Faculty of Electronic and Computer Engineering

DESIGN AND ANALYSIS OF LTE-WLAN WIRELESS ROUTER WITH QOS PRESERVATION

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DECLARATION

I hereby declare that this thesis entitle "Design and analysis of LTE-WLAN wireless router with QoS preservation" is the result of my own research except for works that have been cited clearly in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……

Name : Abdulaziz Mohammed Saleh Ghaleb

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APPROVAL

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

Signature : ……

Supervisor's Name : Dr. Lim Kim Chuan

Date : ……

DEDICATION

Dedicated to my beloved parents, my family members and all my teachers.

ABSTRACT

Future wireless networks are envisioned to embrace a higher level of heterogeneity whereby different wireless technologies such as Long Term Evolution UMTS (LTE), Wireless Local Area Network (WLAN), WCDMA/HSPA, WiMAX, etc, not only will coexist but will also cooperate more closely. This is motivated by the fact that several complementary characteristics exist between these technologies. For example, one technology can be used as access technology while the other can be used for backhaul. To interconnect two or more wireless technologies, the usage of routing device is inevitable. In order to preserve the Quality of Service (QoS) across these technologies which come with different QoS definitions, a more comprehensive approach is required to preserve QoS across two diverse wireless technologies i.e. Enhanced Distributed Coordination Function (EDCA) for WLAN and Uplink/Downlink packet scheduling for LTE. WLAN is reasonably priced, easy to deploy and has been enjoying a wide market acceptance especially in the indoor. The LTE is expected to be the dominant 4G cellular technology. However it will take some time before LTE can attain the same level of adoption as what WLAN has achieved especially in the consumer market.

The main objective of this research project is to design an access router that enables the interworking between WLAN and LTE with QoS preservation. First, the performance of both WLAN and LTE radio interfaces are investigated independently in terms of the data rates, user/system throughput, effect of multiple access and spectral efficiency. Next, different approaches and schemes which facilitate QoS preservation between WLAN and LTE over the router are investigated and evaluated in terms of different performance metrics (voice Mean Opinion Score, video delay, video traffic received, video jitter, video packet loss rate). The design and analysis of the performance are carried out through simulation as the only feasible approach to accomplish this work. OPNET Modeler is used to model the LTE-WLAN router as well as to perform the analysis.

The results of this research verify the feasibility of the proposed router architecture and the interworking paradigm. The elegance of the proposed router implementation is that it does not require massive change in the existing wireless systems, LTE and WLAN to preserve the QoS. The results of the performance analysis show that it is crucial to have a QoS preservation mechanism in the router IP layer at any potential congestion point in the wireless network, to ensure that delay-sensitive and loss-sensitive applications, such as real-time video and voice, pass through unimpeded, relative to the loss-tolerant and delay-tolerant data applications. The comparison of the designed IP QoS preservation scheme namely, Priority Queuing without Block Acknowledgement (PQ noBA) shows that it can support 50% more multimedia application across the router than the other schemes.

ABSTRAK

Masa hadapan rangkaian tanpa wayar 4G sedang dibangunkan dengan tujuan untuk mencapai kepelbagaian yang lebih tinggi dalam teknologi tanpa wayar seperti Evolusi Jangka Masa Panjang UMTS (LTE), rangkaian kawasan tempatan tanpa wayar (WLAN), WCDMA/HSPA, WiMAX, dan sebagainya. Hal ini disokong oleh fakta yang mengatakan beberape ciri pelengkap wujud antara teknologi-teknologi ini. Misalnya, sesebuah teknologi boleh digunakan sebagai teknologi akses sementara yang lain boleh digunakan untuk backhaul. Bagi menghubungkan dua atau lebih teknologi tanpa wayar, peranti laluan diperlukan antara kedua-dua platform yang berbeza ini. Dalam usaha untuk menekalkan kualiti perkhidmatan (QoS) antara teknologi yang berbeza dengan definasi tidak sama, pendekatan yang lebih menyuruh diperlukan untuk memelihara QoS. Dengan kata lain, EDCA untuk WLAN dan pautan naik / pautan turun penjadualan paket untuk LTE. WLAN masih pada harga yang munasabah, mudah untuk digunakan dan digunakan secara meluas terutamanya untuk kegunaan dalaman. LTE dijangkakan mendominasi pasaran 4G selular teknologi. Walaubagaimanapun, ia akan mengambil masa sebelum teknologi LTE mencapai tahap sepertimana yang telah dicapai oleh WLAN dalam pasaran.

Objektif utama projek penyelidikan ini adalah untuk merekabentuk penghala capaian yang membolehkan jalinan kerja di antara WLAN dan LTE. Rekabentuk ini telah disahkan dan prestasi QoS penghala capaian telah pun dianalisis. Pertama, prestasi WLAN dan juga LTE dikaji secara berasingan dari segi kadar data, pengguna/daya pemprosesan sistem, kesan akses pelbagai dan kecekapan spektrum. Seterusnya, pelbagai jenis pendekatan dan skema untuk memelihara QoS antara WLAN dan LTE melalui penghala telah pun dikaji dan dinilai dari pelbagai segi (min suara dan kelewatan, trafik yang diterima, ketaran, kadar hilang bingkisan video). Pemodelan rekabentuk dan analisis prestasi hanya dapat dijalankan melalui perisian 'OPNET Modeler'. Hasil daripada kajian ini mengesahkan kemungkinan untuk seni bina dan paradigma berkerjasama penghala yang dicadangkan. Kebaikan bagi penghala yang dicadangkan adalah ia tidak memerlukan sebarang perubahan dalam sistem LTE dan WLAN yang sedia ada. Hasil analisis prestasi menunjukkan bahawa skema yang sesuai untuk pemeliharaan QoS adalah amat penting dalam lapisan IP apabila jumlah trafik yang masuk melebihi had lalu lintas. Pemetaan IP QoS memastikan bahawa peka kelewatan dan aplikasi peka kehilangan, seperti video masa nyata dan suara, dapat disalurkan tanpa halangan, berbanding dengan aplikasi tahan kehilangan data dan tahan kelewatan. Perbandingan antara skema pemuliharaan IP QoS yang telah direkabentuk, aturan keutamaan tanpa perakuan blok (PQ noBA) menunjukkan bahawa ia dapat menyokokong aplikasi multimedia 50 peratus lebih daripada skema pemuliharaan lain yang sedia ada.

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LIST OF ABBREVIATIONS

ACRONYM	DEFINITION
3GPP	Third Generation Partnership Project
4G	Fourth Generation Communication Networks
AAA	Authentication, Authorization, Accounting
AC	Access Categories
AIFS	Arbitration Inter Frame Space
AMBR	Aggregate Maximum Bit Rate
A-MPDU	MAC Protocol Data Unit Aggregation
A-MSDU	MAC Service Data Unit Aggregation
ARP	Allocation and Retention Priority
AS	Access Stratum
BA	Blocked Acknowledgement
BC	Backoff Counter
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
CW	Contention Window
DCF	Distributed Coordination Function
Diffserv	Differentiated Service
DSSS	Sequence Spreading Spectrum
EDCA	Enhanced Distributed Channel Access

EMM	EPS Mobility Management
EPS	Evolved Packed System
ESS	Extended Service Set
FDD	Frequency-Division Duplex
FHSS	Frequency Hopping Spread Spectrum
GBR	Guaranteed Bit Rate
GTP	GPRS Tunneling Protocol
HARQ	Hybrid Automatic Repeat-Request
HCCA	HCF Controlled Channel Access
HCF	Hybrid Coordination Function
HetNet	Heterogeneous Networks
HT	High Throughput
ICIC	Inter-Cell Interference Coordination
IMS	Internet Protocol Multimedia Subsystem
IMT-Advanced	International Mobile Telecommunications-Advanced
ITU	International Telecommunication Union
LTE	Long Term Evolution
MAC	Medium Access Control
MBMS	Multimedia Broadcast Multicast Services
MBR	Maximum Bit Rate
MCS	Modulation And Coding Scheme
MIMO	Multiple-Input Multiple-Output
NAS	Non-Access Stratum
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access

PAPR	Peak-To-Average Power Ratio
PCF	Point Coordination Function
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDG	Packet Data Gateway
PDN	Packet Data Network
PLCP	Physical Layer Convergence Protocol
PLMN	Public Land Mobile Network
PUCCH	Physical Uplink Control Channel
QCI	QoS Class Identifier
QoS	Quality Of Service
RACH	Random Access Channel
RB	Resource Block
RE	Resource Element
Rel. 8	Release 8
RIFS	Inter-Frame Spacing
RLC	Radio Link Control
RRC	Radio Resource Control
RRM	Radio Resource Management
RTP	Real-Time Protocol
SC-FDMA	Single Carrier- Frequency Division Multiple Access
SDM	Spatial Division Multiplexing
SDM	Spatial Division Multiplexing
SGI	Short Guard Interval
SGW	Serving Gateway

SIFS	Single Inter-Frame Spacing
SIFS	Single Inter-Frame Spacing
SISO	Single Input Single Output
STA	WLAN Station
STBC	Space Time Block Coding
STBC	Space Time Block Coding
TDD	Time-Division Duplex
TTI	Transmit Time Interval
TxBF	Transmit Beamforming
TXOP	Transmission Opportunity
UE	User Equipment
VOIP	Voice Over IP
VoLTE	Voice Over Long Term Evolution
WLAN	Wireless Local Area Network
WR	Wireless Router

LIST OF PUBLICATIONS

Journals:

[1] A M. Ghaleb, David Chieng, Alvin Ting, Ayad Abdulkafi, Kim-Chuan Lim, Heng-Siong Lim. "**Modeling of QoS-Aware Hybrid LTE-WLAN Wireless Router**," Smart Computing Review, 2013, (SCOPUS).

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[1] A M. Ghaleb, David Chieng, Alvin Ting, Kae Hsiang Kwong, KC Lim, HS Lim. "**Throughput Analysis of IEEE802.11n Using OPNET,**" The IET ICWCA2012, Kuala Lumpur, Malaysia, 2012.

[2] A M. Ghaleb, David Chieng, Alvin Ting, Ayad Abdulkafi, Kim-Chuan Lim, Heng-Siong Lim. "**Preservation of QoS Across Hybrid LTE-WiFi Router**," IET ICICT2013,Beijing, China, 2013.

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Other works (not directly related to the thesis but in the field Heterogeneous Networks):

Journals:

[1] Abdulkafi, A.A, Tiong Sieh Kiong, Chieng D., Ting, A M. Ghaleb, Johnny Koh. "**Modeling of Energy Efficiency in Heterogeneous Network**," Research Journal of Applied Sciences, Engineering and Technology, 2013, (ISI)

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CHAPTER 1

INTRODUCTION

Wireless communication technology has turned out to be one of the most important aspects of today's society. Nowadays the number of cellular wireless services subscribers has exceeded the number of the wired telephone services subscribers. Beside cellular wireless technology, other wireless technologies are being extensively used for voice as well as for data communication applications and entertainment services such as Wireless Local Area Networks (WLANs), cordless phones, radars and satellites. During the last two decades considerable numbers of researches have been dedicated for the development of wireless communication technology. Indeed, recently, it has emerged as the most thriving branch of development in the area of telecommunication (Hossain et al., 2009).

1.1 Background

This Section provides quick overview of the 4G wireless communication in general (Section 1.1.1), overview of the heterogeneous wireless networks (Section 1.1.2) and discuss the importance of having the router model in wireless heterogeneous networks and the QoS preservation scheme across the router (Section 1.1.3) .

1.1.1 LTE - 4G wireless networks

The fourth generation of wireless communication networks, which is known as 4G, will fuel the future wireless landscape with greater innovations. The ultimate aim for 4G

networks is to overcome the limitation of the current wireless network by the provision of a comprehensive and secure IP-based solution with much faster data transmission speeds. There is a standard definition as specifications of 4G by International Mobile Telecommunications-Advanced (IMT-Advance). 4G networks are designed to provide a higher quality of service, better reception, less packet loss/drop, improved all-IP multimedia services and interactive roaming between networks in order to fulfill the requirements of the IMT-Advanced issued by International Telecommunication Union (ITU) (Dahlman et al., 2011, Govil, 2008, Khan et al., 2009, Qing et al., 2008). Long-Term Evolution UMTS (LTE) is promising technology to meet the requirements of 4G wireless networks.

1.1.2 Heterogeneous Wireless Networks

The words Heterogeneous Network, referred to as HetNet, describe a network that consist of different access technologies, network that contain nodes operating with different parameters such as power, frequency, etc. Nowadays the demand for data traffic in cellular and other wireless networks is growing exponentially. Improving system spectral efficiency can only be achieved by increasing the number of the deployed nodes in the network since the link efficiency approaches its theoretical limits. However, increasing the number of nodes in dense deployment of macro base stations is not a choice since the sever introduced inter-cell interference significantly decreases the cell splitting gains. To solve the problem, low-power nodes such as pico, femto and relay nodes can be integrated into the network and forming a heterogeneous network containing macrocells and mix of low-power nodes from the same access technology (Damnjanovic et al., 2011). Interworking of different wireless networks under the umbrella of the heterogeneous network is of prime importance, more specifically WLAN and cellular integration (Ferrus

et al., 2010). However, developing solutions and designing architecture for the interworking are still open research.

1.1.3 Router with QoS implementation

WLANs achieve a great penetration in the market as an efficient solution for providing Internet mobile access; around the world, millions of WLANs connections, so-called hot spots, are deployed in particular locations, such as hotels, restaurants or airports. HetNets based on different access technologies, where macro network is based on a cellular technology and low power access points are based on WLANs are targeted in order to reduce the operating cost and double the resources hence, provide wireless access at a reasonable price and with a satisfactory data rates (Damnjanovic et al., 2011). Wireless router has to be implemented properly in order to enable interworking of the two different wireless technologies (WLAN and LTE) to work together in a complementary manner in forming the heterogeneous wireless networks.

Many challenges to the interworking arise when employing 3G/4G cellular networks and WLANs (El-Sayed et al., 2008). WLANs and LTE present different characteristics in terms of mobility management, security support, and end-to-end Quality of Service (QoS) provisioning. These issues should be carefully handled while developing the interworking schemes of the WLANs and LTE in order to achieve seamless integration.

With the increase of bandwidth promised by the WLANs and LTE network, more IP based multimedia applications, e.g. Voice over IP and video conferencing, running simultaneously over the router is to be expected. Running the application in real time, the media content need not be downloaded in full, but is being played out while parts of the content are being received and decoded. Due to its real-time nature, supporting video and audio streaming typically requires the router to guarantee the bandwidth and delay that

maintain the streaming quality. If the data does not arrive in time, the play out process will pause, which is annoying to end users. QoS guaranteed by the router is important when the network capacity is not enough to support both the real-time multimedia streams and non-delay-sensitive applications (e. g. web browsing). On the other hand, wireless network hardly guarantee the QoS due to the changing environment of the wireless medium which affect the capacity of the network (Namee, 2009).

1.2 Problem Statement

4G wireless networks are envisioned to embrace a higher level of heterogeneity whereby different wireless technologies such as LTE, WLAN, WCDMA/HSPA, WiMAX, etc, not only will coexist but will also cooperate more closely. This is motivated by the fact that several complementary characteristics exist between these technologies. The protocols and interworking architectures between different wireless access technologies are still emerging areas of research.

To interconnect two or more wireless technologies, the usage of routing device is inevitable. Unfortunately, there is no complete LTE-WLAN internetworking architectures platform and no visible wireless router design in the research arena. In order to preserve the QoS across these technologies which come with different QoS definitions, a more comprehensive approach is required to preserve QoS across two diverse wireless technologies i.e. Enhanced Distributed Channel Access (EDCA) for WLAN and Uplink/Downlink packet scheduling for LTE. However, QoS preservation across LTE-WLAN interface (router) is not addressed yet. Figure 1.1 show an interworking scheme between LTE network and WLAN where the former is used as backhaul and the later as access technology. To effectively interwork these technologies, both technologies should be analyzed in terms of the data rates, user/system throughput and spectral efficiency. The