Faculty of Electronic and Computer Engineering

CAPACITY ENHANCEMENT OF CELLULAR NETWORK USING WIFI OFFLOADING

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DECLARATION

I declare that this thesis entitled “Capacity Enhancement of Cellular Network using WiFi Offloading Approach” 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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Date :

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 Doctor of Philosophy.

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Date	:

DEDICATION

To my beloved husband, daughter, family and friends for the endless support and prayer.

ABSTRACT

The growing popularity of bandwidth-intensive applications as well as the proliferation of mobile devices in Malaysia has resulted in the accelerated growth of mobile data traffic or also known as the mobile data explosion phenomena. Hence, cellular network providers are struggling to keep pace in providing the demand of network capacity. Since the deployment of WiFi hotspot apparently is more cost-effective than upgrading the network infrastructure, WiFi offloading approach is an alternative that offers the most feasible solution to support cellular networks. This thesis developed a quantitative study on the performance of mobile data offloading through WiFi networks. 100 Android users from various backgrounds were recruited, and a real-time statistics of user's WiFi utilization were collected for 18 days of measurement study using a customized application development. WiFi offloading performance parameters such as temporal and spatial coverage has been studied in depth by conducting a meticulous demographic analysis using few developed algorithms. Findings reported only about 16% WiFi temporal coverage across all users, which reveals that users approximately utilize an average of 4 hours WiFi daily, and indicates higher utilization for student compared to a public group. The acquired whole-day traces also indicates WiFi coverage distribution through spatial coverage analysis which shows dense coverage distribution at residential area, especially between 1400 to 2300 hour. On the other hand, the study also takes into consideration the user's associated WiFi network performance parameters, that reveals low packet loss and moderately skewed throughput analysis. In addition, an analytical study on a single server using Markovian model has been deployed to observe the impact of WiFi offloading on cellular network capacity. In the case of without WiFi offloading deployment, the queue behaviour demonstrates higher traffic intensities when customer arrival rate is high, and therefore decrease cellular network capacity, and vice versa. To the best of our knowledge, this is the first measurement study that carried out a real data trace of user's daily WiFi offloading in the context of Malaysian cellular network subscriber. It shows that WiFi offloading approach has a positive prospect in augmenting the cellular network as well as providing new insights for network planning, policy or creative price plans.

ABSTRAK

Peningkatan populariti aplikasi yang menggunakan kapasiti data yang tinggi, serta pertambahan peranti mudah alih di Malaysia telah menyumbang ke arah peningkatan pesat trafik data mudah alih atau juga dikenali sebagai fenomena ledakan data mudah alih. Ini menambahkan tekanan kepada penyedia rangkaian selular untuk sentiasa menyediakan kapasiti data yang cukup tinggi bagi memenuhi permintaan pengguna. Oleh kerana kos pemasangan hotspot WiFi adalah jauh lebih murah berbanding menaiktaraf infrastruktur rangkaian selular sedia ada, pendekatan pindahan data ke rangkaian WiFi merupakan alternatif yang menawarkan penyelesaian paling sesuai pada masa ini. Tesis ini telah menjalankan sebuah kajian kuantitatif berkenaan dengan prestasi pindahan data mudah alih dari rangkaian selular ke rangkaian WiFi. Seramai 100 pengguna Android daripada pelbagai latar belakang telah di-rekrut, dan masa nyata penggunaan WiFi telah direkodkan selama 18 hari secara automatik melalui Penganalisa WiFi, iaitu aplikasi yang telah khas dibangunkan. Parameter bagi prestasi pindahan data ke WiFi seperti liputan temporal serta liputan kawasan telah dikaji secara mendalam dengan menjalankan analisa demografi menggunakan beberapa algoritma yang juga telah khas dibangunkan. Dapatan melaporkan hanya 16% liputan temporal WiFi yang direkodkan bagi semua pengguna. Secara puratanya setiap pengguna menggunakan WiFi selama 4 jam sehari, dan seterusnya menunjukkan akses yang lebih tinggi di kalangan kumpulan pelajar berbanding orang awam. Hasil dari cerapan data sepanjang hari juga melaporkan analisa liputan kawasan WiFi, di mana taburan liputan padat dikenalpasti cenderung di kawasan kediaman, terutamanya di antara jam 1400 hingga 2300. Dari segi yang lain, kajian ini turut mengambil kira parameter bagi prestasi rangkaian WiFi yang digunakan oleh peserta, yang melaporkan kadar kehilangan paket data yang agak rendah disamping analisa kelajuan pemprosesan data yang mencatatkan variasi bacaan yang sederhana. Sebagai tambahan, analisa analitikal pelayan komputer menggunakan model Markovian telah digunakan untuk mengkaji impak penggunaan pindahan data WiFi terhadap kapasiti rangkaian selular. Dapatan melaporkan sekiranya tanpa menggunakan pendekatan pindahan data WiFi, turutan tingkah laku paket data mencatatkan kepadatan atau keamatan trafik yang lebih tinggi serta berkadar langsung dengan ketibaan pelanggan, seterusnya mengakibatkan kemerosotan kapasiti rangkaian selular, dan sebaliknya. Sepanjang pengetahuan kami, ini adalah kajian kuantitatif pertama di Malaysia dalam konteks kajian pindahan data mudah alih ke rangkaian WiFi di mana cerapan data sebenar diperolehi secara automatik dari pengguna rangkaian selular. Pendekatan ini mempunyai prospek positif dalam menyokong rangkaian selular di Malaysia serta menyumbang maklumat baru yang boleh digunapakai samada dalam perancangan dasar, rangkaian atau bagi tujuan merangka pelan harga yang kreatif.

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3G	-	Third Generation
3GPP	-	Third Generation Partnership Project
4G	-	Fourth Generation
AMI	-	Amazon Machine Image
ANDSF	-	Access Network Discovery and Selection Function
AP	-	Access Point
API	-	Application Programming Interface
AWS	-	Amazon Web Services
CAPEX	-	Capital Expenditure
CDF	-	Cumulative Density Function
CPU	-	Central Processing Unit
CRAN	-	Centralized Radio Access Network
CRM	-	Customer Relationship Management
EC2	-	Elastic Computing Cloud
EDGE	-	Enhanced Data for GSM
EPC	-	Enterprise Private Cloud
FKEKK	-	Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer
FPTT	-	Fakulti Pengurusan Teknologi dan Teknousahawanan
FTP	-	File Transfer Protocol

GPS	-	Global Positioning System
GPU	-	Graphic Processing Unit
HSDPA	-	High Speed Download Packet Access
IO	-	Input Output
ISP	-	Internet Service Provider
LTE	-	Long Term Evolution
MAP	-	Markovian Arrival Process
MBB	-	Mobile Broadband
MCMC	-	Malaysian Communication and Multimedia Commission
MDC	-	Mobile Data Collection
MN	-	Mobile Node
MOHE	-	Ministry of Higher Education
MSS	-	Maximum Segment Size
NSS	-	Network Selection Scheme
OPEX	-	Operational Expenditure
OS	-	Operating System
QOS	-	Quality of Services
RAM	-	Random Access Memory
RAT	-	Radio Access Technology
RO	-	Research Objective
RQ	-	Research Questions
RSS	-	Received Signal Strength
RTT	-	Return Trip Time
SDK	-	Software Development Kit

SINR	-	Signal to Interference Noise Ratio
SPSS	-	Statistical Package for Social Science
SSID	-	Service Set Identification
TCP	-	Transport Control Protocol
TM	-	Telekom Malaysia
UE	-	User Equipment
UTeM	-	Universiti Teknikal Malaysia Melaka
VHO	-	Vertical Handover
VLAN	-	Virtual LAN
VOIP	-	Voice over Internet Protocol
WiFi	-	Wireless Fidelity
WiMAX	-	Worldwide Interoperability for Microwave Access

LIST OF PUBLICATIONS

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CHAPTER 1

INTRODUCTION

1.1 Research background

According to Cisco report (Cisco Visual Networking Index, 2017), the global mobile data traffic is forecasted to increase seven-fold from 2016 to 2021. By 2021, the traffic is expected to grow 122 times more than the total global mobile traffic generated in 2011. The tremendous growth of mobile data traffic is referred to as mobile data explosion. Cisco also reported that in 2016, smartphones represented almost 50 percent from the total 429 million mobile devices and they accounted 89 percent of the total mobile data traffic.

Taking into the context of Malaysian mobile consumer's market, Malaysia has experienced tremendous growth in mobile broadband subscriptions to 30.6 million in the first quarter of 2017, from only 23.35 million in 2007 (MCMC, 2017a). According to Internet Survey 2017 (Malaysian Communications and Multimedia Commission, 2017), it was found that 89.4 percent of internet users in Malaysia used a smartphone as a medium to access the internet. Table 1.1 reveals the data statistics of internet subscription for fixed broadband and mobile cellular network.

The increasing trends in both data traffic and mobile devices indirectly has impact to the cellular network provider in providing network capacity. As the internet rules the world, particularly with the proliferation of bandwidth hungry application, cellular network providers are struggling to keep up with the ever-increasing demand for higher network capacity and wider network coverage.

Table 1.1: Growth of internet subscriptions and smartphone as medium of access

	2015	**2016**	**2017**
	(million)		
Fixed Broadband	2.8	2.5	2.6
Mobile Cellular	27.8	28.5	35.3
	(percentage)		
Broadband Penetration	99.7	99.8	117.3
Mobile Cellular Penetration Rate	143.8	139.9	131.1
Smartphone as Medium of Internet Access	87 .3	87.9	89.4

There are quite a few numbers of solutions to cater this explosive traffic growth problem. The first is to upgrade network infrastructure by building more cell towers and base stations of smaller cell sizes, or upgrading the network to the next generation networks such as Long-Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX).

However, this is not a viable strategy where under the flat price structure, revenue is independent of data usage (Lee et al., 2010), while network upgrade or expansion requires high capital expenditure (CAPEX) and operational expenditure (OPEX). Moreover, upgrading the network capacity may intensify the problem by encouraging more data usages.

The second alternative is to propose price restructuring based on usage, which obviously not an attractive solution to the consumers. Installing more indoor mobile broadband base stations (MBB) is another unattractive solution due to its high cost and inability to provide optimum coverage (Shayea et al., 2017).