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Comparative Performance Evaluation of Scheduling Algorithms using 5G-Air-Simulator

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ABSTRACT

The Third Generation Partnership specified the 5th Generation New Radio standard to fulfill the growing demand of wireless traffic and the increased need for higher data rates. With the spread of new applications, efficient scheduling algorithms are mandatory to handle the allocation of the limited spectrum resources to various types of traffic and to guarantee the requirements of the quality of service and the quality of experience informed by users. In this paper several scheduling algorithms specifically Round Robin, Best Channel Quality Indicator, Proportional Fair, Modified Largest Weighted Delay First, Exponential Proportional Fair, and Logarithm Rule are evaluated and their performances are compared to each other. The simulation shows that Round Robin and Proportional Fair perform well for non-real time services and Voice over Internet Protocol traffic, particularly for simple systems since they offer high level of fairness between users and low packet loss ratio. On the other hand, Best Channel Quality Indicator produces poor performance for its very low fairness index, very high packet loss ratio and long delay values making it impractical to implement in most scenarios. The other three algorithms perform effectively for real time services specifically for video traffic. While Exponential Proportional Fair algorithm has the lowest values of delay, Logarithm Rule algorithm gives the highest data rate and the lowest packet loss ratio with high index of fairness.

Keywords: Throughput, Packet loss ratio, Fairness, Time delay, Real time

1. INTRODUCTION

The International Mobile Telecommunications (IMT-2020) introduced the fifth generation (5G) standards to meet the requirements of the rapid increasing of wireless devices and the new applications which require high data rate and low latency **(Sudhamani et al., 2023)**.

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5G networks can attain up to 20 Gbps of data rates, and a total time delay as low as 10ms for real-time packets **(Damayanti et al., 2023)**. Moreover, 5G provides high system spectral efficiency, larger data density per unit area, higher reliability, and improved energy efficiency **(Degambur et al., 2021)**. 5G networks come with three distinctive use cases, enhanced mobile broadband (eMBB), massive-machine type communication (mMTC), and ultra-reliable low-latency communication (URLLC) services **(Nor et al., 2022)**. Engaging these use cases necessitates a more efficient system since each one of these cases demands explicit requirements **(Samidi et al., 2021)**.
Considering time dependent transmission, traffic may be time-sensitive as in Non-Real-Time (NRT) best-effort application such as file transfer and mail services. Alternatively, Real Time (RT) depends totally on time delay such as voice and video traffic. Each traffic flow is attached one or more Quality of Service (QoS) factors. User equipment always send channel state reports to the packet scheduler process of the Radio resource management (RRM) function **(Elhadad et al., 2021)**. These reports are employed with the assistance of the target QoS parameters to ensure the optimal resources utilization. RRM is a set of procedures, strategies, and algorithms employed to handle resource sharing, user data rates, modulation and coding scheme, beside others **(Li et al., 2021)**. MAC schedulers should be designed efficiently to achieve the target QoS for the various scenarios and to ensure the optimal resources allocation taking into account high user capacity, various services, user channel information, and user mobility **(Madi et al., 2022)**.
Scheduling algorithms may be categorized into channel-aware, QoS-aware, or both. The algorithms use channel status in order to improve the network performance, and the QoS parameters to achieve the required service's quality **(Latiff et al., 2022)**. Packets to be transmitted are buffered in the corresponding queues waiting to be assigned to the available RBs **(Elhadad et al., 2021)**. Real-time interactive services such as Voice over Internet Protocol (VoIP) and video require more advanced QoS parameters such as delivery delay and Packet Loss Ratio (PLR) **(Masli et al., 2022)**.
In **(Habaebi et al., 2013; Hakimi et al., 2014; Ashfaq et al., 2021)**, the authors evaluated and compared the Round Robin (RR), Best-CQI, and Proportional Fair (PF) algorithms in LTE networks. They concluded that the Best-CQI algorithm offers the highest data rates with poor fairness among users, while the RR achieves the best fairness. The PF algorithm results a compromise between fairness and throughput.
The authors of **(Sulthana et al., 2014; Nwawelu et al., 2016; Alsahag et al., 2020)** studied several LTE networks algorithms such as PF, Modified Largest Weighted Delay First (M-LWDF), Exponential Proportional Fair (EXP-PF), Exponential Rule (EXP-Rule), Logarithm Rule (LOG-Rule). The results indicated that the PF algorithm is the best scheme for NRT services. Other algorithms may be used for both real and non-real time services, but they are optimized to prioritize RT flows over NRT flows particularly as the load increases, leading to NRT application starvation.
Authors of **(Perdana et al., 2019; Sanyoto et al., 2019; Damayanti et al., 2023)** assessed the algorithms RR, Best-CQI, and PF in 5G networks. The results show that RR attains the highest throughput and fairness than others for VoIP traffic, while PF performs better for video stream.
The authors in **(Latiff et al., 2022)** studied different algorithms in 5G and LTE-A wireless networks for live video streaming including M-LWDF, EXP-PF, EXP-MLWDF. The research concluded that the simpler M-LWDF algorithm performs best for interactive video traffic by enhancing network performance and decreasing time delay.

In this work, a simulation is conducted using a software named 5G-air-simulator of several algorithms in 5G networks. Then, the result of each algorithm is analyzed and studied against each other in the case of throughput, packet loss ratio, fairness and delay, with three types of traffic which are infinite buffer, VoIP, and video for different number of users.

2. SCHEDULING TECHNIQUE

Scheduling is the efficient allocation of radio resources between users. Several factors impact the scheduling operation, for instance, Channel State Information (CSI), Buffer Status Report, and Quality of Service (QoS) **(Mamode and Fowdur, 2020).** QoS parameters include target delays, available resources, channel status, and traffic types (RT or NRT) **(Madi et al., 2022)**.
5G NR uses the Orthogonal Frequency Division Multiplexing (OFDM), where time and frequency domains are employed for scheduling **(Takeda et al., 2020)**, as shown in **Fig. 1**. OFDM is a multi-carrier transmission technique with an efficient spectrum utilization **(Abdul Majed and Omran, 2020)**, it is broadly used for data transmission due to its immunity to multipath fading **(Al-Haddad, 2014).** A resource element (RE) is considered the tiniest time-frequency resource unit that comprises one subcarrier in the frequency domain and one OFDM symbol in the time domain. Frequency domain is divided into several subcarriers equally spaced **(Idan and Al-Haddad, 2023).** 5G supports different subcarrier spacings which are 15 (as in LTE), 30, 60, 120, and 240 kHz, and a range of channel bandwidths up to 400 MHz **(Madi et al., 2022)**. A Resource Block (RB) contains twelve contiguous subcarriers which is the smallest resources unit that can be allocated to a user **(Bag et al., 2019)**. Time domain is divided into radio frames, subframes, slots and mini-slot. The radio frame interval is 10 ms and is divided into ten subframes of 1 ms each. Every subframe has one or more slots of 14 OFDM symbols per slot. A mini-slot can consist 2, 4, or 7 OFDM symbols. The slot interval relies on the subcarrier spacing **(Mamode and Fowdur, 2020)**. 5G supports two types of duplexing, the Frequency Division Duplex (FDD) which assigns different frequency channels to uplink and downlink traffics, and the Time Division Duplex (TDD) which transmits uplink and downlink packets separated by time through a single channel **(Mamane et al., 2022a)**.

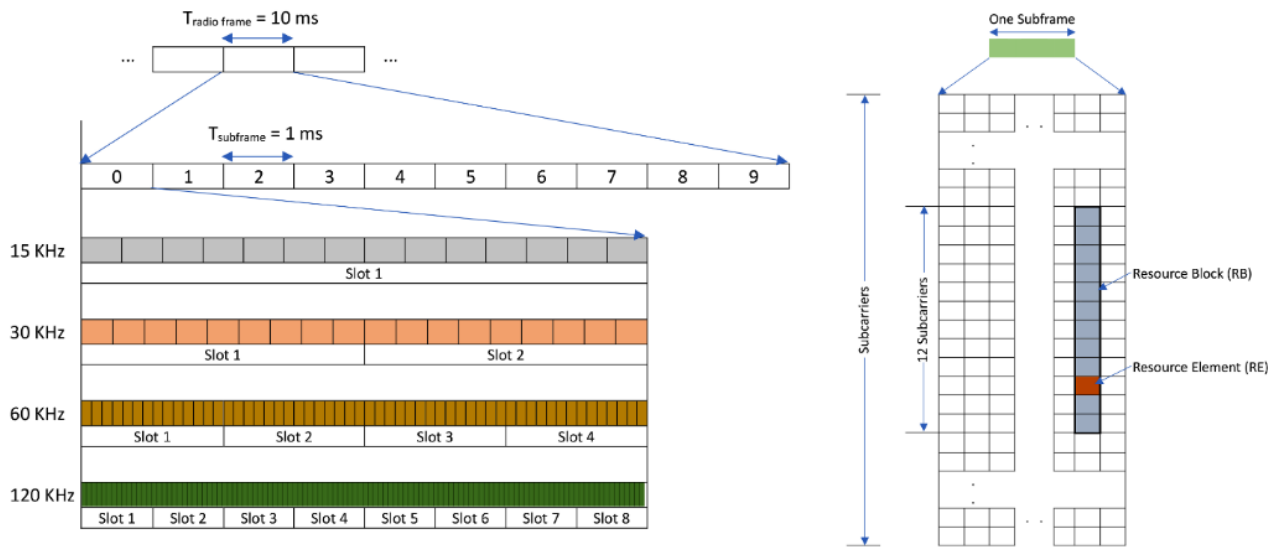

Figure 1. 5G NR radio frame structure and resource grid

The 5G system decides the numerology of bandwidth that specifies the number of RBs, subcarrier spacing which defines the resource element period, Transmission Time Interval (TTI) which relates to packet delay. These numbers are selected properly to suit the use case of the current application and then employed by the scheduler which aims to achieve the optimal performance in case of lowest time delay, maximum throughput, highest reliability, and minimum power consumption.

User Equipment (UE) reports the standard Channel State Information (CSI) at each TTI. CSI has several components of information, such as Channel Quality Indicator (CQI), and precoding matrix indicator **(Ferreira and Guardieiro, 2020)**. CQI is a four bits integer, representing the data speed a device can receive maintaining an error of 10% or less. The CQI value is a function of the signal to interference and noise ratio (SINR), although it depends on the device implementation. According to the users' reported CQI, the RRM component identifies the Modulation and Coding Scheme (MCS) **(Madi and Madi, 2020)**. Packets are stored temporarily in buffers according to QoS requirements **(Elhadad et al., 2019)**. The MAC layer packet scheduler calculates the priority metrics for every user against each resource block to decide the qualified user for the current resource block **(Madi et al., 2022)**. Channel condition, packet delay, and buffer size factors may affect the assignment decision **(Elhadad et al., 2021)**.

3. EVALUATION PARAMETERS

Several parameters are available to study the performance of the scheduling algorithms, following are the mostly common parameters:

3.1 Throughput and Goodput

The throughput is the summation of the packets data rates (R_{rx}) delivered correctly to users per time spent (T). It is measured in bps, as in Eq. (1).

$$Throughput = \frac{1}{T}\sum R_{rx} \tag{1}$$

On the other hand, the goodput is measured by subtracting any overhead caused by control and retransmission data from the throughput **(Mamane et al., 2021)**.

3.2 Packet Loss Ratio (PLR)

The PLR is a percentage index to indicate the ratio of the lost packets to the total sent packets. Packets are lost due to network error or time expiry. This factor is mainly important in time sensitive applications such as real time voice and video flows **(Angri et al., 2018)**. Eq. (2) describes the formula used.

$$Packet\ Loss\ Ratio = \frac{N_{tx} - N_{rx}}{N_{tx}} \times 100 \tag{2}$$

Where N_{tx} is the total count of transmitted packets and N_{rx} is the number of correctly received packets. The number of lost packets is the difference between the total transmitted and the received packet numbers (N_{tx}-N_{rx}).

3.3 Fairness Index

The fairness index described in Eq. (3) is the measurement of the resource allocation fairness between users. The Jain's fairness index is employed which is a function of the users' data rates as shown in equation **(Ferreira and Guardieiro, 2020)**. This index ranges from (1/N) to 1. The higher the value the higher the achieved fairness between users, with 1 being the optimum fairness, when all the data rates have the same value.

$$Jain's\ Fairness\ Index = \frac{(\sum_{i=1}^{N} R_i)^2}{N \cdot \sum_{i=1}^{N} {R_i}^2} \quad (3)$$

Where R_i is the i^{th} user throughput, and N is the total number of users.

3.4 Packet Latency (Delay)

Latency is the time spent by a packet from the source to the destination. It has a noticeable influence on time critical applications like VoIP and Video which require low delay **(Perdana et al., 2019)**. The average delay is the sum of the packet delays divided by the total number of received packets as illustrated in Eq. (4).

$$Average\ Delay = \frac{1}{N_{rx}} \sum_{i=1}^{N_{rx}} (T_{rx,i} - T_{tx,i}) \quad (4)$$

Where N_{rx} is the number of received packets, $T_{rx,i}$ is the time the i^{th} packet received, and $T_{tx,i}$ is the i^{th} time the packet transmitted.

4. SCHEDULING ALGORITHMS

Scheduling algorithm makes a decision for allocating an available resource (j^{th} RB) to the (i^{th}) user by evaluating and comparing metric values for each user ($m_{i,j}$) then assigning the resource to the user with maximum metric value ($w_{i,j}$) **(Monikandan et al., 2020)**, as in Eq. (5).

$$w_{i,j} = max_i(m_{i,j}) \quad (5)$$

Numerous numbers of scheduling algorithms were developed to maintain the QoS targets and to enhance throughput and fairness **(Alsahag et al., 2020)**. Following is a brief description of some of the well-known scheduling algorithms.

4.1 Round Robin (RR)

Round Robin is one of the most basic algorithms which assigns each UE an equal number of resources in a cyclic format without priority to any one of these UEs **(Hani et al., 2018)**.
The advantage of RR is that it allocates resources fairly between UEs, however, RR doesn't take channel condition into account, which may result into poor network performance and a waste of network resource **(Yang and Chen, 2018)**.

4.2 Best Channel Quality Indicator (B-CQI)

The B-CQI scheduler allocates resource blocks to the users with the best channel conditions. Each TTI, the UEs report their CQI to the base station. Higher CQI value represents a better channel condition. This scheduler achieves the best network utilization by scheduling the users with the highest CQI values **(Ashfaq et al., 2021)**. However, UEs at the cell boundary suffer from poor channel and higher inter-cell interference **(Mohammed and Almamori, 2024)**, they may not be scheduled, which results in an unfair distribution of resources.

4.3 Proportional Fair (PF)

The PF algorithm provides an optimal balance between throughput and fairness by allocating the available resources among users, considering the current data rate which depends on the channel quality reported by the user, and the average user's throughput **(Alsahag et al., 2020)**. It intends to reach high level of fairness with acceptable throughput and to improve the QoS for various levels of traffic load conditions **(Monikandan et al., 2020)**.
As shown in Eq. (6), the metric $m_{i,j}$ determines the ratio between $r_{i,j}(t)$ and $R_i(t)$, where $r_{i,j}$ is the UE's instantaneous data rate taking into consideration the CQI value reported by the (i^{th}) UE on the (j^{th}) RB, and $R_i(t)$ is the average data rate of the (i^{th}) UE **(Ma et al., 2020)**.

$$m_{i,j} = \frac{r_{i,j}(t)}{R_i(t)} \tag{6}$$

The previous average data rate of a user (i) represents the history of the users' allocated resources. It enhances the fairness of resource distribution between users by prioritizing users who had low throughput. Every TTI, the achieved instantaneous average data rate $R_i(t)$ is updated as in Eq. (7):

$$R_i(t) = \left(1 - \frac{1}{t_c}\right) R_i(t-1) + \frac{1}{t_c} r_{i,j}(t) \tag{7}$$

Such that $R_i(t-1)$ is the past average data rate, and t_c is the constant time window length used as an averaging filter **(Mamane et al., 2022b)**.

4.4 Modified Largest Weighted Delay First (M-LWDF)

This is a channel and QoS aware algorithm, it considers the delay, fairness and network performance, and handles RT and NRT flow types differently by enhancing real time flows with the highest delay ($D_{HoL,i}$) to be transmitted before reaching the threshold time (τ_i), while maintaining high throughput and fairness achieved by the proportional fair part of the metric. The metric is specified in Eq. (8) and Eq. (9):

$$m_{i,j} = a_i D_{HoL,i} \frac{r_{i,j}}{R_i} \tag{8}$$

$$a_i = -\frac{log(\delta_i)}{\tau_i} \tag{9}$$

Where $r_{i,j}$ and R_i are the same as those in the proportional fair metric. $D_{HoL,i}$ is the packet (i) head of line (HoL) delay, τ_i is the delay threshold of the (i^{th}) real-time flow where lower value gives higher metric value, and δ_i indicates the maximum probability that the delay may exceed the threshold time **(Mamode and Fowdur, 2020)**.

4.5 Exponential Proportional Fairness (EXP/PF)

The EXP/PF enhances the real time traffic of the multimedia services. It intends to enhance RT flows priority over NRT flows by using the average fixed maximum time of all active RT flows **(Nguyen et al., 2016)**. For RT flows, the metric priority is increased when the HoL packet delay reaches the delay threshold time **(Mamane et al., 2022b)**. RT flows metric is employed as illustrated in Eq. (10) and Eq. (11):

$$m_{i,j} = exp\left(\frac{a_i D_{HoL,i} - X}{1 + \sqrt{X}}\right)\frac{r_{i,j}}{R_i} \tag{10}$$

$$X = \frac{1}{N_{rt}}\sum_{i=1}^{N_{rt}} a_i D_{HoL,i} \tag{11}$$

Where *Nrt* is the number of RT flows and other parameters are the same as before.

4.6 Logarithm Rule (LOG-Rule)

This scheduler fulfills the QoS requirements of the network including delay and network utilization. It gives an enhanced priority to flows with high rate. The metric is defined in Eq. (12) and Eq. (13):

$$m_{i,j} = b_i \, log\left(c + a_i D_{HoL,i}\right)\frac{r_{i,j}}{R_i} \tag{12}$$

α_i, b_i, c are tunable variables, the optimal values which showed the best results could be set as follows **(Nwawelu et al., 2016)**:

$$a_i = \frac{5}{0.99\,\tau_i}, \quad b_i = \frac{1}{E\left(\frac{r_{i,j}}{R_i}\right)}, \quad c = 1.1 \tag{13}$$

Where τ_i is the delay threshold, b_i is the reciprocal of the average value of the user's instantaneous data rate ($r_{i,j}$) divided by the average data rate $R_i(t)$.

5. SIMULATION MODEL

The simulation uses a software called 5G-air-simulator **(Martiradonna et al., 2020a)**. In this simulation, the more realistic Single Cell with Interference configuration was employed. As shown in **Fig. 2**, the model has 7 cells, each cell has a radius of 1 Km, a base station at the center serving users, surrounded by six base stations that do not serve users, but produce inter-cell interference which impacts the metrics in the primary cell. Users move in random direction with a constant speed of 3 km/h inside the cell using the RANDOM DIRECTION mobility model. The Urban Macro-cell channel model is used **(Martiradonna et al., 2020b)**.

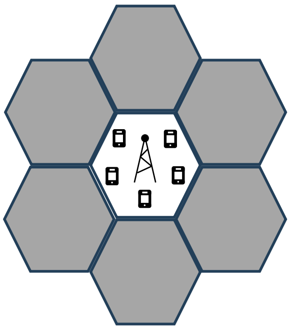

Figure 2. Simulation Model, a primary cell surrounded by 6 cells causing interference.

Three traffic models are used in this simulation. The Best Effort (BE) modeled by Infinite Buffer (IB) model offers infinite supply of data. The VoIP traffic uses the G.729 model which generates packets of constant rate and size at different times imitating the way humans speak. The TraceBased emulates the video streaming traffic which is generated from real video file with full size and time information of every frame.

Each user has one BE flow, one VoIP stream, and one Video stream. To study the effect of varying traffic load, the simulation is applied to different number of users, from 5 to 50 users, with a step of 5 users.

The Round Robin, Best-CQI, Proportional Fair, M-LWDF, EXP-PF, and LOG-Rule schedulers are evaluated and their performance metrics are compared to each other in terms of throughput, Packet Loss Ratio (PLR), fairness, and delay. The simulation parameters are shown in **Table 1**.

Table1. Simulation parameters' values

Parameter	**Value**
Carrier frequency	2.1 GHz
Bandwidth	5 MHz
Frame structure	FDD
UE speed	3 Km/h
Radius	1 Km
Number of Base Stations	7
Simulation duration	46 second
Simulation flow duration	40 second
Channel Model	Urban Macro-cell
Max delay threshold (τ)	0.1 second
Drop probability (δ)	0.005
Video bit-rate	242 kbps
Number Of Users	5, 10, 15, 20 ,25, 30, 35, 40, 45, 50

6. SIMULATION RESULTS AND DISCUSSION

Following is the evaluation and comparison of the performance of RR, Best-CQI, PF, M-LWDF, EXP/PF, LOG-Rule algorithms in case of throughput, PLR, fairness, and delay.

6.1 Throughput and Goodput

From results of the total throughput shown in **Fig. 3**, it is seen that Best-CQI has the highest throughput of more than 18 Mbps, which is expected as Best-CQI serves users with the best channel conditions. Alternatively, RR achieves the lowest throughput as low as 7.7 Mbps since RR does not consider channel state condition when assigning resources. Other algorithms take channel state information into their calculations, they achieve comparable throughput values range from 12 to 16 Mbps.

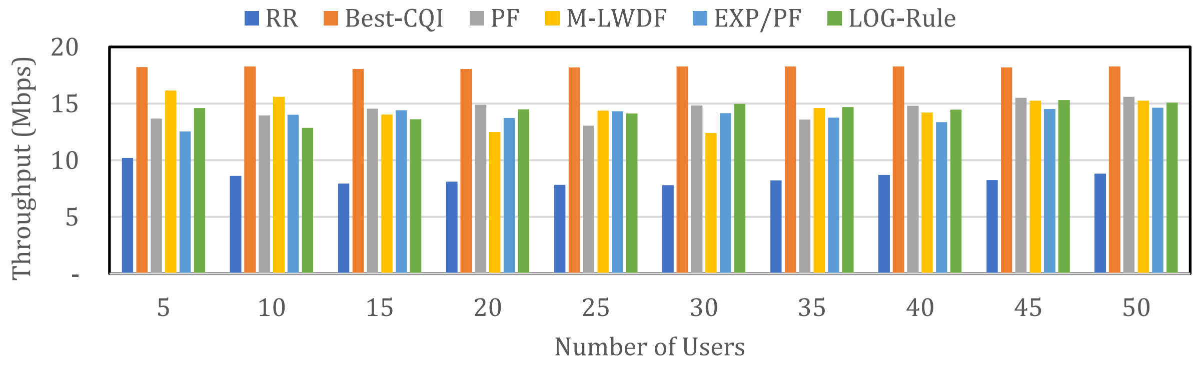

Figure 3. Throughput

On the other hand, total Goodput result is illustrated in **Fig. 4**, where it is obvious that Best-CQI goodput drops down in some scenarios compared to other algorithms due to the loss of real time packets exceeding threshold time since Best-CQI does not take time factor into consideration. Although the RR and PF do not consider time factor, the effect of packet loss is less severe than Best-CQI, since they tend to distribute resources fairly compared to Best-CQI. The other algorithms handle real time packets better, causing less loss of packets, with the advantage for M-LWDF.

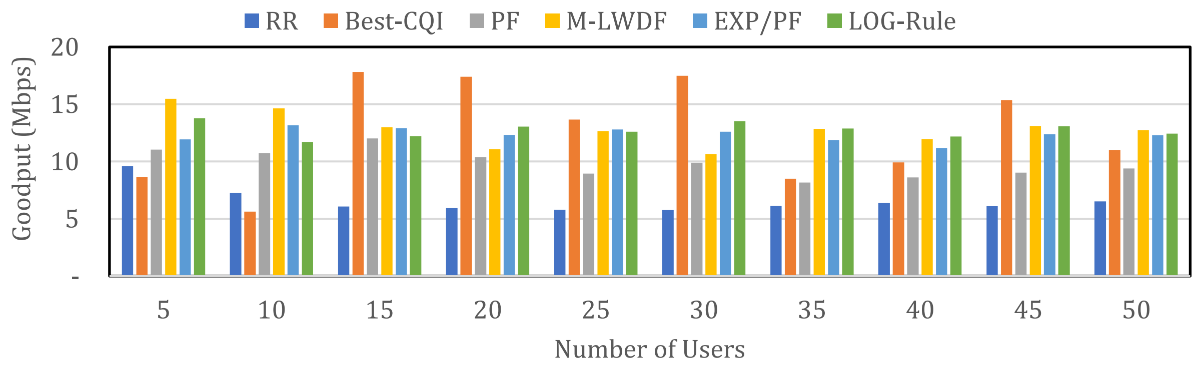

Figure 4. Goodput

6.1.1 Goodput for Infinite Buffer Traffic

Infinite buffer goodput is shown in **Fig. 5**. Generally Best-CQI achieves better than others in most scenarios while RR has the lowest goodput. Other algorithms have near results, with M-LWDF having the highest goodput among them.

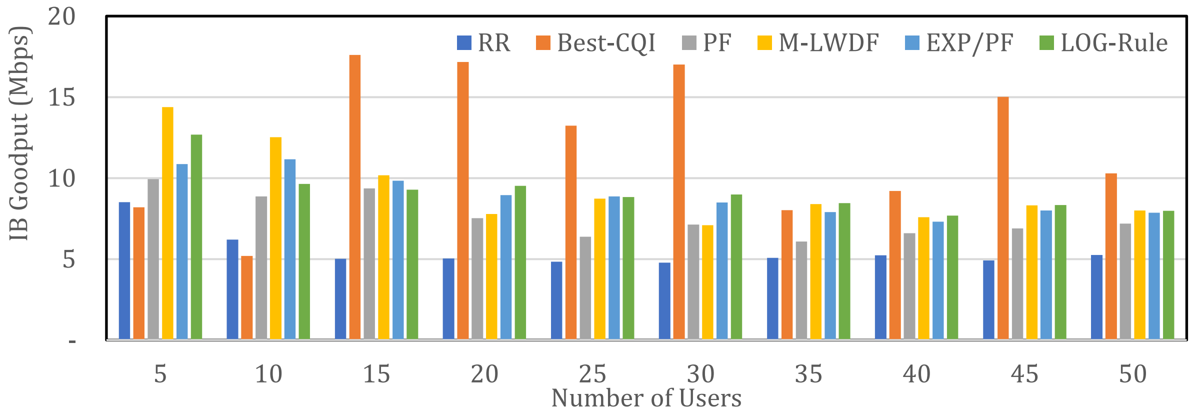

Figure 5. Goodput for Infinite Buffer (IB) Traffic

6.1.2 Goodput for VoIP Traffic

With the exception of Best-CQI which gives poor performance, the other five algorithms perform well, and PF has the best VoIP goodput of more than 0.314 Mbps as in **Fig. 6**. The reason behind this is that VoIP packets have low data rate and are easily handled using these algorithms.

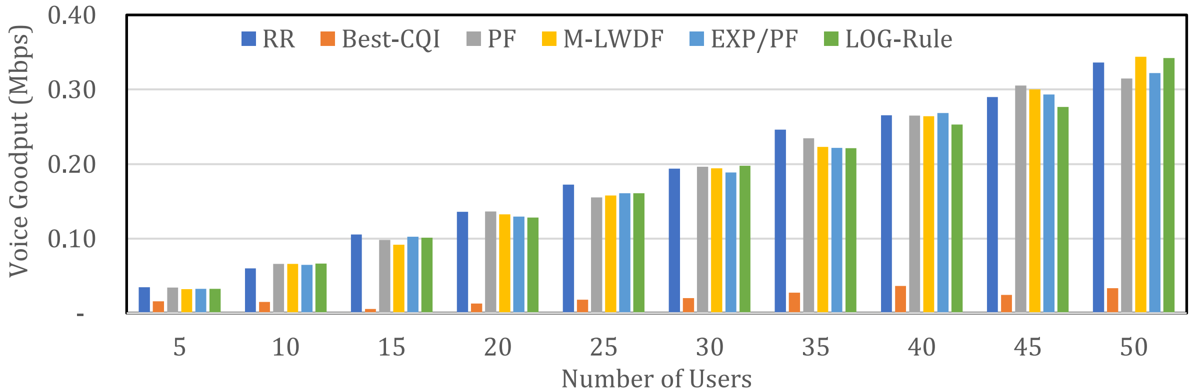

Figure 6. Goodput for VoIP Traffic

6.1.3 Goodput for Video Traffic

Fig. 7 illustrates the Video packet goodput. It is obvious that RR, PF, Best-CQI perform poorly. They do not consider Video traffic quality of service factors and mostly result in large number of lost packets particularly as the network load increases.

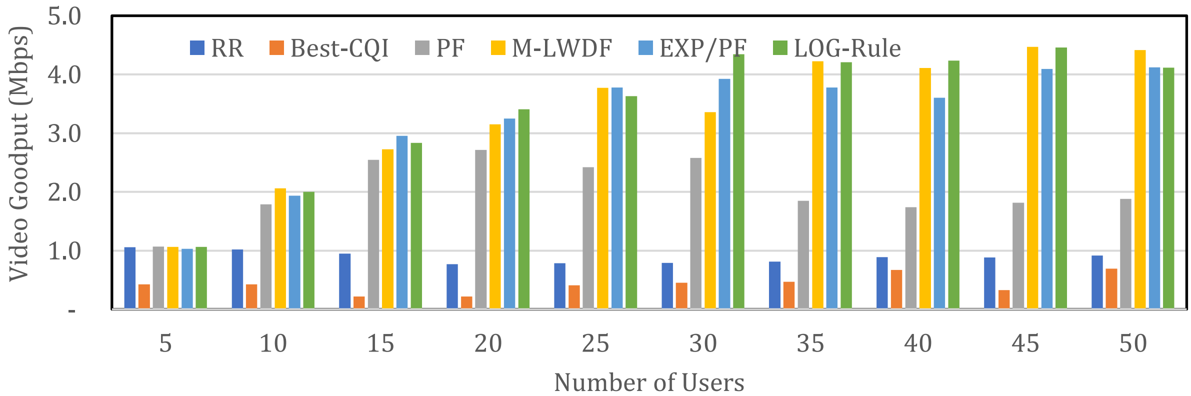

Figure 7. Goodput for Video Traffic

M-LWDF, EXP/PF and LOG-Rule are designed to handle such type of traffic, and clearly achieving better results in all scenarios. Generally, LOG-Rule gets the highest goodput of up to 4.3 Mbps.

6.2 Packet Loss Ratio

Fig. 8 Shows large values of PLR for RR, Best-CQI and PF algorithms up to 38%, 60% and 25% respectively, which result in a waste of resources. Other algorithms achieve less PLR, LOG-Rule has the lowest among them all.

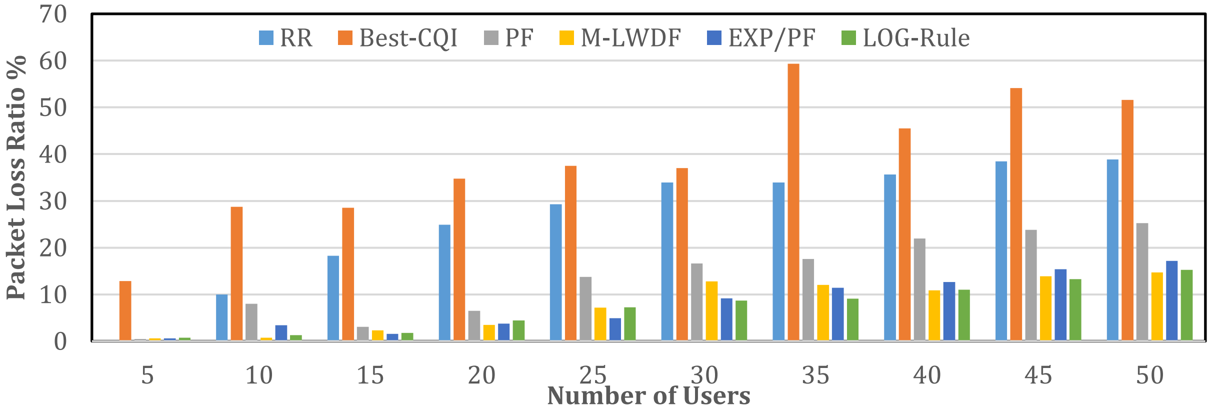

Figure 8. The Packet Loss Ratio (PLR) for VoIP Traffic

6.2.1. PLR for the VoIP traffic

The voice Packet Loss Ratio illustrated in **Fig. 9** shows that RR performs the best of less than 2.2% of PLR. On the other hand, Best-CQI reaches up to 94% of packet loss. M-LWDF, EXP/PF, and LOG-Rule achieves less than 5% of PLR which is acceptable in such application.

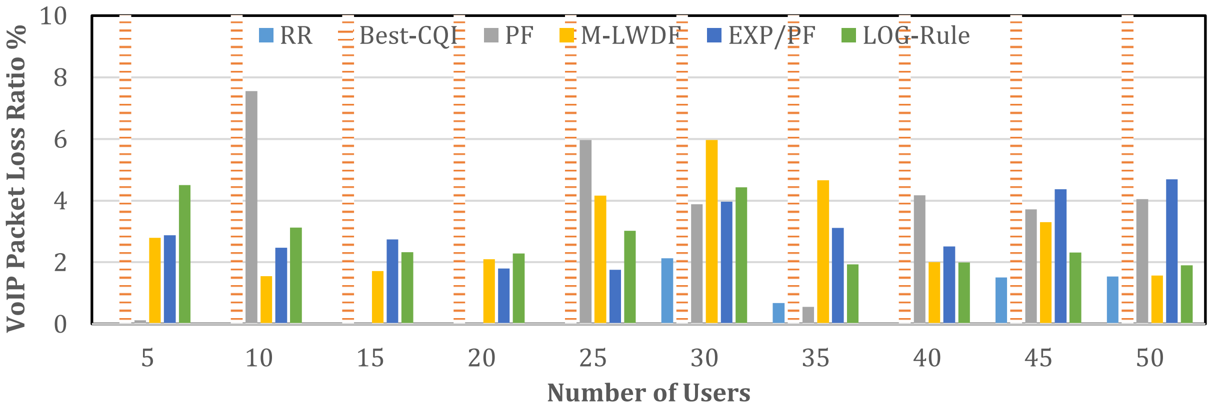

Figure 9. The Packet Loss Ratio (PLR) for VoIP Traffic

6.2.2. PLR for the video traffic

Video traffic PLR in **Fig. 10** shows that RR, Best-CQI and PF do not perform well for video traffic because these algorithms do not consider the delay and its threshold parameters in their metrics which when employed will minimize the lost packets. Whereas other algorithms achieve less PLR since their metrics are designed to take delay parameters into account that prioritize packets with high delay preventing them from being lost. LOG-Rule algorithm has the lowest value of PLR.

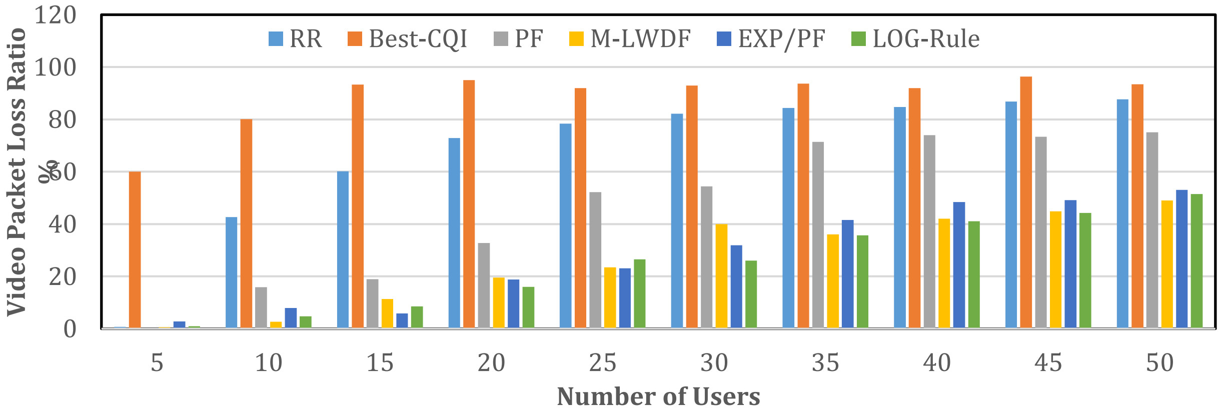

Figure 10. The Packet Loss Ratio (PLR) for Video Traffic

6.3 Fairness Index

The fairness index illustrated in **Fig. 11** shows that, in general, RR has the highest values of fairness index between all users due to the fair distribution of resources between users, not taking into account the channel status which results in lower throughput and higher delays. On the other hand, Best-CQI has the worst fairness values of less than 0.45, since this algorithm targets only users with the best channel status compromising the fair distribution of resources. Others achieve better values for small number of users compared to RR, then the values decrease as the number of users decreases.

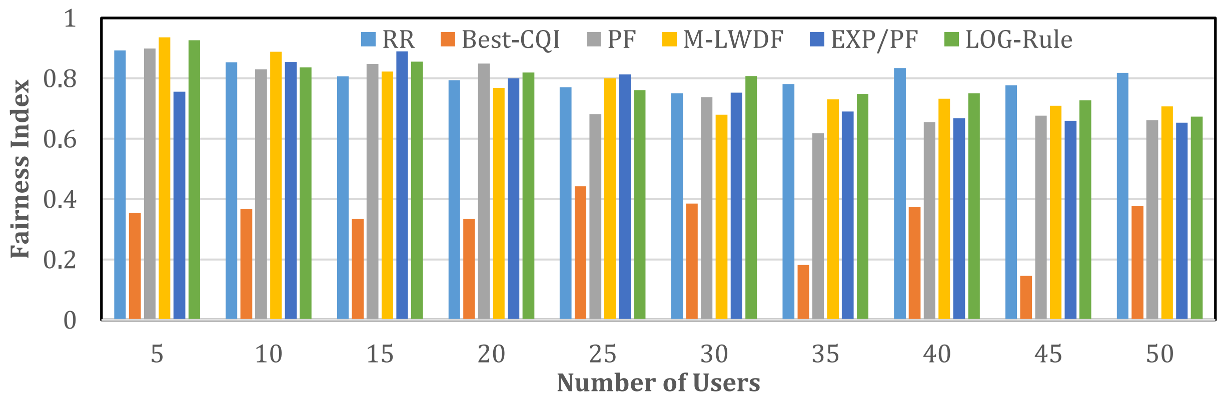

Figure 11. The Fairness Index for VoIP Traffic

6.4 Delay

The left part of **Fig. 12** illustrates the large values of delay achieved by RR, Best-CQI, and PF of up to 1.5, 0.24, and 0.25 s respectively, because these algorithms do not employ the time threshold in their metrics. M-LWDF, EXP/PF, and LOG-Rule delay values shown in the right part of the figure are small of less than 13 ms. The values increase as the number of users increases. EXP/PF has the lowest values of less than 8 ms.

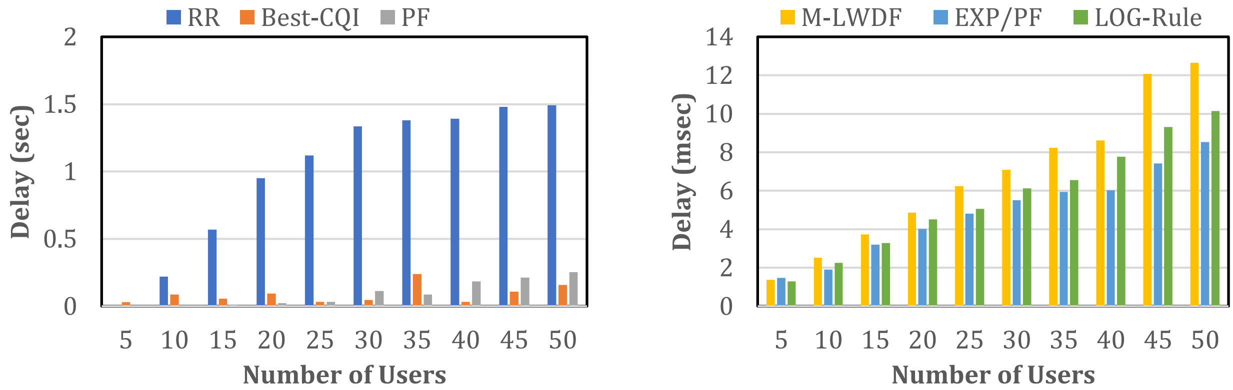

Figure 12. The Average Traffic

6.4.1. Delay for the VoIP Traffic

Fig. 13 shows the low values delay obtained for voice traffic of 16 ms and less for different number of users which is much less than the threshold delay value adopted in this simulation of 100 ms. EXP/PF has the lowest values compared to M-LWDF and LOG-Rule.

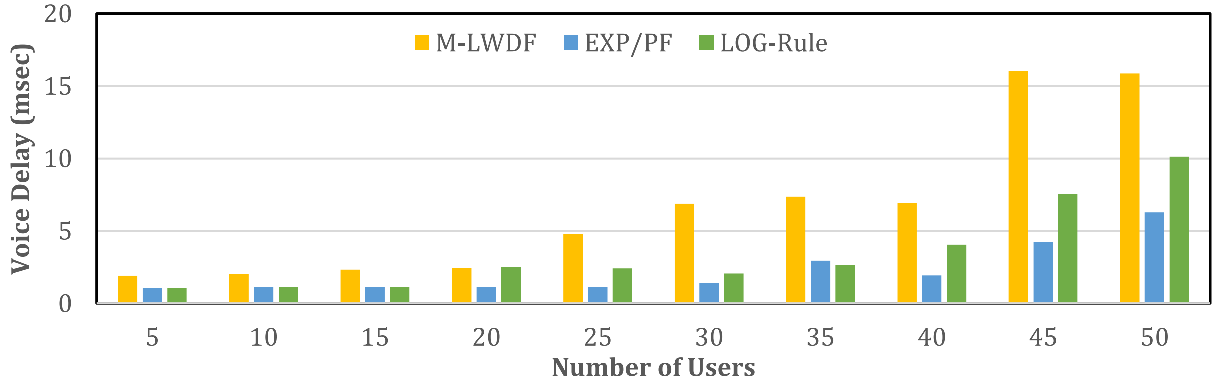

Figure 13. The Average Delay for VoIP Traffic

6.4.2. Delay for the Video Traffic

Fig. 14 illustrates the values of delay obtained M-LWDF, EXP/PF, and LOG-Rule for video traffic of less than 45 ms. EXP/PF has the lowest values compared to others.

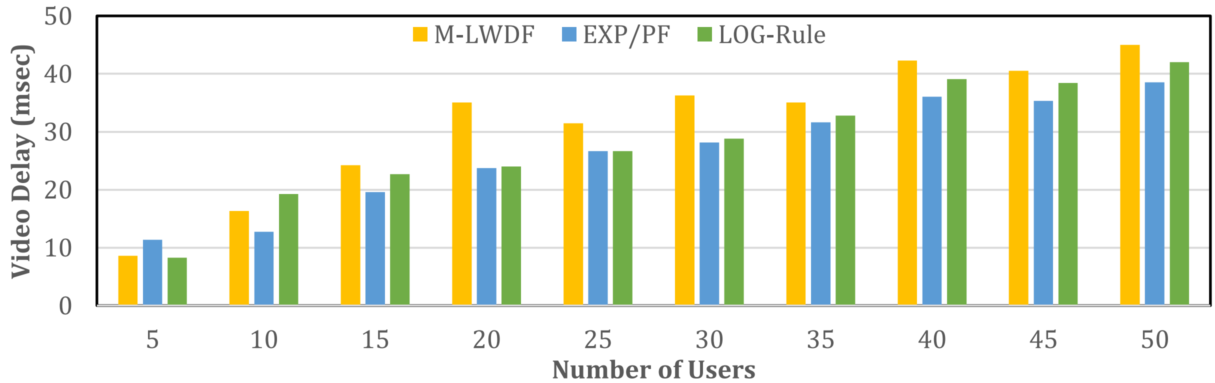

Figure 14. The Delay for Video Traffic

7. CONCLUSIONS

Several algorithms for 5G networks are evaluated and their performance are compared to each other which are Round Robin (RR), Best-CQI, Proportional Fair (PF), Modified Largest Weighted Delay First (M-LWDF), Exponential Proportional Fairness (EXP/PF) and Logarithm-Rule (LOG-Rule) for various number of users using 5G-air-simulator software. This analysis evaluated the algorithms in terms of Throughput, Packet loss ratio, fairness index, and delay, considering Infinite Buffer, Voice, and Video Traffic. Simulation results showed that Round Robin achieves low goodput and high packet loss ratio for infinite buffer and video traffic but high goodput and very low packet loss ratio for VoIP traffic. RR has the best fairness index among other algorithms, but the highest delay time especially for video traffic. This makes RR the choice for infinite buffer and VoIP traffic specially when simple algorithm is required. On the other hand, Best-CQI achieves the highest throughput for Infinite Buffer, but very low for VoIP and video traffic. It results in large number of PLR, low fairness index and high delay, which makes it impractical algorithm to implement.
Proportional Fairness is a balanced algorithm which performs well in several scenarios. It attains a balance between goodput and fairness, with acceptable packet loss ratio and delay values. It performs well for non-real time and VoIP traffic. M-LWDF, EXP/PF, and LOG-Rule are the best candidates for real time traffic such as VoIP and video. They show near results in all scenarios. However, M-LWDF gives the highest goodput for infinite buffer traffic, while LOG-Rule achieves the highest data rate for VoIP and Video traffic. Moreover, LOG-Rule gives the lowest packet loss ratio in all scenarios, and very high fairness index. Finally, EXP/PF gets the lowest values of delay in real time traffic. This work can be extended to simulate and evaluate these algorithms in multi-cell heterogeneous networks with different carrier frequencies while employing user handover between the cells.

NOMENCLATURE

Symbol	Description	Symbol	Description
D_{HoL}	Head of line delay, s	R_{rx}	Received data rate, bps
m	Metric value	T	Delivery time, s
N	Total number of users	t_c	Constant time window length, s
N_{rx}	Number of received packets	T_{rx}	Received packet time, s
N_{tx}	Number of transmitted packets	T_{tx}	Transmitted packet time, s
r	Instantaneous data rate, bps	w	Maximum metric value
R(t)	Average data rate, bps	δ	Maximum threshold probability
R(t-1)	Past average data rate, bps	τ	Packet delay threshold, s

Credit Authorship Contribution Statement

Moaath S. Abdulrahman: Writing – review & editing, Writing – original draft, Validation, Software, Methodology. Buthaina M. Omran: Writing – review & editing, Validation, Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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تقييم أداء خوارزميات الجدولة لشبكات الجيل الخامس

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الخلاصة

شراكة الجيل الثالث حددت معيار الجيل الخامس لتلبية الحاجة المتنامية للتواصل اللاسلكي والطلب المتزايد لمعدلات بيانات أعلى. مع انتشار تطبيقات جديدة، أصبح من الضروري إيجاد خوارزميات جدولة كفؤة لمعالجة تحديد موارد الطيف المحدودة لعدة أنواع من سبل التواصل ولضمان متطلبات جودة الخدمة وجودة التجربة للمستخدمين. في هذا البحث، عدة خوارزميات جدولة تحديدا دورة روبن (RR)، أفضل مؤشر لجودة القناة (Best-CQI)، التساوي النسبي (PF)، التأخير الأكبر المرجح أولا المعدل (M-LWDF)، التساوي النسبي الأسي (EXP/PF)، وقانون اللوغاريثم (LOG-Rule) تم تقييمها ومقارنة اداءها فيما بينها. المحاكاة أظهرت أن (RR) و (PF) كان اداؤهما جيدا للخدمات غير المرتبطة بزمن حقيقي والتواصل الصوتي خصوصا للأنظمة البسيطة حيث توفر مساواة عالية بين المستخدمين ونسبة قليلة لفقدان حزم البيانات. من جهة أخرى، (B-CQI) أعطت أداءً ضعيفًا من حيث ضعف المساواة بين المستخدمين وفقدان عالي للحزم البيانية وقيم تأخر زمني عالية، ولذلك فهي غير عملية للتنفيذ في معظم الحالات. الخوارزميات الثلاثة الأخرى أظهرت أداءً بفعالية عالية مع خدمات الزمن الحقيقي خصوصا في حالة التواصل المرئي. في حين (EXP/PF) أعطت أقل زمن تأخير، قدمت (LOG-Rule) أعلى قيم للمعدلات البيانية وأقل نسبة لفقدان الحزم مع أعلى قيم للمساواة.

الكلمات المفتاحية: معدل البيانات، نسبة خسارة الرزم، المساواة، التأخر الزمني، الزمن الحقيقي