UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electronics and Computer Technology and Engineering

INVESTIGATION OF WIFI OFFLOADING BEHAVIOR TRADE-OFF BASED ON THE QUALITY OF EXPERIENCE MEASUREMENT

Ruliyanta

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INVESTIGATION OF WIFI OFFLOADING BEHAVIOR TRADE-OFF BASED ON THE QUALITY OF EXPERIENCE MEASUREMENT

RULIYANTA

A thesis submitted
in fulfilment of the requirements for the degree of Doctor of Philosophy
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DECLARATION

I declare that this thesis, "Investigation of Wi-Fi Offloading Behaviors Trade-off Based on the Quality of Experience Measurement," is the result of my research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted as a candidature for any other degree.

Signature	:
Name	: Ruliyanta
Date	: 01 November 2024

APPROVAL

I now declare that I have read this thesis, and in my opinion, it is sufficient in terms of scope and quality for the award of a Doctor of Philosophy.

Signature	:
Supervisor Name	: Associate Prof. Dr. Mohd Riduan Ahmad
Date	: 01 November 2024

DEDICATION

To my beloved wife, son, daughter, and parents

for the endless support and prayer

ABSTRACT

Global mobile data traffic is forecast to grow by 63 percent in 2016; at the country level, Indonesia leads the highest global growth at 142 percent. From the results of a 2017 survey released by the Indonesian Internet Service Providers Association, internet user penetration by city/district is concentrated in urban areas with a percentage of 72.41 %, rural-urban (49.49 %), and rural regions (48.25 %). The problem statement in this research is the lack of sufficient data on Wi-Fi offloading in Indonesia has prompted research into its socio-economic impacts. The study analyzes differences between economic strata, focusing on Wi-Fi usage patterns, network performance, and user behaviour. It aims to assess Wi-Fi performance through metrics like data usage, quality of service, and user experience, comparing these findings with manual survey data. The research objectives are to design a method for measuring Wi-Fi usage as a tool for conducting studies and to analyze network performance parameters, including end-to-end throughput and packet loss. Additionally, the study aims to measure QoE through user feedback and identify correlations between socio-economic groups in terms of Wi-Fi utilization patterns, network performance, and QoE Fairness Indexes. The methodology involves monitoring the internet usage patterns of volunteers who access office Wi-Fi. This study investigates the pattern of Wi-Fi offloading in the workplace. The goal is to see the effectiveness and pattern of using Wi-Fi in office buildings using 100 volunteers. The users are grouped into two groups; the first group is for workers with salaries according to government standards and is called the Socio 1 group, and the second group with a wage higher than the salary of Group 1 is called Socio 2. The survey results show that internet user penetration in Indonesia grew by 8 % to 143.26 million, or 54.68 % of the population. The most common internet usage is 1-3 hours daily, with popular activities including chat applications, social media, and video viewing. In Socio 1, average Wi-Fi usage is 2.88 hours per day with 4.2 GB of data, an 87.11 % QoS rate, and an 86.19 % QoE. In Socio 2, usage is 2.37 hours with 2.55 MB of data, a 92.45 % QoS rate, and a 91.36 % QoE.

PENYIASATAN KESEIMBANGAN TINGKAH LAKU PEMUNGGAHAN WIFI BERASASKAN PENGUKURAN KUALITI PENGALAMAN

ABSTRAK

Trafik data mudah alih global diramalkan berkembang sebanyak 63 peratus pada 2016; di peringkat negara, Indonesia mendahului pertumbuhan global tertinggi pada 142 peratus. Daripada tinjauan 2017 yang dikeluarkan oleh Persatuan Penyedia Perkhidmatan Internet Indonesia, penembusan pengguna internet mengikut bandar/daerah tertumpu di kawasan bandar dengan peratusan 72.41 %, luar bandar-bandar (49.49 %), dan kawasan luar bandar (48.25 %). Pernyataan masalah dalam penyelidikan ini ialah kekurangan data yang mencukupi mengenai pemunggahan Wi-Fi di Indonesia telah mendorong penyelidikan terhadap kesan sosio-ekonominya. Kajian ini menganalisis perbezaan antara strata ekonomi, memfokuskan pada corak penggunaan Wi-Fi, prestasi rangkaian dan gelagat pengguna. Ia bertujuan untuk menilai prestasi Wi-Fi melalui metrik seperti penggunaan data, kualiti perkhidmatan dan pengalaman pengguna, membandingkan penemuan ini dengan data tinjauan manual. Objektif penyelidikan adalah untuk mereka bentuk kaedah untuk mengukur penggunaan Wi-Fi sebagai alat untuk menjalankan kajian dan untuk menganalisis parameter prestasi rangkaian, termasuk pemprosesan hujung ke hujung dan kehilangan paket. Selain itu, kajian ini bertujuan untuk mengukur QoE melalui maklum balas pengguna dan mengenal pasti korelasi antara kumpulan sosio-ekonomi dari segi corak penggunaan Wi-Fi, prestasi rangkaian dan Indeks Kesaksamaan QoE. Metodologi ini melibatkan pemantauan pola penggunaan internet sukarelawan yang mengakses Wi-Fi pejabat. Kajian ini menyiasat corak pemunggahan Wi-Fi di tempat kerja. Matlamatnya adalah untuk melihat keberkesanan dan corak penggunaan Wi-Fi di bangunan pejabat menggunakan 100 sukarelawan. Pengguna dikelompokkan kepada dua kumpulan; kumpulan pertama adalah untuk pekerja dengan gaji mengikut piawaian kerajaan dan dipanggil kumpulan Sosio 1, dan kumpulan kedua dengan gaji lebih tinggi daripada gaji Kumpulan 1 dipanggil Sosio 2. Hasil tinjauan menunjukkan penembusan pengguna internet di Indonesia meningkat. sebanyak 8 % kepada 143.26 juta, atau 54.68 % daripada populasi. Penggunaan internet yang paling biasa ialah 1-3 jam setiap hari, dengan aktiviti popular termasuk aplikasi sembang, media sosial dan tontonan video. Dalam Sosio 1, purata penggunaan Wi-Fi ialah 2.88 jam sehari dengan 4.2 GB data, kadar QoS 87.11 % dan QoE 86.19 %. Dalam Sosio 2, penggunaan ialah 2.37 jam dengan 2.55 MB data, kadar QoS 92.45 % dan QoE 91.36 %.

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LIST OF ABBREVIATION

3G	– Third Generation
3GPP	– Third Generation Partnership Project
4G	– Fourth Generation
5G	– Fifth Generation
ANN	– Artificial Neural Network
ANDSF	– Access Network Discovery and Selection Function
AP	– Access Points
BTS	– Base Transceiver Station
CAPEX	– Capital Expenditures
DAWONs	– Delay-Aware Wi-Fi Offloading and Network Selection
DHCP	– Dynamic Host Configuration Protocol
DPI	– Deep Packet Inspection
GZRP	– Genetic Zone Routing Protocol
HEW	– High-Efficiency Wireless
HWN	– Heterogeneous Wireless Networks
IEEE	– Institute of Electrical and Electronics Engineers
ISP	– Internet Service Provider
KPI	– Key Performance Indicator
LTE	– Long Term Evolutions
MAC	– Media Access Control
MADM	– Multi-Attribute Decision-Making
MAPE	– Mean Average Percentage Error
MN	– Mobile Node
MNO	– Mobile Network Operators
MOS	– Main Opinion Score
NSS	– Network Selection Scheme
OPEX	– Operating Expenditure
OS	– Operating System
QoS	– Quality of Services
QoE	– Quality of Experience
RAM	– Random Access Memory
RAT	– Radio Access Technology
RO	– Research Objective
RQ	– Research Questions
RSS	– Received Signal Strength
RTT	– Return Trip Time
SINR	– Signal to Interference Noise Ratio
SSID	– Service Set Identification
TCP	– Transport Control Protocol

UE	– User Equipment
UTeM	– Universiti Teknikal Malaysia Melaka
VHO	– Vertical Handover
Wi-Fi	– Wireless Fidelity

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LIST OF PUBLICATIONS

Conference Articles

Ruliyanta, R., Ahmad, M. R., Md Isa, A. A., Ronald Repi, V. V., Yasher, L. O., and Jusuf, H., 2022. Wifi-6 Antenna Design to Increase Data Traffic Offloading with HFSS and PCAAD Software. International Conference on Electrical Engineering, Computer Science and Informatics (EECSI), 06-07 October 2022, pp. 441–445.

Journal Articles

Ruliyanta, Ahmad, M. R., and Isa, A. A. M., 2024. QOE Measurement model in wi-fi networks : analysis of socio- economics influences in Indonesia. *Przegląd Elektrotechniczny*, 2024(6), pp. 83–87.

Ruliyanta, Ahmad, M. R., and Isa, A. A. M., 2023. Wi-Fi offloading on mobile data communication in the office, the measurement study. *Przeglad Elektrotechniczny*, 2023(10), pp. 165–170.

Ruliyanta, R., Riduan Ahmad, M., and Md Isa, A. A., 2022. Adaptive Wi-Fi offloading schemes in heterogeneous networks, the survey. *Indonesian Journal of Electrical Engineering and Computer Science*, 28(1), pp. 254–268.

CHAPTER 1

INTRODUCTION

1.1 Research Background

There remains controversy about the use of smartphones for work. Some employers still prohibit the use of smartphones during work hours. Some businesses even use smartphones to boost employee efficiency at work. Naturally, smartphone productivity only applies to some kinds of employment. According to Cisco, the world's first 5G (fifth generation) networks are expected to be launched early in 2017 (Cisco Visual Networking Index, 2017). This includes wireless networks and smartphone manufacturers. The carriers have already fought to be perceived as having the best network, and chipmakers have already revealed their first 5G modems. With higher speeds and more dependable connections, 5G networks represent the next generation of mobile internet connectivity for smartphones and other devices with state-of-the-art network technology, and the most recent research will enable 5G to deliver connections millions of times faster than today, with average download rates of about 1 GBps predicted to become the standard so on (Andrews et al., 2014).

There has been a significant surge in global mobile data traffic, and no indications of it decelerating. Due to the escalating speed, greater utilization of mobile data will be seen in the future. The increasing utilization of massive data traffic volumes poses a significant challenge for service providers in meeting the surging demand.

Cellular networks view Wi-Fi offloading, also known as Wireless Fidelity offloading, as a potential solution to the problem of excessive mobile data usage (Cheng et al., 2014). Wi-Fi offload involves transferring data traffic from costly cellular networks to Wi-Fi infrastructure, significantly reducing infrastructure expenses. Furthermore, it improves user connectivity and provides additional value-added Wi-Fi services.

Nevertheless, the deployment of Wi-Fi offloading presents challenges. A Wi-Fi operator warned at the Wi-Fi Global Congress 2015 that the maximum capacity of 200 simultaneous active users severely restricts the ability to provide carrier-grade voice service on Wi-Fi. This translates to approximately 4 to 10 active voice calls. It is imperative to deliver solutions that employ efficient algorithms to address the constraints imposed by the restrictive conditions. This will ensure the reliability of Wi-Fi offloading, allowing a seamless transition between Wi-Fi and cellular networks based on the user's requirements.

In 2016, there will be a 63 % increase in cellular data traffic worldwide. The Middle East and Africa have the highest growth rates (96 percent), followed by Asia Pacific (71 percent), Latin America (66 percent), and Europe Central and East (64 percent). In 2016, growth in Western Europe was over 52 %, whereas North America expanded at a slower rate of 44 %. India, China, and Indonesia had the fastest global growth rates at the national level—142, 86, and 76 percent, respectively. These three nations also had the quickest traffic increase in 2015. However, in 2016, Indonesia's traffic growth accelerated (129 % in 2015), while China and India's traffic growth decreased from 2015 (89 % in India and 111 % in China).

Based on cities and districts, metropolitan areas had the highest percentage of Internet users (72.41 %), followed by rural-urban regions (49.49 %) and rural areas (48.25 %), according to the findings of a 2017 survey published by the Indonesian Internet Service Providers Association (APJII, 2017). This high penetration indicates the prevalence of fiber optics and other internet-related infrastructure. The results of this poll pertain to Indonesia's overall internet penetration rate, which increased by only 8 % to 143.26 million users, or 54.68 % of the country's 262 million total population, relative to the 132.7 million individuals in the prior results, as shown in Figure 1.1.

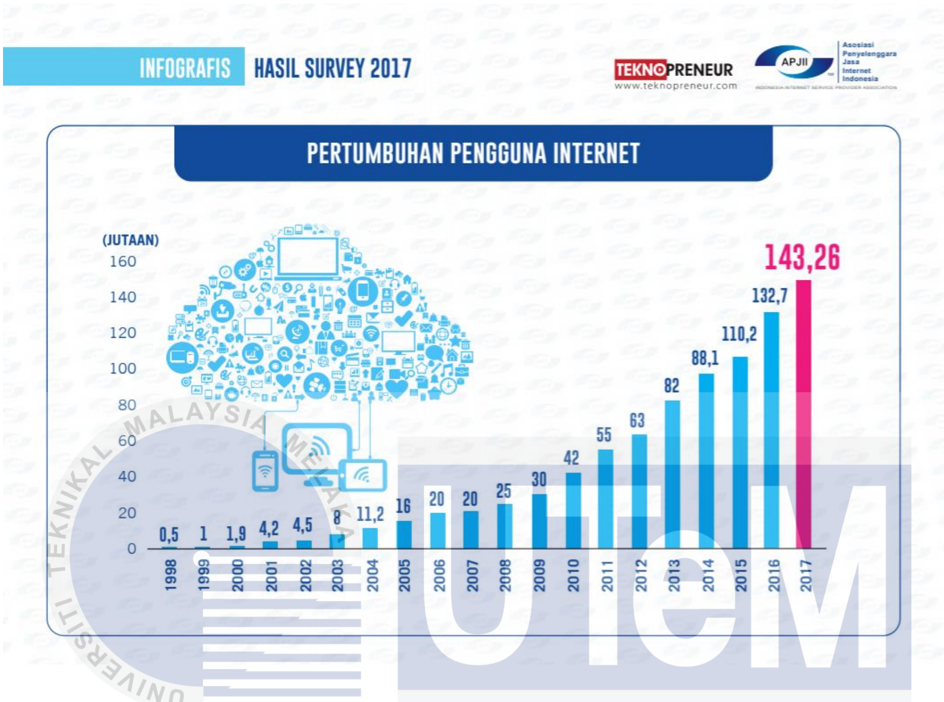

Figure 1.1: Internet user growth in Indonesia 2017

People most commonly use a smartphone to access the internet. The ownership of smartphones in urban areas stands at 70.96 %, while in rural-urban regions, it is 45.42 %, and in rural areas, it is 42.06 %. Urban areas (31.55 %), rural-urban areas (23.42 %), and rural areas (23.83 %) use computers less frequently. According to the APJII (2017)l, most individuals (43.89 %) spend 1-3 hours daily using the internet, the longest reported length. As a result, there are 4–7 hours, accounting for 29.63 % of the total, and more than 7 hours, accounting for 26.48 %. Most users primarily access chat programs (89.35 %), social media platforms (87.13 %), search engines (74.84 %), see photographs and photos (72.79 %), view videos (69.64 %), and engage in various other internet activities. The study results indicate that the least popular activity among respondents is accessing banks, with a participation rate of 7.39 %.

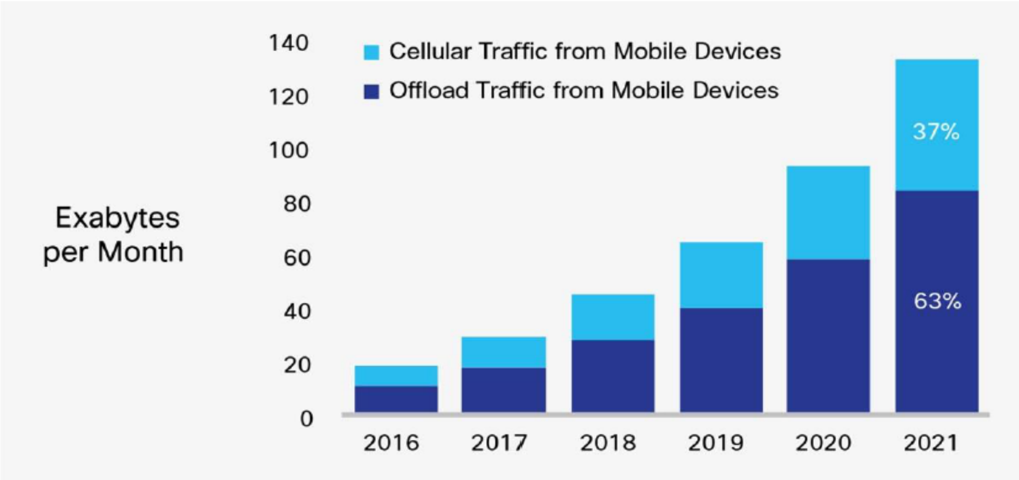

Figure 1.2: In 2021, 63 percent of total mobile data traffic will offload to Wi-Fi

One possibility is to increase the present network to the next-generation network to overcome the expansion of cellular data traffic (He et al., 2016). Another alternative is to increase the number of BTS (base transceiver stations) and construct smaller cells to boost cellular network capacity. The drawback is that this approach involves a relatively substantial capital investment (CAPEX) and operating costs (OPEX). The second option is to propose pricing restructuring based on data usage, which is extremely unprofitable for consumers. Adding the number of femtocell stations is also not an attractive solution because of the high cost and inability to provide appropriate coverage (Shayea et al., 2019).

Exploiting Wi-Fi networks has long been the ultimate solution to fulfilling the need for exploding bandwidth demand (Cisco, 2020). Predictions indicate that the advancement of Wi-Fi standards will increase the connection speed for the Wi-Fi offloading process. Globally, there will be over 628 million public Wi-Fi hotspots by 2023, up from 169 million hotspots in 2018, or a fourfold growth. In 2023, Asia Pacific will grow by 46 percent to become the most significant global public hotspot. Community hotspots, or home pots, will increase. In this concept, clients are grouped into a regional group or a residential community to share the internet through access points provided by partnerships or directly from operators. Hotspot 2.0 on a Wi-Fi gateway will automatically transition to a better speed by adopting IEEE 802.11ac or Wi-Fi 5 and the newer 802.11ax or Wi-Fi 6 standard. Globally, Wi-Fi 6 hotspots will expand 13 times from 2020 to 2023 and will be 11 % of all public Wi-Fi hotspots in 2023. Figure 1.3 Shows the historical evolution and future of wired and wireless technologies.

The prevalence of IEEE 802.11ac, the latest Wi-Fi standard, will gain momentum from 2018 to 2023. In 2023, 66.8 percent of all WLAN endpoints will be equipped with 802.11ac or Wi-Fi 5. IEEE 802.11n or Wi-Fi 4, ratified in 2007, provides various speeds that allow users to view media with high-resolution video streaming. However, IEEE 802.11ac, or Wi-fi 5, offers a much higher speed and will be updated with the latest IEEE 802.11ax or Wi-Fi,6 also called High-Efficiency Wireless (HEW), which can provide average throughput per user with a speed factor of four times a dense user environment.