Current Developments in LTE/LTE-Advanced : Adaptive-Proportional Fair Scheduling in LTE

M. K. Ismail, A. A. M. Isa, M. S. Johal, M. S. I. M. Zin
Centre for Telecommunication Research and Innovation, Faculty of Electronic and Computer Engineering,
Universiti Teknikal Malaysia Melaka, Malaysia
azmiawang@utem.edu.my

***Abstract*—This paper provides analytical expressions to validate and evaluate the performance of Long Term Evolution (LTE) network in terms of throughput, spectral efficiency and SINR which are subjected to the constraint of proportional fairness amongst users from the EnodeB. The proportional fair scheduling (PFS) algorithm is mainly focused on bandwidth allocation criterion in LTE networks for supporting high resource utilization while maintaining high fairness among network flows to each distributed User Equipment (UE). The most challenge of a PFS problem is the lack of analytic expression. Though the PFS algorithm has been a research focus for some time, the results are mainly obtained from computer simulations. The current existing research applies a simplified form of the PFS preference metric and the given analytic expression is capable to support certain cases. The proposed model is refined with respect to uniform modulation and coding, as applied in LTE networks. Besides, we show that our models are approximate estimates for the performance of rate-based proportional fair scheduling, while they outperform some simpler prediction models from related work significantly.**

***Index Terms*—LTE, OFDMA, Proportional Fair Scheduling, Throughput, SINR.**

I. INTRODUCTION

LTE Release 10 has been finalized at the end of 2011 by Third Generation Partnership Project (3GPP) which conforms to the IMT-Advanced specifications. Currently, the LTE Release 11, 12 and 13 that are the enhancements of the previous completed LTE Release 10 specification are being researched to provide better performance. The capability of LTE-Advanced are highly recommended by 3GPP because it can support transmission bandwidths up to 100MHz and increase the capacity of the User-Equipment (UE) during transmission and reception processes [1] [2].

Orthogonal Frequency Division Multiple Access (OFDMA), which is a combination of OFDM and FDMA that use modulation/multiple access techniques, has been recommended by the ITU as the core PHY layer technology for the next generation of LTE-Advanced systems [1] because it is a promising air interface technique for the next generation of broadband wireless system. OFDMA offers flexibility in radio frequency allocation and it is an inherent resistance to frequency selective multi-path fading. This modulation/multiple access technique has been incorporated in the IEEE802.16e/m (Mobile WiMAX) and 3GPP Long Term Evolution standards due to its superior properties.

One of the key components of OFDMA is referred to as Radio Resource Management (RRM) which is critical in achieving the desired performance by managing key components of both PHY and MAC layers [3]. This component is also crucial for OFDMA wireless broadband networks where scarce spectral resources are shared by multiple users in the same channel of transmission and they are just separated by different subcarriers. This concept is well developed and a number of techniques are already existed and implemented in the latest released of IEEE802.16m and 3GPP Release 10.

In wireless communication, scheduling plays as an important element of system performances like throughput, delay, jitter, fairness and loss rate [4]. Different from wired cases, scheduling in LTE networks need to consider the unique characteristics such as location-dependent channel status and time varying. Among various related researches on scheduling, the proportional fair scheduling (PFS) algorithm has been widely conceived as an attractive solution since it provides a good compromise between the maximum throughput and user fairness by exploiting multi-user diversity and game-theoretic equilibrium in fading wireless environment [5]. Referred to the low implementation complexity and good performance, the PFS scheduler has received much attention for some time [6] [7]. Currently, [7] and [8] analyzed the PFS algorithm with the objective of obtaining an analytic expression for the throughput. Using the ratio of the instantaneous signal to interference-plus-noise ratio (SINR) to the average SINR as the preference metric instead of the original PF metric of the ratio of the feasible rate of the average rate (or throughput), by assuming the SINRof user follows exponential distribution, [8] obtained an analytic expression for the user throughput of PFS. Meanwhile, the closed-form expression obtained is valid only for networks where there are large numbers of user[7]. Though the analytic results given in [8] and [7] are obtained either for a simplified form of the original PFS preference metric or for large user number case, so far as we know, the formula presented in [8] and [7] are the only two closed-form expressions available for the throughput of the PFS algorithm. In this paper, we analyze the PFS scheduler under various realistic network platforms and derive accurate closed-form expression for both network throughput and user throughput without the limitation of [7] and [8].

The rest of the paper is organized as follows. In Section II, we recapitulate the principles of the PFS algorithm approximation to channel throughput. Then, we describe a simple mathematical model of the user throughput and the network throughput of PFS in an environment in Section III. In Section IV, simulations are conducted to validate the analytic expression for various scenarios. In particular, we show that our closed form formulae for the throughput of PFS provide highly accurate estimates of simulation results. We give a brief conclusion. Lastly, in Section V our conclusion was intended to summarize the discussion.

II. PROPORTIONAL FAIR SCHEDULING PREPARATION

In this section, we first described the principles of the PFS algorithm and how it affected the instantaneous data rate.

Consider a single-cell system shown in Figure 1, *N* mobile users (denoted as users *m1, m2*, …, and m_N) are randomly located within the cell served by a eNodeB (eNB).

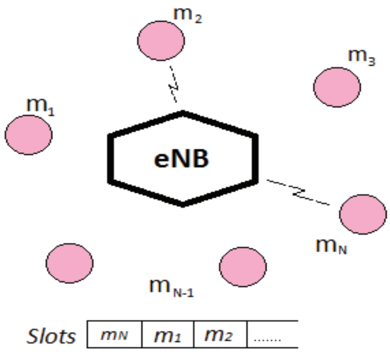

Figure 1: Single-cell Networks

Consider the problem where these *N* users wishing to transmit data from the base station to *N* destinations. The data rates of transmission will be randomly varying. Time is divided into small scheduling intervals, called slots. Until further notice, in each slot only one user is chosen to transmit. In next scheduling slot, the system will estimate the rates by estimating the SINR, by the use of a pilot signal broadcasted periodically, with a very short delay. The selection of the user to schedule is based on a balance between the current possible rates and fairness. The proportional fair scheduling (PFS) algorithm [4] [7] [10] [11] performs this by comparing the ratio of the feasible rate for each user to its average throughput tracked by an exponential moving average, which is defined as the preference metric.

The packet scheduling of data is one of the critical technologies in transporting multimedia traffic across wireless networks to provide QoS differentiation and guarantees because it determines the overall behaviour of the system.The dynamic scheduling is a basic operation of the scheduler and it is functioning to transmit scheduling information about 1ms Transmission Time Interval (TTI) from the BS to the selected terminal [12]. Besides that, the other dynamic scheduling capabilities are to control both uplink (UL) and downlink (DL) transmission activities slot [13]. This is described mathematically as follows.

III. SYSTEM MODEL

Basically, we consider the down-link of a LTE OFDMA systems and time is divided into transmission slots considered with index *t*. The slots are also referred to as Transmission Time Intervals (TTI) in the LTE context. They have a duration of T TTI seconds. Orthogonal frequency division multiplexing (OFDM) is the basic transmission scheme. Hence, the system bandwidth *B* is split into many subcarriers out of which R adjacent ones are always bundled together for resource allocation. We refer to these bundles as resource blocks (RBs) and assume that there are N such resource blocks in the system. A resource block is the smallest frequency unit of resource allocation at the base station.

We will evaluate based on the throughput, Signal-Interference-Noise ratio (SINR) and spectral efficiency as our indicator to show the improvement of this enhancement algorithm.

In this part, we defined the time-domain of scheduling such as in the case of NFSS scheme. Implement proportional fair scheduling (PFS), eNB assigns the *n*th subframe to each UE *m** [9].

$$m*(n) = arg \max_{m=1,2,\ldots,M} \frac{[R_m(n)]^{\alpha}}{[T_m(n)]^{\beta}} \qquad (1)$$

Where *Rm (n), m = 1,2,….M* defined as the data rate for *m*th UE in the *n*th subframe scheme. For the average throughput, T_m *(n)* is considered as *m*th UE in the past window and will be updated at each subframe based on the:

$$T_m(n+1) = \begin{cases} \left(1-\frac{1}{t_c}\right) T_m(n) + \left(\frac{1}{t_c}\right) R_m(n), m = m*(n) \\ \left(1-\frac{1}{t_c}\right) T_m(n), \qquad m \neq m*(n) \end{cases} \qquad (2)$$

Where t_c is defined as the window length and the fairness over a predetermined time-horizon where it can be adjusted by tuning this t_c it. We considered that PFS algorithm schedules an UE when its channel quality is better than its average channel quality condition over the time scale t_c. When t_c value is getting smaller, the fairness over short time periods will become maintain, but the delay sensitive services could occur. In addition, the smaller value of t_c will make the user scheduled at relatively lower peaks reducing the gain of scheduling. For larger value of t_c, throughput is averaged and the scheduler will be able to wait longer before scheduling a user at its peak. Besides, the largest value of t_c could cause the system throughput improved at the expense of increased latency.

The PFS algorithm basically can be maximized [9] based on :

$$\sum_{m=1}^{M} \log(T_m) \qquad (3)$$

Where T_m is long term average throughput for each UE, m. The system utility function of PFS algorithm can be referred to the log (T_m) that can be interpreted as the level of satisfaction or utility of UE, *m* :

$$U(n) = \sum_{m=1}^{M} \log[T_m(n)] \tag{4}$$

For this system model, we implement eNB transmission to the UE user *m** in the *n*th subframe :

$$m*(n) = arg \max_{m=1,2,\dots,M} U(n+1|m) \tag{5}$$

Which

$$U(n+1)|m) = \sum_{m=1}^{M} \log\ [T_m(n+1|m)] \tag{6}$$

Where $T_m(n+1|m)$ distributes $T_m(n+1)$ which n subframe was scheduled to the UE, m. the reason PFS algorithm is scheduling at UE in the subframe n is because it will give the highest instantaneous rewards for the utility function system *U(n)*.

So, in this paper, we able to rewrite the general form of scheduling expression as:

$$m*(n) = arg \max_{m=1,2,\dots,M} \frac{[R_m(n)]^{\alpha}}{[T_m(n)]^{\beta}} \tag{7}$$

In this case, we could apply these α and β parameters inside the a-PFS algorithm to improve the LTE downlink system by referring to the channel quality or data rate *R*.

IV. EXPERIMENTAL ANALYSIS OF PFS SCHEDULING

Optimal solutions in such a scenario with our objectives of throughput and QoS is prohibitively complex. However, the parameters of α and β in Equation 7 can still be used to improve the performance of PFS scheduling schemes. Our model is motivated by the LTE system for high-speed data transmission in wireless networks. We assume a base station transmitting data to UEs, *m* in high mobility to validate the capability of PFS algorithm. Time is divided into time slots. In each time slot the base station can transmit to at most one user.

For the first step we apply all these parameters considered in this system as a benchmark to show that by using α and β parameters could improve the throughput, Signal-Interference-to-Noise Ratio (SINR) and spectral efficiency of the LTE system.

Table 1
Simulation parameters

Parameter	Value
Total Bandwidth	3 MHz
User distances	100 meters
UE speeds	139 km/h
Total frequency	2.1 GHz
Transmission-Time-Interval (TTI)	1000 subframes
Network geometry	Regular hexagonal grid
Transmission mode	Close loop spatial multiplexing (CLSM)
Total power	1 W

A. *Offline PFS Algorithm*

In this part of PFS algorithm, we simulated a basic simulation of LTE downlink by applying just a single cell with 10 UEs inside the cell. All the performance in this simulation will be an indicator for the next performance of α and β parameters in PFS algorithm.

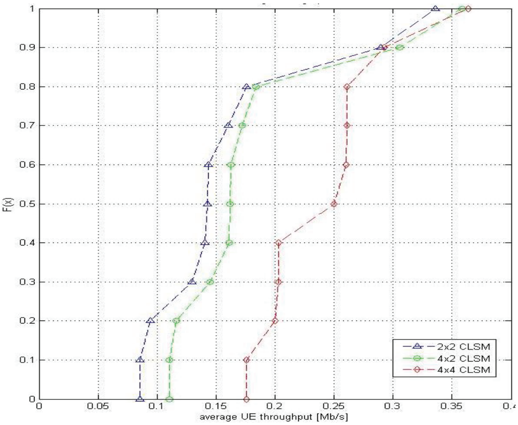

Figure 2: UE Average Throughput

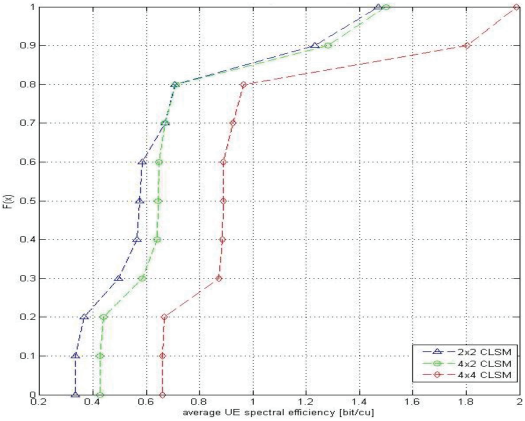

Figure 3: UE Average Spectral Efficiency

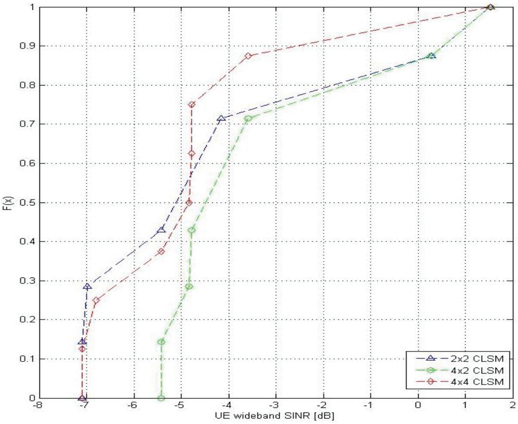

Figure 4: UE Wideband SINR

These three basic simulations were set up to determine the current simulation done by previous researchers about the LTE downlink system. Figure 2 simulates average UE throughput by applying different spatial multiplexing techniques (2x2, 4x2 and 4x4) number of transmit and receive antennas. In this figure, 4x4 spatial multiplexing takes the highest throughput ,although at certain points, the throughput is slidely drop comparable to 2x2 and 4x2 spatial multiplexing techniques. It may refer to the channel quality of distributing UE that locates at the edge of the cell. Meanwhile, for Figure 3 , it shows the performance of average UE spectral efficiency with similar spatial multiplexing technique from Figure 2. Lastly, Figure 4 indicates the average UE wideband SINR. All these basic simulations will be a threshold before we implement α and β parameters to validate the overall system performances

B. *Online PFS Algorithm (α = 1, β = 0)*

Here, we consider *α = 1 and β = 0* in the PDF algorithm to validate the performance of LTE system based on throughput, SINR and spectral efficiency.

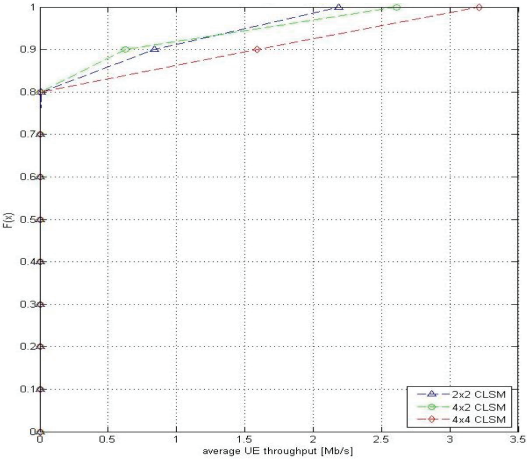

Figure 5: UE Average Throughput (α = 1, β = 0).

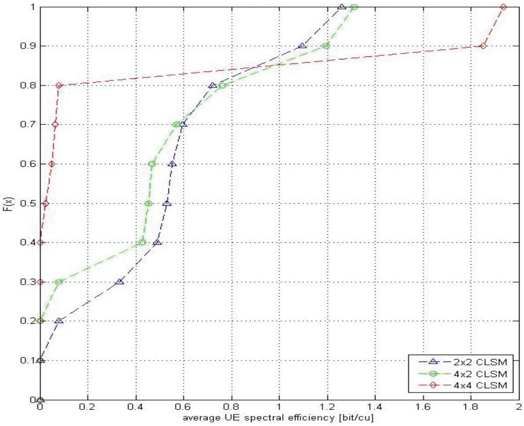

Figure 6: UE Average Spectral Efficiency (α = 1, β = 0).

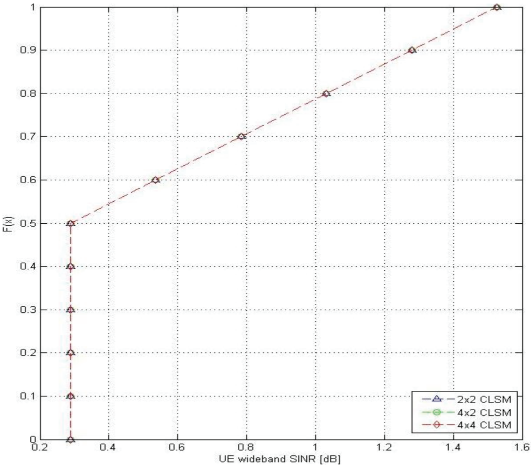

Figure 7: UE Wideband SINR (α = 1, β = 0).

From Figure 5, we can observe that for average UE throughput, in all spatial multiplexing techniques. It has beene increased almost 23% from the offline PFS algorithm. However, for average UE spectral efficiency in Figure 6, the result shows that these three spatial multiplexing techniques experience a drop efficiency about 13% from the original scheduler. In Figure 7, the UE wideband SINR also shows an overlapping result, each of the three techniques and abilities are still the same. This shows that this algorithm stabilizes each of the techniques used, although the highest spatial multiplexing could show better performance.

C. *Online PFS Algorithm (α = 0, β = 1)*

Next, we consider *α = 0 and β = 1* in the PDF algorithm to validate the performance of LTE system based on throughput, SINR and spectral efficiency.

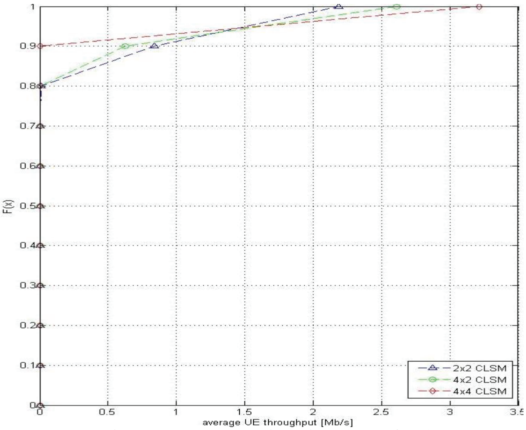

Figure 8: UE Average Throughput (α = 0, β = 1).

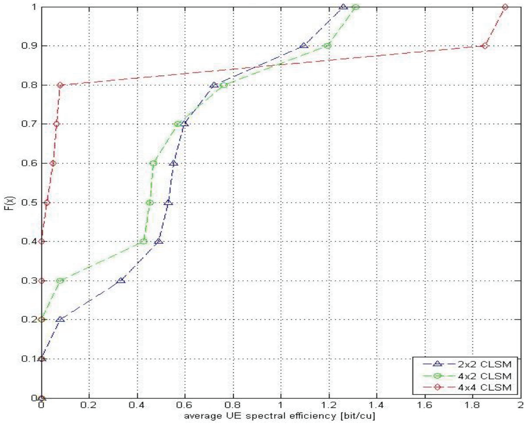

Figure 9: UE Average Spectral Efficiency (α = 0, β = 1).

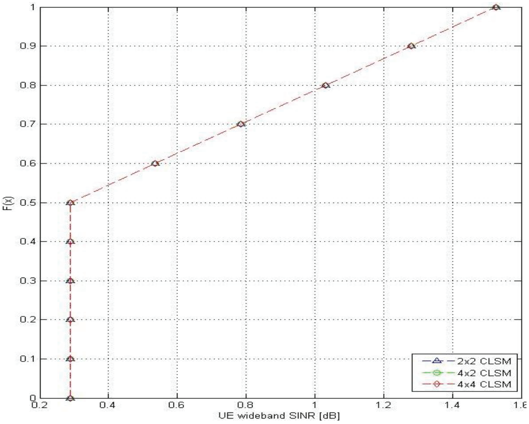

Figure 10: UE Wideband SINR (α = 0, β = 1).

For this part, we can observe that throughput performance in Figure 8 increased about 23% same as to Figure 2. Meanwhile for Figure 9, the average spectral efficiency dropped slightly to 10% from the offline algorithm. Lastly in Figure 10, the UE wideband SINR also indicates an overlapping performanes for all spatial multiplexing techniques. All the simulation of these a-PFS algorithm have the same performance results as shown in previous figures for *α = 1, β = 0*. It is likely that this algorithm is able to duplicate the abilities of a-PFS algorithm (*α = 1, β = 0)* based on a specific measured parameter, average UE throughput, spectral efficiency and wideband SINR.

D. Comparison Online A-Pfs Algorithm With Higher Bandwidth.

Here, we test a-PFS algorithm with higher bandwidth from before to compare the performance of LTE system. Besides, the throughput of this PFS algorithm is divided into peak, average and edge throughput to validate the capability of this algorithm in order to increase the overall system performance. Below are the simulation setup to validate this algorithm :

Table 2
Simulation parameters

Parameter	Value
Total Bandwidth	20 MHz
User distances	100 meters
Number of UEs	10
UE speeds	139 km/h
Total frequency	2.1 GHz
Transmission-Time-Interval (TTI)	1000 subframes
Network geometry	Regular hexagonal grid
Transmission mode	Close loop spatial multiplexing (CLSM)
Total power	46 dBm

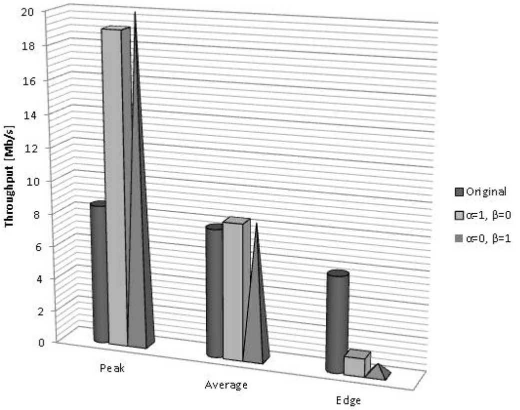

Figure 11: Comparison between peak, average and edge throughput.

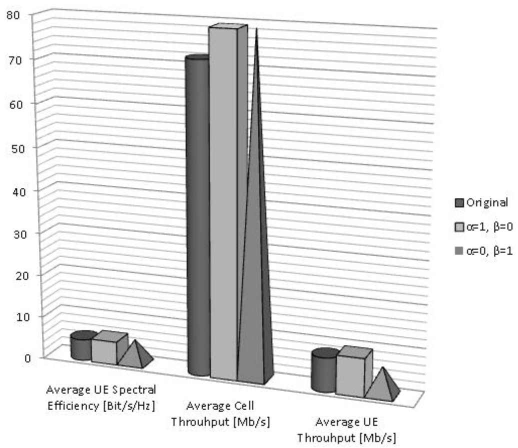

Figure 12: Overall performance of PFS algorithm.

From the observation of these two graphs, we can see the overall performances of *(α = 0, β = 1)* are getting decreased especially from the aspects of UE, *m*. In Figure 11, we can also observe that the performances *(α = 0, β = 1)* algorithm for peak throughput is the highest result but it may cause throughput at the edge cell becomes worst. This is because the algorithm most likely serving all users equally without referring to the channel or data rate R. It can be seen from Figure 11 and 12, where the average throughput become the lowest compare from the others algorithm. However, the overall average UE spectral efficiency and average cell throughput of this algorithm increased from the offline a-PFS algorithm.

Meanwhile, for *(α = 1, β = 0)* algorithm makes overall measured parameters better than offline a-PFS algorithm. It can also be seen in Figure 11 and 12 where *(α = 1, β = 0)* algorithm schedules each UE, *m* with the best channel conditions and still consider the UE throughput, spectral efficiency and wideband SINR. It could also mean that the peaks of the weak UE may never overcome in channel quality and caused the weak UE, *m* may never scheduled. Besides, this algorithm is capable to maximize the system throughput system, but it may cause unfairness between UE, *m* inside the cell as can be seen in Figure 11 and 12. This algorithm performs a better result of throughput, spectral efficiency and wideband SINR.

V. CONCLUSION

This paper has discussed adaptive-PFS algorithm in the context of time-domain scheduling. The comparisons of simulation results have validated the analytic expressions presented in Section III and IV. Furthermore, this algorithm can be easily extended in frequency-selective scheduling for both Single Carrier-FDMA and OFDMA to overcome the unfairness problem in future research to make radio resource management developments in LTE system performance. As we know, scheduler is one of the most important RRM tools in delivering packet data either for downlink or uplink transmission precisely without experiencing any losses of data. Besides that, this tool is also responsible in ensuring the transmission throughput and Quality of Service (QoS) are maximized. For future investigation on effective packet scheduling, the process in designing the packet scheduler, one has to be concerned about delay requirements of scheduling, which may be represented by a time-utility function that can be set as the main priority and also the efficiency of radio resource usage.

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