Sumrate Analysis of eMBB and URLLC Co-existence Using NOMA AND Network Slicing for 5G

A Project report submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY
IN
ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

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ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES
(UGC AUTONOMOUS)
(*Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC*)
Sangivalasa, bheemili mandal, Visakhapatnam dist. (A.P)
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PRAGNANAM BRAHMA

ANITS

CERTIFICATE

This is to certify that the project report entitled **"Sumrate Analysis of eMBB and URLLC Co-existence Using NOMA and Network Slicing for 5G"** submitted by **A. Sahitya(319126512001),R.Anusha(320126512L08),M.JayShankar(319126512031) , G. Hema Kalyani(319126512014)** in partial fulfillment of the requirements for the award of the degree of **Bachelor of Technology** in **Electronics & Communication Engineering** of Anil Neerukonda Institute of technology and sciences, Visakhapatnam is a record of bonafide work carried out under my guidance and supervision.

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ABSTRACT

The Fifth-generation mobile communications systems(5G) will feature three generic services: enhanced Mobile Broad Band (eMBB), massive Machine-Type Communications (mMTC) and Ultra-Reliable and Low-Latency Communications (URLLC). eMBB applications support extremely high data rate communications, while URLLC services aim to provide stringent latency with high reliability communications. Due to their diverse requirements of services, spectrum sharing between URLLC and eMBB services becomes a challenging scheduling issue. Network Slicing, which enables the multiplexing of virtualized and independent logical networks on the same Radio Access Network (RAN) is proposed as a solution that creates customized slices of network specifically designed to meet the requirements in orthogonal and non - orthogonal Multiple Access Schemes. The Non-Orthogonal Multiple Access (NOMA) is used to improve the number of URLLC users that are connected in the uplink to the same base station (BS), in coexistence with eMBB users .Successive Interference Cancellation(SIC) is used while decoding the EMBB and URLLC user to reduce the noise at every stage .In the analyses of the system performance, Spectrum efficiency is the key factor which should be high .It is directly proportional to the net data rate achieved by all the kinds of users in the system .NOMA techniques performs with better spectral efficiency than OMA technique while decoding the EMBB and URLLC users with the guarantee of meeting the reliability requirements.

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LIST OF SYMBOLS

C	Channel capacity
nu	Total number of active URLLC users
r_u^{sum}	Total sum rate achieved by all the URLLC users
r_u	Rate achieved by URLLC user
F_u	Number of frequency channels allocated for simultaneous transmission of URLLC.
$\in_u$	Reliability requirement of URLLC user
$P_r(E_u)$	Error probability of URLLC
I_u^{sum}	Sum rate of the u-th user
r_b^{out2}	Outage rate where there is an interference is present for eMBB device from another device
r_b^{sum}	Net rate achieved by eMBB user
$\sigma_{u,f}$	Available SINR while decoding the signal of the URLLC device
n2	Total number of eMBB devices with effect of interference.
r_b^{tar}	Target SNR
P_r ($\mathrm{E_B}$)	Outage probability of an eMBB device
$\gamma_{(a,b)}$	Lower incomplete gamma function
n1	Total number of eMBB devices without no effect of interference
R_x	Received SNR
L	Number of receiving antenna elements
K	Threshold SNR required for the transmission
a_B	Activation probability
r_b^{out1}	Outage rate achieved by eMBB user in no interference case

$Gu_{u,f}$	Instantaneous wireless channel gain in the frequency channel f for URLLC
r_U^{net}	Net data rate of any system with nu active URLLC users
γ_B^{min}	Target SNR
γ_B	Received SNR
$X_{U_{u,t,f}}$	Symbol transmitted by the u-th URLLC user in the frequency channel f
B	Channel Band width
SNR	Signal to Noise Ratio
ŋ	Channel spectral efficiency
R_C	Bit rate transmitted on the channel
F_u	Frequency allocated for URLLC users
F_b	Frequency allocated for eMBB users
$H_{B,f}$	Wireless channel coefficient of eMBB user
$X_{B,t,f}$	Symbol transmitted by the eMBB user
$W_{t,f}$	AWGN sample at the receiver antenna
$H_{u_{u,f}}$	Wireless channel coefficient of u-th URLLC device in the frequency channel f

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LIST OF ABBREVIATIONS

eMBB	Enhanced Mobile Broadcast band
URLLC	Ultra Reliable Low Latency Communication
mMTC	Massive Machine Type Communication
OMA	Orthogonal Multiple Access
NOMA	Non – Orthogonal Multiple Access
RAN	Radio Access Network
CVaR	Conditional Value at Risk
NR	New Radio
SIC	Successive Interference Cancellation
UE	User Environment
QoS	Quality of service
DNN	Deep Neural network
CSI	Channel State Environment
TTI	Transmission Time Interval
OFDMA	Orthogonal Frequency Division Multiple Access
BS	Base Station
SD – RAN	Software Domain Radio Access Network
SNR	Signal To Noise Ratio
SINR	Signal to Interference and Noise Ratio

CHAPTER-1

INTRODUCTION

1.1 5th Generation Communication

The fifth mobile network generation, or 5G. It is a brand-new wireless standard used globally, after 1G, 2G, 3G, and 4G networks. 5G makes it possible for a new kind of network to link almost everyone and everything, including machines, objects, and devices. With 5G wireless technology, more users will have access to higher peak data speeds of several gigabits per second (Gbps), extremely low latency, improved stability, huge amounts of network capacity, and a more consistent user experience. Performance and efficiency improvements offer new user experiences and link new industries.

1.2 Benefits of 5G

Faster Speeds: Compared to 4G LTE networks, 5G networks can deliver speeds of up to 20 Gbps.

Lower Latency: 5G networks offer substantially lower latency than 4G LTE, which implies that data is received and sent more quickly.

Greater Capacity: 5G networks are able to support more devices concurrently.

Greater Reliability: 5G networks are intended to provide greater dependability and coverage.

Higher data rates: 5G networks will be able to support new technological alternatives like 4K streaming or virtual reality (VR) streaming in close to real time.

1.3 5G Key Services

5G is mainly categorized into 3 major generic technologies. They are:

1. eMBB (Enhanced Mobile Broad Band)
2. URLLC (Ultra reliable Low latency Communication)
3. mMTC (massive-Machine Type communication)

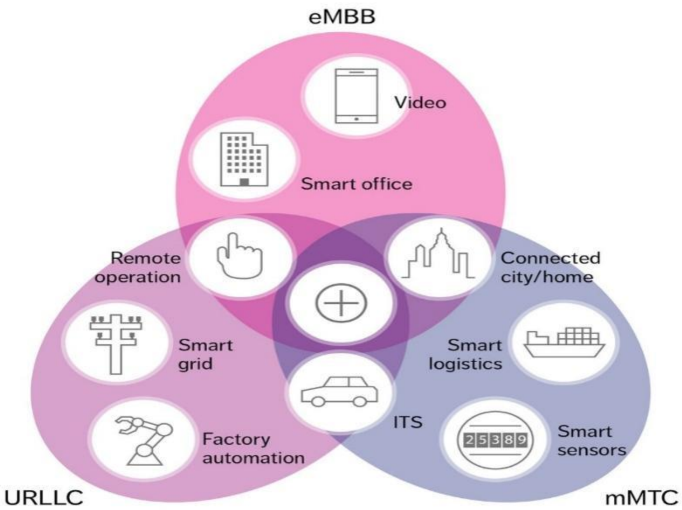


Fig.1.1: Three generic services of 5G

eMBB (Enhanced Mobile Broad Band)

The 5G use case class eMBB, which stands for "Enhanced Mobile Broadband" or "Extreme Mobile Broadband," sets a target for peak download speeds of over 10 Gbps, which is far faster than the highest download speed of 3 Gbps that 4G LTE Advanced Pro can attain.

URLLC (Ultra reliable Low latency Communication)

The URLLC use case class, also known as URLLC (kbps), is a requirement for 5G networks to accept low data rates and offer communication with high dependability (99.99%), extremely low latencies (below one millisecond), and support for them. It covers a wide range of use cases, such as industrial automation, mission-critical applications, and automated vehicles.

mMTC(Massive Machine Type Communication)

The focus of mMTC is on IoT applications, which demand the ubiquitous deployment of billions of cheap, low-powered devices and sensors. Among the 5G applications that come within this use case are Intelligent Agriculture Systems, Smart Cities, Smart Homes, and Smart Buildings, Traffic Management Systems, and Patient Monitoring Systems.

1.4 Slicing of 5G Network

The 5G network is divided to allow commercial clients to benefit from the data connectivity in order to meet service requirements. Simply said, a network slice is a logical network that can support end-to-end data sharing while maintaining the highest level of service. It can cover a wide range of network components, including terminals, access networks, core networks, transport networks, and more.

Network slicing can use any number of different approaches. When slicing the available Radio Access Network, the most common techniques are Orthogonal Multiple Access (OMA) and Non-Orthogonal Multiple Access (NOMA) (RAN). In terms of coexistence amongst various services like mMTC, URLLC, and eMBB, NOMA performs better than OMA. Since the reliability and latency criteria of eMBB, which coexists with URLLC, are substantially less stringent than those of URLLC, the URLLC device should be decoded first in the situation of eMBB-URLLC coexistence with (Successive Interference Cancellation) SIC.

The demand for internet has been growing recently. Higher spectral efficiency and assigning the same radio resource for several devices at once have become significant issues for 5G technology. NOMA has developed into a promising technology that can overcome the difficulties. Compared to OMA, NOMA can accommodate more users on the radio resource. There are several other similar techniques, including power domain NOMA, multiple accessing with low density spreading, and multi-user shared access.

Multiple UEs are co-scheduled and shared radio resources, such as time, frequency, and/or codes, with NOMA.NOMA might or might not perform better than standard OMA-based methods like MU-MIMO. However, the special characteristics of NOMA offer the opportunity to create new methods for simplifying its implementation, which might make it more appropriate for actual use. Therefore, in order for the industry to embrace NOMA, it is necessary to increase spectral efficiency and implementation usability.

Despite causing interservice interference, non-orthogonal transmission was found to give potentially considerable improvements for both URLLC and eMBB services. The rate improvements of the resulting Heterogeneous-NOMA (H-NOMA) strategy come from its ability to employ spectrum resources for eMBB traffic more effectively while lowering collisions and blockages for URLLC data. This is in addition to the lower URLLC access latency. Time in the 5g system is split into slots, which are then further broken down into minislots. Scheduling-wise, eMBB resource allocations take place at slot boundaries, however

URLLC traffic is preemptively overlapping at the minislot timescale to save latency, which causes eMBB resource allocations to be selectively superimposed or punctured. This method may result in a rate loss for eMBB traffic but allows for minimal URLLC latency.

A 5G New Radio (NR) application called Ultra Reliable Low Latency Communication (URLLC) has severe latency and reliability requirements. eMBB users with low data rates are protected by a risk-sensitive based formulation to allocate resources to the incoming URLLC traffic while maximizing URLLC reliability and reducing the risk of the eMBB transmission. using the CVaR (Conditional Value at Risk) function to calculate the risk of eMBB.

We looked at the slicing for two services in two separate scenarios: eMBB and URLLC in one case, and eMBB and mMTC in the other. The URLLC device needs to be decoded first in the scenario of eMBB and URLLC coexistence with SIC because URLLC's decoding cannot rely on eMBB's decoding since the latter has much laxer reliability and latency constraints. To take advantage of non-orthogonal slicing in the case of eMBB and mMTC, the decoding of eMBB should be carried out after the decoding of one or more mMTC devices, given that the number of active mMTC devices is likely to be significant.

The examination of the net data rates attained for various sorts of systems is what we have to offer in this project. We looked at the net data rate because Shannon's capacity theorem says that it is one of the key factors in determining how well the system performs. The net data rate attained by all system users is directly proportional to the spectral efficiency. System is essentially how the communication devices are connected to the base station (BS) and how it is structurally organized. Considering the system's net data rate is crucial, thus. In this approach, we first examine the case when only one type of device, such as an eMBB or URLLC, is connected to the BS in both the conceivable scenarios of interference and no interference. While decoding the URLLLC devices under interference during URLLC studies, we used the Successive Interference Cancellation (SIC) approach. The two well-known network slicing techniques OMA and NOMA are examined in the decoding of the coexistence of eMBB and URLLC. Again, SIC decoding is used in the NOMA network slicing scheme, but now it is done between the eMBB and URLLC depending on the needs.

CHAPTER -2

LITERATURE SURVEY

With the evolution of wireless communication technologies, the fifth generation (5G) of cellular networks has been developed to cater to the ever-increasing demand for high-speed, lowlatency and reliable communication services. However, the two main categories of 5G services enhanced mobile broadband (eMBB) and ultra-reliable and low latency communications (URLLC), pose challenges in terms of coexistence, as they have different requirements in terms of throughput, latency, reliability, and resource allocation. To address this challenge, two promising technologies, network slicing and non-orthogonal multiple access (NOMA), have been proposed for eMBB and URLLC coexistence in 5G and beyond networks. Network slicing is a concept that allows the creation of multiple virtual networks on a shared physical network infrastructure, with each network slice being tailored to meet the specific requirements of different applications and services. On the other hand, NOMA is a multiple access technique that allows multiple users to share the same time and frequency resources, by assigning different power levels to different users, thus achieving higher spectral efficiency and system capacity. Several research studies have been conducted to investigate the performance of eMBB and URLLC coexistence using network slicing and NOMA in 5G and beyond networks. These studies mainly focus on developing resource allocation and power control schemes to achieve efficient coexistence of eMBB and URLLC services while meeting their respective quality of service (QoS) requirements. This literature survey aims to provide an overview of the research conducted on eMBB and URLLC coexistence using network slicing and NOMA in 5G and beyond networks. The survey discusses the challenges and opportunities associated with these technologies, as well as the different resource allocation and power control schemes proposed in the literature.

H. Chien et al. [1], introduced the concept of end-to-end slicing and discussing its potential benefits in 5G networks. The authors then describe the proposed framework, which is composed of four main components: 1) a network slice template, 2) a resource allocation module, 3) a computing resource allocation module, and 4) a slice orchestration module. The author provides a detailed explanation of each component and how they work together to enable efficient resource allocation for multi-tenant 5G systems. A future direction, such as improving the efficiency of the resource allocation algorithm and considering the impact of mobility on end-toend slicing is also provided.

Zhang, et al. [2], proposes a power allocation scheme for the coexistence of enhanced Mobile Broadband (eMBB) and Ultra-Reliable and Low Latency Communications (URLLC) services in 5G networks. By effectively allocating electricity to customers and meeting the quality of service standards of both eMBB and URLLC services, the plan seeks to increase the network's energy efficiency. The suggested plan is based on the non-orthogonal multiple access (NOMA) technology, which allows numerous users to simultaneously share the same radio resources. The optimum energy efficiency of the network is sought by solving the power allocation problem as an optimization problem, subject to restrictions on the minimum data rate, the maximum delay for URLLC users, and the maximum transmit power for eMBB users. The Lagrange dual decomposition technique is used by the authors to resolve the optimization problem.

Ren, Y. et al. [3], provides an overview of the coexistence of enhanced mobile broadband (eMBB) and ultra-reliable low latency communication (URLLC) in 5G networks using non-orthogonal multiple access (NOMA) technique. The authors also discuss the benefits of NOMA for the coexistence of eMBB and URLLC, including higher spectral efficiency and energy efficiency, as well as improved fairness in resource allocation. Various NOMA based resource allocation schemes are presented, including power domain NOMA, code domain NOMA, and hybrid NOMA. The performance of these schemes is evaluated using various metrics such as outage probability, sum-rate, and energy efficiency.

Zhang, et al. [4], proposed a scheme which is aims to minimize the power consumption while maintaining a target reliability level for URLLC users and a target quality of service for eMBB users. The authors formulate an optimization problem to minimize the total power consumption subject to constraints on the minimum rate and maximum delay for URLLC users, and on the minimum rate and maximum delay violation probability for eMBB users.

Wu, Q., He, et al. [5], Address the following points; Multi-objective resource allocation is necessary for NOMA-based coexistence of eMBB and URLLC in 5G networks to balance system throughput and latency. Joint optimization of resource allocation and interference management can improve the system performance of NOMA-based coexistence of eMBB and URLLC. Future research directions include energy efficiency optimization and security in NOMA-based coexistence of eMBB and URLLC.

M. A. Imran et al. [6], Provides a comprehensive review of network slicing for 5G with coexistence of eMBB and URLLC services Discusses key challenges and requirements for network slicing, including resource allocation, QoS management, and security Analyzes different network slicing architectures and techniques, such as virtualization and software-defined networking Proposes a framework for network slicing that considers multiple factors, including QoS requirements, traffic characteristics, and resource availability identifies research directions and open issues for future work.

H. Liu et al. [7], Proposes a resource allocation scheme for coexisting eMBB and URLLC services in 5G networks with network slicing uses a deep reinforcement learning approach to optimize the allocation of radio resources, including subcarriers and power levels considers multiple objectives, including throughput, latency, and fairness, and adapts the allocation based on the changing network conditions evaluates the performance of the proposed scheme using simulations, and compares it with other resource allocation methods.

J. Yu et al. [8], Presents a joint scheduling and resource allocation scheme for coexisting eMBB and URLLC services in 5G networks uses a deep reinforcement learning approach to optimize the allocation of radio resources, including time slots and power levels, for different services Considers multiple constraints, including QoS requirements, traffic characteristics, and interference management Evaluates the performance of the proposed scheme using simulations, and compares it with other scheduling and resource allocation methods.

J. Li et al. [9], Proposes a network slicing framework for coexisting eMBB and URLLC services in 5G networks Uses a virtual network function approach to provide customized services to different users with different requirements Considers multiple factors, including QoS requirements, resource availability, and security, and uses different virtual network functions for different services Evaluates the performance of the proposed framework using simulations, and compares it with other network slicing approaches.

Petar Popovski et al. [10], proposes a novel approach for network slicing using a communication-theoretic framework, which considers the different requirements of eMBB, URLLC, and mMTC in terms of data rate, latency, and reliability. The proposed approach utilizes multi-objective optimization techniques to allocate resources in a way that maximizes the QoS of each service while ensuring efficient resource utilization.

Eduardo Noboro Tominaga et al. [11], proposes a framework for coexistence of enhanced mobile broadband (eMBB) and ultra-reliable low-latency communications (URLLC) in 5G using non-orthogonal multiple access (NOMA) and network slicing. A thorough examination of the proposed framework reveals that, when compared to traditional orthogonal multiple access (OMA) strategies, it can offer considerable advantages in terms of spectrum efficiency and user fairness.

Y. Huang, et al. [12], proposes a novel approach for dynamic multiplexing of enhanced Mobile Broadband (eMBB) and Ultra-Reliable and Low-Latency Communications (URLLC) services in 5G New Radio (NR) networks using deep reinforcement learning (DRL). The proposed DRLbased approach utilizes a Q-learning algorithm to determine the optimal resource allocation for eMBB and URLLC services based on network conditions, such as channel quality, traffic load, and delay requirements.

J. **Zhang et al.** [13], proposes a machine learning (ML) based flexible transmission time interval (TTI) scheduling approach for coexistence of enhanced mobile broadband (eMBB) and ultrareliable low-latency communication (uRLLC) in the 5G New Radio (NR) systems. The proposed approach utilizes a deep neural network (DNN) to predict the optimal TTI for each user based on the instantaneous channel state information (CSI), traffic load, and delay requirements.

CHAPTER-3

METHODOLOGY

3.1 NOMA

Non-orthogonal multiple access (NOMA) is one of the most promising radio access techniques for next-generation wireless communications. Orthogonal frequency division multiple access (OFDMA), the current industry standard for orthogonal multiple access (OMA) technology, offers a number of desirable potential benefits over NOMA, including increased spectrum efficiency, decreased latency with excellent dependability, and huge connection. The primary premise of NOMA is to regularly and concurrently provide several customers with the same resource.

3.1.1 OFDMA and NOMA

Orthogonal frequency division multiple access (OFDMA), in which information for each user is assigned to a subset of subcarriers, is utilised in ordinary 4G networks. On the other hand, each user in NOMA has access to every subcarrier. The spectrum sharing for two users using OFDMA and NOMA is shown in the figure.

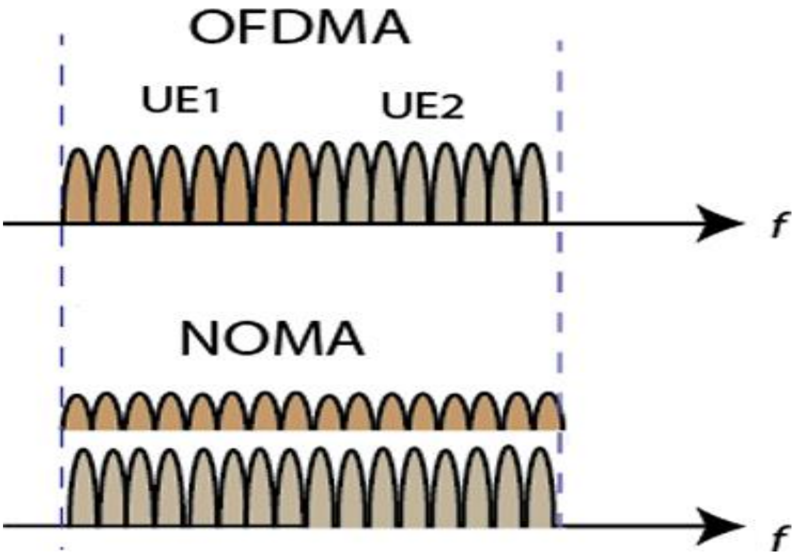


Fig 3.1: spectrum sharing for OFDMA and NOMA for two users.

Superposition coding at the transmitter and successive interference cancellation (SIC) at the receiver enable all users to utilise the same frequency. At the transmitter, the many information streams are merged into a single waveform, and the SIC decodes each signal separately until it finds the desired signal.

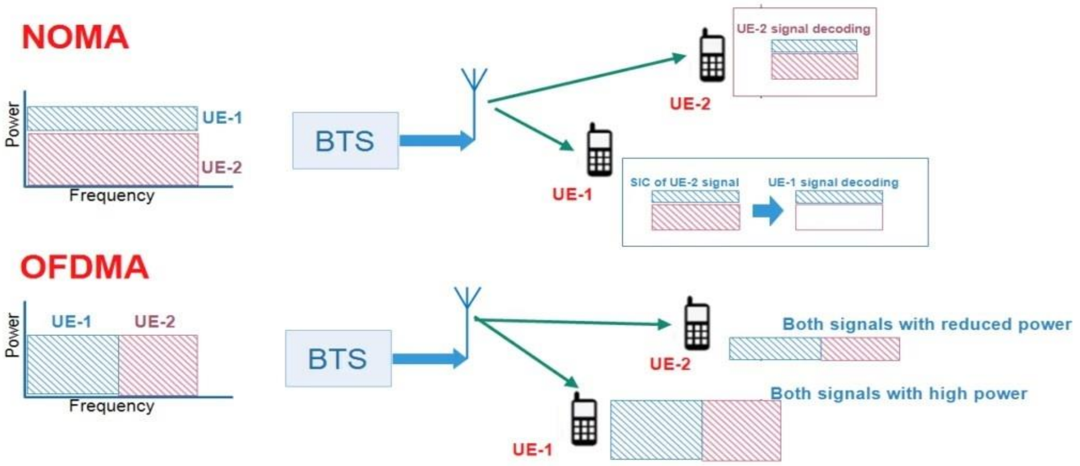


Fig 3.2: Resource sharing between two users for OFDMA and NOMA

3.1.2 Working of Noma

The two key operations that make NOMA possible are superposition coding, which must be carried out at the transmitter side, and successive interference cancellation (SIC), which must be carried out at the receiver side in both the uplink and the downlink channels.

3.1.2.1 Superposition Coding

Let's assume that two users, User 1 and User 2, will speak at the same time on the same frequency. Let x1 and x2 stand for User 1's and User 2's data, respectively. Let's assume for the sake of simplicity that each user can only submit 4 bits of data. Although this assumption is distant from the truth, it is adequate to comprehend how NOMA functions in its fundamentals.

Let x1 and x2 both equal 1010. Below is a graphical representation of x1 and x2.

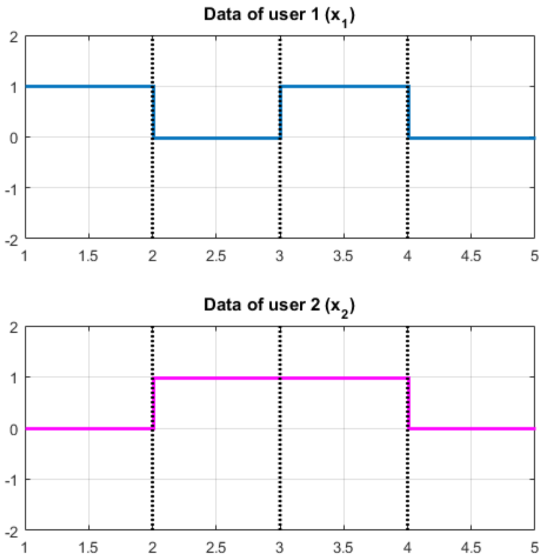


Fig 3.3(a) example values of x1, x2

Before transmission, digital modulation must be applied to x1 and x2. Let's utilise BPSK to keep things simple. In BPSK, 0s correspond to -1s and 1s to +1s. Following BPSK modulation, as illustrated below, x1 is mapped to +1 -1 +1 -1 while x2 is mapped to -1 +1 +1 -1.

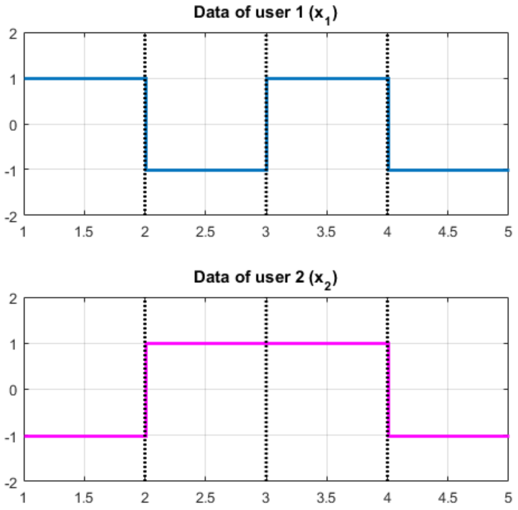


Fig 3.3(b) values of x1, x2 after BPSK modulation

Superposition coding is necessary for NOMA on the transmitter side. Power domain multiplexing is also known as superposition coding. To superpose is to include. In essence, we will add x1 and x2 together. Before doing that, though, we'll multiply them by various powers. After that, we will total them up. We can observe from the previous graphic that x1 and x2 both have a peak amplitude of 1. That indicates that they each have a unit power of one watt (power=amplitude^2).

Let's imagine that user 1 receives a power weight of 0.75 and user 2 receives a power weight of 0.25. Here, it is a rule that a1 and a2 must add up to 1.We have used fixed power allocation in this case. That is fixed a1 and a2 values. Scale x1 and x2 first using a1 and a2, correspondingly. Considering that a1 and a2 stand for the power scaling factors. We take the square root of them to indicate amplitude. The signals look as follows after scaling. Keep in mind that the amplitudes of x1 and x2 have been scaled, respectively, to give them respective values of a1 = 0.866 and a2 = 0.25. the following are our amplitude scaled renditions of the data: $\sqrt{a1}x1$ = 0.866 -0.866 0.866 -0.866 and $\sqrt{a2}x2$ = -0.5 0.5 0.5 -0.5.

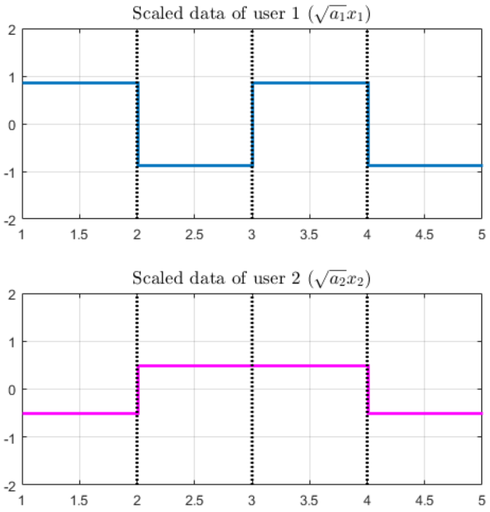


Fig 3.3(c): x1, x2 values after power allocation

It is now time to combine the two scaled. The signal that results is known as a superposition coded signal and is represented by the equation $x = \sqrt{a_1}x_1 + \sqrt{a_2}x_2$. Together, they add up to x = 0.366 -0.366 1.366 -1.366. The graph below shows how to visualise x. The graph of x presented is created by adding up each relevant term of $\sqrt{a_1}x_1$ and $\sqrt{a_2}x_2$ from the preceding figure.

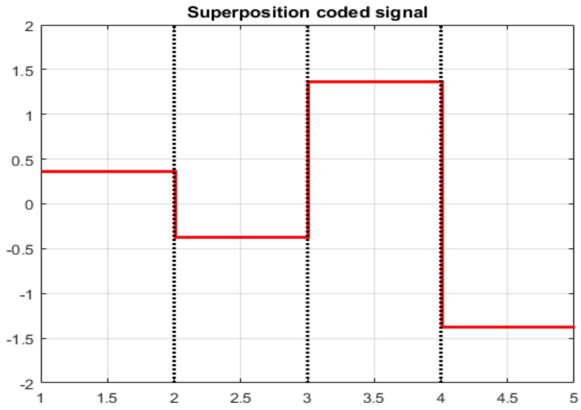


Fig 3.3(d): Superposition coded signal

The superposition coded NOMA signal that is actually sent into the channel is represented by this signal, x. Therefore, that is how superposition coding is carried out. Using successive interference cancellation (SIC) at the receiver end, we can extract x1 and x2 from x.

3.1.2.2 Successive Interference Cancellation (SIC)

Using an iterative procedure known as SIC, data is decrypted in decreasing power level order. Or, to put it another way, data for the user with the greatest power is decoded first, then data for the person with the next-highest power. Up until all user data has been encrypted, this process is repeated. The following list outlines the SIC stages for our simple two-user NOMA system scenario:

Step 1: Directly decode x to obtain the signal with the highest power. For instance, when x1 is assigned more weight (i.e., a1 > a2), x1 is the result of direct decoding of x.

Step 2: Subtract x from the signal that was decoded in Step 1 after being multiplied by the matching Weight.

Step 3: Decodify the signal you got in step 2 to get the other signal, which was low-power multiplexed.

Let's now gradually apply SIC to our example. In our instance, the transmitter side employed BPSK modulation. Therefore, we will directly apply BPSK demodulation to x. In essence, BPSK demodulation is just thresholding. Set the threshold to 0 first. We will decode each symbol as 1 if its amplitude is greater than zero and as 0 otherwise.

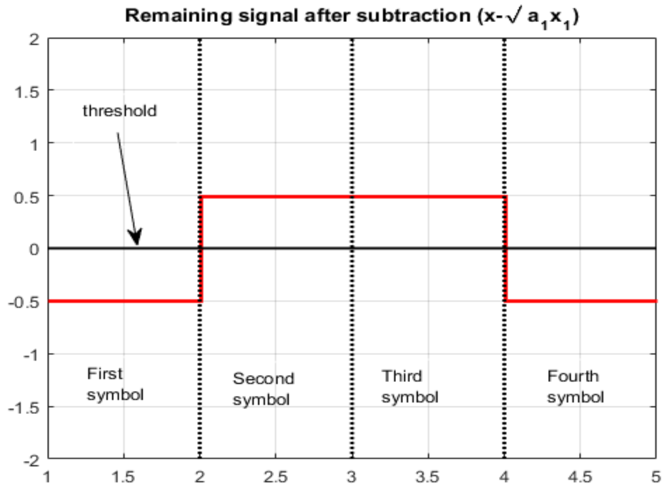


Fig 3.3(e): Remaining signal after subtracting the first signal

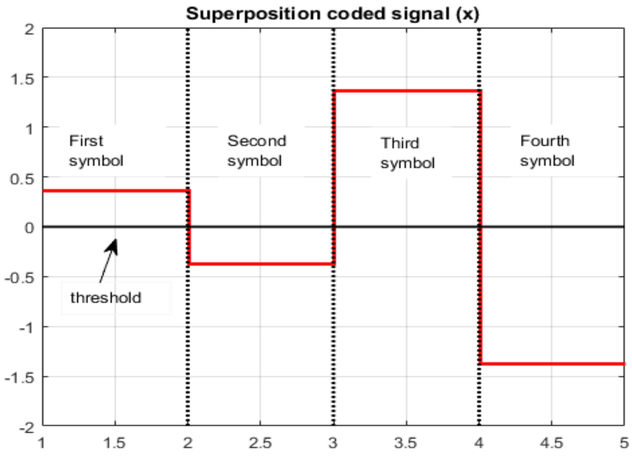


Fig 3.3(f): Signal after SIC decoding

Let's decode x symbol by symbol while keeping in mind the plot of x. The first and third symbols are found to be above the zero-threshold line. The first and third transmitted bits are therefore determined to be ones. Below the threshold are the second and fourth symbols. The second and fourth transmitted bits are therefore determined to be zeros. The decoded sequence is therefore 1010 in order. which is equivalent to x1. In other words, we completely disregarded the fact that x also contained a component of x2 and instead arrived at x1 by doing direct BPSK demodulation on x. This was made possible since we gave the x1 component of x a higher power weight. Thus, it is acceptable to disregard the existence of the additional component x2 in x. In other words, we ignore x2 and treat it as interference.

After completing the first stage of the SIC process, we now know that $x = \sqrt{a_1}x_1 + \sqrt{a_2}x_2$. Being design decisions, the values of a1 and a2 are known as. In addition, we got x1 by going through step 1. Therefore, if we deduct $\sqrt{a_1}x_1$ from x, we are left with $\sqrt{a_2}x_2$. It is rather simple to obtain from$\sqrt{a_2}x_2$.

Let's go to step 2 now. The x1 component must be multiplied by the equivalent power weight before being subtracted from x. We discovered that x1 is equal to 1010. However, x1 can be found in x in its BPSK modulated form. This means that x does not have the value 1010 for x1.

The BPSK modulated form of 1010 is included in x as 1 -1 1 -1. Therefore, from x, we must subtract this BPSK modulated form of the x1 component. The graph would look like this after subtraction.

The second step is complete. On to phase three. Following subtraction, all that remains is to demodulate the signal using the BPSK rule as previously. We can see that, according to the

BPSK rule, the first and fourth symbols would be demodulated as zeros and the other symbols as ones. As a result, the demodulated signal's order, 0110, is the same as x2.

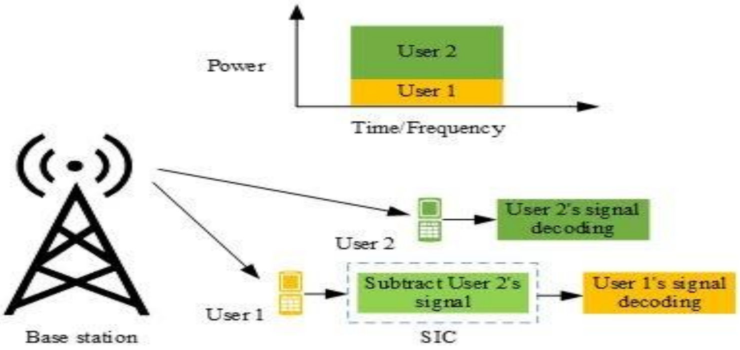


Fig. 3.4: The SIC decoding for 2 users at the base station

The base station (BS) sends two users superposed signals, with User 1 having a greater channel gain than User 2. The stronger user in NOMA is often referred to as the user with the higher channel gain, while the weaker user is typically referred to as the user with the lower channel gain. The strong user first subtracts the weak user's signal using SIC before decoding its own signal, whereas the weak user perceives the strong user's signal as noise and detects it immediately. In NOMA, more power is granted to the weak user in order to maintain equity when channel gain is worse and interference is higher.

3.1.3 NOMA for Downlink

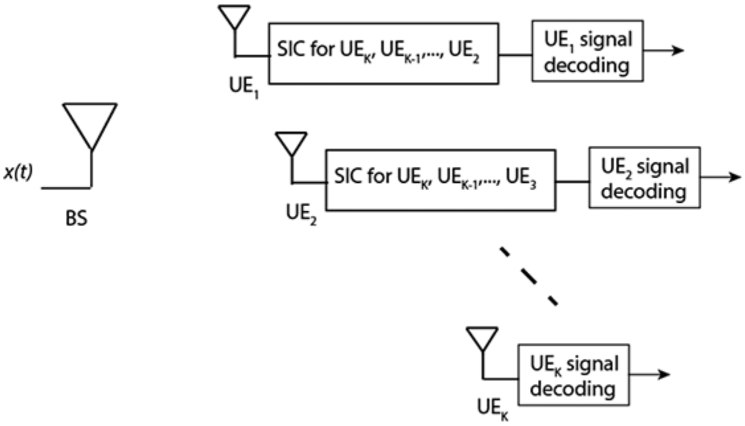


Fig.3.5(a): Downlink NOMA.

The base station superimposes the information waveforms for its serviced customers during NOMA downlink. SIC is used by each user equipment (UE) to identify its own signals. a BS and K number of UEs with SIC receivers are depicted in Fig. 3.5(a). It is considered that in the network, UE$_1$ is the node that is closest to the base station (BS), and UE$_K$ is the node that is farthest.

The UE that is positioned the furthest away from the base station (BS) receives more power during NOMA downlink, while the UE that is closest to the BS receives the least power. The identical signal, which contains data for each user, is received by each UE in the network. Each UE begins by decoding the strongest signal, after which the decoded signal is removed from the received signal. The SIC receiver repeatedly does the subtraction until it finds its own signal. A UE near the BS may cancel the signals of the far-off UEs. As a result of its greater contribution to the received signal, the furthest UE will decode its own signal first.

3.1.4 NOMA for Uplink

NOMA is implemented significantly differently uplink than it is downlink. Fig. 3.5(b) depicts a network that multiplexes K UEs using NOMA in the uplink. This time, BS utilises SIC to divide the user signals.

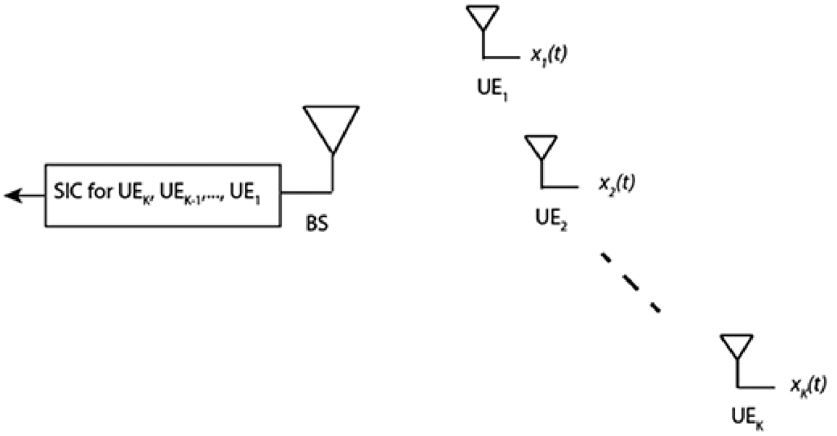


Fig.3.5(b): Uplink NOMA

The receiver's BS puts SIC into practice. The signal from the closest user will be the first signal it decodes, and the signal for the farthest user UE_K will be the last signal the BS decodes.

3.1.5 NOMA Techniques

There are two primary NOMA methods:

1. Power-domain
2. Code-domain.

While the code-domain NOMA achieves multiplexing in the coding domain, the power-domain NOMA does it in the power domain. A variety of multiple access algorithms that rely on sparse code multiple access and low-density spreading can be further subdivided into code-domain NOMA.

3.2 NETWORK SLICING

It may be characterised as a type of network architecture that permits the development of several networks—both independent and virtualized—on top of a single physical infrastructure. The overall 5G architectural environment has developed to significantly rely on this architecture. Each slice or segment of the network can be assigned based on the particular needs of the application, use case, or client.

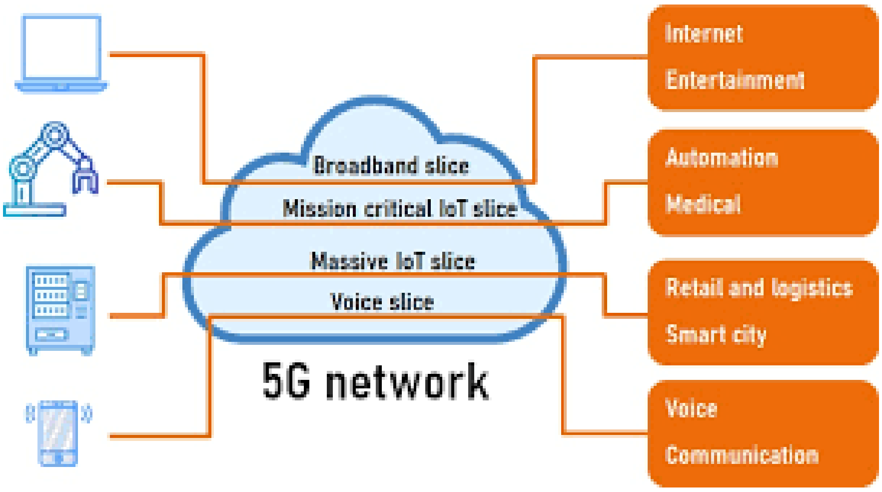


Fig.3.6: Concept of Network Slicing

3.2.1 Working of Network Slicing

Network slicing builds many networks or slices across a single common network using virtualization technology. The latency, throughput, security, and bandwidth characteristics of each slice are particular to it.

Software-Defined By dividing the network control plane from the data plane responsible for handling packets, networking enables this segmentation to take place. The control plane establishes packet handling rules on the data plane to build virtual networks.

Network administrators can physically split traffic on various radio networks and, if necessary, combine the resources of other networks thanks to network slicing via an SD-RAN. With the help of these alternatives, service providers and private businesses can significantly increase resource utilisation and spectrum efficiency compared to earlier cellular generations.

3.2.2 Architectural Overview

Generic 5G Network Slicing Framework

The architecture for network slicing can be thought of as consisting of two primary parts, one for slice implementation and the other for slice administration and configuration. Three levels (service layer, network function layer, and infrastructure layer) make up the first block's multi-tier architecture, each of these contributes to the definition and deployment of slices by performing a different task. In order to effectively coordinate the presence of numerous slices, the second block is created to monitor and regulate the functionality between the three levels.

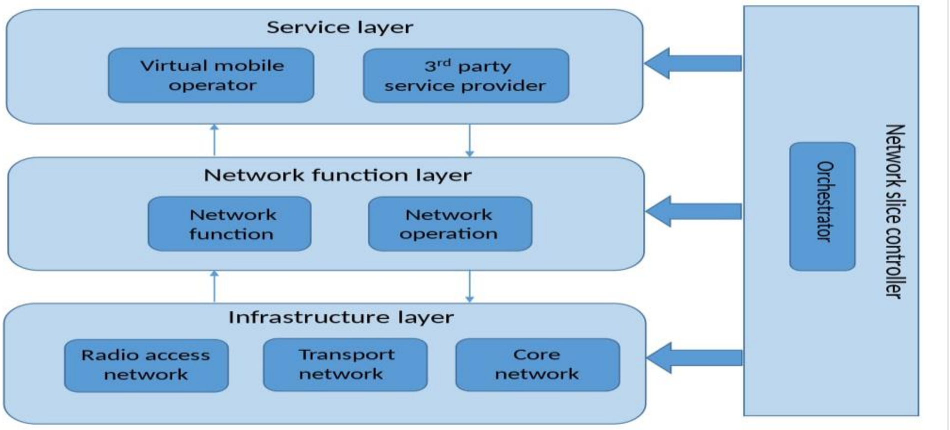


Fig. 3.7: Architecture of Network Slicing

Service Layer

The service layer offers a single understanding of the service requirements and interacts directly with the network business entities (for example, third party service providers) that share the underlying physical network.

Network Function Layer

Each network slice is created by the network function layer in response to requests for service instances made by the top layer. To establish an end-to-end network slice instance that reflects the network properties required by the service, various network functions are placed across the virtual network architecture and connected together.

Infrastructure Layer

The infrastructure layer provides the physical network resources to host the various network services that make up each network slice. It reflects the real physical network architecture (radio access network, transport network, and core network) over which every network slice is multiplexed. A diverse range of infrastructure elements, such as data centers, tools that enable network communication, such as routers (networking resources), and base stations, are included in the network domain of the resources that are available. (radio bandwidth resources).

Network Slice Controller

The network slice controller is referred to as a network orchestrator that manages each slice request by interacting with the various activities carried out by each tier. The advantage of such a network component is that it makes it possible to create slices that are effective, versatile, and reconfigurable during the course of their lifetime. The following operational responsibilities of the network slice controller provide better coordination across the aforementioned layers:

End-to-end service management

Whole-lifecycle service managementthe coordination of several service instances that are characterised in terms of SLA requirements with suitable network functions capable of fulfilling the service constraints.

Virtual resources

To make resource management activities for assigning network services easier, virtualize physical network resources.

Slice life-cycle management

The three levels' slice performance is tracked in order to dynamically modify each slice to take changing SLA requirements into consideration.

The network slice controller may consist of a number of orchestrators, each of which manages a particular aspect of each layer's functioning depending on how complicated the activities being done, which address various issues, are. By communicating high-level information about the status of the actions involved in the slice production, the various orchestration entities must collaborate with one another.in order to fully satisfy the service needs.

note: orchestration - network orchestration refrers to automating interactions across mutiple types of devices, domains, and even potentially other related system in the network.

3.2.3 Challenges of Network Slicing

There are some specified challenges in network slicing based on their Properties of slicing:

1. Isolation
2. Assurance
3. Scalability
4. Reusability

Isolation

First and foremost, we need to keep one group of users, services, and apps apart from another.

It consists of two parts: 1. Connectivity isolation.
2. Performance separation.

Assurance

Second, there needs to be a way to guarantee connectivity and performance isolation. The type of this depends on the level of trust needed; for example, a crucial medical service has different needs than a sensor network for a smart home.

Scalability

Thirdly, everything must be easily deployable; otherwise, the expenses will outweigh the advantages. Low-level configurations must be automatically created from high-level requirements in order to provide the desired isolation.

Reusability

Fourth, in order to maximise scale economies, a smart slicing solution must address the whole spectrum of use cases. These include existing telcos who provide wholesale services, numerous wholesalers who use the same underlying infrastructure, and numerous owners of the infrastructure with access rights.

03.2.4Advantages of Network slicing

Customization: Network slicing allows network operators to customize network resources and services to meet the specific needs of different applications, users, or industries. For example, a network slice for autonomous vehicles may require low latency and high reliability, while a network slice for video streaming may require high bandwidth and low jitter.

Efficient resource allocation: Network slicing allows network operators to allocate resources more efficiently by dedicating specific resources to specific services. This ensures that resources are not wasted and are used in the most efficient way possible.

Improved security: Network slicing can enhance security by enabling network operators to isolate sensitive applications or services from other applications or services on the network.

Better scalability: Network slicing can improve network scalability by allowing network operators to allocate resources dynamically as the demand for different services or applications changes.

Reduced operational costs: Network slicing can reduce operational costs by simplifying network management and reducing the need for specialized hardware.

3.2.5 Disadvantages of Network slicing

Increased complexity: Network slicing can increase network complexity, as it requires specialized infrastructure and management tools to create and manage the virtual networks. This can make it more challenging for network operators to maintain and troubleshoot the network.

Resource constraints: Creating multiple virtual networks can lead to resource constraints, as each slice requires a portion of the network resources such as processing power, storage, and bandwidth. If network resources are not properly allocated or managed, it can lead to degraded performance or service disruptions.

Interference between slices: Multiple network slices running on the same physical infrastructure can cause interference between slices, leading to reduced network performance or degraded service quality. This can be mitigated by proper network design and management.

Potential security risks: Network slicing can create new security risks, as each virtual network has its own security requirements and vulnerabilities. If security policies and controls are not properly implemented or maintained, it can lead to security breaches or unauthorized access.

Compatibility issues: Network slicing may not be compatible with all types of network equipment or services. This can limit the ability of network operators to offer network slicing services to all customers or applications.

CHAPTER-4

CO-EXISTENCE OF EMBB AND URLLC

Network slicing in 5G enables different services to coexist within the same network architecture. Orthogonal several Access (OMA) techniques were primarily used in earlier generations of wireless communications systems to enable access to several users. In such schemes, the users are given access to radio resources that are, ideally, orthogonal to one another in time, frequency, or coding domain. The total amount of available orthogonal resources limits the maximum number of users, which is one disadvantage of OMA designs.

Non-Orthogonal Multiple Access (NOMA) emerges as a potential technology for beyond-5G and 6G to address the different criteria of very high data speeds, ultra-reliability, low latency, huge connection, and spectral efficiency.

4.1 System Model

Consider the uplink scenario of a 5G network where independent data packets are continuously transmitting to a common base station (BS) from multiple eMBB and URLLC devices.We consider the system model where time-frequency framework composed of frequency slots indicated by f where $f \in \{1,2,3,..,F\}$ and mini slots indicated by t where $t \in \{1,2,3,..,T\}$. The set of mini slots is called a timeslot.

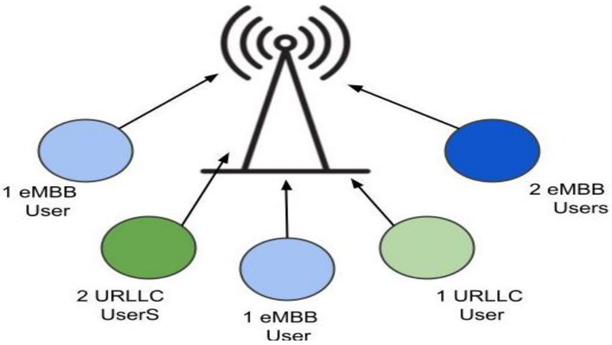
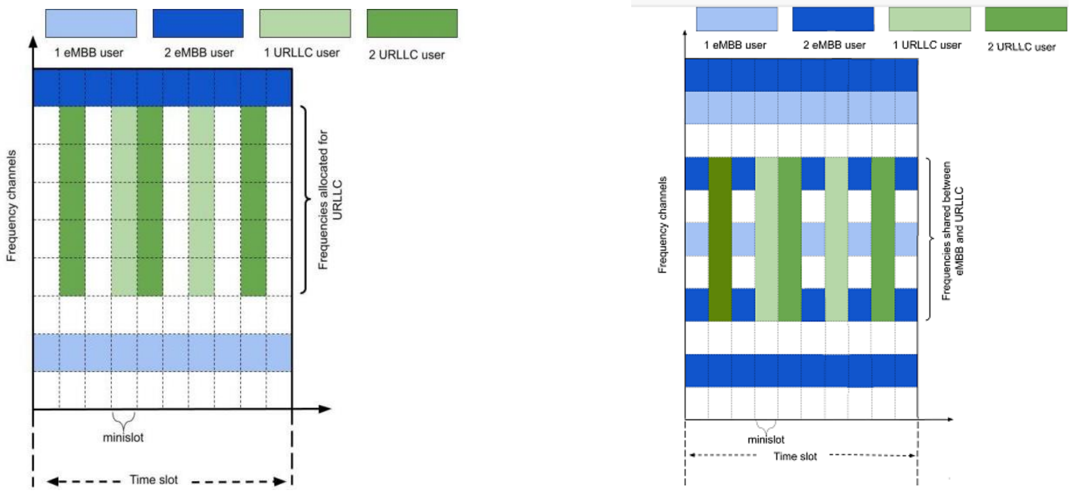


Fig.4.1: Uplink transmissions to a common base station (BS) from multiple eMBB and URLLC users. The blue circles represent the eMBB users, whereas the green circles represent the URLLC users.

The two network slicing schemes namely orthogonal and non-orthogonal slicing between eMBB and URLLC is demonstrated in fig 4.2. Where Fu=5 frequency channels are allocated for URLLC transmission and T=10 mini slot . We considered the worst case scenario where two eMBB devices are simultaneously utilizing the same frequency channel as indicated with dark blue color in fig10.



(a) (b)

Fig.4.2: Illustration of the time-frequency framework used for the network slicing between the eMBB and URLLC devices (a) in the orthogonal multiple access (OFDMA)
(b) non orthogonal multiple access (NOMA) scenario.

The eMBB device occupies entire timeslot for the transmission over a frequency channel f since the for the main intension of achieving higher data rates. Parallelly, a URLLC device uses a single mini slot across the frequency slots allocated for URLLC transmission (Fu ≤F) in order to meet the low latency constraint while decoding with guarantee of meeting the reliability requirement. In a practical scenario where there are n number of URLLC devices connected to a BS at a time but we consider that only few of them are active in a time slot. We analyse the spectral efficiency of the system from the channel capacity derived from Shannon theorem.

$$C=B\log_2(1+SNR)$$

Where C= Channel capacity, B=Channel Band width and

SNR= Signal to Noise Ratio.

From the capacity formula, the channel spectral efficiency is,

$$\eta = R_C/B_C$$

Where ŋ = channel spectral efficiency and R_C= bit rate transmitted on the channel.
It is seen that the spectral efficiency is directly proportional to net data rate achieved by all the users which is scaled by (1/B). So, analysing the net data rate is the key factor for the analyses of spectral efficiency. In the upcoming sections of this work, we analyse the spectral efficiency individually for different services.

4.2 Orthogonal Slicing for Coexisting eMBB and URLLC

The total frequency allocated F is divided for eMBB and URLLC users as F=$F_u + F_b$

Where, F_u is frequency allocated for URLLC users

F_b is frequency allocated for eMBB users

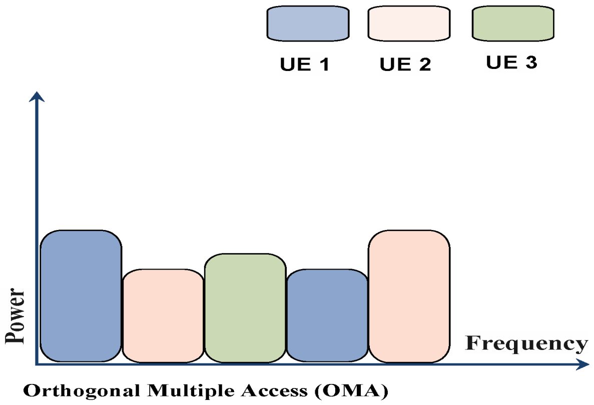


Fig. 4.3: Frequency allocation in OMA

We pre sum that there are many URLLC users connected to the same BS, but that only some of them are concurrently active in the same minislot. The baseband signal received at the serving BS in small slot s and frequency channel f is used for the orthogonal slicing.

$$\boldsymbol{Y_f^{orth}} = \begin{cases} H_{B,f}X_{B,t,f} + W_{t,f} & ,if\ f\ is\ allocated\ for\ eMBB \\ \sum_{u=1}^{n_u} H_{u_{u,f}}X_{U_{u,t,f}} + W_{t,f}, & ,if\ f\ is\ allocated\ for\ URLLC \end{cases} \quad (1)$$

Traditional orthogonal allocation distributes different frequency channels to eMBB and URLLC devices and works in the frequency domain. Transmissions over several time resources are permitted for eMBB. In contrast, URLLC broadcasts are localised in time and dispersed over several frequency channels to achieve diversity in order to guarantee the latency constraints described above. Additionally, because URLLC traffic is bursty, it's possible that the resources allotted to URLLC users go completely unused. This is due to the fact that in the absence of URLLC transmission, the channels set aside for it remain empty. It's important to note that orthogonal slicing does not prevent devices of the same type from sharing wireless resources. An orthogonal sharing of the permitted frequency channels by several eMBB customers, for instance, would be considered a traditional Orthogonal Multiple Access (OMA). As an alternative, they might use NOMA to simultaneously communicate on the same frequency channels. As a result, Heterogeneous Orthogonal Multiple Access (HOMA) is used to separate the orthogonality of signals coming from devices of the same kind from those of different services. (H-OMA).

4.3 Non-Orthogonal Slicing for Coexisting eMBB and URLLC

Under the non-orthogonal slicing assumption, all F frequency channels are used for both eMBB and URLLC services, such that F_u = F_B = F.

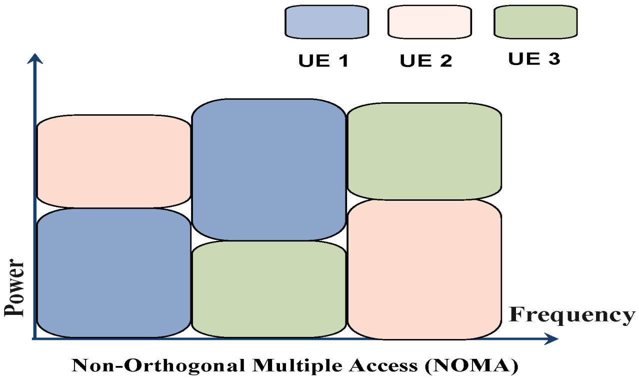


Fig 4.4: Frequency allocation in NOMA

The frequency resources that were only given to URLLC traffic under H-NOMA can now also be made available to eMBB customers. In this way, compared to H-OMA, H-NOMA may enable a more effective use of radio resources by preventing the wastage of resources brought on by inactive URLLCs. For the eMBB customers who can profit from the intermittent nature of URLLC traffic, this could result in a higher spectral efficiency. The performance of all the associated services could be severely hampered by the mutual interference between eMBB and mMTC or URLLC transmissions. Thus, with H-NOMA, achieving desired performance levels is more difficult.

The baseband signal vector for non-orthogonal slicing received at the BS in the small slot s and frequency channel f is

$$Y_{t,f} = H_{B,f} X_{B,t,f} + \sum_{u=1}^{n_u} H_{u_{u,f}} X_{U_{u,t,f}} + W_{t,f} \qquad (2)$$

$H_{B,f}$ is wireless channel coefficient of eMBB user,

$X_{B,t,f}$ is symbol transmitted by the eMBB user,

$W_{t,f}$ is the AWGN sample at the receiver antenna,

$H_{u_{u,f}}$ is the wireless channel coefficient of u-th URLLC device in the frequency channel f

$X_{U_{u,t,f}}$ is the symbol transmitted by the u-th URLLC user in the frequency channel f.

The decoding of a URLLC transmission cannot wait for the decoding of the eMBB traffic due to latency restrictions.

The decoding of the eMBB broadcasts can wait until the URLLC messages have been decoded because their latency constraints are less strict.

As a result, the BS makes an initial attempt to decode each packet in turn from each of the n_u active URLLC users in a minislot during the SIC decoding process.

The BS only tries to decode the eMBB users' packets after successfully decoding the URLLC packets. As a result, eMBB interference is constantly present throughout URLLC decoding.

On the other hand, there is no longer any URLLC interference when the BS tries to decode the eMBB packets.

CHAPTER-5

SIMULATION RESULTS

5.1 Analysis of Sum rate of the eMBB System Model

Consider a system model where multiple eMBB devices are connected to a single a single BS. The time -frequency frame work is as shown in fig 5.1.

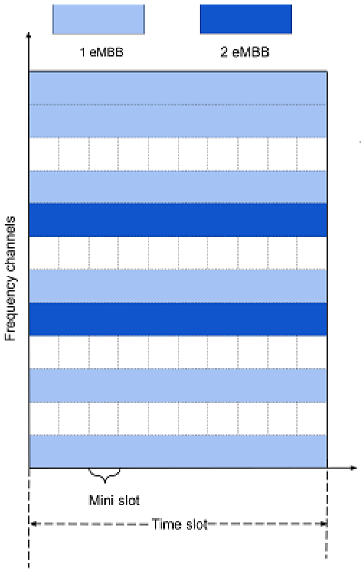


Fig .5.1: Illustration of the time-frequency framework for Performance Analysis of eMBB Users

Considering the worst-case scenario where two eMBB devices share the same frequency channel acting as the interference to one another. From network slicing.pdf; we analyse the performance of eMBB device where the BS is constructed with multiple receiver antenna elements (antenna diversity). The number of receiver antenna elements is denoted by L. eMBB device adjusts its transmitted power P_B (γ_B) as claimed by the instantaneous channel gain for every fixed SNR. The main aim of the eMBB device is to transmit at the highest possible rate r_B with a constraint on satisfying the reliability requirement ϵ_B. So, optimization problem can be expressed as;

$$P_r\{\log_2[1 + P_B(\gamma_B)\gamma_B \leq r_B\} \leq \epsilon_B \qquad (3)$$

where γ_B is the received SNR and γ_B^{min} is the target SNR. a_B activation probability.

The maximum rate can be achieved in the case where;

$$a_B = P_r\{\gamma \geq \gamma_B^{min}\} \qquad (4)$$

So, the outage probability of an eMBB device can be written as;

$$P_r\ (\mathrm{E_B}) = 1 - a_B \qquad (5)$$

Imposing the reliability requirement P_r (EB) = ϵB

$$K = Rx * \gamma^{-1}(L, \in_B\ (L-1)!\ ) \qquad (6)$$

Where K is the Threshold SNR required for the transmission, R_x= received SNR.

$\gamma_{(a,b)}$ is the lower incomplete gamma function

Where $\gamma(a^z) = \int_0^z t^{a-1} e^{-t} dt$

The target SNR can be;

$$r_b^{tar} = \frac{R_x * (L-1)!}{\gamma\left(L-1, \left({}^{K}/_{R_x}\right)\right)} \qquad (7)$$

So, if there is no interference for an eMBB device from another eMBB device;

The outage rate achieved in no interference case is;

$$r_b^{out1} = log_2(1 + r_b^{tar}) \qquad (8)$$

If we consider the case where there is an interference is present for eMBB device from another device, then the outage rate can be expressed as;

$$r_b^{out2} = \ log_2\left(1 + \frac{r_b^{tar}}{1+r_b^{tar}}\right) \qquad (9)$$

Simply the net rate (r_b^{sum})

$$r_b^{sum} = \mathrm{n1} * r_b^{out1} + \mathrm{n2} * r_b^{out2} \qquad (10)$$

Where n1 is the total number of eMBB devices without no effect of interference and n2 is the total number of eMBB devices with effect of interference.

5.2 Analysis of Sum rate of the URLLC System Model

Consider a system model where only multiple URLLC devices are connect to a single BS at different mini slots as shown in fig 5.2.

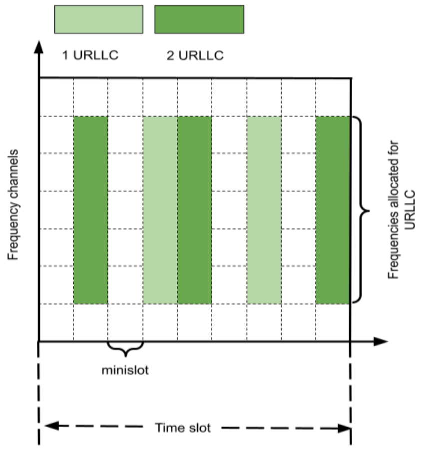


Fig 5.2: Illustration of the time-frequency framework for Performance Analysis of URLLC Users.

In this case we have taken the worst-case scenario where two URLLC users are active in a single mini slot leading to interference to each other. Unlike eMBB, here we deploy SIC decoding where the strongest user is decoded first and then its interference is eliminate for the successive users. The strongest user is the one who achieves the highest sum data rate from all frequencies allocated for URLLC transmission (Fu). The SNR for the u-th URLLC user in the frequency slot (f) is

$$\sigma_{u,f} = \frac{Gu_{u,f}}{1+\sum_{j=u+1}^{n_u} Gu_{i,f}} \qquad (11)$$

The active URLLC device is decoded successfully if

$$\frac{1}{F_u}\sum_{f=1}^{F_u}\log_2(1+\sigma_{u,f}) \geq r_U \qquad (12)$$

In order to find the strongest one among the URLLC devices the sum rate is calculated for every device considering remaining all the devices are acting as the interference. The sum rate of the u-th user from all the frequencies Fu can be calculated from the below equation

$$I_u^{sum} = \sum_{f=1}^{F_u} log_2\left(1+\sigma_{u,f}\right) \qquad (13)$$

Imposing the reliability requirement ($\in_u$)

$$P_r(E_u) \leq \epsilon_U$$

$$P_r(E_u) = P_r\left(\frac{1}{F_u}\sum_{f=1}^{F_u} log_2\left(1 + G_{u,f}\right) < r_u\right) = E_u \quad (14)$$

$$E_u = P_r\left(\sum_{f=1}^{F_u} log_2\left(1 + G_{u,f}\right) < F_u . r_u\right) \quad (15)$$

$$E_u = P_r\left(\prod_{f=1}^{F_u}(1 + G_{u,f})^{-t} \geq 2^{-r_uF_ut}\right) \quad (16)$$

$$E_u \leq E\,\frac{\left[\prod_{f=1}^{F_u}(1 + G_{u,f})^{-t}\right]}{2^{-r_uF_u}t} \quad (\ 17)$$

$$E_u = E\,\frac{[\ (1 + G_{u,_1})^{-t}]^{F_u}}{2^{-r_uF_u}t} \quad (18)$$

Eq 14 obtained from 13 By morkov inequality

Morkov inequality: -

$$P(X \geq a) \ \leq \frac{E[X]}{a} \quad (19)$$

Where X is a random variable

On rearranging term in 4

$$r_u \geq \frac{1}{tF_u} log_2 E_u - \frac{1}{t} log_2 E[\left(1 + G_{u,_1}\right)^{-t}] \quad (20)$$

Where, $Gu_{u,f}$ is Instantaneous wireless channel gain in the frequency channel f for URLLC,$\sigma_{u,f}$ is available SINR while decoding the signal of the URLLC device, $I_u^{sum}$is the sum rate of the u-th user,$P_r(E_u)$ is the error probability of URLLC,$\in_u$ is reliability requirement of URLLC user,F_u is the number of frequency channels allocated for simultaneous transmission of URLLC, r_u is the rate achieved by URLLC user

The total sum rate r_u^{sum}achieved by all the URLLC users

$$r_u^{sum} = \text{n1*(r1) + n2*(r2+r3)} \quad (21)$$

where n1 is the number of users having no effect of interference and r1 is the data rate achieved by it.

n2 is the number of mini slots containing 2 devices transmitting simultaneously,
r2 is the data rate achieved by the strong user and r3 is the data rate achieved by the weak user.

Generally, the net data rate of any system with nu active URLLC users is

$$r_U^{net} = n_U r_U \qquad (22)$$

Where nu is the total number of active URLLC users r_u is the total data rate achieved by the URLLC users

5.3 Network Slicing Between Coexistence of eMBB and URLLC

We consider the coexistence of eMBB and URLLC devices for both NOMA and OMA.

5.3.1 Analysis of Sum rate of the OMA System Model

In OMA, out of total frequency channel(f) available, the frequency channels exclusively allocated for URLLC devices (fu) and the remaining frequency channels i.e ($F - F_u$) are exclusively allocated for eMBB devices(fb).

The sum rate in oma is simply the summation of net rate achieved by all eMBB devices and net rate achieved by all the URLLC devices from the above sections.

$$r^{orth} = r_b^{sum} + r_u^{sum} \qquad (23)$$

Where r_b^{net} is given in eq (10) and r_u^{sum} is given in eq (22).

we calculated the maximum URLLC rate r_u that guarantees the reliability constraint $P_r(E_u) \leq$ U for all n_u URLLC devices transmitting simultaneously.

5.3.2 Analysis of Sum rate of the NOMA System Model

In NOMA, the total frequency channels(f) can be utilized by both eMBB and URLLC simultaneously (f=fb=fu). Due to the latency requirement of the URLLC devices, the eMBB devices are decoded at the last (i.e., after all URLLC devices are decoded) as eMBB has greater demand in date rate than the latency. This enables the SIC decoding where the URLLC devices are decoded successively. During this decoding process of URLLC device the interference due to eMBB device is always taken into consideration. But in the decoding process of eMBB, the interference due to URLLC is not considered because we calculated the rate for the URLLC device with the guarantee of all URLLC devices are decoded successfully. The interference due to eMBB device for the URLLC traffic is aimed to be minimum. So, a minimum target SNR is chosen for the eMBB device. So, from the below inequality.

$$G_{B,f}^{tar} \leq \frac{\tau_B}{\tau\left(0, \frac{G_{B,f}^{min}}{\tau_B}\right)} \qquad (24)$$

So, the u-th URLLC device will have the SINR as

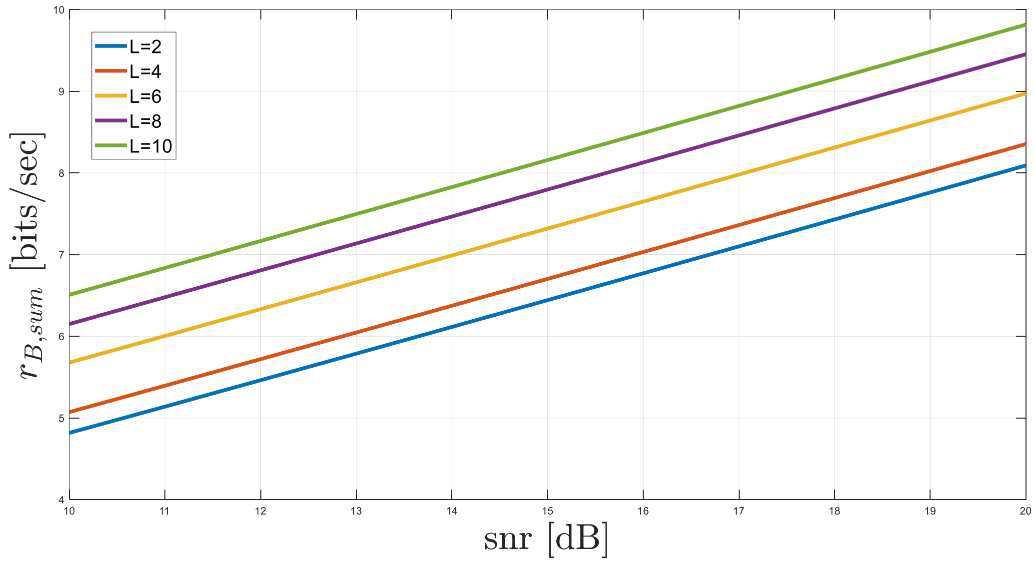
$$\sigma_{u,f} = \frac{G_{U_{u,f}}}{1+G_{B,f}^{tar}+\sum_{j>u}^{n_u} G_{U_{j,f}}} \qquad (25)$$

Using the above SINR in the data rate analysis of the URLLC as discussed above, a rate was deducted at which the URLLC device is decoded successfully even the interference due to eMBB device.

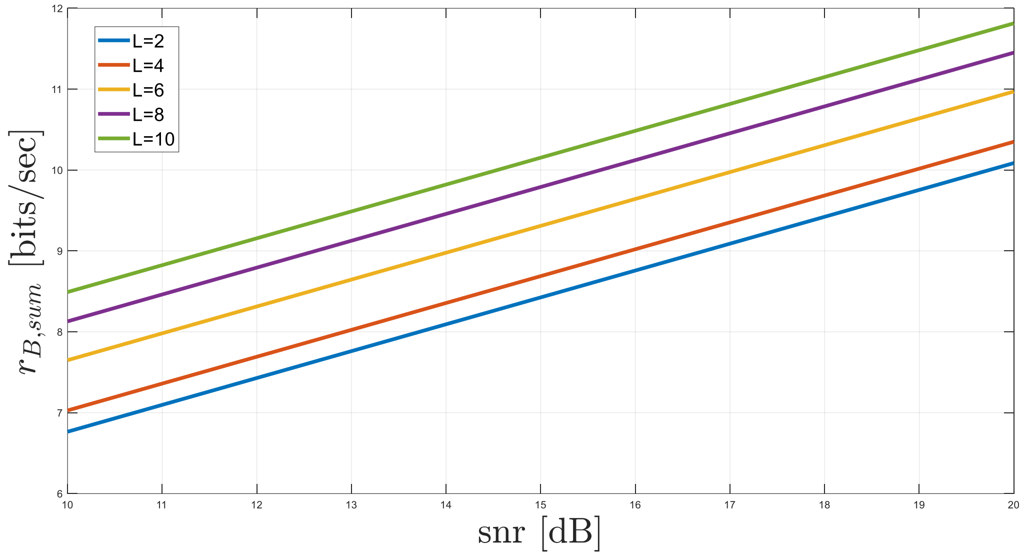
5.4 Numerical Results

We have taken 10^5 Monte Carlo Simulations for orthogonal and Non-orthogonal network slicing between eMBB and URLLC.

We simulated the net data rates achieved vs snr by one eMBB user and 3 eMBB(2 eMBB devices with interference + 1eMBB device with no interference) for different values of number of receiver antenna elements(L) where L ∈ {2,4,6,8} and $\epsilon_B = 10^{-3}$



(a)



(b)

Fig 5.3: (a)eMBB sum rate r_b^{sum} versus snr(Γ) for the single user case (b) eMBB sum rate r_b^{sum} versus snr(Γ) for the three users' case with ϵ_B = 10−3 and L ∈ {2,4,6,8}.

SNR values(dB)	Sum Rate(bits/sec)	
	1 eMBB device	3 eMBB devices
14	6.989	14
16	7.649	16
18	8.311	18

Table (1): Comparison between the sum rate achieved by 1eMBB and 3 eMBB devices

From the above comparison table, we can observe that the higher sum rate was achieved in 3 eMBB devices case than that of in single eMBB device case and as the number of receiver antenna elements L increases sum data rates are increased correspondingly due to diversity in the receiver antenna.

The analysis results for Fig 5.1 where we considered the size of the time-frequency frame work as 10x12 where two of the total frequency channels containing two eMBB transmissions each, six of them are containing only one eMBB transmission and remaining are idle channels. we considered the practical reliability requirement for the eMBB transmission i.e., $\epsilon_B = 10^{-3}$. We presented the results for different values of number of number of receiver antenna elements (L) where L ∈ {2,4,6,8}.

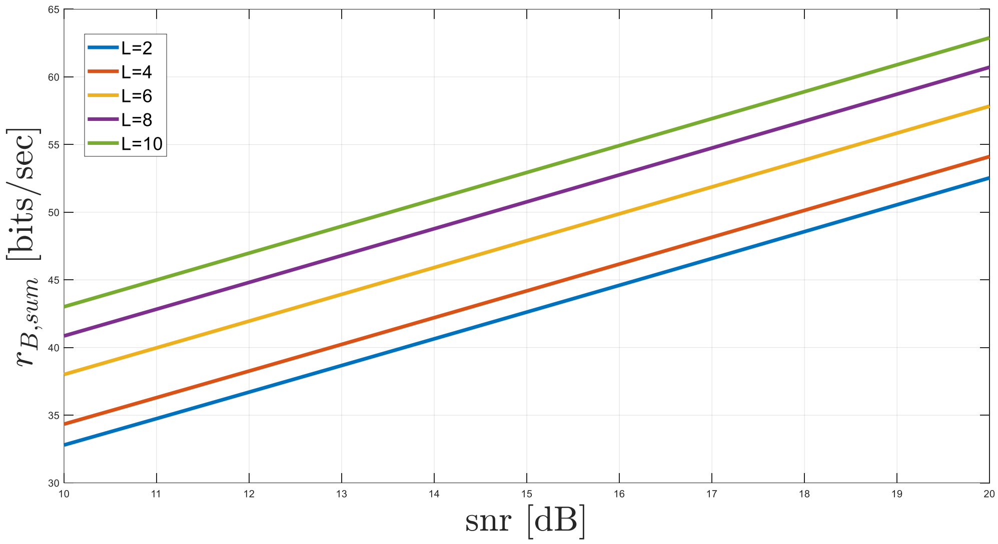
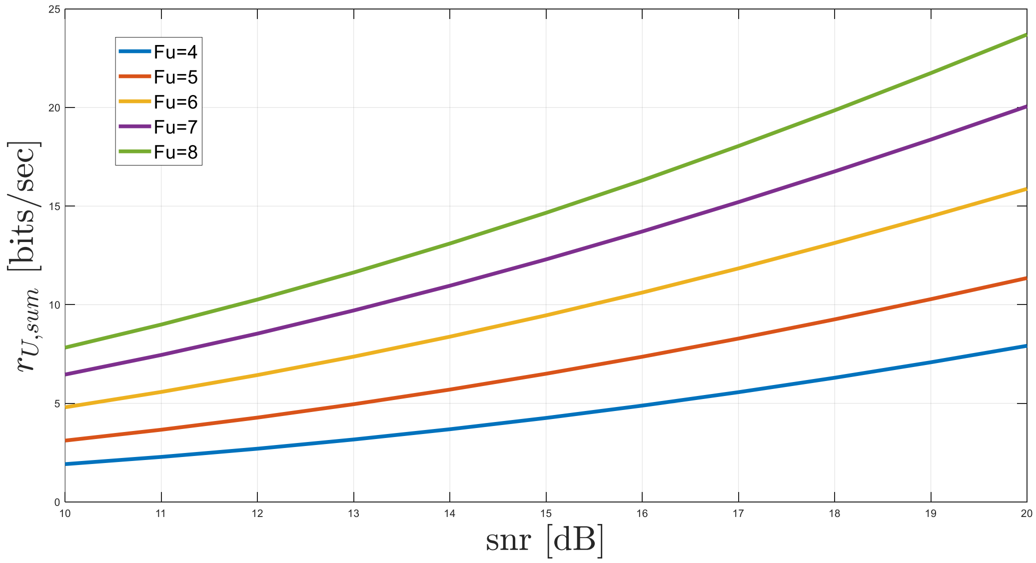


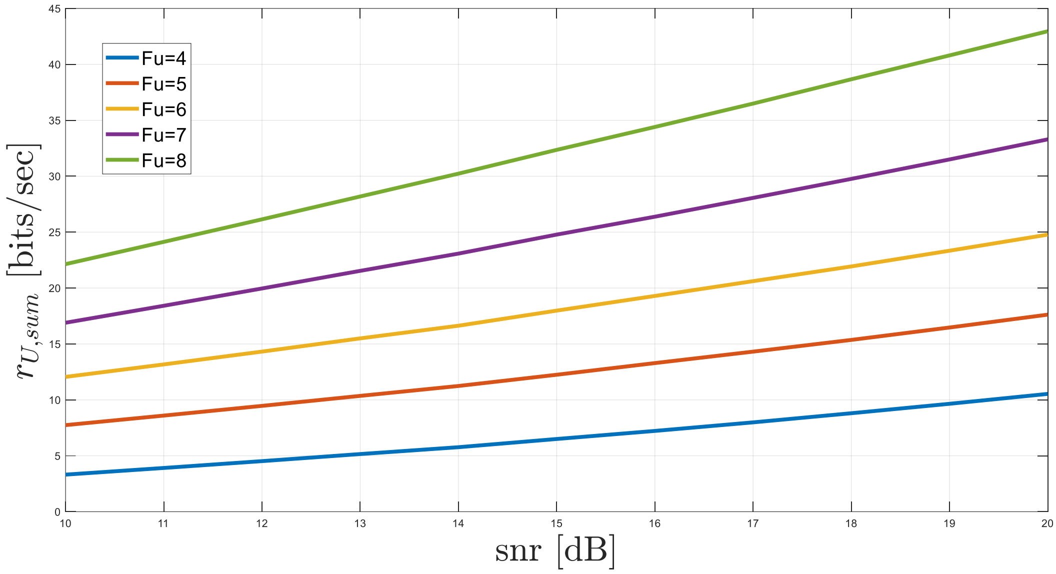
Fig. 5.4**:** eMBB sum rate r_b^{sum} versus snr(Γ) for the Fig.5.1 with $\epsilon_B = 10-3$ and L ∈ {2,4,6,8}.

We can observe higher data rates are achieved for the system shown in (fig (5.1)) as the number of eMBB devices are increased with the increase in L.

We simulated the net data rates achieved vs snr by single URLLC user and 3 URLLC (2 URLLC devices with interference + 1URLLC device with no interference) for different values of number of frequency channels allocated for URLLC transmission (F_U) where F_U ∈ {4,5,6,7,8} and $\epsilon_U = 10^{-5}$.



(a)



(b)

Fig 5.5:(a) URLLC sum rate r_U^{sum} versus snr(Γ) for the single user case

(b) URLLC sum rate r_U^{sum} versus snr(Γ) for the three users case with $\epsilon_U = 10^{-5}$ and $F_U \in \{4,5,6,7,8\}$.

SNR values(dB)	Sum Rate(bits/sec)	
	1URLLC device	3 URLLC devices
14	10.03	14
16	12.58	16
18	15.37	18

Table (2): Comparison between the sum rate achieved by 1 URLLC and 3 URLLC devices

From the above comparison table, we can observe that the higher sum rate was achieved in 3 URLLC devices case than that of in single URLLC device case and as the number of frequency channels allocated for the URLLC transmission, sum data rates increased correspondingly due to the low latency is at ease.

The results we obtained after the analysis of the URLLC shown in fig 5.2 where we take the URLLC interference into account for different values $F_U \in \{4,5,6,7,8\}$. and the reliability requirement $\epsilon_U = 10^{-5}$.

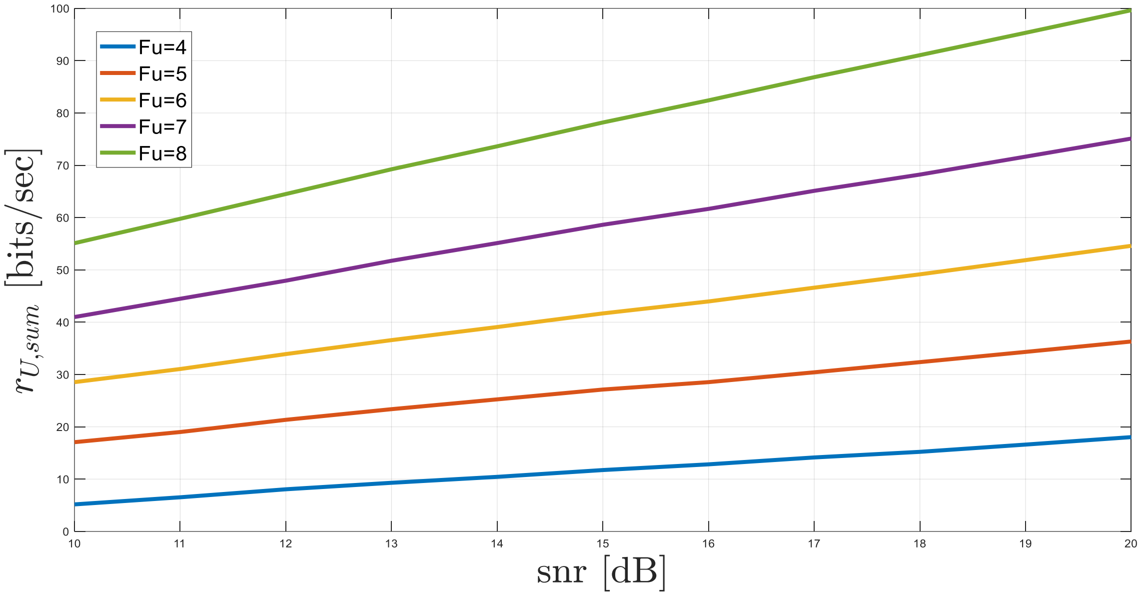


Fig 5.6: URLLC sum rate r_U^{sum} versus snr(Γ) for the fig.5.2 with $\epsilon_U = 10^{-5}$ and $F_U \in \{4,5,6,7,8\}$.

We can observe higher data rates are achieved for the system shown in fig as the number of URLLC devices are increased with the increase in F_U.

The main motto of this work is the analysis of the sum rate of the different network slicing schemes namely, OMA and NOMA. We have considered the number of frequency channels allocated for URLLC transmission are $F_U = 5$ and the receiver antenna elements $L = 1$.

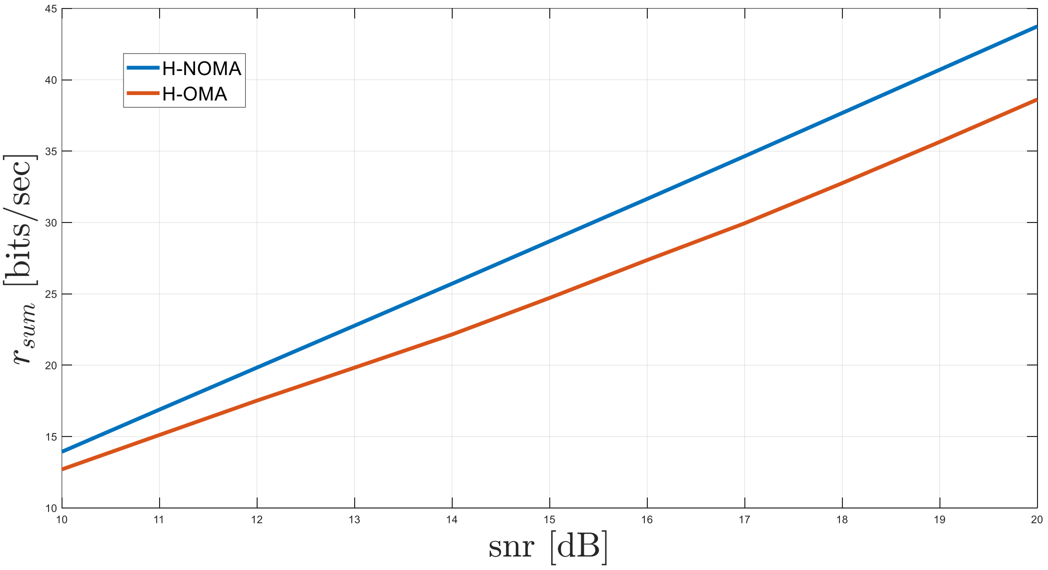


Fig.5.7: Sum rate vs SNR for the coexistence between eMBB and URLLC for the orthogonal and non-orthogonal slicing when $F_U = 5$, $L = 1$, $\epsilon_U = 10^{-5}$, $\epsilon_B = 10^{-3}$.

SNR values(dB)	Sum Rate(bits/sec)	
	NOMA	OMA
11	16.98	11
14	25.86	14
16	31.80	16
18	37.80	18

Table (3): Comparison between the sum rate achieved in NOMA and OMA schemes

From the above comparison table, it is seen that for a fixed SNR, higher data rate is achieved in NOMA than OMA because, in NOMA a single frequency channel can be shared simultaneously for the transmission of eMBB and URLLC devices.

CONCLUSION

We analysed the use of NOMA and SIC decoding. It is a best solution to transmit the maximum number of URLLC data packets to the same BS and when they share the same radio resources with eMBB users, in both orthogonal and non-orthogonal slicing of radio resources between the two services. We showed that, the coexistence between eMBB and URLLC is possible with a guarantee of meeting the respective reliability requirements. We projected through simulations that the non-orthogonal slicing is preferred over the orthogonal slicing for the whole range of SNR because higher data rates are achieved on using the same frequency channel for the transmission of eMBB and URLLC. With increase in sum rate and also by increasing the number of active devices, spectral efficiency is enhanced more.

The analysis can be further extended for Bit Error Rate to increase the spectral efficiency and can be extended for the frame work for 6G wireless technology where a greater number of URLLC and eMBB devices are transmitted data simultaneously.

REFERENCES

1. H. Chien et al. “End-to-End Slicing as a Service with Computing and Communication Resource Allocation for Multi-Tenant 5G Systems”. In: IEEE Wireless Communications 26.5 (2019), pp. 104–112.
2. H. Zhang et al. “Network Slicing Based 5G and Future Mobile Networks: Mobility, Resource Management, and Challenges”. In: IEEE Communications Magazine 55.8(2017), pp. 138–145.
3. Hossain, E., Hasan, M. Z., & Bhuiyan, M. Z. A. “Non-orthogonal multiple access for 5G: solutions, challenges, opportunities, and future research trends”. IEEE Communications Magazine, Year: 2017, 55(7), 22-29. https://doi.org/10.1109/MCOM.2017.1600936.
4. Amjad Saeed, Saqib Saleem, Ziaul Haq Abbas, Muhammad Ali Imran, Athanasios V.Vasilakos, and Ejaz Ahmed “NOMA-Based Coexistence of eMBB and URLLC in 5G Networks: A Survey” IEEE Communications Surveys and Tutorials Year: 2020 Volume: 22 Issue: 1 Pages: 764-805 https://doi.org/10.1109/COMST.2019.2951335
5. Yang, L., Zhang, Y., & Zheng, K. (2020). Coexistence of eMBB and URLLC in 5G and Beyond Networks: A NOMA Perspective. IEEE Wireless Communications, 27(4), 120-126. https://doi.org/10.1109/MWC.001.190069324
6. H. Zeng, X. Liu, K. Zhang, H. Zhang, & X. Wang. (2018). Power allocation for NOMA-based coexistence of eMBB and URLLC in 5G networks. IEEE Communications Magazine, 56(12), 110-117. https://doi.org/10.1109/MCOM.2018.1800595
7. Khattab, T. A., Zaki, M. H., Almotairi, M. A., & Al-Naffouri, T. Y. (2020). Multi-objective Resource Allocation for NOMA-Based Coexistence of eMBB and URLLC in 5G Networks. IEEE Access, 8, 34629-34641. https://doi.org/ 10.1109/ ACCESS. 2020.2977731
8. M. A. Imran, M. A. Naeem, S. Mumtaz, H. V. Poor, and J. Xu, " Network Slicing for 5G with eMBB and URLLC Coexistence: A Review, Key Issues and Challenges, " in IEEE Communications Magazine, vol. 56, no. 11, pp. 138-145, Nov. 2018, https://doi.org/10.1109/MCOM.2018.1800246.
9. Khan, N. A., Javaid, N., Ejaz, W., Khan, Z. A., & Alrajeh, N. A. (2018). Resource Allocation for Coexisting eMBB and URLLC Services in 5G Networks with Network

Slicing. IEEE Communications Magazine, 56(3), 58-65. https://doi.org/ 10.1109/MCOM. 2018.1700486

10. Alhakbani, Z., Al-Enezi, A., Al-Bayatti, A. H., & Al-Ruwais, A. (2021). A Joint Scheduling and Resource Allocation Scheme for Coexisting eMBB and URLLC Services in 5G Networks. Wireless Communications and Mobile Computing, 2021.https://doi.org/10.1155/2021/6629297
11. Li, J., Yu, F. R., & Leung, V. C. M. (2019). Network slicing for coexisting eMBB and URLLC services in 5G networks. IEEE Wireless Communications, 26(2), 50-57. doi:10.1109/MWC.2019.1800043
12. P. Popovski et al. “Wireless Access for Ultra-Reliable Low-Latency Communication: Principles and Building Blocks”. In: IEEE Network 32.2 (Mar. 2018), pp. 16–23. doi:10.1109/MNET.2018.1700258.
13. E. N. Tominaga et al. Non-Orthogonal Multiple Access and Network Slicing: Scalable Coexistence of eMBB and URLLC. 2021. arXiv: 2101.04605 [eess.SP].