Performance Analysis of Uplink Scheduling Algorithms in the Urban and Rural Environments in LTE

Shafinaz Bt Ismail, Darmawaty Bt Mohd Ali, Norsuzila Ya'acob

***Abstract* - Long Term Evolution (LTE) is the evolution of an existing 3G mobile network towards a higher capacity, a lower latency and a more efficient core network and radio access. LTE was chosen in order to deliver higher data rate and application demands with trustworthy and reliable connections. This paper makes an attempt to study and compare the performance of two well-known uplink schedulers namely, First Maximum Expansion (FME), and Round Robin (RR). The evaluation is considered for a single cell with three flows, which are the Best Effort, video, and VoIP in an urban and rural environment using the LTE-SIM network simulator. The comparative study 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 among those strategies and RR is the most suitable scheduling algorithms for VoIP and video flows while FME is better for BE flows in both urban and rural environment in LTE networks.**

***Index Terms* — LTE, Scheduling algorithms, Uplink, Urban, Rural.**

I. INTRODUCTION

LTE is an evolutionary phase beyond the 3G in mobile wireless communication. LTE has ambitious requirements for better higher data rate, capacity, spectrum efficiency, improved coverage, better battery lifetime and low latency. In order to meet these requirements, OFDMA (Orthogonal Frequency Division Multiple Access) in downlink and SC-FDMA (Single Carrier Frequency Division Multiple Access) in the uplink is the multiple access scheme that is used in the LTE system.

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OFDMA properties are less favorable for the uplink due to higher peak-to-average power ratio (PAPR) properties of an OFDMA signal, resulting in worse uplink coverage, thus, the LTE uplink transmission scheme is based on SC-FDMA where the signals of SC-FDMA have better PAPR properties compared to the OFDMA signal [1].

The PAPR characteristics are important for the cost-effective design of the User Equipment (UE) power amplifiers. Despite the advantage of SC-FDMA, that is providing lower PAPR effect, SC-FDMA requires that all subcarriers assigned to a single UE must be adjacent to each other in the frequency domain [2]. The contiguity constraint is one of the major concerns in the uplink scheduling as it dramatically reduces the freedom in resource allocation, especially when compared to the OFDMA, where such constraint is generally not required.

The most important objective of LTE scheduling is to satisfy the Quality of Service (QoS) requirements. LTE's QoS framework is designed to provide an end-to-end QoS support. The main challenge of the scheduler in the uplink transmission is to find the optimal balance such as average throughput, fairness among active UEs, and QoS satisfaction.

Several LTE uplink-scheduling schemes have been proposed by many network researchers [1-8]. The performance evaluation of the scheduling schemes have been discussed in [3][4][5], where these papers focused on maximizing the basic objectives such as throughput and fairness in an urban environment. Meanwhile, the paper in [3][4] simulated a single-cell environment assuming no inter-cell interference. The paper in [2] focused on multiple traffic such as video, VoIP, and Best Effort

(BE) in the uplink transmission in an urban environment. The paper in [6] evaluated the performance of the uplink schedulers and focused on the throughput and fairness. However, other performance metrics are not taken into consideration in order to maximize the systems' performance. The paper in [7] provides a comprehensive study focusing on LTE and LTE-Advanced. The aim of the study is to compare and evaluate several uplink schedulers within different traffic scenarios in an urban environment. The paper in [8] evaluated the performance of multiple traffic in a rural and urban environment focusing on the downlink schedulers. Very few papers have focused on the investigation of multiple traffics in the pedestrian environment and none of the papers have focused on the uplink transmission in urban and rural environments. In this paper, we investigated the performance of two channel-aware scheduling algorithm namely the Round Robin (RR) and First Maximum Expansion (FME) algorithms. The performance evaluation is conducted in terms of throughput, fairness, delay and PLR for different traffic flows such as VoIP, video and BE applications in two scenarios; urban and rural environment. Different environment thus contributed to the different traits of propagation loss and subsequently affect the performance of the scheduling algorithm. The scheduling algorithms have to consider the propagation loss in order to provide fair transmission opportunities. The simulation results were generated using the open source LTE system simulator called Long Term Evolution-SIM (LTE-SIM) [9].

The rest of the paper is organized as follows. Section II outlines the characteristics of the overall system architecture and describes on the LTE-SIM network simulator. Section III introduces the background, motivation and basic principles of the scheduling algorithm in LTE. Section IV discusses the simulation parameters and describes the performance evaluation scenario for different flows for different scheduling schemes in LTE. Section V discusses the simulation results. Section VI elaborates on future works and finally, Section VII concludes the paper.

II. SYSTEM ARCHITECTURE FOR UPLINK.

In the uplink transmission, Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) are two duplexing techniques used in LTE. In FDD, different frequency bands are utilized for the uplink transmissions, while in TDD the uplink shares the same frequency bands but are separated in time [10]. 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 that consist of 10 subframes. A subframe duration is 1 ms in length and each subframe is also 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, or a group of RBs, with common Modulation and Coding Scheme (MCS). Each TTI contains at most one transport block per UE [9]. In the frequency domain, each slot is divided into a number of resource blocks. The frequency domain structure of a time slot 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 in the smallest uplink bandwidth (1.4 MHz) and 100 PRBs in the largest uplink bandwidth (20 MHz) [11]. The MAC schedulers in the eNodeB, are mainly responsible for allocating RBs among UEs to support the diverse QoS requirements.

Scheduler plays an important role in optimizing the network performance in the Medium Access Control (MAC) layer. The MAC schedulers in the eNodeB, are mainly responsible for allocating RBs among UEs to support the diverse QoS requirements [9]. The schedulers depend 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 allocates RBs accordingly [12]. The uplink scheduler is responsible for RBs allocation in the uplink direction, while the downlink scheduler for the downlink direction.

The LTE-SIM simulator models different uplink and downlink scheduling strategies in multiuser environments, it takes into account user mobility, radio resource optimization, frequency reuse techniques, the adaptive modulation, and coding (AMC) module. It also includes other aspects that are relevant to the industrial and scientific communities, types of mobility models were developed, known as random direction [9]. The propagation loss corresponds to the path loss model and environments respectively.

III. LTE UPLINK SCHEDULERS

The main challenge of the scheduler in the uplink transmission is to find optimal balance between fairness and QoS satisfaction among the active UEs. These performance metrics are the most common target in the schedulers' optimization process. Scheduling and resource allocation are two main factors that have gained great importance when delivering the multimedia applications because these applications require more radio resources and consume high data rate in order to provide better QoS.

In this paper, the performance of the, First Maximum Expansion (FME) (channel aware) and Round Robin (RR) (channel unaware) scheduling algorithms are evaluated in terms of throughput, fairness, delay and Packet Loss Ratio (PLR) .

1) 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 fig 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	$\cdots$	$RB_{N_{RB}}$
UE_1	$M_{1,1}$	$M_{1,2}$	$\cdots$	$M_{1,N_{RB}}$
UE_2	$M_{2,1}$	$M_{2,2}$	$\cdots$	$M_{2,N_{RB}}$
$\vdots$	$\ldots$			$\ldots$
UE_N	$M_{N,1}$	$M_{N,2}$	$\cdots$	$M_{N,N_{RB}}$

Fig1: The UEs channel quality for each RB [3]

2) 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 the equal number of RBs. Thus, every UE gets its' fair share. The scheduling is only based on the available RBs, and the RB is grouped into a 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 a reduction in the efficiency of the system since every UE does not have the same QoS requirement and experienced different channel condition.

IV. SIMULATION PARAMETERS

In this paper, video and VoIP flows are the real-time services while infinite-buffer which is known as Best Effort (BE) flow represent the non-real time service in rural and urban environments. The simulation model consists of a single cell with 1 km of radius and the eNodeB is located at the center of the cell, where the number of UEs is varied in the range of 10 to 100. The UEs are uniformly distributed in each cell. The UEs travel following the random direction mobility model and are uniformly distributed within the cell. The speed of the UE is set to 3 km/h, which resembles the pedestrian movement. The whole bandwidth is distributed among a cluster of 4 cells, to guarantee a 10 MHz of bandwidth in the uplink transmission, for each cell. Each user receives one H.264 video flow, one G.729 voice flows and one BE flow.

The propagation loss has been implemented in this study and two different environments of macro-cell urban and rural are taken into consideration. The simulations consider four different phenomena including the path loss, penetration loss which is being set to 10 dB, shadowing fading, which is modeled using the log-normal distribution with 0 dB mean and 8 dB standard deviation and the effect of fast fading due to the signal multipath. The fast fading channel Jakes model is used in both propagation models.

Macro-cell urban and rural environments have different path loss equation [9], [13]. The path loss model for urban and environment can be expressed as:

$$Urban\ area, L = 128.1 + 37.6log10(R) \qquad (1)$$
$$Rural\ area, L = 100.54 + 34.1log10(R) \qquad (2)$$

where R, is the distance between two nodes at 2 GHz in kilometer.

The performance of FME and RR algorithms is evaluated based on throughput, fairness index, delay and PLR. The Fairness index is calculated using the Jain's Fairness Index (FI) as in eq. (3):

$$FI = \frac{(\sum_1^N x_i)^2}{N\sum_1^N x_i^2} \qquad (3)$$

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 the successful packet being delivered over the physical channel. The parameter is calculated by dividing the number of successfully received bits to the duration of the flow and can be mathematically expressed as:

$$\text{Throughput} = \frac{1}{T}\sum_{i=1}^{K}\sum_{i=1}^{T} \text{ptransmit}_i(t) \qquad (4)$$

Where ptransmit_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.

The simulation parameters used in the LTE-SIM are summarized in Table 1.

Table 1: LTE Uplink Simulation Parameters

Parameter	Value
Simulation Duration	120 seconds
Transmission Power	43dBm
Cell radius	1 km
Macro-cell Urban Model	L = 128:1 + 37:6 log10 d
Macro-cell Rural Model	L = 100.54+34.1 log10 d
Number of Users	10 to 100 Users
Traffic flows	1 BE, 1 VoIP, 1 Video
Mobility Model	Random Direction
Channel Realization	Jakes Model
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	242 kbps

V. RESULTS AND DISCUSSIONS

This section presents the results of simulation. The performance metrics are investigated in terms of throughput, fairness index, delay and PLR for VoIP, video, and best effort flows.

The throughput of VoIP and video flows are shown in fig 2 and fig 3 respectively. In the case of VoIP, it is observed that the throughput for RR algorithm increases as the number of users increases. The performance of the RR schedulers as shown in fig 3 increases as the number of users increases and relatively much the same for both rural and urban areas. However, when the number of UEs exceeds 30 users, the throughput experienced by RR for both areas start to decrease. Fig 4 shows the average throughput for BE flows. FME algorithm has the highest throughput for both scenarios, while the RR algorithm starts to decrease as the number of users increases. It is observed that RR scheduler achieves the best throughput for VoIP and video flows in both rural and urban areas. In the case of best effort flow, FME is the best as it delivers higher throughput in both rural and urban areas. This is mainly because RR prioritized the real-time flows over BE flow and thus, delivers the lowest throughput for BE flow.

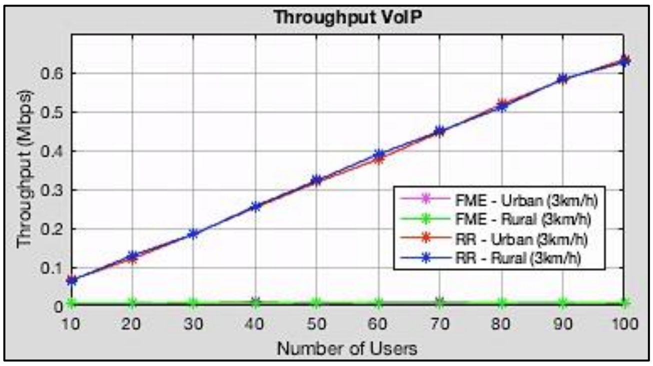

Fig 2: Throughput for VoIP Flows

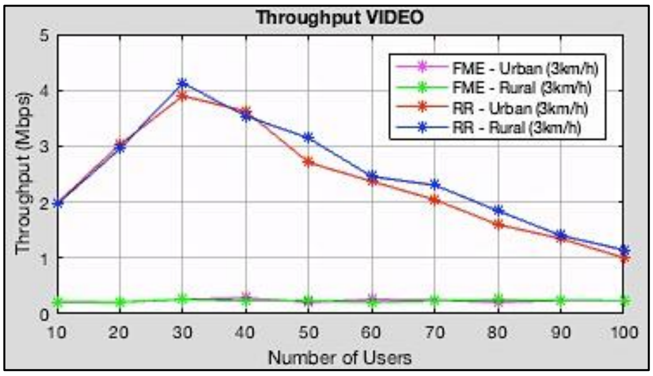

Fig 3: Throughput for Video Flows

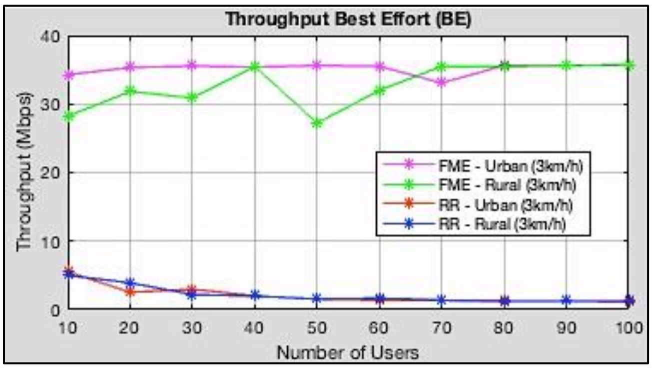

Fig 4: Throughput for BE Flows

The fairness index for VoIP, video and BE flows are presented in Fig 5 to 7 respectively. From the figures, it is shown that RR and FME algorithms are having similar values of fairness index for all the traffic flows. The fairness index for RR algorithm in both rural and urban area is maintained as the number of users increases. It is observed that the fairness index for FME in the urban area is higher than RR because RR algorithm delivers higher throughput for video and VoIP flows as shown in fig. 2 to 3.However, the fairness index of FME algorithms starts to reduce and lies between 0.5 to 1.0 in both rural and urban areas when the number of users increases.

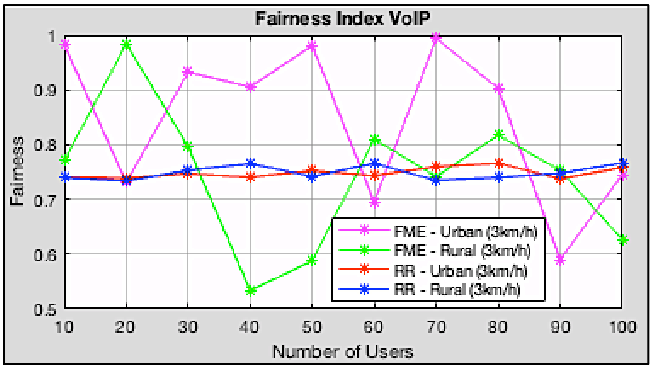

Fig 5: Fairness Index for VoIP Flows

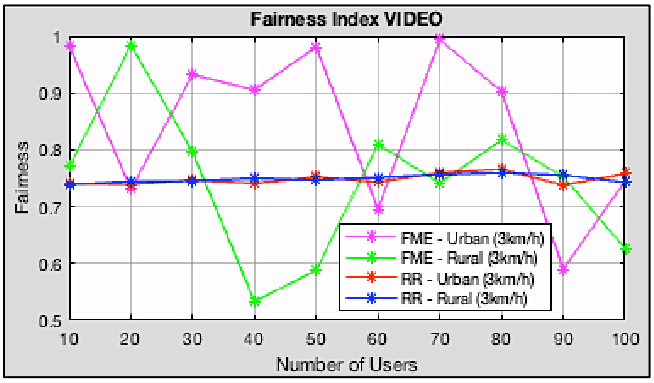

Fig 6: Fairness Index for Video Flows

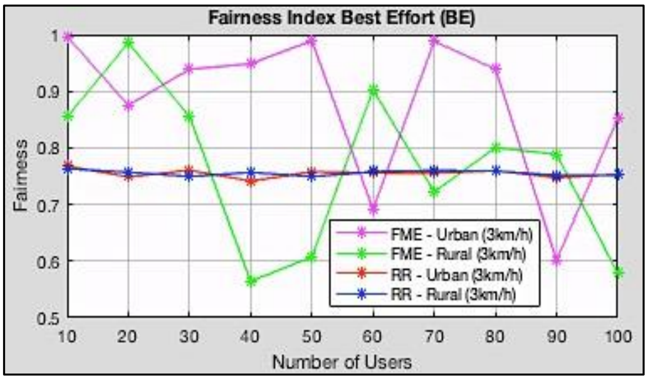

Fig 7: Fairness Index for BE Flows

In communication channel, delay is one of the most important metrics, especially when involving real-time multimedia services such as video and VoIP. VoIP flows have much stricter delay requirement than video and best effort flows. Users will demand services with less delay, and it is noticeable especially when the users are engaged on the service. The delay experienced by VoIP is illustrated in fig 8 for both rural and urban areas, which is significantly less than the delay experienced by video flows. This is mainly due to the packets associated with voice traffic must be given high priority and assigned to a guaranteed bandwidth channel in order to ensure that the packet delivery is within an acceptable delay limit. The delay for VoIP flows of RR in both rural and urban areas increases as the number of users increases. The FME algorithm has much higher delay in both rural and urban areas as compared to the RR algorithm. However, in the rural area, after exceeding 30 users, the delay raises up to 0.01 second. This is probably due to the heavy network load that causes the delay spreads in typical urban area with the mountainous landscape. Fig 9 shows the delay experienced by video flows. The FME algorithm shows a constant delay, and delivers the lowest delay while the RR algorithm is having the highest delay in both rural and urban areas and increases as the number of users increases. The delay experienced for BE flow is presented in Fig 10. The delay will always be a constant value of 0.001 seconds because it is modeled using the infinite buffer model, for all scheduling strategies in both rural and urban areas.

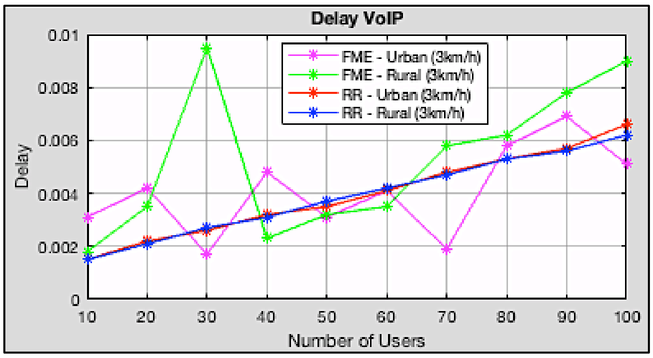

Fig 8: Delay for VoIP Flows

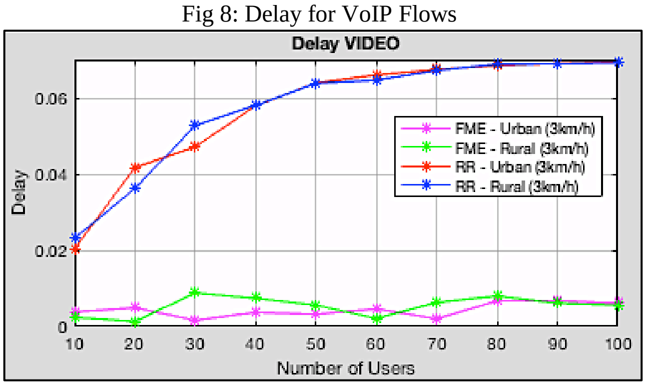

Fig 9: Delay for Video Flows

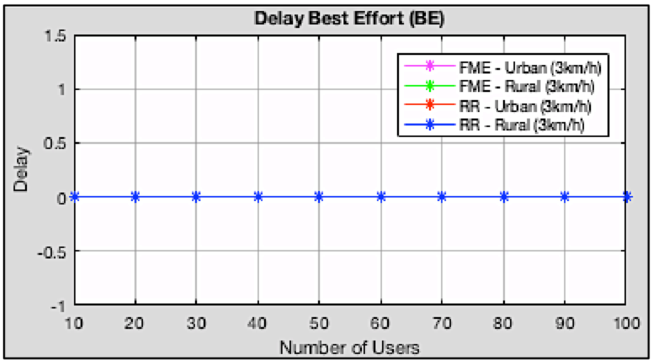

Fig 10: Delay for BE Flows

The PLR experienced by all flows are demonstrated in Fig 11 to 13. The PLR of VoIP flows for RR algorithm is significantly lower than the video flows and it is constant as the number of users increases as illustrated in fig 11. The main reason behind this is that VoIP is delivering low source bit rate as compared to video flows. In the case of video service, as in fig 12, the PLR of the RR algorithm increases as the number of users increases and relatively similar for both rural and urban areas. On the other hand, the FME algorithm has the highest PLR for both rural and urban areas. This is possibly because of the weak radio signal due to distance or multipath fading. RR algorithm has achieved the lowest PLR for video and VoIP by sacrificing the available resources for BE flows as illustrated in fig 13 in both rural and urban areas. Moreover, lower value of the target delay implies a higher value of PLR due to a larger quota of packets violating the deadline, which is observed for the video flows

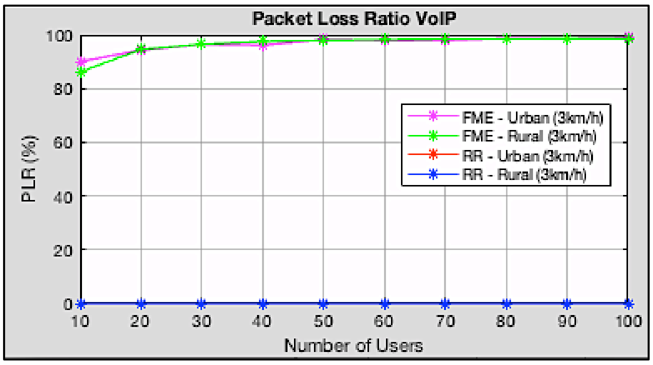

Fig 11: PLR for VoIP Flows

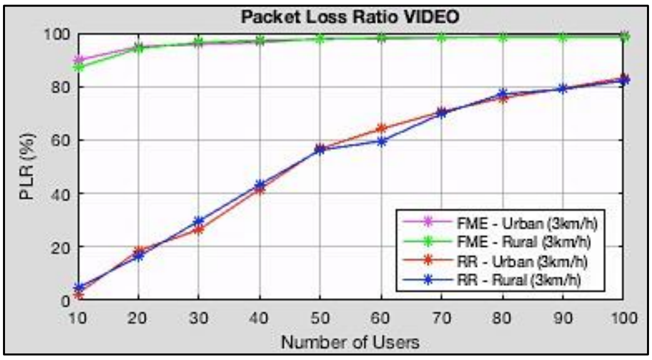

Fig 12: PLR for Video Flows

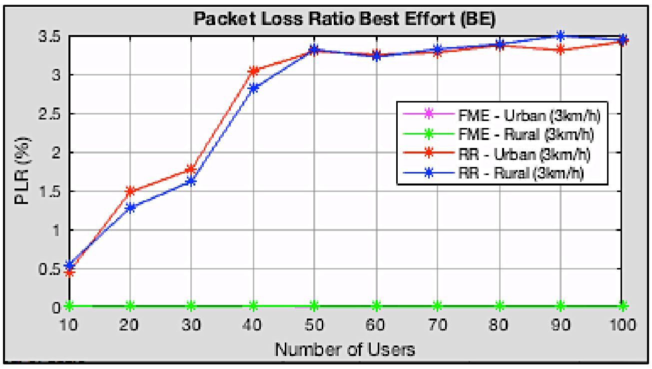

Fig 13: PLR for BE Flows

VI. FUTURE RECOMMENDATIONS

Nowadays, the RT and NRT services is becoming more crucial and requires special attention due to more traffic flows in the uplink transmission. The channel-aware scheduler is good in either maximizing system's throughput or achieving fairness. However, the drawback of this approach is users with low quality channel might suffer from the starvation problem. On the other hand, the PRB contiguity constraint must be taken into consideration especially in the uplink scheduling. This constraint is connected to the physical access transmission-multiplexing mode used in SC-FDMA. Thus, it limits the flexibility of the scheduling and therefore, adversely affects the multiuser frequency and diversity gain that can be derived from it. Furthermore, it can also contribute to high PAPR that leads to increase power consumption and UE will run out of power more quickly. Thus, the LTE uplink-scheduling algorithm must abide to the contiguity constraints and provision the QoS towards the realization of seamless end-to-end service delivery.

VII. CONCLUSION

This paper has investigated the performance of two scheduling algorithms and the effect of different path loss using the LTE-SIM simulator. The study compares the performance of 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 urban and rural environments, which is moving at 3 km/h. For RT Traffic, FME has the highest packet loss ratio value and the lowest throughput. Therefore, this algorithm 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 the LTE network for urban and rural areas. The environments of high buildings, thick forest, trees and mountains must be taken into consideration when selecting the schedulers. Future work will focus on the development of a new uplink scheduling algorithm that guarantees the QoS, satisfy the contiguity constraint, and suitable for the RT and NRT. This is to ensure that the users' quality of experience (QoE) for both urban and rural environments in the uplink transmission is provisioned.

VIII. ACKNOWLEDGEMENT

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