organization: "3GPP uses a system of parallel 'Releases' which provide developers with a stable platform for the implementation of features at a given point and then allow for the addition of new functionality for subsequent Releases" [3GPP2022]. 3GPP is made up of seven organizations in the telecommunications standards field. These organizations all work together to provide reports and specifications on 3GPP technologies which include 3G, 4G, 5G, and now a recent release of 5G Advanced. 3GPP's Release 15 introduced the 5G mobile communication network, building off that of 4G and Long-Term Evolution (LTE) networks. Release 15 includes the first complete definition of 5G standards and with it came an introduction of an air interface for mobile telecommunications called New Radio (NR) [3GPP2022]. Releases 16 and 17 build off this interface studied in Release 15 that provide the foundation for 5G technology. Release 16 improves the 5G network and brings to completion the development of the 5G system as a whole. Release 17 builds off the enhancements made in Release 16 and makes futuristic developments to evolve 5G towards 5G Advanced [3GPP2022]. Finally, 3GPP's Release 18 is the most recent release that is still in its research and development phase and is the harbinger for the start of 5G Advanced [Rahman2022]. A timeline of what critical features will be developed per each release in terms of 5G is displayed in Figure 1 below:

Figure 1: A timeline of the 5G evolution into 6G per each 3GPP Release [draw.io]

Studies and specifications are in development to support the release of 5G Advanced as part of 3GPP protocols. As defined by 3GPP, the goals of 5G Advanced are enhanced Mobile Broadband (eMBB) driven work, non-eMBB driven functionality, and cross-functionality for both eMBB and non-eMBB [3GPP2022]. These are the high-level goals of the 3GPP standards project for Release 18, which is otherwise known as the beginning of 5G Advanced.

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2 5G Advanced Features

As mentioned, the primary demand for 5G spurs from the heavy traffic load which is exacerbated by the IoT applications that have extreme deployment densities which will increase disruption and cause higher congestion within the network [Henry2020]. A few additional goals for 5G Advanced made in 3GPP Release 18 are outlined in Figure 2 below:

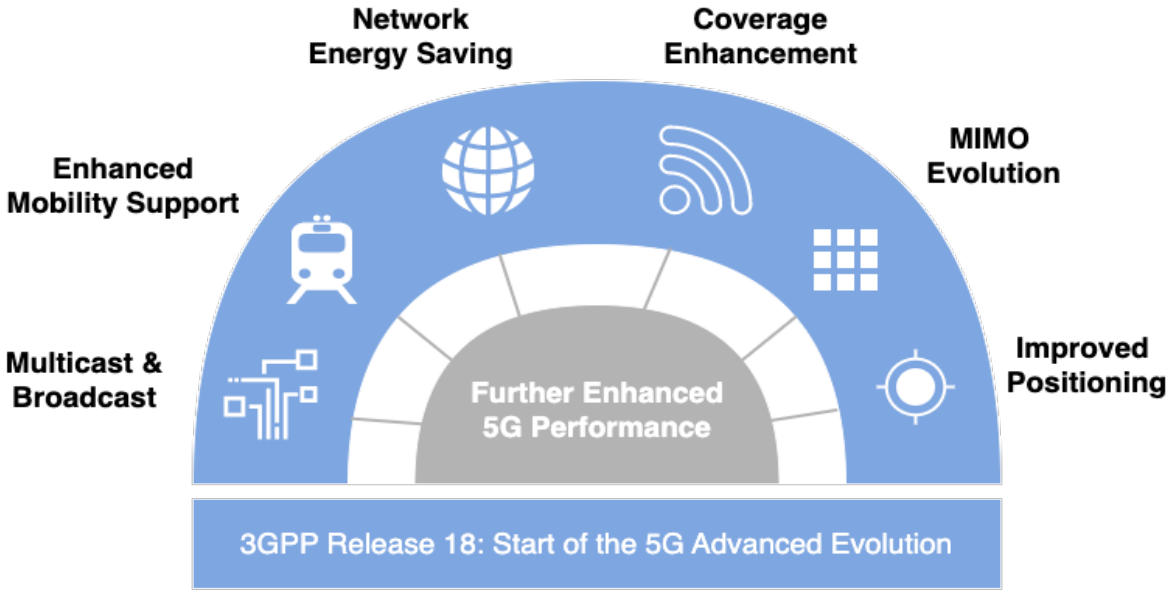

Figure 2: 5G Advanced features detailed by 3GPP Release 18 [draw.io]

Some of the requirements for 5G included enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communications (URLLC), and massive Machine-Type Communication (mMTC). 3GPP defined standards for what is termed 5G New Radio (NR) to accomplish these goals and in the future have a role in IoT devices. The goals of 5G Advanced are to extend and enhance the features of 5G NR included eMBB, URLLC, and mMTC [Chen2022].

2.1 5G New Radio (NR)

5G NR was standardized by 3GPP as a new air interface for the 5G network. Qualcomm, one of the leading wireless technology companies, defines 5G NR as a unified and more capable air interface based on orthogonal frequency division multiplexing (OFDM) [Qualcomm2020]. 5G NR was initially considered in 3GPP Release 15 which built the standard for 5G. 5G NR is a radio access technology (RAT) that is the successor of 4G and LTE. The goals for 5G NR in Release 15 and subsequent releases are laid out in Figure 3 below:

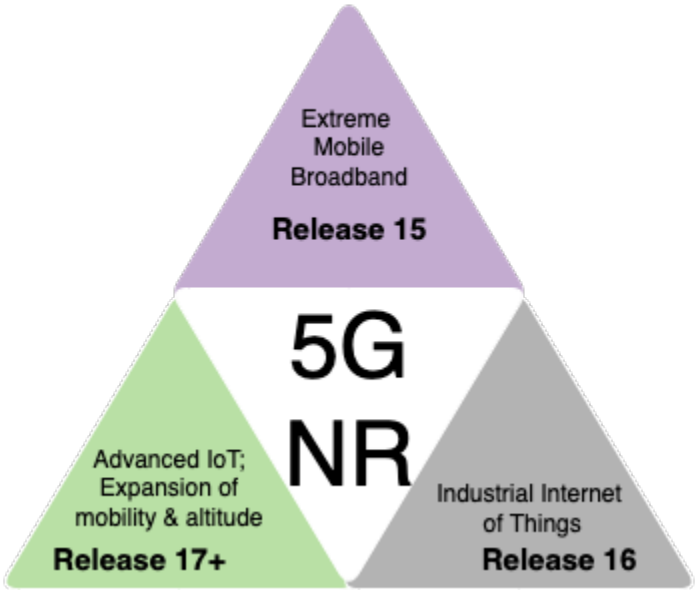

Figure 3: Evolution of 5G NR through successive 3GPP Releases [draw.io]

5G technology adopts NR as an air interface RAT design based on the frameworks of LTE OFDM and multiple input multiple out (MIMO) technology [Tang2021]. The beginning of 5G defined in Release 15 includes in the 5G Core (5GC) network and 5G NR. The 5GC network is the architecture of the 5G network which includes functionality and performance. The combination of 5GC and 5G NR makes up the foundation of 5G Advanced. With functionality and features laid out in the 5GC network and the 5G NR air interface, 5G Advanced is set up to enhance almost every aspect of the existing 5G network. The initial rollout of 5G NR in Release 15 included non-standalone (NSA) NR, which leveraged the 4G/LTE network to build the air interface. NSA infrastructure refers to how the air interface utilizes the controls of the former 4G/LTE network. In this structure, 5G NR is strictly resourced for the user plane while 4G/LTE networks manage the control plane. After subsequent iterations and entrance into 5G Advanced architecture, there is standalone (NR), which utilizes 5GC instead of the 4G/LTE network. This allows for full dependence on the 5G network as compared to having some dependence on the preceding network.

2.2 Enhanced Mobile Broadband (eMBB)

Enhanced Mobile Broadband services are to support high-throughput networks. The 5G network needs to maintain high throughput in order to target the enormous amount of traffic that the 4G and LTE networks could not handle. There is a growing number of devices trying to connect within a small area which leads to very large amounts of traffic within the network by allowing more devices to be connected at once within a small area. The term "broadband" is used to describe wireless transmissions with high throughput or large bandwidth. "Mobile broadband" therefore refers to the wireless transmissions among mobile devices. eMBB is one of the primary features of 5G and 5G Advanced as the evolution of the network and growing number of devices demands a boost in the content distribution capabilities [Abdullah2021]. One classic tradeoff that often occurs with higher throughput is higher latency. That is, to acheive many devices or requests within a network, the speed or latency of the network will need to be sacrificed. This is easily explained in that having a larger number of devices will require a longer amount of time to respond to a

request, whereas having a smaller number of devices will allow for a faster response time. The aim of 5G Advanced is to have eMBB to achieve high throughput while also maintaining low latency or a fast-speed network.

2.3 Ultra-Reliable Low-Latency Communication (URLLC)

Ultra-Reliable Low-Latency Communications (URLLC) is a feature introduced by the 5G network and is one that differentiates the network from its predecessors. It is argued to be one of the most innovative features of the 5G network [Popovski2018]. URLLC has many utilizations and applications such a mission-critical communications, which are messages sent or received that have high urgency such as remote actions and coordination in vehicles [Popovski2018]. The research and studies done on URLLC support its potential for enhancing the 5G network in 5G Advanced to support applications related to AI/ML and XR. A few current applications URLLC include IoT, Internet of Vehicles (IoV), telemedicine communication, and mission-critical messages [Huang2022]. These applications require that communication is reliable, meaning that messages sent are received within a strict timeframe [Huang2022]. URLLC supports the enhancement of 5G into 5G Advanced due to its strict requirements to create a dependable network within a timeframe. The enhancements of 5G that are to be addressed by 5G Advanced include reliability, capacity or throughput, and latency constraints, among others.

2.4 Massive Machine-Type Communication (mMTC)

Machine-Type Communication (MTC) has played a critical role in the digital evolution of wireless networks. MTC is an adjunct of IoT in that it refers to the communication of devices not operated by humans such as sensors and actuators [Sachs2016]. MTC is a supportive infrastructure for IoT technology and directly correlates with the goals of 5G Advanced in support IoT. 5G NR supports MTC and yet there are still more demanding requirements continually being introduced which are exceeding the ability of the 5G network and increasing the need for 5G Advanced [Mahmood2020]. 5G Advanced will implement massive MTC (mMTC) which will provide support for more demanding requirements to be met while under strict standards and guidelines. MTC is essential for the emerging IoT technologies because it will allow Machine-Type Devices (MTDs) within IoT, to connect without the need for human intervention [Mahmood2020]. 5G Advanced will enhance the existing MTC infrastructure that is currently implemented in the 5G network by including mMTC. Massive MATC is a new service offered by 5G that will support extremely high connection density for online devices [EPRS2019]. That is, MTC supports some number of communication devices within the network and mMTC will allow for even more devices to communicate within the network. This addresses the growing congestion within the network made by an increasing number of IoT devices [EPRS2019].

2.5 Improved Massive MIMO (mMIMO)

MIMO refers to the number of transmitter and receiver antennas in a wireless system. MIMO inherently has more than one transmitting and receiving antenna. Massive MIMO is implemented in the current 5G network where the massive descriptor refers to the number of antennas at the transmitter and receiver. The number of antennas in a massive MIMO system is orders of magnitude larger than a system that implements standard MIMO [Adnan2016]. The benefits of

massive MIMO are larger capacity, energy efficiency, and lower cost and power consumption [Adnan2016]. Massive MIMO is an enhancement to MIMO, where both improve performance by increasing the number of antennas over having single input and single output systems that are not able to scale nor handle a large amount of traffic. Massive MIMO is known to be one of the key technologies implmented in the 5G network. Looking ahead to 5G Advanced, improved massive MIMO will be addressed. Bell Labs Institute states: "Significant capacity increase can be expected using mid-band spectrum combined with extreme MIMO antenna arrays at base stations with up to 1024 elements and larger antenna arrays at the terminals" [Holma2021]. One of the enhancements made on the current 5G network present in 5G Advanced is far greater capacity. Having "extreme MIMO," that is, improved massive MIMO, will allow for these capacity goals to be met, allowing for higher throughput while maintaining low latencies and thereby resulting in an efficient system.

2.6 Accurate Positioning

The accuracy of locating a device is becoming ever-more important as new applications and use cases for mobile telecommunication networks are emerging. For example, smart vehicles are becoming more intelligent, thereby increasing the importance of having accurate positioning within a mobile network. Location-Based Services (LBS) are becoming more prevalent to support the rapid development of IoT, cloud computing, and intelligent devices [Mogyorosi2022]. With 5G Advanced applying machine learning techniques to the network scheme, more accurate positioning can be attained. In order to offer LBS, accurate timing and positioning is important. That is, 5G Advanced networks will be able to locate user devices more efficiently with greater accuracy. The architecture of 5G positioning includes a Radio Access Network (RAN) and multi-RAT in addition to cloud-based technology to locate User Equipment (UE) such as mobile devices in relation to base stations (BSs) [Mogyorosi2022]. Considering that 5G Advanced will enhance the NR RAT, the positioning architecture in turn will be more refined.

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3 5G Advanced Performance & Use Cases

5G Advanced will enhance network performance and thereby provide new avenues for building new applications and evolving existing ones. Namely, 5G Advanced will add support to applications that require high data rates, large throughput, and low latency. Additionally, 5G Advanced will utilize AI/ML using data from the existing 5G network to apply to these complex use cases such as multiple IoT device communication and private business networks. With features such as massive Machine-Type Communication, IoT devices have unbounded potential where they can utilize the network and not have to rely on programming by humans. Additionally, the complexity of the 5G Advanced network will require an entirely reformed security infrastructure to fend against a growing number of threats.

3.1 Artificial Intelligence & Machine Learning (AI/ML)

The key features of 5G Advanced will include intelligent network automation. This requires the use of artificial intelligence and machine learning, two connected fields that are gaining momentum in the digital world and will soon touch all areas of technology. Ericsson, a leading

wireless communications company, states, "Artificial intelligence (AI) and machine learning (ML) have the capability to solve complex and unstructured network problems by using a large amount of data collected from wireless networks. Thus, there has been a lot of attention lately on utilizing AI/ML-based solutions to improve network performance and hence providing avenues for inserting intelligence in network operations" [Rahman2022]. By using AI/ML in networking technology, there is potential for more accuracy and precision by using various modeling techniques and large quantities of data to build ML models. It is predicted that the 5G Advanced network will support the ML model life-cycle management that is used to improve the correctness of models, for example [Rahman2022]. The 5G Advanced network will be the foundation for building an architecture of data and analytics for AI/ML-based networking models and will help further support the growing number of complex use cases [Rahman2022].

3.2 Internet of Things (IoT)

IoT technology has a large impact on various industries. By introducing smart devices, such as home automation devices, wearable technologies, and transportation, among others, IoT is gaining momentum and has unbounded potential to influence all areas of human life and technology. While 5G is already "capable of linking thousands of Internet-enabled devices, including smartphones, sensors, and IoT devices, and handles multiple high-demand applications at once," 5G Advanced will enhance these capabilities [Raturi2022]. This means 5G Advanced will be able to link even more devices, as given by eMBB and will handle more and more high-demand applicatins. 5G Advanced will support IoT devices with higher throughput and lower latency which allows for more devices to be connected within a fast network. This will limit communication delays among devices and increase the quality of devices for better use and functionality.

3.3 Extended Reality (XR)

Extended reality (XR) includes virtual reality (VR), augmented reality (AR), mixed reality (MR), and cloud gaming (CG), among others. This application requires extremely high data rates for an immersive experience that includes 360A0 streaming, meaning when the user has a complete view at every possible angle. Better quality streaming requires even higher data rates. The current 5G network cannot support high quality streaming and advanced versions of VR that are continually being developed. This is where 5G Advanced will make an impact since VR is evolving within the digital era and technological development. Nokia claims, "5G Advanced will offer users a superior XR experience while on the move, truly enabling a high-data-rate experience. It requires high data rates with strictly bounded latency constraints as well as a high degree of application awareness" [Nokia2022]. The 3GPP Release 18 is currently being iterated on and studying the network characteristics specific to XR and how 5G Advanced will cater to these characteristics. Additionally, 5G Advanced will have better timing and positioning which will aid the implementation and quality of XR applications.

3.4 Secure 5G Advanced Networks

It is no doubt that wireless networks are particularly vulnerable to security threats. The emergence of an overwhelming amount of IoT devices within the 5G network brings a need for a secure infrastructure to manage communication. Additionally, the prevalence of IoT devices within

wireless mobile networks brings new security challenges to be addressed to meet the demands of new types of devices. 5G and 5G Advanced networks require high data rates and extremely low latencies which puts stringent requirements on building a secure network. Additionally, with the increasing number of devices bringing heavy traffic and high demand, there is higher susceptibility to security vulnerabilities. Massive MIMO, a key component of 5G Advanced, brings its own set of challenges in relation to maintaining a secure network. The idea behind massive MIMO is that a base station is equipped with many antenna elements that can serve a large number of client terminals [Ahmad2019]. The specific security vulnerabilities this setup brings are passive eavesdropping and active eavesdropping [Ahmad2019]. Passive eavesdropping is where the attacker tries to intercept the already transmitted signals while active eavesdropping is where the attacker sends malicious signals as if they were uncorrupted. Some solutions to these vulnerabilities include transmitting random pilots to detect active eavesdropping or maintaining cooperative base stations that exchange information to achieve an estimate on the level of active eavesdroppers. This is a single example of how the features of the 5G Advanced network bring their own set of security vulnerabilities. Looking ahead, there is discussion of ways to build an entirely new security infrastructure in the form of AI-based security, automated security, and even the role of blockchain in security [Ahmad2019]. The influx of data brought by the increasing number of connected devices will require proactive, self-aware, and intelligent security systems in place which brings the need for AI-based security. Instead of reacting to security threats after they have already occurred, the AI-based security approach will be proactive in helping to predict security threats and mitigating them before they occur. AI-based security can be utilized for the massive amount of data that has been accumulated within the wireless network in terms of security. From AI-based security comes an automated security network which addresses the increasing complexity of the security infrastructure within wireless mobile networks. The increasing complexity of networks such as 5G Advanced brings more room for error which exposes this need for automated protocols.

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4 Conclusion

5G Advanced is still emerging and is currently being studied and researched as part of 3GPP Release 18. 5G Advanced could be considered the steppingstone between the current 5G network and 6G. 5G Advanced provides enhancements to what the standard 5G network provides such as enhanced Mobile Broadband, Machine-Type Communication, and greater support for IoT devices and technology. Additionally, 5G Advanced incorporates artificial intelligence and machine learning concepts in order to improve performance within the network. This allows for better support for IoT devices as well as extended reality, which will put a lot of load on the network and less load on the device itself. 5G Advanced is built to handle a great load with a large throughput while maintaining low latency, higher accuracy and precision, and energy efficiency.

Acronyms

- 3GPP: 3rd Generation Partnership Project
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- 5G: Fifth Generation
- 5GC: 5G Core
- AI: Artificial Intelligence
- AR: Augmented Reality
- BS: Base Station
- CG: Cloud Gaming
- eMBB: Enhanced Mobile Broadband
- IoT: Internet of Things
- LTE: Long Term evolution
- ML: Machine Learning
- MTC: Machine-Type Communication
- MTD: Machine-Type Device
- mMTC: Massive Machine-Type Communication
- mMIMO: Massive Multiple Input Multiple Output
- MIMO: Multiple Input Multiple Output
- OFDM: Orthogonal Frequency Division Multiplexing
- RAN: Radio Access Network
- RAT: Radio Access Technology
- UE: User Equipment
- URLLC: Ultra-Reliable Low-Latency Communication
- VR: Virtual Reality
- XR: Extended Reality

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