IMPLEMENTATION OF LOSS RECOVERY TECHNIQUES FOR JOINT SCHEDULING IN 5G NETWORKS

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in partial fulfillment of the requirement for the degree of

Bachelor of Engineering in Information Technology

By

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BONAFIDE CERTIFICATE

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JADAVPUR UNIVERSITY
Dept. of Information Technology

Vision:

To provide young undergraduate and postgraduate students a responsive research environment and quality education in Information Technology to contribute in education, industry and society at large.

Mission:

M1: To nurture and strengthen professional potential of undergraduate and postgraduate students to the highest level.

M2: To provide international standard infrastructure for quality teaching, research and development in Information Technology.

M3: To undertake research challenges to explore new vistas of Information and Communication Technology for sustainable development in a value-based society.

M4: To encourage teamwork for undertaking real life and global challenges.

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Graduates should be able to:

PEO1: Demonstrate recognizable expertise to solve problems in the analysis, design, implementation and evaluation of smart, distributed, and secured software systems.

PEO2: Engage in the engineering profession globally, by contributing to the ethical, competent, and creative practice of theoretical and practical aspects of intelligent data engineering.

PEO3: Exhibit sustained learning capability and ability to adapt to a constantly changing field of Information Technology through professional development, and self-learning.

PEO4: Show leadership qualities and initiative to ethically advance professional and organizational goals through collaboration with others of diverse interdisciplinary backgrounds.

Mission - PEO matrix:

Ms/ PEOs	M1	M2	M3	M4
PEO1	3	2	2	1
PEO2	2	3	2	1
PEO3	2	2	3	1
PEO4	1	2	2	3

(3 – Strong, 2 – Moderate and 1 – Weak)

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At the end of the program a student will be able to:

PSO1: Apply the principles of theoretical and practical aspects of ever evolving Programming & Software Technology in solving real life problems efficiently.

PSO2: Develop secured software systems considering constantly changing paradigms of communication and computation of web enabled distributed Systems.

PSO3: Design ethical solutions of global challenges by applying intelligent data science & management techniques on suitable modern computational platforms through interdisciplinary collaboration.

ABSTRACT

5G joint scheduling is a crucial feature in fifth generation (5G) wireless networks that optimizes resource allocation and enhances network efficiency. It enables multiple base stations to collaboratively schedule user transmissions, improving overall system performance. By leveraging the coordination capabilities of neighboring cells, 5G joint scheduling reduces interference, increases spectral efficiency, and ensures fair distribution of network resources among users.

The fifth generation (5G) wireless communication networks have ushered in a new era of connectivity, offering unprecedented capabilities to support diverse services and applications. To fully harness the potential of 5G, efficient resource allocation and management are crucial. Joint scheduling has emerged as a critical technique that enables optimal utilization of network resources, improved performance, and enhanced Quality of Service (QoS) provisioning.

We discuss the challenges posed by the diverse requirements of various services and applications, such as ultra-reliable low-latency communication (URLLC), massive machine-type communication (mMTC), and enhanced mobile broadband (eMBB).

By considering the interdependence between different resources, joint scheduling facilitates optimized allocation decisions. It considers factors like channel conditions, QoS requirements, user mobility, and network congestion levels. Moreover, joint scheduling enables efficient multiplexing and coordination of resources, leading to increased spectral efficiency, reduced latency, and improved fairness among users.

We also discuss various loss recovery techniques to ensure that low priority eMBB users also get their fair share of resources.

SYMBOLS, ABBREVIATIONS AND NOMENCLATURE

5G : Fifth Generation

eMBB : Enhanced Mobile Broadband

URLLC : Ultra Reliable Low-Latency Communications

mMTC : Massive Machine-Type Communications

RB : Resource Block

UE : User Equipment

gNB : Next Generation Node B

OFDMA : Orthogonal Frequency Division Multiple Access

SNR : Signal-to-Noise Ratio

MCS : Modulation and Coding Scheme

SIC : Successive Interference Cancellation

NOMA : Non Orthogonal Multiple Access

QoS : Quality of Service

NR : New Radio

SIC : Successive Interference Cancellation

BS : Base Stations

AP : Access Point

TTI : Transmission Time Interval

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1. INTRODUCTION

1.1 Background and Motivation

5G is the fifth generation of wireless technology. It can provide high speeds, low latency and massive capacity which helps in revolutionizing industries and make businesses more efficient. It enables a more responsive and vaster Internet of Things (IOT).
In 5G, users are divided into three categories – eMBB, URLLC and mMTC. Given the coexistence of all three users in the same network there arises a requirement of Joint Scheduling of resources among them.
Due to resource sharing because of Joint Scheduling, certain users may experience lack of resources and do not meet their QoS requirements. This is why we have decided to explore various loss recovery techniques to satisfy the QoS needs of these users.

1.2 Review of Literature

1.2.1 Properties of eMBB

Enhanced Mobile Broadband (eMBB) is a key use case of the fifth generation (5G) wireless technology, designed to deliver an unprecedented level of performance and user experience in terms of data rates, connectivity, and network capacity. eMBB aims to meet the ever-increasing demands for high-speed data services in diverse scenarios, ranging from dense urban areas to remote rural regions.

Peak Data Rate:
eMBB in 5G networks provides peak data rates ranging from 10 to 20 Gbps, enabling ultra-fast downloads, seamless video streaming, and immersive virtual reality experiences. This substantial increase in data rate over previous generations ensures that users can enjoy high-quality multimedia content without any latency or buffering issues.

On-Demand Connectivity:
In addition to the impressive peak data rates, eMBB guarantees a minimum data rate of 100 Mbps whenever needed. This ensures a consistent and reliable connectivity experience, even in congested network conditions, by dynamically allocating resources to accommodate varying traffic demands.

Traffic Handling:
eMBB is capable of handling approximately 10,000 times more traffic compared to its predecessor, 4G. This scalability enables network operators to efficiently accommodate the exponential growth of data-intensive applications, such as high-definition video streaming, augmented reality (AR), and Internet of Things (IoT) devices, without compromising the quality of service.

Cell Support:
eMBB supports both macro and small cells, allowing for optimal coverage and capacity in diverse environments. Macro cells serve larger geographic areas, such as cities, while small cells are deployed in densely populated areas to offload traffic and provide localized coverage. The combination of macro and small cells ensures seamless connectivity and consistent data rates across various locations.

High Mobility Support:
One of the remarkable features of eMBB is its ability to support high mobility scenarios, such as high-speed trains and vehicles traveling at speeds up to 500 km/h (310 mph). This ensures uninterrupted connectivity for users on the move, enabling applications like streaming video content, real-time gaming, and interactive communication during high-speed travel.

Energy Savings:
eMBB contributes to significant network energy savings by approximately 100 times compared to previous generations. This is achieved through advanced techniques such as dynamic spectrum allocation, adaptive modulation and coding, and efficient resource utilization. By optimizing power consumption, eMBB not only reduces operational costs but also minimizes the environmental impact of wireless networks.

1.2.2 Properties of URLLC

Ultra Reliability and Low Latency Communications (URLLC) is an essential component of the 5G network architecture, designed to support mission-critical applications that require ultra-responsive and reliable connections. URLLC aims to enable real-time communication and control applications, such as autonomous vehicles, industrial automation, remote surgery, and critical infrastructure management.

2. Air Interface Latency:
URLLC offers air interface latency of less than 1 millisecond, ensuring instantaneous responsiveness and minimal delay in transmitting data between the user equipment (UE) and the 5G base station (gNB). This near-instantaneous latency allows for highly time-sensitive applications, enabling rapid decision-making and seamless interactions in real-time scenarios.

3. End-to-End Latency:
URLLC guarantees an end-to-end latency of 5 milliseconds between the UE and the 5G gNB. This includes the overall delay introduced by the network, transport protocols, and application processing. The low end-to-end latency ensures swift and timely delivery of data, supporting critical applications where even slight delays can have significant consequences.

4. Reliability:
URLLC is designed to be ultra-reliable, providing availability of 99.9999% (also known as six-nines reliability) of the time. This high level of reliability ensures uninterrupted connectivity and communication for mission-critical applications, minimizing the risk of service disruptions and failures in demanding scenarios.

5. Data Rates:
URLLC offers low to medium data rates, typically ranging from about 50 kilobits per second (kbps) to 10 megabits per second (Mbps). While the data rates may be lower compared to other 5G use cases like Enhanced Mobile Broadband (eMBB), URLLC prioritizes ultra-low latency and high reliability over maximum throughput, catering to applications that require real-time response and highly dependable connections.

6. High-Speed Mobility Support:
URLLC also provides support for high-speed mobility, enabling seamless communication and connectivity for fast-moving devices or vehicles. This capability is essential for applications such as high-speed trains, autonomous drones, and connected vehicles, ensuring continuous and reliable connectivity even during high-velocity movements.

1.2.3 Properties of mMTC

Massive Machine Type Communications (mMTC) is a fundamental component of 5G networks, dedicated to enabling connectivity for a massive number of low-power IoT devices. mMTC aims to address the diverse requirements of IoT applications, including smart cities, industrial automation, environmental monitoring, and asset tracking, by providing efficient and scalable communication solutions.

2. High Device Density:
mMTC supports a high density of devices, accommodating approximately 2 x 10^5 devices per square kilometer (km^2) in each area. This capability ensures that the 5G network can handle the massive scale of IoT deployments, enabling seamless connectivity and data transmission for a wide range of devices.

3. Long-Range Support:
mMTC is designed to support long-range communication, allowing devices to connect to the network even when they are located far from the base station. This feature ensures extensive coverage for IoT devices, enabling connectivity in remote areas and providing network access for applications such as agricultural monitoring, smart metering, and rural connectivity.

4. Low Data Rate:
mMTC operates with low data rates, typically ranging from 1 to 100 kilobits per second (Kbps). This low data rate is optimized for IoT applications that primarily involve intermittent, small-sized data transmissions. By prioritizing energy efficiency and conserving network resources, mMTC ensures that IoT devices can operate efficiently with minimal power consumption.

5. Benefits of Low-Cost M2M Communication:
mMTC leverages the benefits of low-cost machine-to-machine (M2M) communication, enabling cost-effective connectivity for IoT devices. This cost efficiency is achieved through optimized device design, efficient network protocols, and streamlined communication mechanisms, making mMTC a suitable solution for large-scale IoT deployments that require economical connectivity solutions.

6. Battery Life:
To cater to the requirements of low-power IoT devices, mMTC offers extended battery life,

enabling devices to operate autonomously for up to 10 years without requiring frequent battery replacements or recharging. This prolonged battery life is crucial for IoT applications deployed in remote or inaccessible locations, where frequent maintenance may not be feasible.

7. Asynchronous Access:
mMTC provides asynchronous access, allowing devices to transmit data to the network without requiring strict synchronization or coordination. This flexibility in access enables IoT devices to transmit data based on their individual schedules and requirements, optimizing network resources and minimizing contention for channel access.

1.2.4 Inference

- The traffic pattern of eMBB is regular.
  They exist for a long time in a network and have longer TTI of 1 millisecond.
- Extremely high reliability requirements of URLLC.
  Since URLLC is 99.99% reliable, priority of resource allocation of URLLC is more than eMBB. For more information, refer to [3].
- The traffic pattern of URLLC is random.
  URLLC users are fewer in number and can enter and exit the network instantaneously and randomly. They have TTI of 0.125 millisecond.
- The traffic patterns of mMTC and URLLC are similar.
  Since traffic patterns of mMTC and URLLC are similar, we focus on Joint Scheduling between eMBB and URLLC only. For more details, refer to [6].

1.2.5 Architecture of Resource Block

In 5G, the resource block (RB) is a fundamental unit of radio resources allocation in the time-frequency domain. It is used to transmit data and control information between the base station (gNB) and the user equipment (UE). The architecture of a resource block in 5G can be described as follows:

1. Time Division: A resource block in 5G is defined in the time domain as a fixed duration of time. The time duration of a resource block depends on the subcarrier spacing used in the system. In 5G, subcarrier spacing can be either 15 kHz or 30 kHz, and the duration of a

resource block can be 0.125 ms, 0.25 ms, or 0.5 ms. For our purposes, we use 0.125ms spacing and we call them minislots, which is the same as TTI of URLLC.

2. Frequency Division: A resource block in 5G is also defined in the frequency domain as a group of consecutive subcarriers. The number of subcarriers in a resource block depends on the channel bandwidth of the system. In 5G, the channel bandwidth can be up to 100 MHz, and the number of subcarriers in a resource block can be 12, 24, 48, 96, or 192, depending on the subcarrier spacing. For our purposes, we fix the frequency spacing as per numerology $\mu = 0$, at 180khz for each Resource Block.

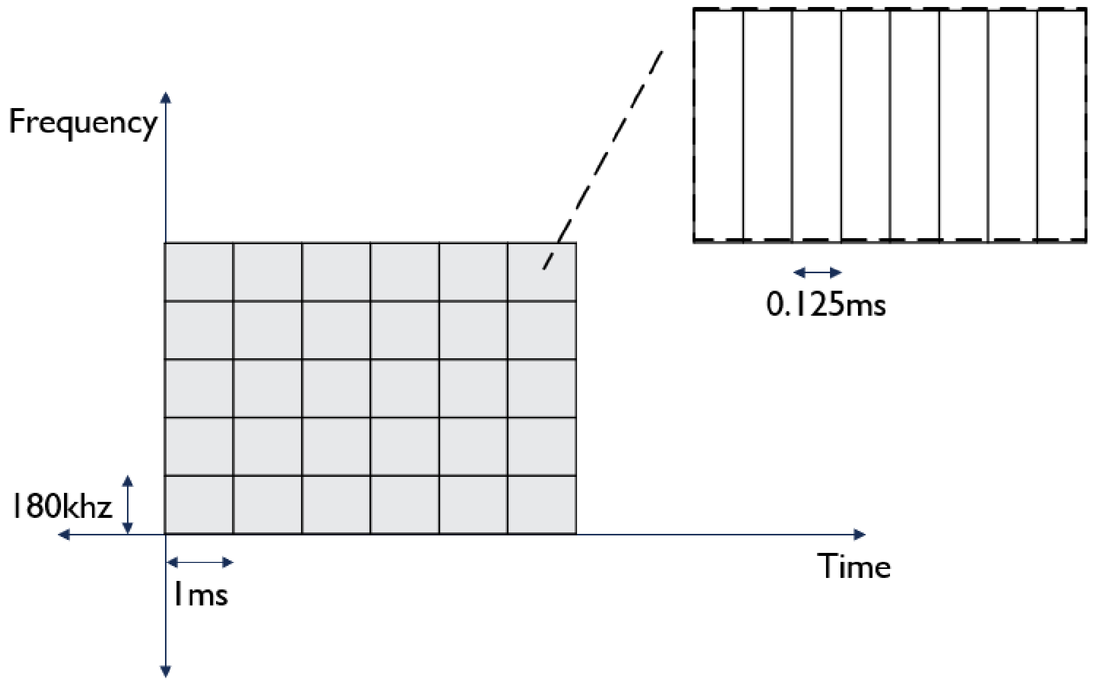

Figure 1. Pictorial Representation of Resource Blocks in Frequency-Time domain

1.3 System Model

In this research, we consider a system model that involves the joint scheduling of enhanced Mobile Broadband (eMBB) and Ultra-Reliable Low-Latency Communication (URLLC) users in a 5G network. The objective is to efficiently allocate radio resources in joint scheduling while giving priority to URLLC users and providing loss recovery to eMBB users.

The system model consists of a fixed number of eMBB users and a variable number of URLLC users coming in each minislot. Specifically, we consider 10 eMBB users. The number of URLLC users varies between 1 and 5, reflecting the dynamic nature of URLLC traffic demands. Each eMBB and URLLC user requires a certain number of resource blocks (RBs) for data transmission, which is determined based on their modulation index, code rate, and spectral efficiency, which is acquired from MCS table [5]. The RB allocation for eMBB is subjected to dynamic adjustments to accommodate URLLC users and optimize resource utilization. The number of URLLC users in each minislot is randomly determined within the range of 1 to 5, reflecting the variability in URLLC traffic.

The system model considers factors such as channel quality, power allocation, RB availability, and RB allocation strategy to effectively manage the limited radio resources. The RB allocation process considers the varying channel qualities of both eMBB and URLLC users, ensuring fair resource distribution and maximizing overall system performance.

To evaluate the proposed joint scheduling approach, simulations are conducted over multiple time slots. Each time slot represents a series of 8 minislots, where RB allocation is dynamically adjusted based on changing network conditions and user demands. Performance metrics such as user data rates, system capacity, and loss of RBs are analyzed to assess the effectiveness and efficiency of the joint scheduling approach.

By considering the fixed number of eMBB users and the variable number of URLLC users, the system model captures the coexistence of different traffic types in 5G networks and provides a framework for investigating the joint scheduling of eMBB and URLLC users, offering insights into resource allocation techniques and loss recovery approaches that can enhance the performance of 5G networks in supporting diverse service requirements.
This ensures high data rates for eMBB users while meeting the stringent reliability and latency demands of URLLC users.

2. JOINT SCHEDULING IN 5G NETWORKS

Joint scheduling in 5G refers to a resource allocation technique where multiple base stations (BSs) collaboratively schedule user equipment (UE) transmissions. It aims to optimize the allocation of radio resources across multiple cells or sectors in order to enhance system performance, improve spectral efficiency, and provide better user experience.

In joint scheduling, instead of each BS independently making scheduling decisions for the UEs within its coverage area, the involved BSs exchange information and coordinate their scheduling decisions. This coordination allows for more efficient utilization of network resources and better management of interference among UEs. Some of the key aspects of Joint Scheduling include the following:

1. Resource Coordination: Joint scheduling involves coordination among multiple BSs to allocate radio resources such as frequency bands, time slots, or subcarriers. The coordination is typically facilitated through backhaul or fronthaul links, allowing the exchange of information about UEs, channel conditions, and scheduling decisions.

2. Interference Management: Joint scheduling addresses the interference issue that arises when multiple UEs are scheduled in proximity. By coordinating the scheduling decisions among neighboring cells or sectors, joint scheduling aims to minimize interference and maximize system capacity.

3. User-centric Approach: Joint scheduling considers the individual requirements and quality of service (QoS) needs of UEs. It considers factors such as UE priority, channel conditions, data rates, latency constraints, and QoS parameters to optimize the allocation of resources and provide a better user experience.

4. Multi-connectivity Support: 5G introduces the concept of multi-connectivity, where UEs can simultaneously connect to multiple cells or sectors. Joint scheduling enables efficient resource allocation across these multiple connections, ensuring seamless handover and improved performance for UEs with multiple connections.

5. Dynamic and Adaptive Scheduling: Joint scheduling in 5G is designed to be dynamic and

adaptive. It continuously monitors and updates scheduling decisions based on changing channel conditions, traffic demands, and network conditions. This allows for efficient resource utilization and adaptation to varying user and network requirements.

Keeping these aspects in mind, Joint Scheduling uses two techniques – SIC with NOMA and Puncturing

2.1 SIC WITH NOMA

SIC (Successive Interference Cancellation) with NOMA (Non-Orthogonal Multiple Access) is a combined technique used in 5G networks to improve spectral efficiency and enhance the capacity of the system. It combines the benefits of SIC and NOMA to allow multiple users to share the same time-frequency resources. This is a joint resource scheduling method that works on a certain condition, that is, URLLC users have lower channel quality than some eMBB user. The working of SIC with NOMA can be elaborated in the following way:

Non-Orthogonal Multiple Access (NOMA):
NOMA is a multiple access scheme where multiple users are allocated the same time-frequency resources, but their signals are distinguished through power domain multiplexing. In NOMA, users are assigned different power levels, allowing them to coexist on the same resources. Users with weaker channel conditions are assigned higher power levels, while users with better channel conditions are assigned lower power levels.

Successive Interference Cancellation (SIC):
SIC is a technique used to mitigate interference in multi-user scenarios. It allows a receiver to decode and subtract the larger interfering signals from the received signal, one user at a time. The user with the lowest channel quality will perform direct decoding as the rest of the users have already subtracted and decoded the lower signals for their resource allocation. In our case, eMBB transmissions are decoded first and canceled from the received signal prior to decoding of the URLLC messages.

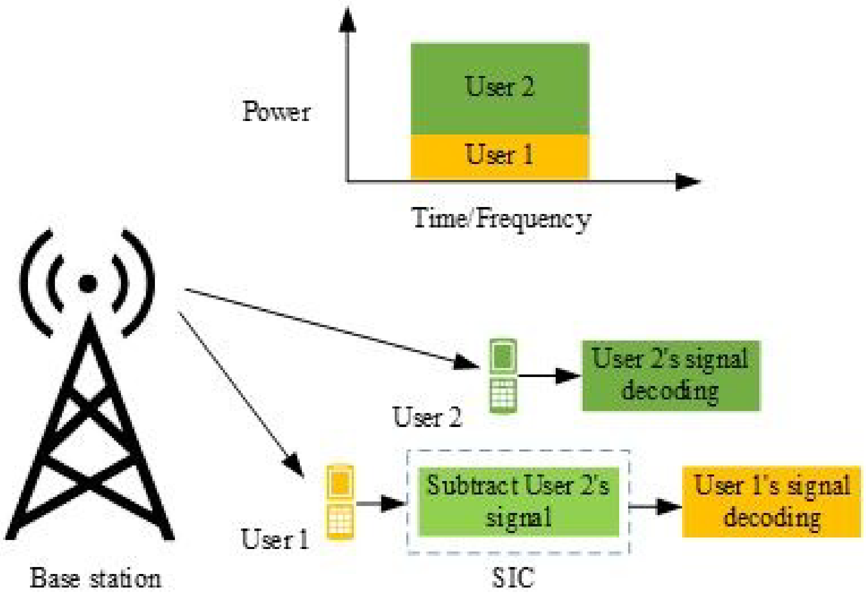

Figure 2. Downlink SIC with NOMA using one BS and two users [1]

The BS is responsible for picking compatible pairs of users which can be sent together, then it superimposes the signals of them and sends the combined signal. It has a stronger signal component and a weaker signal component. The receiver tries to decode the larger signal of them. It decodes the larger signal and cancels it from the superimposed signal (performing SIC). It sends the larger signal to the next user, keeping the smaller signal for itself.
The second user decodes the received signal for itself.

2.2 Puncturing

Puncturing is employed to manage interference and optimize resource allocation in various scenarios. This technique can be used when NOMA superposition technique fails to be applied where channel quality of URLLC user is more than channel quality of all the eMBB users. The working of Puncturing can be elaborated in the following way:
1. Resource Element Allocation:
In 5G, radio resources are allocated to users based on factors such as channel conditions, quality of service (QoS) requirements, and scheduling decisions. These resources include subcarriers, symbols, or time slots in the frequency-time grid.

2. Interference Management:
In situations where interference may be present, puncturing is utilized to mitigate the

interference effects. Interference can arise due to factors such as co-channel interference from neighboring cells, adjacent channel interference, or overlapping resource allocation among users.

3. Selective Resource Removal:
Puncturing involves selectively disabling or removing certain resource elements from the transmission of a user. By puncturing specific resources, the interference caused by those resources is reduced, improving the quality and reliability of the desired signal.

4. Puncturing Patterns:
The specific puncturing pattern determines which resource elements are punctured for a particular user. Puncturing patterns can be predefined or dynamically determined based on the interference scenario, channel conditions, or system configuration.

5. Receiver Processing:
At the receiver side, the receiver is aware of the puncturing pattern used for a specific user. The receiver can then adapt its decoding and processing algorithms to account for the punctured resources during signal detection and recovery.

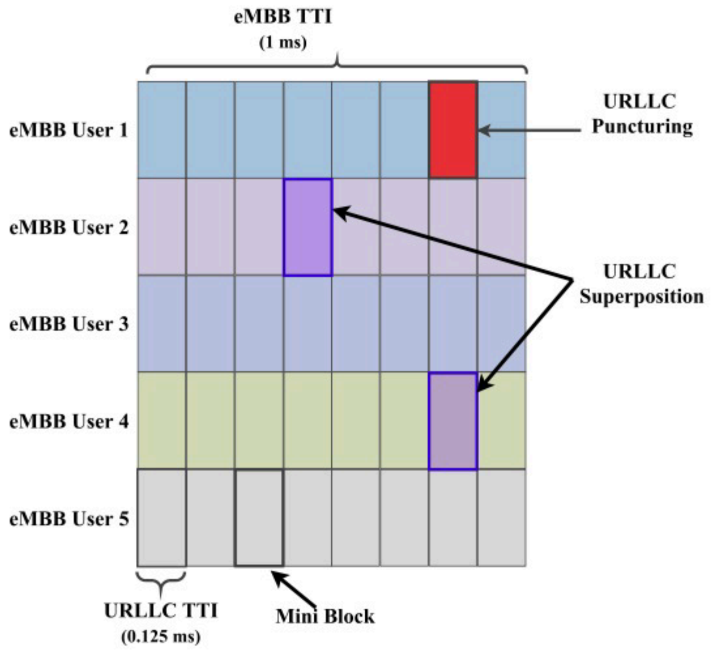

Figure 3. Pictorial Representation of Joint Scheduling between eMBB and URLLC users [2]

2.3 Programmatical Approach to Joint Scheduling

Our code, which is written in C++, attempts to replicate the Joint Scheduling functionality of a Base Station.

- We first create a class called "User" that stores the modulation index, code rate, and spectral efficiency for both eMBB and URLLC users. This class serves as a blueprint for creating user objects.

```
class User
{
        public:
                int mod_index;
                double code_rate;
                double spec_eff;
                User(int mod = 0, double code = 0, double spec = 0)
                {
                        mod_index = mod;
                        code_rate = code;
                        spec_eff = spec;
                }
};
```

- Next, we create an array of objects of the "User" class to store the entries of the MCS (Modulation and Coding Scheme) table[5], each for eMBB and URLLC. This array holds the necessary information for each user, such as modulation index, code rate, and spectral efficiency.
- To begin scheduling, we randomly select 10 eMBB users and calculate their channel quality and required resource blocks using known formulas. We store this information in an array of pairs, with each pair representing a user's channel quality and required resource blocks.
- To prioritize users for scheduling and to optimize our algorithm, we sort the array of pairs in decreasing order based on the channel quality values. This allows us to address users with better channel conditions first.
- To initiate the scheduling process, we initialize pointers. One pointer starts at the beginning of the eMBB array(called count_embb), another starts at the beginning of the URLLC array(called count_urllc), and a third pointer(called backptr) is positioned at the end of the eMBB array.

- In each iteration, we compare the channel quality of the eMBB and URLLC users to decide whether to perform successive interference cancellation (SIC) with Non-Orthogonal Multiple Access (NOMA) or puncturing. This comparison helps to determine the appropriate scheduling method based on the channel conditions of each pair of users.

```
for (int count_urllc = 0, count_embb = 0, backptr = no_of_embb_users - 1; count_urllc <
no_of_urllc_users && count_embb < no_of_embb_users && backptr >= count_embb;)
        {
          //store channel quality and required RB in separate variables

          if (channel quality of eMBB > channel quality of URLLC)
          {
            //perform SIC with NOMA
          }
          else
          {
            //perform Puncturing
          }
        } // end of scheduling
```

The complete code implementation using the above format is available at [KR2206/5g-loss-recovery (github.com)](). As visible from outline, the scheduling is very similar to the merge operation of a Merge Sort algorithm. Hence it can be deduced that the time complexity of this scheduling approach is O(no_of_urllc_users + no_of_embb_users).

We also need to ensure that whenever puncturing happens, it should happen from the eMBB user with least channel quality to increase the chances of those with higher channel quality to participate in SIC with subsequent URLLC users. The pointer backptr is used for this implementation. However, this will lead to some eMBB users getting stuck in the issue of starvation when they will never get any resource blocks if puncturing occurs. To reduce such problems, we have used two sets (prev and curr) in our algorithm. If a user gets no RB's in a minislot, they get stored in curr and in the next minislot it is checked whether this user was previously able to receive any RB's or not. Based on the outcome, we may puncture this user's resource blocks or skip this user for the current iteration and check another user for puncturing.

3. TYPES OF LOSS RECOVERY TECHNIQUES

Loss recovery is defined as the process of attempting to mitigate the loss of Resource Blocks assigned to eMBB users due to spontaneous arriving of URLLC users. Since URLLC users are of higher priority than eMBB users, they must be assigned the required RBs immediately, which may lead to some eMBB users getting less than promised RBs. It is crucial to address these losses to maintain the QoS of eMBB services and provide fair user experience. All the techniques mentioned below follow the same strategy of calculating the loss and adding the decided RB in the next slot. We will discuss four loss recovery techniques, they are: -

- Give 1 RB to lowest average data rate eMBB user
- Give required RB to lowest average data rate eMBB user
- Give whole number of RBs to all loss incurred eMBB users
- Give 1RB in ratio and proportion to all loss incurred eMBB users

3.1 Give 1 RB to lowest data rate eMBB user.

Over 8 minislots in 1 slot, we perform joint scheduling of existing eMBB users and spontaneous arriving URLLC users, performing SIC with NOMA and puncturing. We calculate rolling average data rate(as given in [4]) of every eMBB user over the 8 minislots and identify the lowest data rate eMBB user in the slot. We provide 1 RB as loss compensation and data rate recovery to that lowest data rate user in the next slot.

3.2 Give required RB to lowest data rate eMBB user.

Over 8 minislots in 1 slot, we perform joint scheduling of existing eMBB users and spontaneous arriving URLLC users, performing SIC with NOMA and puncturing. We calculate rolling average data rate (as given in [4]) of every eMBB user over the 8 minislots and identify the lowest data rate eMBB user in the slot. We further compute the difference between received RB's and initially promised RBs of that user in the slot and provide the difference of RBs as loss compensation and data rate recovery to the user in the next slot.

3.3 Give whole number of RBs to all loss incurred eMBB users.

Over 8 minislots in 1 slot, we perform joint scheduling of existing eMBB users and spontaneous arriving URLLC users, performing SIC with NOMA and puncturing. We calculate the difference between the received RB's and initially promised RBs of every eMBB user in the slot. We provide the whole number of calculated loss of RB's to every user as loss compensation and data rate recovery to the user in the next slot.

3.4 Give 1 RB in ratio and proportion to all loss incurred eMBB users.

Over 8 minislots in 1 slot, we perform joint scheduling of existing eMBB users and spontaneous arriving URLLC users, performing SIC with NOMA and puncturing. We calculate the difference between the received RB's and initially promised RBs of every eMBB user in the slot. We provide 1 RB, which is shared in ratio and proportion amongst the loss-incurred eMBB user according to their incurred losses.

4. CONCLUSION

Determining the best loss recovery technique among the four approaches mentioned (Approach 1, Approach 2, Approach 3, and Approach 4) depends on several factors, including the specific requirements and priorities of the eMBB and URLLC users, as well as the desired fairness and resource allocation goals. Let "e" be number of eMBB users, "u" be number of URLLC users and "slot_count" be the number of slots over which the program is executed to evaluate the time complexities. Each approach has its own advantages and considerations. Here's an analysis of the techniques:

1. Approach 1: Give 1 RB to the lowest average data rate eMBB user.
In this approach, the eMBB user with the lowest average data rate is allocated the required RBs to mitigate their losses. This technique provides a minimal allocation to compensate for losses. It is easy to implement as the resource compensation value is constant. Delay in resource allocation for loss recovery is minimal but it may not be sufficient to fully recover the losses of the user since it does not take its loss into consideration. Additionally, it does not consider the losses incurred by other eMBB users and provides no loss compensation to those users. The time complexity achieved here is $\Theta(e\log(e) + slot\_count * (u*\log(u) + 8*(2*e+u)))$.

2. Approach 2: Give required RBs to the lowest average data rate eMBB user.
In this approach, the eMBB user with the lowest average data rate is allocated the lost RBs in the next slot. This technique aims to prioritize a particular user who is experiencing the lowest data rate. Delay in resource allocation for loss recovery is minimal and the throughput of the user is stabilized. However, it does not address the losses incurred by other eMBB users and provides no loss compensation to those users. The time complexity achieved here is $\Theta(e * \log(e) + slot\_count * (u * \log(u) + 8 * (2 * e + u) + 8 * e ^ 2)))$.

3. Approach 3: Give whole number of RBs to loss-incurred eMBB users.
This approach aims to compensate the loss-incurred eMBB users by allocating a whole number of RB's measure of losses to them in the next slot. It ensures that the eMBB users receive a fair share of resources, mitigating their losses effectively. There is some delay in resource allocation owing to calculations related to losses of all eMBB users but provides dynamic resource compensation depending on losses incurred by eMBB users in each slot.

The time complexity achieved here is $\Theta(e * log(e) + slot\_count * (u * log(u) + 8 * (3 * e + u) + 9 * e))$.

4. Approach 4: Give 1 RB in ratio and proportion to loss-incurred eMBB users.

Approach 4 distributes a single RB in a ratio and proportion that reflects the losses incurred by eMBB users. This approach aims to provide a balanced and fair allocation to mitigate losses for all affected eMBB users. By considering the losses incurred by multiple users, it can offer a more equitable distribution of resources. However, it may require additional complexity in determining the appropriate ratio and proportion based on the individual losses which may lead to delay in resource allocation in the next slot. However, it is easier to implement because of fixed resource compensation of 1RB. The time complexity achieved here is $\Theta(e * log(e) + slot\_count * (u * log(u) + 8 * (3 * e + u) + 8 * e))$.

Based on our observations, Approach 3, which considers losses of all eMBB users, and provides fair resource allocation for eMBB users, is the best approach for loss recovery. Its dynamic resource allocation aims to stabilize throughput of all eMBB users by providing sufficient loss recovery. However, it is important to assess the impact of each approach on the overall system performance, including the impact on URLLC services and the fairness of resource allocation across different user groups. Evaluating these approaches through simulations or practical implementations can help determine the most suitable technique based on the specific network and application requirements.

5. APPENDIX

Some of the generic formulas which were used in this report include the following:

- $Data\ Rate = Spectral\ Efficiency\ * Bandwidth$

- $Required\ Resource\ Block\ = \left\lceil \frac{(32*1024)}{mod\ index\ *code\ rate\ *12*14*0.6} \right\rceil * 4$

- $Power = \frac{39.81}{Required\ Resource\ Block}$

- $SNR = 2^{\frac{spectral\ efficiency}{bandwidth}} - 1 = \frac{Power * (Channel\ Quality^2)}{Noise}$

- $Channel\ Quality = \frac{SNR}{Power}$

- $1\ gNB = 46\ dBm = 39.81\ Watt$

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7. FUTURE WORK

The future of loss recovery in joint scheduling of 5G is expected to evolve with advancements in network technologies and the introduction of new features. Here are some potential aspects that could shape the future of loss recovery in joint scheduling:

1. Machine Learning-Based Loss Recovery: Machine learning techniques have shown promise in various network optimization tasks. Future work may investigate the use of machine learning algorithms to predict and recover lost packets in eMBB networks. This could involve training models to predict packet loss patterns, adaptively adjust loss recovery parameters, or optimize the selection of specific loss recovery techniques based on network conditions. Artificial intelligence techniques can be employed to analyze network conditions, predict potential losses, and optimize loss recovery strategies.

2. Intelligent Retransmission Strategies: Intelligent retransmission strategies can be developed to adaptively adjust retransmission parameters based on network conditions, traffic type, and priority. This can include dynamic selection of retransmission mechanisms, adaptive redundancy allocation, and optimized retransmission scheduling.

3. Network Coding: Network coding is a technique that can improve reliability and recovery in lossy networks by encoding and transmitting combinations of packets. Future research may explore the application of network coding in joint scheduling scenarios to enhance loss recovery capabilities.

4. Multi-Path Transmission: Leveraging multiple paths for data transmission can improve loss recovery in eMBB scenarios. Future work may focus on developing efficient multi-path transmission schemes that utilize the available network resources effectively. This could involve dynamic path selection, load balancing across multiple paths, and congestion-aware routing to enhance loss recovery capabilities.

5. Ultra-Reliable and Low-Latency Communication (URLLC) Enhancements: Loss recovery mechanisms for URLLC traffic, which requires high reliability and low latency, will continue to be a focus area. Future developments may include ultra-fast retransmission techniques,

redundancy elimination, and advanced error recovery strategies specifically designed for URLLC applications.

These are some potential directions that could shape the future of loss recovery in joint scheduling of 5G. As 5G networks continue to evolve and new technologies emerge, it is likely that loss recovery mechanisms will be further optimized to meet the diverse requirements of different applications and enhance the overall performance and reliability of joint scheduling operations.