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PERFORMANCE ANALYSIS OF QUALITY OF SERVICE AND ENERGY EFFICIENT AWARE (QEEA) SCHEDULING ALGORITHM FOR LONG TERM EVOLUTION (LTE)

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Abstract

The growing demands for wireless communication services pose new challenges in the coming generation of cellular networks design. In Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) networks, ever-higher data rate and energy efficiency are required to meet the increasing demands in cellular traffic. This paper proposed an efficient algorithm, namely, the Quality of Service and Energy Efficient Aware (QEEA) to improve energy efficiency (EE) and also maximizing the throughput by using minimum power of 43 dBm (20 W) according to the 3GPP LTE specifications in order to achieve green communication. The QEEA algorithm is compared to the conventional scheduling algorithms, namely, the Channel and Quality of Service (QoS) Aware (CQA), Priority Set Scheduler (PSS), and Proportional Fair (PF) based on the performance metrics of throughput, delay, packet loss ratio (PLR), energy consumption rate (ECR), and EE for the voice over IP (VoIP), video and File Transfer Protocol (FTP) applications. The results show that the QEEA algorithm outperformed the other algorithms as it could achieve up to 18% of maximum throughput, 27% reduction in ECR and also 36% improvement in EE. Thus, it can be concluded that QEEA algorithm is the most energy efficient algorithm for VoIP, video and FTP applications.

Keywords: QEEA, Scheduling algorithm, LTE, Energy efficiency, Throughput.

1. Introduction

Mobile communication plays an important role in the current technology-driven world. The need for data and information has become a necessity, nowadays. With time, new mobile generations are being introduced and each of them have to fulfil

Nomenclatures

$d_{hol}^{j}(t)$	Head of line (HOL)
D	Data rate, bps
E	Energy, W
g	Grouping parameter
GBR^{j}	Target throughput, bps
j	Users
M	Application bits
$m_{fd}^{(k,j)}(t)$	Metric in frequency domain
mtd	Metric in time domain
P	Power, W
Ptx	Transmitter power, W
$\overline{R^{j}(t)}$	Past average throughput, bps
T	Time, s

Abbreviations

3GPP	Third Generation Partnership Project
BAT	Blind Average Throughput
BS	Base Stations
BEM	Bandwidth Expansion Mode
CQA	Channel and QoS Aware
eNodeB	Evolved Node B
EE	Energy Efficiency
ECR	Energy Consumption Rate
FD	Frequency Domain
FTP	File Transfer Protocol
GBR	Guaranteed Bit Rate
HOL	Head of Line
LTE	Long Term Evolution
LENA	LTE-EPC Network Simulator
MT	Maximum Throughput
MCS	Modulation and Coding Scheme
MAC	Medium Access Control
MMEs	Mobility Management Entities
PSS	Priority Set Scheduler
PF	Proportional Fair
PLR	Packet Loss Ratio
PRB	Physical Resource Blocks
QoS	Quality of Service
QEEA	Quality of Service (QoS) and Energy Efficient Aware
RAN	Radio Access Network
RBG	Resource Block Group
RR	Round Robin
S-GW	Serving Gateways
TD	Time Domain
TBR	Target Bit Rate
TTI	Transmission Time Interval
UE	User Equipment
UTRAN	Evolved Universal Terrestrial Radio Access Network
VoIP	Voice over Internet Protocol

the increasing requirements of users, as they demand better improved Quality of Service (QoS). However, these advancements come with challenges that need to be addressed such as high energy consumption and adverse environmental impacts. The Information and Communication Technology (ICT) sector is playing its part to resolve energy crisis and is increasing efforts in making the environment greener.

Long Term Evolution (LTE) standardization is being carried out in the Third Generation Partnership Project (3GPP) which is a mobile broadband access technology to support the increasing demand for high data rates [1]. The main motivation for LTE development is to offer higher and more reliable data rates to accommodate the increasing demand for mobile traffic. Besides that, the LTE is able to reduce packet delays, increase throughput speed, improve spectrum flexibility and reduce the cost of ownership and operations for the network operators and the end users [2]. Figure 1 shows the basic architecture components of LTE, which consists of Evolved Node B (eNodeB) at the radio access network (RAN), Mobility Management Entities (MMEs) and Serving Gateways (S-GW) at the core [3].

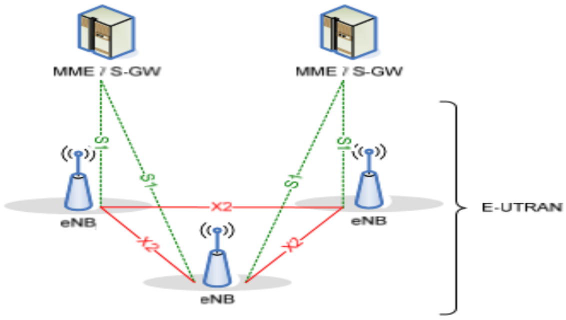

Fig. 1. Overall architecture [3].

Energy consumption in base stations (BS) and downlink transmission seems to be the two major areas where significant energy conservation can be achieved [4]. Therefore, it is beneficial to develop a new scheduling algorithm in which users may experience better services with lower power consumption. The key benefits of this new algorithm include; increasing throughput, and also improvement in energy efficiency (EE).

The theoretical basis of an energy-efficient scheduling policy is mainly contributed by the low transmit power from the BS and user equipment (UE). The amount of transmitted power from the BS is influenced by the bandwidth, channel quality and modulation mode. A framework for measuring the EE of a telecommunication network and equipment is found in [5]; where the power consumption to throughput ratio was proposed as an Energy Consumption Rate (ECR) metric as in equation (1),

$$ECR = \frac{E}{M} = \frac{PT}{M} = \frac{P}{D} \quad (1)$$

The ECR is defined as the energy per delivered application bit (Joules/Bit), where E is the energy required to deliver M application bits over time T, $D = M/T$

is the data rate in bits per second and P is the power. The ECR is low if the total transmit power is reduced. Thus, high energy-efficiency can then be achieved.

2.Literature Review

Very few researchers [6-12] are focusing on this particular area, especially in reducing energy consumption in the Evolved Node B (eNodeB). Packet scheduling strategies are being studied in order to achieve better EE. For the evaluation of EE, the ECR performance of wireless access is necessary to compare the performance of different scheduling schemes. As explained by Yan et al. [6], there are four elements to trade off in exchange for green communication. Firstly, the deployment efficiency (DE) which can be traded off with EE in which cell radius is decreased to reduce power required for transmission. Secondly, the spectrum efficiency (SE). SE-EE trade-off is studied in most researches such as in [7, 8]. In [7] EE is achieved by increasing user's required bandwidth for given data rate under non-full load conditions. Thirdly, bandwidth-power trade-off which is expanding the signal bandwidth to reduce the transmit power, thus, providing EE. Lastly, delay-power trade-off which is a measure of Quality of Service (QoS) and user experience. In order to build a green radio, it is important to know when and how to trade tolerable delay for low power. Turyagyenda et al. [8] proposed a proportional fair-energy policy that is available for both low and high load conditions.

From the perspective of energy efficiency, the performance of three conventional scheduling algorithms, namely Max C/I, round robin (RR) and Proportional Fairness (PF) algorithm in multi cell scenario are compared in LTE downlink transmission in [9] which proved that the spectrum efficiency and energy efficiency of Max C/I algorithm is the best, but the delay and PLR is not considered since Max C/I is not a QoS scheduler. Mohammad et al. [4] have proposed an energy efficient algorithm for low-load conditions only. Meanwhile, the authors [10] showed that the resource scheduling algorithms can be adopted to improve the system gain by exploiting multiuser diversity gain, which can be translated into energy saving. Congzheng and Simon [11], and Stefan and Harald [12] proposed an energy-efficient scheduling strategies under low load conditions for LTE downlink. In [11], the relationship between modulation and coding scheme (MCS) level and energy-saving was discussed, which indicated the feasibility of spectrum in exchange for power under non-full load conditions, and it presents the energy-efficient strategy in which the users' modulation level are lowered step by step. In [12], a Bandwidth Expansion Mode (BEM) technique that allocates more resource blocks with lower transmit power to users under low load conditions in order to reduce the energy consumption was presented. It should be noted that the BEM techniques fail to produce energy savings under high load conditions.

Therefore, the contribution of this paper is to achieve green environment in wireless network by using the lessen power in eNodeB according to 3GPP LTE specifications [13]. Basically, a typical value of power in eNodeB for macrocell is between 43 dBm to 48 dBm (20W-60W). Besides that, the highest throughput is also the most significant metric in order to meet data requirement for each UEs. However, the biggest problem faced in wireless network is that it requires the maximum power to achieve the highest throughput level.

This study presents a new energy consumption aware packet scheduling, known as QoS Energy Efficient Aware (QEEA) scheduler.

3. Quality of Service and Energy Efficient Aware (QEEA) Scheduler

The Quality of Service and Energy Efficient Aware (QEEA) is the scheduling algorithm that is proposed for this paper. This algorithm considers the head of line (HOL) delay, achievable throughput, past average throughput and transmitted power. The goal of QEEA is to achieve maximum throughput and improve the energy efficiency (EE) by using low transmitted power. The algorithm works for real-time (RT) and non-real-time (NRT) applications. Thus, different classes of traffic such as VoIP, video and FTP are considered in this paper.

Basically, the QEEA scheduler is based on the time domain (TD) and frequency domain (FD) scheduling where it is dependent on the Quality of Service (QoS) requirements to allocate resources. Firstly, the QEEA scheduler divides UEs according to the priority in the TD scheduling. This scheduler then groups the UEs into flows and ensures that the FD scheduler allocates resources starting with a flow with the highest computed metric.

In the TD, at each transmission time interval (TTI), the QEEA scheduler group users according to priority. The purpose of grouping is to enforce the FD scheduler to consider first the flows with the highest HOL delay. The metric of the QEEA, m_{td} for user $j = 1, \dots, N$ is defined as in equation (2):

$$m_{td}^{j}(t) = \left\lceil \frac{d_{hol}^{j}(t)}{g} \right\rceil \tag{2}$$

where $d_{hol}^{j}(t)$ is the current value of HOL delay of flow j, and g is a grouping parameter that determines granularity of the groups which is the number of flows that will be considered in the FD scheduling iteration. The grouping is used to select the most urgent flows which have the highest value of HOL delay.

The group of flows selected in the TD iteration is forwarded to the FD scheduling starting from the flows with the highest value of the $m_{td}^{j}(t)$ metric until all RBGs are assigned in the corresponding TTI. In the FD, for each RBG $k = 1, \dots . K$, the QEEA scheduler assigns the current RBG to the user j that has the maximum value of the FD metric which is express as:

$$m_{fd}^{(k,j)}(t) = d_{HOL}^{j}(t).GBR^{j}.\overline{R^{j}(t)}.\left(1/P_{tx}\right) \tag{3}$$

where $d_{HOL}^{j}(t)$ is the current value of HOL delay of flow j, GBR^{j} is the bit rate specified in Evolved Packet System (EPS) bearer of the flow j and $\overline{R^{j}}(t)$ is the past averaged throughput performance that is calculated with a moving average perceived by user j.

P_{tx} is the power transmitted in the Evolved Node B (eNodeB) which is set to 43 dBm or equal to 20 W. 43 dBm is the lowest power setting being specified by the 3GPP LTE [13]. The main reason that P_{tx} was set as $1/P_{tx}$ in equation (3) is when the power transmitted was set to the lowest, 43 dBm), then the value of $m_{fd}^{(k,j)}(t)$ increases. When the metric is high, there is higher chance or possibilities that the flow will be selected. On the other hand, when the power transmitted was set to the highest which is 48 dBm (60 W), the value of $m_{fd}^{(k,j)}(t)$ decreases. Table 1 shows the total BS transmit power for LTE [13] and Fig. 2 shows the flow chart of the QEEA scheduler.

Table 1. BS power model for LTE [13].

Parameters	Value
Total BS transmit power	43 dBm (20 W) for Frequency Division Duplex (FDD) 46 dBm (40 W) for 10 MHz LTE, 49 dBm for 40 MHz LTE-A

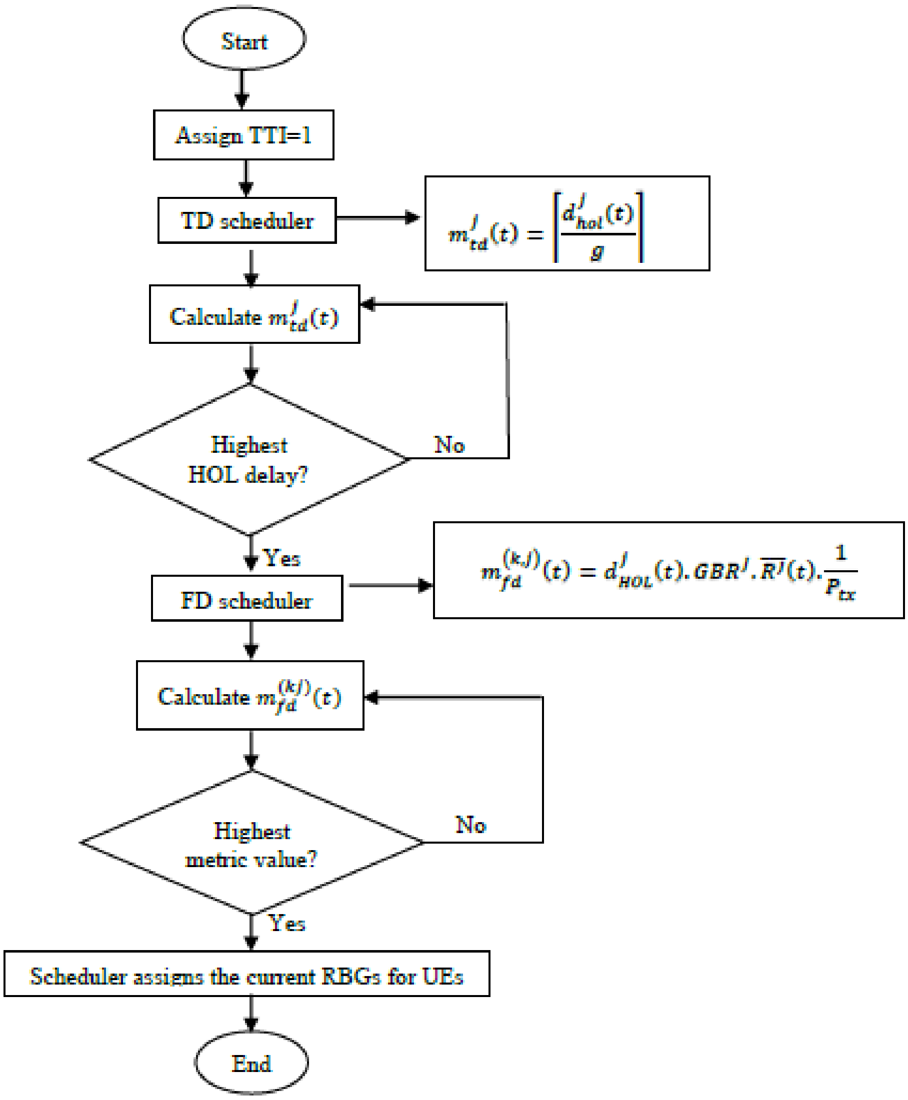

Fig. 2. Flow chart of FD scheduling in QEEA.

4. Simulation Parameter

In this paper, VoIP and video flows are used for real time services while FTP flows represent non-real time. VoIP flows have much stricter delay requirement than that of video and FTP flows. In addition, G.711 voice flows adopted in the simulation are generated by the VoIP application. Particularly, voice flows are modelled by using ON and OFF Markov chains. ON is the duration of time when the users spend on talking whereby constant packets are transmitted at regular intervals. The OFF duration is the time where the user stops from talking and packets are not transmitted [14]. A trace-based video streaming application that can send packets on the basis of realistic trace files is modelled for the simulation. The module uses the st_highway_cif.st as the trace file for video traffic [15].

Furthermore, the throughput metric (in Mbps) represents the rate of successful message which is delivered over physical channel [16]. The throughput parameter is calculated by dividing the number of successfully received bits with the duration of the flow and can be mathematically expressed as [17, 18].

$$throughput = \frac{1}{T}\sum_{i=1}^{K}\sum_{i=1}^{T} ptransmit_i(t) \qquad (4)$$

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.

This simulation is done using the NS-3 simulator along with the LTE-EPC Network Simulator (LENA) module [19]. This simulator is used to evaluate the performance of the QEEA and compare it against algorithms such as CQA, PSS and PF. The throughput, delay, PLR, ECR, and EE are calculated as the performance metrics for three traffic flows. The simulation consists of a single LTE cell with radius variation of 200 m to 1000 m away from the Evolved Node B (eNodeB) in which 50 users are distributed uniformly in the cell. Table 2 shows the LTE downlink simulation parameters.

Table 2. LTE downlink simulation parameters.

Parameter	Value
Simulation Duration	20 second
eNodeB	1 eNodeB
Transmission Power eNodeB	43 dBm
Frame Structure	FDD
Number of RBs	50
Bandwidth	10 MHz
Carrier Frequency	2.16 GHz
UEs Speed	3 km/h
VoIP Codec	G.711
VoIP Guaranteed Bit Rate	64 kbps
Video File (MPEG-4)	st_highway_cif
Video Guaranteed Bit Rate	242 kbps
Pathloss Model	Cost231
Fading Model	Pedestrian EPA 3 km/h
AMC	PiroEW2010

5. Results and Discussion

Figure 3(a) shows the throughput analysis of the VoIP flow. The throughput of PSS and PF algorithms were moderate between 600 m to 100 m of distances. Traffic with guaranteed bit rate (GBR) needs more physical resource block (PRBs) to satisfy the Quality of Service (QoS) requirement. Hence, the requirement of traffics with GBR cannot be satisfies commendably for PSS and PF algorithms.

Furthermore, VoIP transmission using QEEA algorithm has the highest throughput as compared to other algorithms. The QEEA throughput is showing an improvement compared to the CQA even though the difference is insignificant. The QEEA throughput for all the distances: 200 m, 400 m, 600 m, 800 m and 1000 m have shown an increase which are 0.08%, 0.24%, 0.059%, 0.082% and 0.03% respectively in comparison to the CQA algorithm. The justification behind this improvement is that the QEEA algorithm can guarantee the QoS for RT service in advance. The throughput analysis of video and FTP flows are given in Figs. 3(b) and 3(c) respectively. All algorithms provide higher throughput for users near to eNoddB. However, both figures show that the throughput decreases sharply up to 400 m of distances for all scheduling schemes. One possible explanation of the cause of the decrease is due to the distance between users and Evolved Node B (eNodeB) which is considerably far and located at the cell edge. However, the throughput of the QEEA algorithm in video flow is slightly higher which 0.4% as compared to the CQA algorithm is shown in Fig. 3(b). On the other hand, the throughput of the QEEA is slightly higher which is from 0.54% to 2.04% as compared to the PF algorithm. From Fig. 3(c), it is observed that QEEA provides the highest throughput in FTP flow as compared to the other algorithms because it allocates resources to users with good channel quality.

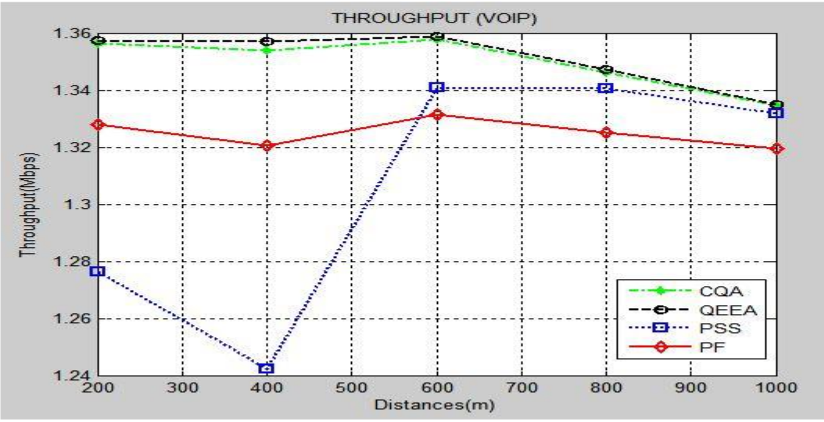

Fig. 3(a). VoIP throughput.

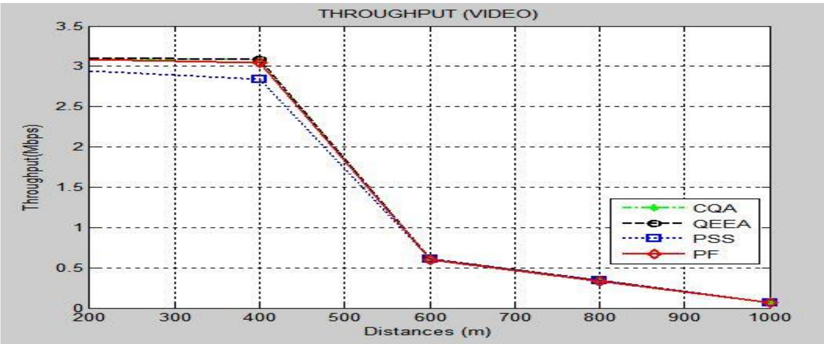

Fig. 3(b). Video throughput.

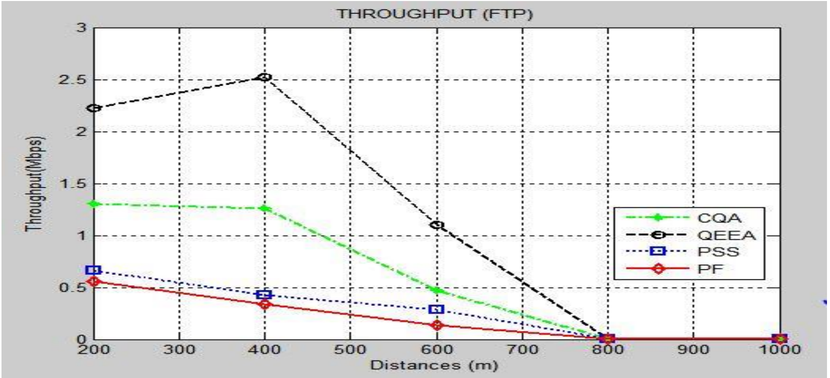

Fig. 3(c). FTP throughput.

Figure 4(a) shows that VoIP users suffering a longer latency when the distances of the eNodeB increases accordingly. The QEEA and CQA consider end-to-end delay as the scheduling metric, thus, the end-to-end delay is kept minimum as illustrated in Fig. 4(a). QEEA has considerably longer delay performance as compared to the CQA. This is because there is a limitation to the proposed algorithm, when throughput of the larger system is improved, data packets are scheduled in order to ensure throughput is maximized, and this affected the delay performance. There is a trade-off between throughput and delay; when throughput is maximized the delay will increase. Figure 4(b) shows the delay of the video flows. From this figure, it is shown that the packet delay remains almost the same for QEEA and CQA schedulers with the increase of the distances.

As aforementioned, this is mainly due to slight increase in throughput being delivered by the QEEA algorithm as compared to CQA, thus UEs spend more time in the queue to send their packet correctly. However, the delay of the QEEA is still acceptable and within the range of the QoS provisioning. Obviously, in Fig. 4(c) (FTP delay), it is shown that the QEEA has the lowest delay up until 600 m as compared to other scheduler. However, when distance between 600 m to 800 m, the delay of QEEA start to increase. The explanation behind this is that, a user of FTP that does not end its transmission in the current frame, must wait for a period of two frames to continue sending packets, which increases the average delay of FTP packets. This can be observed from Fig. 4(c) where the trending of delay for all algorithms start to increase at 600 m. However, since QEEA considers head of line delay (HOL) in the scheduling decision, thus, QEEA manage to reduce the delay as the distance increases to 1000 m. Therefore, the best suitable downlink scheduling algorithm is QEEA algorithm which has short end-to-end delay of less than 10μs with the increase of distance and also good performance for all traffic whether real time or non-real time traffic.

Figure 5(a) shows that the packet loss increases as long as the distance increase in QEEA and CQA scheduler for VoIP flow. As expected, with the increasing system delay as shown in Fig. 4(a), there will be more packets being discarded since there are insufficient resource blocks (RBs) to transmit all the packets which HOL packet delays are approaching the delay threshold. In Fig. 5(a), the PLR rises steadily for QEEA and CQA schedulers as the number of distances increase and there are no significant changes between 200 m to 600 m. At this distance, the

QEEA algorithm has the lowest PLR as compared to all three schedulers. Although QEEA does not have lower PLR as compared to the CQA scheduler when the distance is 1000 m, the QEEA algorithm has the lowest PLR at 200 m, 400 m, 600 m which is 9.85%, 23.28%, and 3.60% respectively as compared to the CQA scheduler. The PLR in QEEA algorithm can be reduced to about 75% and 67% as compared to PSS and PF respectively.

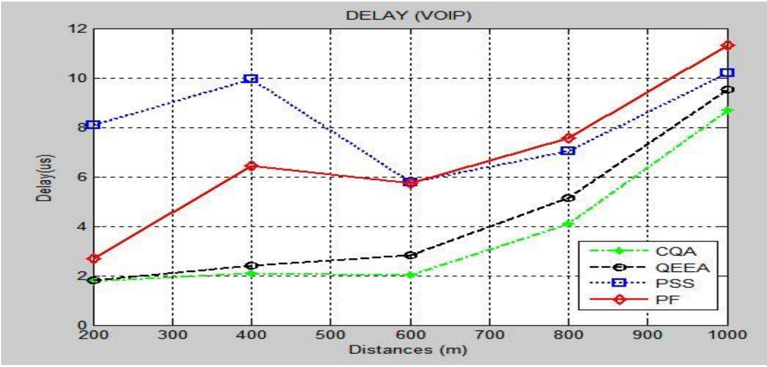

Fig. 4(a). VoIP delay.

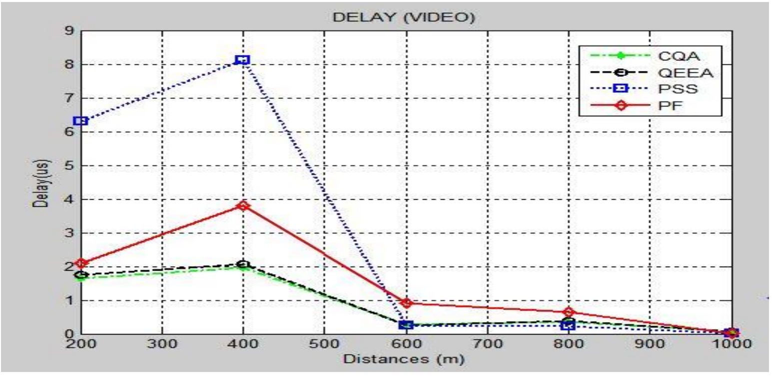

Fig. 4(b). Video delay.

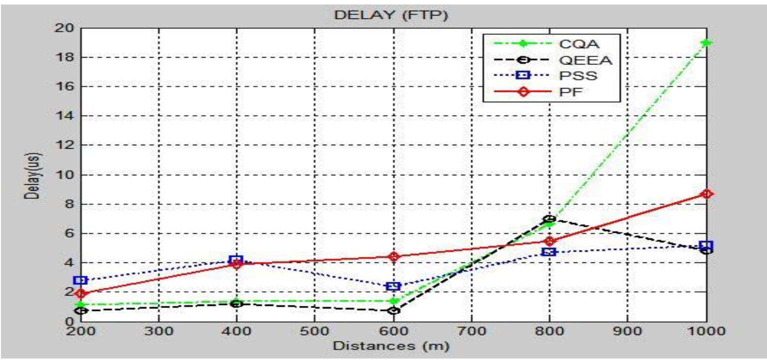

Fig. 4(c). FTP delay.

For the video flow, as shown in Fig. 5(b), the PLR for QEEA and CQA algorithms is almost similar between 200 m until 600 m. Although the QEEA has slightly increased PLR value as compared to the CQA at 800 m, the lowest PLR is still achieved at 200 m, 400 m, 600 m, and 1000 m. Furthermore, PSS has the highest value at 400 m which is 5 times higher than the QEEA algorithm. However, the PLR for PSS is lower than QEEA when the distances up to 800 m for both VoIP and video flows. This is due to higher delay as shown in Figs. 4(a) and 4(b). When reliable delivery is necessary, packet loss increases latency due to additional time needed for retransmission. The PF algorithm maintains almost the same between the starting point until the end for both VoIP and video flows. Therefore, the proposed scheduler outperformed all scheduling algorithms. In Fig 5(c), it can be observed that PLR in QEEA is the lowest at about 78% as compared to CQA, and 85% and 87% as compared to PSS and PF schedulers respectively. However, beyond 800m, all the schedulers did not receive any data due to cell edge factor. The QEEA algorithm shows a very good PLR performance when the system is at 600 m distance. Thus, it is proven that proposed algorithm is suitable for QoS and non-QoS guarantees.

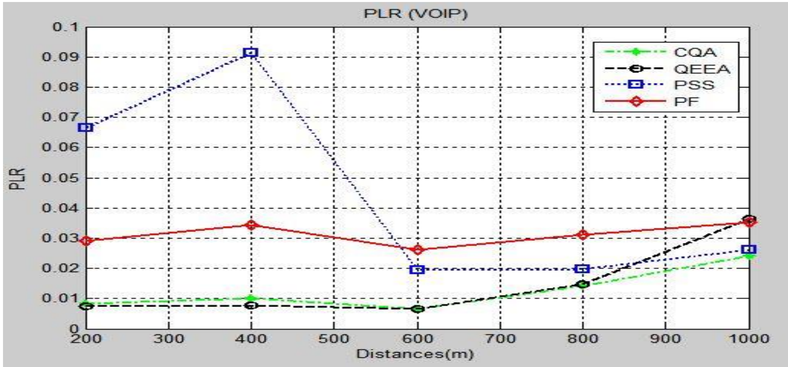

Fig. 5(a). VoIP PLR.

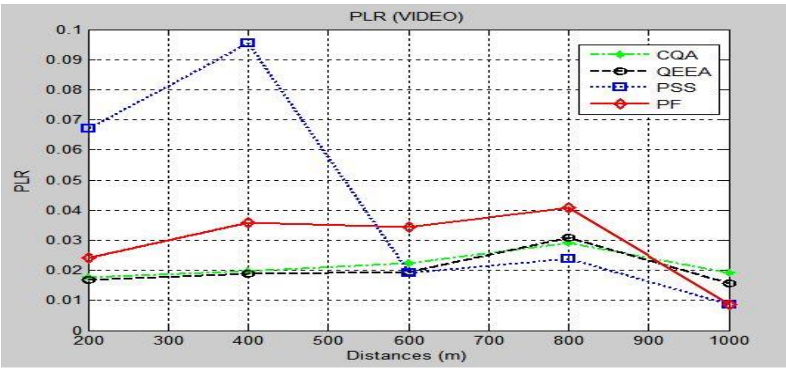

Fig. 5(b). Video PLR.

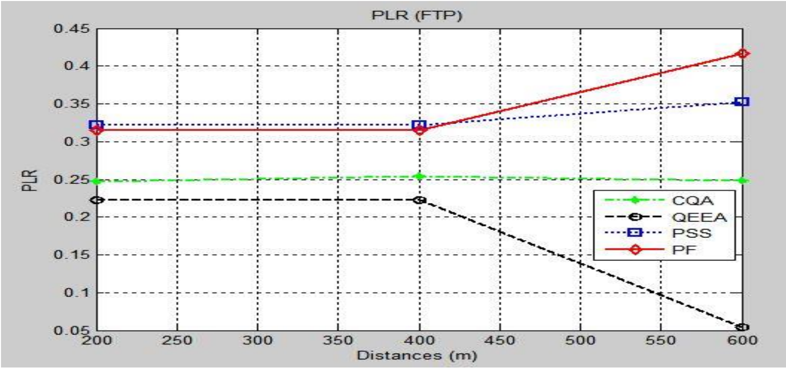

Fig. 5(c). FTP PLR.

Figures 6 and 7 show the total ECR and energy efficiency (EE) respectively for VoIP, video and FTP flows. Based on Fig. 6, it is noted that when the distances is increased, more energy is consumed for all the schedulers. The QEEA algorithm has the lowest ECR value. When the UEs is far from the eNodeB, higher transmit power is needed to deliver and receive the packets successfully. The QEEA has the lowest energy which is about 33% to 35% lesser than the other scheme. This is mainly due to the objective of the QEEA which is to improve the EE and ECR of. Thus, the goal for this study has been achieved since the proposed scheduler has the lowest ECR as compared to the other scheduling. The lower the ECR value, the higher the EE value can be accomplished as shown in Fig. 7. The results show that the energy efficiency of QEEA is capable of achieving up to 54% as compared to other algorithms. However, when the distances increased, EE can be ignored since it is hard to save the energy for UEs due to distance factor. Table 3 shows the improvement of energy efficiency of QEEA algorithm as compared to other algorithms.

Table 3. Improvement of energy efficiency of QEEA.

Distances (m) / Algorithms	200	400	600	800	1000
CQA	16.22%	22.12%	26.14%	0.083%	0.014%
PSS	36.86%	54.43%	37.45%	0.29%	0.14%
PF	34.6%	48.07%	48.86%	1.69%	1.04%

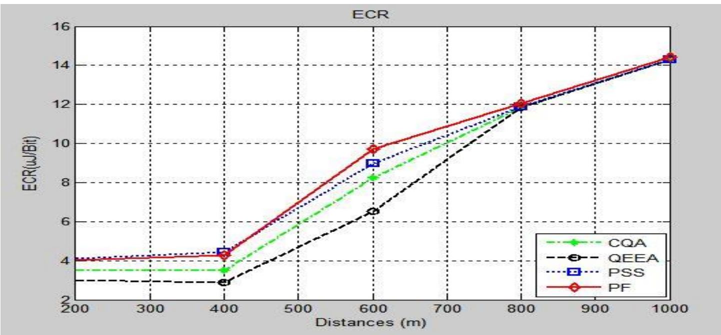

Fig. 6. Total of ECR for VoIP, video and FTP in eNodeB.

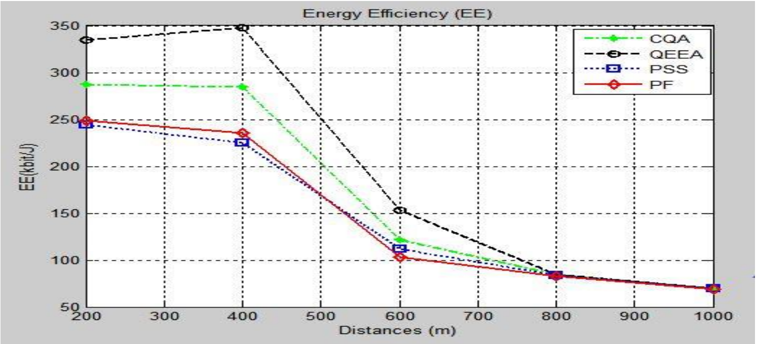

Fig. 7. Total of EE for VoIP, video and FTP in eNodeB.

Figures 8(a), 8(b), and 8(c) show the impact of transmitted power, distances on the throughput for VoIP, video and FTP in proposed scheduler QEEA respectively. The comparison of transmission power is between 43dBm to 48dBm (20W-60W). In Figs. 8(a), 8(b), and 8(c), it is shown that the highest throughput was achieved as the transmitted power decreases. The throughput increased up to 5% in VoIP, 3% and 330% in video and FTP simultaneously. Thus, the objective of this paper is achieved with the higher system throughput by using low power in LTE network. In short, the QEEA algorithm outperforms all other schedulers when VoIP, video and FTP traffic are considered.

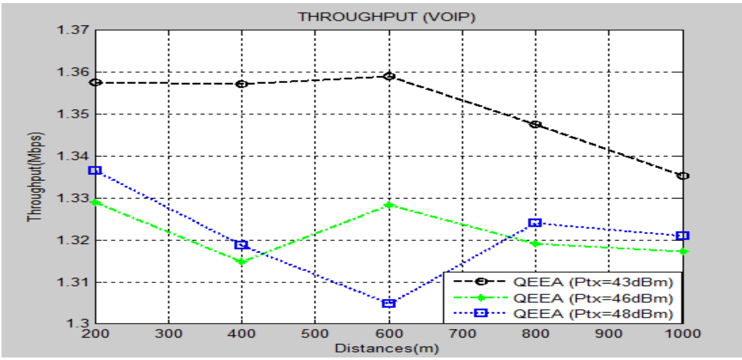

Fig. 8(a). VoIP throughput for different Ptx in QEEA.

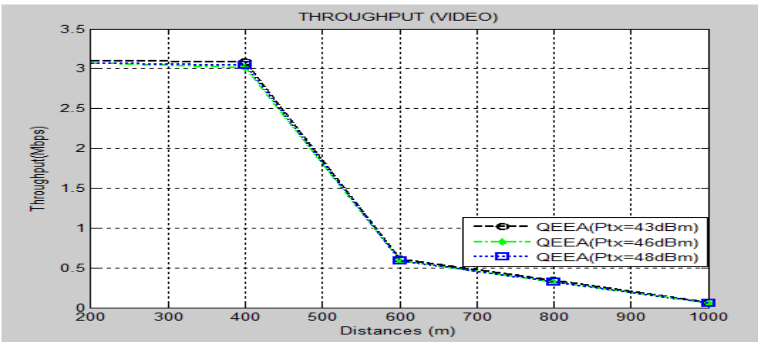

Fig. 8(b). Video throughput for different Ptx in QEEA.

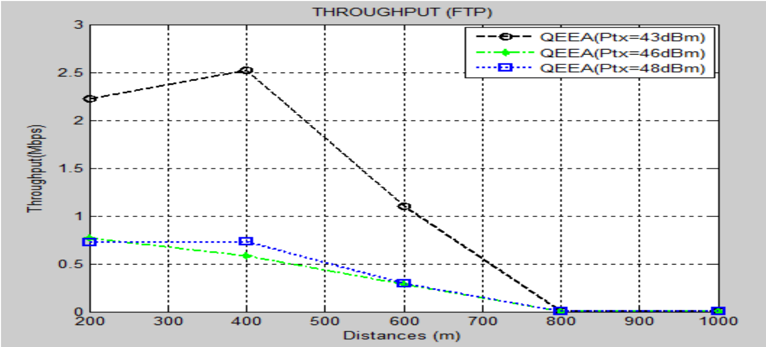

Fig. 8(c). FTP throughput for different Ptx in QEEA.

6. Conclusion

This paper evaluates the performance of three packet scheduling algorithms in LTE cellular networks, namely, CQA, PSS and PF schedulers with the proposed algorithm known as QEEA. The performance metric of throughput, delay, PLR, ECR and EE were analysed for video streaming, VoIP and FTP applications. The results from simulation showed that the proposed algorithm outperformed the other algorithms in all traffic flows since it delivered higher throughput and reduced energy consumption by using low power to achieve green communication environment. In addition, the proposed algorithm can support both real-time and non-real time environment. Hence, it can be concluded that QEEA is the most suitable algorithm as energy efficient scheduler for VoIP, video and FTP flows. Further studies needs to be conducted on how to reduce the energy consumption while maintaining fairness at cell edge users.

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