AN ENHANCED PACKET SCHEDULING ALGORITHM FOR DOWNLINK COGNITIVE LONG TERM EVOLUTION-ADVANCED

BY

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A thesis submitted in fulfilment of the requirement for the degree of Master of Science (Computer and Information Engineering)

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ABSTRACT

The demand for Real Time (RT) and Non-Real Time (NRT) multimedia contents on mobile devices are increasing at a high pace as internet are becoming easier to access. These demands are mostly fulfilled by Long Term Evolution-Advanced (LTE-A) mobile communication standard. However, these exponential demands also will cause LTE-A to face a challenge to provide satisfactory Quality of Service (QoS) mobile users in the near future. This is due to spectrum scarcity because LTE-A operates at a fixed spectrum that will cause the spectrum soon to be congested on most frequency bands. Therefore, a study on increasing spectrum availability and efficiency is needed. Recently, Cognitive Radio (CR) technology is highly researched as a promising technology to overcome spectrum scarcity. Spectrum availability and efficiency of the network can be improved via implementation of CR into LTE-A. Furthermore, addition of Packet Scheduling (PS) in the downlink Cognitive LTE-A will further satisfy the required QoS of mobile users. However, the study on the stated implementation is very limited. Thus, this research aims to investigate packet scheduling performance in the downlink Cognitive LTE-A. The goal of this thesis is to provide satisfactory QoS which are system throughput, fairness and packet loss ratio whilst increasing the system capacity of RT and NRT multimedia contents users in the downlink Cognitive LTE-A. This thesis proposed an enhanced packet scheduling algorithm in the attempt to achieve the stated goal and using simulation of the enhanced algorithm in Cognitive LTE-A. The performance of the proposed packet scheduling algorithm is compared with well-known packet scheduling algorithms based on several performance metrics in a simulation environment limited to a single hexagonal cell to reduce complexity of simulation. Based on the simulation results, it is shown that the proposed packet scheduling algorithm supports 185%, 200% and 131% more Cognitive LTE-A users compared to SC M-LWDF in first, second and third scenario while supporting 9.6% and 15.4% more Cognitive LTE-A users at the required RT PLR compared to MM-LWDF at the expense of degradation of the NRT PLR which is considered acceptable due to the vacancy of radio spectrums when compared to the well-known packet scheduling algorithms.

خلاصة البحث

يزداد الطلب على الوقت الحقيقي (Real Time) والغير حقيقي (Non-Real Time) لمحتوى الوسائط المتعددة بسرعة مع سهولة الوصول إلى الانترنت. هذا الطلب غالبًا ما يتم إشباعه عن طريق معيار اتصالات الأجهزة اللاسلكية المحمولة ذات التطور المتقدم طويل المدى (Long Term Evolution-Advanced). ومع ذلك، فإن هذا الطلب الأُسّي يجعل التطور المتقدم طويل المدى في مواجهة مع تحدي توفير جودة خدمة (Quality of Service) مُرضية لمستخدمي الهاتف المحمول في المستقبل القريب. وهذا يعود إلى نُدرة الطيف (spectrum scarcity) لأن التطور المتقدم طويل المدى (LTE-A) يعمل على طيف ثابت وهذا يتسبب في ازدحام الطيف في معظم موجات التردد. لذلك، فهناك احتياج لدراسة زيادة إتاحية الطيف والكفائة. مؤخرًا، أُقيمت العديد من الأبحاث الخاصة بالراديو المعرفي (Cognitive Radio) كتقنية منتظرة للتغلب على نُدرة الطيف. يمكن تحسين إتاحية الطيف وكفائة الشبكة عن طريق تطبيق الراديو المعرفي بداخل التطور المتقدم طويل المدى (LTE-A). كذلك، فإن إضافة مُجَدوِل رُزم البيانات (Packet Scheduling) إلى الوصل السفلي المعرفي للتطور المتقدم طويل المدى (LTE-A) سيُزيد من إشباع جودة الخدمة لدى مستخدمي الهاتف المحمول. رغم ذلك، فإن دراسات هذا التطبيق محدودة جدًا. ولهذا، فإن هذه الدراسة تطمح إلى فحص أداء مُجَدوِل رزم البيانات في الوصل السفلي المعرفي للتطور المتقدم طويل المدى (LTE-A). هدف هذا البحث هو توفير جودة خدمة مُرضية والتي تشمل إنتاجية النظام، و الوضوح، و نسبة فقدان رزمة البيانات (packet loss) مع زيادة إمكانية النظام الخاصة بالوقت الحقيقي والغير حقيقي لمستخدمي محتوى الوسائط المتعددة في الوصل السفلي المعرفي للتطور المتقدم طويل المدى (LTE-A). هذا البحث يقترح خوارزمية مُحسَّنة لمُجَدوِل رزم البيانات في محاولة للوصول إلى الهدف واستخدام محاكاة مُحسَّنة في التطور المعرفي المتقدم طويل المدى (LTE-A). تم مقارنة أداء خوارزمية مُجَدوِل رُزم البيانات المُقترح مع خوارزمية أحد مُجَدولي رُزم البيانات المشهورة بناءً على مقاييس الأداء في بيئة محاكاة مُقيدة بخلية واحدة سداسية الشكل للتقليل من تعقيد المحاكاة. بناءً على نتائج المُحاكاة، فإن خوارزمية مُجَدوِل رُزم البيانات المُقترح تدعم 200% ,185%و131% من مستخدمي التطور المعرفي المتقدم طويل المدى (LTE-A) مقارنة بالتأجيل الأكبر المرشح أولًا أحادي التنقل (SC M-LWDF) في المشهد الأول والثاني والثالث ، في حين دعمها لمستخدمي التطور المعرفي المتقدم طويل المدى (LTE-A) بنسبة 9.6%و 15.4% في الوقت الحقيقي لنسبة فقدان رزمة البيانات مقارنة بالتأجيل الأكبر المرشح أولًا متعدد التنقل (MM-LWDF) على حساب تراجع الوقت الغير حقيقي لنسبة فقدان رزمة البيانات والذي يعتبر مقبول بسبب شغور أماكن في طيف الراديو عند مقارنته بخوارزمية مُجَدوِل رُزم البيانات المشهور.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Computer and Information Engineering)

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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Firstly, it is my utmost pleasure to dedicate this work to my dear parents and my family members, who granted me the gift of their unwavering belief in my ability to accomplish this goal: thank you for your support and patience.

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LIST OF ABBREVIATIONS

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
A-EPSA	Adaptive Efficient Downlink Packet Scheduling Algorithm
AMC	Adaptive Modulation and Coding
AMPS	Analogue Mobile Phone System
APS	Adaptive Packet Scheduling
CA	Carrier Aggregation
CAQA	Cross-Layer Design Approach
CBQA	Cross-Layer Based Packet Scheduling Scheme
CC	Component Carriers
CDMA	Code Division Multiple Access
CP	Cyclic Prefix
CQI	Channel Quality Information
CR	Cognitive Radio
DSCS	Dynamic-Slot based Carrier Scheduling
DSSS	Direct Sequence Spread Spectrum
DVB	Digital Video Broadcasting
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
EM-LWDF	Enhanced Maximum-Largest Weighted Delay First

eNodeB	enhanced Node B
EPC	Evolved Packet Core
EPSA	Efficient Downlink Packet Scheduling Algorithm
EQ	Elastic traffic Queue
ET	Elastic Traffic
EXP	Exponential Rule
FADSA	Fairness Aware Downlink Scheduling Algorithm
FD	Frequency Domain
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FIFO	First-In-First-Out
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communications
HARQ	Hybrid Automatic Repeat Request
HOL	Head-of-Line
HSDPA	High-Speed Downlink Packet Access
HSPA+	High-Speed Packet Access +
HSUPA	High-Speed Uplink Packet Access
ISI	Inter-Symbol Interference
ITU-R	International Telecommunication Union-Radio
JTACS	Japanese Total Access Communication Systems
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
M-LWDF	Maximum-Largest Weighted Delay First
Max-Rate	Maximum Rate

MCS	Modulation and Coding
MEXP	Modified Exponential Rule
MMax-Rate	Modified Maximum Rate
MM-LWDF	Modified Maximum-Largest Weighted Delay First
MME	Mobility Management Entity
MPF	Modified Proportional Fair
MRR	Modified Round Robin
NMT	Nordic Mobile Telephone
NRT	Non-Real Time
NR	New Radio
OFDMA	Orthogonal Frequency Division Multiple Access
P-GW	Packet Data Network Gateway
PF	Proportional Fair
PLR	Packet Loss Rate
PS	Packet Scheduling
PSM	Packet Scheduler Module
PT	Primary Traffic
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoED	Quality of Experience-Driven LTE Downlink
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
QSRUS	QoS-based Separated Random User Scheduling
RB	Resource Block
RE	Resource Element

RR	Round Robin
RRM	Radio Resource Management
RQ	Real-time traffic Queue
RT	Real Time
S-GW	Serving Gateway
SC-FDMA	Single Carrier Frequency Division Multiple Access
SINR	Signal-to-Interference-plus-Noise-Ratio
SRUS	Separated Random User Scheduling
SC M-LWDF	Single-User Maximum-Largest Weighted Delay First
TACS	Total Access Communication Systems
TD	Time Domain
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TGM	Traffic Generator Module
TTI	Transmission Time Interval
UMTS	Universal Mobile Telecommunications System
VoIP	Voice over Internet Protocol
WCDMA	Wide Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The number of mobile cellular subscriptions around the globe has experienced a drastic growth since 2013. A statistic from Ericsson, a multinational networking and telecommunications company (Ericsson, 2017), illustrates that the mobile cellular subscriptions has reached 7.8 billion in 2017 and expected to exceed 9 billion subscriptions by 2023 (see Figure 1.1).

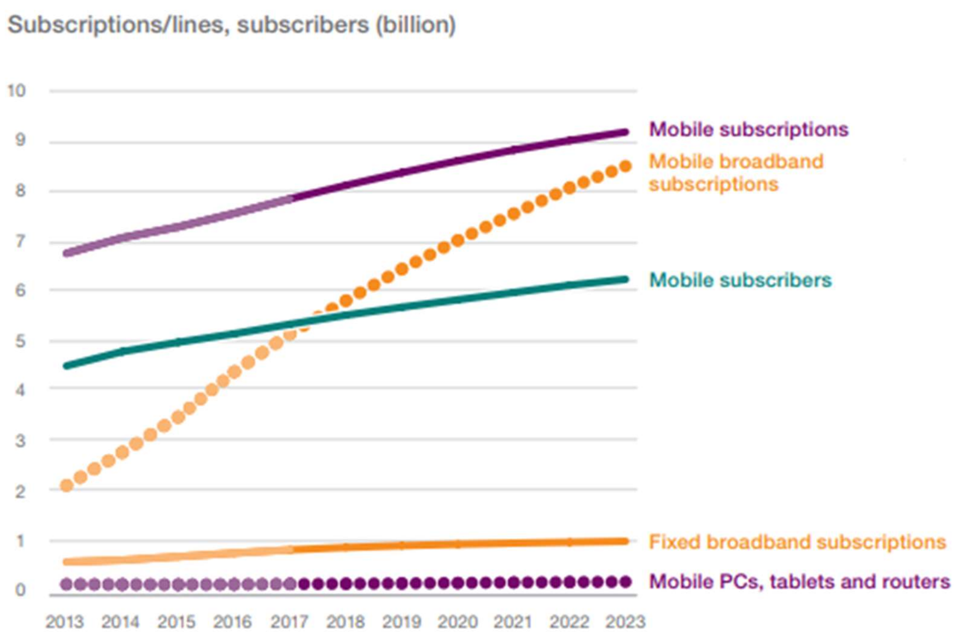


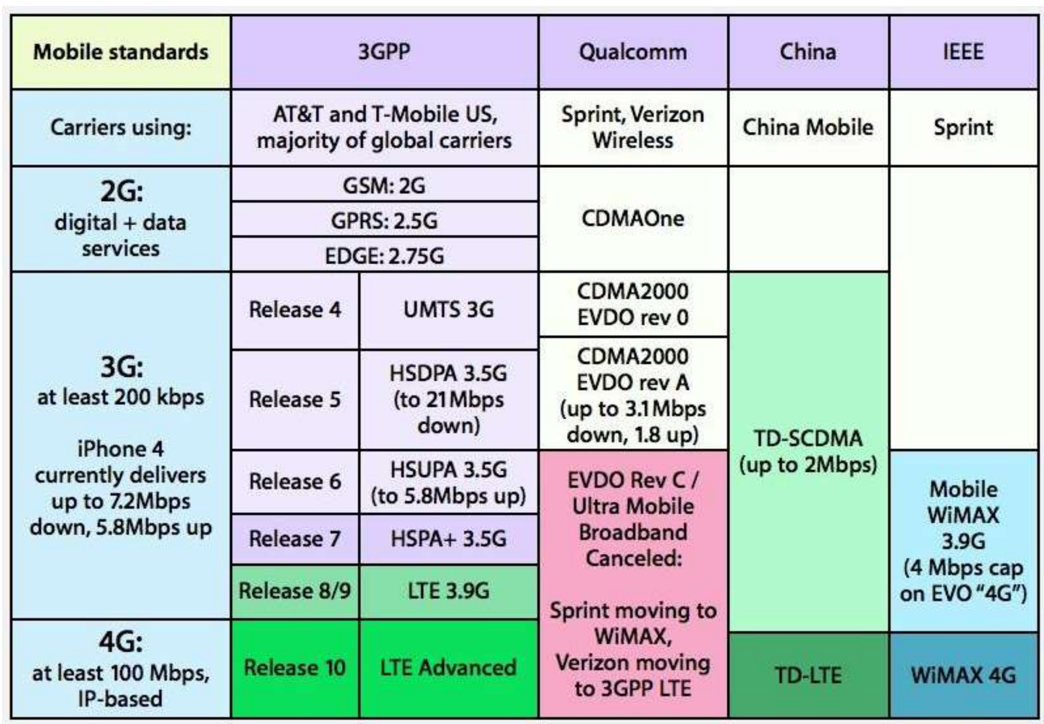
Figure 1.1: Mobile Cellular Subscriptions since 2013 (Ericsson, 2017)

The history of the mobile cellular systems began in early 1980s where the First Generation (1G) systems were introduced. The 1G mobile cellular systems were based on circuit-switching technology that were designed for voice telephony and use analogue modulation. The 1G systems also used a channel access method known as Frequency Division Multiple Access (FDMA) to multiplex different telephony channels. Nordic Mobile Telephone (NMT), Analogue Mobile Phone System (AMPS), Total Access Communication Systems (TACS), Radiocom 2000 and Japanese TACS (JTACS) were the first 1G systems (E. Dahlman et al., 2007). There were various limitations of 1G systems and the most common are lack of consistency in voice quality, heavy mobile user equipment (phone), inefficient usage of radio spectrum resources, and frequent loss of calls (R. Ramachandran, 2003).

Second Generation (2G) mobile cellular systems were first introduced in the early 1990s. Unlike its predecessor (1G systems), 2G systems were fully digital replacing the analogue 1G systems (Agrawal et al., 2015). The multiple access techniques used in 2G systems include Time Division Multiple Access (TDMA)/FDMA/Code Division Multiple Access (CDMA) technology. There were a number of 2G systems deployed including the well-known Global System for Mobile Communications (GSM), TDMA, cdmaOne as well as Personal Digital Communications (PDC) (E. Dahlman, 2007). GSM is the most commercially successful compared to other 2G systems as it accounts more than 80% of mobile cellular subscriptions worldwide (F. Ivanek, 2009). Being fully digital, 2G systems overcome some of the common limitations of 1G systems such as provided improved call quality and security and more efficient radio spectrum usage. However, 2G systems are not suitable for high data rate services because it supports a very low data rate (i.e. up to 9.6 kbps). Given the stated limitation and due to the increasing demand for multimedia contents with high-speed transmission and meeting satisfactory Quality of Service (QoS), General Packet Radio Services (GPRS) was standardized as an enhancement to the 2G systems. GPRS is one of the 2.5G systems and it used packet switching technology. GPRS provides compelling improvement in data rates (i.e. up to 114kbps) as well as covers wider range of packet-switched multimedia contents.

Third Generation (3G) is the advancement of mobile cellular system after 2G and 2.5G systems. Third Generation Partnership Project (3GPP) standardized Universal Mobile Telecommunications System (UMTS) for 3G with data rate improvement up to 384kbps. UMTS used Wideband CDMA (WCDMA) technology which was defined in 3GPP Release 99 (R. Ramachandran, 2003) and this system is compatible with GSM/GPRS. Similarly, the 3GPP2 organization introduced a 3G system known as CDMA2000 where it was deployed to be backward compatible with cdmaOne system. The next step for the 3G evolution is High-Speed Downlink Packet Access (HSDPA) system. HSDPA is also known as 3.5G system and it is based on Hybrid Automatic Repeat Request (HARQ) and Adaptive Modulation and Coding (AMC) that enables more efficient and reliable communications. The 3.5G systems were further enhanced into High-Speed Uplink Packet Access (HSUPA) and later High-Speed Packet Access + (HSPA+).

To ensure the competitiveness of the 3GPP over other organizations, the Long Term Evolution (LTE) was developed. The LTE supported higher uplink and downlink data rates (3GPP, 2006), increased coverage and capacity (A. M. Rao et al., 2009) and reduced latency (T. Saito et al., 2009) compared to the legacy 3GPP systems. However, based on the new technical requirements given by the International Telecommunication Union-Radio communication (ITU-R), LTE did not succeeded these requirements and referred to as 3.9G system. Therefore, in its attempt towards the 4G evolution, the 3GPP enhanced the LTE into Release 10, also known as Long Term Evolution-Advanced (LTE-A). The LTE-A provides 1 Gbps in downlink and 500 Mbps in uplink peak data rates. The higher data rates allow LTE-A to meet the increasing demand for multimedia contents with satisfactory QoS on mobile cellular. One of the key technologies that enables the higher data rate in LTE-A is the Carrier Aggregation (CA). CA technology allows two or more radio spectrums (also referred to as Component Carriers, CC) in the same or different frequencies to be aggregated to increase the radio spectrums. This enables LTE-A to support up to 100 MHz wide radio spectrums compared to LTE and allows LTE-A to achieve higher data rates while improving QoS. LTE-A is currently the most dominant mobile cellular system with over 7.8 billion mobile subscribers in 2017 and is expected to account for 60% of mobile subscription by 2023 (Ericsson, 2017) and the system is also backward compatible with legacy LTE. A summary of the evolution of mobile cellular standards/systems with their relevant organizations is given Figure 1.2.



Mobile standards	3GPP		Qualcomm	China	IEEE
Carriers using:	AT&T and T-Mobile US, majority of global carriers		Sprint, Verizon Wireless	China Mobile	Sprint
2G: digital + data services	GSM: 2G GPRS: 2.5G EDGE: 2.75G		CDMAOne		
3G: at least 200 kbps iPhone 4 currently delivers up to 7.2Mbps down, 5.8Mbps up	Release 4	UMTS 3G	CDMA2000 EVDO rev 0	TD-SCDMA (up to 2Mbps)	
	Release 5	HSDPA 3.5G (to 21Mbps down)	CDMA2000 EVDO rev A (up to 3.1Mbps down, 1.8 up)		
	Release 6	HSUPA 3.5G (to 5.8Mbps up)	EVDO Rev C / Ultra Mobile Broadband Canceled: Sprint moving to WiMAX, Verizon moving to 3GPP LTE		Mobile WiMAX 3.9G (4 Mbps cap on EVO "4G")
	Release 7	HSPA+ 3.5G			
	Release 8/9	LTE 3.9G			
4G: at least 100 Mbps, IP-based	Release 10	LTE Advanced		TD-LTE	WiMAX 4G

Figure 1.2: The Evolution of Mobile Cellular Standards/Systems and their Relevant Organizations (Taiwan4G, 2018)

The next breakthrough in the evolution of mobile cellular systems is migration towards Fifth Generation (5G). Currently, 5G is not yet standardized nor available for commercial use. However, in September 2015, 3GPP organized a conference to plan the development for the new standard (3GPP, 2015). The development of 5G standards involves New Radio (NR) interface, LTE-A pro radio enhancement and new core network architecture development. 3GPP aims to complete first phase of 5G specifications in Release 15 by September 2018 and complete the second phase in Release 16 by March 2020. The performance criteria for 5G have been set by the ITU-R organization in their International Mobile Telecommunication for year 2020 (IMT-2020) recommendations (ITU, 2017).

In the development of 5G systems, ITU-R has identified several improvements required for these systems and one of the main improvement needed is satisfactory QoS for more multimedia users (3GPP, 2018). However, given the explosive growth of multimedia users (i.e. following the rapid growth and changes that came with the expanding Internet of Things (IoT) technology), the available radio spectrums will soon be operating at its maximum capacity. Reclaiming for more radio spectrums (licensed) cost billions. A report by the Federal Communication Commission states that current licensed radio spectrums usage is not uniform. Some radio spectrums licensed for the WiMAX and Bluetooth systems are heavily used whereas other radio spectrums licensed for the TV and Digital Video Broadcast systems are underutilized. Motivated by the above situation, Cognitive Radio (CR) was proposed as one of the promising solutions for addressing the inefficient use of the licensed radio spectrums whilst addressing the exponential increase of multimedia contents. The CR technology enables unlicensed users to opportunistically access the vacant portions of licensed radio spectrums and quickly release these portions when the licensed users become active. It is expected that the 5G systems as well as future generation of the mobile cellular systems to further increase the available radio spectrums and hence improving its performance by including CR feature in its implementation.

1.2 LTE-A OVERVIEW

In order to meet the rapidly increasing demand for multimedia contents delivery with high quality, accommodation of higher data rates, coverage and capacity and lower latency while supporting satisfactory QoS are required. Thus, LTE-A with its latest technology that have these requirement is envisaged to meet this demand. As discussed in Section 1.1, LTE-A provides similar features as LTE system as it is basically an enhancement of LTE Release 8/9. However, the distinct feature that differentiate between the two systems is the CA feature that only presents in the LTE-A. Some technological components of LTE-A are discussed in the following sub-sections.

1.2.1 Spectrum Flexibility

LTE-A provides spectrum flexibility as it is able to operate in different radio spectrum (varying from 1.4 MHz to 20 MHz), different frequency bands and different modes of operation (support both Frequency Division Duplex, FDD and Time Division Duplex, TDD) (A. Hadden, 2009). The scalable radio spectrum ranging from 1.25 MHz up to 20 MHz (3GPP, 2006) as shown in Figure 1.3, allow ease of deployment of LTE-A systems that is using the GSM bands due to the smaller radio spectrum (E. Dahlman et al., 2007) whereas the wider radio spectrum can be utilized to improve data rates for increasing amount of traffic on an LTE-A network.