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A New Power Efficient – Delay Aware Downlink Algorithm for 3GPP LTE Cellular Networks

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ABSTRACT

Scheduling in downlink transmission in long term evolution (LTE) is a very important process accomplished in the eNodeB. Through the scheduling process, the network dynamically allocates the available radio Resource Blocks (RBs) to users based on the used scheduling technique. RBs are allocated to users to satisfy their Quality of Service (QoS) needs. In this paper, a novel scheduling algorithm is proposed, which is considered as power- awareness of a system, and at the same time a delay aware scheduling algorithm. In our algorithm, the user with more considerable delays and lower power consumption will have the priority to obtain resources. A new power efficient-delay aware (PE-DA) algorithm is introduced. It integrates a delay-aware algorithm and a proposed power-aware algorithm. Performance analysis for the proposed algorithm is compared with well-known algorithms like maximum throughput (MT) algorithm, proportional fair (PF) algorithm, and DBWPF algorithm. Simulation results show that the implementation of the proposed algorithm provides significant improvement in power efficiently utilization in the cell by decreasing the overall transmitted power from eNodeB to the user's equipment. At the same time, the proposed algorithm maintains delay fairness very close to that of DBWPF algorithm and achieves a throughput fairness value with a small degradation from the value obtained by the PF algorithm.

Index terms- LTE; Scheduling algorithm; Downlink; Delay; Power-aware; Fairness.

1. INTRODUCTION

There is a continuous rapidly increasing demand for high data rate network services, essentially real-time applications, such as live video streaming, VoIP, video telephony, and web browsing. This great challenge imposes new efforts in the planning and design of cellular networks. Long Term Evolution (LTE) is a wireless broadband technology that was introduced by the 3rd Generation Partnership Project (3GPP) to meet the requirements of future communication. The aims of LTE are to increase data rates, improve system coverage and capacity, decrease latency, improve high spectral efficiency, and increase the efficiency of cell edge users' throughput [1, 2]. LTE utilizes advanced technologies such as Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink channel from the eNodeB to the user equipment (UE), and Multiple Input Multiple Output antenna techniques (MIMO), using these advanced technologies can fulfill high system capacity and provide high data rates [3]. OFDMA radio access technology, which used in the downlink in LTE networks divides the total available bandwidth into parallel narrowband orthogonal subcarriers, and each set of subcarriers are allocated to a specific user depending on user’s different requirements and the scheduling Algorithm used. So, the Scheduling mechanism is an an important process in LTE network design because it is responsible for distributing available radio resources between the active users in order to satisfy their quality of service (QoS) requirements [4].

Because of the importance of resource allocation scheduling techniques in LTE networks, many publications focused on performance evaluation of various downlink scheduling algorithms in LTE network.

In [2], Capozzi F. et al provide an overview of the key issues that ascend in the design of scheduling algorithms in LTE networks, and a good survey on several allocation techniques is introduced including Performance comparisons of several good known schemes.

B. Liu et al in [5] displayed the performance of several LTE Downlink Packet Scheduling Algorithms, and introduce a new Scheduling Algorithm which is suitable for real-time traffics and the performance of the scheduling algorithm is evaluated in terms of traffic flow throughput, packet loss ratio (PLR), packet delay, and fairness index.

In [6], the authors proposed a scheduler which takes into account the buffer status of Users and channel conditions, this scheduler is proposed to reduce packet loss rate due to a buffer overflow and maintaining a high system throughput and good fairness index

In [7], a new scheduler was introduced that make a trade-off between throughput and fairness. The planned algorithm has been tested in different situations and compared with Round Robin and Best CQI good known scheduling algorithms.

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S. A. Al-Qahtani et al proposed a new scheduling algorithm for LTE networks and the performance of this new algorithm was compared to the performance of Best-CQI and Round Robin Uplink schedulers, the new algorithm achieved a good fairness index and keeps the network capacity as good as possible [8].

In [9], Q. U. Ain et al introduce a novel algorithm that aims to enhance the characteristics of Proportional Fair (PF) algorithm by estimating the channel quality index (CQI) in the future, to provide higher data rate to all users according to their running applications. The Performance measurement of the new algorithm on the downlink is performed in terms of throughput and block error rate.

A new proposed scheduling algorithm named DP-VT-MLWDF was introduced in [10], the novel scheduler simulation results show a good improvement of the QoS performance parameters for real-time services, like packet loss rate, average throughput, and fairness index.

A dynamically adopted Proportional Fair (PF) new scheduling algorithm for capacity enhancement of LTE system is proposed in [11], the new algorithm is dynamically adopted Proportional Fair (PF), performance comparison with the conventional PF downlink algorithm and the Best-Channel Quality Indicator (Best-CQI) scheduling algorithm was done. The simulation results show that the proposed scheduling strategy improves the overall system capacity and provides a high level of fairness between all active Users Equipment (UEs). The new algorithm enhances the average cell throughput by more than 31 %, with a slight reduction in the fairness level with respect to the conventional PF algorithm. The authors in [12] propose a new queue-aware scheduling algorithm that depends on probability guess of buffer data flow, this novel technique proposes the estimation of UEs maximum delay. Simulation results show that the proposed algorithm achieves lower delay, and at the same time it maximizes the overall throughput of the system. In paper [13], the authors propose a new scheduling algorithm for using in LTE networks that depends on the urgency level of the data that should be transmitted, the algorithm must know the QoS requirements for each UE, each packet urgency level, and data rate and throughput achieved when choosing a specific users to receive RBs, the simulation concludes that the new algorithm can satisfy real-time QoS requirements for optimized number of users and at the same time reserves accepted QoS level for non-real time packets.

High information data rate applications like real-time services in new smart networks extremely increase energy consumption. So, there is a necessary need to pay attention to the energy efficiency aspect of communication networks. Green energy-based network is important technology to achieve the high data rate requirements as well as to improve spectrum and energy efficiency [14]. In this paper, we propose a new scheduling algorithm that takes into account the power consumption aspect and tries to achieve acceptable power efficiency as well as to improve delay fairness among the UEs.

The rest of this paper is organized as follows. Section 2 presents the major concept of LTE Downlink scheduling. Some scheduling algorithms are reviewed in Section 3. The proposed scheduling algorithm is introduced in Section 4. In Section 5, simulation results are introduced and discussed. Finally, the conclusions are presented in Section 6.

2. LTE DOWNLINK SCHEDULING

In LTE networks, Scheduling is an extremely important process because it is responsible for allocating available radio resources to the active UE to satisfy their QoS requirements [4]. Since LTE networks utilize OFDMA techniques, active UEs share the same channel, and radio resource blocks should be divided among them every Transmission Time Interval (TTI) by scheduling process which performed at the eNodeB, as shown in Figure 1. Where CQI is the Channel Quality Indicator and PDCCH is the Physical Downlink Control Channel.

The LTE system frame is 10 ms in length (Figure 2), and each frame is splitted in the time domain into 10 subframes. The subframe duration is 1 ms in length, and each subframe is divided into 2 slots where each slot length is 0.5 ms. In the frequency domain, the total available bandwidth is divided into sub-channels, each sub-channel is 180 kHz, and contains 12 successive and equally spaced OFDM sub-carriers [15].

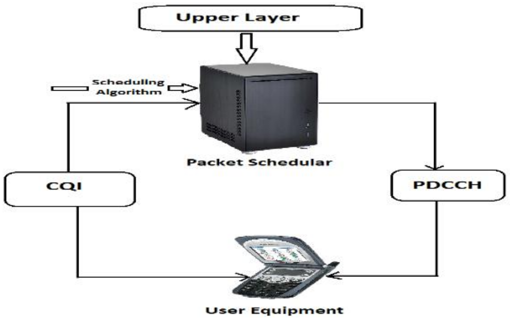

Figure 1. Packet Scheduler for Downlink LTE

The resource block is the smallest unit of time/frequency resources that can be allocated to an UE in a certain TTI for data transmission. One resource block contains two-time slots in the time domain and one sub-channel in the frequency domain [16].

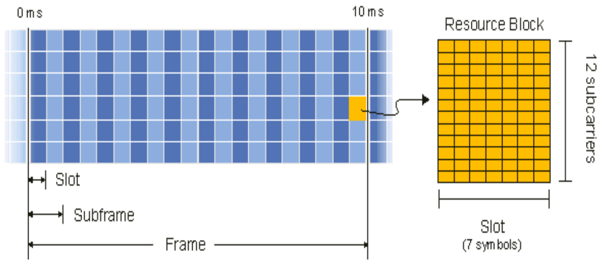

Figure2. LTE frame and resource block structure

3. SCHEDULING ALGORITHMS

There are various scheduling algorithms proposed based on the knowledge of channel state information (CSI) in LTE network. Some algorithms' goal is to maximize the overall throughput of the network like maximum throughput (MT) algorithm while another kind of algorithm aims to enhance fairness between users like a proportional fair (PF) algorithm, and there are many other algorithms aim to satisfy various QoS requirements of UEs.

Each scheduling algorithm has a unique technique to calculate the metric considered for allocating the available radio resource blocks to different users. In general, most of scheduling algorithms need to know the past average throughput $TH_u\ (n)$ of each flow associated with the u_{th} user, and periodically in every TTI need to know the u_{th} user instantaneous throughput, $th_u\ (n)$.

At TTI number n, the resource block number k will be allocated to the user number j if j executes the following equation:

$$j = \text{argument } max_u\ [m_{u,k}\ (n)] \tag{1}$$

$m_{u,k}\ (n)$ is calculated based on the channel quality indicator (CQI) feedback from the user to eNodeB.

According to Shanon law, the capacity of the transmission channel can be calculated as follow:

$$d_{u,k}\ (n) = log_2\left[1 + SIR_{u,k}(n)\right] \tag{2}$$

Where $SIR_{u,k}(n)$ is the signal to noise ratio of individually UE on every RB, and $d_{u,k}\ (n)$ represents the upper limit of data rate, but it doesn't represent the real size of the data rate.

3.1. Maximum Throughput (MT) scheduling algorithm

The main purpose of MT scheduling is to maximize the overall throughput in the cell and every RB should be assigned to the UE which have greatest capacity in his transmission channel [6], metric of MT algorithm is given by:

$$m_{u,k}^{MT}\ (n) = d_{u,k}\ (n) \tag{3}$$

3.2. Proportional Fair (PF) scheduling algorithm

Unlike MT algorithm which aims to maximize the overall throughput in the cell, the PF scheduling technique aims to create a balance between overall throughput of the cell and throughput fairness between all UEs by tacking into accounts the past throughput of each UE. PF algorithm metric can be represented as:

$$m_{u,k}^{PF}(n) = \frac{d_{u,k}\ (n)}{TH_u\ (n-1)} \tag{4}$$

With:

$TH_u\ (n)$ = β $TH_u\ (n-1)$+ (1 - β) $th_u\ (n)$, 0≤ β ≤ 1 (5)

TH_u (0)=0. Where:

$th_u\ (n)$ represents u_{th} user throughput that achieved during the n_{th} TTI, and $TH_u\ (n)$ indicates the u_{th} user overall previous achieved throughputs during all previous TTIs.

3.3. Delay-Based Weighted Proportional Fair Scheduling Algorithm (DBWPF)

Unlike MT, and PF algorithms, the DBWPF algorithm is a delay-aware scheduling algorithm that aims to give a priority of allocating resources to the user which has the largest delay [17]. The metric of DBWPF algorithm is given by:

$$m_{u,k}^{DBWPF}\ (n) = \begin{cases} 0, & b_u\ (n) = 0 \\ \frac{D_u\ (n)\ d_{u,k}\ (n)}{TH_u\ (n-1)}, & b_u\ (n) > 0 \end{cases} \tag{6}$$

Where:

$b_u\ (n)$: represents the i_{th} user buffer volume during the n_{th} TTI, *and* $D_u\ (n)$ represents the i_{th} user weighted value of average delay. UE buffer size $b_U(n)$ can be obtained as follows:

$$b_u\ (n) = \begin{cases} 0, & n = 0 \\ b_u\ (n-1) - th_u\ (n-1) + c_u\ (n), & n > 0 \end{cases} \tag{7}$$

Where $c_U\ (n)$ is the data brought to the U_{th} user during TTI number n. $D_u\ (n)$ comprises two terms, the first term represents the already existing data in the buffer delay, and the second term represents the already sent data actual delay, the two terms can be expressed by $D_u^b(n)$ and $D_u^a(n)$, respectively

$D_u\ (n)$ can be calculated from:

$$D_u\ (n) = \begin{cases} D_u^b(n), & b_u\ (n) \geq \delta \\ \left[1 - \frac{b_u(n)}{\delta}\right] D_u^a(n) + \frac{b_u(n)}{\delta} D_u^b(n) & b_u\ (n) < \delta \end{cases} \tag{8}$$

Where δ actually represents the past data size from which the UE weighted value of the average delay can be calculated. From the above equation, it is clear that if δ is less than the buffer size, $D_u(n)$ will be calculated from $D_u^b(n)$ only, and $D_u^a(n)$ is neglected. But if δ is greater than buffer size, $D_u\ (n)$ will be calculated using the two terms, $D_u^b(n)$, and $D_u^a(n)$.

$D_u^b(n)$ can be calculated from:

$$D_u^b(n) = \begin{cases} 0, & n = 0 \\ \frac{[D_u^b(n-1)+\tau\,]\, b_u\,(n-1) - t_u\,(n-1)\; th_u\,(n-1)}{b_u\,(n)}, & n > 0 \end{cases} \qquad (9)$$

Where:
τ represents the actual value of a TTI duration, which equal to one millisecond, and $t_u(n)$ represents the u_{th} user weighted average delay calculated on the transmitted data during TTI number *n*.

and $D_u^a(n)$ can be calculated from:

$$D_u^a(n) = \begin{cases} 0, & n = 0 \; or \; b_u\,(n) \geq \delta \\ \left[1 - \frac{th_u\,(n-1)}{\delta - b_u\,(n-1)}\right] D_u^a(n-1) + \frac{th_u\,(n-1)}{\delta - b_u\,(n-1)}\; t_u\,(n-1)\,, & other \end{cases} \qquad (10)$$

4. THE PROPOSED ALGORITHM

The proposed algorithm is power aware algorithm, which aims to reduce the power consumption transmitted from the eNodeB as much as possible, and at the same time maintains good levels of delay fairness, throughput fairness, and overall throughput in the cell.

4.1. Power-Based Weighted Proportional Fair scheduling Algorithm

Through (PBWPF) scheduling technique, the user with the lowest power consumption is more likely to obtain resources.

In any communication system, the received power can be calculated using the Friis transmission equation which can be expressed as:

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi R}\right)^2 G_t G_r \qquad (11)$$

Where P_r and P_t are the received power, and the transmitted power respectively, and G_t and G_r are the transmitting antenna gain, and the receiving antenna gain respectively, R is the distance between transmitting and receiving antennas, and λ is the wavelength.

The power transmitted from the eNode to the u$_{th}$ user in the n_{th} TTI, can be calculated from the Friis equation as:

$$P_{t_u}(n) = \left(\frac{4\pi R_u(n)}{\lambda}\right)^2 \frac{P_{r_u}(n)}{G_t G_{r_u}} \qquad (12)$$

Where $R_u(n)$ is the distance between the eNode and the u$_{th}$ user at the n_{th} TTI, $P_{r_u}(n)$ is the received power at the u$_{th}$ user in the n_{th} TTI, $G_{r_u}$is the u$_{th}$ the user receiving antenna gain, and G_t is the transmitting antenna gain. For simplicity, it is assumed that the transmitting antenna gain and all receiving antenna gain equal unity.

The metric of PBWPF algorithm is given by:

$$m_{u,k}^{PBWPF}\,(n) = \begin{cases} 0, & b_u\,(n) = 0 \\ \frac{d_{u,k}\,(n)}{P_{t_u}(n) * TH_u\,(n-1)}, & b_u\,(n) > 0 \end{cases} \qquad (13)$$

4.2. Power-Efficient Delay-Aware Proposed Scheduling Algorithm

The metric of the new Power Efficient– Delay Aware (PE-DA) proposed scheduling Algorithm can be expressed as:

$$m_{u,k}^{PE-DA}\,(n) = \begin{cases} 0, & b_u\,(n) = 0 \\ \frac{D_u\,(n) * d_{u,k}\,(n)}{P_{t_u}(n) * TH_u\,(n-1)}, & b_u\,(n) > 0 \end{cases} \qquad (14)$$

It is clear from the PE-DA previous metric equation that the algorithm gives priority of allocating RBs to the user which have largest delay and lowest transmitted power.

5. SIMULATION RESULTS

In this section of the paper, performance analysis of the proposed PE-DA algorithm will be introduced and compared with other algorithms like MT algorithm, PF algorithm, and DBWPF algorithm. Table I introduces the most important simulation parameter and conditions used in the simulation environment.

Table I. Simulation Parameters

Parameters	**Value**
Simulation time	100 s
Bandwidth	10MHz which means (50 RBs per TTI)
Carrier frequency	1.9 GHz
Number of users	20:120
User speed	40 Km/h
Packet arrival	Poisson arrival
Packet size	8 Kbit
Traffic volume	Uniformly distributed in range[0.2-0.6] Mbps for each user
Distance from users to eNodeB	Uniformly distributed in range[100-1000] meter for each user
(β)	0.01
(δ)	40 Kbit

Fairness index calculation for throughput, delay, or any other parameter can be calculated using the well-known general Jain's fairness equation [17], which can be expressed as:

$$J^{fairness} = \frac{\left(\sum_{u=1}^{U} x_u\right)^2}{U \sum_{u=1}^{U} {x_u}^2} \qquad (15)$$

Where U is the number of users which fairness calculated between them, and (x) represents the parameter in which we want to calculate the fairness index for it like throughput, delay, or any other parameter.

Figure 3 displays the overall throughput achieved in the overall network for a different number of UEs. When there are a few numbers of UEs, twenty or forty users only, it is clear that all the five scheduling algorithms obtain the same throughput. In this case, the reason behind this is when the number of UEs is small, the network traffic size is also small. Therefore, the entire data in any UEs buffers will be delivered to the received user by implementation of any one of the five algorithms, so the aggregate throughput nearly equals the traffic volume. With increasing in the number of UEs, MT algorithm achieves the highest throughput, while PBWPF algorithm and the proposed PE-DA algorithm achieve the second-largest throughput after the MT algorithm.

Figure 4 shows that if the number of UEs is about twenty or forty users only, all algorithms have equal throughput fairness. In the case of a small number of UEs, the cell traffic size is small and any UE will achieve a throughput approximately equivalent to its traffic volume by using any one of the five scheduling algorithms. When a number of UEs is relatively high, the PF algorithm achieves the maximum throughput fairness index, while the proposed algorithm (PE-DA) achieves a throughput fairness value with a small degradation from the highest value obtained by the PF algorithm.

Figure 5 shows the delay fairness for a different number of users. It is clear from the figure that DBWPF achieves the highest delay fairness value, and this is because of the original goal of the DBWPF algorithm is to serve the UE with considerable delay first to decrease its delay as much as possible and so, guarantee good delay fairness between all users. It is also shown from Figure 5., that the proposed scheduling algorithm (PE-DA) achieves a delay fairness index very close to that of DBWPF algorithm, and this is because the priority metric of the proposed algorithm gives a weight for users average delay as same as in DBWPF algorithm.

As can be seen from Figure 6, the PBWPF algorithm achieves the lowest average transmitted power from the eNodeB, while the proposed PE-DA algorithm achieves average transmitted power with a slight increment of that achieved by the PBWPF algorithm. The figure also shows that MT, PF, and DBWPF algorithms required high average transmitted power compared with the proposed algorithm.

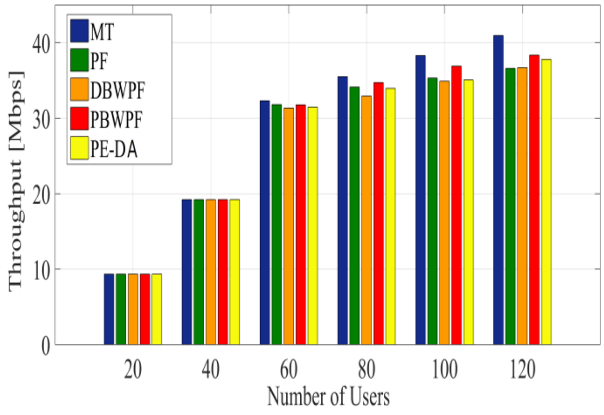

Figure3. Overall throughput of the cell for different number of users

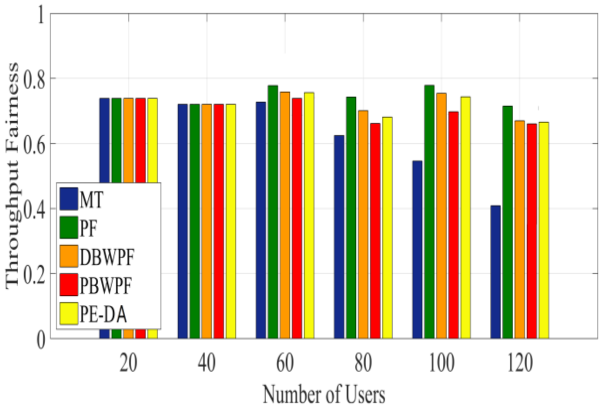

Figure 4. Throughput fairness for different number of users

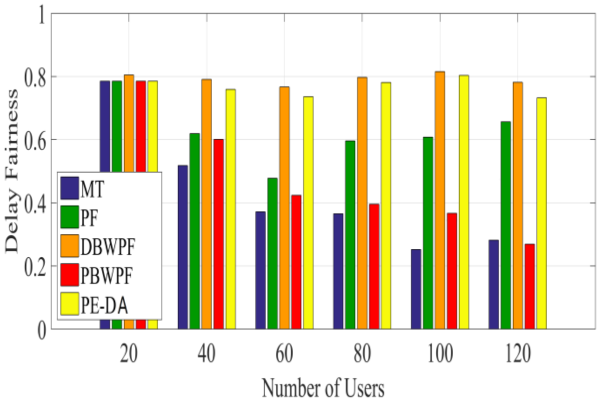

Figure 5. Delay fairness for different number of users

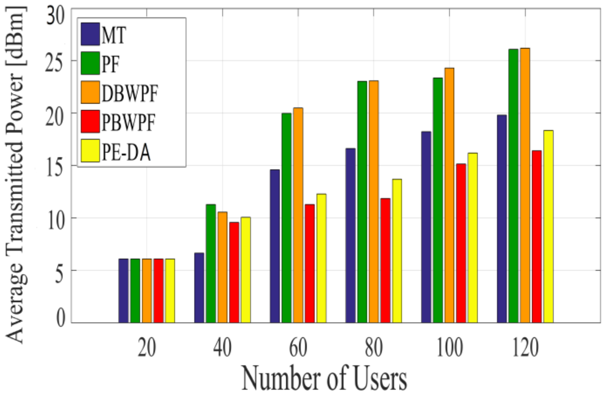

Figure 6. Average transmitted power for different number of users

From all the previous figures, it is clear that although PBWPF algorithm is the best algorithm from power consumption reduction point of view, it has a very bad performance from a delay fairness point of view. On the other side,there is no doubt that the novel proposed PE-DA algorithm preserves a reasonable power consumption reduction, and at the same time maintains delay fairness very closed to that of DBWPF algorithm.

6. CONCLUSION

This paper proposes the PE-DA algorithm, which considered a power-aware, and at the same time a delay aware scheduling algorithm. By this scheduling algorithm, the user with larger delay and lower power consumption will have the priority to get resources. The proposed algorithm performs better than MT, PF, and DBWPF from power consumption reduction point of view, and at the same time maintains delay fairness very closed to that of DBWPF algorithm. The proposed algorithm is considered a suitable algorithm for LTE downlink scheduling when the matter concerns power reduction and delay fairness.

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