Gradual Increase in Bandwidth Allocation for HARQ Retransmissions for URLLC in 5G

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DECLARATION OF AUTHORSHIP

This is to certify that this thesis titled, **GRADUAL INCREASE IN BANDWIDTH ALLOCATION FOR HARQ RETRANSMISSIONS FOR URLLC IN 5G,** is supervised by Prof. Dr. Mohammad Tawhid Kawser and it is our original work which has been done for the partial fulfillment of the Bachelor of Science in Electrical and Electronic Engineering at the university. Any material reproduced in this project has been properly acknowledged.

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LIST OF ABBREVIATIONS

3GPP	Third-generation partnership project
5G	Fifth Generation of Mobile Communications
ACM	Automatic Repeat Request
ACK	Acknowledgment (in ARQ protocols)
ACS	Adjacent Channel Selectivity
ARQ	Automatic Repeat-Request
AS	Access stratum
CA	Carrier aggregation
CB	Code Block
CP	Cyclic prefix
CSI	Channel State Information
CB	Code Block
D2D	Device-to-device
DCCH	Dedicated control channel
DCH	Dedicated channel
DL	Downlink
DL-SCH	Downlink-shared-channel
DRX	Discontinuous reception
EMBB	Enhanced Mobile Broadband
eMTC	Enhanced machine-type communication
eNB	Evolved NodeB
EPC	Evolved packet core
EPS	Evolved packet system
EVM	Error vector magnitude
FEC	Forward error correction
FER	Frame error rate
HARQ	Hybrid ARQ
IEEE	Institute of Electrical and Electronics Engineers
LAN	Local area network
LDPC	Low-density parity check code
LTE	Long-term evolution
MAC	Medium access control

MBB	Mobile broadband
MC	Multi-carrier
MCH	Multicast channel
MCS	Modulation and coding scheme
MIB	Master information block
NACK	Negative Acknowledgment (in ARQ protocols)
NAS	Non-access stratum
NFV	Network Function Virtualization
NR	New Radio
PBCH	Physical broadcast channel
PCCH	Paging control channel
PCH	Paging channel
PDCCH	Physical downlink control channel
PDSCH	Physical downlink shared channel
PDN	Packet data network
PHY	Physical layer
PRACH	Physical random access channel
PRB	Physical resource block
PUCCH	Physical uplink control channel
PUSCH	Physical uplink shared channel
QAM	Quadrature amplitude modulation
QoS	Quality-of-service
QPSK	Quadrature phase-shift keying
RAN	Radio-access network
RAT	Radio-access technology
RB	Resource block
RE	Resource element
RLC	Radio link control
RRC	Radio-resource control
RTT	Round Trip Time
RV	Redundancy Version
RX	Receiver
SDN	Software Defined Network
SIB	System Information Block
SINR	Signal-to-Interference-and-Noise Ratio
TB	Transport Block

TTI	Transmission Time Interval
TX	Transmitter
UE	User Equipment (3GPP name for the mobile terminal)
UL	Uplink
UL-SCH	Uplink Shared Channel
UMTS	Universal Mobile Telecommunications System
URLLC	Ultra-Reliable Low-Latency Communication

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ABSTRACT

There has been a myriad of research investigations on the ways through which network connectivity can be made swifter, and the enrollment of 5G over the whole wide world was intended to achieve just that, to make consumer services much more reliable, and achieving fleeting data rates. The promising service category of 5G, popularly known as URLLC, is devoted to provide users with the staunchest fail-safe connections, in the splits of a second. Despite the propositions being highly auspicious, it's not an easy job to provide relentless coverage when the communications being conducted over the link is over interspaces of thousands of miles. Every time there occurs a drop within the channel during the dispatch of packets, Hybrid ARQ, the featurette protocol supported in 5G NR, sends back a repeat request, ceasing the firm connection, and holding off till the accurate information bit is recognized, with the sacrifice of targeted speed limits. In this thesis, the requirements of the continual HARQ retransmissions was reduced to better secure the system reliability, by tweaking the system Bandwidth and other congruent parameters through a befitting margin and creating a suitable framework to optimally alleviate the transmission delay. Performance analysis through Frame error rates and a few other metrics is accomplished for a varying number of SNR and modulation schemes. Escalation of the system throughput and curbing of the Frame error rates successfully validate our proposal. Our research is expected to be a beacon for future revolutions to bring forth the stringent demands of URLLC services. The findings imply that a stable ultra-fast 5G link with top-notch performance may be created implementing the strategies stated.

CHAPTER 1
INTRODUCTION

1.1 Introduction

The fifth generation (5G) communications systems should be able to deliver global services, according to the goal of the Next Generation Mobile Networks (NGMN) alliance. 5G is specifically designed for increasing demands of technical trends and large growth of data along with technical advancements. Real time applications are one of the major parts of tech revolutions and creating a constant impact, like: IOT, IOE, V2X etc. In order to make real time application much faster and efficient the reliability and latency of the system are two major factors.

In the following research we took and approach to make the overall 5G URLLC system more efficient and reliable, at the same time improving the HARQ retransmission method to decrease the overall latency.

1.2 Historical Background

The road to the fifth generation has been paved with numerous advancements and standardizations, as each release has provided a solution for providing a better service and meeting the needs. Today, corporate meetings, university online courses, and long-distance travel are commonplace. 5G is specifically designed for the increasing demands of technical trends and large growth in data with an amazing data speed of 20gbs. It has lower latency, uniform data rates and lesser cost per bit. This 5G era is believed to lead to a revolution in IoT applications as well. 5G offers a significant reduction in latency, making it ideal for a whole new set of services[1]. It is anticipated that the fifth-generation (5G) cellular network will serve a number of future mission-critical services, including industrial automation, cloud robotics, and safety-important vehicle communications.

1.2.1 Earlier Research

Mobility and globalization were the first goals of communications. New architecture has emerged as a direct result of LTE's System Architecture Evolution (SAE) and Radio Port (RP). Standardization of Long Term Evolution (LTE) started in 2004, and RELEASE 8 was completed in June 2005 with changes. Important LTE Release 8 Features: Reduced Connection Establishment and Transmission Delays; Increased throughput of User data; Increased Cell-EDGE bitrate; Reduced cost per bit implies enhanced spectral efficiency; Streamlined network design; The use of several Radio-Access technologies to provide continuous mobility[2]; power consumption suitable for mobile devices, etc. These elements led to the progress of radio technology.

The radio interface of the fourth-generation radio technology interface system was created using multi-carrier, MIMO multiple antenna technology, and packet switching[3]. As a result of the extraordinary efforts of a greater number of organizations. In December 2007, the requirements for Release 8 were completed. Around the end of 2009, the first commercial rollout of LTE in northern Europe occurred. In 2011, 2012, 2013, and 2016, Release 10, 11, 12, 13 of advanced LTE targeted Multi cell HSDPA, HETNET, Coordinated Multipoint, Carrier Aggregation, and massive MIMO.

The moment has come to transition from a services paradigm to a multiservice architecture. The transition from LTE to LTE Advanced will include the development of pervasive networks in which users can connect to many wireless access technologies simultaneously and effortlessly switch between them[4].

This method is utilized to deliver high data transfer rates over a large area within a cell. Cognitive radio technology would enable user equipment to study its surrounding radio environment and choose the ideal Radio Access Network, modulation scheme, and other characteristics for the best connection and performance. Smart Antennas will be redirected to maximize the user's connection. In addition, 5G will utilize both wireless and optical technologies. Software Network Functions Virtualization (NFV) and Software-Defined Networking (SDN), the Internet of Things (IoT), the Internet of Everything (IoE), and Mobile Content Delivery Networks will power 5G. (CDN).

5G (Fifth Generation Mobile and Wireless Networks) is an unrestricted wireless link that will provide the entire world with access to the World Wide Web (WWW). 5G is the next significant phase of mobile telecommunications technologies, following 4G/IMT-Advanced. 5G is not an official word for any particular specification, nor is it used in any published official document by telecommunications corporations or standardization groups such as 3GPP, WiMAX Forum, or ITU-R. Each subsequent release will significantly improve system performance and include additional application-specific features. Several other applications that benefit from mobile connectivity include home automation, intelligent transportation, security, and e-books. Institute of Electrical and Electronics Engineers has approved the IEEE 802.16 family of Wireless Broadband standards (IEEE). WiMAX has been marketed by the WiMAX Forum's industry collaboration (short for "Worldwide Interoperability for Microwave Access"). IEEE 802.16 standardizes the air interface and associated wireless local loop operations[5]. 5G mobile technology has altered the utilization of extremely high-bandwidth mobile phones. User has never before encountered such a valuable technology. 5G technologies will be the most powerful and in great demand in the near future as a result of their incorporation of several new characteristics. Bluetooth technology and Pico nets are currently accessible for children's rocking fun. Users can connect their 5G mobile phones to their laptops to gain Internet access via a broadband connection. The 5G technology includes a camera, an 8 MP3 recorder, a video player, an enormous phone memory, rapid calling, an audio player, and much more. A user terminal and numerous autonomous, independent RAT compose the fifth-generation Network Architecture[6]. 5G mobile system is an interoperability idea for IP-only wireless and mobile networks.

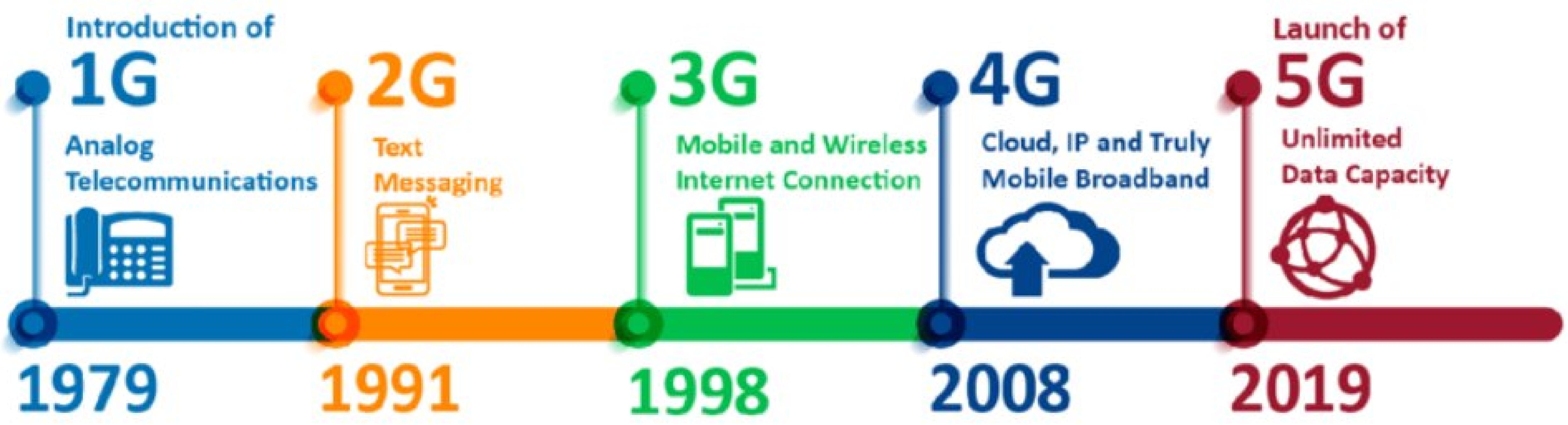

Figure 1.1 Evolution of Communication Technology over Five Generations[7]

Each terminal's radio access technology serves as the IP connection to the Internet's exterior. Availability of bandwidth was emphasized when assessing the LTE issue. In addition, the project aimed to enable ubiquitous connectivity that would provide users with rapid and adaptable Internet access whether they are on land, sea, or in the air. The LTE standard incorporates the Machine Type 10 Communications (MTC) version for the Internet of Things. 5G technologies are designed to accommodate MTC-like devices from the ground up[8]. Regarding new technologies, nearly all previous technologies are necessary for the most recent versions. The 5G network would include 2G, 3G, LTE, LTE-A, Wi-Fi, and M2M. Among the applications that 5G will likely be able to serve are the Internet of Things, augmented reality for HD streaming, connected wearables, and immersive gaming.

In addition, 5G will be able to manage a vast number of interconnected devices and diverse sorts of traffic. 5G will offer significantly quicker connections for streaming HD video and low data rates for sensor networks[9].

1.2.2 Recent Research

5G networks would leverage new architectures, such as Radio Access Networks (RAN) categories such as cloud RAN and virtual RAN, to establish a more centralized network and optimize server farms through the usage of localized data centers at network edges[10].

5G would utilize cognitive radio techniques to enable the infrastructure to autonomously pick the type of channel being sent, differentiate between moving and stationary objects, and quickly adapt to the environment. In other words, 5G networks would concurrently handle industrial network applications and social network applications[11].

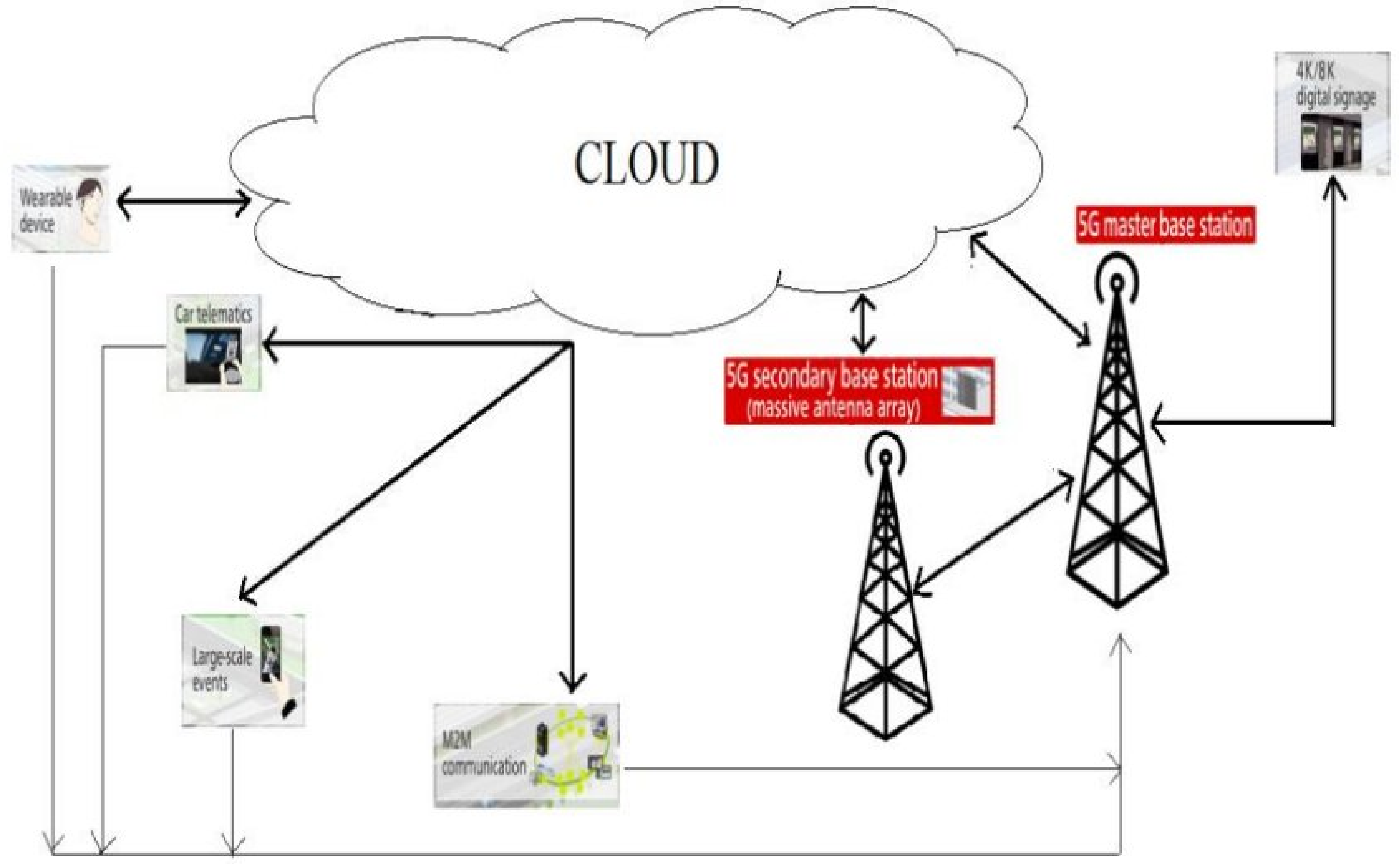

Figure 1.2 5G Cloud Network Architecture[11]

1.2.3 State of the Art Technology

Using Ultra-Reliable Low Latency Communications (URLLC), a key feature of the 5G network, users may schedule data transfers more efficiently, resulting in reduced transmission times through a bigger subcarrier and even the ability to schedule overlapping transmissions. Self-driving cars and remote surgeries may benefit from its low latency capabilities.

3 important service areas were considered in the design of the 5G network architecture:

1. **Massive Machine-Type Communications (mMTC)** A band new use case of 5G capable of supporting massively high-densities of online-connected devices. It is projected that this would transform the IoT market by connecting a massive number of devices.

2. **Enhanced Mobile Broadband (eMBB)** When high-bandwidth apps like as streaming and AR/VR become more popular, it will lead to faster download speeds as well as better user experiences.

3. Ultra-reliable Low-Latency Communication (URLLC) A low-latency, assured connection will be utilized for mission-critical applications.

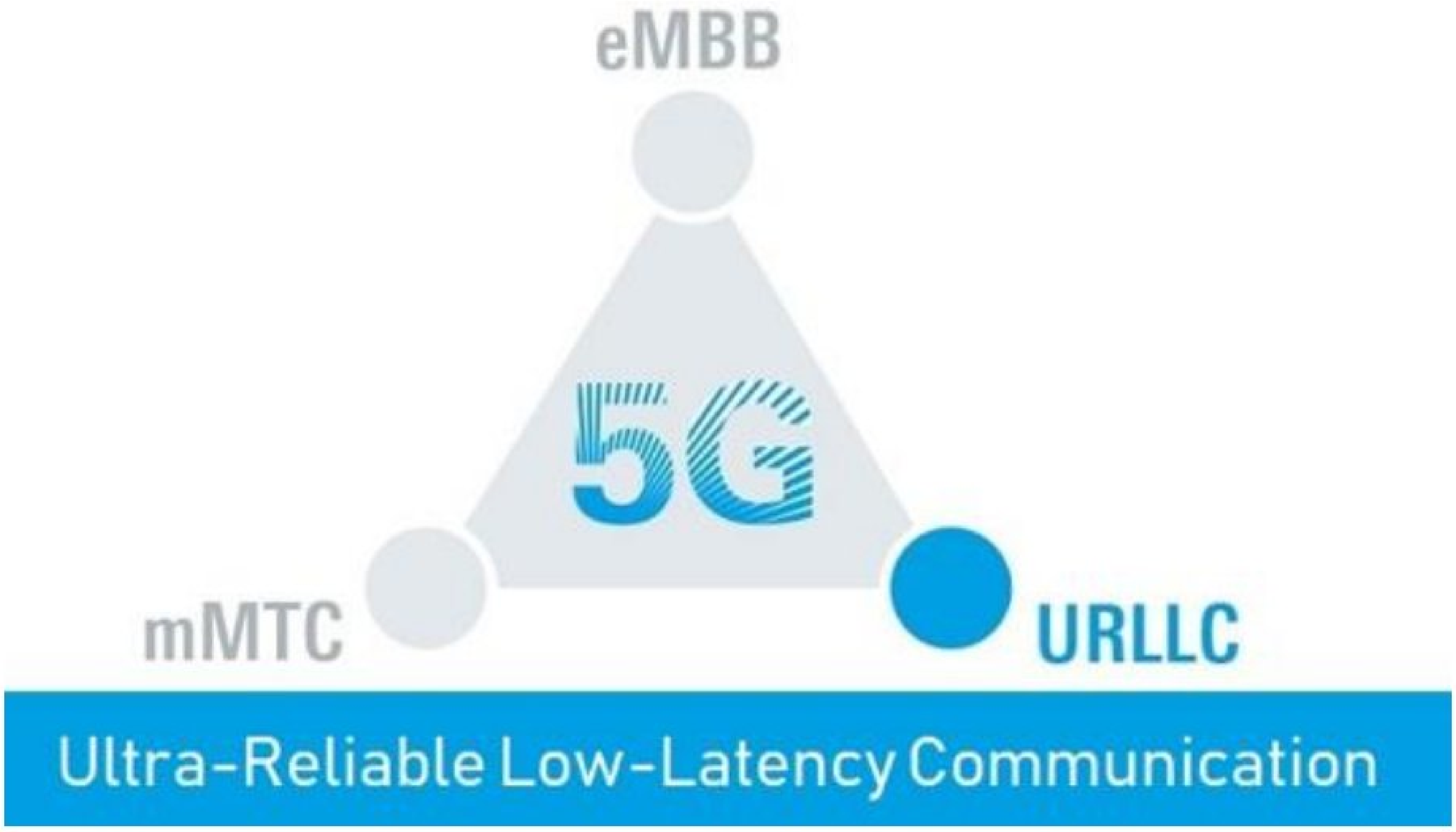

Figure 1.3 URLLC, a prominent use case of 5G[12]

There are use situations where 99.999 percent network uptime and a latency of 1 millisecond or less are required, and URLLC can meet such demands. Autonomous driving, for example, would demand such a link because of the high degree of danger. There are numerous advantages to autonomous driving, including time savings and increased safety due to the elimination of driver mistake. However, all vehicles would need to be connected to one another and to roadside systems, vehicle-to-infrastructure, and emergency services and road maintenance programs. Due to safety requirements for ultra-reliable connections, data must be sent in real-time with minimal latency[13].

Industry 4.0 and intelligent factories both require real-time interaction between machines and robots[14]. They may also require sensor data from the entire manufacturing facility collected in real time. It is possible to enhance industrial operations by using these machine-operated systems with low-latency systems. Remote and augmented reality healthcare applications, such as remote surgery, smart power distribution, cloud-based gaming and entertainment, and cloud-based electricity distribution, are all conceivable use cases for the technology.

Network slicing, also known as SDN technology or software-defined networking, allows each of the three 5G sectors to operate independently inside the 5G ecosystem[15]. Each slice functions as its own network, requiring independent provisioning, security, and service quality. Therefore, mMTC, which requires less security and bandwidth, is separated from URLLC, which offers superior security and reliability. However, each slice exists inside the same physical network architecture.

URLLC is targeted to exhibit high dependability and minimal latency. After 1 millisecond, less than 0.001% of 20-byte packets is supposed to fail to be delivered. Using beamforming, network slicing, and packet retransmission protocols, the 5G network design intends to address these delivery problems and faults.

Utilizing grant-free uplink access, 5G technology may deliver communications with ultra-low latency. Before transferring data in a 4G LTE system, the user device and base station are expected to exchange a series of signaling requests, or a "handshake." Access must be granted by the base station prior to data transmission, resulting in delays of up to 11 milliseconds[16].

A 5G URLLC system can utilize grant-free uplink access, allowing base stations to reserve uplink transmission capacity. End-to-end latency is drastically decreased due to the fact that the user device is not required to wait for scheduling requests prior to granting access. Similar to downlink data, network slices can be utilized to allocate resources. This is referred to as pre-emption[17], and the device will be notified that the connection type has changed.

The launch of the 5G network increases network complexity, allowing the deployment of new technologies to satisfy a wide range of consumer and commercial requirements. As 5G becomes more generally available throughout the world, the communications industry will diversify, and a variety of new opportunities will emerge. URLLC will provide mobile connection to mission-critical applications that have been conceptualized for years but are just now being implemented.

Electrical equipment designers and software developers will face even larger obstacles when it comes to developing high-performance gadgets. To ensure optimal security and dependability, software engineers may be necessary to implement unique protocols, coding strategies, and provisioning methods for specific systems. Existing hardware will also need to be upgraded to match 5G frequency band regulations, as well as the ever-changing needs for speed and battery life.

URLLC use case is aided by HARQ procedure, a physical layer technology that employs feedback and retransmissions to increase transmission resistance over channel changes and system dependability. If there were no mistakes in the data block at the receiver, an acknowledgment (ACK) is provided to the transmitter to certify correct data reception. If the block included problems, HARQ will attempt to rectify them using its coding error correction capabilities. If all errors are resolved, the block is approved and an ACK is transmitted to the transmitter[18].

HARQ employs Forward Error Correction (FEC) and Automatic Repeat Request (ARQ) as its two techniques. FEC is a powerful telecommunications technique that corrects faults based on the type of codes employed and the coding rate that has been determined. In addition, it does not require feedback, hence it retains a modest latency increase in comparison to retransmission-based methods. ARQ employs feedback and retransmission to enhance the probability of proper reception. At the receiver, the data block is examined for errors; if none are found, the block is accepted and an ACK is transmitted; otherwise, the block is discarded.

HARQ is utilized to increase the link's dependability at the cost of an increase in delay. This is HARQ RTT (HARQ Round Trip Time), a physical delay that cannot be avoided.

5G offers hybrid ARQ, a combination of error correction and retransmissions. When feasible, errors are rectified. When error correction is not possible, errors are discovered and a retransmission request is transmitted. The receiver attempts to understand the packet in light of current and previous broadcasts.

HARQ is supported at both the MAC and PHY layers in 5G[19]. Retransmissions at the MAC layer are undertaken. PHY layer at the receiver mixes many broadcasts in order to maximize the likelihood of precise decoding.

URLLC and eMBB use cases gain from 5G's support for HARQ. HARQ's normal residual error rate falls between 0.1 and 1 percent. Better performance can be obtained by increasing feedback signaling, power, or spectrum efficiency.

1.3 Future Scope of this Study

1.3.1 Future Scope

In case of 5G URLLC (Ultra-Reliable Low Latency Communications) for the most out the system we need it to be reliable and have the least latency at the same time. It should offer a significant reduction latency, making it ideal for whole new set of services. Along with a whole new set of Innovations in 5G it introduces URLLC also known as ultra-reliable low latency communication. For example, when we are making and international we often come across delay compared to our local calls and the explanation is simple because data have to come across a wide range of devices to reach us. So, when we are using real time services like a phone call or a video conference latency quickly becomes an issue for us. Video conferencing, financial transactions, remote operation machinery, automation in factory, smart traffic lights, are just a few example of digital services where the latency needs to be as low as possible. While previous generations of mobile networks did meet certain latency requirements none were really considered candidates to address the needs of vertical industries and critical real time applications. 5G provides us URLLC to provide consistent network characteristics that allow new applications to be built.

Addressing both reliability and latency at the same time is the challenge that we are facing. So, we need a way how we can address both simultaneously. To increase reliability on way is to increase retransmission, but an increment of retransmission means a gradual increase in latency. So, a method needs to be figured out to increase reliability but we can't increase the latency by the process as 5G has real-time application.

1.3.2 Recommendation

For the existing retransmission systems in HARQ method, they play as a huge drawback in case of latency of the overall transmission. If the data sent initially is incorrect it is sent back for retransmission over and over. This process reduces the overall efficiency of the system, thus not meeting the needs of real time applications. In order to reduce this problem we are recommending to increase the transmission bandwidth by taking the advantage of 5G communication and reducing the latency of the system.

1.4 Limitations of the Study

The limitations that we are facing in terms of our proposed methodology is that we are using abundant bandwidth for initial transmission. This might increase the overall cost but in the long run it will be much more effective than that. Also we know 5G has a wide range of bandwidth which is ultimately not being effected by the proposed methodology.

1.5 Research Objective

The predominant goal of our study was to increase reliability and decrease latency of URLLC simultaneously. The following are the research's specific objectives:

- Make Data Transmission more reliable.
- Decrease system latency.
- Simultaneously work on both reliability & latency.
- Ensure a minimum number of retransmission.
- Ensure the minimum rate of delay in data transmission.

1.6 Research Motivation

The research presented in this dissertation aims at finding the most optimal way to provide Gradual Increase in Bandwidth Allocation for HARQ Retransmissions for URLLC in 5G.

As the existing methods weren't efficient enough to increase reliability and decrease latency at the same time we started looking for an efficient way to do so. We started working on the retransmission system and our goal was to minimize the retransmission number as much as possible for the most efficient output. After a lot of time and effort, we had to come to a conclusion that although reliability can be increased by existing retransmission methods we cannot minimize the latency that way which is a big requirement in case of efficiency.

Then we shifted our focus to finding the most efficient solutions to work on both aspects simultaneously. We then came up with a method of increasing the overall bandwidth resulting in the minimization of retransmission and increasing the overall reliability of the whole system. We tried to use the most recent and efficient methods in our research process.

1.7 Introduction to this thesis

In this study, our main focus was to design and implement a better efficient and faster transmission system fir 5G URLLC. This thesis study is divided into five chapters as follows:

In chapter 1, an initial idea of the work, historical background, future scopes, limitations, advantages over transmission schemes, is described.

In chapter 2, paper reviews of various types of works in the same field have been conducted.

In chapter 3, brief description of all the components, parameters, and metrics have been discussed.

In chapter 4, simulation results have been provided and performance improvement has been analyzed.

In chapter 5, all the scopes of this study have been explored, and all the future works that can be done have been discussed, and finally the whole study has been concluded.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Our primary objective is to attain URLLC in 5G. URLLC applications such as material Web, mechanical computerization or shrewd networks contribute to expanding requests on the fundamental communication framework which have not existed as such some time recently. So to attain that we are attempting to diminish the number of retransmission in HARQ by expanding the transmission capacity in progressive retransmissions. By diminishing the number of retransmission able to send the flag in a brief period of time which can guarantee the moo latency part. The chances of bundle drop too diminishes by doing so and from this, the ultra-reliable part is additionally guaranteed. This is predominantly a noble thought. No work has been conducted regarding this division specifically. However, a few of the related works that we have seen will be examined within the following article.

2.2 Goals and Potential Benefits

Expanded bandwidth and speed are the most talked-about features of 5G. In comparison to 4G LTE, data throughput of 5G which shoots up to 10 Gbps will deliver a 10 to a 100 times of improvement in performance. As there's no shortage of transmission capacity in 5G, some innovation is indispensable to utilize this attribute to our advantage. By expanding the transmission capacity, we will accomplish our objective. Primary target from our end is to diminish retransmission as retransmission increases the inactivity. So, we are being able to send information more rapidly than the past advances. There are numerous operations or errands which require a quick and reliable response for that kind of work. So, in order to guarantee unwavering quality within the communication pursuits, our work can stay strong and offer reliable assistance for future research.

2.3 Enhanced machine learning techniques for early HARQ feedback prediction in 5G[20]

Automated EHARQ (EHARQ) response systems are augmented by machine learning techniques in this article to provide ultra-reliable and low latency communications (URLLC). Predicting the result of the decoding process before transmission has been advocated via machine learning approaches. A wide range of input characteristics and classification techniques were examined, spanning from classic approaches to novel supervised auto encoders.. According to URLLC standards, the effective block error rate must be less than 10-5 at the tradeoff of low latency for these solutions to be considered. EHARQ has been proven to be feasible over a wide range of signal-to-noise ratios, sub-code lengths, channel circumstances, and system load, demonstrating an advantage over traditional HARQ and previous EHARQ schemas that do not use machine learning. Early feedback on the decoding capabilities of the received signal is a key component of EHARQ techniques, which strive to lower HARQ RTT. Part of the transmission may be used in order to speed up the time it takes to retransmit data after first receipt.

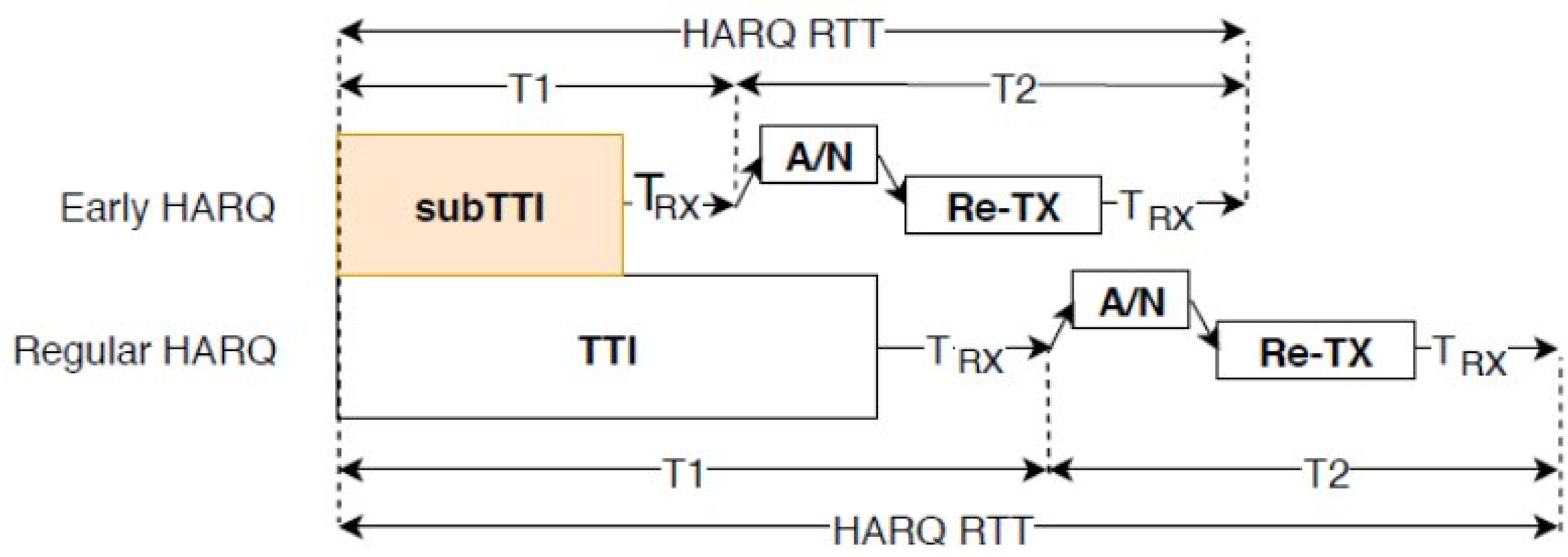

Figure 2.1 Timeline of regular HARQ compared to E-HARQ

2.4 A blind retransmission scheme for ultra-reliable and low latency communications[21]

A 5G radio concept is developed focused on ultra-reliable, low latency communication (URLLC) use cases is discussed in this article. It is primarily intended to meet the stringent delay and reliability requirements of air interface transmissions. 99% chance of success within 1 millisecond. To efficiently meet these requirements it is one of the main challenges of new wireless standardization without running out of network capacity. In this article a scheme is proposed to perform blind retransmissions via the shared radio resource and sequential squelch applied to receive the remaining undecrypted data with a slow delay. The additional control errors and delays inherent in response-based retransmission schemes are avoided. Studies have shown that blind transfers over shared resources are more resource efficient than single paths, depending on the number of users sharing the resource.

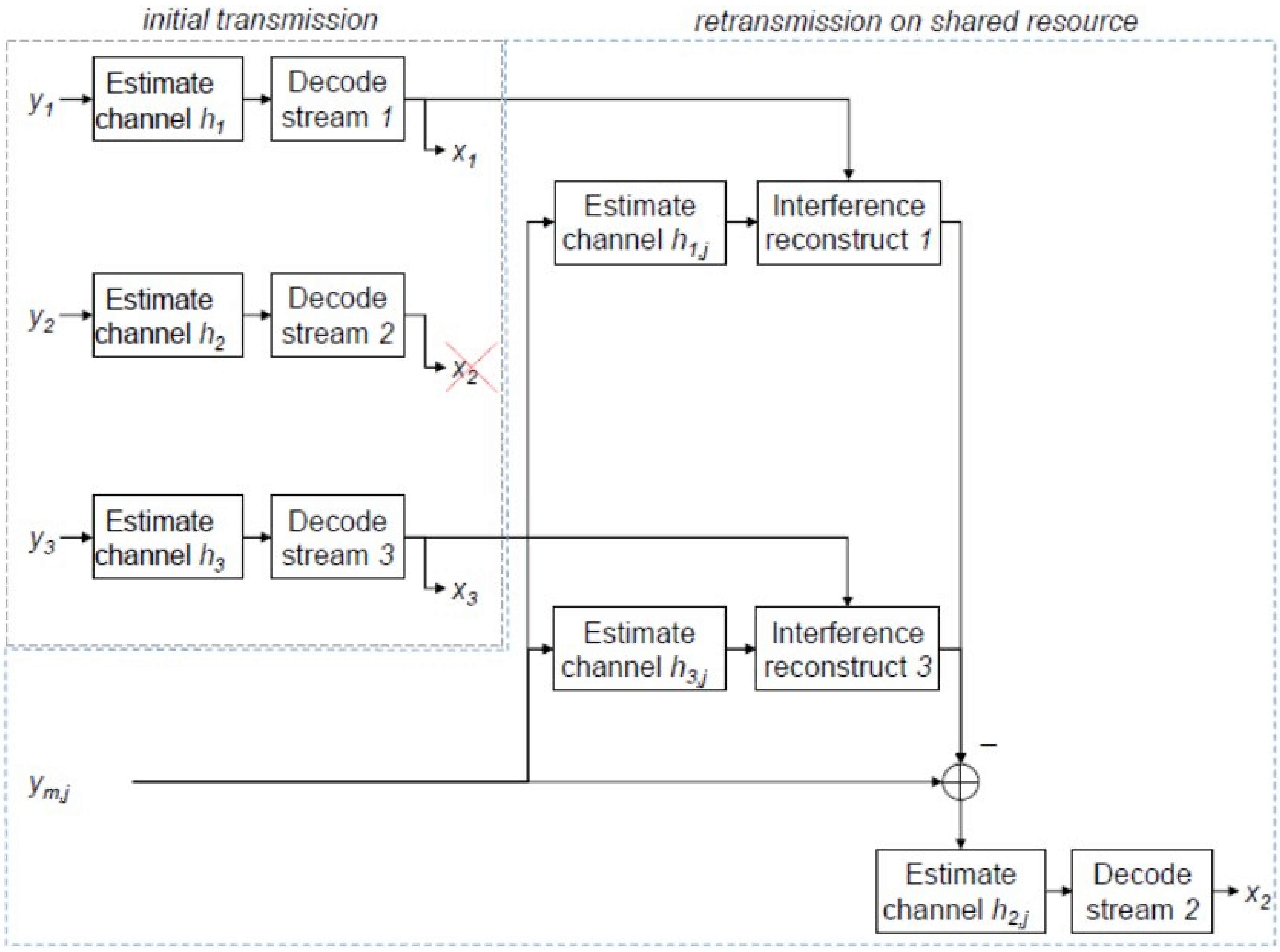

Figure 2.2 Example of reception process with shared retransmission resource

2.5 Radio resource allocation and retransmission schemes for URLLC over 5G networks[22]

The low latency goal of ultra-reliable low latency communication (URLLC) can conflict with strict reliability requirements as it requires retransmissions. This paper focused on the Internet of Things for industrial use and considered various outbound and retransmission resource allocation schemes, depending on the underlying service requirements and traffic characteristics. A pool of individual booking schemes and competitively reserved resources. A new resource allocation scheme for initial and retransmission was provided and a corresponding analytical model of loss rate was derived. It showed how to set system parameters that allow you to meet URLLC requirements with low resource consumption.

The combination of TTI and sub channel is called a resource block and corresponds to the smallest radio resource unit assigned to the UE for data transmission. To meet the reliability goals of URLLC, users are assigned a robust modulation and coding scheme (MCS) that guarantees a low block error rate.

2.6 Analysis of transmission methods for ultra-reliable communications[23]

It is predicted that the fifth cellular framework age would greatly strengthen communications between machines of all kinds (MTC). Because of the wide range of potential uses for MTC, existing remote frameworks are unable to provide all of the required criteria. Low latency communications (URC) are essential for mission-critical applications such as mechanical computerization and open access security. This assures a high degree of unwavering quality in communication. The feasibility and efficacy of URC across distant connections were examined in this work. Additionally, it examined the efficacy of various transmission tactics, including geographical disparities and the use of cross-breeding to repeat a program's instructions (HARQ). Finally, the need of reliable criticism data was made clear.

This is a link between two devices that use the same cellular network. For example, this interface may be used between a base station and a mobile device, or between two D2D communication devices. In the event that HARQ is used, this channel may also be used to convey blunder control data. Discussed here are three subcategories.

- Single-input single-output (SISO) antenna system with no retransmission,
- Spatial diversity with no retransmission,
- Spatial diversity with HARQ.

2.7 Resource allocation and HARQ optimization for URLLC traffic in 5G wireless network[24]

5G remote systems are anticipated to bolster ultra-reliable moo inactivity communications (URLLC) activity which needs exceptionally moo parcel delays (< 1ms) and greatly tall unwavering quality (~99.999%). In this paper, it was centered on the arrangement of an inaccessible system supporting downlink URLLC action. Employing a lining network-based demonstrate for the remote framework, it has characterized the impact of different plan choices on the most extreme URLLC stack it can back, some are:

1) System parameters such as the bandwidth, link SINR, and QoS requirements;
2) Resource allocation schemes in orthogonal frequency-division multiple access (OFDMA)-based systems; and
3) Hybrid automatic repeat request schemes.

Key commitments of this paper which are of down to earth intrigued are:

1. Ponder of how the least required framework transmission capacity to back a given URLLC stack scales with related QoS imperatives;
2. Characterization of ideal OFDMA asset assignment plans which maximize the allowable URLLC stack; and
3. Optimization of a reiteration code-based parcel re-transmission plot.

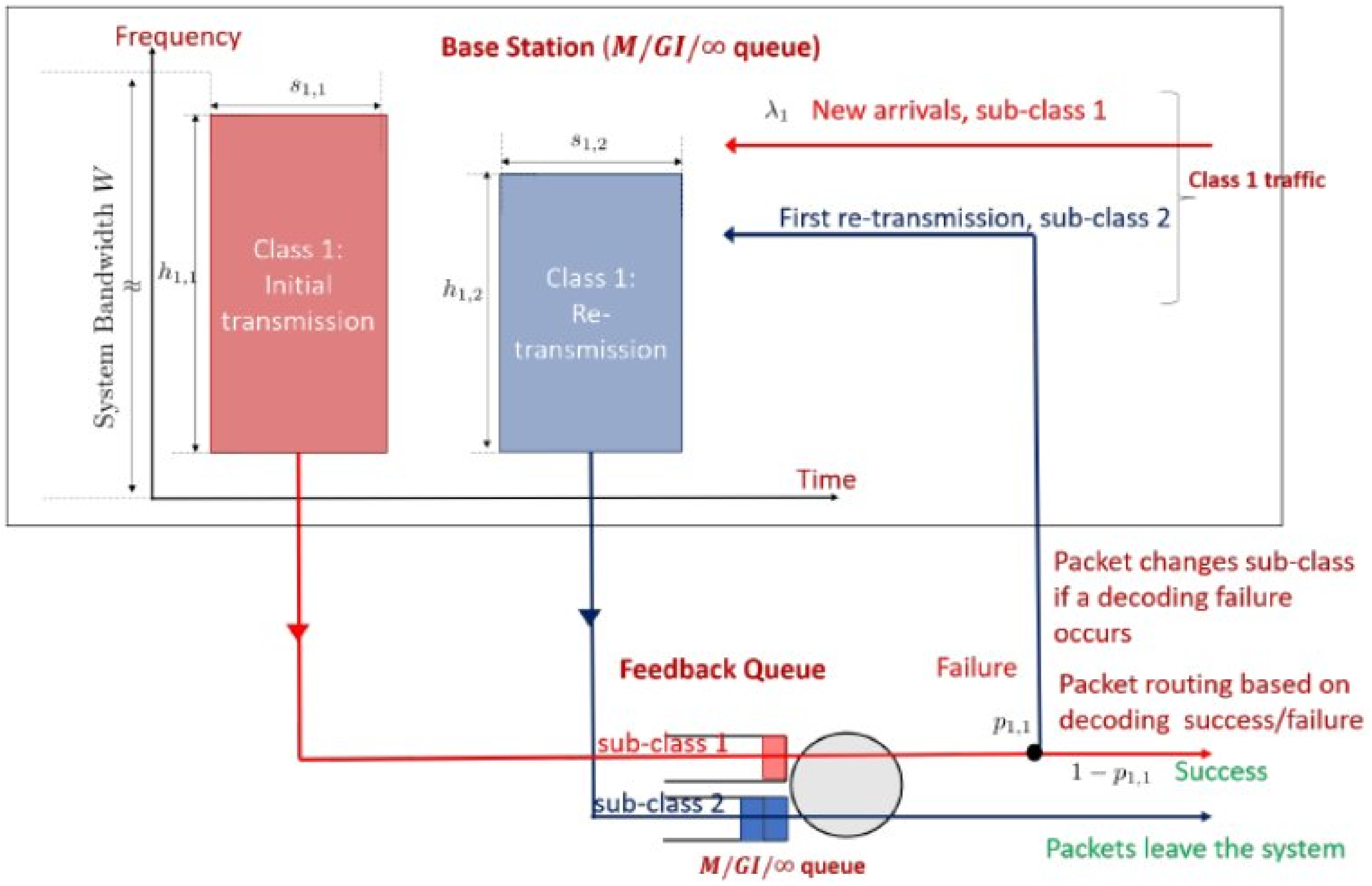

Figure 2.3 A wireless system with a single class of URLLC users modeled as a network of two M/G/infinity queues

Downlink transmissions in a remote framework are centered with a single Base Station serving an energetic populace of URLLC clients and their related bundles. A URLLC parcel may endure from lining delays at the BS, transmission and engendering delays, and collector preparing delays. So different schemes have been proposed which are, System model (one shot transmission), infinite system bandwidth, effect of finite system bandwidth, finite block length model, capacity scaling. Too the same strategy has been connected with different transmissions.

2.8 Bandwidth efficient variable rate HARQ under orthogonal space-time block codes[25]

A hybrid Automatic Repeat reQuest (HARQ) transceiver system with full retransmission diversity was shown using orthogonal space-time block codes (OSTBC) with minimal decoding complexity. It was necessary to build this innovative HARQ system on top of the traditional OSTBC transmission in order to achieve the desired level of space-time diversity. To decrease bandwidth consumption and accomplish joint detection of multiple transmissions without training, space-time encoding may be shortened in time during retransmissions after packet losses. The combination of bandwidth reduction and full transmission diversity may be achieved by changing the joint detection model at the receiver into a Quasi-Orthogonal Space-Time transmission model. Even more bandwidth efficiency may be gained by using this receiver's proposed semi-blind channel estimate without retraining during retransmissions.

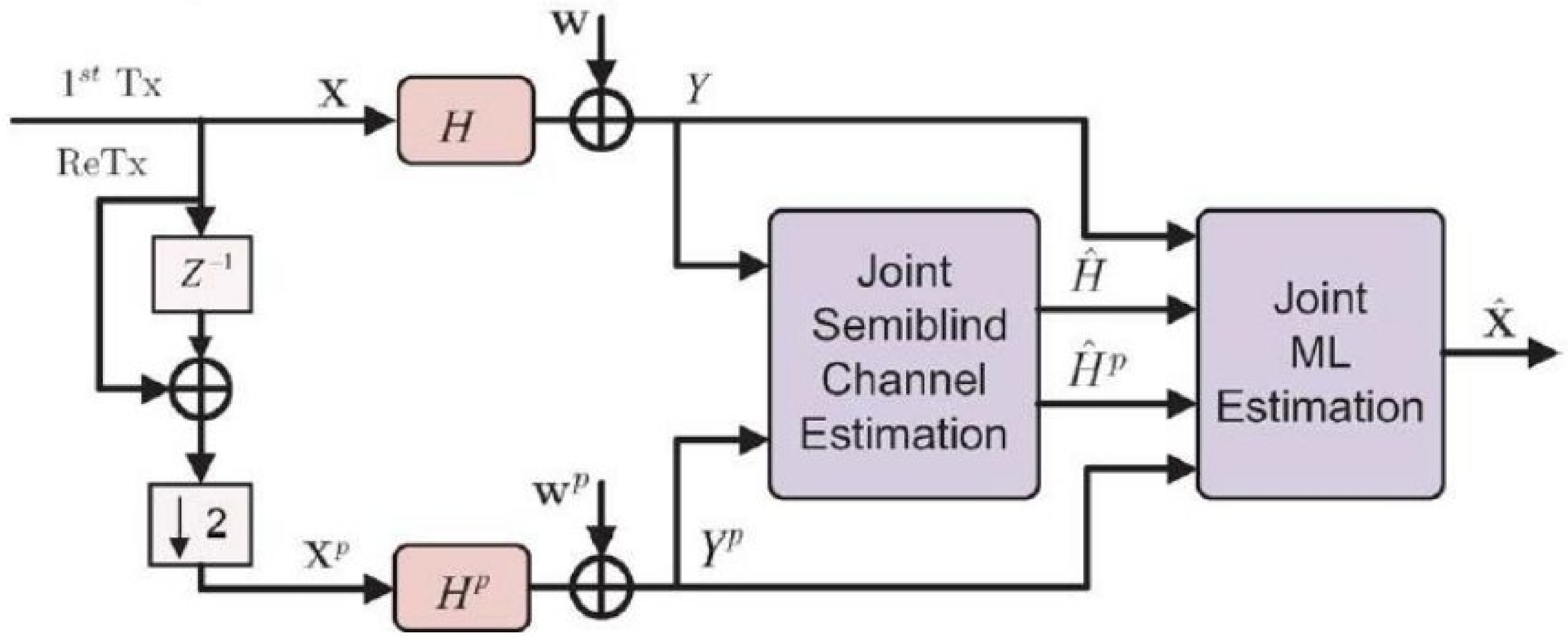

Figure 2.4 Partial Retransmission model for bandwidth efficiency under OSTBC

For simplicity, we considered sending the same data frame twice in a row with ARQ for joint detection, without loss of generality. We investigated a special case of PARQ retransmission with simple superposition for two adjacent code words. Figure 2.4 shows a MIMO hybrid ARQ model between OSTBCs. The upper branch represents the first transmission with data training inserted for channel estimation and coherent detection. Shows only one retransmission shown in the branch below as a PARQ retransmission without training, without loss of generality. To combine the partial responses of the symbol being retransmitted, double the consecutive code words before decimation. As a result, each new code word is made up of an odd STBC code word followed by the next (even) STBC code word. With sufficient memory, the receiver can store both transmissions and perform joint channel estimation and detection.

2.9 Short Block-Length Codes for Ultra-Reliable Low Latency Communications[26]

This article discusses current URLLC channel coding schemes. URLLC services' rigorous criteria, such as ultrahigh dependability and low latency, have made them the most difficult aspect of 5G mobile networks. The challenge is considerably more difficult for applications that go beyond 5G's promise, such tele surgery and factory automation, which require latencies of less than 1ms and packet error rates of fewer than 10-9. This article examines and contrasts several URLLC channel coding schemes in terms of performance and complexity. A number of key research directions are highlighted and examined in further depth.

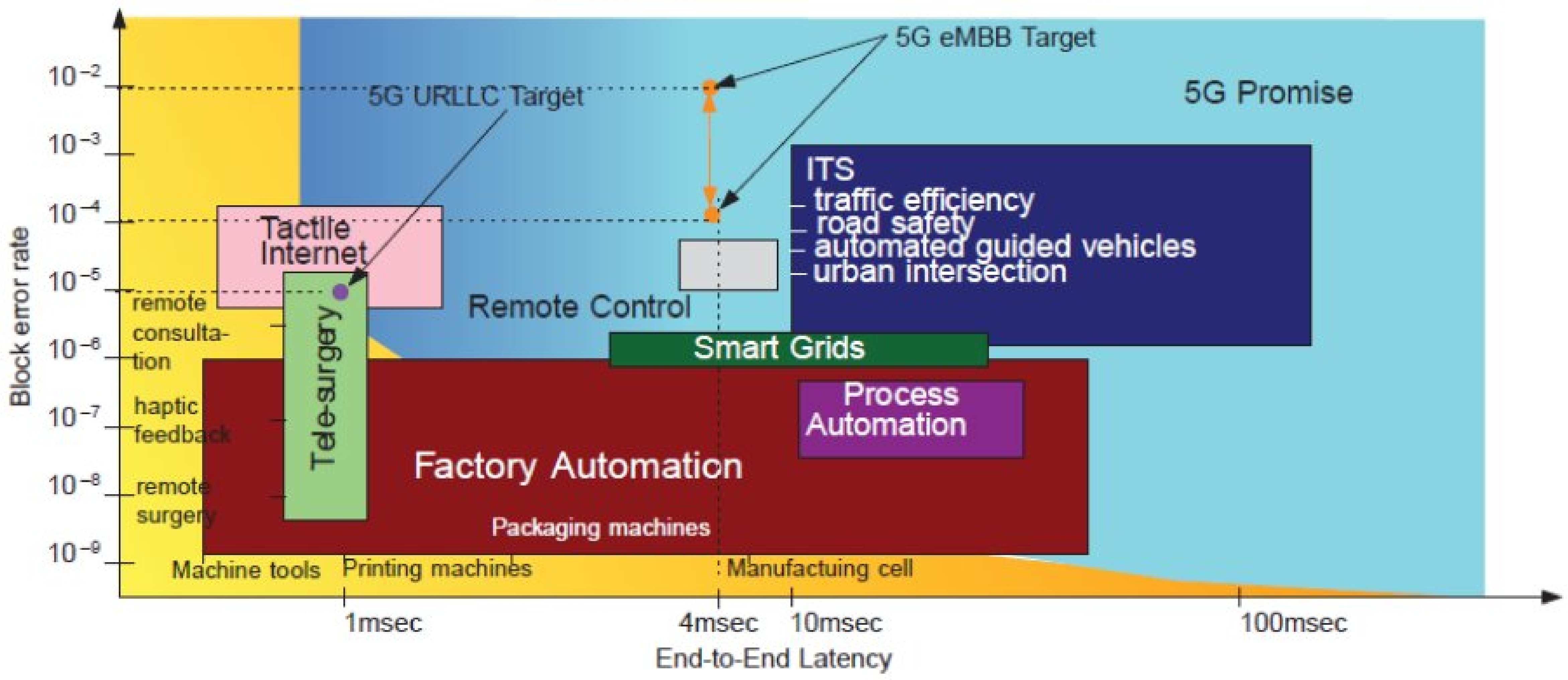

Figure 2.5 Latency and reliability requirements for different URLLC services

Three primary directions where considerable improvements are required to attain ultra-high dependability and low latency have been identified. Each path has its own set of recommendations.

- Self-Adaptive Joint Coding and Modulation Schemes
- Space-Frequency Channel Coding
- Developing Low-Complexity OSD Decoders

2.10 Ultrareliable and Low-Latency Wireless Communication: Tail, Risk, and Scale[27]

There has been a lot of emphasis paid to ensuring ultra-reliability and low latency communication (URLLC) beyond 5G wireless networks. Iot (IoT) technologies from Machine - to - machine Communications (MTC) to mission-critical communications such as driverless cars, drones, and enhanced/VR are causing an enormous rise in data traffic. And the capacity to grow. In essence, URLLC takes a detour from the usual user-centered approach to network architecture. It's no longer a choice, but a need, to depend on measures like averages (throughput, latency, reaction time, etc.). We are missing an overarching framework for making choices about network topology and topology-as-a-service that takes into account factors such as latency and dependability. This white paper's main objective is to begin the process of bridging that chasm. With this perspective in mind, after defining latency and dependability, we examined the URLLC enablers and the associated trade-offs they entail. A variety of URLLC-related approaches and procedures were then examined, along with specific examples of their implementation. Wireless networks with low latency and high reliability may benefit greatly from these findings.

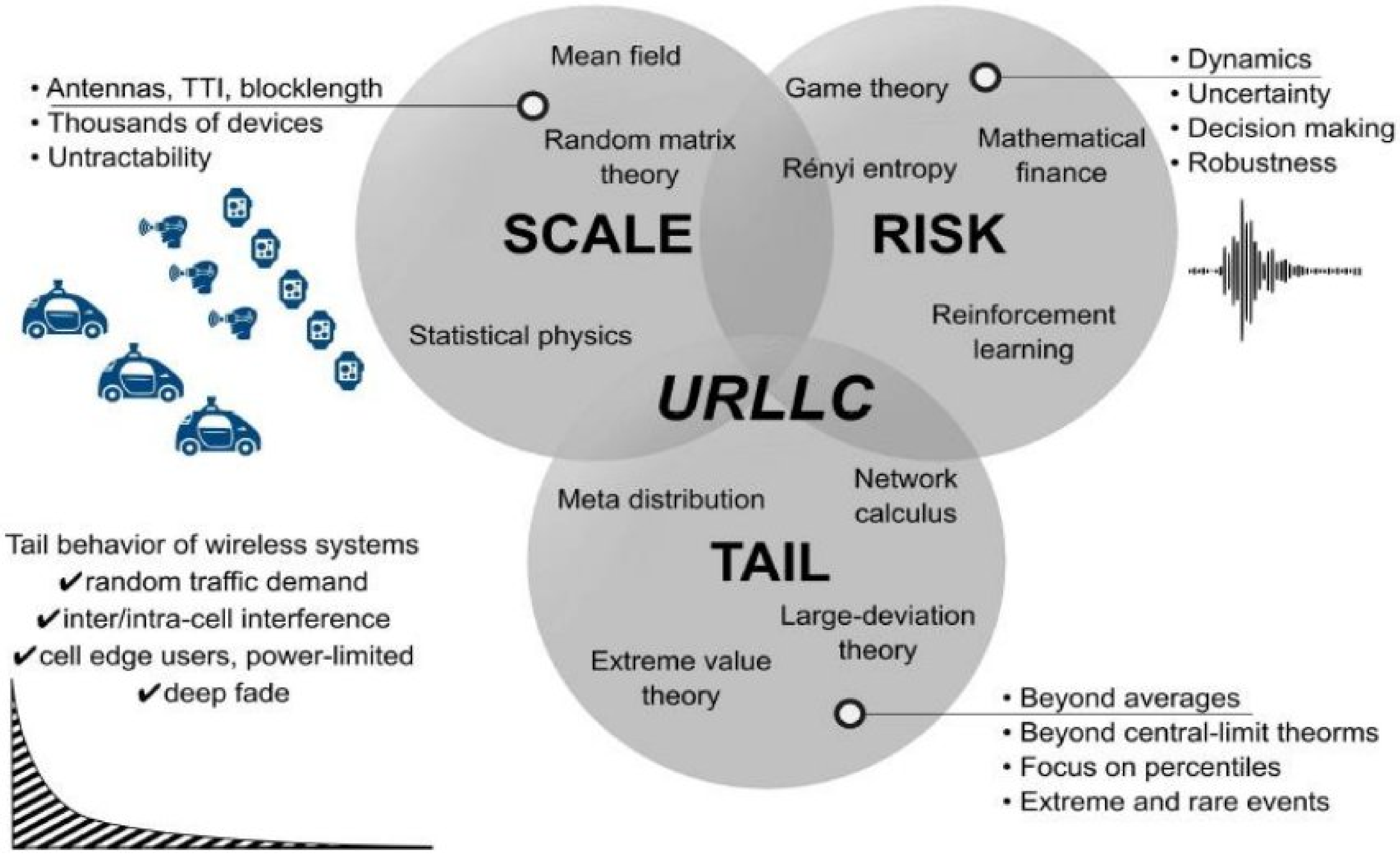

Figure 2.6 Anatomy of the URLLC building blocks, composed of tail, scale and risk

There are three main parts to the URLLC:

In situations where decision-making must be done in the face of ambiguity, with channels that change over time, and with network dynamics, risk is a common issue.

Users near cell edges, power-limited networks, or those in deep fade are all affected by the tails of random traffic demand and the distribution of delays, as well as by intra- and inter-cell interference. The sheer quantity of devices, antennas, sensors, and other nodes creates significant resource allocation and network design challenges. If you're dealing with a big number of sensors and actuators and controllers in a mission-critical machine communication use case, such as in industrial process automation, then scalability is vital.

2.11 Generalized HARQ protocols with delayed channel state information and average latency constraints[28]

In many wireless systems, the signal-to-interference-and-noise ratio that applies to a particular transmission, known as channel state information (CSI), may only be determined after the transmission has occurred, delaying the transmission. Hybrid automated repeat request (HARQ) protocols are frequently employed in such systems to provide high throughput with minimal latency. This study introduced the EMS protocol family, which generalizes the HARQ protocol and allows for rate modification based on delayed CSI at the transmitter (CSIT).

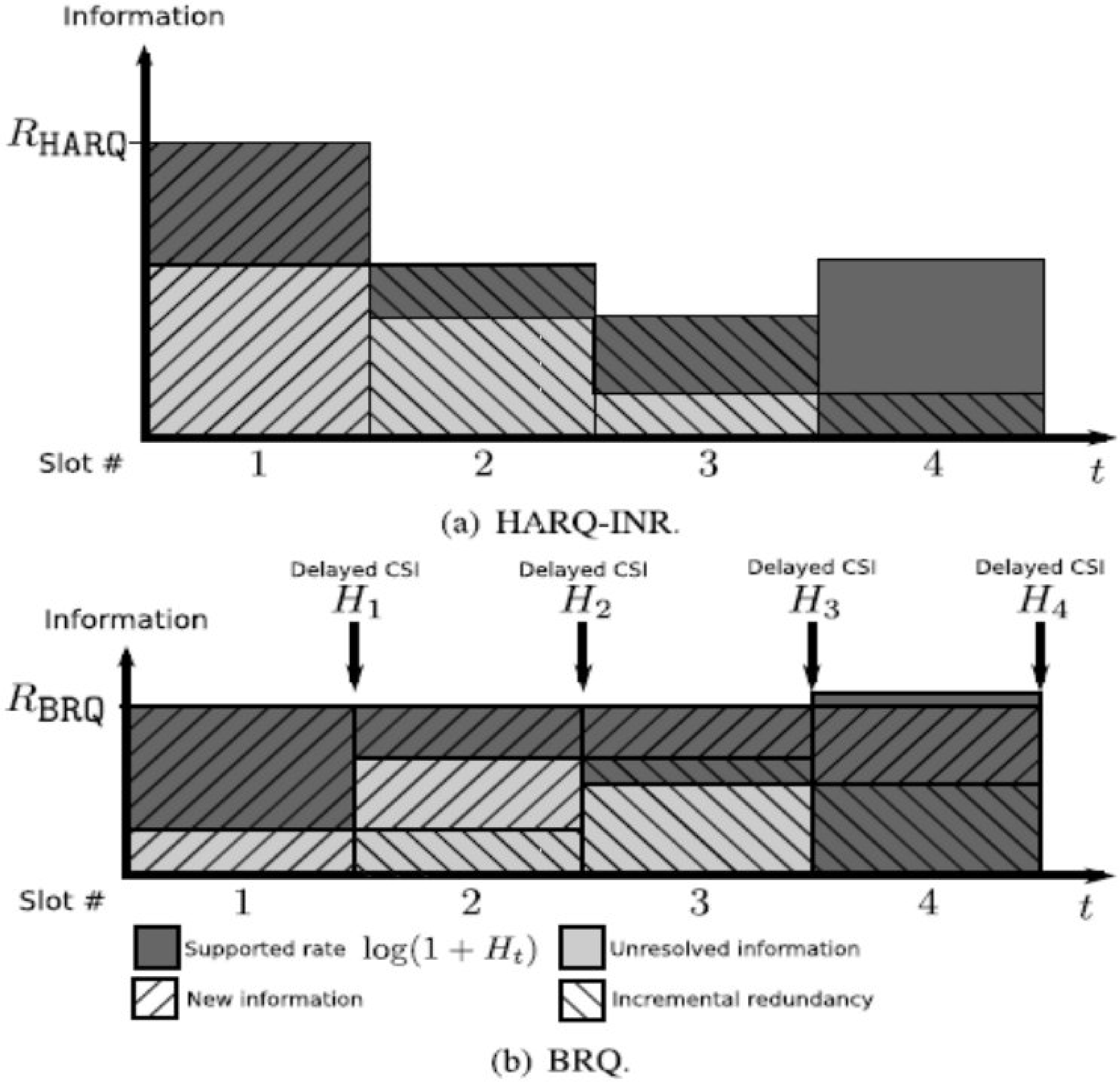

Figure 2.7 Comparison between HARQ-INR and BRQ

The suggested EMS protocols were studied using dynamic programming, assuming a block-fading channel. When complete delayed CSIT was available and the average decoding time was constrained, the ideal zero outage EMS protocol was found to have a relatively easy operational interpretation and throughput that was equivalent to the backtrack retransmission request (BRQ) protocol. EMS protocols were also developed in the event that CSIT was only available through a limited number of feedback messages. When compared to HARQ, the numerical findings show that BRQ achieves ergodic capacity rapidly, while EMS protocols with only three and four feedback messages produce throughputs that are only slightly lower.

The goal of this study is to expand and generalize the BRQ protocol. When the CSI is only accessible after the transmission, EMS methods come in handy. As a result, EMS protocols provide an intuitive solution to construct communication protocols that approach ergodic capacity while maintaining a low average decoding time. In contrast to BRQ, EMS procedures benefit from less input in general.

2.12 Dynamic Bandwidth Part Allocation in 5G URLLC for Unmanned Aerial Vehicles with High Data Rate Traffic[29]

eMBB (enhanced mobile broadband) and URLLC (ultra-reliable low-latency communications) coexist in 5G New Radio thanks to 3GPP's standardization of the physical layer requirements (AV). URLLC traffic is continuously multiplexed in order to maximize failover capacity. DM punctures ongoing eMBB traffic by assigning a completely overlapping bandwidth fraction (BWP) of eMBB and URLLC AV enabling prompt scheduling of URLLC traffic. DM, on the other hand, is plagued with punctuation problems. According to eMBB and URLLC traffic load, BWPs for eMBB and URLLC may be orthogonally sliced to avoid resource overprovisioning. DM and OS multiplexing techniques are proposed in this paper as a way to reduce the effect of URLLC traffic on eMBB traffic via a dynamic BWP allocation approach that shifts between the two multiplexing methods. For effective BWP allocation, physical layer characteristics, such as bandwidth use, are taken into consideration. DM and OS MCS levels and code block group sizes are discussed in section B. However, DM's error repair capabilities for URLLC's puncturing impact are severely restricted due to the OS's ability to improve eMBB throughput under URLLC delay constraints. eMBB traffic's tolerance for punctures depends on the relative MCS level of eMBB and URLLC traffic. The URLLC load threshold is used to measure tolerance levels and discover performance trade-offs between the DM and the OS. It's presented in a fashion that's practically closed. This is a crucial resource for determining whether to use DM or OS, since it enables for URLLC-AV to be dynamically assigned to BWP.

Service Scenario	Reliability	Latency
AR/VR	$1-10^{-5}$	1 to 4 ms (user-plane)
Factory Autonmation	$1-10^{-6}$	1 ms (user-plane)
Transport Industry	$1-10^{-5}$	3 or 7 ms (user-plane)
Power Distribution	$1-10^{-6}$	3 or 6 ms (user-plane)
Command and Control of UAV Network	$1-10^{-3}$	10, 40, or 140 ms (end-to-end)

Table 2.1 Use cases and their performance requirements for URLLC

The BWP size of URLLC AVs is considered to be equal to the CBW, which reduces the effect of eMBB traffic puncturing. URLLC traffic is considered to be distributed uniformly throughout its assigned BWP in a specific BWP, preempting the eMBB resource, as illustrated in Figure 2.8. Because URLLC AVs are unaware of ongoing eMBB traffic, consistent URLLC traffic preemption is the best option for instant scheduling.

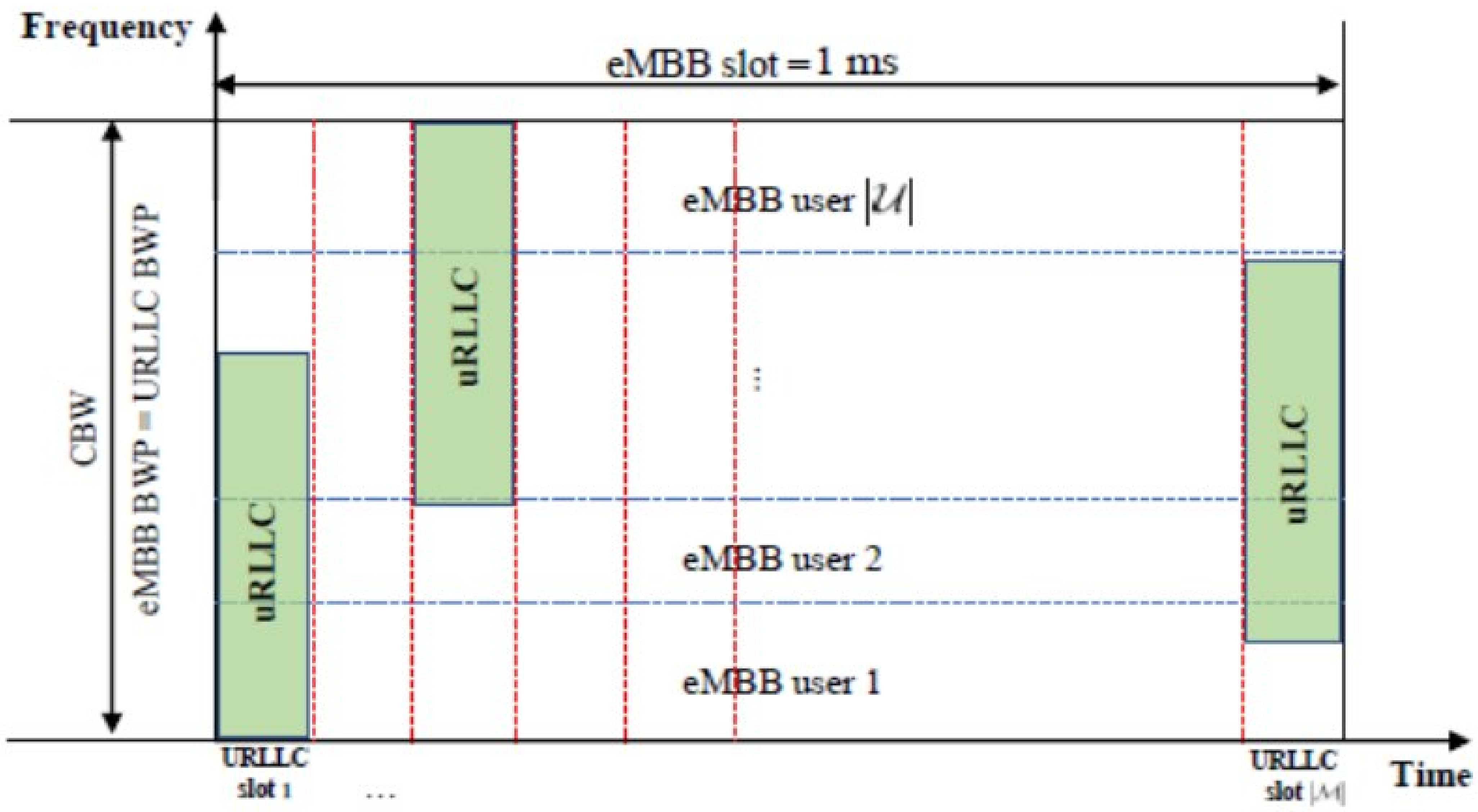

Figure 2.8 Dynamic Multiplexing

The resources for eMBB and URLLC AVs are orthogonally sliced in OS-based URLLC multiplexing, as shown in Figure 2.9. As a result, URLLC AVs are assigned an exact BWP size to support a load of D with a portion of the eMBB slot, while the eMBB BWP takes up the remaining resources in the CBW. The bigger the URLLC load, the poorer the eMBB throughput performance in both DM and OS is projected, with a clear performance tradeoff between both.

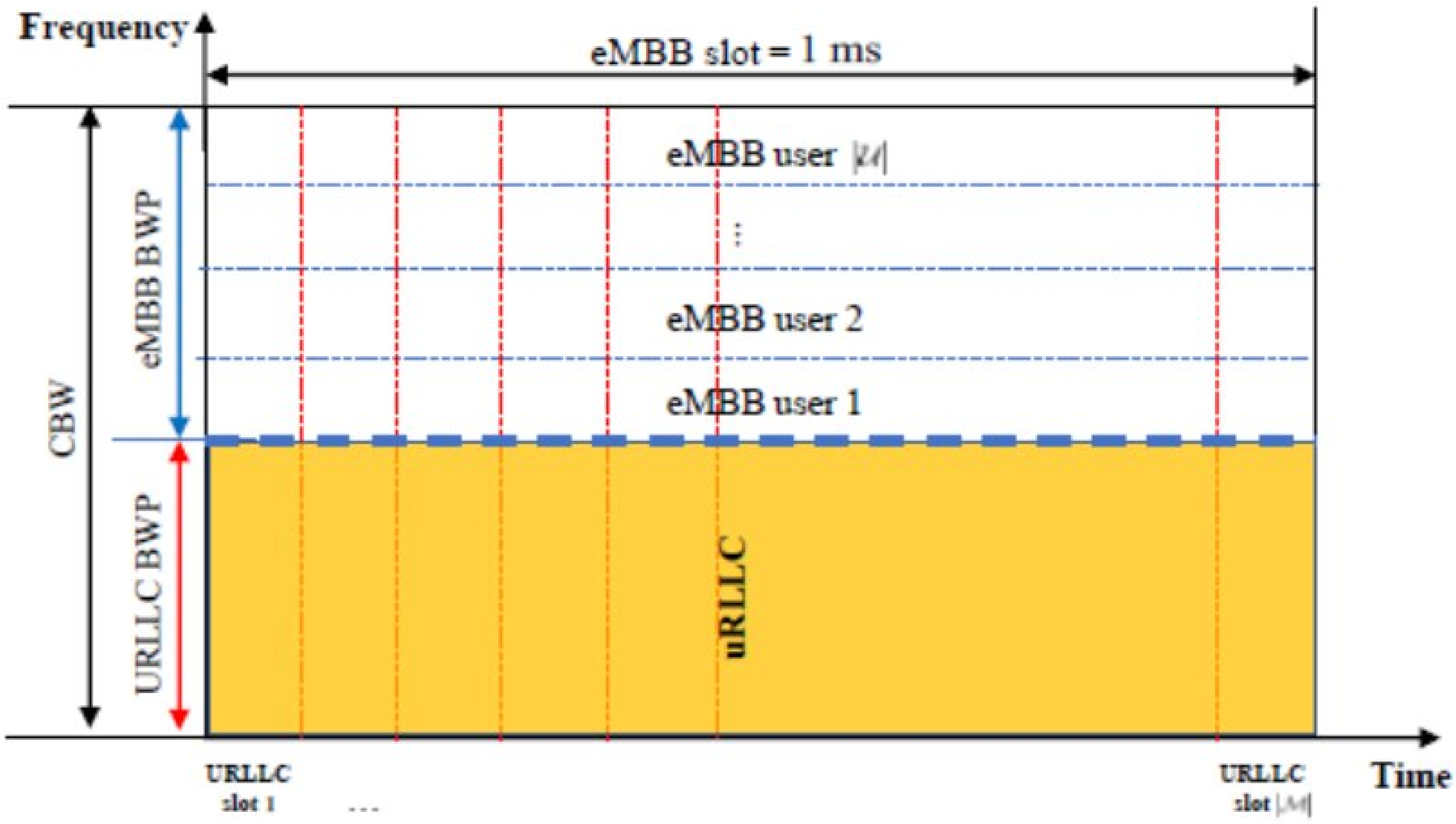

Figure 2.9 Orthogonal Slicing

CHAPTER 3
METHODOLOGY

3.1 Introduction

The methodology used in this project is discussed in this chapter. In this section, we discuss the details of the components we have been working with regarding 5G New Radio Technology and all the parameters that are related to it. Also, we tried to explain their roles in this project. Fig 3.1 below is a block diagram that overviews the transport channels in the Link layer of 5G NR, where our research work expedites.

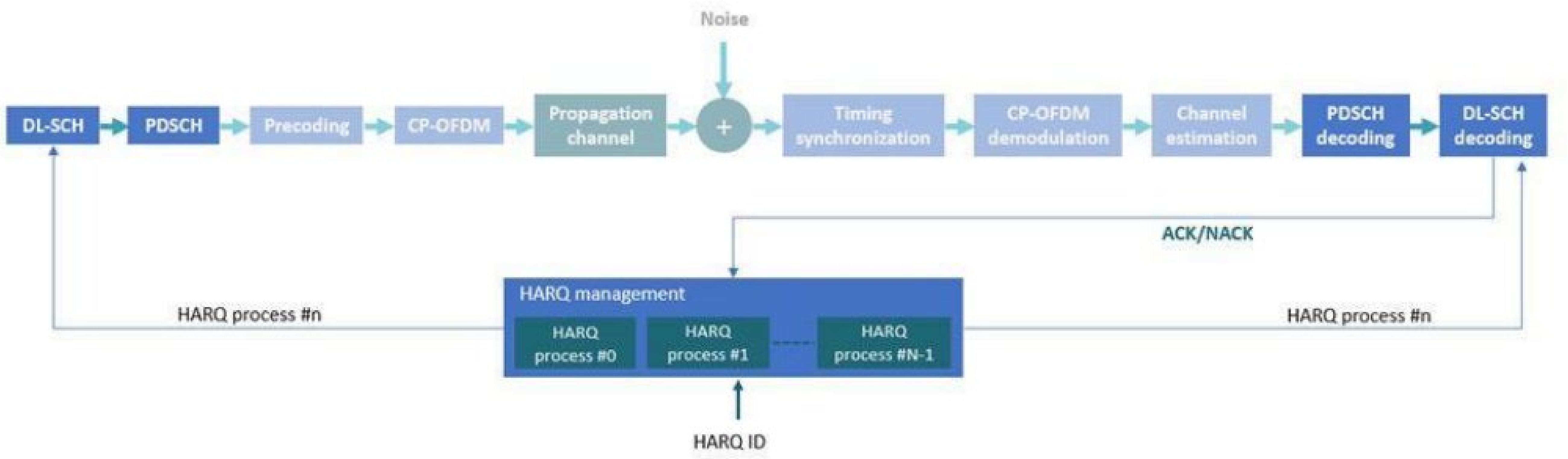

Figure 3.1 5G NR Transport Channels with HARQ[30]

This figure shows the link elements that are modeled in the context of a 5G downlink link which include:

- DL-SCH(Downlink Shared Channel) encoding and decoding
- PDSCH(Physical downlink shared channel) encoding and decoding
- Channel Coding, Modulation & Demodulation HARQ management

Our work resides in the management of HARQ scheme through specific channel coding, Modulation & Demodulation techniques, and working with various parameters and resource elements in the 5G Physical Link layer, to bring about an improvement and ease in the overall strategy of data transmission.

3.2 Component of Work

Our prime target in our work was to lower latency levels in the 5G URLLC scheme and also increase reliability. We earn that by lowering modulation levels to restrict subsequent retransmissions so that the chances of requirements of further retransmissions reduce. To understand it, we need to have a brief overview of a fair few concepts and terminologies. As such, a brief idea about the components of our work has been laid down in this ensuing section.

3.2.1 Overview

The 5G network architecture has been designed with three key service areas in mind:

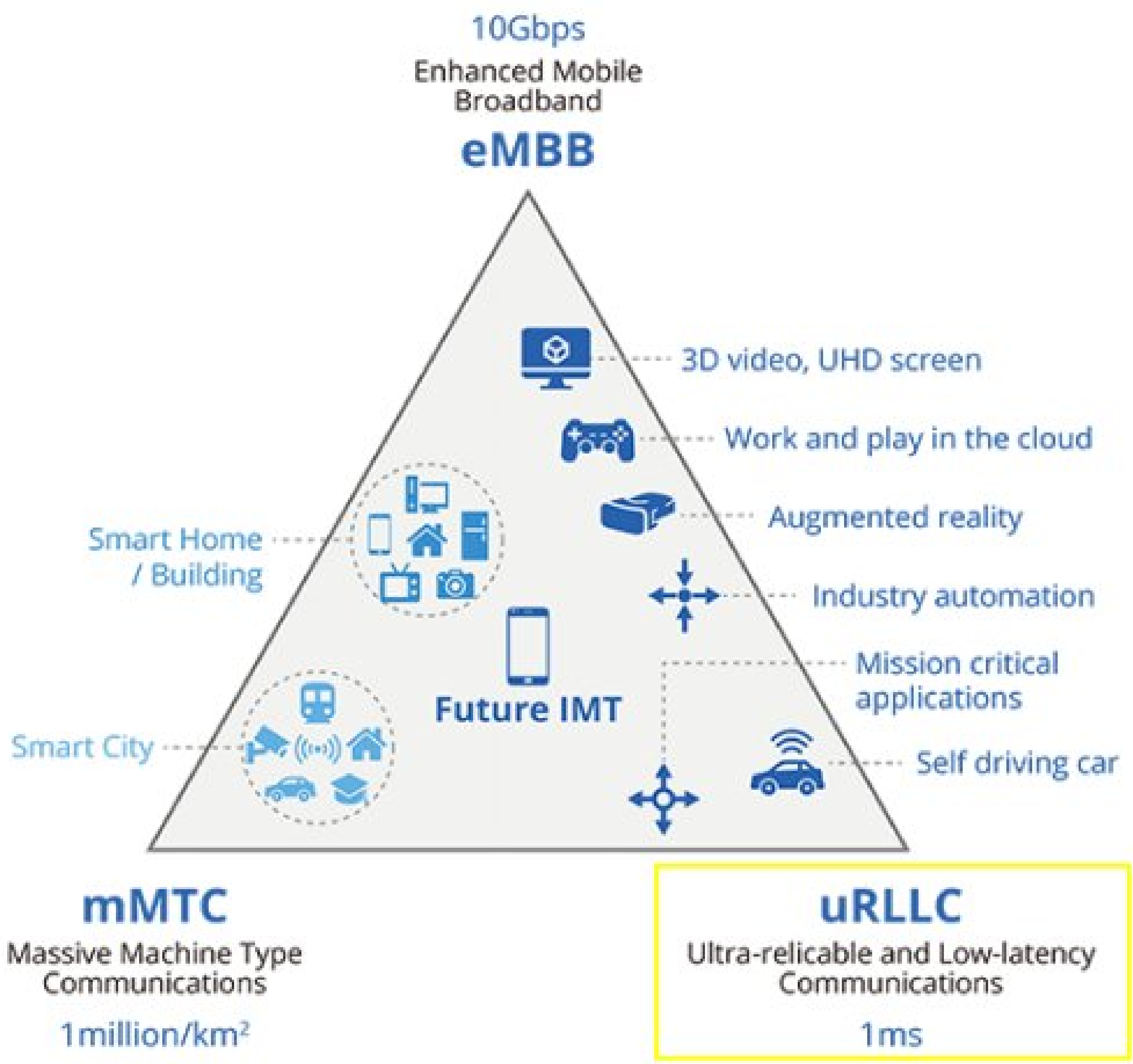

Figure 3.2 5G Network Service Areas[31]

1. Massive Machine-Type Communications (mMTC): This will be utilized to connect a large number of devices and is anticipated to revolutionize the IoT market.

2. Enhanced Mobile Broadband (eMBB): This enables high-bandwidth apps such as augmented/virtual reality (AR and VR) and streaming, as well as quicker download speeds and enhanced user experiences.

3. Ultra-reliable Low-Latency Communication (URLLC): This will be utilized for mission-critical applications requiring a secure connection and low latency.

3.2.2 URLLC

3.2.2.1 Introduction

Ultra-Reliable Low Latency Communications (URLLC), a component of 5G network design, provides more efficient scheduling of data transfers, achieving shorter transmissions via a larger subcarrier, and even scheduling overlapping transmissions[32]. It allows the delivery of vital data that requires low latency, such as autonomous vehicles and remote surgery.

The advent of the 5G network increases network complexity, allowing new technologies to be implemented to fulfill a variety of consumer and commercial needs. This, in turn, will result in the diversification of the communications business, with a multitude of new opportunities emerging as 5G becomes more widely available around the world. URLLC will provide mobile connectivity to mission-critical applications that have been proposed for years but are just now being implemented[33].

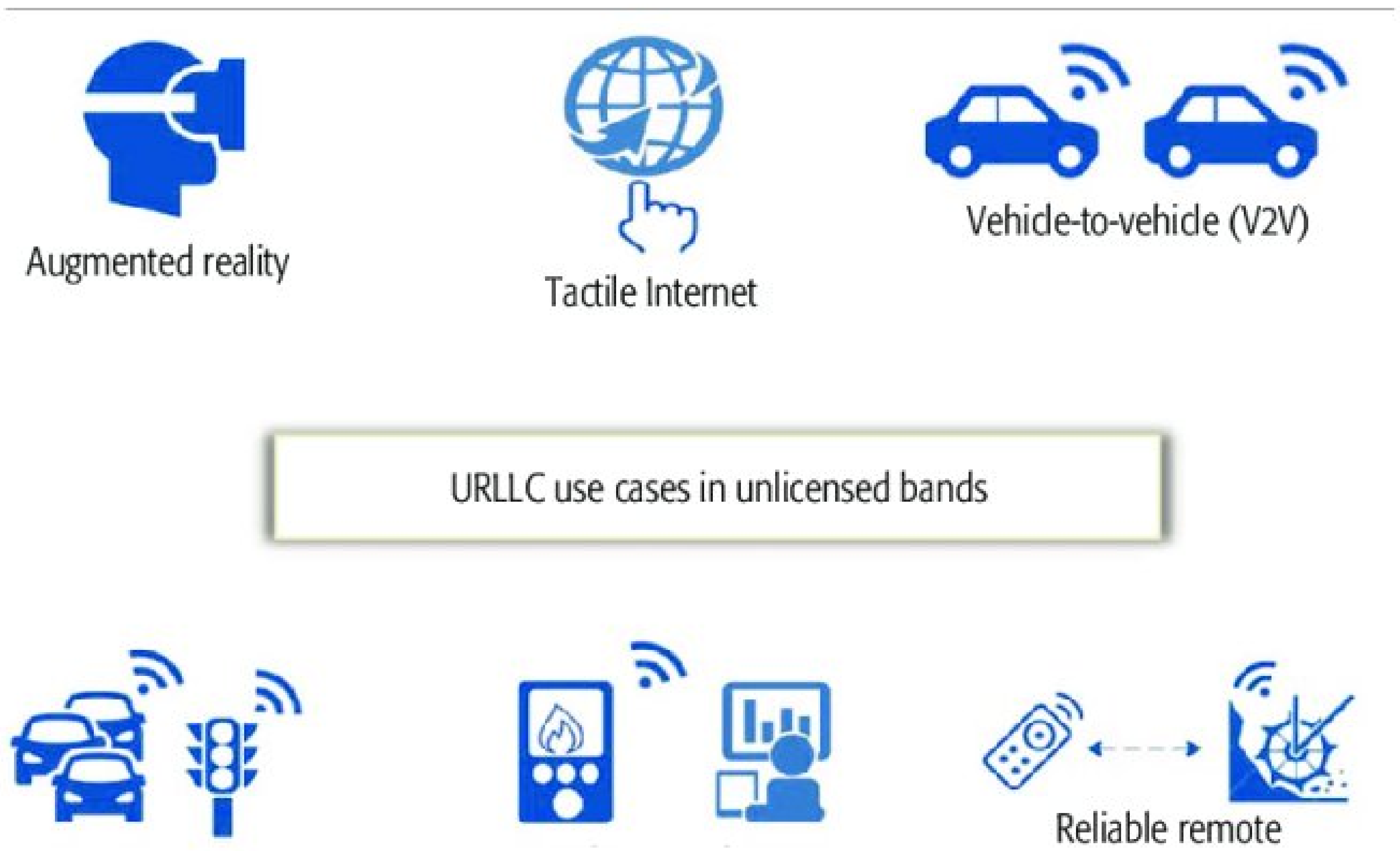

Figure 3.3 5G URLLC Use Cases[34]

3.2.2.2 Characteristics

URLLC offers use cases that need high network availability, greater than 99.999 percent, and extremely low data transfer latency, about 1 millisecond. It must be mistake sensitive and delay sensitive simultaneously. Autonomous driving, for instance, would require such a link due to the significant risk involved, as it would require all vehicles to be connected to each other and to roadside systems, vehicle-to-infrastructure, such as traffic signal systems, emergency services, and road maintenance programs[35]. As safety regulations demand ultra-reliable connections, data would need to be shared in real-time with minimal delay.

3.2.3 HARQ

3.2.3.1 Introduction

Hybrid ARQ, a combination of retransmissions and error correction, is supported by 5G New Radio. HARQ is applied to improve link dependability at the expense of increased delay. When practicable, errors are rectified. When error correction is not possible, errors are recognized and retransmission of the packet is requested. Based on current and prior broadcasts, the receiver attempts to decipher the packet[36]. HARQ functions at both the MAC and PHY layers in 5G NR. Retransmissions are performed at the MAC layer. PHY layer at the receiver mixes many broadcasts to improve the likelihood of accurate decoding.

HARQ is essentially a physical layer approach that utilizes feedback and retransmissions to increase transmission resistance over channel changes and improve system reliability. If the data block at the receiver contained no errors, an acknowledgment (ACK) is sent to the transmitter to confirm correct data reception. If the block contained errors, HARQ attempts to correct those errors through coding error correction capabilities. If all errors are corrected, the block is accepted, and an ACK is sent to the transmitter[37].

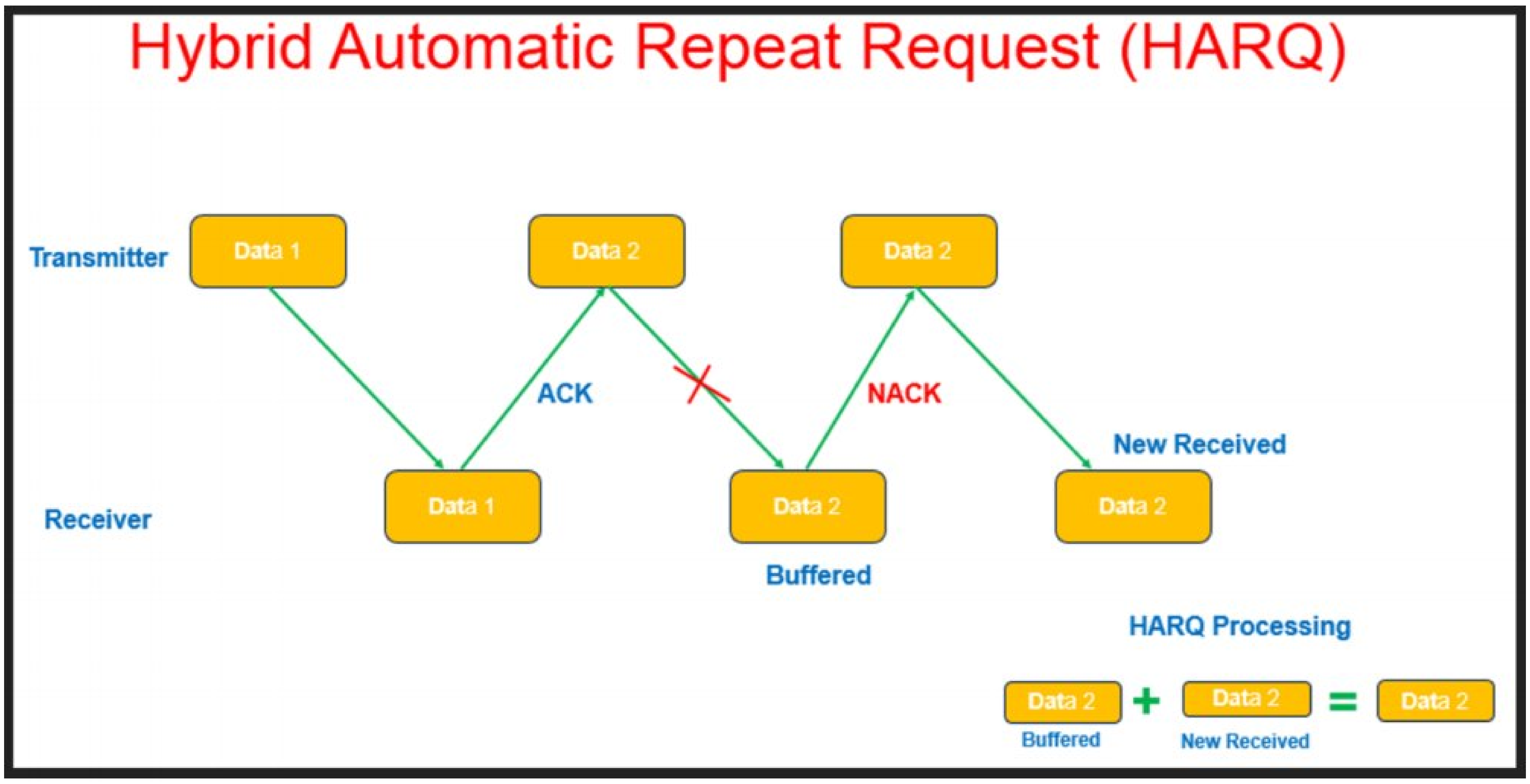

Figure 3.4 HARQ Scheme[38]

3.2.3.2 Characteristics

HARQ consists of two techniques: (a) Forward Error Correction (FEC): FEC is a powerful telecommunications tool that corrects errors based on the type of codes used and the selected code rate. Additionally, it does not require feedback, which means it maintains low additional latency compared to retransmission-based techniques.

ARQ utilizes feedback and retransmission to improve the likelihood of accurate reception. The data block is reviewed for faults at the receiver; if none are discovered, the block is accepted and an ACK is transmitted; otherwise, the block is rejected.

HARQ can be one of two varieties:

- Chase Combining, sometimes referred as Type 1 HARQ

- Incremental Redundancy is often referred to as Type 2 or Type 3 HARQ.

Information = Data + Error Detection Bits (ED) + Forward Error Correction bits for Type 1 HARQ (FEC).

Before transmission, FEC bits are inserted to each message. If the quality of the channel is satisfactory, defects are found and fixed. If channel quality is poor, however, not all faults can be repaired, and the receiver requests retransmission (similar to ARQ). FEC adds a substantial cost.

Information = Data + Error Detection Bits (ED) + Forward Error Correction Bits (FEC).

On each retransmission, however, a unique subset of data, ED, and FEC is transmitted. In the initial transmission, for instance, only a subset of information is transmitted; subsequent transmissions use a different collection of data, ED and FEC.

In Type 2 HARQ, redundancy is added to each retransmission, and the receiver must decode each one in order to receive the packet.

In Type 3 HARQ, each retransmission is sufficient to decode data, and retransmission is performed only if the channel conditions are not optimal and data was not correctly decoded.

3.3 Parameter Briefs

3.3.1 Bandwidth Allocation in 5G

3.3.1.1 Introduction

We will begin by defining bandwidth. Bandwidth is the maximum data transfer rate along a particular path. However, as bandwidth increases, the amount of data that can traverse a network in a particular time period may increase. Customers get a faster Internet connection with minimum to no delay when bandwidth is raised[39].

In addition, let's investigate the network's response to increasing capacity. The network experience of end users can differ depending on their bandwidth capacities. This is why a growing number of business owners favor having a fiber optic network installed at their company. Certified fiber optic professionals often recommend fiber optics because to its ability to provide increased bandwidth and lower latency[40]. And in this day and age, it is essential for businesses to have high bandwidth in their business locations in order to thrive, as higher bandwidth provides, among other benefits, faster application performance, increased user interactivity, improved data transfer capability, the ability to accommodate more simultaneous network visitors, fewer crashes and bounces, multiple concurrent sessions, and improved video streaming.

Bandwidth allocation is the process of assigning radio frequencies to specific applications. Radio spectrum is a finite resource that requires an efficient allocation process.

3.3.1.2 5G Bandwidth Situation

According to some estimations, with 5G, data carried via wireless broadband connections can move at multi gigabit speeds, with peak speeds as high as 20 gigabits per second (Gbps). These speeds surpass those of wireline networks, which is advantageous for applications requiring real-time input. 5G will allow for a significant increase in the amount of data that can be transmitted through wireless networks as a result of increased bandwidth and enhanced antenna technology.

The air interface established by 3GPP for 5G is referred to as New Radio (NR), and it is broken into two frequency bands: a)FR1 (less than 6 GHz) and b)FR2 (24–54 GHz).

3) Frequency band 1 (less than 6 GHz)

The maximum channel bandwidth defined for FR1 is 100 MHz, sometimes known as sub-6, due to the shortage of continuous spectrum in this busy frequency range. 3,3–4,2 GHz is the band most commonly utilized for 5G in this frequency range. The Korean carriers utilize the 3.5 GHz n78 band.

Some parties used the term "mid-band frequency" to refer to the portion of this frequency range that had not been utilized in prior generations of mobile communication.

b) Range of frequencies 2 (24–54 GHz).

The lowest channel bandwidth defined for FR2 is 50 MHz and the highest is 400 MHz, with 3GPP Release 15 supporting two-channel aggregation. The higher the frequency, the better the capacity to enable rapid data transport. Signals of this frequency are referred to as mm Wave.

3.3.1.3 How it’s unique from LTE

LTE carriers have a maximum bandwidth of 20 MHz, which can be coupled to generate a channel bandwidth of 100 MHz in LTE-Advance and 640 MHz in LTE-Advanced Pro. In comparison, 5G NR has a maximum carrier bandwidth of up to 100 MHz in frequency range 1 (FR1: 450 MHz to 6 GHz) or up to 400 MHz in frequency range 2 (FR2: 24.25 GHz to 52.6 GHz), which can be aggregated to a maximum bandwidth of 800 MHz.

At lower frequencies, the wireless spectrum comprises of low- and midband frequencies. Low-band frequencies vary from 600 to 700 megahertz (MHz), whereas mid-band frequencies range from 2.5 to 3.5 gigahertz (GHz) (GHz). This is in contrast to mmWave transmissions with a high frequency band, which operate between 24 and 39 GHz. Thus, "Low-band 5G" and "Mid-band 5G" employ frequencies between 600 MHz and 6 GHz, specifically 3.5-4.2 GHz[41].

As a result, 5G supports expansive bandwidth ranges.

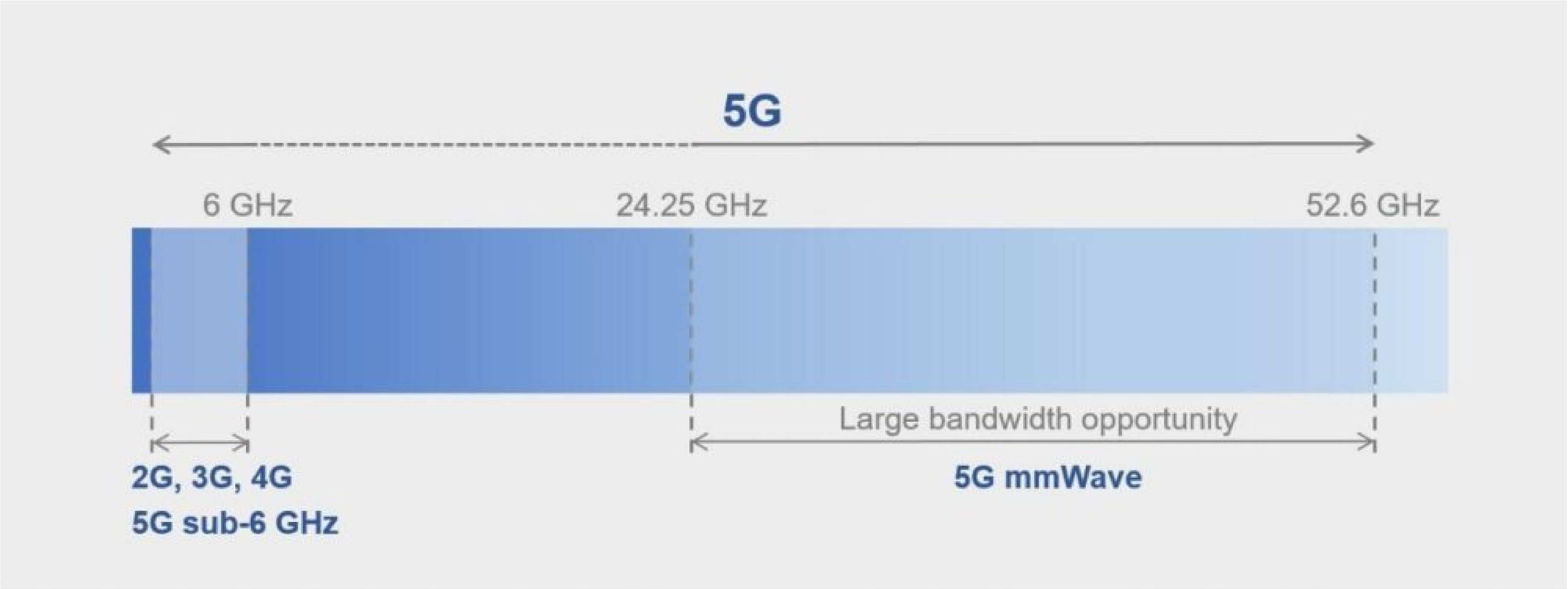

Figure 3.5 5G Bandwidth Range[42]

3.4 Adaptive Method of Bandwidth increase

3.4.1 Introduction

Bandwidth is the greatest amount of data that may be transferred or the maximum throughput capacity of a network. It indicates how much data may be transferred and received simultaneously. The units of bandwidth measurement are bits, megabits, and gigabits per second. The need for higher bandwidth among consumers continues to rise, particularly due to the rapid expansion of video traffic, which now accounts for about 90 percent of all internet traffic.

3.4.2 Procedure for increasing the Bandwidth

In packet-switched network traffic management and control, it has been difficult to efficiently allocate bandwidth to provide quantitative packet-level QoS (Quality of Service) to aggregate traffic due to the unpredictability and lack of knowledge regarding the statistical characteristics of aggregate traffic. Using static bandwidth allocation with inaccurate traffic data results in an underused network or a failure to meet the QoS requirement. Therefore, the ideal strategy for our research is to adopt Adaptive Bandwidth Control (ABC) from [43], in which the assigned bandwidth is routinely adjusted throughout the packet-level time scale to satisfy a specific QoS criterion.

ABC is an alternative to static bandwidth allocation for attaining aggregate QoS (per-node) in a straightforward and effective manner. Under static bandwidth allocation, each node reserves the required bandwidth calculated for each aggregate traffic flow upon its arrival (using some protocol such as RSVP). ABC, on the other hand, begins with an initial bandwidth allocation to the queue and updates it over time on a packet-level time scale, such as on the order of seconds, to ensure that the allocated bandwidth is just sufficient to meet the QoS criteria.

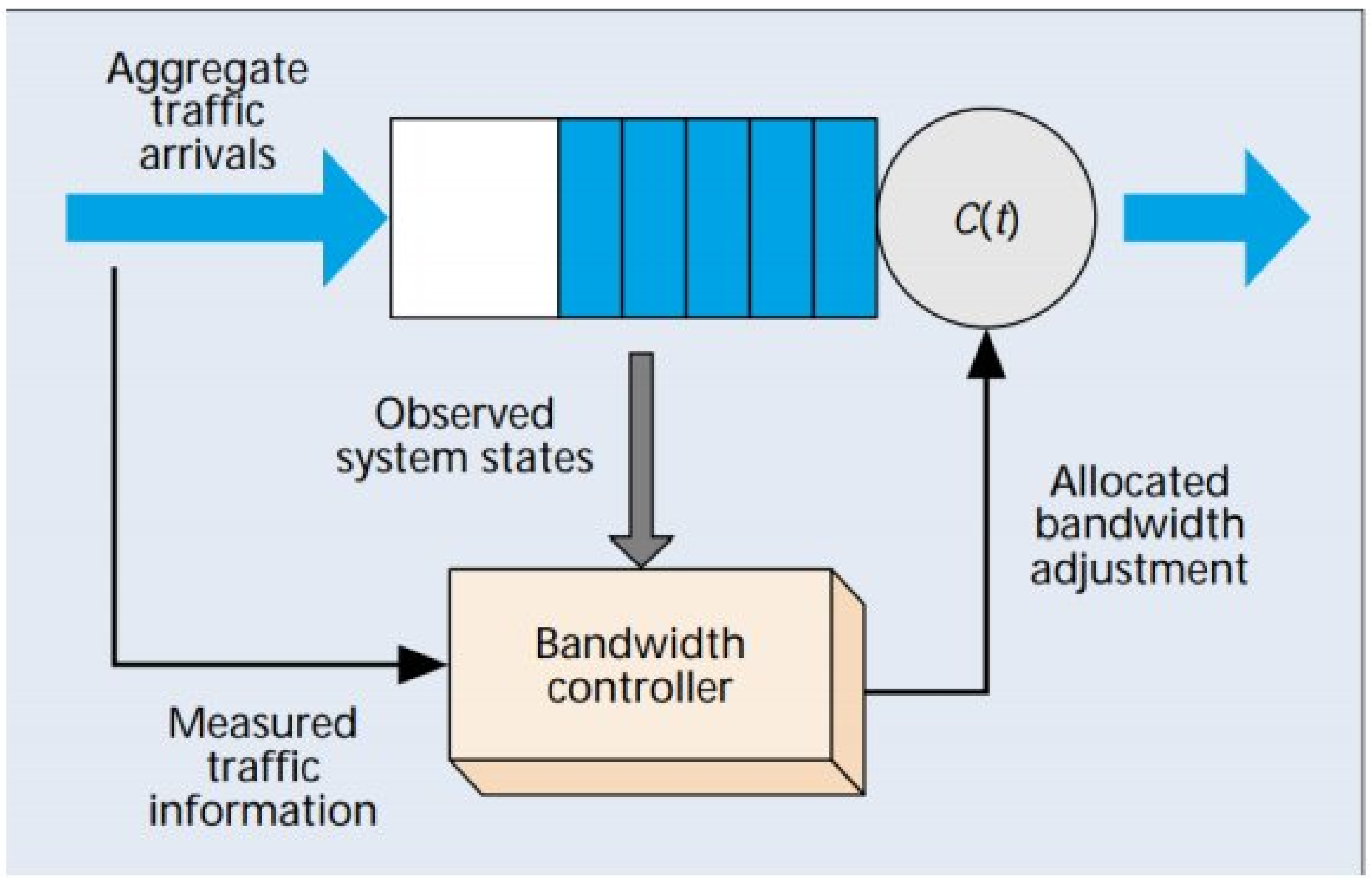

Figure 3.6 Adaptive increase of Bandwidth Algorithm

For our purpose of aggressive Bandwidth increase, any of the Adaptive Bandwidth Control algorithms may be used as given by Pitsillides[44], Rampal[45], Hsu[46] or any others.

3.5 Latency in 5G

3.5.1 Introduction

Let's examine the nature of delay. Latency is the interval between the commencement of an event and the observer's awareness of it. In networking and telecommunications, latency is the period of time between a sender producing a change in a system's state and an observer receiving the information. Informally, network delay and 'lag' are frequently used interchangeably[47].

Now, latency, i.e., how quickly a data can be sent across the network, in most cases manifests itself in the form of a delay. For example when we are making an international phone call, we often come across delay compared to our local calls and the explanation is simple cause data have to come across a wide range of devices to reach us. So when we are using real time services like a phone call or a video conference, latency quickly becomes a challenging issue. Video conferencing, financial transactions, remote operation machinery, automation in factory, smart traffic lights, are just a few example of digital services where the latency needs to be as low as possible. While previous generations of mobile networks did meet certain latency requirements none were really considered candidates to address the needs of vertical industries and critical real time applications.

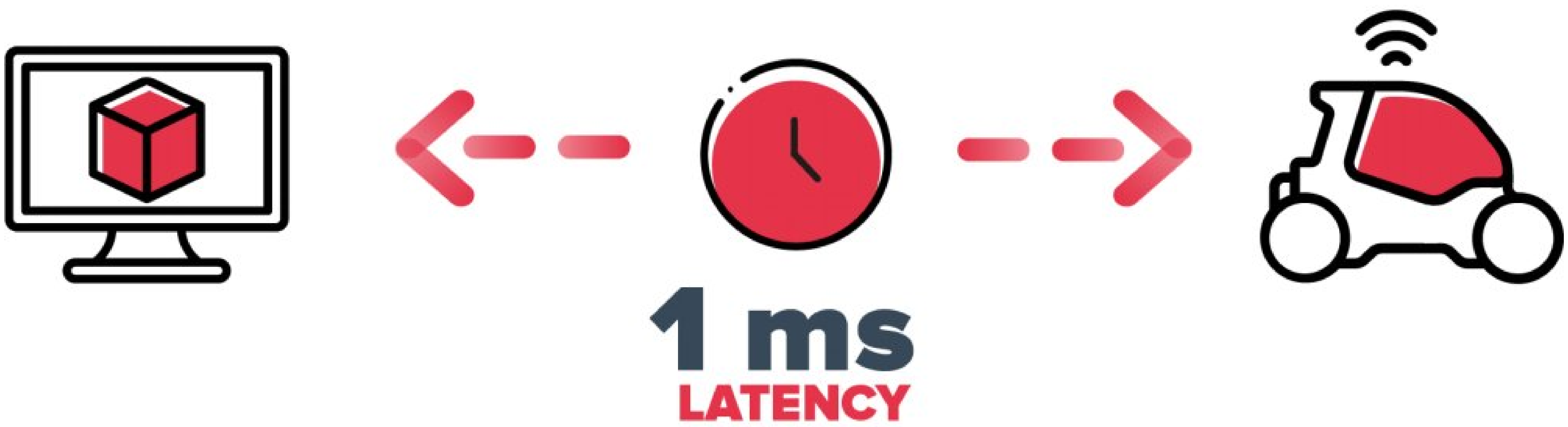

Figure 3.7 Latency in 5G[48]

3.5.2 How 5G URLLC improves the latency

5G provides a substantial reduction in latency, making it suitable for an entirely new set of services. The whole end-to-end latency of this wireless generation is anticipated to drop by a factor of ten. This can significantly enhance existing user experiences and open the door to whole new ones.

The 5G URLLC scheme is set up to provide consistent network characteristics that allow new applications to be built. Latency in 3G is typically 100 ms and in 4G, it's around 20 to 30 ms and currently in 5G, it's around 4-5 ms. 5G URLLC targets providing ultra-responsive connections with even more reduced latency on the air interface, and on the end to end devices, and also the 5G base station[49].

3.6 Reliability in 5G

3.6.1 Introduction

Let's investigate what dependability means. Reliability is the property of any computer-related component (such as software, hardware, or a network) that continuously performs as intended. In communication networks, it indicates that calls and messages are assured to arrive at their destination complete, securely, and in the order they were sent. It is the network's capacity to continue providing identical services in the event of a failure[50].

As wireless and mobile services continue to proliferate, infrastructure problems in the network become increasingly evident. Emerging wireless applications, such as e-commerce and high-bandwidth Internet access, may be hindered by failures in addition to existing voice and data consumption. In all industrial applications, reliability is an essential metric that incorporates all aspects, including service availability, dependability, availability, maintainability, and system integrity[51].

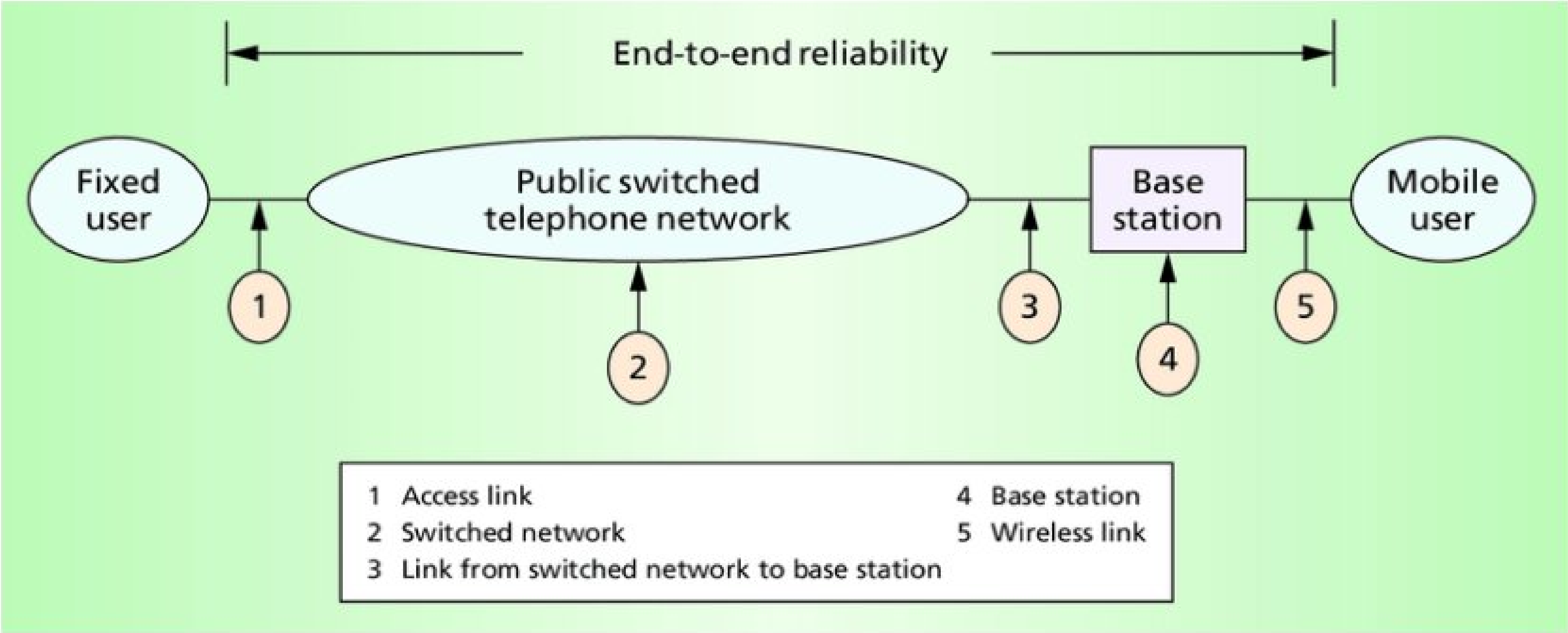

Figure 3.8 End to End Reliability in 5G

3.6.2 How 5G URLLC improves the Reliability

5G key performance indicators (KPI) stipulated that Ultra Reliable Low Latency Communication (URLLC) service needs must have a fail limit of no more than 10-5, or 0.001% of 20 bytes. This packet and latency service level is typically offered by network service providers and has a reliability and availability of approximately 99.999 percent and 99.999 percent, respectively. The reliability performance indicator fails if:

- An excessive number of packets are dropped
- Too many packages come late and in excess
- Packets include mistakes

This low packet error rate is advantageous, but networks must be accessible around-the-clock, every day of the year. Customers are expected to receive a service with high dependability and uninterrupted connectivity.

3.7 Transport Block

3.7.1 Introduction

Transport Block is a data packet that is transmitted downhill by the transmitter and received upward by the receiver. Before being mapped onto the PDSCH for transmission through the air-interface, the Physical layer of a Transport Block is processed at the transmitter. UE must identify the Transport Block Size (TBS) prior to attempting to decode data received over the PDSCH[52]. The UE combines semi-static information provided by RRC signaling with dynamic information provided by Downlink Control Information (DCI) on the PDCCH. The UE begins by determining how many Resource Elements are available for data transport within the bandwidth of a single Resource Block. Resource block (RB) is the fundamental LTE resource entity in the frequency domain, occupying approximately 180 kHz. A terminal may be assigned one or more resource blocks for data transmission and reception. Data packets from a higher layer are multiplexed onto transport blocks and given to the LTE physical layer for transmission. One transport block (or two in the case of MIMO spatial multiplexing) can be transmitted each LTE transmission time interval of 1 millisecond.

3.7.2 How TB (Transport Block) appears in 5G

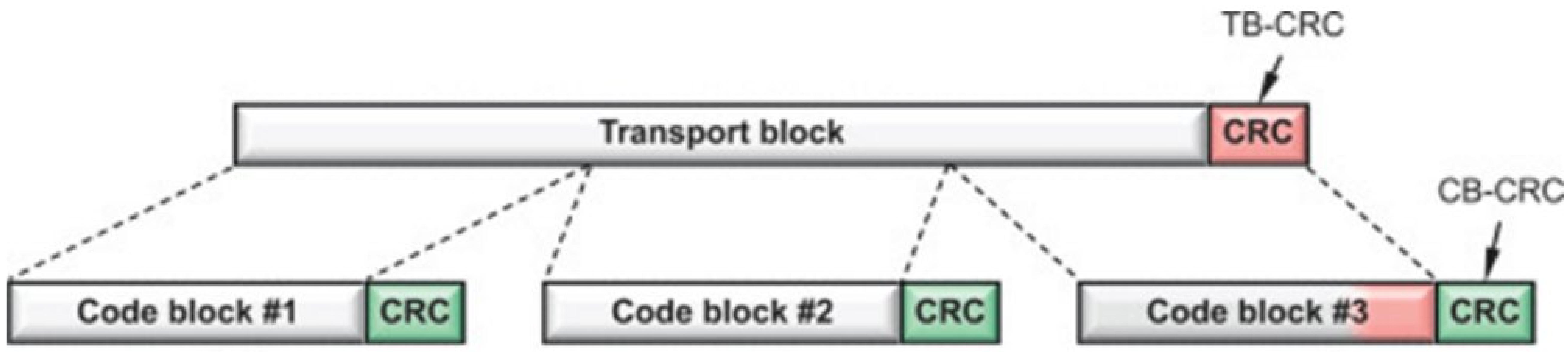

Figure 3.9 5G Transport Block

In 5G New Radio, a Transport Block is the payload that is passed between the MAC and Phy Layers, particularly for shared data channels such as PDSCH and PUSCH. Before being sent to the channel coding and rate matching modules, transport blocks are divided into code blocks. The code blocks are concatenated following their output by the rate matching module. Each transport block is appended with CRC (cyclic redundancy check), which allows error detection. The transport block may have up to one million bits, whereas the code block may include up to 8448 bits.

This figure provides a summary of the channel coding steps. First, a CRC is added to the transport block to enable error detection, followed by segmentation of the code block. Each code block is LDPC-encoded and rate matched independently, including physical-layer hybrid-ARQ processing, and the resulting bits are concatenated to represent the coded transport block.

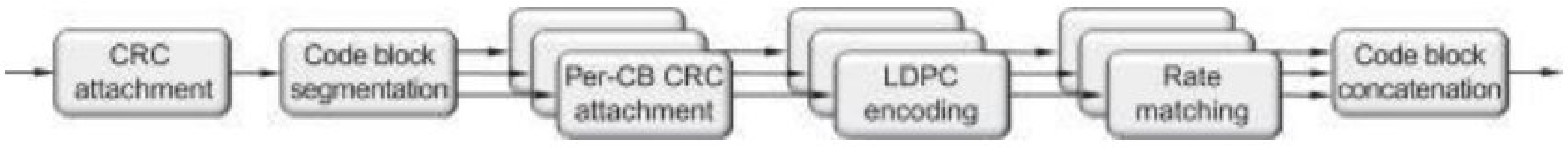

Figure 3.10 Steps of Channel Coding[53]

3.7.3 Characteristics

Determination of the size of the Transport Block is done by assessing the following factors[54]:

1. No. of Transmission Layers
2. Modulation Order
3. Coding Rate
4. No. of Physical Resource Block
5. Transmission Duration

3.8 Channel Quality Indicator (CQI)

3.8.1 Introduction

CQI is an abbreviation for Channel Quality Indicator. As its name suggests, it is an indicator that conveys information on the quality of the communication channel. LTE has multiple performance indicators. CQI is reported by the UE in the uplink direction. This data is transmitted by the UE to the network[55].

Essentially, the UE/Mobile calculates the CQI for the downlink channel in LTE. And the UE mostly accomplishes this by evaluating channel quality using the downlink cell-specific reference signal. The UE is responsible for calculating the SINR depending on the signal strength of the reference signal, and it often provides a lookup table indicating how the SINR corresponds to the CQI. Upon completion, UE transmits this CQI via PUCCH or PUSCH.

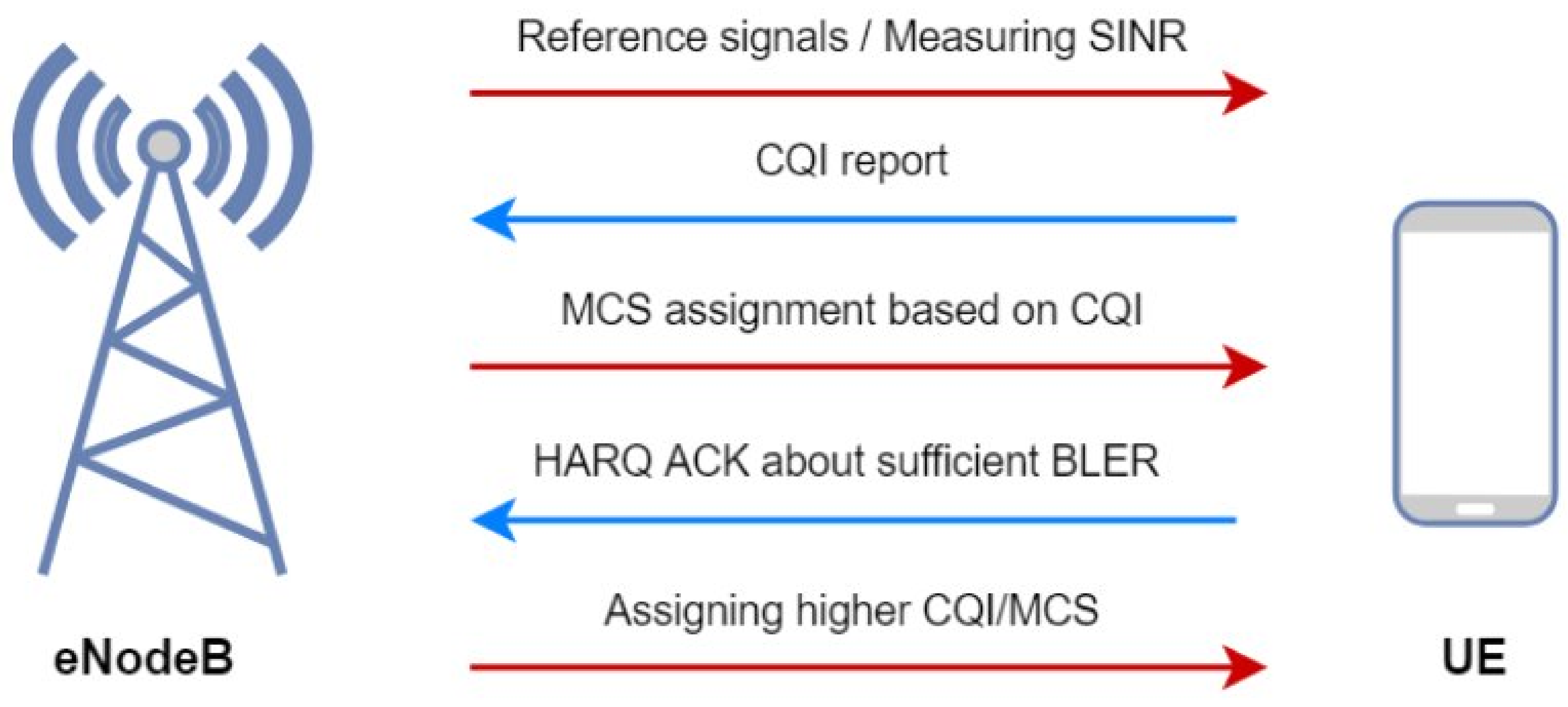

Figure 3.11 CQI Assigning

3.8.2 Characteristics

CQI is typically a 4-bit integer and is derived from the reported signal-to-interference-plus-noise ratio (SINR) at the user equipment (UE). The CQI estimation procedure considers the UE's capabilities, such as the number of antennas and the type of receiver utilized for detection. Estimation of CQI takes into account the highest modulation and code rate at which the block error rate (BLER) of the studied channel does not exceed 10%. The CQI supports discrete values ranging from 0 to 15

3.9 Modulation and Coding Scheme (MCS)

3.9.1 Introduction

The Modulation Coding Scheme (MCS) index is a well-known industry indicator that takes into account many aspects of a Wi-Fi connection between a client device and a wireless access point, such as data speed, channel width, and the number of antennas or spatial streams in the device[56].

The Modulation and Coding Scheme (MCS) specifies the number of relevant bits that can be conveyed by a single symbol in any communication technique. As opposed to 5G and 4G, a symbol is defined as a Resource Element (RE), and MCS is defined as the number of meaningful bits that can be transmitted per RE. MCS is dependent on the quality of the radio signal in a wireless link; the higher the quality, the higher the MCS and the greater the number of useful bits that can be transferred within a symbol, whereas poor signal quality results in a lower MCS, allowing for the transmission of less pertinent data.

3.9.2 Characteristics

MCS defines the following two aspects[56]:

- Code rate: Code rate is defined as the ratio of usable bits to the total bits transferred (Usable + Redundant Bits). The ratio between the numbers of bits mapped to PDSCH and the number of bits at the top of the Physical layer. It is also a measurement of the redundancy provided by the Physical layer. A poor coding rate is associated with an increase in redundancy. Consequently, Code Rate = n/(n+k)

- Modulation: Modulation specifies the number of bits that can be conveyed by a single RE, regardless of whether they are usable bits or parity bits. 5G NR supports the modulation schemes QPSK, 16 QAM, 64 QAM, and 256 QAM. With QPSK, two bits can be communicated each RE, while with 16QAM, four bits can be transmitted, 64QAM, six bits, and 256QAM, eight bits. These 16, 64, and 256 are known as QAM Modulation's modulation order. The number of bits for every modulation order can be determined using the formula 2n. For example, 22=4, 23=8, 24=16.

The MCS table maps the CQI value to the concurrent modulation and coding rate, as presented in the next page:

	Before Rel.12			Rel.12 and beyond		
CQI	Modulation	Code rate	Bits per RE	Modulation	Code rate	Bits per RE
0	Out of range					
1	QPSK	0.0762	0.1524	QPSK	0.0762	0.1524
2	QPSK	0.1172	0.2344	QPSK	0.1885	0.377
3	QPSK	0.1885	0.377	QPSK	0.4385	0.877
4	QPSK	0.3008	0.6016	16QAM	0.3691	1.4764
5	QPSK	0.4385	0.877	16QAM	0.4785	1.914
6	QPSK	0.5879	1.1758	16QAM	0.6016	2.4064
7	16QAM	0.3691	1.4764	64QAM	0.4551	2.7306
8	16QAM	0.4785	1.914	64QAM	0.5537	3.3222
9	16QAM	0.6016	2.4064	64QAM	0.6504	3.9024
10	64QAM	0.4551	2.7306	64QAM	0.7539	4.5234
11	64QAM	0.5537	3.3222	64QAM	0.8525	5.115
12	64QAM	0.6504	3.9024	256QAM	0.6943	5.5544
13	64QAM	0.7539	4.5234	256QAM	0.7783	6.2264
14	64QAM	0.8525	5.115	256QAM	0.8634	6.9072
15	64QAM	0.9258	5.5548	256QAM	0.9258	7.4064

Table 3.1 MCS Table[57]

When all connection parameters are known, the MCS table serves as a lookup that may be used to determine which data rate will be negotiated between two stations. There is a unique MCS index for each feasible combination of modulation, coding rate, number of spatial streams, channel width, and guard interval.

3.10 Performance Metrics

3.10.1 Signal to Noise Ratio (SNR)

For optimal performance in a wireless setting, it is essential that wireless devices can identify incoming signals as valid information they should be listening to and reject background signals on the spectrum. SNR, or Signal-to-Noise Ratio, is a notion that guarantees optimal wireless performance. The SNR is the ratio between the wireless signal received and the noise floor. The noise floor consists of erroneous background broadcasts made by equipment that are either too far away for the signal to be decipherable or that are unwittingly causing interference on the same frequency[58].

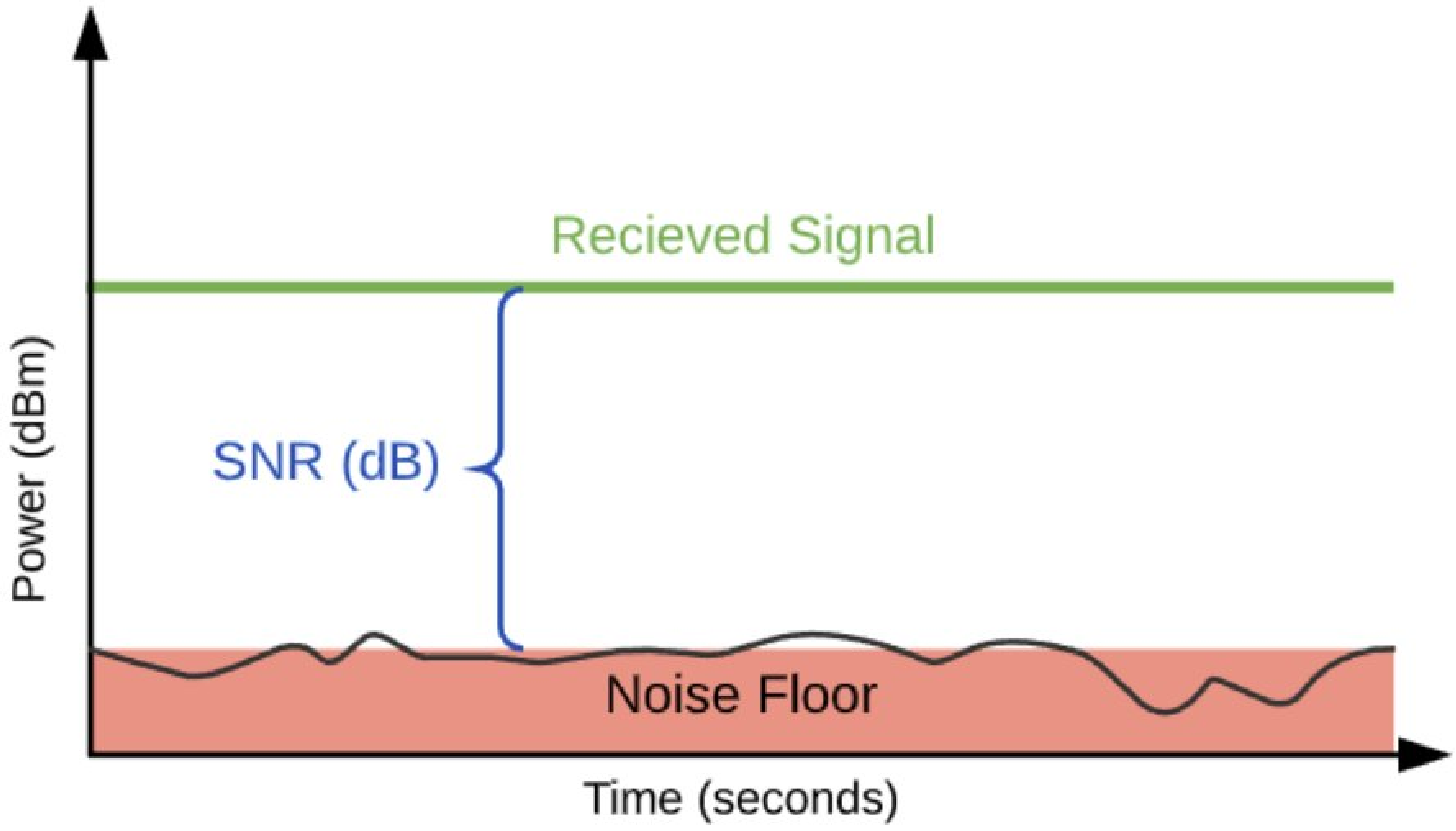

Figure 3.12 Signal-to-Noise ratio

SINR is a comparable statistic that also takes interference in the system into consideration (Signal to Interference and Noise Ratio). The signal-to-interference-plus-noise ratio (SINR) is the ratio between the received signal level and the sum of interference and noise. The SINR parameter is not included in the 3GPP specification. User equipment (UE) does not return results to the network. SINR is only measured and utilized in UE. It is utilized to represent the relationship between radio circumstances and throughput more precisely. For instance, it can be utilized to calculate CQI value.

3.10.2 Frame Error Rate (FER)

FER is a metric that measures the quality of a signal connection. If the FER is excessively high (too many errors), the link could be severed.

Sub frame, slot, and symbol configurations are displayed in the 5G NR frame structure. Frame error rate is the ratio of data received with errors to the total amount of data. Physical layer frames are submitted. Frames are made up of symbols. Bits constitute symbols. Thus, FER is the chance that any symbol contains an error, whereas SER is the likelihood that each bit has an error.

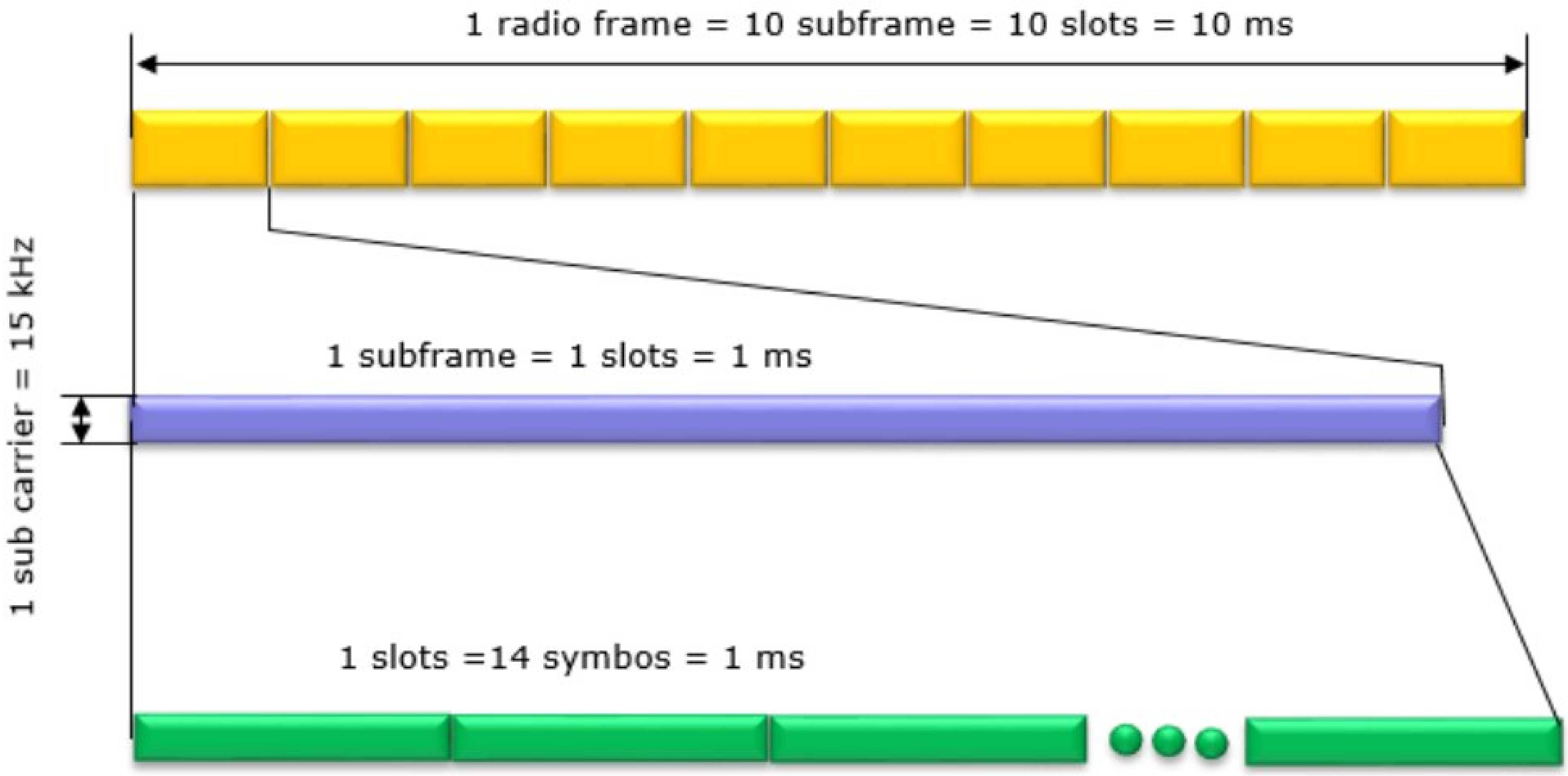

Figure 3.13 A Typical 5G Frame Structure[59]

The Frame Error Rate (FER) is used to evaluate the performance of the receiver of a mobile station. FER measurements are restricted to the forward traffic channel only (F-Traffic). The test equipment transmits a series of frames to the mobile station during a FER measurement. Each frame contains CRC (Cyclic Redundancy Code) bits, which offer a frame quality indication and allow the mobile station to check that the frame has been decoded correctly. The test set maintains a running tally of the measured frames and the number of frames with bit errors, providing a suitable metric for evaluating the quality of the radio link.

3.10.3 Bit Error Rate (BER)

As its name implies, bit error rate is the frequency of transmission system errors. The bit error ratio (also BER) is the number of bit errors divided by the total number of bits sent over a given time interval. Bit error ratio is a unit less performance statistic that is commonly expressed as a percentage. This is directly proportional to the amount of errors that occur in a string of a certain number of bits. A basic formula expresses the definition of bit error rate: BER = Incorrect bits divided by the total amount of bits

Consider the following examples of transmitted and received bit sequences: 1 0 0 0 0 1 0 0 1 and 0 1 0 1 0 1 0 1 0 0 1.

In this instance, there are three bit errors (highlighted bits). 3 incorrect bits divided by 9 transferred bits results in a bit error rate of 0.333, or 33.3%.

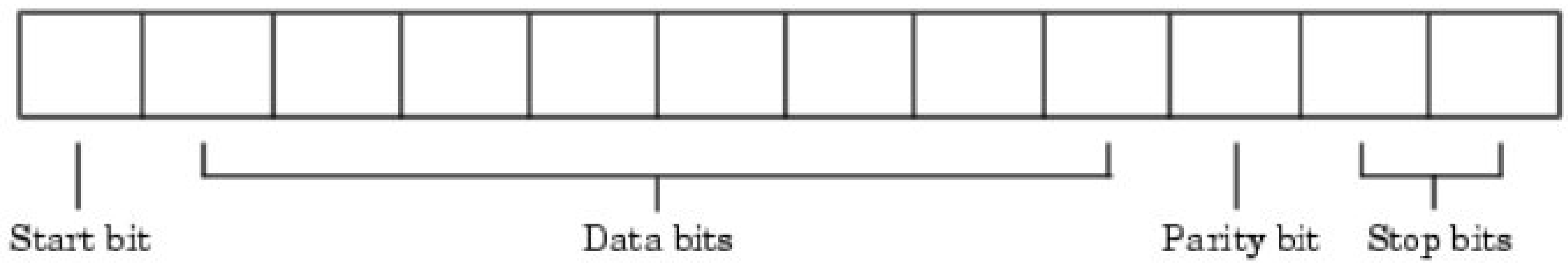

Figure 3.14 5G data bit

The Bit Error Rate is a crucial performance statistic for data networks. When transmitting data across a radio/wireless link or a wired telecommunications link, the most essential characteristic is the number of errors that will be present in the data at the remote end. BER is therefore applicable to fiber optic lines, ADSL, Wi-Fi, cellular communications, and IoT networks, among others.

Although data lines may use drastically different types of technology, the foundations of determining the bit error rate remain the same. It is possible for errors to be introduced into the system during data transfer across a data link. If data inaccuracies are introduced, the integrity of the system may be compromised. Therefore, it is essential to analyze the system's performance, and bit error rate (BER) is an effective tool for doing so. BER measures the full end-to-end performance of a system, including the transmitter, the receiver, and the medium in between. In this sense, BER permits testing of the actual performance of a system in operation, as opposed to evaluating the component parts and assuming that the whole will function well when completed.

3.10.4 Throughput

Network throughput (or simply throughput) is the rate of successful message delivery via a communication channel, such as Ethernet or packet radio, in communication networks. These messages' related data is transmitted via the physical link or a chosen network node.

Throughput is commonly measured in bits per second (bit/s or bps) and sometimes in data packets per second (p/s or pps) or data packets per time slot, which has evolved to include bytes per second (Bps), kilobytes per second (KBps), megabytes per second (MBps), and gigabytes per second (Gbps) (GBps)[60].

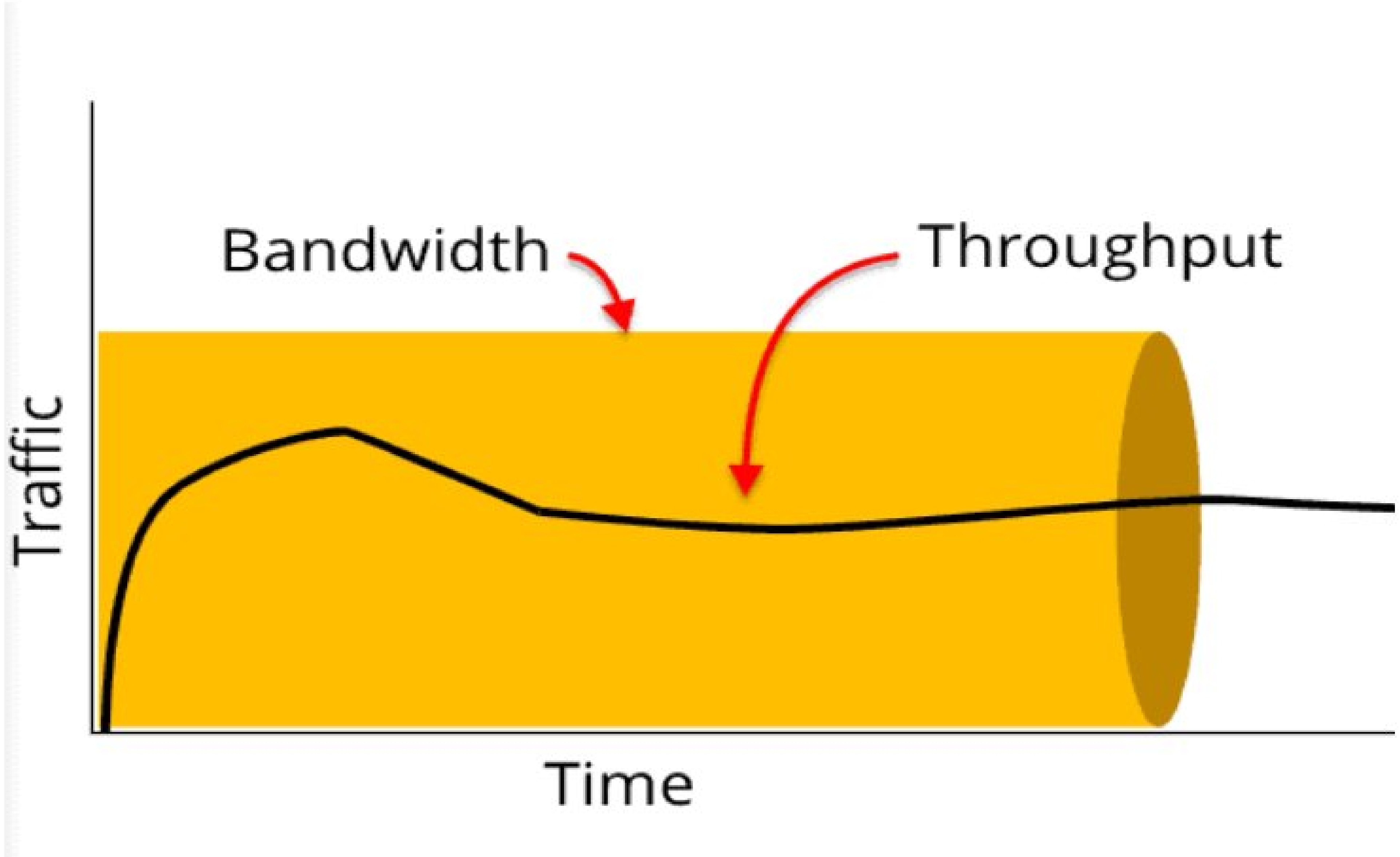

Figure 3.15 Throughput in 5G

System throughput, also known as aggregate throughput, is the sum of the data rates provided to all network terminals. Throughput is essentially synonymous with digital bandwidth consumption; it may be mathematically analyzed using the queueing theory, where the load in packets per time unit is indicated as the arrival rate and the throughput is denoted as the departure rate[61].

To determine the throughput rate for a given number of aggregated carriers in a band or band combination for 5G NR, the Number of Component Carriers, Modulation Order, and Modulation Frequency must be considered. Tally of layers Scaling Factor NR calculation study the amount of PRBs assigned (Physical Resource Block) overhead[62].

3.11 Procedure

So, the basic idea here was to reduce the number of times that HARQ retransmits in Downlink Transmission. To achieve that, we increase the bandwidth allocation. This implies that the transport block size will increase.

Transport block is just the packet of data that underwent physical layer processing at the transmitter before being mapped into the PDSCH for transfer across the air interface

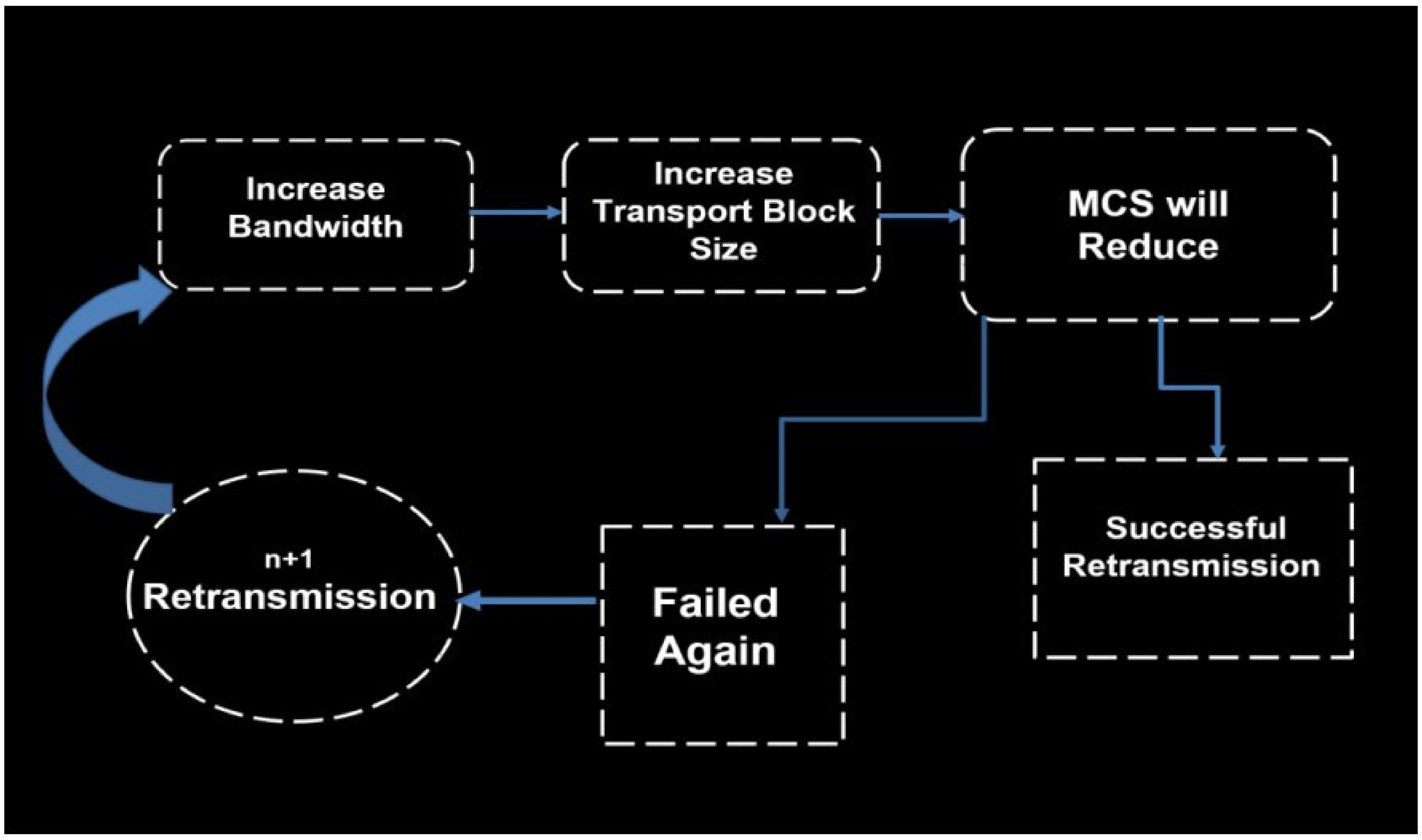

Figure 3.16 Latency Reduction process flowchart

The question comes as to why the bandwidth was increased for URLLC. It's because there is no certainty that this retransmission will bring forward the correct data bit. This transmission could be erroneous as well. Then it will lead to again another retransmission heightening latency periods. Thus, if we increase the bandwidth, the probability of a successful transmission increases.

So we keep on increasing the bandwidth aggressively in an adaptive method which will select the best frequency levels for us. Suppose we used 720 Hz which brought a retransmission. So we will increase it to 1440 Hz. Therefore, success rate of successful transmission will increase.

To increase the bandwidth, we use adaptive method with the AMC algorithm as shown above.

When the transport block size increases, MCS level goes down. MCS refers to Modulation and Coding Scheme which defines two aspects: Code Rate and Modulation.

Modulation levels can be QPSK, 16 QAM, 64 QAM, and 256 QAM. Both are mapped according to the CQI table.

CQI table is the channel quality indicator. It's used by the mobile to indicate channel quality to the base station. It ranges from 0 to 15. It specifies Modulation levels and coding rates for the User Equipment.

As the modulation level is lowered, the chances of further retransmissions also reduces, thus bringing down latency.

CHAPTER 4

RESULT ANALYSIS

Here is a preview of the findings of the simulation. Here, the curves of FER versus SNR are displayed. Various simulations of the system using various scenarios have been conducted. By simulating the system by modifying the aforementioned parameters and exposing it to various scenarios, as well as by employing a set of prediction models, the following findings are produced, computed over a range of SNR values for a set of potential HARQ process number of broadcasts.

4.1 FER performance in Downlink

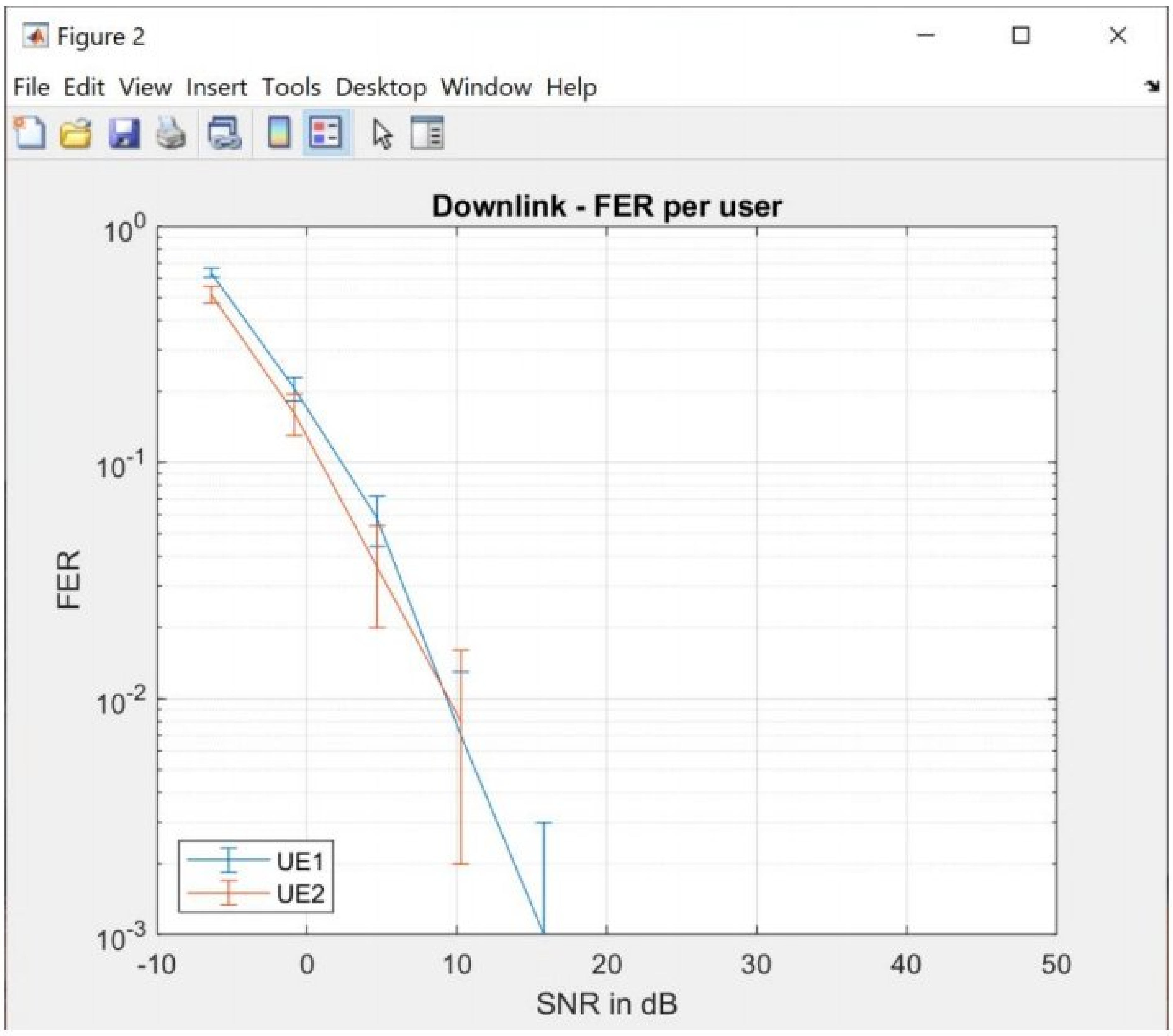

Figure 4.1 Performance for CQI=1

The simulation maps the decrease of Frame error rates as SNR improves in downlink channels

Continued performance

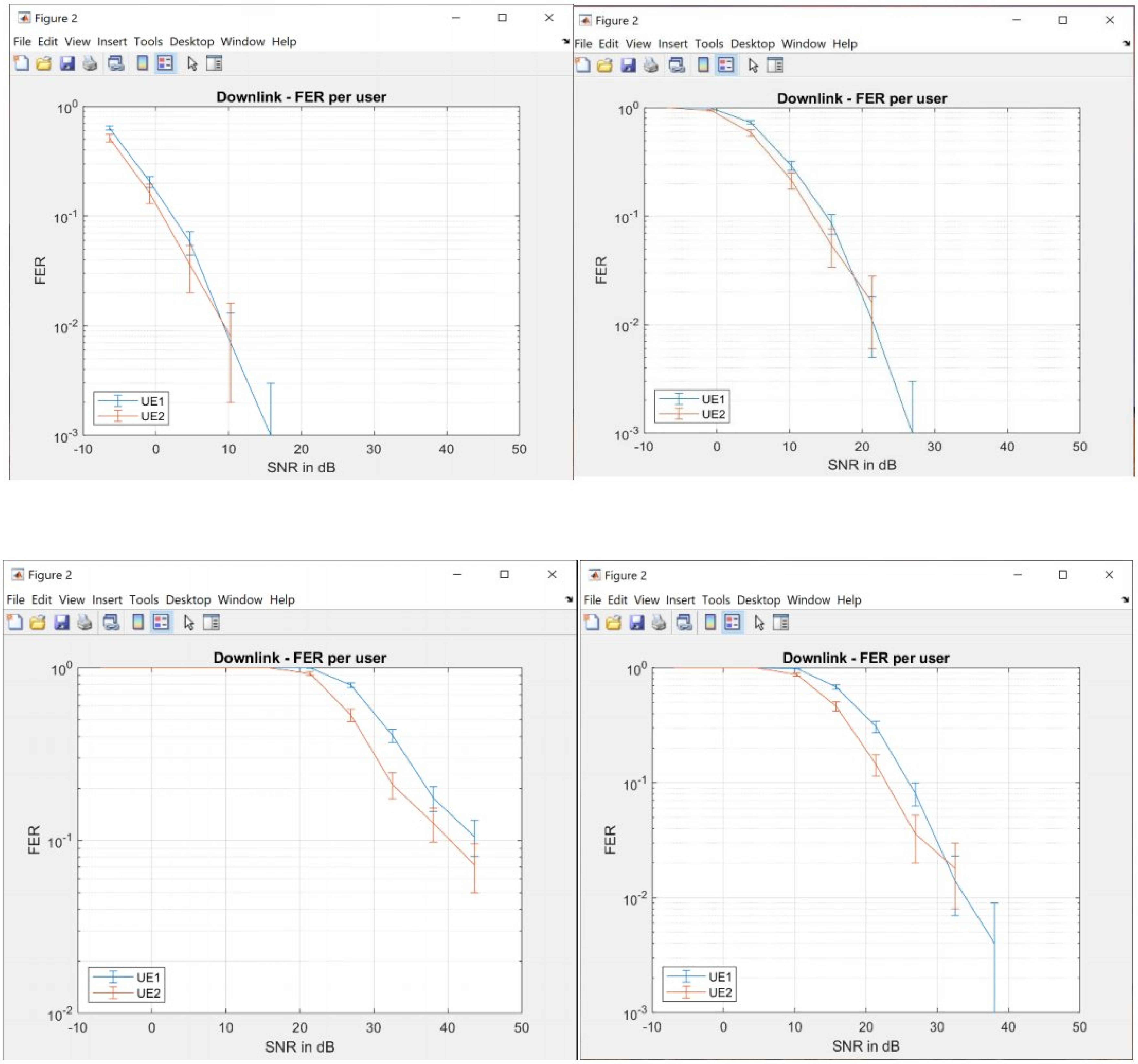

Figure 4.2 Performance for CQI=1, 4, 9, 15

These graphs map out the decrease of frame errors as the CQI keeps increasing. Therefore, successful transmissions are increasing.

4.2 FER performance in Uplink

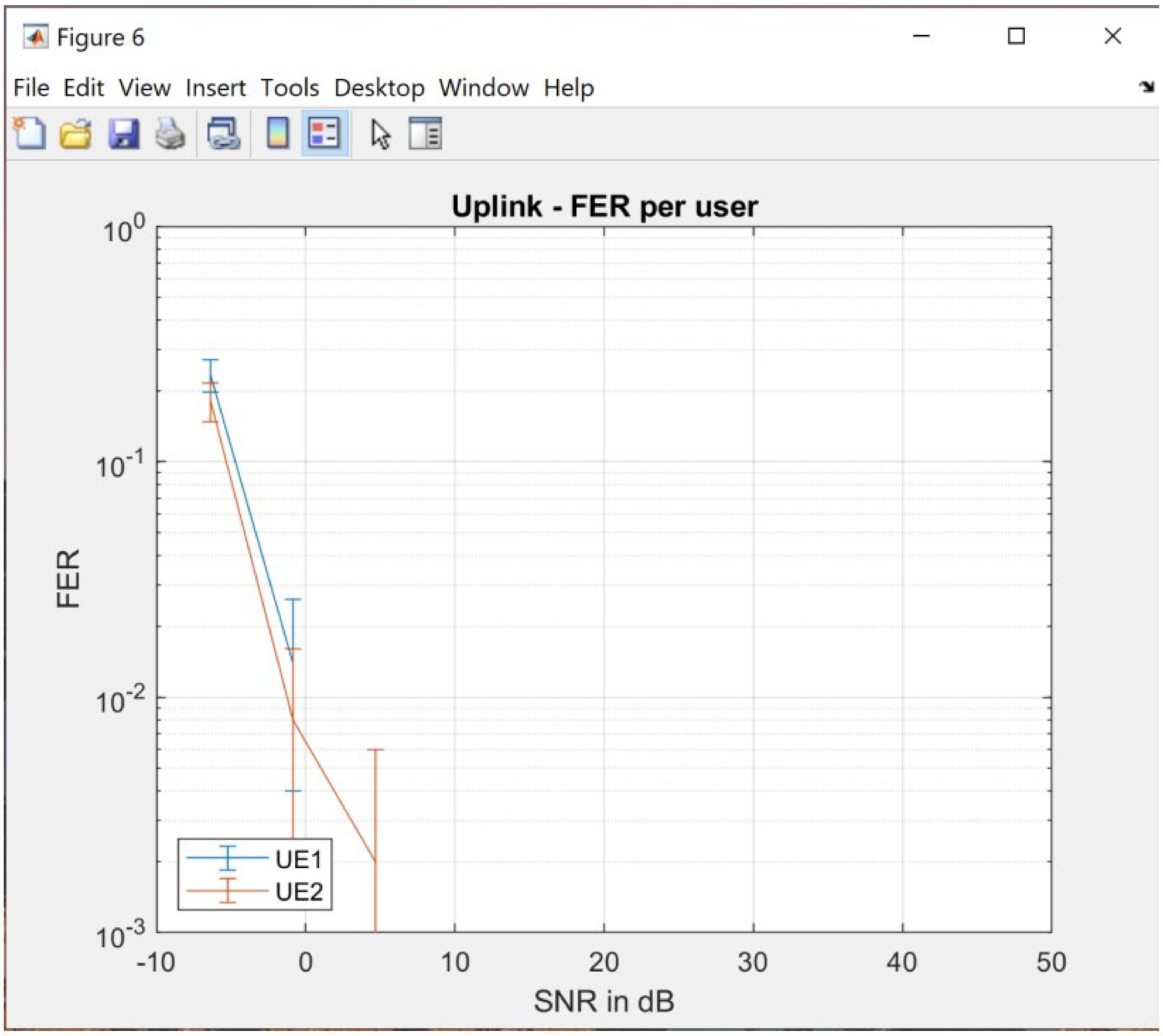

Figure 4.3 Performance for CQI=1

This simulation maps the decrease of Frame error rates as SNR improves in uplink channels.

Continued Performance

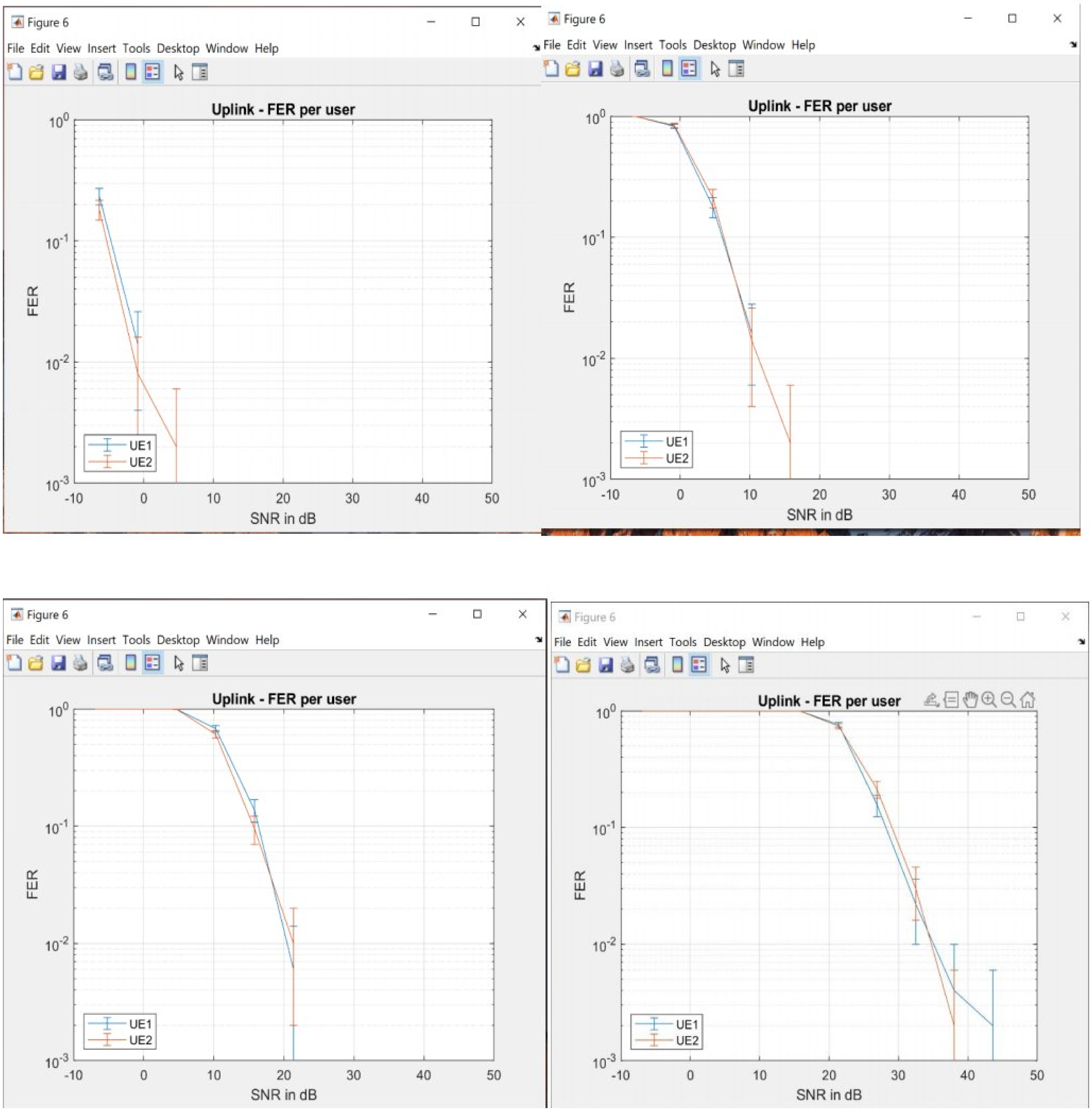

Figure 4.4 Performance for CQI=1, 4, 9, 15

These graphs show the decrease of frame errors in the uplink channels as well as the CQI keeps increasing. Therefore, unsuccessful transmissions keep decreasing. Here we can see as the CQI increases and the modulation order is thus going up, just as the SNR increases, Frame error rates decrease. Same for the uplink, FER reduces as SNR peaks.

4.3 BER performance in Downlink

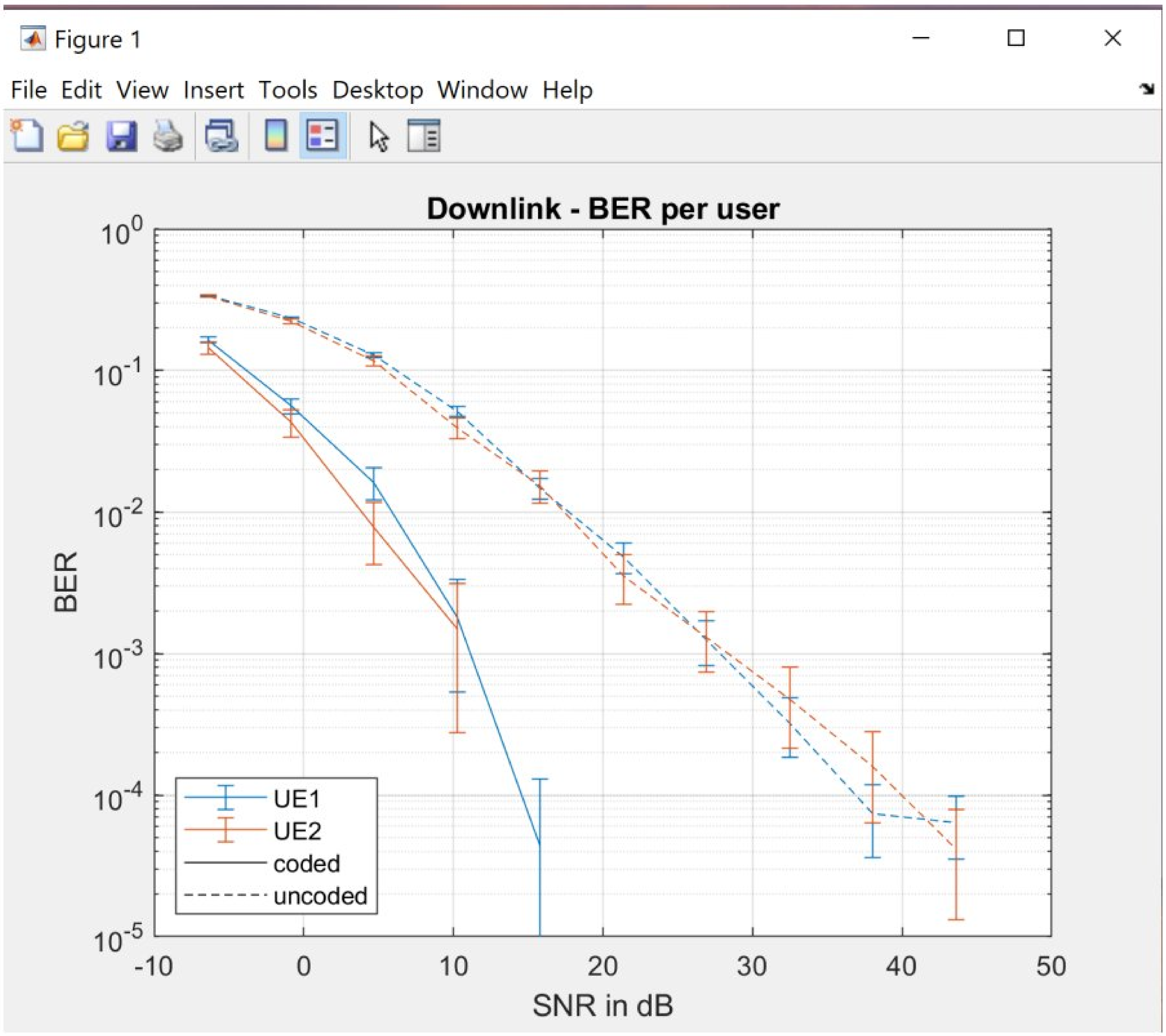

Figure 4.5 Performance for CQI=1

This simulation calculates the decrease of bit error rates as SNR improves in downlink channels.

Continued Performance

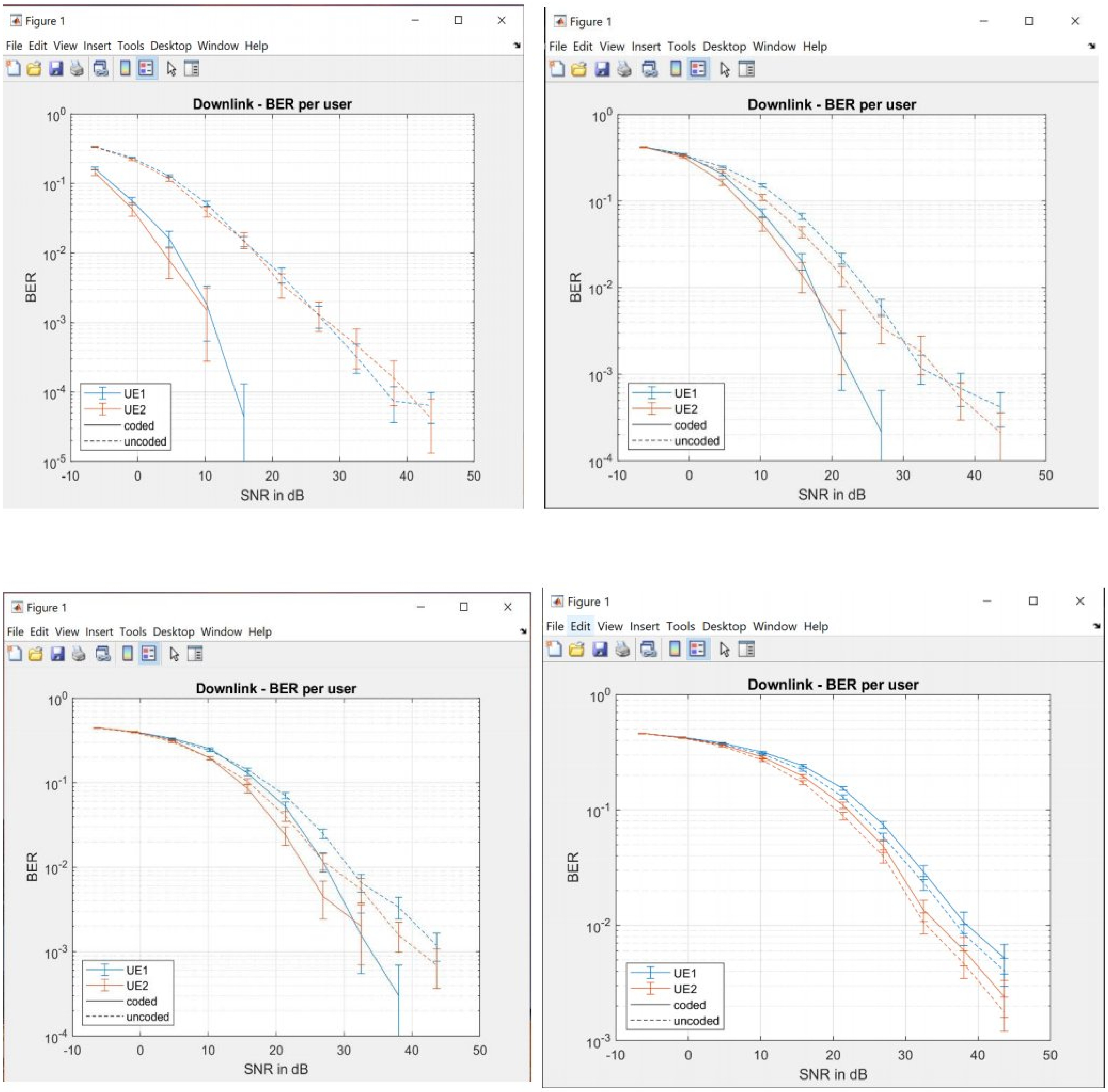

Figure 4.6 Performance for CQI=1, 4, 9, 15

Similarly, the bit error rate keeps reducing, for the rising CQI.

4.4 BER performance in Uplink

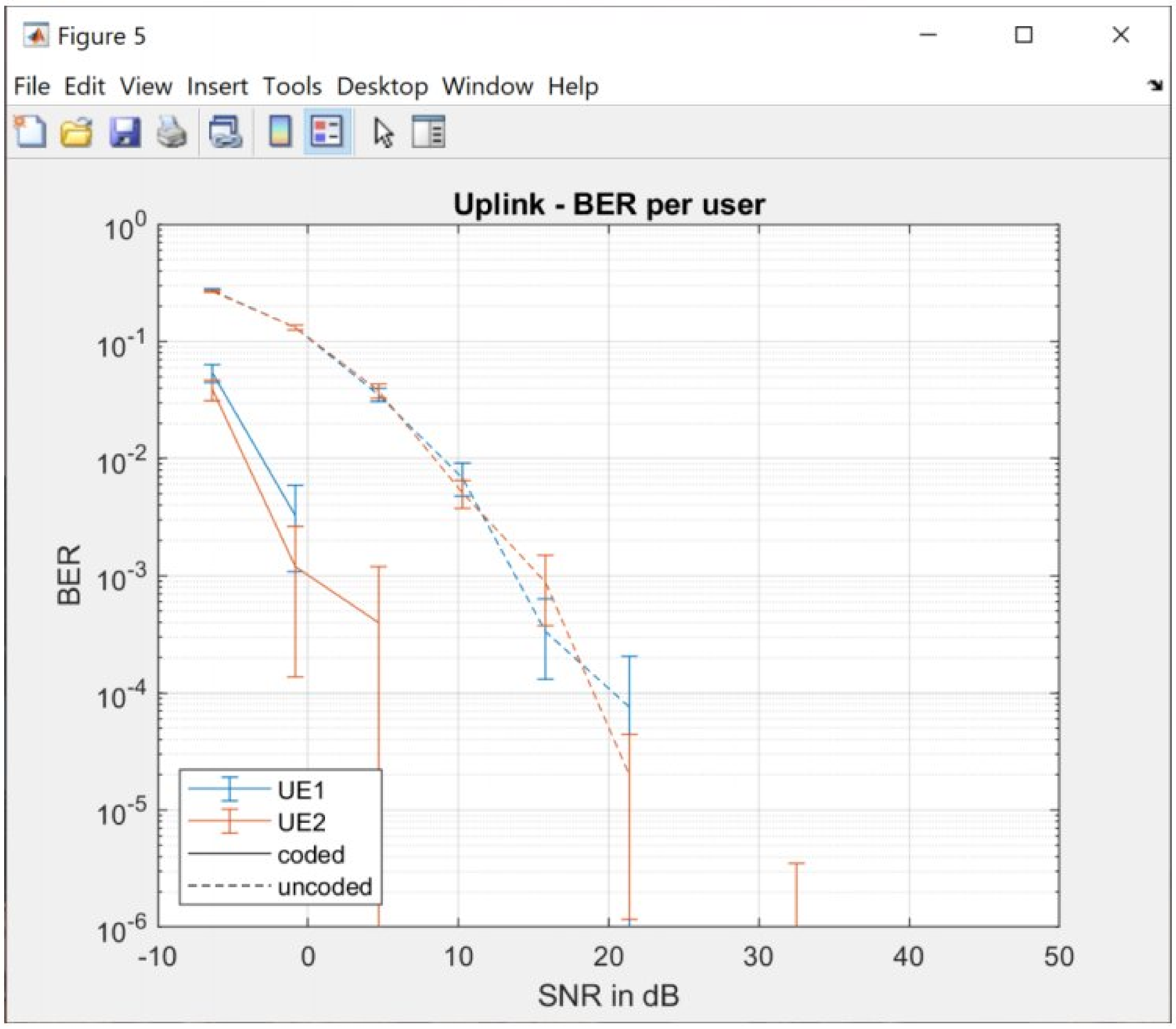

Figure 4.7 Performance for CQI=1

Similar performance is seen in uplink channels for the bit error metrics.

Continued Performance

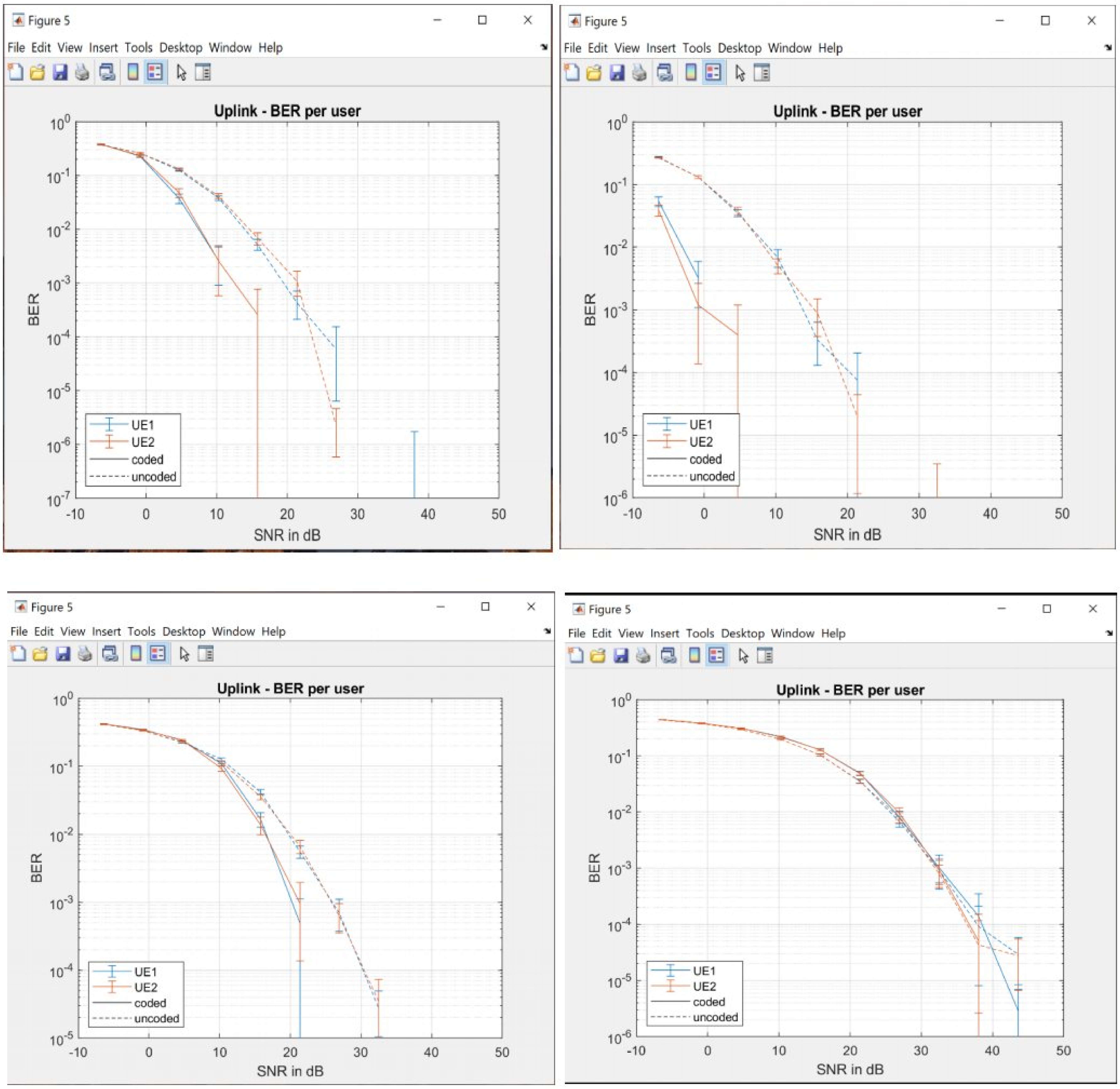

Figure 4.8 Performance for CQI=1, 4, 9, 15

These graphs prove the decrease of bit errors in uplink channels as well for the uprising CQI. Therefore, bits are becoming less erroneous, both in downlink and uplink.

Throughput performance

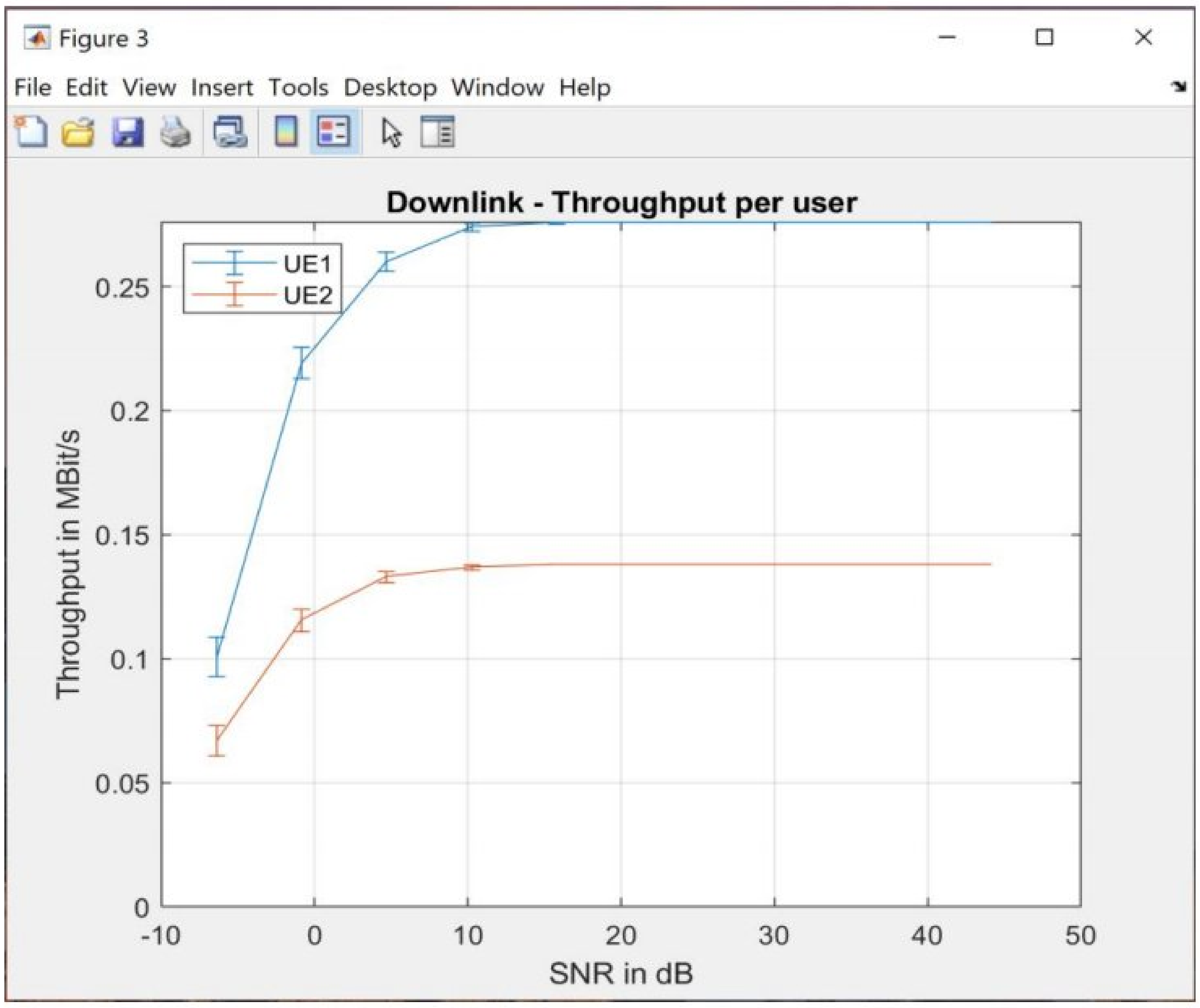

Figure 4.9 Performance for CQI=1

Next comes the throughput curves. This simulation calculates the rise of throughput ratios as SNR improves in downlink channels.

Continued Performance

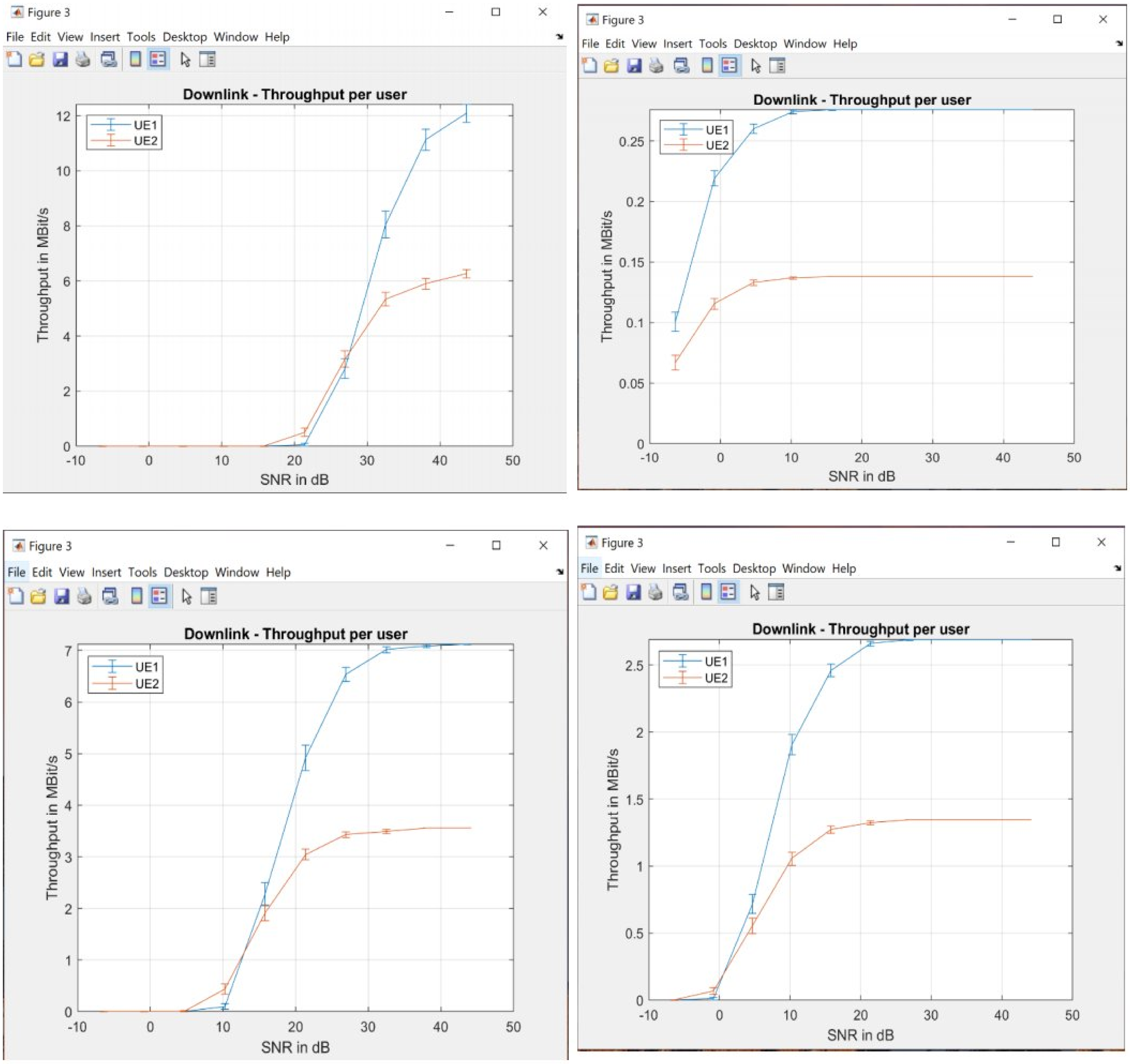

Figure 4.10 Performance for CQI=1, 4, 9, 15

These simulations prove the improvement of throughput ratios with the parallel increment of SNR. Therefore, channel performance improves for the change in the MCS parameters that was accomplished.

Combined Performance Analysis for FER

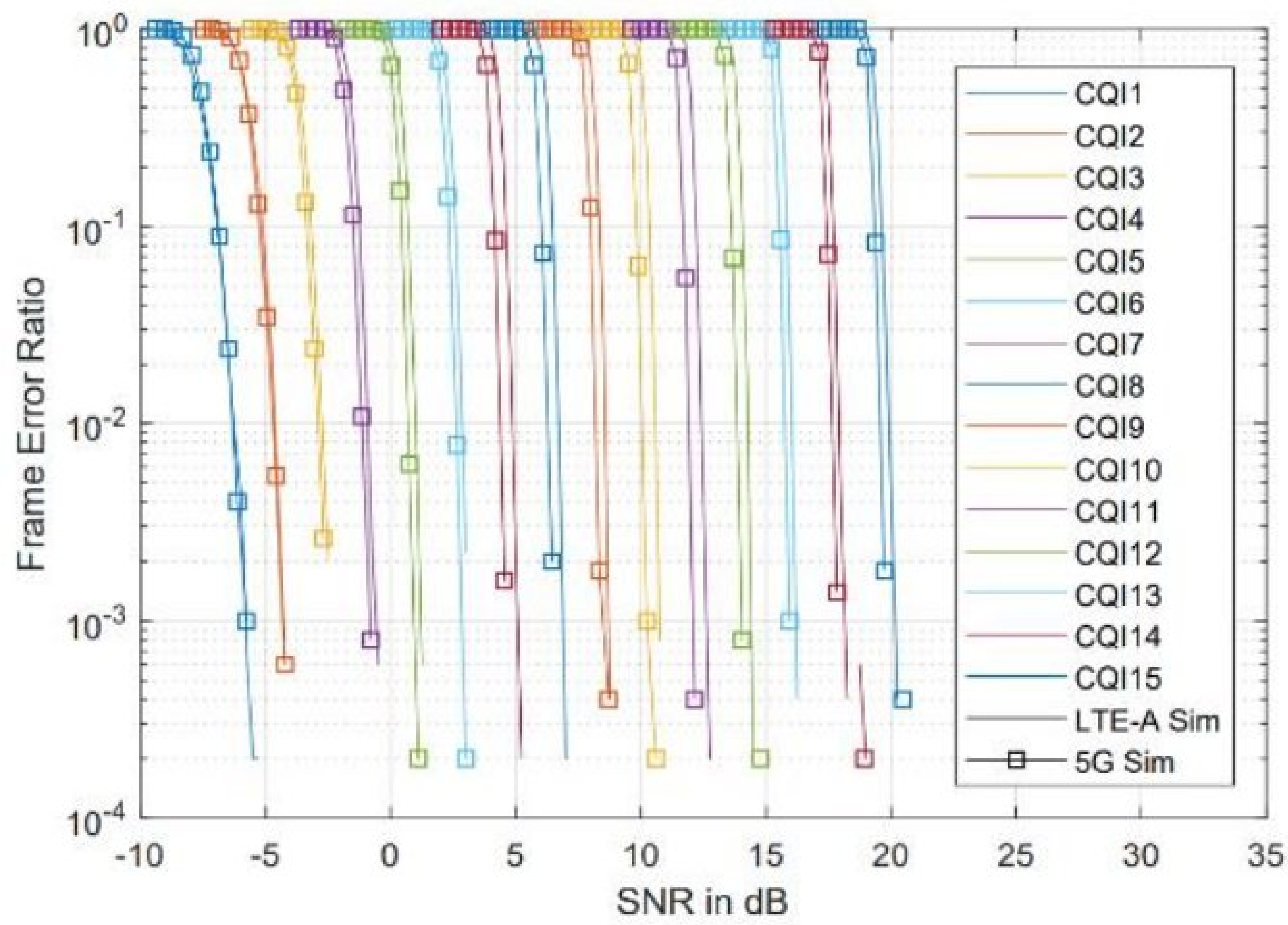

Figure 4.11 FER Performance for all CQIs

This is the combined analysis for the FER reduction for every CQI parameter in the setup. Successful reduction of Frame errors is unmistakably clear.

Combined Performance Analysis for Throughput

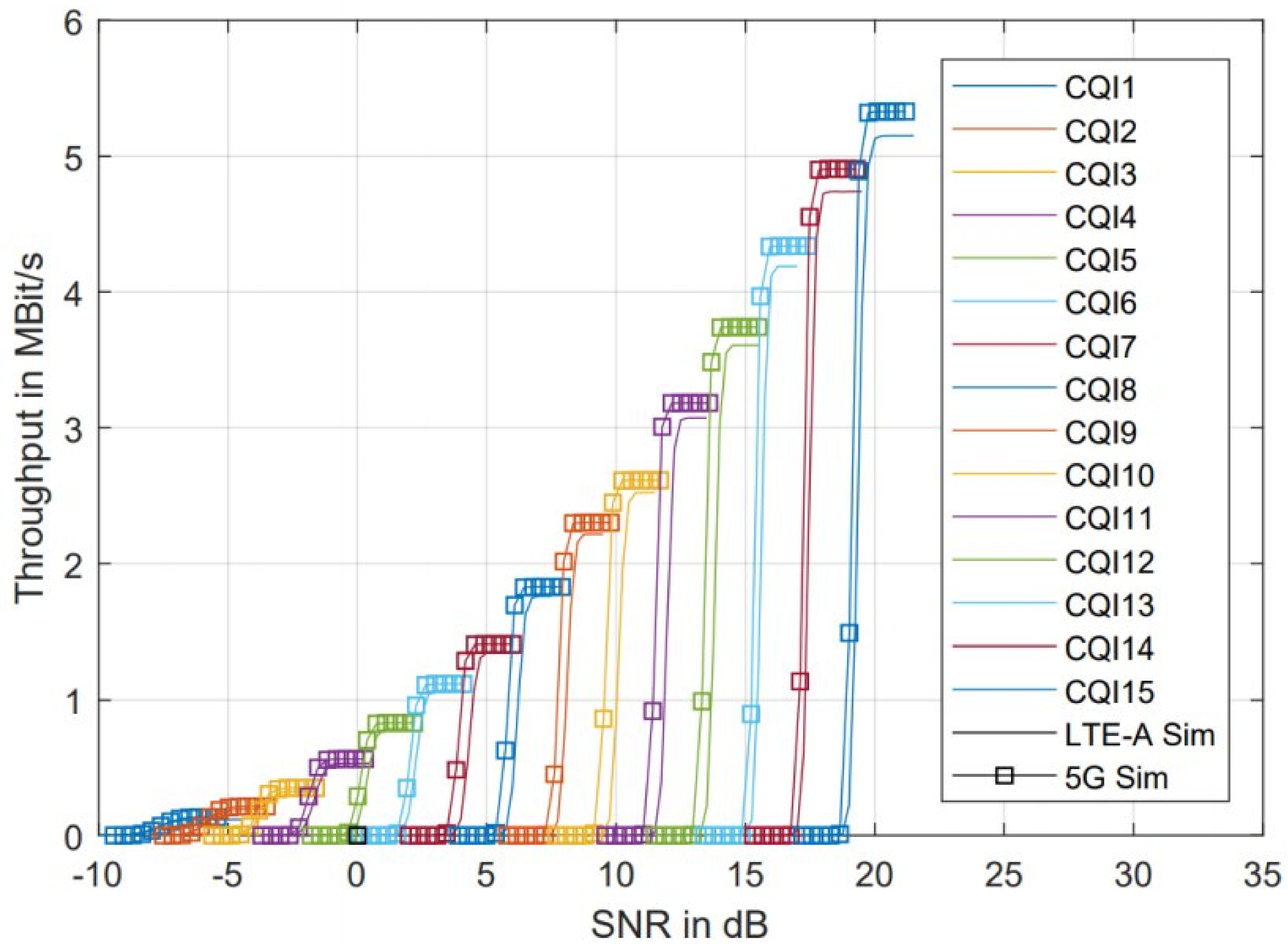

Figure 4.12 FER Performance for all CQIs

The parallel rise of Throughput performance is also crystal clear for the changing CQI.

4.5 Result Discussion

The produced plots are known as the waterfall performance curves. These simulation plots map out the improvement of any performance metric with reference to the current SNR(Signal-to-Noise) ratio in the channel.

This analysis thus highlights that packet error has dropped as was increased the bandwidth and decreased MCS. Therefore, requirements of further retransmissions is unnecessary now as the transmissions are becoming more and more successful. Correct and positive ACK(Acknowledgement) will be sent by the HARQ now. Connections won't fall and packet drops will be reduced. This means better reliability.

Furthermore, lesser retransmissions mean less timing delay. Each and every time a further retransmission is needed and called for(by sending N-ACK), the delay period for the URLLC scheme shoots up. Hence, for the improvement of the concerned Bandwitdh parameters, comes down the latency.

Thus, the requirements of URLLC, Ultra-Reliability, and Ultra-Low Latency, both are being fulfilled, simultaneously.

CHAPTER 5
DISCUSSION AND CONCLUSIONS

5.1 Discussions

It's easy to understand why wireless communications technology has become increasingly important over time. By facilitating increased access to information on the go, advances in wireless communications have facilitated improvements in business, education and technology around the world. As mobile communications improves, so too do connections among people. 5G is not only important because it has the potential to support millions of devices at ultrafast speeds, but also because it has the potential to transform the lives of people around the world.

At present the whole world is connected. It is only possible because of the internet. Without internet the prosperity the world has reached now will decrease to a great extent. So to keep pace with this fast growing connectivity we need fast internet. With 5g it is possible. By achieving the URLLC, ultra-reliable low latency communication, mankind can prosper faster than ever.

But 5g is not yet complete. It has many obstacles. It is not easy to achieve the URLLC feature. Our work focuses on the URLLC of 5g. The works that are reviewed in this book includes the importance of 5g and techniques to achieve the feature. We have worked with the HARQ scheme which is a combination of high-rate forward error correction (FEC) and automatic repeat request (ARQ) error-control. It focuses on the retransmission if for any reason the send data is not received. If the number of retransmission increases then the latency will increase which lead a failure in the URLLC. That's why we proposed a solution by which there will be a reduction in the number of retransmission. Our work is proven with the help of matlab. We tried to prove our theory with the help of waterfall performance curves. It has been shown that the retransmissions were being successful after changing the required parameters.

5.2 Suggestions for future work

Our work is mainly to prove by increasing the bandwidth we can reduce the number of retransmission in case of HARQ. But our resources were limited as 5g is still a current research topic and to do research on such topic advance tools are necessary where the presence of advanced features are necessary. We have proved our work by indicating the plots of FER vs SNR. The FER performance in downlink and uplink for different CQI, along with the BER performance downlink and uplink for different CQIs. We hope to find a better tool where our proposed method can be directly proven which is by changing the bandwidth for the retransmission in HARQ, for different scenarios, it is possible to reduce the number of retransmission.

5.3 Conclusion:

With the increasing number of devices every single second, the necessity for a wider spectrum and more efficient system leads us towards an era of 5G. In case of real-time applications, the necessity of decreased latency is undeniable. So in order for 5G to be a part of these applications, it needs an effective solution to its URLLC HARQ retransmission system. In order to minimize latency and maximize the overall reliability of the system the existing methods might not be proven efficient.

To reach our goal of achieving both processes simultaneously, we have taken a completely new approach. Through our research and the methodological approach we have come to an effective conclusion of success by the method that we are following. This will lead 5G URLLC system to a more efficient beginning.

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