Novel Scheduling Algorithms for LTE Downlink Transmission

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Abstract **— Long Term Evolution (LTE) is the new standard specified by 3GPP on the way towards the fourth generation mobile network. The LTE introduces enhanced data link mechanisms to support successful implementation of new data services across the network. The incorporated scheduling mechanisms can significantly contribute to this goal. In this paper novel scheduling algorithms are presented and compared to the Max C/I Downlink scheduler for LTE, which is characterized by high data rates at cell level, but poor fairness. The newly developed algorithms allow fair distribution of available resources. Simulation results presented in the paper show that the implementation of these newly developed algorithms enables improvement of the overall system capacity and user level performances.**

Keywords **— LTE, MAC layer, scheduling.**

I. Introduction

THE 3G Long-Term Evolution (LTE) is the next step towards the wireless broadband taken by cellular providers and equipment vendors. The LTE introduces evolved radio interface with major enhancement implementing advanced technologies such as Orthogonal Frequency Division Multiplexing (OFDM), multiple antenna techniques (MIMO), Orthogonal Frequency Division Multiple Access (OFDMA). It is designed to be an all-IP packet based system targeting provision of 300Mbps in the downlink and 75Mbps in the uplink. It contains fewer network nodes in the core network part, thus reducing protocol processing overhead and leading to reduced latency [1][2][3][4].

LTE can operate as a purely scheduled system (on the downlink shared data channel), meaning that all traffic including delay-sensitive services needs to be scheduled. The scheduling is a MAC (Medium Access Control) layer mechanism. Considering that the scheduling mechanism is not standardized but it is implementation specific, an efficient scheduling mechanism is a crucial differentiator among the different LTE network systems.

The design of a downlink scheduling algorithm is a complex procedure and presents a number of design challenges, such as maximization of the system capacity and spectral efficiency, fairness approach, bit error performances, etc. This paper presents two novel scheduling algorithms named MY_SCH_Not_Fair and MY_SCH_Fair. The performances of the system with implemented new algorithms are evaluated and compared to the performances of the system using the Maximum Carrier-to-Interference ratio (Max C/I) scheduler [1]. The Max C/I provides maximum system capacity but lacks mechanisms for fair distribution of the shared resources. The goals of the newly developed scheduling algorithms are to provide fairness in the distribution of the resources, while at the same keeping the system capacity utilization as high as possible.

The rest of the paper is organized as follows. Section II describes the LTE downlink framework. Section III describes the LTE scheduling strategies, the newly developed scheduling algorithms and their comparison with the Max C/I algorithm. Section IV describes simulation parameters. The results of simulations are presented and discussed in Section V. Section VI concludes the paper.

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II. LTE Downlink Framework

The LTE downlink transmission scheme is based on OFDM, preferable due to several reasons. The relatively long OFDM symbol time in combination with a cyclic prefix provides a high degree of robustness against channel frequency selectivity. The OFDM parameters and related definitions, (i.e. resource blocks (RBs)), timing and frequency settings, channel quality feedback and channel quality indicator (CQI)) are standardized according the 3GPP standards [5][6][7][8].

The basic principle for the downlink scheduler in LTE is to dynamically determine, which terminal(s) are supposed to receive Downlink Shared Channel (DL-SCH) transmission and on what resources, at every 1ms interval. The overall goal of the schedulers is to take advantage of the channel variations between the mobile terminals (users) and to schedule transmissions to a mobile terminal on resources with favorable channel conditions. Multiple terminals can be scheduled in parallel.

III. LTE Scheduling Mechanisms

A. Packet Scheduling

Different wireless users experience different channel conditions at a given time. At any given time there will be a high probability that some users will have good radio link condition. By scheduling such users, the shared channel resource is used in the most efficient manner and the total system capacity is maximized. Scheduling the user with the instantaneously best radio link conditions is referred to as Max-C/I scheduling. Mathematically, the Max-C/I scheduler is expressed as scheduling a user *k* given by

$$k = \arg\max_i R_i \quad (1)$$

where R_i is the instantaneous data rate for a user *i* [1]. In terms of fairness this scheduling principle is not fair in all situations and could be very biased. In real life, different mobile terminals will experience differences in the (short-term) average channel conditions, due to differences in the distance and shadow fading between the base station and the mobile terminal. In this case, for a relatively long time, the channel conditions experienced by one mobile terminal could be worse than the channel conditions experienced by other mobile terminals, and a max-C/I-scheduling strategy may 'starve' the mobile terminals with the bad channel condition in the way that the mobile terminal(s) with bad channel conditions will never be scheduled (i.e. example users at the cell edge). In a worst case scenario, (virtually all the time) only one user could be scheduled. Although resulting in the highest system capacity, this situation is often not acceptable from a quality-of-service point-of-view [1]. A different approach does not take into account the instantaneous channel conditions, but rather schedules all users sequentially, in a round-robin fashion. Performances of different scheduling algorithms for different scenarios and some improvement directions are investigated in [9], [10], [11].

A practical scheduler should be capable of exploiting the fast variations in channel conditions while still satisfying some degree of fairness between the users. The proposed scheduling algorithms tend to distribute the resources evenly among different users, therefore enabling fairness while at the same time trying to maximize system capacity performances within the cell. The following subsection briefly presents the referenced Max C/I algorithm and the proposed novel scheduling algorithms.

B. Novel Scheduling Algorithms

The following scheduling algorithms assume that in a real LTE system, the eNodeB would receive the CQI feedback as a matrix with dimensions Number_UEs x RB_grid_size. The value of each field in the matrix is the CQI feedback of each user for each RB. The specifics of each algorithm are as follows:

Max C/I – The Max C/I scheduler will find the maximum value for each RB. It will then search for the user(s) whose CQI feedback value equals the maximum found per each RB (if there is more than one user per RB that would have the maximum value, a random user would be picked), which could see one or more users scheduled with more RBs [12].

MY_SCH_Not_Fair – With the first developed algorithm, named MY_SCH_Not_Fair, a different user is scheduled for each RB. The algorithm finds the maximum value in the CQI_Feedback matrix, and schedules a user in the RB where he would experience the highest CQI value. Until the end of the TTI, this user will not have a permission to be scheduled. An outline of the algorithm would be as follows:

1) *Get the CQI_Feedback matrix;*
2) *Find the maximum value in the CQI_Feedback Matrix and corresponding user;*
3) *Schedule that user in that RB;*
4) *Until the end of the TTI, this user will not have permission to be scheduled;*
5) *Repeat this cycle until there are free RB left.*

This algorithm takes into consideration only the current TTI (transmission time interval), not the scheduling decisions from the previous TTI. The drawback is that it could still favor a large group of users.

MY_SCH_Fair - The second developed algorithm, named MY_SCH_Fair, is more complex, because the users that were not assigned any resources in the previous TTI are firstly scheduled, a different user is scheduled in each RB, the decision criterion is the same as in the first algorithm. An outline of the algorithm would be as follows:

1) *Get the CQI_Feedback matrix;*
2) *Find out which users were scheduled in the previous TTI, and don't take into consideration for this TTI;*
3) *Find the maximum value in the CQI_Feedback Matrix and corresponding user;*
4) *Schedule that user in that RB;*
5) *Until the end of the TTI, this user will not have permission to be scheduled;*
6) *Repeat this cycle until there are free RB left;*
7) *If there are available RBs left unused, perform normal scheduling, taking all users into consideration.*

The increased complexity compared to MY_SCH_Not_Fair is obvious, but the fairness distribution is maximized while keeping the criteria for scheduling the users on the RBs where they experienced best channel conditions.

The focus of both of the algorithms is to optimize the resource assignment in scenarios where the number of users is bigger than the number of available RBs ("overbooking"). It is considered that these scenarios represent a bigger challenge for the scheduling algorithm, how to serve as better as possible a large number of users, when the resources are limited, while ensuring to meet some kind od QoS metrics, fairness criteria, etc.

IV. SIMULATION PARAMETERS

The performance evaluation of the three scheduling algorithms (MY_SCH_Not_Fair, MY_SCH_Fair and Max C/I,) is done by using the LTE Link Level Simulator [12]. The Max C/I algorithm is named as Best-CQI in the simulator. The simulator is Matlab based and implements a standard compliant LTE downlink with its main features such as Adaptive Modulation and Coding (AMC), MIMO transmission, multiple users, scheduling, Hybrid-ARQ, etc [12].

The simulations cover single-cell multi user scenarios.

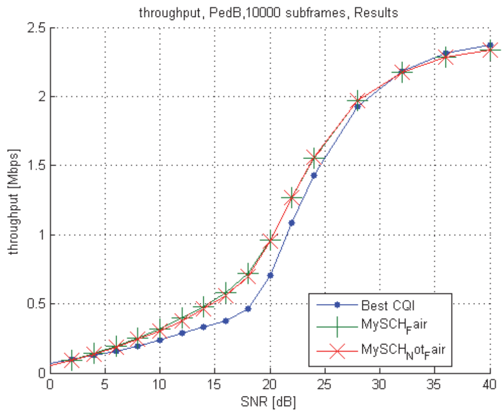
Simulations are performed for frequency-selective channels modeled by the ITU and 3GPP Power Delay Profiles (PDPs), for Pedestrian B (PedB) and Vehicular B (VehB) channel models [13]. Simulations are performed with a minimum specified bandwidth for LTE, (the 1.4MHz band), where six RBs are allocated. The multiuser scenarios consider 8 and 12 users (which is more users than available RBs), for SNR ranging from 0 to 40 dB. The simulation was performed for a time length equivalent of 10,000 subframes. These values are enough to present a Proof of Concept of the performances of the scheduling algorithms [12]. The distribution of users is semi-random, such that the first user experiences the best channel conditions and the last one has the worst channel conditions. For every multiuser scenario all three algorithms are tested, assuming the same user uniform distribution.

V. SIMULATION RESULTS

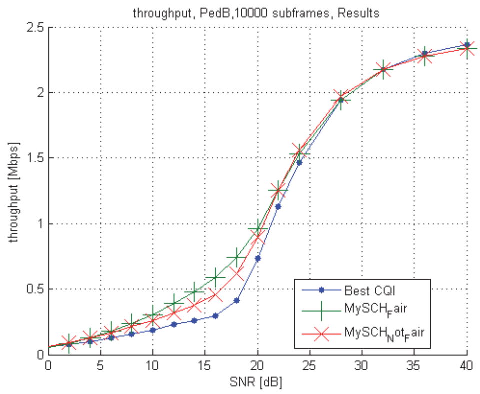
This section presents the results of the simulation-based evaluation of the scheduling algorithms. The relevant metrics include the overall cell throughput, overall cell BER and the selected user's throughput for each multiuser case and for both channel models.

Fig. 1.a and Fig. 1.b show the overall cell throughput for the PedB channel model for the 8 and 12 users environments. It can be observed that the newly developed scheduling algorithms have improved cell performances, especially in the SNR interval of 10-20dB. This is explained when examining more extensive simulation results, such as the CQI feedback of all users for the simulation intervals. Namely, below 10dB some users still return CQI value equal to "1" or very small values, CQI = 1, CQI = 2 or CQI = 3. From 20dB and higher the CQI feedback of all users throughout the cell is maximized and reaches "13" or "14" in the interval between 20-25dB, and a maximum value of "15" from 30dB and higher. The improvement in the performances due to the scheduler is up to 30% for the SNR values of 16-18dB. In this interval, the differences in the CQI feedback values among the users are most evident, and hence the scheduler performances are most obvious. In this interval the scheduling algorithm can perform the scheduling decisions on broader variety on users' channel conditions, which is exploited to maximize the system capacity and provide a fair distribution of the resources.

Fig. 2.a and Fig. 2.b show that the resulting degradation of overall cell error performances (the BER) is very small and negligible. Improving the downlink throughput performances over the shared wireless medium, at the expense of worsening the cell error performance is something which would not have been accepted. The novel scheduling algorithms provide cell BER performances which are at the same level with the Max C/I scheduler. The results show that it is possible to increase the system throughput, while at the same not drastically increasing the level of bit error rate, by implementing advanced techniques of scheduling and radio resource management.

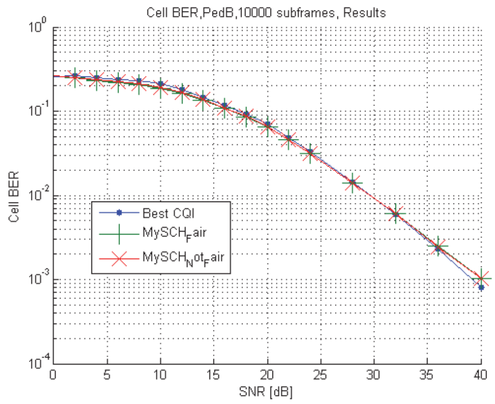


a. Overall cell throughput, PedB channel model, 8 users.

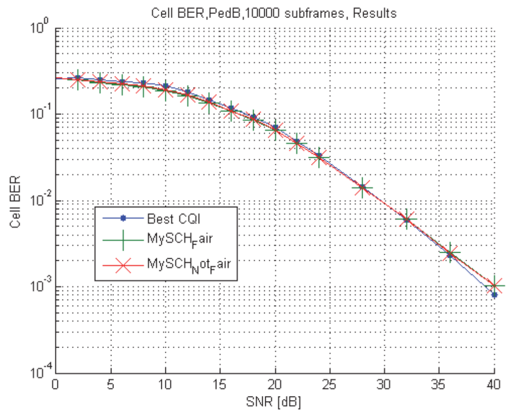


b. Overall cell throughput, PedB channel model, 12 users.

Fig. 1. Overall cell throughput, PedB channel model.



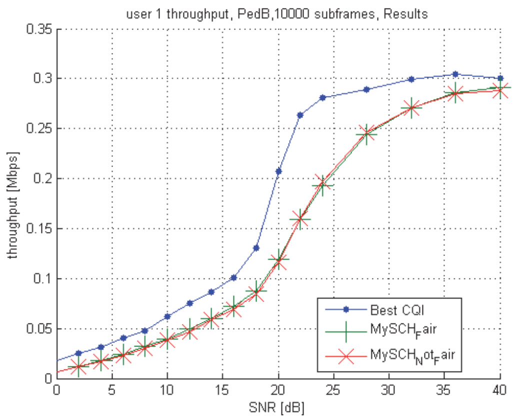
a. Overall cell BER, PedB channel model, 8 users.



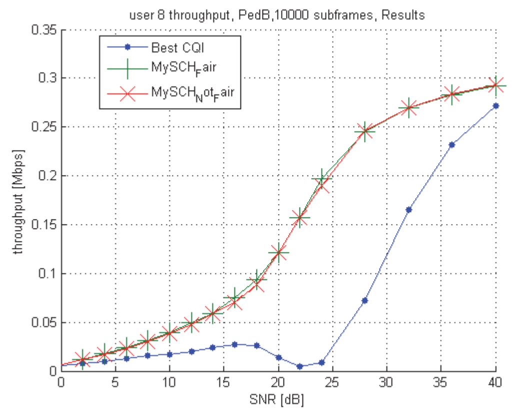
b. Overall cell BER, PedB channel model, 12 users.

Fig. 2. Overall cell BER, PedB channel model.

Fig. 3.a and Fig. 3.b, show the impact of throughput performances of the selected users for PedB channel model with 8 users simulation environment. UE1 (User Equipment - UE) and UE8 are selected, since as indicated in the previous section, UE1 always experiences favorable channel conditions, while UE8 experiences the worst channel conditions: the channel quality drops from UE1 to UE8 respectively. Fig. 4.a, Fig. 4.b and Fig. 4.c show the impact of throughput performances of the selected users for PedB channel model with 12 users simulation environment. UE1, UE8 and UE12 are selected due to the same reasons as above: UE1 always experiences the best channel conditions, UE12 always experiences the worst channel conditions (the channel quality drops from UE1 to UE12 respectively). UE8 experiences intermediate channel conditions and is selected to present the performances of the novel scheduling algorithms performances also for intermediate users' cases. Users with the best channel conditions experience degradation of performances, due to the "fairness approach", but the users with a bad channel that were previously not scheduled, with the new algorithms experience throughput performances that are balanced with the users with the best channel condition. Moreover, more extensive simulation results show that using the Best-CQI in some cases allows only one user to get all the available RBs (max of 6), which is a worst case scenario, proving that all other users are "starved" of resources. The new algorithms allow max two RBs per user (for the simulated users environments and system bandwidth).

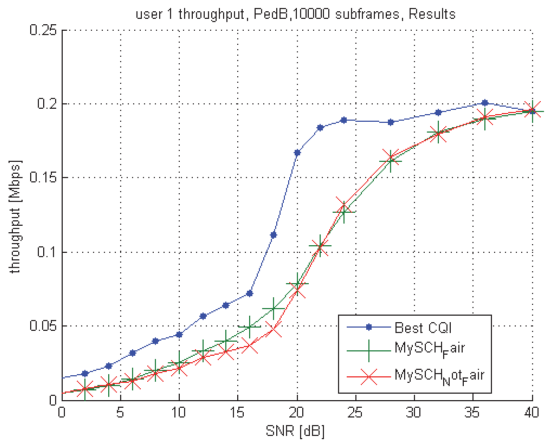


a. User 1 throughput.

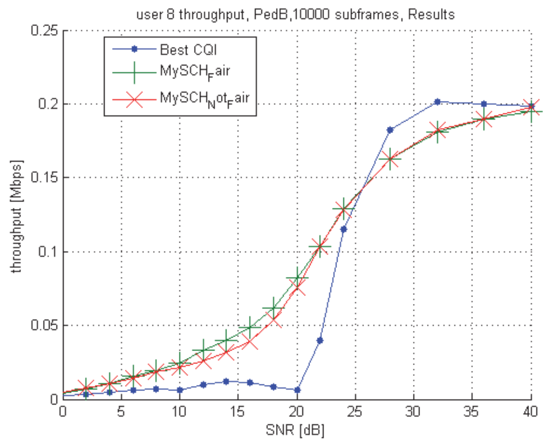


b. User 8 throughput.

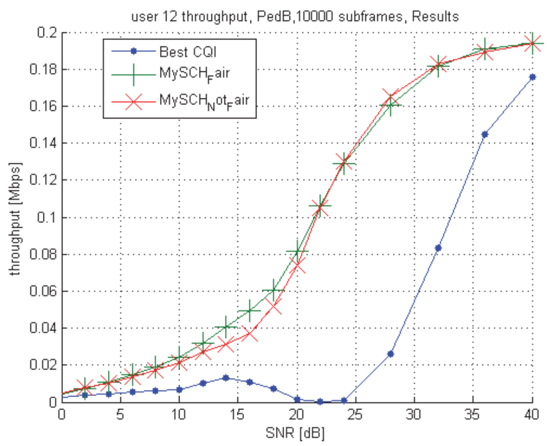
Fig. 3. User’s throughput, PedB channel model, 8 users.



a. User 1 throughput.



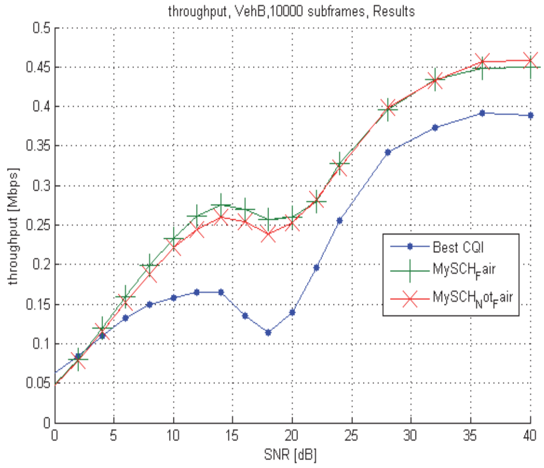
b. User 8 throughput.



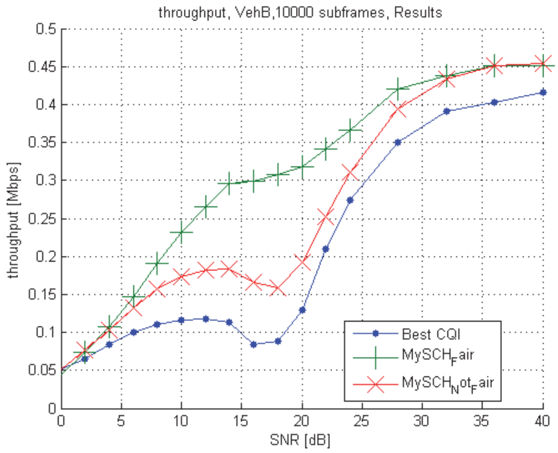
c. User 12 throughput.

Fig. 4. User’s throughput, PedB channel model, 12 users

Fig 5.a and Fig. 5.b show the overall cell throughput for the VehB channel model for the 8 and 12 users environments, with similar results as for the PedB channel models. Is is noticeable that even a higher improvement of more than 100% is experienced. This dramatic increase can be explained with the specific nature of the VehB channel due to the fast moving terminal (where rapid changes in path loss, multipath fading, delays and etc. could occur).



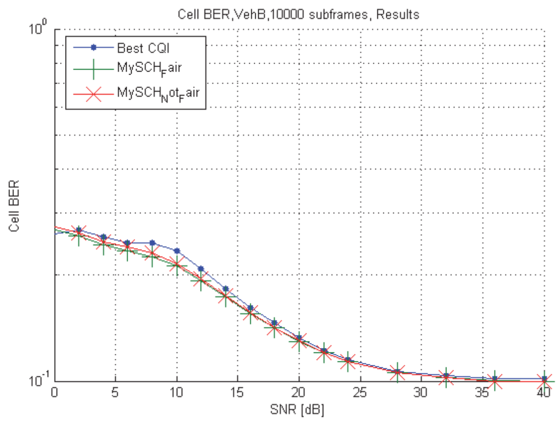
a. Overall cell throughput, VehB channel model, 8 users.



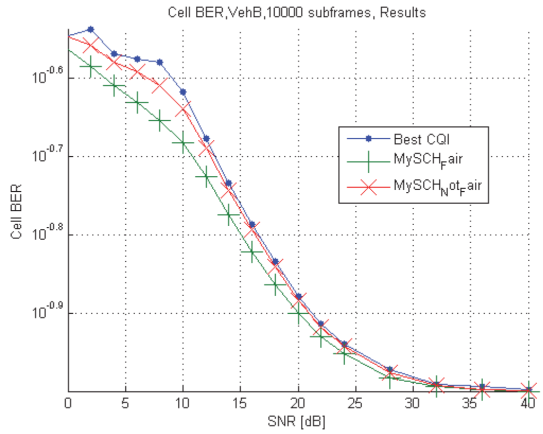
b. Overall cell throughput, VehB channel model, 12 users.

Fig.5. Overall cell throughput, VehB channel model.

Fig. 6.a and Fig. 6.b show that the resulting degradation of overall cell error performances (the BER), both for 8 and 12 users environment is very small and negligible (similar as for the PedB channel models). The novel scheduling algorithms provide cell BER performances which are almost at the same level with the Max C/I scheduler, for this channel model as well.



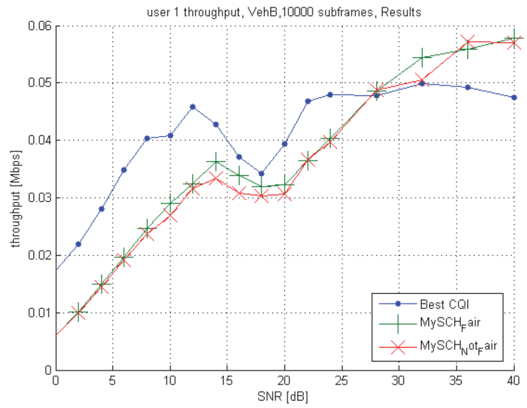
a. Overall cell BER,VehB channel model, 8 users.



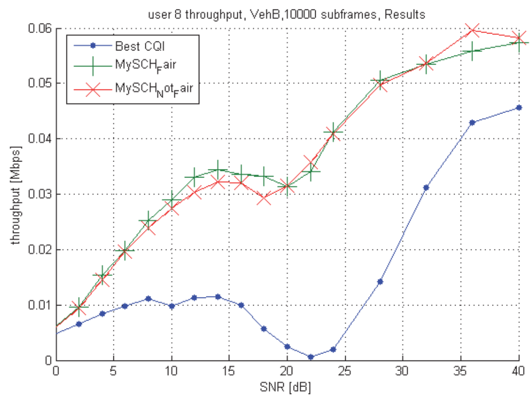
b. Overall cell BER,VehB channel model, 12 users.

Fig. 6 Overall cell BER, VehB channel model.

Fig. 7.a and Fig. 7.b, show the impact of throughput performances of the selected users for VehB channel model with 8 users simulation environment, while Figs. 8.a, 8.b, 8.c show the impact of throughput performances of the selected users for VehB channel model with 12 users simulation environment. (with similar behavior as in the PedB case). The user selection is done in the same manner as with the PedB results presentation. The users with the best channel conditions experience performance degradation, while the users with bad channel conditions benefit from this fairness approach, and the throughput performances are balanced and equalized for all users.

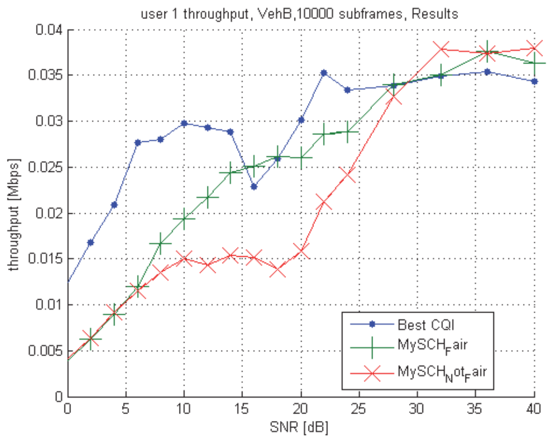


a. User 1 throughput.

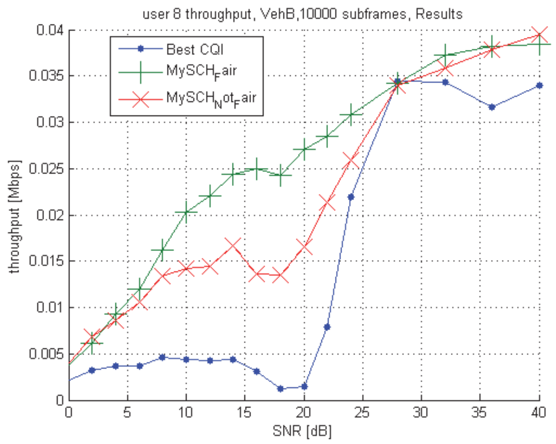


b. User 8 throughput.

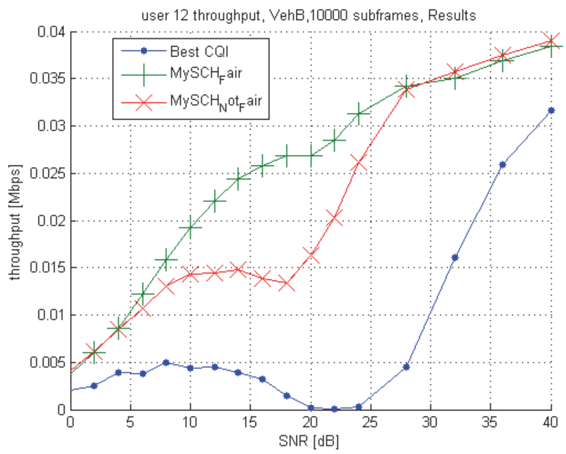
Fig. 7. User's throughput, VehB channel model, 8 users.



a. User 1 throughput.



b. User 8 throughput.



c. User 12 throughput.

Fig. 8. User's throughput, VehB channel model, 12 users.

VI. CONCLUSIONS

This paper elaborates the downlink packet scheduling framework in LTE presenting novel scheduling algorithms, and comparing their performances with the Max C/I algorithm. The Max C/I algorithm is not suitable for a fair-oriented approach since it could provide the users with bad channel conditions to "starve" for resources, and could even assign all available resources to only one user in one subframe. The new proposed algorithms are more complex than the Max C/I algorithm, but they introduce criteria for fairness regarding resource distribution. The simulation results prove that the proposed novel algorithms improve the overall cell throughput, both for PedB and VehB channel models. The improvement in the overall cell throughput does not increase the overall cell error bit rate. Introducing fairness in effective and fair balancing of the resources in the cell, the novel scheduling mechanisms prevent that no user in the system is degraded or starved. The future developments could include a QoS metrics when making the scheduling decisions.

REFERENCES

[1] E. Dahlman, S. Parkvall, J. Sköld, and P. Beming, *3G Evolution HSPA and LTE for Mobile Broadband*, Academic Press, 2007.

[2] F. Khan, *LTE for 4G Mobile Broadband: Air Interface Technologies and Performance*, Cambridge University Press, 2009

[3] H. Holma and A. Toskala, *LTE for UMTS – OFDMA and SC-FDMA Based Radio Access*, John Wiley & Sons Ltd., 2009

[4] St Sesia, I. Toufik, and M. Baker, *LTE – The UMTS Long Term Evolution From Theory to Practice*, John Wiley & Sons Ltd., 2009

[5] 3GPP TS 36.321 V9.0.0, *Medium Access Control (MAC) protocol specification (Release 9)*, 2009.

[6] 3GPP TS 36.201 V8.3.0, *LTE Physical Layer - General Description (Release 8)*, 2009.

[7] 3GPP TS 36.213 V8.8.0, *Physical layer procedures (Release 8)*, 2009.

[8] 3GPP TS 36.401 V8.7.0, *Architecture description (Release 8)*, 2009.

[9] B. F. Mata, "Investigation of HSDPA schedulers," TU Wien Institute of Communications and Radio-Frequency Engineering, 2008.

[10] J. Eriksson, "Providing Quality of Service for Streaming Applications in Evolved 3G Networks," Linkopings universitet, 2004.

[11] M. Gidlund, J-C Laneri , "Scheduling Algorithms for 3GPP Long-Term Evolution Systems: From a Quality of Service Perspective," *IEEE Communications magazine*, 2008.

[12] C. Mehlfuhrer, M. Wrulich, J. Colom Ikuno, D. Bosanska, andM. Rupp, "Simulating the Long Term Evolution physical layer," In *Proc of 17th EUSIPCO*, Glasgow, 2009.

[13] "Recommendation ITU-R M.1225: Guidelines for evaluation of radio transmission technologies for IMT-2000," Tech. Rep., 1997.

[14] A. Pokhariya T. E. Kolding, and P. E. Mogensen, "Performance of downlink frequency domain packet scheduling for the UTRAN Long Term Evolution", *17th IEEE PIMRC* 2006.

[15] J.Obers, "Evaluation of Scheduling Algorithms for a Web browsing servise in WCDMA High Speed Downlink Shared Channel," Lulea University of Technology, 2002.

[16] E. Eriksson, "Channel Quality Information Reporting and Channel Quality Dependent Scheduling in LTE," Linköpings universitet, 2008.

[17] B.Sadiq, R. Madan, and A. Sampath, *"Downlink Scheduling for Multi-class Traffic in LTE,"* Qualcomm-Flarion Technologies (QFT), NJ, USA, 2009.

[18] R. Kwan, C. Leung, and J. Zhang, "Multiuser Scheduling on the Downlink of an LTE Cellular System", *Hindawi Publishing Corporation, Research Letters in Communications*, 2008.

[19] A. Larmo, M. Lindström, M. Meyer, G. Pelletier, J. Torsner, and H. Wiemann, "The LTE Link-Layer Design," *IEEE Communications magazine*, 2009.