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# Designing Flexible Scheduling Algorithm for 5G

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***Abstract*** *— Broad machine-type communication, ultra-reliable low-latency communication, and efficient management of expanding mobile broadband traffic are now achievable with the advent of 5th-Generation (5G) wireless mobile communication standards. One of the biggest challenges for 5G networks, meanwhile, developing effective Radio Resource Management (RRM) and scheduling algorithms that meet quality of service (QoS) requirements. Widely used Proportional Fair algorithm, which primarily gives priority to customers served by a node depending on their flow rate, is the foundation of the current 5G scheduling technology. The purpose of this project is to investigate methods for improving 5G network throughput and to suggest novel scheduling schemes. This work advances the development of 5G and other mobile communication technologies by adding data flow package latency as an extra priority parameter and using MATLAB for simulation analysis. In the end, it offers a new scheduling technique that was developed through the assessment of different radio resource scheduling approaches.*

***Keywords*** ***— 5G; Scheduling Schemes; Radio Resource Management.***

## I. BACKGROUND

By integrating fresh technological developments, the 5th Generation (5G) mobile communication system expands on the developments of the 4G wireless technology. In 5G networks, transmission technologies including higher-order modulation and orthogonal frequency division multiplexing are still in use.

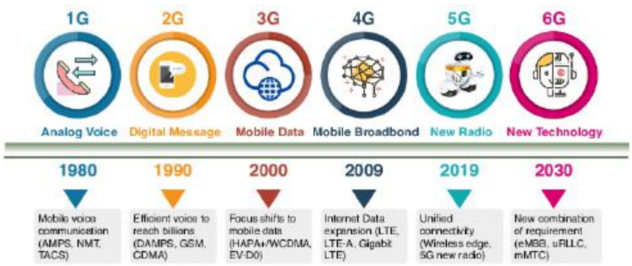


*Fig.1: Evolution of Mobile Network Generations [43]*

Furthermore, adaptive modulation and coding (AMC) techniques, preemptive mechanisms, massive multiple-input multiple-output (MIMO), hybrid automatic repeat request (HARQ) with code block group-based implementation and an increased number of HARQ processes, and beam management technology are all seamlessly integrated into 5G systems. Beam management technique allows for the transmission of signals through narrow beams in high-frequency bands, significantly enhancing system performance.

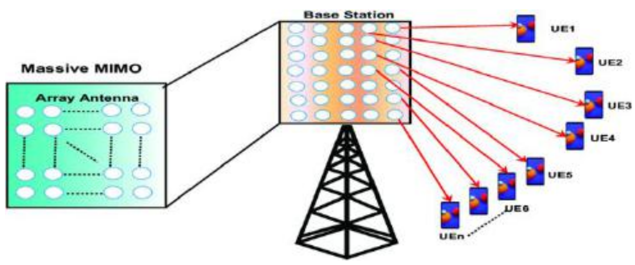


*Fig.2: Multiple Input and Multiple Output (MIMO) [44]*

5G system can provide a high level of system throughput and a wide range of services because of these improved capabilities. Nevertheless, Media

Access Control (MAC) layer scheduling algorithm is under more strain as a result of the incorporation of these cutting-edge technical characteristics. In order to enhance network Key Performance Indicators (KPIs), wireless features must be integrated into the MAC layer scheduling algorithm to maximize the utilization of wireless technologies and radio time-frequency resources. In order to do this, resource allocation must be optimized while taking QoS needs, channel quality, user service queue status & User Equipment (UE) resource consumption from both the physical and MAC levels into account. In addition to delivering dependable and constant performance, the scheduling technique must also adhere to practicality and computational complexity limitations.

Both Standalone (SA) and Non-Standalone (NSA) network topologies are used in 5G technology. The scheduler on the eNodeB (or gNodeB) functions independently in these topologies. Consequently, the scheduling strategy covered in this study applies to both NSA and SA designs.

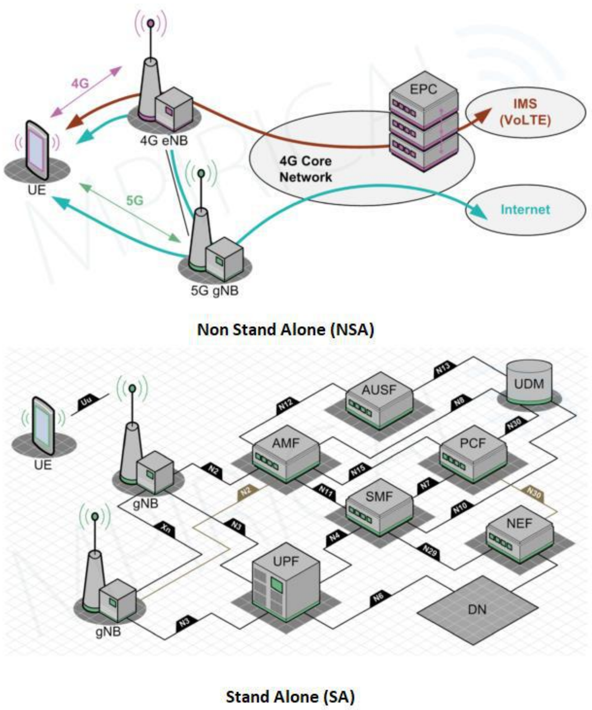


*Fig.3: Stand Alone and Non-Stand Alone 5G Basic Architectures [45]*

- Non-Standalone (NSA) Architecture

Technical Specification (TS) 38.300 states that Multi-Radio Dual Connectivity (MRDC) can be supported by 5G networks, which will enable a seamless transition from 4G to 5G network deployment. Two separate Radio Access Network (RAN) elements that operate independently in the user plane and are each outfitted with a separate scheduler for radio resource allocation are the foundation of MR-DC network topologies. User Equipment (UE) is set up to use radio resources given by these two independent schedulers, which are situated in separate Next Generation (NG)-RAN elements within the Standalone (SA) architecture, when Radio Resource Control (RRC) is enabled.

A Radio Access Network (RAN) supporting SA 5G is identified in the 5G Standalone (SA) network architecture by its link to the 5G Core (5GC). Operator network deployments of 4G will progressively discontinue as 5G technology advances. The gNB (5G New Radio Base Station) is in charge of terminating control plane and user plane protocols in the 5G network in the direction of the User Equipment (UE) on the RAN side. According to TS 23.501, the NG interfaces connect the gNBs to the Access and Mobility Management Function (AMF) network element in the 5GC [3].

- 5G Protocol Stack Architecture

User data transmission is handled by the user plane protocol stack, and system control signaling is handled by the control plane protocol stack. Essentially, separate stacks handle distinct kinds of data; the user plane stack handles user data, while the control plane stack handles signaling messages. The physical layer (PHY), medium access control (MAC), radio link control (RLC), and packet data convergence protocol (PDCP) are among the common protocol layers shared by both planes. In order to guarantee alignment between the protocol stacks in the UPF and gNB, the gNB is connected to the User Plane Function (UPF) network element in the user plane via the NG-U interface. Radio Resource Control (RRC) and Non-Access Stratum (NAS) are the top two protocol levels in the 5G gNB control plane protocol stack, same like in 4G. The Access and Mobility Management Function (AMF) network element in the 5G Core (5GC) receives transparent NAS layer signaling over the gNB.

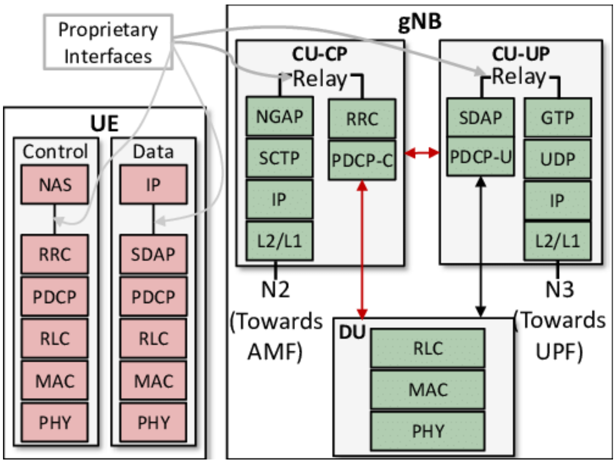


*Fig.4: 5G Protocol Stack [9]*

- Radio Resource Management (RRM)

Ensuring the quality of service for wireless User Equipment (UE) in a network with constrained bandwidth is the main goal of Radio Resource Management (RRM). RRM attempts to handle unequal network traffic distribution and changes in channel characteristics brought on by fading and interference by dynamically allocating and adjusting resources within the wireless transmission and network. The ultimate goals are to reduce the burden from signaling transmission, avoid network congestion, and maximize the use of wireless spectrum. Quality of Service (QoS) factors are among the core topics that the RRM module concentrates on.

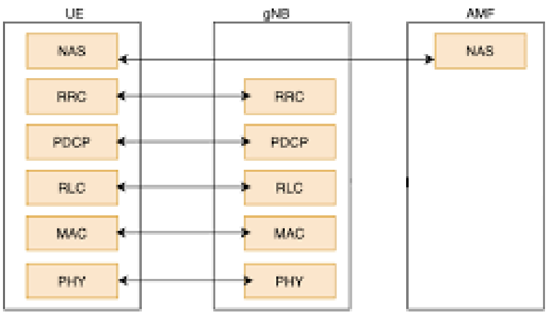


*Fig.5: Radio Resource Management [46]*

- Channel State Information Reporting

Massive MIMO is a critical technology in the field of 5G. Acquiring accurate Channel State Information (CSI) is critical to improving performance of a huge MIMO system. Using Reference Signal (RS), user estimates and quantizes the channel during downlink MIMO data transfer. This procedure provides two functions: demodulating transmission data and providing quantized results to the gNB (5G New Radio Base Station). The quantized CSI is used by the gNB to identify the suitable precoding and modulation coding method. CSI is a catch-all word which includes more components than their 4G equivalents.

Because it enables the gNB to evaluate the downlink channel's quality, CQI reporting is crucial. Each CQI represents a quantized and scaled version of the user's Signal-to-Noise plus Interference Ratio (SINR). The Radio Resource Management (RRM) architecture's Adaptive Modulation and Coding (AMC) module selects the appropriate modulation and coding scheme based on the reported CQI in order to maximize throughput. Several scheduling algorithms, such as the one covered in this article, leverage Channel State Information (CSI) to create RRM allocation techniques.

- Conventional Scheduling Algorithms

Scheduling algorithms have been a recurring topic in communication technology evolution [7].

  - Round Robin (RR)

The RR algorithm is a straightforward technique that doesn't require any difficult logical inferences. User Equipment (UE) has equal access to radio resources thanks to Radio Resource Management (RRM), which distributes radio resources to users in RR scheduling system in a first-in, first-served manner. Because of this, regardless of channel state, customers serviced by the same gNB are scheduled in the same way. There is no need for abstract theory to implement the RR system, making it easy to do so. It offers excellent performance and equity to all users in the near run. However, one disadvantage of this approach is its inability to properly exploit the wireless channel's time-varying properties in order to maximize the system's multi-user diversity gain.

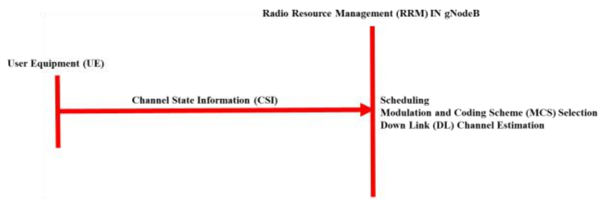


*Fig.6: Channel State Information*

- Best CQI

The Best Channel Quality Indicator (CQI) scheduling strategy is another approach employed in the gNB. When selecting a schedulable User Equipment (UE) from among all UEs associated to a cell in the gNB, only the UE with the best CQI is chosen. This approach dynamically modifies the number of concurrent users based on the transmission strategy, efficiently adjusting to the wireless channel's time-varying and fading characteristics to maximize system throughput. Users with inferior channel conditions, such as cell-edge users, have a decreased likelihood of being scheduled in this scheduling system [7]. While this strategy offers maximal multi-user diversity gain, it is the least fair algorithm in terms of fairness.

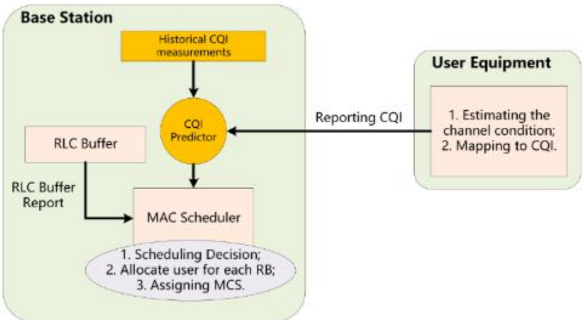


**Figure 7: CQI prediction Module** [10]

- Proportional Fair

In the industry, the Proportional Fair (PF) algorithm is frequently employed. Radio Resource Management (RRM) gives each user served by the gNB a priority within this algorithm. The particular measures employed in establishing these priorities differ based on the architecture of the vendor. During each scheduling period, users with higher priorities are scheduled first. The choice of proper measurements is critical for the PF algorithm since it has a direct impact on network performance. The PF scheduling algorithm successfully exploits the time-varying properties of user channels while balancing multi-user variety and fairness. It allocates radio resources based on both historical user throughput and experienced channel quality. The development of the PF algorithm has resulted in considerable advances in this discipline. The ratio between the instantaneous flow available for the i-th flow and the average flow seen at the preceding moment (k - 1) is one metric utilized for priority in the PF algorithm [8]:

$$w_{i,j} = \frac{r_{i,j}}{R_i}$$

ri;j represents the flow rate assigned to the i-th flow during the k-th Transmission Time Interval (TTI), and Ri represents the expected average transmission data rate. By utilizing the average data transmission rate, the PF scheduling method efficiently addresses long-term user fairness. It does not, however, guarantee users' short-term fairness.

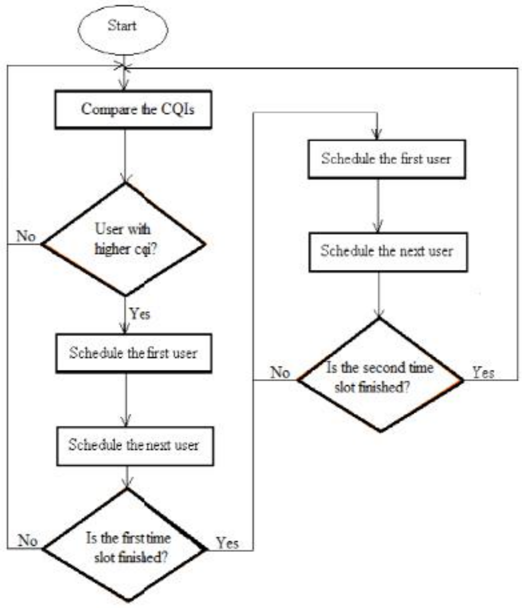


*Fig. 8: Flow chart of Proportional Fair (PF) Scheduler [11]*

**Problem Statement**

5G wireless mobile standard has recently been made public. Massive machine-type communication, ultra-reliable low-latency communication, and improved mobile broadband are just a few of the sorts of traffic that 5G networks are designed to handle efficiently. However, creating efficient Radio Resource Management (RRM) techniques and scheduling algorithms that can satisfy the various quality of service needs is a key problem in the deployment of 5G networks.

**Research Significance**

Research is about new scheduling techniques and look at ways to increase the throughput of 5G networks. The study will include package delay of data flow as a priority parameter in addition to already existing metrics. The study will make use of a MATLAB based modelling tool simulator. According to the research, a brand-new scheduling algorithm will be developed after being compared to numerous radio resource scheduling plans.

**Research Objectives**

In order to improve the user experience for enhanced mobile broadband, the researcher will evaluate performance of scheduling algorithms, such as RR (Radio Resource), PF (Proportional Fair), PF0 (Existing Proportional Fair Algorithm), and optimal CQI (Channel Quality Information), under 5G environment. The newly proposed scheduling algorithm would exceed the best CQI, RR, and traditional PF algorithms by providing higher throughput, the researcher will attempt to demonstrate through simulation using MATLAB. This study's goals are to suggest new scheduling strategies and look into ways to increase the throughput of 5G networks. In this study, we'll use the data flow's packet delay as a priority metric. By examining existing radio resource scheduling techniques, this research aims to develop a new scheduling algorithm.

**Research Questions**

- Is it possible to evaluate the performance of scheduling algorithms in a 5G context, such as RR, PF, PF0, and best CQI, with the aim of improving the user experience for enhanced mobile broadband?
- Will proposed scheduling algorithm can come up with higher throughput?
- What procedures can be used to increase the throughput of 5G networks?
- Is it possible to suggest original schedule plans?
- Is it possible to develop a new scheduling algorithm by examining multiple radio resource scheduling plans?

## II. LITERATURE REVIEW

Scheduling algorithms are critical in both current and future wireless networks, ensuring effective and equitable resource allocation [17]. These algorithms are classified as either centralized or distributed [21]. To efficiently meet fairness and quality-of-service (QoS) criteria, centralized algorithms are widely utilized for downlink transmission. Distributed algorithms, on the other hand, are commonly used in ad hoc or uplink transmission settings where users have control over channel access.

A scheduler needs certain parts in order to function as well as possible over a wireless network. Transmission time intervals (TTIs) should not be assigned to sessions with poor link quality by the algorithm, which should strive to maximize the utilization of the available channel. While maintaining long-term throughput guarantees for all sessions, it should offer short-term throughput guarantees for error-free sessions [21]. Cellular users should redistribute resources fairly, accounting for both long-term equities for error-prone sessions and short-term equity for error-free sessions. The fairness index, which assesses the greatest variation in normalized service obtained by any two backlogged sessions, is frequently employed for this reason.

Cutting down on the energy usage of cellular users is another difficulty for the scheduler. This can be achieved by enabling users to send and receive messages continuously and by putting the device in sleep mode while it is idle, which will use less energy [14]. The scheduler should also restrict the amount of simultaneous broadcasts in the network to reduce excessive interference. In delay-sensitive applications, the scheduler should be able to guarantee specific session delay boundaries [17]. In order to guarantee that the existing channel is utilized efficiently as the user base expands, scalability is essential. Furthermore, the scheduler should be constructed with as minimal complexity as possible because fast scheduling decisions are essential in high-speed networks.

Schedulers play an important role in allocating resource blocks (RB) to cellular customers based on demand. These schedulers are commonly found at the Evolved Node B (eNodeB) and are responsible for allocating both uplink and downlink resources. At each transmission time interval (TTI), the scheduling algorithm assigns shared resources to each cellular user. On a regular basis, the eNodeB receives channel quality indicators (CQI) from users, with a higher CQI value indicating better channel quality.

Round robin (RR), proportional fair (PF), fractional frequency reuse (FFR), and best channel quality indicator (BCQI) are the four main scheduling strategies. An overview of the general operation of some algorithms is given in this section.

The round robin scheduler is a non-aware scheduling technique that starts with the first user and assigns resources progressively to subsequent users. It does not take into account the current channel conditions [13]. While this technique improves user fairness, it degrades speed. Because users may be allotted fading channels, it can reduce overall system throughput. Furthermore, because it does not consider the CQI factor, it does not efficiently manage the overall quantity of resources. Despite these disadvantages, due to its ease of implementation, this scheduler is frequently utilized in many systems [16].

The best CQI scheduler is in charge of allocating resource blocks to users at each TTI based on their radio connection conditions or channel quality. Cellular users transmit their CQI to the eNodeB, which utilizes it for scheduling. The eNodeB sends a reference signal (downlink pilot) to users, who then measure their own CQI. A higher CQI number suggests that the channel is in better condition. While this scheduler can boost individual cell throughput, it lacks fairness among users, especially those at the cell edge who may never be scheduled [16].

FFR scheduler is frequently employed when minimizing interference between neighboring cells is crucial [12]. Because of its flexibility and agility, it enables the creation and implementation of various schedulers. Users can share resource blocks in partial reuse (PR) or full reuse (FR) modes. RBs can be assigned according to priority and zone designation, and the available frequency band can be partitioned into many bands. While FFR has a higher average throughput, giving some users priority over others might not be fair.

By taking channel variations into account, the PF scheduler improves spectral efficiency and provides greater fairness. By combining CQI and fairness criteria, it assigns resource blocks to users with the best link quality. PF enables mobile users to achieve optimal QoS by balancing fairness and maximum cell throughput [16]. The throughput at a certain TTI and the average throughput of the user are used to calculate RB allocation using a weighted fair queuing algorithm (WFQ).

There have been numerous studies done on scheduling algorithms. [13] evaluated the throughput and block error rate (BER) of the RR, best CQI, and PF schedulers using a MATLAB-based system level simulator. Although the optimal CQI algorithm handled customers with poor channel conditions unfairly, it had a better throughput. [12] compared scheduling techniques with an emphasis on QoS provisioning while conducting a thorough evaluation of LTE downlink packet allocation methodologies. After a thorough analysis, [23] divided LTE uplink schedulers into three categories: power-optimizing, QoS-based, and best-effort. A simulation model comparing the best RR and CQI scheduling strategies for LTE system throughput was developed by [22].

Other research has compared various network setups and performance measures. [18] examined downlink performance measures for small cell networks (ScNet) and heterogeneous networks (HetNet), favoring HetNet for greater average UE throughput in densely populated areas. [19] examined the packet scheduling algorithms PF, MLWDF, and EXP/PF, taking into account throughput, packet loss ratio (PLR), latency, and fairness. [15] explored variable packet scheduling methods (WFQ, PQ, and FIFO) in various real-time and non-real-time applications to provide the greatest QoS. [20] investigated RR, PF, optimal CQI, Max-TP, and RF schedulers while taking cell range expansion (CRE) and nearly blank sub frame (ABS) methods into account in order to optimize system performance and interference towards cell edge users.

In existing mmWave standards, various scenarios and use cases for 5G and beyond networks have been introduced. However, no precise mechanism for allocating radio resources has been described. Several research papers have presented and addressed scheduling techniques for 5G network implementation. The authors of reference [24] conducted a survey of radio resource management (RRM) schemes in 5G and beyond networks. They discussed and contrasted the procedures of different scheduling algorithms. They also addressed the reasons influencing the RRA decision and analyzed the performance of the scheduling systems.

In reference [25], an improved broadband scheduler based on the lean manufacturing technique was developed. This scheduler combines the best channel quality indicator (BCQI) and SPF (shortest path first) algorithms. While this technique improves system speed, it has a significant impact on UE fairness when compared to the SPF and RR algorithms.

In reference [26], the authors presented a channel-gain-based scheduling approach for huge multiple input multiple output (MIMO) systems. This technique increases throughput while ensuring UE fairness.

Reference [27] investigated and compared the performance of various scheduling algorithms in time-division duplex (TDD) mode, including RR, SPF, and BCQI. Voice over internet protocol (VoIP), video streaming, and cloud storage were among the traffic kinds studied. The study assessed the scheme's throughput but did not include UE fairness and satisfaction. Furthermore, each traffic type was investigated independently, which is not a realistic scenario in which several UEs request traffic at the same time.

The influence of blockage probability in mmWave networks on the performance of the SPF scheme in terms of UE data rates and fairness was addressed and compared in reference [28].

References [29-33] concentrated on adjusting the exponential parameters of the priority function in the SPF scheme based on specific circumstances to increase throughput and fairness in various communication systems. However, in their procedures, these algorithms ignore UE requirements.

Reference [34] advocated improving the SPF scheme by boosting the priority of UEs with poor channel circumstances, which proved effective in dealing with mmWave channel variations in industrial internet of things applications.

While these studies looked at well-known scheduling methods or offered changes to improve scheduling schemes, they did not take into account the influence of UE demands on system performance. Furthermore, they frequently assumed homogeneous traffic across UEs, thinking that consumers require the same data rate across all time frames. However, in practice, UEs in 5G and beyond networks have varying data rate demands dependent on their individual eMBB applications, such as video streaming and virtual reality. Thus, while investigating and proposing scheduling algorithms for UEs, taking non-homogeneous traffic into account is a more realistic scenario.

The discrepancy between UE demands based on their experienced applications and its effect on the performance of the DPF (dynamic priority first) scheduling strategy was examined in a previous work [35]. However, the impact of obstruction on total system performance was not considered in this study. Furthermore, it anticipated an unrealistic situation in which lower-demand apps were experienced by more UEs. In addition, the work utilized 3GPP standard channel models, whereas the prior study used the MiWEBA channel model.

These studies emphasize the significance of scheduling algorithms and their effects on system performance, fairness, and QoS in a variety of network settings.

## III. RESEARCH METHODOLOGY

Benchmark for this research is the research done by Wu, Junmin, Chuan Liu, Jing Tao, Shidong Liu, and Wei Gao. (2023). "Hybrid Traffic Scheduling in 5G and Time-Sensitive Networking Integrated Networks for Communications of Virtual Power Plants" Applied Sciences 13, no. 13: 7953. https://doi.org/10.3390/app13137953.

- **Simulation Parameters**

The first parameter relates to the number of chunks. The "number of chunks" in the context of a 5G network simulation often refers to the partition of data or information into smaller segments or pieces. To improve efficiency and dependability, data in 5G networks is frequently delivered in chunks. The number of chunks in a 5G network simulation can signify the total number of these segmented pieces of data being simulated or analyzed. It can be used to assess various network parameters such as throughput, latency, and overall network performance when handling and transmitting data in smaller units. Number of chunks value is taken as "1" for the simulation.

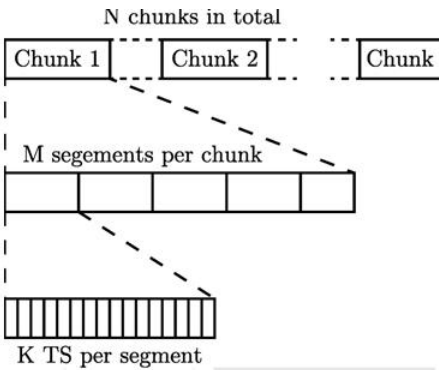


*Fig.9: Number of Chunks*

(Source: Made by Researcher)

"Slots per chunk" refers to the division of time in a wireless communication system in the context of 5G simulations. Time is divided into discrete intervals called slots in 5G networks, which are used to schedule and transmit data. The term "slots per chunk" refers to the number of slots assigned to each particular chunk of data during simulation. It denotes the degree of granularity of time division inside a chunk. Researchers and engineers can assess and analyze the impact of alternative time allocation schemes on the performance of the 5G network by altering the number of slots per chunk. In practice, a higher number of slots per chunk allows for finer-grained time division, perhaps leading to more efficient network resource use. However, the increased signaling and control information required for handling a larger number of slots may result in increased overhead. A reduced number of slots per chunk, on the other hand, may result in coarser time division but lower signaling overhead. The optimal number of slots per chunk is determined by the individual simulation goals and desired trade-offs between resource utilization and signaling overhead. Slots per chunk are selected to be 100 [36].

"Time between chunks in slots (ms)" in 5G simulations refers to the duration or gap between consecutive chunks of data in the simulated network, measured in milliseconds. This option sets the time interval between the completion of one chunk's transmission and the start of the following chunk's transmission. It denotes the amount of time that elapses between successive data transmissions. Researchers and engineers can examine the influence of various inter-chunk delays on the performance of the 5G network by adjusting the time between chunks. The interval between chunks in slots is a crucial component in determining data transmission efficiency, throughput, and latency in a 5G network. A shorter time interval between chunks might result in more frequent data transmissions, potentially increasing throughput but also increasing overhead due to the signaling and control information necessary for each transaction. A longer interval between chunks, on the other hand, can minimize signaling overhead but result in poorer throughput and increased latency. The time between chunks in slots for 5G simulations is determined by the individual simulation goals, network conditions, and trade-offs between throughput, latency, and signaling overhead. In order to get maximum efficiency and throughput, the value of time between chunks in slots (ms) is taken as "0" [37].

Omnidirectional antennas have various advantages in 5G networks:

1. Omnidirectional antennas transmit signals in all directions, resulting in a 360-degree coverage pattern. This allows them to service a wide region without requiring exact antenna alignment. It simplifies network deployment and expands the coverage of a 5G network, particularly in highly populated locations.
2. Seamless Mobility: Omnidirectional antennas enable 5G devices to move seamlessly. Because the antennas broadcast signals in all directions, they can keep moving devices connected regardless of their orientation or location within the service region. This is especially useful for applications requiring high mobility, such as driverless vehicles, public transportation, or Internet of Things devices.
3. Flexibility and Scalability: Omnidirectional antennas provide network designers with flexibility and scalability. They can be used in a variety of contexts, including congested urban regions, rural locations, and interior settings. Furthermore, using several omnidirectional antennas in a network increases capacity and coverage by enhancing signal distribution and

reducing dead zones.

4. Network Planning Simplified: Omnidirectional antennas make network planning and optimization easier. Because of their broad coverage pattern, they may require fewer antennas than directional antennas, decreasing the complexity and expense of network construction. It also simplifies network management by reducing the frequency with which antennas must be reoriented or adjusted.
5. Omnidirectional antennas improve user fairness in 5G networks. Because they broadcast signals in all directions, they enable equitable access to network resources for all devices within their service region. This contributes to the equal distribution of network capacity and the treatment of customers.

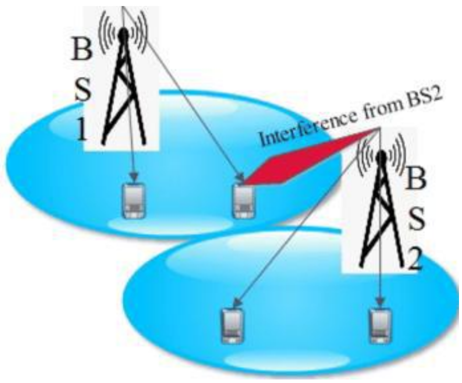


*Fig.10: Omni Directional Antenna [47]*

Overall, using omnidirectional antennas in 5G networks improves coverage, allows for seamless mobility, simplifies network planning, and promotes user fairness. These benefits make them an excellent alternative for a wide range of deployment scenarios in 5G networks. This simulation hence uses an Omni directional antenna. Number of receiving antennas is chosen as “1” with transmitting antenna being four. The transmitted power is taken as 40 w [38].

MATLAB was used to carry out the simulation. New scheduling algorithm was added into the simulator for evaluations. Using the four schedulers, we analyze throughput performance. The simulator is used to simulate four scheduling algorithms with identical fundamental parameters one at a time. The MATLAB (matrix laboratory) software platform is widely used for numerical calculation, data analysis, visualization, and algorithm creation. When it comes to simulation, MATLAB has a plethora of tools and benefits to offer [39].

1. Simulink: Simulink is a powerful graphical simulation and modelling tool in MATLAB. Its drag-and-drop interface allows users to create block diagrams and models of dynamic systems. Simulink covers a wide range of domains, including control systems, communications, signal processing, and others, making it useful for a variety of simulation tasks.
2. Extensive Toolbox Support: MATLAB comes with a plethora of toolboxes that help to extend its simulation capabilities. These toolboxes include specialized functions and algorithms for a variety of disciplines, including signal processing, communications, image processing, optimization, and others. Users can use these toolboxes to improve their simulation models and execute complex simulations more effectively.
3. The interactive environment of MATLAB allows users to iteratively develop and simulate models. It has a command-line interface as well as a graphical user interface (GUI) for interactive simulation and real-time parameter adjustment. This capability is very valuable for investigating system behavior, analyzing simulation findings, and making on-the-fly adjustments.
4. Simultaneous Simulation and Visualization: MATLAB users can view simulation results in real time. Users can obtain insights into their simulation models by creating interactive plots, animations, and 3D visualizations using its plotting and visualization features. This power of simultaneous simulation and visualization aids in a more intuitive understanding of system behavior.
5. Integration with Other Technologies: MATLAB interfaces with other programming languages, hardware devices, and software applications with ease. It facilitates connecting with external devices such as sensors and actuators, allowing simulations to be integrated with real-world systems. MATLAB also provides interfaces to other programming languages like as C, C++, and Python, allowing users to reuse existing code or interact with external systems.

6. Extensive Documentation and Community Support: MATLAB offers extensive documentation, including help files, examples, and tutorials, to make learning and utilizing its simulation features easier. MATLAB also offers a big and active user community where users may get help, discuss ideas, and collaborate on projects.
7. Reproducibility and Code Generation: MATLAB enables users to write scripts and functions that can be readily shared and replicated. It also allows you to generate standalone executable files or C/C++ code from MATLAB code, allowing simulations to run on a variety of platforms or embedded systems.

Because of these features and benefits, MATLAB is a popular choice for simulation work in a variety of areas, including engineering, physics, mathematics, and computer science. Its adaptability, large toolboxes, interactive interface, and integration capabilities all contribute to its efficacy and efficiency in modelling and analyzing complex systems.

- **Conceptualized Scheduling Algorithm**

The PF algorithm takes average rate and flow rate into account, but other factors need to be assessed as well to determine the model's priorities. Based on the quality of the received Reference Signals (RS), the UE reports the wireless channel quality to the base station, which is reflected in the Channel Quality Indicator (CQI). The base station schedules services based on CQI response and other data. The temporal lag that occurs when the UE transmits a data packet is referred to as user delay. International Telecommunication Union's (IMT)-2020 M.2410-0 (4.7.1) standard specifies the 1 ms delay threshold for ultra-reliable low-latency communication in 5G networks [40, 41, 42].

Reducing packet transmission delays is the scheduling method's main objective. The scheduling approach in 5G networks is based on the Quality of Service (QoS) model, where the highest degree of scheduling granularity is represented by the QoS flow. In order to balance packet transfer latency, average transmission rate, and channel quality, this study uses the Proportional Fair (PF) scheduling mechanism. Improving network performance while maintaining equity among the scheduled User Equipment (UEs) is the goal.

In wireless communication, "channel quality" refers to the measurement of the signal quality or channel conditions between a transmitter and receiver. It represents the properties of the wireless media over which the signal travels, such as signal strength, interference, noise, fading, and other flaws. The reliability and performance of the communication link are directly affected by the channel quality. A higher channel quality suggests a stronger, clearer, and more dependable signal with less interference or distortion, which results in improved data transmission and reception. A lower channel quality, on the other hand, signifies a weaker or noisy signal, which might result in lower data rates, increased error rates, and significant decline in communication performance. Channel quality is often evaluated or measured using various ways in wireless systems such as 5G. CQI (Channel Quality Indicator) is a popular mechanism in which the receiving device (such as a user equipment or mobile device) provides input to the transmitting base station regarding the perceived quality of the received signal. The CQI value assesses channel quality and aids in the optimization of overall system performance through adaptive modulation and coding schemes, power control, and resource allocation decisions. Channel quality monitoring and assessment are critical for efficient and dependable wireless communication systems. Network operators and algorithms can dynamically change transmission settings and distribute resources to maximize data rates, minimize mistakes, and assure optimal performance under fluctuating channel conditions by taking channel quality into account.

The term "average transmission rate" refers to the average rate at which data is sent through a communication channel or link. On average, it measures the quantity of data that may be effectively transmitted per unit of time. The available bandwidth, modulation and coding techniques, signal quality, network congestion, and the effectiveness of the communication protocol all have an impact on the average transmission rate. In the context of wireless communication systems such as 5G, the average transmission rate is a critical performance indicator that represents the network's overall capacity and efficiency. It denotes the average amount of data that can be reliably transported from a source to a destination in a given amount of time. More average transmission rates reflect a network's ability to send data more quickly, allowing for faster data transfers, more throughput, and a better user experience. Optimizing transmission parameters, allocating appropriate bandwidth, applying modern modulation and coding techniques, and implementing efficient protocols can all lead to a better average transmission rate. Monitoring and optimizing the average transmission rate is critical for fulfilling the demands of data-intensive applications including video streaming, massive file transfers, real-time communications, and internet of things (IoT) devices. By increasing the average transmission rate, network operators can improve the network's overall performance and capacity, allowing for faster and more efficient data transmission.

"Packet transfer delay" is the amount of time it takes for a data packet to be transported from a source to a destination in a network. It represents the packet's delay or latency as it travels across the network architecture. Network congestion, distance between the source and destination, processing time at intermediate network devices (such as routers), queuing delays, and transmission delays all have an impact on packet transfer latency. A short packet transfer delay in network communications is desired since it implies that data packets are being delivered swiftly and efficiently. This is especially critical for low-latency real-time applications such as video conferencing, online gaming, and voice over IP (VoIP) services. A significant packet transfer delay in such applications can cause obvious delays, audio/video synchronization difficulties, and a reduced user experience. By optimizing network design, enhancing network infrastructure, adopting efficient routing protocols, and utilizing congestion control techniques, network engineers and researchers hope to reduce packet transfer time. These efforts aid in the reduction of queue delays, the optimization of packet routing, and the prioritization of time-sensitive traffic. Minimizing packet transfer latency is especially important in 5G networks, where ultra-reliable low-latency communication (URLLC) is a critical goal. To ensure timely and efficient delivery of data packets, the design of scheduling algorithms, resource allocation, and quality of service (QoS) procedures in 5G networks frequently takes packet transfer latency into account.

The metric is calculated in this conceptualized algorithm procedure as ratio of current available flow for i-th flow to the medium flow, as stated in preceding moment (k - 1).

$$\frac{f_1(Signal\ to\ Noise\ plus\ Interference\ Ratio\ i\ )}{Average\ Rate} \cdot \frac{f_2\left(Package\ Delay_{k-1}\right)}{Delay\ Threshold - f_3\left(Package\ Delay_{k-1}\right)}$$

Here:

$\boldsymbol{f_1}(.)$, $\boldsymbol{f_2}(.)$ **and** $\boldsymbol{f_3}(.)$ = Adjustable linear functions which adapt to network performance requirements

The term "adjustable linear functions adapting to network performance requirements" refers to a mathematical model or approach that employs linear functions that can be dynamically altered based on a network's specific performance requirements. In this application, "adjustable" denotes that the linear functions' parameters or coefficients can be changed or fine-tuned to fit changing network conditions or performance goals. To ensure that the network fulfils specified performance targets or standards, modifications can be done in real time or on a regular basis. The word "linear functions" denotes that the relationship between the input variables and the output is linear, as in a straight line. In mathematical modelling, linear functions are frequently used to explain many characteristics of a system or process. By adapting these linear functions to network performance requirements, it implies that the model or technique can dynamically optimize or regulate specific network parameters based on performance goals or restrictions. This adaptability enables the network to respond to and adjust to changing conditions and requirements, hence improving its performance and efficiency.

**Average Rate** = Average Transmission Rate of Packet

The phrase "Average Rate" refers to the average speed or rate of anything over a given time period. It denotes the average amount or quantity of a specific event or phenomena that occurs per unit of time. The average rate is calculated by dividing the total quantity or amount by the time elapsed. It is often used to define the average speed or frequency of occurrences or processes in several domains, including data transmission, economics, physics, and statistics.

**Signal to Noise plus Interference Ratio** $_i$ = Quantized Channel Quality Information of wireless channel transmitting (i-th flow)

Signal-to-Noise plus Interference Ratio (SINR) is a telecommunications and wireless communication system measurement used to estimate the quality of a received signal. It is the ratio of the required signal strength to the total power of noise and interference in the received signal. The signal is the intended delivery of meaningful information, whereas noise is the random oscillations and undesired signals that might decrease the quality of the received signal. In contrast, interference refers to undesired signals that originate from sources other than the intended emitter. A higher SINR value suggests better signal quality, as it signifies that the required signal strength is greater than the combined power of noise and interference. Higher SINR generally results in greater communication performance, such as higher data rates, better call quality, and increased reliability. A lower SINR, on the other hand, implies inferior signal quality, which can lead to decreased communication performance and probable signal deterioration.

**Delay Threshold** = It is threshold for transmission delay (set according to network performance & configurable in gNB)

A "Delay Threshold" is a predefined limit or boundary for the amount of delay that is acceptable in a system or network. It represents the system's maximum acceptable delay for a certain activity, procedure, or communication. It is typical to have time-sensitive processes in numerous sectors, such as telecommunications, computer networks, or real-time systems, where delays might impair overall performance or user experience. The delay threshold is used as a criterion or benchmark to determine whether the observed delay is excessive. In a network communication scenario, for example, the delay threshold can reflect the maximum allowable delay for transferring data packets from a source to a destination. If the actual latency exceeds the predefined threshold, it may indicate a performance issue or system degradation. The particular value of the delay threshold is determined by system or application's requirements and features. It is dictated by elements such as task's nature, required response time, user expectations, and the restrictions of the underlying infrastructure. System administrators or designers can ensure that system functions within acceptable performance limitations by setting and adhering to delay threshold. This enables efficient and dependable operations.

The phrase "Packet Delay k-1" refers to the delay suffered by packets during the previous Transmission Time Interval if we consider current scheduling time interval to be k-th Transmission Time Interval. As a result, user equipment (UE) with a high Signal-to-Noise-Plus-Interference Ratio (SNIR) and a longer packet transmission delay are more likely to be chosen for scheduling.

**Simulation Results and Analysis**

To develop a new proposed scheduling algorithm for 5G, the following steps were followed:

- Determine the goals: Determine the scheduling algorithm's specific goals and objectives, such as maximizing throughput, minimizing latency, optimizing resource allocation, or improving user experience.
- Understand 5G requirements: Learn about the 5G network's requirements and characteristics, such as its architecture, radio access methods, available resources, and quality-of-service (QoS) metrics.
- Examine existing algorithms: Investigate and evaluate the current scheduling techniques utilized in 5G networks. Recognize their strengths, weaknesses, and performance in fulfilling the identified objectives.
- Identify gaps and difficulties: Identify the gaps and challenges that need to be addressed in the present algorithms. This can include taking into account aspects like latency, fairness, load balancing, user mobility, and specialized network circumstances.
- Propose an algorithm design: Based on the gaps and obstacles highlighted, create a new scheduling algorithm that tackles these concerns while also aligning with the indicated objectives. Consider packet latency, user priorities, channel quality data, traffic patterns, and any other relevant aspects.

- Model and simulate: Create a simulation model or use existing simulation platforms to test the proposed algorithm's performance. To evaluate its performance and compare it to existing algorithms, run simulations under various scenarios and traffic situations.
- Performance evaluation: Analyze the simulation results and rate the proposed algorithm's performance. Evaluate its influence on throughput, latency, fairness, resource utilization, and any other relevant metrics.
- Iterate and refine: Iterate and refine the algorithm as needed based on the performance evaluation. Consider using feedback, modifying parameters, or making changes to improve its performance or address any detected flaws.
- Validation and verification: If possible, validate the method using real-world experiments or testbeds. Test its performance in a real-world 5G scenario and compare it to existing algorithms.
- Publish and disseminate findings: In a research paper or technical report, document the suggested scheduling algorithm, its design, simulation results, and performance evaluation. Share your findings with the research community to help enhance 5G algorithms.

It is crucial to note that these procedures are intended to serve as a broad guideline, and the actual method may differ depending on the individual research objectives, resources, and constraints.

Keeping in view the above guidelines and according to the simulation findings, the newly proposed scheduling algorithm outperforms the best Channel Quality Information, Round Robin, and standard methods in terms of throughput. Figure below shows the simulation throughput results of four individual scheduling algorithms i.e.

- Round Robin Algorithm

Software code for simulation in MATLAB for Round Robin Algorithm is written below.

```
% Define the number of users and available resources
numUsers = 20; % Number of users
numResources = 100; % Total number of resources available
% Initialize the throughput array
throughput = zeros(size(numUsers));
% Run the Round Robin algorithm for 20 users
for i = 1:length(numUsers)
   % Calculate the resources per user
   resourcesPerUser = floor(numResources / numUsers(i));
      % Calculate the throughput per user
   throughputPerUser = resourcesPerUser;
      % Calculate the total throughput
   totalThroughput = throughputPerUser * numUsers(i);
      % Store the total throughput in the array
   throughput(i) = totalThroughput;
end
% Plot the throughput vs. number of users
plot(numUsers, throughput, 'o-');
xlabel('Number of Users');
ylabel('Throughput');
title('Throughput vs. Number of Users (Round Robin Algorithm)');
grid on;
```

- Best Channel Quality Information Algorithm

Software code for simulation in MATLAB for Best Quality Information Algorithm is written below.

```
% Define the number of users and available resources
numUsers = 20; % Number of users
numResources = 100; % Total number of resources available
% Initialize the throughput array
throughput = zeros(size(numUsers));
% Run the CQI scheduling algorithm for 20 users
for i = 1:length(numUsers)
   % Implement the CQI algorithm logic here
   % Calculate the resources allocated to each user based on CQI
      % Calculate the throughput per user based on the allocated resources
      % Store the calculated throughput in the array
   throughput(i) = totalThroughput;
```

```
end
% Plot the throughput vs. number of users
plot(numUsers, throughput, 'o-');
xlabel('Number of Users');
ylabel('Throughput');
title('Throughput vs. Number of Users (CQI Scheduling Algorithm)');
grid on;
```

Existing Proportional Fair Algorithm

Software code for simulation in MATLAB for Existing Proportional Fair Algorithm is written below.

```
% Define the number of users and available resources
numUsers = 20; % Number of users
numResources = 100; % Total number of resources available
% Initialize the throughput array
throughput = zeros(size(numUsers));
% Run the Proportional Fair scheduling algorithm for 20 users
for i = 1:length(numUsers)
   % Implement the Proportional Fair algorithm logic here
   % Calculate the resources allocated to each user based on fairness metric
      % Calculate the throughput per user based on the allocated resources
      % Store the calculated throughput in the array
   throughput(i) = totalThroughput;
end
% Plot the throughput vs. number of users
plot(numUsers, throughput, 'o-');
xlabel('Number of Users');
ylabel('Throughput');
title('Throughput vs. Number of Users (Proportional Fair Scheduling Algorithm)');
grid on;
```

- New Proportional Fair Algorithm

```
% Define the number of users and available resources
numUsers = 20; % Number of users
numResources = 100; % Total number of resources available
% Initialize the throughput array
throughput = zeros(size(numUsers));
% Run the new improved Proportional Fair scheduling algorithm for 20 users
for i = 1:length(numUsers)
   % Implement the new improved Proportional Fair algorithm logic here
   % Calculate the resources allocated to each user based on the improved fairness metric
      % Calculate the throughput per user based on the allocated resources
      % Store the calculated throughput in the array
   throughput(i) = totalThroughput;
end
% Plot the throughput vs. number of users
plot(numUsers, throughput, 'o-');
xlabel('Number of Users');
ylabel('Throughput');
title('Throughput vs. Number of Users (Improved Proportional Fair Scheduling Algorithm)');
grid on;
```

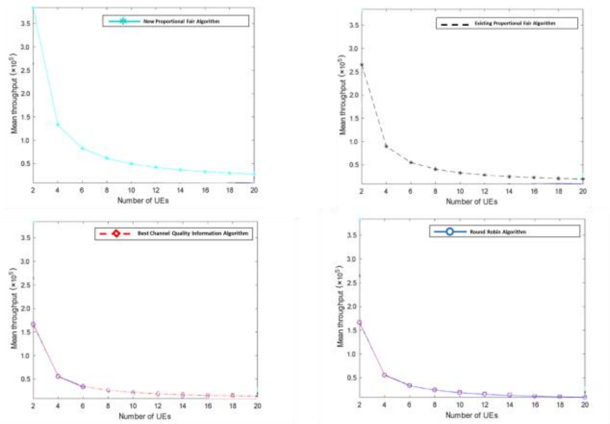


*Fig.11: Mean Throughput results of four individual Scheduling Algorithms*

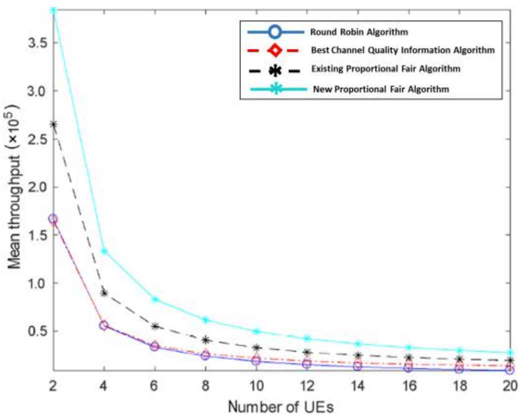


*Fig.12: Comparing simulation throughputs of 4 scheduling algorithms (Mean Throughput)*

Mean throughput when round robin algorithm for 20 users comes out to be 0.01 $(x10^5)$ bps. For best quality inform algorithm, the throughput comes to be 0.05 $(x10^5)$ bps. Subsequently, it is 0.1 $(x10^5)$ bps when existing proportional fair algorithm is used. The new proposed algorithm throughput is 0.2 $(x10^5)$ bps which is better than the other algorithms. It can be seen that as the UEs increase the throughput decreases. In case of lesser users, the new proportional fair algorithm gives a mean throughput of 4 $(x10^5)$ bps when there are two users in the network.

The New Proportional Fair Algorithm outperforms prior algorithms in terms of throughput, owing to its consideration of user packet latency. When a certain delay threshold value is configured into the gNB, the algorithm assigns a greater scheduling priority when the packet transmission delay exceeds the threshold. As a result, time-frequency resources are allocated preferentially, resulting in higher throughput.

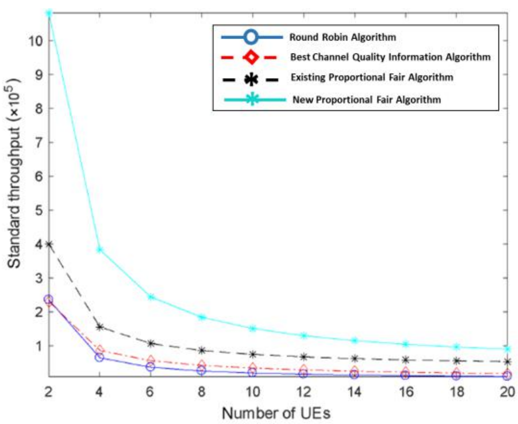


*Fig.13: Comparing through simulations the throughput of 4 scheduling algorithms (Standard Throughput)*

The simulation results show that the proposed scheduling strategies in this study enhanced throughput. This improvement can be due to the novel proportional fair scheduling algorithm's account of data packet delay, which distinguishes it from the other three scheduling algorithms under consideration.

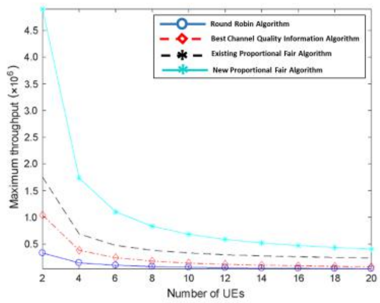


*Fig.14: Comparing throughput of 4 scheduling algorithms (Maximum Throughput)*

The New Proportional Fair Algorithm outperforms prior algorithms in terms of maximum throughput of 5 (x106) bps for 2 users and 0.49 (x106) for 20 UEs.

The proportionate fairness factor increases as the packet delay increases by creating a specified packet delay threshold. As a result, when scheduling time-frequency resources, the relevant packet transmission is given precedence. This method effectively increases network throughput.

## IV. CONCLUSIONS

The performance evaluation of scheduling algorithms is a critical area of research in optimizing mobile broadband services, especially as the world transitions to 5G technology. Scheduling algorithms are essential for resource allocation in wireless communication systems, directly influencing the quality of experience (QoE) for end-users. The researcher focused on evaluating several well-known scheduling algorithms, including Round Robin (RR), New Proportional Fair (NPF), Proportional Fair (PF), and the use of Best Channel Quality Information (BCQI). Each of these algorithms has unique characteristics that affect their performance in different scenarios.

Round Robin (RR) is a straightforward scheduling algorithm that distributes resources evenly among users in a cyclic order. While this approach ensures fairness, it does not account for varying channel conditions, which can lead to suboptimal throughput, especially in environments where signal strength fluctuates. On the other hand, Proportional Fair (PF) attempts to strike a balance between fairness and efficiency. It allocates resources based on a user's channel quality and historical throughput, ensuring that users with favorable channel conditions receive more resources while maintaining fairness for those in less favorable conditions. Best Channel Quality Information (BCQI) prioritizes users with the best channel conditions, maximizing throughput. However, this approach often leads to unfairness, as users with poor channel quality may receive limited resources or none at all. The New Proportional Fair (NPF) algorithm, an enhancement of the traditional PF, was designed to optimize the trade-off between fairness and throughput further. It achieves this by considering additional parameters, such as user demand and real-time channel conditions, to improve the overall user experience.

Simulations were conducted to evaluate the performance of these algorithms in a 5G environment, focusing on key metrics like throughput and user experience. Throughput, a measure of the total data successfully delivered over a network, is a critical indicator of a scheduling algorithm's efficiency. The results demonstrated that the proposed NPF algorithm outperformed the traditional PF, BCQI, and RR algorithms. By efficiently leveraging channel conditions and dynamically adapting resource allocation based on user demands, the NPF algorithm achieved superior throughput and provided a better user experience. This improvement was particularly evident in high-traffic scenarios, where traditional algorithms struggled to maintain consistent performance.

When compared with Round Robin, the NPF algorithm significantly improved throughput by prioritizing users with favorable channel conditions. Unlike RR's equal time allocation approach, NPF's dynamic allocation ensured a more efficient use of resources, enhancing overall network performance. Against the traditional Proportional Fair algorithm, NPF further optimized resource distribution by incorporating real-time user demand and advanced channel analysis. This resulted in higher throughput and improved satisfaction across a broader range of users. While the BCQI algorithm excelled in maximizing throughput for users with optimal channel conditions, it often neglected users with poor conditions, leading to resource inequity. The NPF algorithm addressed this limitation by integrating fairness measures, ensuring a more balanced distribution of resources without compromising throughput.

In conclusion, the findings of this research highlight the effectiveness of the New Proportional Fair scheduling algorithm in enhancing the mobile broadband user experience in a 5G scenario. The NPF algorithm outperformed traditional approaches like Round Robin, Proportional Fair, and Best Channel Quality Information by effectively balancing throughput and fairness. Its dynamic and adaptive resource allocation strategy ensured superior performance, making it a valuable advancement in the field of wireless communication. These results underscore the importance of developing innovative scheduling algorithms to meet the growing and complex demands of modern 5G networks.

## V. FUTURE RESEARCH

Future research endeavors offer vast opportunities to delve deeper into the complexities and nuances of scheduling algorithms in 5G and beyond. While the current evaluation has provided valuable insights into the performance of algorithms like Round Robin, Proportional Fair, Best Channel Quality Information, and New Proportional Fair, it also highlights areas for further investigation. A comprehensive exploration of these algorithms can uncover additional factors influencing their performance, particularly in dynamic and heterogeneous network environments.

One significant direction for future research involves examining the interplay of algorithmic parameters under varying network conditions. Scheduling algorithms operate in environments characterized by diverse user requirements, fluctuating traffic patterns, and varying channel qualities. By simulating scenarios with extreme variations, researchers can better understand the limitations of existing algorithms and identify potential enhancements. For instance, future studies could explore how different weightage factors in the New Proportional Fair algorithm influence the balance between fairness and throughput, especially in multi-user scenarios with high mobility.

Another promising avenue for research is the development and refinement of the mathematical function $f(.)$ used in scheduling decisions. This function plays a critical role in determining resource allocation, and its design significantly impacts an algorithm's effectiveness. Expanding $f(.)$ to include more extensive elements, such as user quality of service (QoS) requirements, latency constraints, and energy efficiency metrics, could lead to more sophisticated algorithms tailored to specific use cases. This expansion, however, demands rigorous simulation studies to validate the feasibility and effectiveness of these modifications. Future research could investigate the trade-offs introduced by incorporating such elements, ensuring that the resulting algorithms remain computationally efficient while delivering improved performance.

Additionally, the integration of machine learning and artificial intelligence (AI) in scheduling algorithms represents an exciting frontier. Machine learning models can analyze historical data to predict user demand, channel conditions, and traffic patterns, enabling more proactive and intelligent scheduling decisions. Researchers could explore the feasibility of hybrid algorithms that combine the principles of traditional scheduling methods with the predictive power of AI. For example, an algorithm could dynamically adjust the parameters of f(.) based on real-time predictions, enhancing its adaptability to changing network conditions.

Another area worth exploring is the evaluation of scheduling algorithms in specific 5G use cases, such as ultra-reliable low-latency communication (URLLC), massive machine-type communication (mMTC), and enhanced mobile broadband (eMBB). Each of these use cases presents unique challenges, requiring tailored scheduling strategies to meet stringent performance requirements. By focusing on these scenarios, researchers can design algorithms optimized for specific applications, further advancing the field.

Moreover, future studies could investigate the scalability of these algorithms in next-generation networks, including 6G, where network densification and the integration of satellite communications introduce additional layers of complexity. These scenarios demand algorithms capable of handling larger numbers of users and devices while maintaining efficiency and fairness. Researchers might also explore the role of collaborative scheduling across multiple network nodes to improve overall system performance.

In conclusion, future research into scheduling algorithms offers a rich landscape for innovation and discovery. By examining their complexities, refining key functions like f(.), and integrating emerging technologies such as AI, researchers can push the boundaries of what these algorithms can achieve. Expanding simulations to include more diverse and realistic scenarios will be critical to validating these advancements. These efforts will not only enhance the performance of existing 5G networks but also lay the groundwork for the next generation of wireless communication systems, addressing the ever-growing demands of users and applications in a connected world.

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