Faculty of Electronic and Computer Engineering

DESIGN AND ANALYSIS OF MODIFIED-PROPORTIONAL FAIR SCHEDULER FOR LTE/LTE-ADVANCED

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Master of Science in Electronic Engineering

2016

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Electronic Engineering

Faculty of Electronic and Computer Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

DECLARATION

I declare that this thesis entitle "Design and Analysis of Modified-Proportional Fair Scheduler For LTE/LTE-Advanced" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

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DEDICATION

To my beloved mother and father

ABSTRACT

Nowadays, Long Term Evolution-Advanced (LTE-Advanced) is well known as a cellular network that can support very high data rates in diverse traffic conditions. One of the key components of Orthogonal Frequency-Division Multiple Access (OFDMA), Radio Resource Management (RRM), is critical in achieving the desired performance by managing key components of both PHY and MAC layers. The technique that can be done to achieve this is through packet scheduling which is the key scheme of RRM for LTE traffic processing whose function is to allocate resources for both frequency and time dimensions. Packet scheduling for LTE-Advanced has been a dynamic research area in recent years, because in evidence, the increasing demands of data services and number of users which is likely to explode the progress of the LTE system traffic. However, the existing scheduling system is increasingly congested with the increasing number of users and requires the new scheduling system to ensure a more efficient data transmission. In LTE system, Round Robin (RR) scheduler has a problem in providing a high data rate to User Equipment's (UEs). This is because some resources will be wasted because it schedules the resources from/ to UEs while the UEs are suffering from severe deep fading and less than the required threshold. Meanwhile, for Proportional Fair (PF) scheduler, the process of maximizing scheme of data rate could be very unfair and UE that experienced a bad channel quality conditions can be starved. So, the mechanism applied in PF scheduler is to weight the current data rate achievable by a UE by the average rate received by a UE. The main contribution of this study is the design of a new scheduling scheme and its performance is compared with the PF and RR downlink schedulers for LTE by utilizing the LTE Downlink System Level Simulator. The proposed new scheduling algorithm, namely the Modified-PF scheduler, divides a single sub-frame into multiple time slots and allocates the resource block (RB) to the targeted UE in all time slots for each sub-frame based on the instantaneous Channel Quality Indicator (CQI) feedback received from UEs. Besides, the proposed scheduler is also capable to reallocate RB cyclically in turn to target UE within a time slot in order to ensure the process of distributing packet data consistently. The simulation results showed that the Modified-PF scheduler provided the best performance in terms of throughput in the range of up to 90% improvement and almost 40% increment for spectral efficiency with comparable fairness as compared to PF and RR schedulers. Although PF scheduler had the best fairness index, the Modified-PF scheduler provided a better compromise between the throughput in /spectral efficiency and fairness. This showed that the newly proposed scheme improved the LTE output performances while at the same time maintained a minimal required fairness among the UEs.

ABSTRAK

Pada masa kini, Jangka Panjang-Termaju (LTE-Termaju) terkenal sebagai rangkaian selular yang boleh menyokong kadar data yang tinggi dalam keadaan trafik yang pelbagai. Salah satu komponen utama Ortogonal Frekuensi-Bahagian pelbagai Akses (OFDMA), Pengurusan Sumber Radio (RRM), adalah faktor penting dalam mencapai prestasi yang dikehendaki dengan menguruskan komponen utama kedua-dua lapisan PHY dan MAC Kedua-dua teknik yang boleh dilakukan untuk mencapai matlamat ini adalah melalui penjadualan paket yang merupakan skim utama RRM untuk pemprosesan trafik LTE yang berfungsi untuk memperuntukkan sumber untuk kedua-dua frekuensi dan dimensi masa. Penjadualan paket untuk LTE-Termaju telah menjadi kawasan penyelidikan yang dinamik dalam tahun-tahun kebelakangan ini, kerana sebagai keterangan, permintaan data yang semakin meningkat dan pertambahan bilangan pengguna yang mungkin memerlukan kemajuan trafik sistem LTE. Walau bagaimanapun, sistem penjadualan yang sedia ada semakin sesak dengan peningkatan jumlah pengguna dan memerlukan sistem penjadualan baru untuk memastikan penghantaran data yang lebih cekap. Dalam sistem LTE, penjadual Pusingan Robin (RR) mempunyai masalah dalam menyediakan kadar data yang tinggi untuk Peralatan Pengguna (UEs). Ini kerana beberapa sumber akan menjadi sia-sia kerana ia menjadualkan sumber dari / ke UEs manakala UEs mengalami peluntursan mendalam teruk dan kurang daripada tahap yang diperlukan. Sementara itu, bagi penjadual Berkadaran Adil (PF), proses memaksimumkan skim kadar data boleh menjadi sangat tidak adil dan UE yang mengalami saluran yang tidak baik menyebabkan saluran kualiti keadaan boleh kebuluran. Jadi, mekanisme yang digunakan dalam penjadual PF adalah untuk lebih berat kepada kadar data semasa dicapai oleh UE oleh kadar purata yang diterima oleh UE a. Sumbangan utama kajian ini adalah reka bentuk skim penjadualan baru dan prestasinya dibandingkan dengan PF dan RR penjadual pautan turun untuk LTE dengan menggunakan Simulator Tahap Sistem LTE Penjadual Pautan Turun. Cadangan penjadualan algoritma baru iaitu penjadual Modified -PF, membahagikan sub-rangka tunggal ke dalam slot masa pelbagai dan memperuntukkan blok sumber (RB) untuk UE yang disasarkan dalam semua slot masa bagi setiap sub-rangka berdasarkan Petunjuk Kualiti Saluran (CQI) maklum balas yang diterima daripada UEs. Selain itu, penjadual yang dicadangkan juga mampu mengagihkan semula RB secara bergilir, seterusnya untuk menyasarkan UE dalam slot masa bagi memastikan proses mengedarkan data paket secara konsisten. Keputusan simulasi menunjukkan bahawa penjadual Modified-PF menyediakan prestasi terbaik dari segi pemprosesan dalam julat sehingga 90% peningkatan dan hampir 40% kenaikan untuk kecekapan spektrum dengan adil setanding berbanding penjadual PF dan RR. Walaupun penjadual PF mempunyai indeks keadilan terbaik, penjadual Modified-PF menyediakan kompromi yang lebih baik antara pemprosesan dalam kecekapan / spektrum dan kesaksamaan. Ini menunjukkan bahawa skim baru yang dicadangkan meningkatkan prestasi keluaran LTE dan pada masa yang sama mengekalkan keadilan minimum yang diperlukan antara UEs.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious and Most Merciful. Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this thesis. Special appreciation goes to my head supervisor, Assoc. Prof. Dr. Azmi Bin Awang Md Isa, for his supervision and constant support. Not forgotten, greatest gratitude to my co-supervisor, Assoc. Prof. Muhammad Syahrir Bin Johal and Dr. Mohd Riduan Bin Ahmad for guidance and sharing their experience and knowledge regarding this topic. Not to forget, Ministry of Education, Malaysia (formerly known as Ministry of Higher Education) for the funding through grant no. RAGS/2012/FKEKK/TK06/1 B00007 for Univesiti Teknikal Malaysia Melaka.

I would like to express my sincere acknowledgement to my mentor, Assoc. Prof. Dr. Kamarul Ariffin Bin Nordin from FKE, University of Malaya, Kuala Lumpur for his guidance and knowledge in this field.

Sincere thanks to all postgraduate lab members at FKEKK especially Taufiq, Sam, Ariffin, Hanif, Qalbi, Nikman, Azamiah, Thoriq, Syafiq, Zuhair, Thailis, Hafiz, Yusof and Zaki for helping me during my absentee in UTeM.

Last and for all, my deepest gratitude goes to my beloved parents; Ismail Bin Ahmad and my late mother Noriah Bt Abdul Rahman although she could not able to see my study anymore and to my siblings for their love, prayers and support mentally and physically. Thank you to anyone who directly and indirectly contributed to this research.

Thank you very much.

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3G	-	Third-Generation
3GPP	-	Third Generation Partnership Project
ABS	-	Advanced-BS
AMC	-	Adaptive Modulation and Coding
AP	-	Access Point
APP	-	Application Layer
AP-UE	-	Access Point-User Equipment
ARQ	-	Automatic Repeat Request
BF	-	Best Fit
BLER	-	Block Error Rate
BS	-	Base Station
CBS	-	Cluster Base Station
CC	-	Carrier Components
CDMA	-	Code Division Multiple Access
CLO	-	Cross-Layer Optimiser
CoMP	-	Coordinated Multipoint System
CoMP-CS	-	CoMP-Coordinate Scheduling
CP	-	Cyclic Prefix
CQI	-	Channel Quality Indicator
CSI	-	Channel State Information
DFT-s-FDMA	-	Discrete Fourier Transform-spread-FDMA
EAP	-	Extensible Automatic Protocol
FDD	-	Frequency-Division Duplex
FDMA	-	Frequency Division Multiple Access
FDS	-	Frequency Time Scheduling
FFT	-	Fast Fourier Transform
GBR	-	Guaranteed Bit Rate
H-ARQ	-	Hybrid-ARQ
ICI	-	Inter-cell interference
ICI cancellation	-	Inter-Carrier Interference cancellation
IDFT	-	Inverse Discrete Fourier Transform
IFFT	-	Inverse-Fast Fourier Transform
IMS	-	Instant Messaging System
IMT-Advanced	-	International Mobile Telecommunication-Advanced
ISI	-	Inter-Symbol Interference
ITU	-	International Telecommunications Union
JP	-	Joint Processing

ksps	-	kilo symbols per second
LA	-	Link Adaptation
LTE	-	Long Term Evolution
LTE-Advanced	-	Long Term Evolution-Advanced
MA	-	Margin Adaptive
MAC	-	Medium Access Control Layer
Mbps	-	Mega bit per second
MBS	-	Multicast and Broadcast
MHB	-	Mobile Hashing Balancing
MIMO	-	Multiple Input Multiple Output
MN	-	Mobile Network
Modified-PF	-	Modified-Proportional Fair
MRC	-	Maximal Ratio Combining
MS	-	Mobile Station
MU-MIMO	-	Multi-User MIMO
NRT	-	Non-Real Time
OFDMA	-	Orthogonal Frequency Division Multiple Access
OFDM	-	Orthogonal Frequency Division Multiple
PAPR	-	Peak-to-Average Power Ratio
PC	-	Power Control
PCI	-	Physical Layer Cell Identities
PF	-	Proportional Fair
PHY	-	Physical Layer
PMIPv6	-	Proxy Mobile IPv6
QAM	-	Quadrature Amplitude Modulation
QCI	-	QoS Class of Identifier
QoE	-	Quality-of-Experience
QoS	-	Quality-of-Service
QPSK	-	Quadrature Phase Shift Keying
RA	-	Rate Adaptive
RB	-	Resource Block
RF	-	Radio Frequency
RR	-	Round Robin
RRA	-	Radio resource allocation
RRB	-	Round Robin Balancing
RRM	-	Radio Resource Management
RS	-	Relay Station
RT	-	Real Time
SC-FDMA	-	Single-carrier FDMA
SINR	-	Signal to Interference and Noise Power Ratio
SISO	-	Single Input Single Output
SNR	-	Signal-to-Noise Ratio

TASB	-	Traffic Aware Score Based
TCP	-	Transmission Control Protocol
TDD	-	Time Division Duplex
TDS	-	Time Domain Scheduling
TTI	-	Transmission Time Interval
UE	-	User-Equipment
VoIP	-	Voice over IP
WCDMA	-	Wideband Code-Division Multiple Access
WiMAX	-	Worldwide Interoperability for Microwave Access

LIST OF PUBLICATION

The research papers produced and published during the course of this research are as follows:

JOURNAL

1. **Ismail, M. K.**, Isa, A. A. M. and Johal, M. S., 2014. Review of Radio Resource Management For IMT-Advanced System. *Journal Teknologi*, 72(4), pp. 113-119.
2. **Ismail, M. K.**, Isa, A. A. M., Johal, M. S. and Zin, M. S. I. M., 2015. Current Developments in LTE/LTE-Advanced: Adaptive-Proportional Fair Scheduling in LTE. *Journal of Telecommunication, Electronic and Computer Engineering,* 7(1), pp. 103-108.
3. **Ismail, M. K.**, Isa, A. A. M., Husain, M. N., Johal, M. S. and Ahmad, M. R., 2016. Design and Development of Modified Proportional Fair Scheduler for LTE/LTE-Advanced. *ARPN Journal of Engineering and Applied Sciences*, 11(5), pp. 3280-3285.
4. **Ismail, M. K.**, Isa, A. A. M., Johal, M. S., Ahmad, M. R., Zin, M. S. I. M., Isa, M. S. M., Nikman, H., and Mahyuddin, M. F. M., 2016. Design and Analysis of Modified-Proportional Fair Scheduler for LTE Femtocell Networks. *Journal Teknologi*. (Accepted)

CONFERENCE

1. **Ismail, M. K.**, Johal, M. S. and Isa, A. A. M., 2014. Current Developments in LTE-Advanced: Radio Resource Management Review. *2014 IEEE Student Conference on Research and Development (SCOReD),* pp. 1-7.

CHAPTER 1

INTRODUCTION

In this chapter, the 3GPP Long Term Evolution (LTE) is presented and all its significant structures under the International Telecommucation Mobile-Advanced (IMT-Advanced). The chapter begins with the research background information on the subject presented in section1.1. Then, the thesis comes out with the research motivation in Section 1.2 to clarify the direction of enhancement in the LTE system. In the next section, the thesis' research objectives and its goals are stated in Section 1.3. For section 1.4, the scope of work is presented to mention the works that will be conducted. The last section of 1.5 discusses the reseach contributions in LTE communication system.

1.1 Research Background

In recent years, the demand for wireless communication services has been enormous. Even the near future sets new challenges for the performance of the cellular multiple access wireless communication systems in the form of pressure for more sophisticated, as well as resource-consuming, multimedia services for the users. In addition, while enabling the mobility of the users, the future systems must assure quality-of-service (QoS) for all customers.

Currently, International Telecommunications Union (ITU) is working on specifying system requirements towards the next generation mobile communication systems called International Mobile Telecommunications-Advanced (IMT-Advanced). IMT-Advanced systems are mobile broadband communication systems that include new capabilities that go significantly beyond those of the IMT-2000 family of systems such as wideband code-division multiple access (WCDMA) or Worldwide Interoperability for Microwave Access (WiMAX). It is a further evolution as IMT-Advanced is expected to fulfil the requirements of the so-called 4G systems and already believed to be operational around the year 2015. The IMT-Advanced system will provide access to a wide range of telecommunication services, including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet-based (Kumar and Marchetti, 2009). The IMT-Advanced systems will support low to high mobility applications and wide range of data rates, in accordance with the service demands in a multiuser environment. Essentially, 100 Mbit/s for high and 1 Gbit/s for low mobility conditions are established as the research objectives (Series, 2003).

Motivated by the increasing demand for mobile broadband services with higher data rates and QoS, Orthogonal Frequency Division Multiple Access (OFDMA) which is a combination of Frequency Division Multiple Access (FDMA) and Orthogonal Frequency Division Multiplexing (OFDM) and a novel Modulation/multiple access technique, has been recommended by the ITU as the core Physical (PHY) layer technology for the next generation of IMT-Advanced systems (S.Pietrzyk, 2006). In the OFDMA, the base stations allow multiple users to transmit simultaneously on different subcarriers during the same symbol period. This novel modulation/multiple access technique has been incorporated in the IEEE802.16e/m (Mobile WiMAX) and 3GPP Long Term Evolution-Advanced (LTE-Advanced) 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 for higher system loads by managing key components of both Physical (PHY) and Medium Access Control (MAC) layers (J. Lim, 2006). This component is also crucial for OFDMA wireless broadband networks where scarce spectral resources are shared by multiple users. This concept is well-developed and a number of techniques had already existed and implemented in the latest releases of IEEE802.16m and 3GPP Release 10.

LTE Release 10 had been finalized at the end of 2011 by 3GPP, with the support for positioning services, broadcast/multicast services, and enhanced emergency-call functionality (Kumar and Marchetti, 2009). The capability of LTE-Advanced are highly recommended by 3GPP because it could support transmission bandwidths of up to 100MHz and increase the capacity of the User-Equipment (UE) at a time of transmission and reception process (Parkvall et al., 2008). LTE allows for operation in both paired and unpaired spectrum by providing a single radio-access technology supporting Frequency-Division Duplex (FDD) as well as Time Division Duplex (TDD) (Kumar and Marchetti, 2009). Figure 1.1 illustrates the basic operation of LTE when it enables a pair of frequency spectrum.

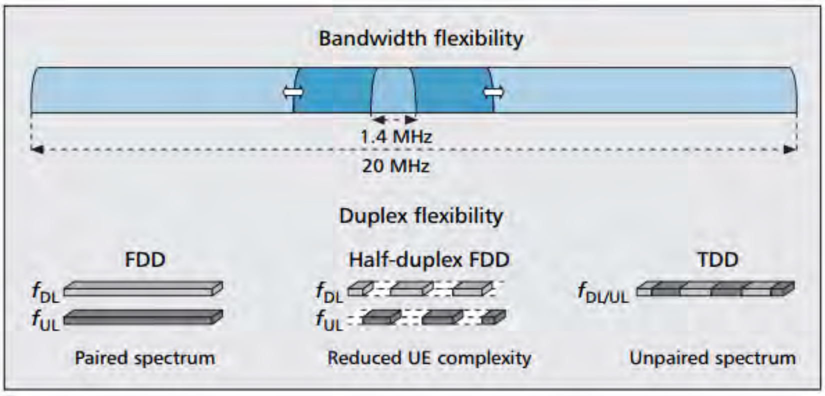

Figure 1.1 LTE spectrum (bandwidth and duplex) flexibility. Half duplex FDD is seen from a terminal perspective(Astély et al., 2009).

There is some requirements that LTE–Advanced need to fulfil in order to achieve the IMT-Advanced specification such as the peak data rate, spectrum allocation, latency and spectrum efficiency. Table 1.1 shows the detail for the LTE-Advanced requirements to fulfil the standards that ITU and 3GPP has recognized. The requirements function to follow and meet the current requirements in providing the best QoS and high throughput of data rates.

Table 1.1 ITU and 3GPP requirement for LTE-Advanced (Agilent, 2011).

Quantity		IMT-Advanced	LTE-Advanced
Peak data rate	UpLink	-	1 Gbit/s
	DownLink	-	500Mbit/s
Spectrum allocation		Up to 40MHz	Up to 100MHz
Latency	User plane	10 ms	10 ms
	Control plane	100 ms	50 ms
Spectrum efficiency (4 ant BS, 2 ant terminal)	Peak	15 bit/s/Hz DL 6.75 bit/s/Hz UL	30 bit/s/Hz DL 15 bit/s/Hz UL
	Average	2.2 bit/s/Hz DL 1.4 bit/s/Hz UL	2.6 bit/s/Hz DL 2.0 bit/s/Hz UL
	Cell-edge	0.06 bit/s/Hz DL 0.03 bit/s/Hz UL	0.09 bit/s/Hz DL 0.07 bit/s/Hz UL

Actually, LTE-Advanced is a backward compatible technology in the sense that it must be possible to apply LTE-Advanced in the available spectrum that is provided for LTE without giving any negative impact to the LTE terminal (Parkvall et al., 2008). Besides that, being a backward compatibility technology, LTE-Advanced should also consider such elements; capacity, low-cost deployment and data rates including the possibility for peak data rates of up to 1 Gbit/s in the downlink and 500 Mbit/s in the uplink to fulfil the criteria to be IMT-Advanced.

1.2 Research Motivations

Generally, there are various factors that contribute to the throughput and spectral efficiency performance of a Mobile Station (MS) such as scheduling algorithms, MS speed, multipath environment, distance from Base Station (BS) and diversity. Consequently, a more efficient radio resource management technique has been studied by taking advantage of the Adaptive Modulation & Coding (AMC) and multiuser diversity in order to improve the system's capacity and QoS requirement for IMT-Advanced.

There are premium subscribers who always want to have a better user experience on their 4G LTE devices. These users are willing to pay more for a high bandwidth and better network access on their devices. Not only the subscribers, but some services itself need better priority in handling the network (e.g. VoIP call). To be able to fulfill this, QoS plays the key role for both WiMAX and LTE. For example, many researchers have actually investigated the use of RSs in order to improve a cell's coverage, especially for the benefit of the MS located at the boundary of the cell (Pabst et al., 2004; Omer Mubarek, 2005).

Eventually, every MS user is assigned a specific bandwidth based on the network subscription package and this bandwidth is based on one of the QoS classes in WiMAX/LTE. QoS defines priorities for certain customers / services during the time of high congestion in the network. For LTE, there are two categories of QoS, namely the Dedicated Bearer and Default Bearer. Dedicated Bearer can be subdivided into Guaranteed Bit Rate (GBR) and non-GBR types whereas for Default Bearer, there is only Non-GBR type. Both types (GBR and non-GBR) are further identified by their QoS Class of Identifier (QCI) parameter. For GBR, the QCI determines from 1 to 4 whereas for non-GBR, the QCI is 5 to 9. In total, there are 9 QCIs for both types.