Performance Evaluation of Proportional Fairness Scheduling in LTE

Yaser Barayan and Ivica Kostanic

Abstract **—In 3GPP LTE OFDMA cellular systems, radio resource scheduling schemes are significant processes in which the available scarce and prohibitively expensive radio resources are assigned to each active user efficiently in terms of quality of service (QoS). An efficient scheduling algorithm plays an important role for effective utilization of radio resources, high data rate, low latency, fairness among users within a system as well as for the entire system performance. This paper evaluates the performance of three basic packet scheduling algorithms in downlink 3GPP LTE cellular network under universal frequency reuse scheme by executing a simulation in different channel conditions in terms of maximum throughput and fairness metrics.**

Keywords – LTE, OFDMA, scheduling, proportional fairness.

I. Introduction

Long Term Evolution (LTE) is a standard in modern wireless communication network. Recently, the increasing demand for using web browsing, mobile TV, video streaming, VoIP ,and online gaming requires high data rate and low latency system. The LTE downlink is capable of supporting up to 3 to 4 times of spectral efficiency when compare to HSPDPA release 6 [1].

In order to achieve the high spectrum efficiency requirement, Orthogonal Frequency Division Multiplexing (OFDM) is used as a basic modulation scheme by 3GPP LTE network. The main idea of OFDM is to split the total available system bandwidth into a set of orthogonal subcarriers. The bandwidth of each subcarrier is narrower than the coherence bandwidth of the fading channel. OFDM access (OFDMA), a multiple access scheme used by the downlink of 4G LTE networks, is based on the OFDM technique and has the same immunity to inter-symbol interference (ISI) and frequency selective fading. Owing to these characteristics, OFDMA is chosen as one of the most suitable multiple access schemes in multiuser environment, as it is capable to provide radio resources to multiple user equipment (UEs) at the same time slot.

In 3GPP LTE network architecture, the eNodeB is the only node between the UE and the core network

Manuscript received June 30, 2013; revised July 17, 2013.

Y. Barayan is a PhD candidate in the Electrical and Computer Engineering Department, Florida Institute of Technology, Melbourne, FL 32901 USA, (phone: 321-961-8424; e-mail: ybarayan@my.fit.edu).

I. Kostanic is with the Electrical and Computer Engineering Department, Florida Institute of Technology, Melbourne, FL 32901 USA, (phone: 321-674-7189); e-mail: kostanic@fit.edu).

Therefore, the eNodeB is responsible for the radio resource management (RRM) functions such as transmission power management, mobility management and radio resource scheduling [2]. Since the bandwidth of wireless communication system is extremely scarce and very expensive, the RRM is central to OFDMA. Thus, the radio resource scheduling is a significant process in which the available limited resources are assigned to each active user efficiently in terms of QoS requirements.

Various scheduling strategies have been implemented in OFDMA systems. For example, a maximum rate scheduling is demonstrated to enhance both system throughput and fairness in multicarrier OFDMA systems [3]. In [4]-[6] proposed proportional fair (PF) scheduling algorithm that exploits the multiuser diversity to achieve fairness among users without sacrificing the system throughput. Resent researches [7]-[11] showed that if both a proper scheduling algorithm along with Adaptive Modulation and Coding (AMC) are utilized in radio resource allocation, substantial performance improvements can be achieved. Although The LTE standard provides a very flexible radio interface, the allocation of the radio resources is left to the equipment manufacturers. So long as the operation of the scheduler is not standardized, there are many different implementations and one is always faced with the question on how well a particular implementation of a scheduler perform in a given set of circumstances.

In this paper, we consider a scheduling algorithm; proportional fairness based scheduler. We perform evaluations of different approaches to a practical implementation of the algorithm through a custom LTE system simulator.

The remainder of this paper is organized as follows. In section II, the scheduling techniques in LTE are introduced, and different approaches that were tasted in the simulator are defined. Simulation setup and channel model are presented in details in section III. Simulation results are discussed in section IV and section V concludes the paper.

II. Scheduling Technoques in LTE

In the medium access control (MAC) layer of the eNodeB, the functionality of the scheduler is to distribute the radio resources among UEs served by a given cell and represents methodology for radio resource assignment. The throughput of each UE and the throughput of the entire cell area are affected by the methodology selected by the scheduling algorithm. Thus, there is a need to evaluate the efficiency of different scheduling methods prior to any practical deployment under most circumstances. The scheduling algorithm is indeed the core part that determines the overall

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

system performance in terms of throughput and fairness. A complete and deep survey of various wireless networks scheduling algorithms are presented and discussed in [12].

In 3GPP LTE networks, there are three basic scheduling algorithm types. They can be easily compared on the basis of fairness and overall throughput. One of the simplest scheduling algorithms is a Round Robin (RR) scheduling. RR provides fairness and identical priority among all UEs within a cell. It assigns the radio resources in equal time slots and in an ordered manner. RR schedules resources fairly, regardless of taking in consideration of the channel state conditions experienced by different UEs. However, it is less efficient in providing a high data rate to UEs. Consequently, it wastes some resources because it schedules resources from/ to UEs while the UEs are suffering from severe deep fading and less than the required threshold [13].

An opportunistic scheduler such as the Maximum Rate (MR) scheduling algorithm, on the other hand, prioritizes UEs which have favorable channel state condition. In other words, this scheduling algorithm schedules the UEs that have higher signal to interference plus noise ratio (SINR) above the required SINR threshold whereas it does not schedule those UEs which experience sever channel fading. As a result, the MR scheduling algorithm provides higher capacity and throughput than any other kind of scheduling algorithms. However, it completely ignores fairness among UEs within a cell. It is well known in wireless cellular systems that UEs located in different distances have different fading conditions. Consequently, scheduling the UEs that have high SINR leads to unfair resource allocation amongst UEs [14].

A Proportional Fair scheduling algorithm (PF) provides balance between fairness and the overall system throughput. It was first presented in code-division multiple access high data-rates (CDMA-HDR) [15, 16], but is now used extensively in OFDMA based systems as well. The algorithm tries is provide fairness among UEs while maximizing the system capacity. This is achieved by means of exploiting the multiuser diversity over temporally independent channel fluctuations.

The PF algorithm functions as follows: first, the eNodeB obtains the feedback of the instantaneous channel quality condition (CQI) for each UE k in time slot t in terms of a requested data rate $R_{k,n}(t)$. Then, it keeps track of the moving average throughput $T_{k,n}(t)$ of each UE k on every physical resource block (PRB) n within a past window t_c length. The parameter t_c controls the system latency, that is, if t_c is large, the scheduler approaches MR algorithm; if $t_c$becomes small, the scheduler becomes RR algorithm. The scheduling mechanism gives a priority to the UE k^* in the t^{th} time slot and PRB n that satisfy the maximum relative channel quality condition:

$$k^* = \arg\max_{k=1,2,..,K} \frac{\left[R_{k,n}(t)\right]^{\alpha}}{\left[T_{k,n}(t)\right]^{\beta}} \tag{1}$$

- If $\alpha = 1, \beta = 1$, (1) describes PF algorithm.
- If $\alpha = 1, \beta = 0$, it becomes MR algorithm.
- If $\alpha = 0, \beta = 1$, it denotes the RR algorithm.

The eNodeB updates $T_{k,n}(t)$ of the k^{th} UE in the t^{th} time slot using the exponential moving average filter below:

$$T_{k,n}(t+1) = \begin{cases} \left(1-\frac{1}{t_c}\right)T_{k,n}(t) + \frac{1}{t_c}R_{k,n}(t), k^* = k \\ \left(1-\frac{1}{t_c}\right)T_{k,n}(t)..........., k^* \neq k \end{cases} . \tag{2}$$

The PF scheduling algorithm treats the PRBs independently, and then updates the system in every time slots.

III. System model

A. Simulation Setup

This section presents the system level simulation platform used for the downlink of 3GPP LTE OFDMA. The platform is used to evaluate the performance of basic radio resource scheduling methods under universal frequency reuse. The cellular system deployment consists of 19 cells. The antenna configuration deployed in all cells is SISO (Single Input Single Output), namely omnidirectional antenna. A carrier frequency of 2 GHz FDD (Frequency Division Duplex) and a system bandwidth of 10 MHz are considered. The UEs are distributed randomly in the network. For each cell the radius is 500 meter as it is shown in Figure 1. The entire system bandwidth is divided into 50 PRBs. Each PRB is grouped into 12 adjacent subcarriers in frequency domain and the duration is one transmit time interval (TTI), namely 0.5millisecond and consist of 6 or 7 OFDM symbols. The power profile is considered consistent over all available subcarriers. The detailed simulation parameters are summarized in Table I.

B. Channel model

The wireless channel between the eNodB and the UE is prone to multiple fading sources. The large scale fading channel and small scale multipath fading channel for 3GPP LTE system (Urban-Macro cell Area) are considered in this paper can be expressed as in (3)[17].

$$PL_{j,k} = 128.1 + 37.6 * \log(d_{j,k}) + X_{\sigma} + \left|H_{k,n}\right|^2 \tag{3}$$

Where, $PL_{j,k}$ is the path loss between eNodB j and UE k at the distance $d_{j,k}$ in kilometer, X_{σ}represents the shadow fading has an independent lognormal distribution with a standard derivation of σ which is assumed in this paper σ=8dB, and the multipath fading coefficient $H_{k,n}$ is the frequency response of the time-variant channel of UE k on PRB n.

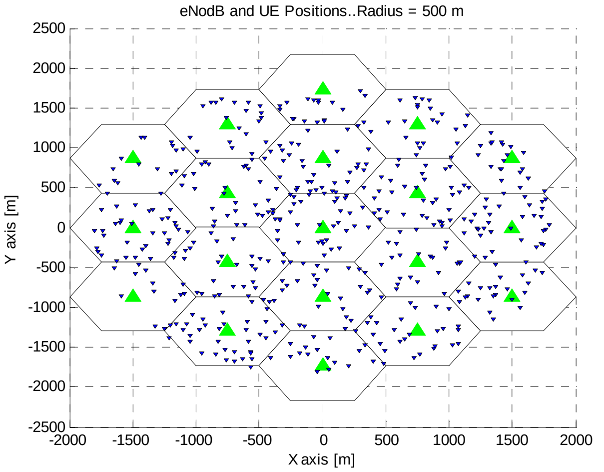

Figure1 System Configuration Model

TABLE I
SIMULATION PARAMETERS IN LTE

Parameters	Values
Cellular Layout	Hexagonal grid,19 cell Sites
Antenna Pattern	Omnidirectional Antenna
Number of transmitter antennas	1
Number of receiver antennas	1
Frequency re-use	1
Carrier Frequency	2 GHz
System bandwidth	10 MHz
Inter-Site distance	500 m
Minimum. distance between UE and eNodB	>=35 m
Distance-dependent Path loss	PL=128.1+37.6 $\log_{10}$(d) , d unit is in Kilometers
Lognormal Shadowing	Log Normal Fading with 0 mean , 8 dB standard deviation
BS transmit Power	46dBm(40 W)
UE Noise Figure	9dB
UE antenna gain	0dBi
Traffic Model	Full queue traffic
Link Adaptation	See Table II
Scheduling algorithms	Round Robin, Maximum Rate, Proportional Fair
Channel Model	EPA (3 km/h), EVA (30km/h), ETU (30km/h) [18]
Number of PRBs	50 (PDSCH)
Subcarriers per PRB	12
Subcarrier Spacing	15kHz
Frequency spacing of a PRB	180kHZ
Number of UEs per cell	Uniformly Distributed
AWGN p.s.d.(N_0)	-174 dBm/Hz
TTI duration	0.5msec (6 OFDM symbols)
Frame duration	10msec

The instantaneous signal to interference plus noise ratio ($SINR_{k,n}$) between serving eNodB j and UE k on PRB n can be modeled as

$$SINR_{k,n} = \frac{P^{S}_{RX_{j,k,n}}}{\sum_{j=1,S\neq I}^{q} P^{I}_{RX_{j,k,n}} + P_N} \quad (4)$$

Where, $P^{S}_{RX\,j,k,n}$ denotes the useful received power of serving eNodB j to UE k on PRB n, $P^{I}_{RX\,j,k,n}$ denotes the inter-cell interference (ICI) which is formed of the received power of the neighboring eNodBs on the same PRB n, and P_N is the white noise power. q indicates the total number of co-channel cells. j is the index of the co-channel cells.

Link adaptation is an important strategy in multiuser wireless environment, as it overcomes the fluctuations of the channel which is based on the Adaptive Modulation and coding (AMC) scheme. AMC is standard in 3GPP LTE technology [19].each UE have different SINR value and compare that value to the ACM mapping table II in order to determine the spectral efficiency of that UE [20].

TABLE II

ADAPTIVE MODULATION AND CODING SCHEME

CQI	Modulation Scheme	Coding rate	SINR(dB)	Spectral efficiency (Mbps/HZ)
0	-	-	-	-
1	QPSK	0.076	-7.27	0.1523
2	QPSK	0.12	-4.76	0.2344
3	QPSK	0.19	-2.06	0.377
4	QPSK	0.3	0.61	0.6016
5	QPSK	0.44	2.81	0.877
6	QPSK	0.59	4.69	1.1758
7	16QAM	0.37	6.29	1.4766
8	16QAM	0.48	8.69	1.9141
9	16QAM	0.6	11.37	2.4063
10	64QAM	0.45	13.11	2.7305
11	64QAM	0.55	16.44	3.3223
12	64QAM	0.65	19.62	3.9023
13	64QAM	0.75	23.01	4.5234
14	64QAM	0.85	26.19	5.1152
15	64QAM	0.93	28.66	5.5547

IV. SIMULATION RESULTS

This section presents simulation results to evaluate the performance of the three basic scheduling algorithm types in downlink LTE system. Figure 2, 3 and 4 provide the cumulative distribution functions (CDF) curves of cell's scheduling probability versus cell throughput under extended pedestrian A (EPA), extended vehicular A (EVA), and extended typical urban (ETU) channel models, respectively. It can be seen from the figures that the cell throughput by RR scheduling scheme reaches the lowest value, because RR algorithm does not take the multiuser diversity into account, whereas MR scheduling scheme achieved the highest cell throughput. The PF scheduling algorithm lay between the two which is the trade-off between the extreme fairness and extreme unfairness methods. It also can be seen from the figures that the cell throughput of the all scheduling algorithms increased when UE speed is increased. As we

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

exploit the frequency selectivity of fading channels as well as the multiuser diversity.

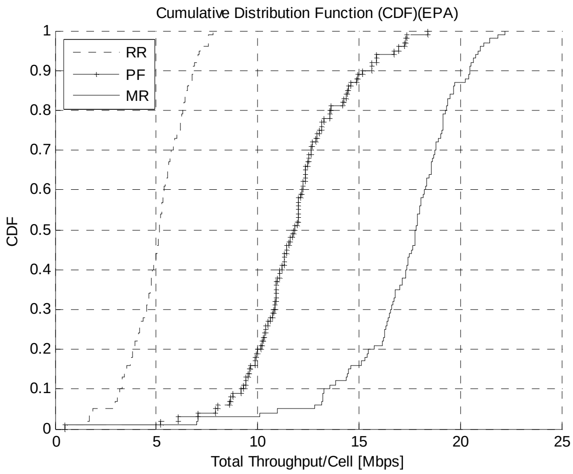

Figure 2 Central Cell Throughput for EPA Scenario

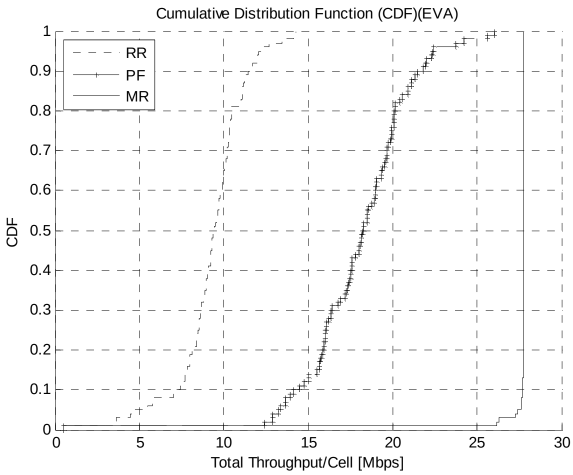

Figure 3 Central Cell Throughput for EVA Scenario

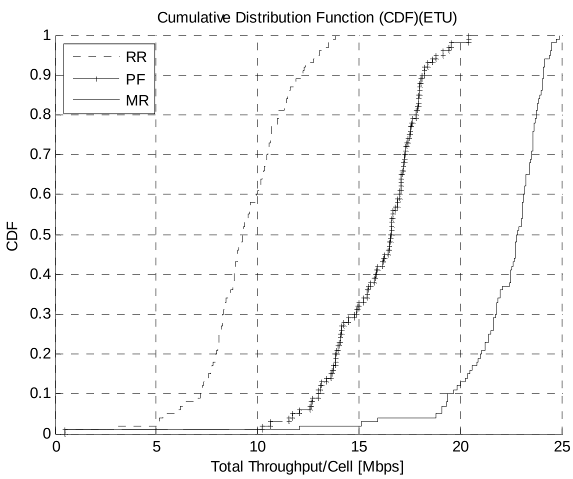

Figure 4 Central Cell Throughput for ETU Scenario

Figure 5 illustrates the distribution of the radio resources among UEs and we can see that the user which has the higher throughput is always selected by the (MR) scheduler. The light silver area in the figure represents resources assigned to a single UE. It can be seen that the MR allocated more PRBs to a UE because it has higher channel state condition. On the other hand, only a portion of RBs is assigned to the UEs with lower channel state conditions. Figure 6 shows the radio resource distributed among UEs and it can be observed that each UE take multiple RBs in the same time slots in the case of PF scheduling scheme. The RR scheduling scheme in Figure 7 shows that all the radio resources are distributed equally regardless of the channel state condition.

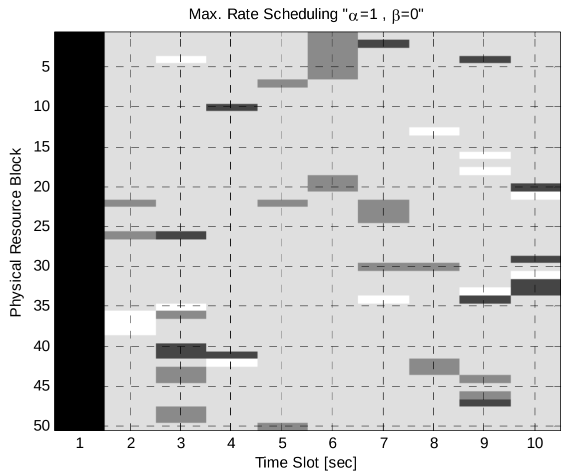

Figure 5 Distribution of PRBs for MR scheme

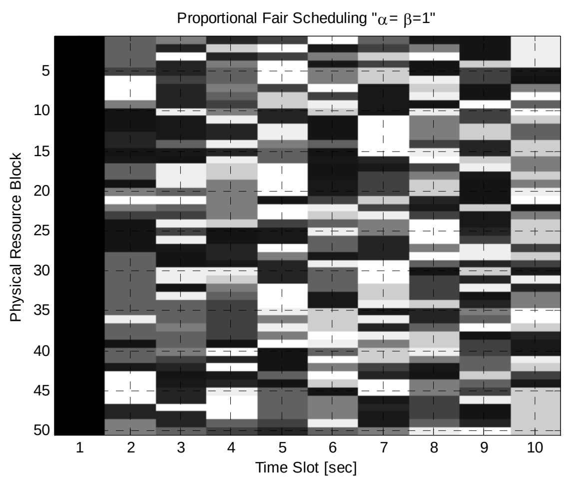

Figure 6 Distribution of PRBs for PF scheme

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

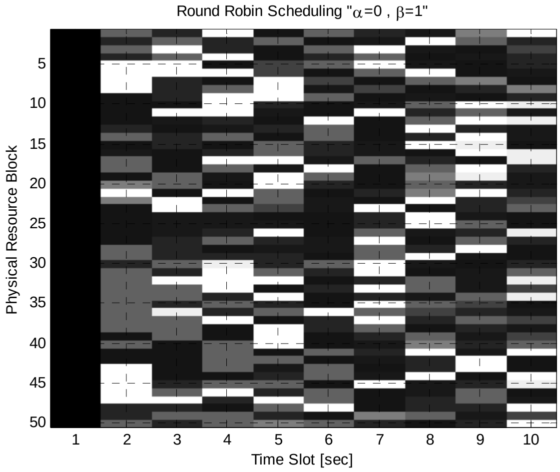

Figure 7 Distribution of PRBs for RR scheme

Figure 8, 9, and 10 represent the CDF curves of entire system's scheduling probability versus system throughput of the three basic scheduling algorithms under various channel conditions, respectively. It can be seen from the figures that PF scheduling is the balance between RR and MR in various channel models.

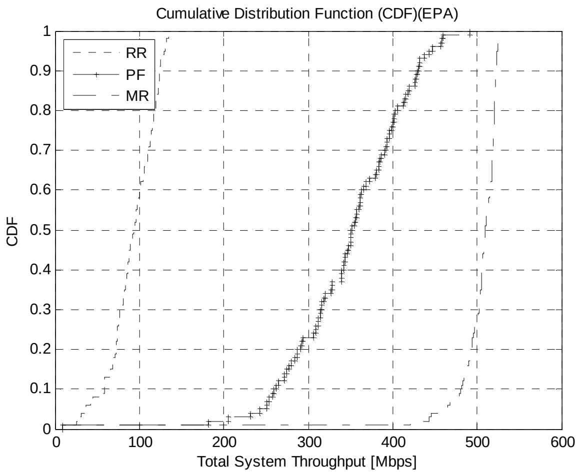

Figure 8 System Throughput for EPA Scenario

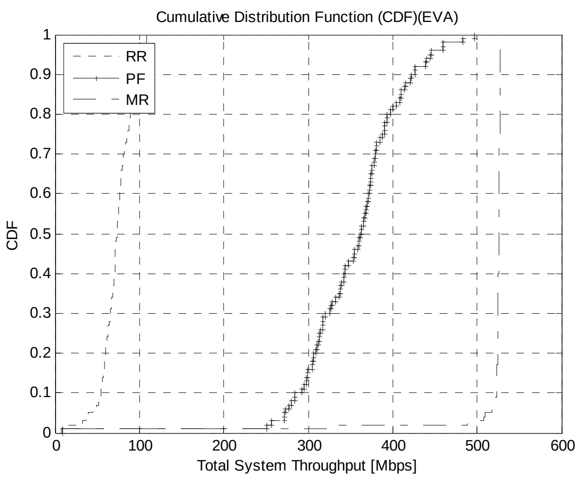

Figure 9 System throughput for EVA Scenario

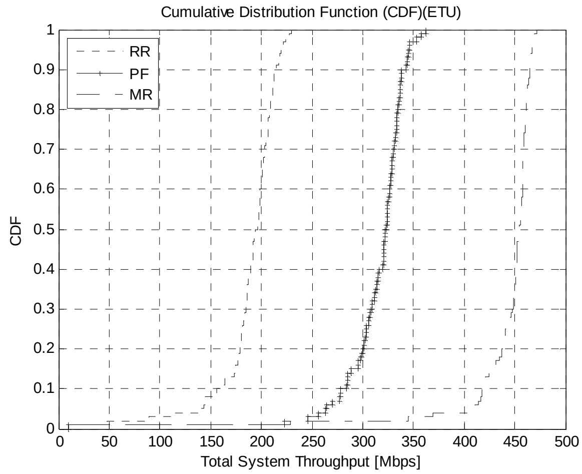

Figure 10 System throughput for ETU Scenario

V. Conclusions

In this paper, evaluations of three basic packet scheduling algorithms (MR, PF, and RR) for the downlink of 3GPP LTE systems are considered. As a platform for the evaluation of the algorithms, a system level simulation of the LTE was developed using MATLAB. The comparison among the algorithms is performed under various channel fading models. Simulation results illustrated that the MR algorithm achieved higher maximum rate, while RR provides maximum fairness among UEs. The PF scheduling method, on the other hand, achieved a good tradeoff between the throughput and the fairness among UEs.

References

[1] "Long Term Evolution (LTE): A Technical Overview". Motorola. Retrieved July 3, 2010.

[2] S. Hussain, "Dynamic Radio Resource Management in 3GPP LTE", Blekinge Institute of Technology, January, 2009.

[3] L. C. Wang and W. J. Lin, "Throughput and fairness enhancement for OFDMA broadband wireless access systems using the maximum C/I scheduling," in Proc Vehicular Technology Conference, 2004, pp. 4696-4700.

[4] I. Koutsopoulos and L. Tassiulas, "Channel state-adaptive techniques for throughput enhancement in wireless broadband networks," in INFOCOM 2001, vol. 2, 2001, pp. 757-766.

[5] H. J. Zhu and R. H. Hafez, "Scheduling schemes for multimedia service in wireless OFDM systems," IEEE Wireless Communications, vol. 14, pp. 99-105, Oct. 2007.

[6] N. Ruangchaijatupon and J. Yusheng, "Simple proportional fairness scheduling for OFDMA frame-based wireless systems," in Proc. IEEE Wireless Communications and Networking Conference, 2008, pp. 1593-97.

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

[7] R. Almatarneh, M. H. Ahmed, and O. A. Dobre, "'Frequency-time scheduling algorithm for OFDMA systems," in Proc. IEEE Canadian Conference on Electrical and Computer Engineering, 2009, pp. 766-771.

[8] C. Y. Wong, R. S. Cheng, K. B. Letaief, and R. D. Murch, "Multiuser OFDM with adaptive subcarrier, bit, and power allocation," IEEE J. Select. Areas Commun., vol. 17, no. 10, pp. 1747-1758, Oct. 1999.

[9] S. Pietrzyk and G. J. M. Janssen, "Multiuser subcarrier allocation for QoS provision in the OFDMA systems," in Proc. VTC 2002, vol. 2, 2002, pp. 1077-1081.

[10] Y. J. Zhang and K. B. Letaief, "Multiuser adaptive subcarrier-and-bit allocation with adaptive cell selection for OFDM systems," IEEE Transactions on Wireless Communicaitons, 3(4):1566-1575, September 2004.

[11] 3GPP, TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures". Version 8.8.0 Rel.8, 2009.

[12] Yaxin Cao; Li, V.O.K.; "Scheduling algorithms in broadband wireless networks," Proceedings of the IEEE , vol.89, no.1, pp.76-87, Jan 2001.

[13] Hahne, E.L.; "Round-robin scheduling for max-min fairness in data networks," Selected Areas in Communications, IEEE Journal on vol.9, no.7, pp.1024-1039, Sep 1991.

[14] Yueming Cai; Jiang Yu; Youyun Xu; Mulin Cai, "A comparision of packet scheduling algorithms for OFDMA systems," Signal Processing and Communication Systems, 2008. ICSPCS 2008. 2nd International Conference on, vol., no., pp.1-5, 15-17 Dec. 2008.

[15] Jalali, A.; Padovani, R.; Pankaj, R.; "Data throughput of CDMA-HDR a high efficiency-high data rate personal communication wireless system," Vehicular Technology Conference Proceedings, 2000. VTC 2000-Spring Tokyo. 2000 IEEE 51st , vol.3, no., pp.1854-1858 vol.3, 2000.

[16] Viswanath, P.; Tse, D.N.C.; Laroia, R.; , "Opportunistic beamforming using dumb antennas," Information Theory, IEEE Transactions on , vol.48, no.6, pp.1277-1294, Jun 2002.

[17] 3GPP TR 36.942 V10.2.0 "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) system scenarios".Release 10.

[18] Ericsson, Nokia, Motorola, and Rohde & Schwarz, "R4-070572: Proposal for LTE channel models," www.3gpp.org, 3GPP TSG RAN WG4, meeting 43, kobe, Japan, May 2007.

[19] 3GPP TS 36.213 V10.1.0, Technical Specification Group Radio Access Network (E-UTRA); Physical layer procedures, (2011-04).

[20] 3GPP TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures". Version 8.8.0 Release 8, 2009.

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)