Performance Analysis of Scheduling Algorithms in Simulated LTE Network

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Abstract – The ongoing widespread use of mobile devices has boosted demand for accessibility to e-commerce, social media, and entertainment applications anywhere, at any time. Mobile traffic that was traditionally voice-only is now dominated by video and data owing to applications like live video streaming, Netflix, Facebook, Twitter, and mobile browsing. As the number of subscribers grows, so too does the demand for an enhanced user experience with differentiated service levels. To achieve this, the LTE network elements must incorporate techniques to manage diverse traffic characteristics of the growing range of multimedia applications and services. Analysing the performance of the LTE network can enable the efficient deployment and optimization. In this paper we analyse the performance of the LTE network, in terms of average throughput and delay, under different traffic models, real and non-real time traffic, when the number of users is increased. These analyses we make help us understand how the requirement of the network vary, as the traffic generated by different users change, in order to have a propriate deployment, optimization and techniques used to guarantee best user experience. Further in the paper, we do analyse, different scheduling schemes and the effect that each algorithm has in the network under different traffic models. The estimation is done in terms of average user and cell throughput, delay, and fairness.

Keywords – LTE, Throughput, Delay, Real Time Traffic, Non-Real Time Traffic, Scheduling Algorithms.

I. INTRODUCTION

Mobile broadband subscriptions reached over 6.5 billion in 2021 are projected to reach 7.2 billion by 2027, according to Statista and ITU 2021 statistics [1]. Mobile traffic that was traditionally voice-only is now dominated by video and data owing to applications like live video streaming, Netflix, Facebook, Twitter, and mobile browsing. This trend continues to increase as the variety and number of applications and services increases, and the subscriber base grows. As the number of subscribers grows, so too does the demand for an enhanced user experience with differentiated service levels. Different applications and services place different demands on the network, and together these are driving the need for a comprehensive approach to QoS. Real time traffic and non-real time impose different QoS requirements. For example, real-time, person-to-person video streaming requires high bandwidth on both the uplink and downlink, minimum latency and jitter, high priority under different scheduling algorithms. In real time traffic generators can be: VOIP over mobile, Video Streaming over mobile (YouTube, Instagram, Live, Skype, Zoom, Teams), gamming etc. Non-real time traffic, unlike with real-time video, these transfers are buffered and can, therefore, be handled at a more "leisurely" pace. The batch nature of such transfers enables the use of best-effort bandwidth scheduling, where packets can be dropped to accommodate higher priority traffic. Types of non-real time traffic are content download (FTP), by users downloading and uploading movies, pictures, music, documents, etc. and browsing (HTTP). A very important element affecting the performance of LTE under different traffic models are also scheduling algorithms. With the growing traffic, one of the elements affecting the quality and performance of LTE network communication is congestion, which may lead to increased dropped packets affecting packet delivery ratio, time dedicated for data transmission, overall throughput etc. One of the ways to overcome network congestion is to schedule users in such a way that each user is served to his minimum need without bringing down the quality of service. Based on the methodology of a scheduling algorithm, it allocates the shared resources to each cellular user at every transmission time interval (TTI).

The paper is organized in three main sections, the first one includes a basic introduction of the LTE architecture and its main functionalities. Also, there is given a short description of some types of traffic models, as well as an explanation of some of the most used scheduling algorithms in LTE network. The second section gives a short overview of related works that are done through the years. The third section describes the methodology we have used for the simulation, metrics of performance, and two simulation scenarios. For the simulation it is used Vienna LTE System Level Simulator, an open-source MATLAB as an efficient 4G LTE network simulator to analyse the performance and ensure reliable communication. In the first part of simulations, we analyse the performance of the network under different traffic types for a simulation time of 100 TTIs. The evaluation is made by plotting throughput and delay. In the second scenario the number of users is varied starting from 15 to 90 users per cell in a three-sector tilted antenna, under different scheduling schemes. The evaluation of network performance is given by plotting average cell/user throughput, delay, and fairness of different scheduling algorithms. These indicators can help in designing, optimizing, and deploying in an optimal way the network. Simulation is run by attaching each user to each corresponding sector in a three-sector tilted cell. Traffic model in this simulation is assumed as all the users have a packet to send.

II. An Overview of Network Components

A. LTE Architecture

Unlike other mobile broadband technologies, such as GSM that are circuit-switched, LTE is based on IP packets. Different services are carried over the radio interface to the evolved base station, or eNodeB (ENB) that connects with user equipment (UE) on one side, and on the other side with the core network, or evolved packet core (EPC). The EPC is then connected to the external IP networks, such as the IP multimedia subsystem (IMS). This LTE architecture is flat because the traditional control functions are collapsed into EPC and the radio network controller (RNC) functions (in a 3G network) are incorporated into the LTE eNodeB. The LTE architecture supports peer-to-peer (eNodeB to eNodeB) connections, which lowers latency and minimizes round-trip delay, enabling LTE to offer throughput rates beyond 100Mbit/s and a latency of around 20ms.

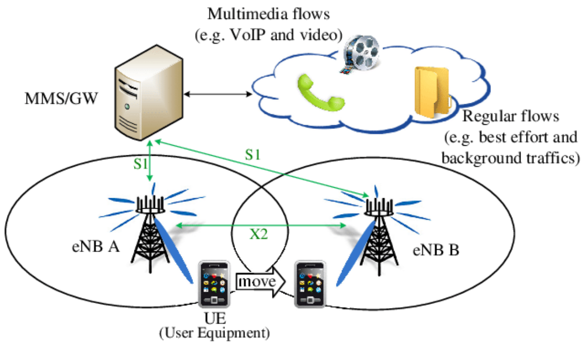


Fig.1 Simplified LTE Network Architecture

B. Traffic Models

Different traffic models have different sizes of data packets and network has a value called Maximum Transmission Unit (MTU), the number of such data packets that collectively need to be sent over the network for the meaningful information to reach to the user, which depends of the type of application. Traffic generated by users can be real time, non-real time, and mixed traffic. Real time traffic and non-real time impose different QoS requirements.

- VOIP over mobile: VoIP is a technology for supporting voice communications over packet networks, such as the Internet.
- Video Streaming over mobile: Real-time, user-generated and on-demand video streaming applications, such as YouTube, Facebook, Instagram, LinkedIn, Twitter Live Streaming,

Skype, Zoom, Teams etc., are therefore a significant factor in QoS in mobile networks as they are continuously asking for high demand of bandwidth causing the dramatic growth in mobile network traffic.

- Gamming: There are thousands of gaming and social media applications available for mobile platforms, and a growing number of these now require differentiated QoS.
- Content download and browsing (HTTP and FTP): A significant amount of mobile bandwidth is consumed by users downloading and uploading movies, pictures, music, documents, etc. HTTP is used with web browsers and servers for providing secure communication. FTP is commonly used for transferring internet pages from server to another server or downloading many files from the server to the user computer.

C. *Scheduling Algorithms*

In this paper there are studied four types of schedulers used in LTE system level, that allocate resources to the users requesting the service, which are, Round Robin, Best CQI (channel quality indicator), Proportional Fair, Priority Set.

- Round Robin: A round robin scheduler is a non-aware scheduling algorithm that assigns resources to every user starting from the first one and assigning resources from there on recursively. It doesn't consider the instantaneous channel condition. Therefore, it provides higher fairness among the users at the expense of performance.
- Best Channel Quality Indicator: The best CQI scheduler assigns resource blocks to the user with the best radio link conditions or channel quality for a particular RB at every TTI.
- Proportional Fair (Prop Fair Sun): PF improves spectral efficiency and provides higher fairness to the system by using the channel variations. This scheduler allocates the resource blocks to the cellular users with the best link quality by combining CQI & level of fairness.
- Priority Set: PSS is a scheduler that combines FD and TD. It targets to provide fairness to UEs by using a specified Target Bit Rate (TBR). PSS works by selecting UEs which Radio Link Control (RLC) buffer is not empty [5].

III. RELATED WORKS

The study of QoS analysis in terms of performance of LTE networks under different traffic conditions has received substantial interest of the researchers. In the paper [6] authors study the performance of a LTE network using under real time traffic with different channel conditions of the UE, using NS3 simulator for RR, PF, PSS, CQA schedulers. PF and PSS have comparable results. CQA scheduler is more suitable for real-time application compared to RR where delay of packets and fairness of resource allocation is an issue for RR. The authors in [7] analyse the QoS parameters under different real time traffic when PF, MLWDF and EXP/PF schedulers are used and number of users is increased. M-LWDF Scheduling algorithm is the most suitable for all the flows while the EXP/PF algorithm didn't show a big capacity to avoid congestion for VoIP flows and for the PF algorithm and due to it high delay, big packet loss ratio and low throughput, it's didn't show high performances[4]. The effects of QoS scheduling strategies on service performance in a traffic mix consisting of VoIP, streaming video, and Session Initiation Protocol (SIP) were studied in [8]. In [9], the authors presented a QoS-aware scheduling approach with an adaptive VolP priority mode which aims at decreasing the negative impact of VolP packets prioritization on the overall system throughput. Mixed traffic scheduling has also been studied for earlier UMTS networks, e.g., for HSDPA [10], [11]

IV. SIMULATION

For the simulation it is used Vienna LTE System Level Simulator, an open source MATLAB as an efficient 4G LTE network simulator to analyze the performance and ensure reliable communication. In the simulator's launcher file in MATLAB are configured the parameters according to the network to be produced. First simulation scenario consists on the evaluation of the network performance under different traffic types under a simulation time of length 100 TTIs (Transmission Time Intervals). The evaluation is made in terms of throughput and delay. In the second simulation scenario the number of users is varied starting from 15 to 90 users per cell in a three-sector tilted antenna, for various traffic models, under different scheduling schemes.

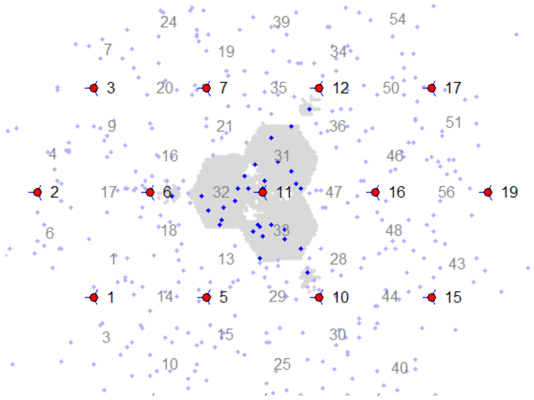


Fig. 1 MATLAB LTE Simulation Scenario

The evaluation of network performance is made by plotting average cell/user throughput, delay and fairness of schedulers. These indicators can help in designing, optimizing and deploying in an optimal way the network. In the Figure 2 is given a visual view of the LTE network, consisting of eNodeB-s showed by red marks, and UEs covered by each of them given in blue marks. The analysis is made using Vienna LTE simulator with MATLAB.

A. *First Scenario: Traffic Models Analysis for real time and non-real time traffic*

In this section the effect of different traffic models on the network, is analysed. The study of traffic models not only helps us to understand network behaviour for particular traffic but also help in optimization and plan the network for the bandwidth and other requirements so that the users can enjoy the better quality of service, at different times of the day when the load on the network is varied. Using this data network is planned and deployed.

The network is configured with the above-mentioned parameters and the number of users in a cell is taken fixed, 60 users per cell or 20 users per sector. The performance of network is evaluated, in terms of throughput and delay for a simulation time of 100TTIs. The network under consideration has the following properties, showed in Table 1.

Table 1. Network parameters of first scenario

Parameters	***Value***
System Bandwidth	20 MHz
System Frequency	2.14 GHz
Number of Users	15, 30, 45,60, 75, 90
Scheduling Algorithm	Proportional Fair
Channel Model	3GPP TU
Pathloss Model	TS36942 – Urban
Simulation Time (TTIs)	100 TTIs
UE average speed	10m/s
Antenna Azimuth Offset	60°
Antenna Gain	20dBi
BS transmitter power	40dBm
Average UE to eNodeB distance	1000m
BS/Receiver height	30m/2m
Traffic Model	FTP, HTTP, Video, VoIP, Gamming, Mix

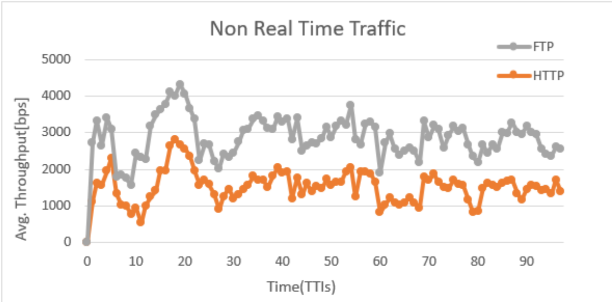


Fig.3 Average user throughput for Non-Real Time Traffic

As expected, the Figure 3 shows that FTP that is commonly used for transferring internet pages from server to another server or downloading many files from the server to the user computer, requires more throughput than HTTP used for browsing. Meaning that when comparing these two traffic models, FTP requires, more resources from the network, in order to satisfy the user experience.

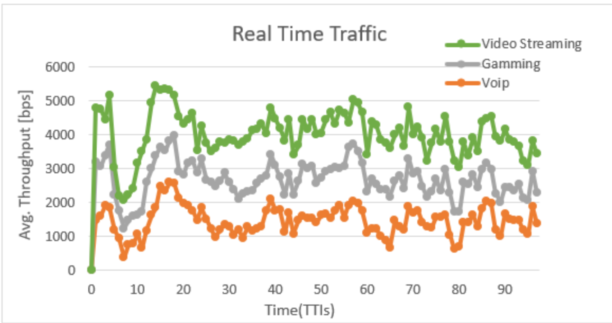


Fig.4 Average user throughput for Real Time Traffic

As shown in Figure 4, video traffic requires higher bandwidth compared to Gamming and VoIP. For quality video/audio streaming, the network must deliver high bandwidth, but with less stringent latency requirements than VoIP, as it will be shown in the above delay plots.

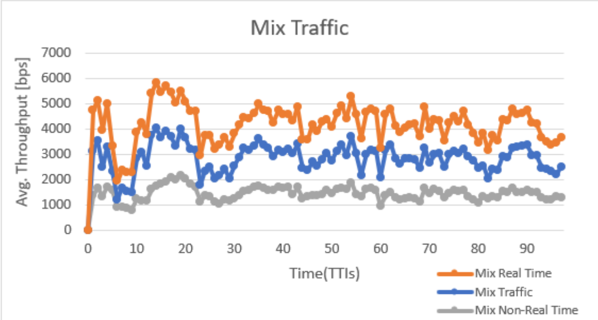


Fig.5 Average User Throughput for Mix Traffic Models

As expected, in Figure 5 can be seen that mix real time traffic requires higher throughput rates when compared to mix non-real time traffic. Non-real time traffic, unlike with real-time, however, these transfers are buffered and can, therefore, be handled at a more "leisurely" pace.

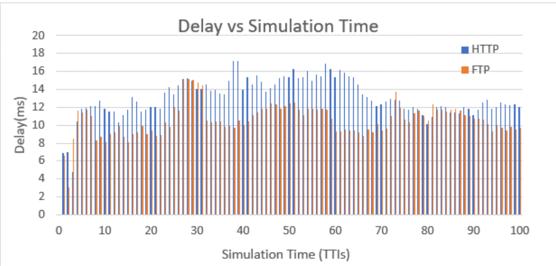


Fig. 2 Delay for Non-Real Time Traffic

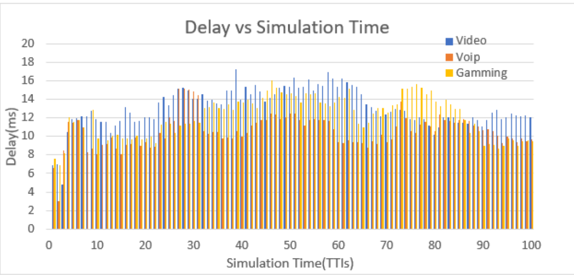


Fig.7. Delay for Real Time Traffic

From Figure 7, can be shown that VoIP traffic requires low delay levels in order to satisfy users requirements when compared to other real time generators such as video and gamming very approximately between

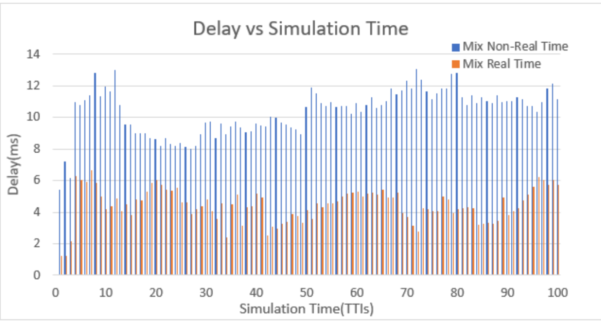


Fig. 3 Delay for Mixed Traffic Models

Unlike with real-time traffic, which uses the User Datagram Protocol (UDP), however, real time traffic transfers use the Transmission Control Protocol (TCP) to retransmit any and all dropped packets, meaning that we do expect higher latencies. Real time traffic models have less stringent latency requirements when compared to non-real time traffic, as shown in Figure 8.

B. *Second Scenario: Analysis of effect of scheduling algorithms*

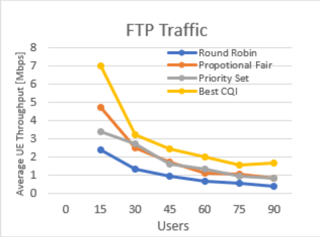
The Vienna LTE simulator has implementation of various scheduling schemes that allocate resources to the users requesting the service. The number of users is varied from 15 to 90 users with random distribution and the resulting fairness, delay, average user throughput and cell throughput are compared for each scheduling scheme starting from the Round Robin. To make a valid comparison between the channel aware and channel unaware scheduling algorithms, we consider users that are distributed in the region between the cell centre and the cell edge. The users are randomly distributed in the region of interest. The network under consideration has the following properties, showed in Table 2

Table 2. Network parameters of second scenario

Parameters	***Value***
System Bandwidth	20 MHz
System Frequency	2.14 GHz
Number of Users	15, 30, 45,60, 75, 90
Scheduling Algorithm	Proportional Fair, Round Robin, Best CQI, Priority Set
Channel Model	3GPP TU
Pathloss Model	TS36942 – Urban
Simulation Time (TTIs)	20 TTIs
UE average speed	5m/s
Antenna Azimuth Offset	60°
Antenna Gain	15dBi
BS transmitter power	40dBm
Average UE to eNodeB distance	500m
BS/Receiver height	20m/1.5m
Traffic Model	FTP, HTTP, Video, VoIP, Gamming, Mix

Therefore, in this analysis we have taken into consideration, average user and cell throughput, delay, and fairness that each scheduling scheme exposes under different traffic models.

B.1 Throughput



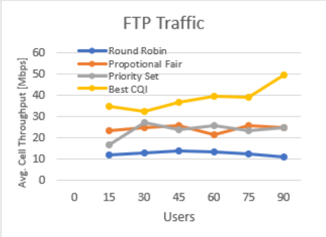
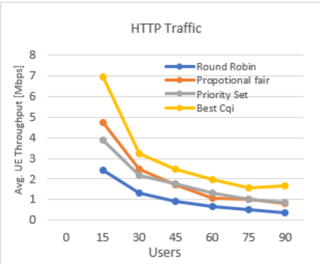


Fig. 9 Avg. UE Thrgh.Vs UE-s   Fig. 10 Avg. Cell Thrgh.Vs UE-s

When FTP traffic model is generated by the users, it can be seen in Figure 9 and Figure 10, that the user average throughput rate is better when Best CQI scheduling algorithm is used. Meanwhile the worst performance of the network is achieved when Round Robin algorithm is used. This is the result of RR allocating resources without considering the channel condition of the UE. UEs with poor channel condition are able to get resources but are unable to transmit resources efficiently on time. The UE taken into consideration may have worst channel condition because it may be on the edges of the cell.



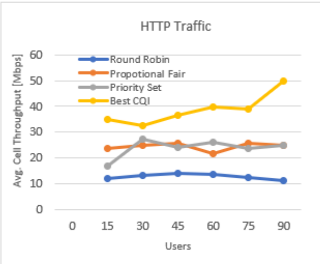
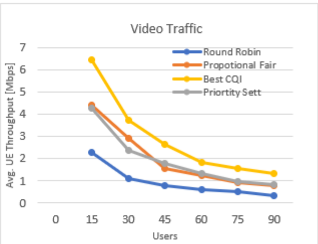


Fig. 11 Avg. UE Thrgh.vs UE-s   Fig. 12 Avg. Cell Thrgh.vs UE-s

As shown in Figure 11 and Figure 12, the video throughput for Best CQI scheduler is higher compared to the other schedulers. This is because Best CQI scheduler allocates RB while considering the GBR of 64kbps for the UE to transmit the video data.



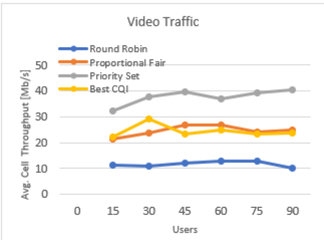
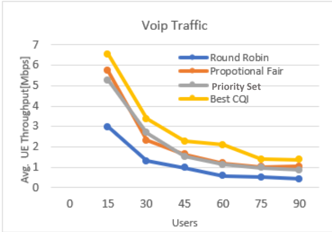


Fig.13 Avg. UE Thrgh.vs UE-s   Fig.14 Avg. Cell Thrgh.vs UE-s

From Figure 12 and Figure 13, we can see that under Video Traffic models, the scheduling algorithms that performs better is Best CQI, followed by Propotional Fair.



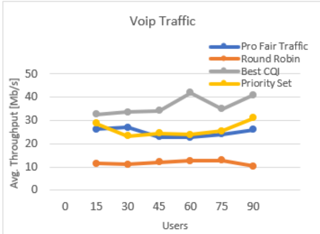
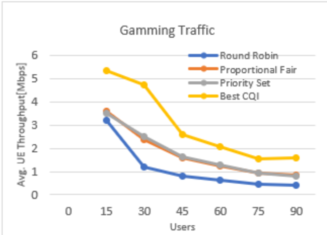


Fig. 15 Avg. UE Thrgh. vs UE-s   Fig.16 Avg. Cell Thrgh. Vs UE-s



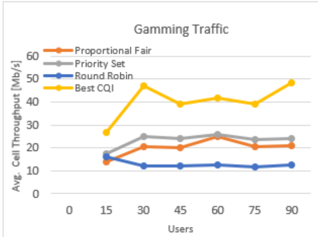
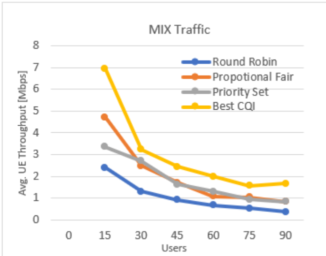


Fig.17 Avg. UE Thrgh.vs UE-s   Fig.18 Avg. Cell Thrgh.vs UE-s



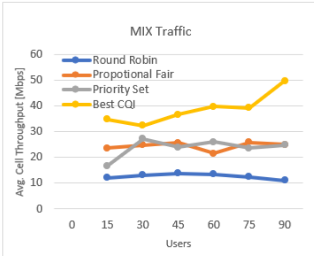


Fig.19 Avg. UE Thrgh. vs UE-s   Fig.20 Avg. Cell Thrgh. vs UE-s

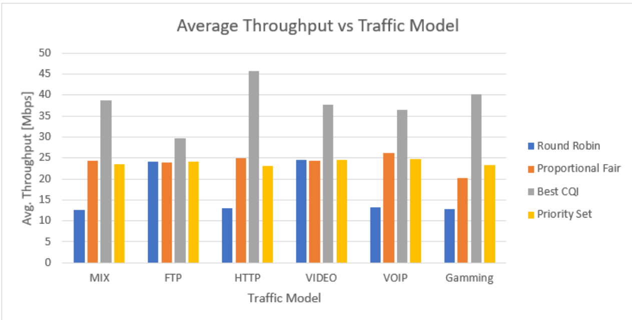


Fig.21 Average Throughput vs Traffic Model

Figure 21, gives a recap view of gained average throughput for scheduling schemes taken into consideration, under different traffic models.

For Round Robin the total cell throughput almost remains the same as the available resource blocks is equally divided between all the users and it increases with number of users for Best CQI and Proportional Fair. The graph indicates that Best CQI scheduling scheme has the ability to achieve the highest throughput in a network as this scheduling scheme is channel aware. Depending on the channel conditions, the resource blocks are allocated to the users.

The Proportional Fair and Priority Set scheduling schemes stands next in achieving best average throughput as this scheme is channel aware. But, due to its ability to be fair enough the average throughput achieved here is less when compared to Best CQI. The Round Robin has the least average throughput as this is channel unaware and allocates the resource blocks to all users requesting service in order.

B.2 Delay

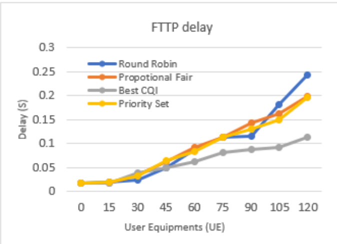


Fig.22 FTTP Delay vs UE-s

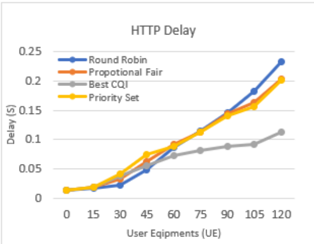


Fig.23 HTTP Delay vs UE-s

When FTP traffic model is generated by the users, it can be seen in Figure 21, that the best performance is achieved when Best CQI scheduling algorithm is used. Meanwhile the worst case in this scenario is when Round Robin algorithm is used, especially when the UE-s number is increased. For HTTP traffic model the best algorithm that gives the lowest delay is also Best CQI. In this case Round Robin, Proportional Fair and Priority Set have almost the same delay, a change can be seen when UE-s number is increased above 95 UE-s.

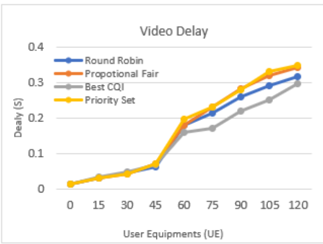


Fig.24 Video Delay vs UE-s

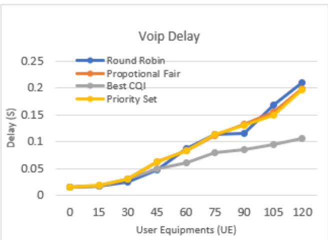
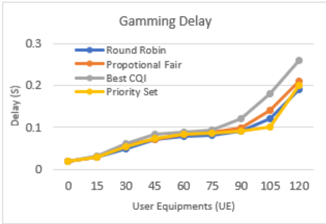


Fig.25 Voip Delay vs UE-s

From figure 23 we can see that the best performance for video Delay vs UE-s is when best CQI algorithm is used. The second-best algorithm in this case is Round Robin. Meanwhile proportional fair and priority set have almost the same performance. When VoIP is used the lowest delay is achieved for Best CQI algorithm. The three other algorithms have the same performance. This can be seen in figure 24.



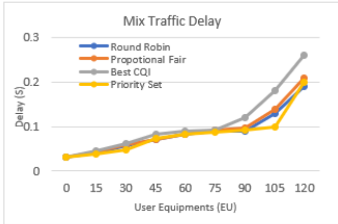


Fig.26 Gamming Delay vs UE-s Fig.27 Mix traffic Delay vs UE-s

In figure 25 the graph indicates that the best algorithm used in gamming for the lowest delay is Round Robin, but in this case all algorithms have almost the same results for 75 and less UE-s, when the number of UE-s is increased Round Robin has the best performance and Best CQI has the biggest delay.

B.3 Fairness

The fairness index is the measure of how each user is served in a network if they had requested for resource blocks.

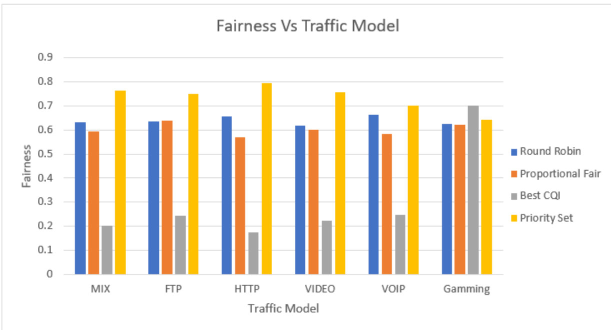


Fig.28 Fairness Vs Traffic Model

From Figure 27 we can see that the Priority Set scheduling scheme has the highest fairness index when compared to other scheduling schemes. We also observe that fairness index decreases in small fractions with increase in number of users. The Proportional Fair scheduling scheme stands next to Round Robin in being fair to allocate the resources to the users. The Best CQI scheduling scheme has the least fairness index among the three scheduling schemes because this scheduling scheme mainly depends on the channel conditions, thus even though a cell edge user has the data to send he is not allocated resources if the channel conditions are bad.

With this analysis of fairness and average user throughput between different scheduling schemes, we draw the conclusion of the best scheduling scheme for the network. If the networks requirement was to be fair with neglecting the average user throughput then Round Robin is the best scheduling scheme for that network. If the networks requirement was to achieve highest average user throughput over fairness then Best CQI scheduling scheme is the best choice for the network. Finally, if the network wanted to have optimal performance between fairness and throughput then the Proportional Fair scheduling scheme has ability to ensure both better fairness and throughput in the network.

V. Conclusions

In the current fast paced environment, with growing technology and population, the communication networks have grown in an unpredictable way. With this evolution of the networks there exists a need for efficient management of spectrum by analysing the existing network traffic. To satisfy all these needs in this project we demonstrate how 4G LTE has been able to mitigate most of the challenges. The study we made in this paper highlights the need of prior analysis of an LTE network under different traffic scenarios to help in designing, optimizing, and deploying in an optimal way the network. From first simulation we can conclude that, real time and non-real time traffic models have different QoS requirements. Real time traffic requires higher throughput rates when compared to non-real time traffic. Non-real time traffic, unlike with real-time, however, these transfers are buffered and can, therefore, be handled at a more "leisurely" pace.

In the second part of simulation is studied the effect that scheduling algorithms have in performance of the network when mix traffic is generated by users. With this analysis of fairness and average user throughput between different scheduling schemes, we draw the conclusion of the best scheduling scheme for the network. If the networks requirement was to be fair with neglecting the average user throughput then Round Robin is the best scheduling scheme for that network. If the networks requirement was to achieve highest average user throughput over fairness, then Best CQI scheduling scheme is the best choice for the network.

Finally, if the network wanted to have optimal performance between fairness and throughput then the Proportional Fair scheduling scheme has ability to ensure both better fairness and throughput in the network.

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