

Performance Analysis of Uplink Scheduling Algorithms in LTE Networks

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ABSTRACT

Scheduling is referring to the process of allocating resources to User Equipment based on scheduling algorithms that is located at the LTE base station. Various algorithms have been proposed as the execution of scheduling algorithm, which represents an open issue in Long Term Evolution (LTE) standard. This paper makes an attempt to study and compare the performance of three well-known uplink schedulers namely, Maximum Throughput (MT), First Maximum Expansion (FME), and Round Robin (RR). The evaluation is considered for a single cell with interference for three flows such as Best effort, Video and VoIP in a pedestrian environment using the LTE-SIM network simulator. The performance evaluation is conducted in terms of system throughput, fairness index, delay and packet loss ratio (PLR). The simulation results show that RR algorithm always reaches the lowest PLR, delivering highest throughput for video and VoIP flows among all those strategies. Thus, RR is the most suitable scheduling algorithm for VoIP and video flows while MT and FME is appropriate for BE flows in LTE networks.

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1. INTRODUCTION

The 3rd Generation Partnership Project (3GPP) has implemented the standardization of the Long Term Evolution (LTE), where the system is recommended to deliver peak data rates of 50 Mbit/s in uplink and 100 Mbit/s in downlink with a 20 MHz spectrum provision (1). Single carrier frequency division multiple access (SC-FDMA) has been chosen as the uplink access scheme while, orthogonal frequency division multiple access (OFDMA) is selected as the downlink access scheme for LTE (2)(3). SC-FDMA offers lower peak-to-average power ratio (PAPR) as compared to OFDMA, thus, making SC-FDMA more suitable for uplink transmission, as the User Equipment (UE) has the advantage of transmitted power efficiency along with increased data rates, in order to improve the battery life of the UE (4)(5). SC-FDMA system ensures to deliver higher throughput, lower PAPR, higher spectral efficiency, and lower bit error rate than the conventional OFDMA technique (6). In spite of the advantages of SC-FDMA, it requires that all subcarriers allocated to a single UE must be adjacent to each other on the frequency domain (4).

The Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) are two duplexing schemes used in the LTE uplink transmission. In FDD, different frequency bands are utilized for the uplink transmission, while in TDD the uplink share the same frequency band but are separated in time. The network architecture for LTE consists of Evolved Node B (eNodeB), Evolved Packet System (EPS) and the UEs. The LTE transmission is divided into frames, which consist of 10 subframes. A subframe duration is 1 ms in length. Each subframe is divided into two slots where each slot is 0.5 ms in length. A subframe is also known as the Transmission Time Interval (TTI). The physical layer interface is a transport block with common

Modulation and Coding Scheme (MCS). Each TTI contains at most one transport block per UE (7). Each slot present in frequency domain is divided into a number of resource blocks. The structure of a time slot in frequency domain is divided into regions of 180 kHz that contain a contiguous set of 12 subcarriers. Hence the total number of uplink physical resource blocks (PRBs) ranges between 6 PRBs for the smallest (1.4 MHz) and 100 PRBs for the largest bandwidth (20MHz) respectively.

In OFDM-based multi-user framework, schedulers plays an important role in optimizing the network performance and provide Quality of Service (QoS) requirements in the Medium Access Control (MAC) layer. The MAC scheduler in the eNodeB is deployed in the uplink and downlink transmission, are mainly responsible for allocating resource block (RBs) among UEs to support the diverse QoS requirements. The task of the scheduler depends on the specific algorithm used and the Channel Quality Indicator (CQI), which provides feedback from UEs on whether the channel condition is good or poor, and allocate RBs accordingly (8) (9). The contiguity constraint is one of the major constraints in the uplink scheduling. This constraint refers to having all PRBs, allocated to a single UE to be adjacent along the frequency domain. The contiguity constraint can reduce the spectral efficiency of the uplink transmission, since UE being allocated a PRB despite the existence of other UEs with better channel quality over the same PRB (10). Channel aware scheduling algorithms is recognize by developing the multi-user diversity gain by assigning the resources among several users depending on their channel conditions. In this paper, the performance of three well-known uplink schedulers is evaluated namely, Maximum Throughput (MT), First Maximum Expansion (FME), and Round Robin (RR).

1.1 Maximum Throughput (MT) Scheduler

The MT is used to maximize the overall throughput by continually assigning each RB to UE that is capable of maximizing the overall throughput in the current TTI interval. In MT scheduler, UE with the highest value of CQI will be served first with the required RBs. Thus, UEs with poor CQI values (such as cell-edge users) are not assigned with sufficient resources. Such UEs will suffer from low throughput, and even starvation may occur (11). The metric calculation of MT is expressed as:

$$m_{i,k}^{MT} = d_k^i(t) \quad (1)$$

where, $m_{i,k}^{MT}$ presents the metric of the i -th user on the k -th RB and $d_k^i(t)$ is the expected data-rate for the i -th user at time t on the k -th RB.

1.2 First Maximum Expansion (FME) Scheduler

The FME scheduler focuses on maximizing the performance of throughput and fairness. The main principle in FME is to assign RB resources starting from the RB with the highest metric in matrix M , and expand on it in both directions of the RB as shown in Figure 1, as long as the channel maintains its best condition among other users. As the algorithm traverse through each RB, it checks its maximum metric and determines whether the maximum metric still belongs to the UE in which resources are currently being assigned, or whether the maximum metric belongs to another UE. If the conditions are fulfilled, the RB is assigned to the selected UE; otherwise, the UE is considered served, and the current selected RB is assigned to a new UE. The scheduler then reiterates the expansion procedure. Assigning the RB to the other UE would break the continuity constraints.

UEs	RB_1	RB_2	...	$RB_{N_{RB}}$
UE_1	$M_{1,1}$	$M_{1,2}$...	$M_{1,N_{RB}}$
UE_2	$M_{2,1}$	$M_{2,2}$...	$M_{2,N_{RB}}$
⋮
UE_N	$M_{N,1}$	$M_{N,2}$...	$M_{N,N_{RB}}$

Figure 1. The UEs channel quality for each RB (12)

1.3 Round Robin (RR) Scheduler

RR scheduler is channel unaware, simple and easy to implement scheduling scheme. In this scheduling strategy, the UEs are allocated with equal number of RBs. The scheduling is only based on the

available RBs, and the RB is grouped into number of RBs for each UE during the scheduling process. The UE is served based on the first come first served strategy. RR may cause reduction in the efficiency of the system since every UE does not have the same QoS requirements and experienced different channel condition.

Several LTE uplink scheduling schemes have been discussed by many researchers. The performance evaluation of the scheduling schemes have been discussed in (13)(14)(15), where these papers focused on maximizing the basic objectives such as throughput and fairness. Therefore, the proposed scheme did not consider the QoS provisioning. The papers of (4)(16)(17)(11) focused on multiple traffic such as video, VoIP and best effort (BE) in the uplink transmission and took the QoS into the consideration. The paper of (16) has evaluated different LTE uplink schedulers with focus on single-bearer and multi-bearer scenario and QoS. The paper of (17) provided a very comprehensive study on LTE and LTE-Advanced. The aim of the study is to compare and evaluate several uplink schedulers for different traffic scenarios such as video streaming, VoIP and FTP within a single-cell environments. Finally, the paper of (11) evaluated the scheduling performance of the uplink schedulers, which focused on throughput and fairness. Nevertheless, other performance metrics such as delay and packet loss ration are not taken into consideration. Very few papers have focused on the investigation of multiple traffics in the pedestrian environment. In this paper, we aim to evaluate the performance of several scheduling algorithms for VoIP, video and BE applications. The performance evaluation is conducted in terms of throughput, fairness, delay and PLR in a pedestrian environment. The simulation results were generated using the open source LTE system simulator called Long Term Evolution-Simulator (LTE-SIM) (7).

2. RESEARCH METHOD

In this paper, video and VoIP flows are used for real time services while infinite-buffer as known as Best effort (BE) flows represented the non-real time. VoIP flows have much stricter delay requirement than that of video and BE flows. Packets transported by a dedicated radio bearer are generated at the application layer by three different traffic generators; trace-based, VoIP and infinite-buffer. The trace-based application delivers packets based on video trace files, which are obtained from (7). The voice flows of G.729 are generating VoIP application. An ON/OFF Markov chain is modeled for the voice flow, where the mean value of 3 s is distributed exponentially with the ON period and the OFF period has a truncated exponential probability distribution function with an average value of 3 s and an upper limit of 6.9 s (18). The source delivers 20 bytes sized packets every 20 ms during the ON period, as the standard source data rate is 8 kbps, while the data rate is zero during the OFF period because of the Voice Activity Detector. Finally, the Infinite-Buffer application model demonstrates a greedy source that constantly possesses packets to be delivered (7).

The performance of MT, FME and RR algorithms is evaluated based on throughput, fairness index, packet delay and PLR. The Fairness index is calculated using Jain’s fairness index method (19) and it is expressed as:

$$FI = \frac{(\sum_1^N x_i)^2}{N \sum_1^N x_i^2} \tag{2}$$

where x_i is the throughput assigned to user i among N competing flows

The performance metric of throughput (in Mbps) represents the rate of successful packet being delivered over physical channel. The parameter is calculated by dividing the number of successfully received bits with the duration of the flow and can be mathematically expressed as:

$$\text{Throughput} = \frac{1}{T} \sum_{i=1}^K \sum_{t=1}^T p_{\text{transmit}_i}(t) \tag{3}$$

where $p_{\text{transmit}_i}(t)$ is the size of transmitted packets of user i at time t , K is the total number of users and T is the total simulation time. A single cell of 1 km of radius with eNodeB located at the center of the cell is modeled. The number of UE is varied from 10 to 50. Each UE is handling three flows which are VoIP, video and BE as shown in Figure 2. The movement of UE in the cell is adopting the random direction model. The speed is set to 3 km/h, which resembles the pedestrian scenario. The simulation parameters used in LTE-SIM are summarized in Table 1.

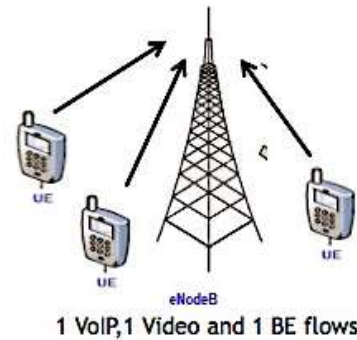


Figure 2. LTE simulated scenario

Table 1. LTE Uplink Simulation Parameters

Parameter	Value
Simulation Duration	40 seconds
Transmission Power	43 dBm
Cell radius	1 km
Channel Model	Macro-cell Urban
Macro cell Propagation Model	$L = 128:1 + 37:6 \log_{10} d @ 2\text{GHz. (20)}$
Number of Users	10,20,30,40,50 Users
Traffic flows	1 BE, 1 VoIP, 1 Video
Mobility Model	Random Direction
Transport Protocol	UDP
System Bandwidth	10 MHz
Frequency Carrier	1.92 GHz
Number of RBs	50
RB Bandwidth	180 KHz
Transmission Time Interval	1 ms (TTI)
Maximum Delay	0.1 s
Speed	3 km/hr
VoIP Bit Rate	8 kbps
VIDEO Bit Rate	128 kbps

3. RESULTS AND DISCUSSIONS

Figure 3 shows the average throughput for BE flows' as the number of user increases. The throughput for RR algorithm decreases as the number of UE increases, while the throughput performance of FME and MT algorithms is kept between 20 Mbps to 40 Mbps. The RR algorithm delivers the lowest throughput since the RR prioritized the real-time flows over BE flow. The throughput of video and VoIP flows are shown in Figure 4 and Figure 5 respectively. It is observed that the throughput of video and VoIP for RR algorithm increases as the number of users increases. MT and FME algorithms gives unsatisfied service to multimedia flows leaving a high quota for BE flow. Moreover, MT and FME tried to maximize throughputs for BE flow and leaving few of RBs to VoIP and video flows that lead to lower values of throughputs for those flows as compared to the RR.

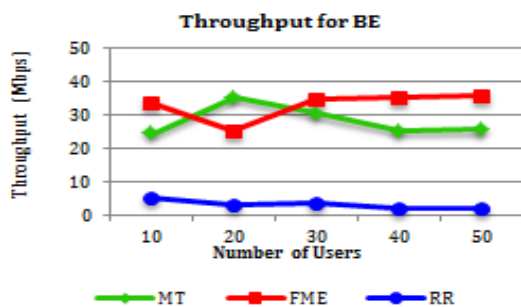


Figure 3. Throughput for BE Flows

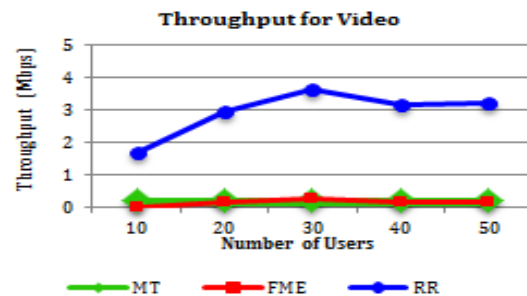


Figure 4. Throughput for Video Flows

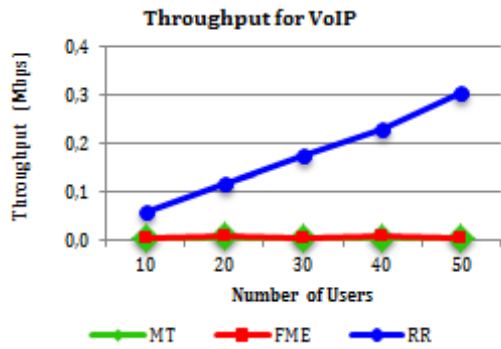


Figure 5. Throughput for VoIP Flows

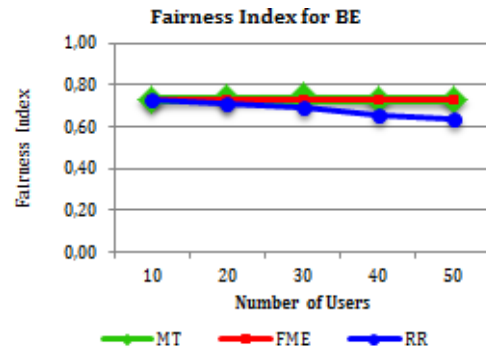


Figure 6. Fairness Index for BE Flows

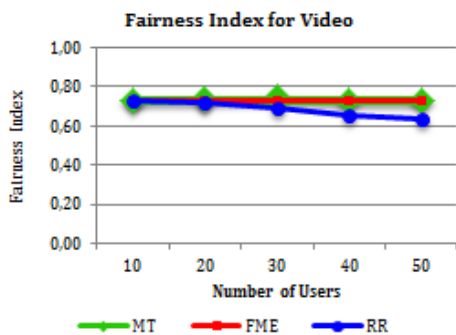


Figure 7. Fairness Index for Video Flows

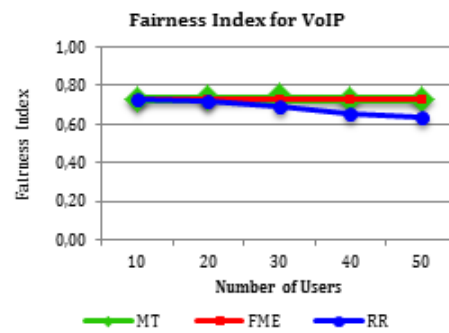


Figure 8. Fairness Index for VoIP Flows

The Jain fairness index for BE, video and VoIP flows are presented in Figure 6, 7, and 8 respectively. From the figures, it is shown that MT and FME algorithms are having similar values of fairness index for all the traffic flows. The fairness index for MT and FME algorithms maintains as the number of users increases. On the other hand, the fairness index for RR algorithm starts to reduce when the number of users increases which is showing the right trend as the RR algorithm is delivering higher throughput for video and VoIP flows. It can be concluded that MT and FME algorithms are fairer than the RR algorithm.

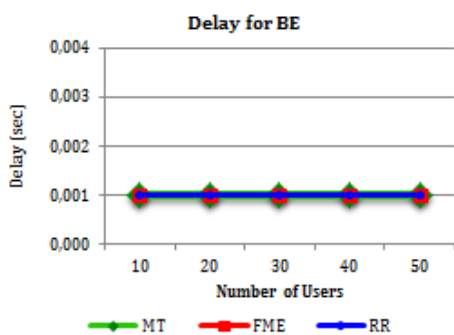


Figure 9. Delay for BE Flows

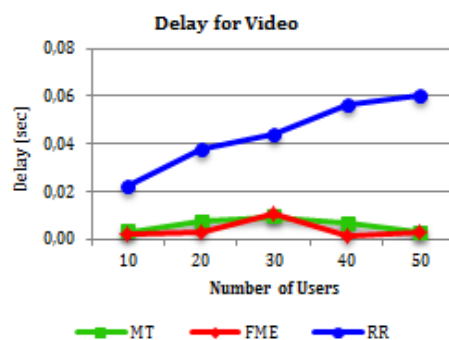


Figure 10. Delay for Video Flows

The delay experienced for BE flow is presented in Figure 9. The delay will always be a constant value of 0.001 seconds for the best effort flows because it is modeled using the infinite buffer model, for all scheduling strategies. Figure 10 shows the delay experienced by video flows. The FME algorithm delivers the lowest delay. The MT and FME algorithms show a stable delay while the RR algorithm is having the highest delay, which in accordance to the throughput being delivered. Accordingly, there is a tradeoff between throughput and delay; when throughput is maximized, the delay will increase. The delay experienced by VoIP is illustrated in Figure 11, which is significantly less than the delay experienced by

video flows. This is mostly due to the packets corresponding with voice traffic must be given very high priority and allocated to a guaranteed bandwidth channel to make sure that the packet sending is within an allowable delay limit. The RR algorithm reaches the lowest delay as compared to the MT and FME algorithm.

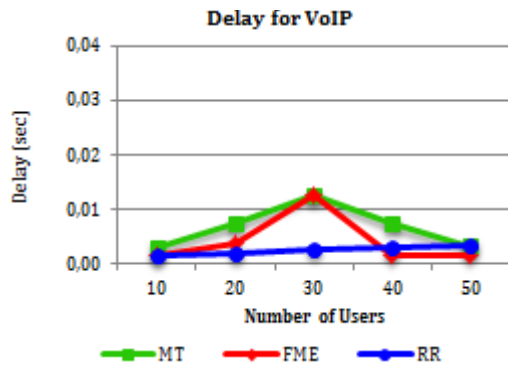


Figure 11. Delay for VoIP Flows

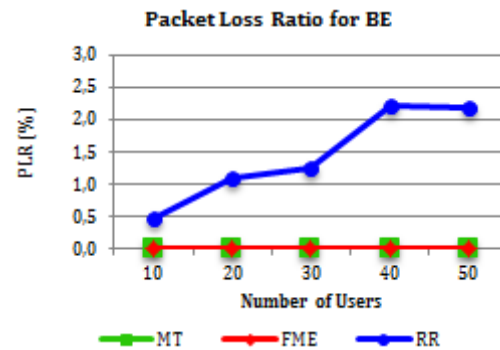


Figure 12. PLR for BE Flows

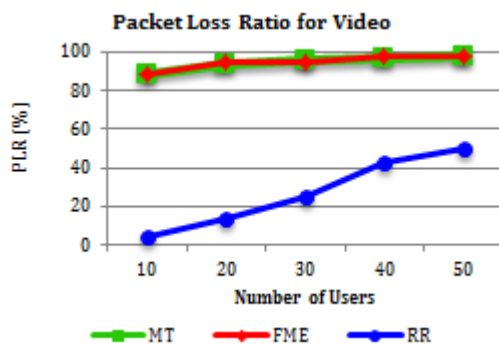


Figure 13. PLR for Video Flows

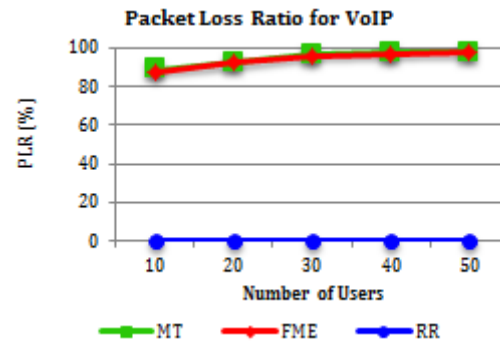


Figure 14. PLR for VoIP Flows

The packet loss ratios (PLR) experienced by all flows are demonstrated in Figure 12, 13, and 14. In the framework of QoS provisioning, PLR is a significant parameter of real time flows. PLR increases when the scheduler is unable to timely deliver the real time packets. It can be describe in Figure 13 and 14 that PLR increases with the number of users due to higher network load. The VoIP flows experienced significantly lower PLR than video flows of RR algorithm because the VoIP traffic is delivering lower source bit rate as compared to video flows as illustrated in 13 and 14. The PLR achieved for the real time (RT) flows have violated the QoS value for PLR. The acceptable range for VoIP and video flows should not exceed 1×10^{-2} to 1×10^{-3} respectively. RR algorithm has achieved the lowest PLR for video and VoIP by sacrificing the available resources for BE flows. Moreover, lower value of the target delay indicates higher value of PLR due to a larger quota of packets violating the deadline, which is adhered for the video flows.

4. CONCLUSION

This paper has studied the performance of three different scheduling algorithms for real-time and best effort services using the LTE-SIM. The study compares the performance of three scheduling algorithms, namely the MT, FME and RR for the performance metrics of throughput, packet delay, PLR, and fairness. The best effort, video and VoIP traffic are delivered by each UE in the pedestrian environments that is moving at 3 km/h. For RT Traffic, MT and FME have the highest packet loss ratio value and the lowest throughput. Therefore, these algorithms may be a good solution for non-real-time flows but is unsuitable to handle the RT multimedia services. RR algorithm reaches the lowest PLR among all those strategies and is the most suitable for VoIP flows and video flows. This study shows the importance of a good scheduling strategy in a network base station. Future work will focus on the development of new algorithm, taking care

of different level of fairness among users as well as quality of services policies that is suitable for real time and non real time traffic.

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