



**Faculty of Electronics and Computer Technology and
Engineering**

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

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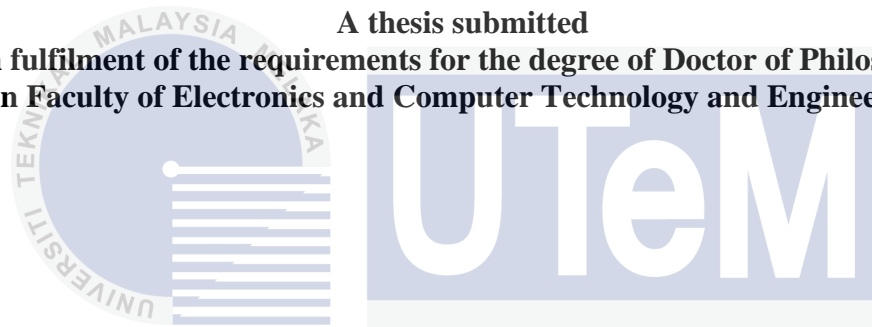
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**INVESTIGATION OF WIFI OFFLOADING BEHAVIOR TRADE-OFF BASED ON
THE QUALITY OF EXPERIENCE MEASUREMENT**

RULIYANTA

**A thesis submitted
in fulfilment of the requirements for the degree of Doctor of Philosophy
in Faculty of Electronics and Computer Technology and Engineering**



Faculty of Electronics and Computer Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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2024

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.



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.



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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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TABLE OF CONTENTS

| | PAGE |
|---|-------------|
| DECLARATION | i |
| APPROVAL | ii |
| DEDICATION | iii |
| ABSTRACT | iv |
| ABSTRAK | v |
| ACKNOWLEDGMENTS | vi |
| TABLE OF CONTENTS | vii |
| LIST OF TABLES | x |
| LIST OF FIGURES | xii |
| LIST OF ABBREVIATION | xiv |
| LIST OF APPENDICES | xvi |
| LIST OF PUBLICATIONS | xvii |
| CHAPTER | |
| 1. INTRODUCTION | 18 |
| 1.1 Research Background | 18 |
| 1.2 Problem Statement | 10 |
| 1.3 Research Questions | 12 |
| 1.4 Research Objectives | 14 |
| 1.5 Scopes of Research | 15 |
| 1.6 Research Significance | 17 |
| 1.7 Research Contribution | 18 |
| 1.8 Organization of Thesis | 19 |
| 2. LITERATURE REVIEW | 21 |
| 2.1 Mobile Data Explosion | 21 |
| 2.1.1 Growth Trend in Indonesia | 22 |
| 2.1.2 Android-based Smartphone | 24 |
| 2.2 Socio-Economics Group of Internet Users in Indonesia | 25 |
| 2.3 Key Player and Internet Services in Indonesia | 26 |
| 2.4 Wi-Fi Offloading | 27 |
| 2.4.1 Requirements of Coexistence from 5G Wireless Systems | 27 |
| 2.4.2 Network Selection Scheme | 28 |
| 2.4.2.1 Factors in Network Selections | 29 |
| 2.4.2.2 Handover Strategy | 29 |
| 2.4.2.3 Access Network Selection Algorithms | 30 |
| 2.5 Classification According to Incentive of Wi-Fi Offloading | 32 |
| 2.5.1 Capacity | 33 |
| 2.5.1.1 Non-Delayed Offloading | 33 |
| 2.5.1.2 Delayed Wi-Fi Offloading | 35 |
| 2.5.2 Cost | 37 |
| 2.5.3 Energy | 38 |
| 2.5.4 Rate | 40 |
| 2.5.5 Continuity | 41 |
| 2.6 User's Trace/Real-Time Measurement Study | 42 |

| | | |
|-----------|--|------------|
| 2.6.1 | Related Works in Indonesia | 44 |
| 2.6.2 | Parameters on Measurement Study | 45 |
| 2.6.2.1 | End-to-End Throughput/QoS | 45 |
| 2.6.2.2 | Behavioral Patterns of Smartphone Users | 46 |
| 2.6.2.3 | Knowing the Sites Opened by Clients/Users | 47 |
| 2.6.2.4 | Quality of Experience (QoE) | 47 |
| 2.7 | Chapter Summary | 70 |
| 3. | RESEARCH METHODOLOGY | 71 |
| 3.1 | Introduction | 71 |
| 3.2 | Research Framework | 71 |
| 3.3 | Research Design | 72 |
| 3.3.1 | Problem Definition | 73 |
| 3.3.2 | Research Flowchart | 74 |
| 3.4 | Research Preparation | 74 |
| 3.4.1 | Data Sources | 74 |
| 3.4.1.1 | Location of Measurement Study | 75 |
| 3.4.1.2 | Population and Android-based Platform | 75 |
| 3.4.1.3 | Sample Size | 77 |
| 3.4.1.4 | Instrumentation | 79 |
| 3.4.1.5 | Procedure of Data Collection | 100 |
| 3.4.2 | Data Understanding | 101 |
| 3.4.2.1 | Data Tables and Parameters | 101 |
| 3.4.3 | Data Preparation | 104 |
| 3.4.3.1 | Cleaning the Data | 105 |
| 3.4.3.2 | Data Collect Tools: Deep Packet Inspection | 105 |
| 3.5 | Implementation of Analysis | 108 |
| 3.5.1 | Descriptive Analysis | 109 |
| 3.5.2 | Inferential Statistics | 109 |
| 3.6 | Validity and Reliability | 111 |
| 3.6.1 | Validity | 111 |
| 3.6.2 | Reliability | 112 |
| 3.6.2.1 | Deep Packet Inspections Testing | 112 |
| 3.6.2.2 | Preliminary Study | 115 |
| 3.7 | Design of ANN Algorithm | 116 |
| 3.8 | Chapter Summary | 117 |
| 4. | RESULTS AND DISCUSSIONS | 118 |
| 4.1 | Introduction | 118 |
| 4.2 | Descriptive Statistics Analysis | 118 |
| 4.3 | Duration of Wi-Fi Offloading | 121 |
| 4.3.1 | The daily total duration of Wi-Fi connectivity | 122 |
| 4.3.2 | Traffic Data Offloading | 123 |
| 4.3.3 | Temporal Coverage | 129 |
| 4.3.4 | Temporal Coverage by Socio-Economics Group | 131 |
| 4.4 | Network Performance | 134 |
| 4.4.1 | Quality of Service Measurements | 135 |
| 4.4.2 | Quality of Experience Measurements | 141 |
| 4.5 | Accessed applications and Categories | 147 |

| | | |
|-----------|---|------------|
| 4.6 | Chapter Summary | 154 |
| 5. | CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH | 156 |
| 5.1 | Introduction | 156 |
| 5.2 | Concluding Remarks | 156 |
| 5.2.1 | Time Duration of Wi-Fi accessed | 156 |
| 5.2.2 | Network Performance Analysis and QoE Metric | 159 |
| 5.2.3 | The User Behaviors | 161 |
| 5.3 | Recommendation for Future Research Direction | 161 |
| | REFERENCES | 163 |



LIST OF TABLES

| TABLE | TITLE | PAGE |
|-------|--|------|
| 1.1 | Research Questions | 13 |
| 1.2 | Summary and relationship of RQ and RO | 15 |
| 2.1 | Smartphone Penetration of Population Indonesia | 23 |
| 2.2 | Mobile Operating System Market Share Worldwide | 24 |
| 2.3 | Mobile Operating System Market Share Indonesia | 24 |
| 2.4 | Considerations for NSS | 29 |
| 2.5 | Traditional Offloading According to Enhancing Capacity | 34 |
| 2.6 | Techniques According to the Further Incentive Continuity | 42 |
| 2.7 | Related Work in Indonesia | 44 |
| 2.8 | Key parameter related to Wi-Fi offloading | 45 |
| 2.9 | The most significant supervised learning approaches | 53 |
| 2.10 | The relationship between biological neural networks and ANN | 68 |
| 3.1 | Detail of Client Statistic | 82 |
| 3.2 | Deep Packet Inspection | 83 |
| 3.3 | Client History Monitor | 83 |
| 3.4 | The QoE Measurement Parameter | 88 |
| 3.5 | Determining the model reliability level concerning the Correlation Model | 100 |
| 3.6 | Key parameter related to Wi-Fi offloading | 102 |
| 3.7 | A Primary Filter | 106 |
| 3.8 | A secondary filter | 106 |
| 3.9 | Android app grouping by category | 107 |
| 3.10 | Summary Table for Descriptive Statistics | 110 |
| 4.1 | The critical parameter related to Wi-Fi offloading | 119 |
| 4.2 | The ratio between average upload and download data on Socio 1 and Socio 2 | 125 |
| 4.3 | User segmentation based on data traffic offload | 127 |
| 4.4 | Average Wi-Fi Traffic in the office compared to Estimated data users per capita in Indonesia in 2021 | 128 |
| 4.5 | Proportion of Temporal Covered in Socio 1 and Socio 2 | 133 |
| 4.6 | quality of service measurement in the Socio 1 | 137 |
| 4.7 | quality of service measurement in the Socio 2 | 139 |
| 4.8 | Important parameters of quality of service measurement results | 140 |
| 4.9 | Comparison between quality of service and QoE | 144 |
| 4.10 | The correlation value and description | 145 |
| 4.11 | The quality of service and QoE Correlation value based on the Pearson Correlation Algorithm | 147 |
| 4.12 | Applications used based on total traffic data | 148 |

| | | |
|------|-------------------|-----|
| 4.13 | Result comparison | 153 |
| 4.14 | Chapter Summary | 155 |



LIST OF FIGURES

| FIGURE | TITLE | PAGE |
|--------|---|------|
| 1.1 | Internet user growth in Indonesia 2017 | 3 |
| 1.2 | In 2021, 63 percent of total mobile data traffic will offload to Wi-Fi | 4 |
| 1.3 | Historical evolution and future of wired and wireless technologies | 6 |
| 1.4 | Mobile Data Offloading | 7 |
| 1.5 | QoE fairness index | 9 |
| 1.6 | Problem Statement Diagram | 12 |
| 1.7 | Research Scope using K-Chart Approach | 16 |
| 2.1 | Offload pertains to traffic from dual-mode devices (excluding laptops) over Wi-Fi or small-cell networks | 22 |
| 2.2 | The market share of Indonesian Cellular Operators 2019 | 26 |
| 2.3 | Classification of Wi-Fi Offloading ((He et al., 2016)) | 32 |
| 2.4 | The main idea of the AMUSE mechanism | 38 |
| 2.5 | The evaluation method of the Quality of Experience | 48 |
| 2.6 | The QoS-QoE domains of the appliance | 49 |
| 2.7 | General block diagram to perform QoE management | 51 |
| 2.8 | Relationship of Quality of Service Parameters with QoE Measurements | 65 |
| 3.1 | Research Framework | 72 |
| 3.2 | Research Flow Chart | 73 |
| 3.3 | Composition of Internet Users in Indonesia | 76 |
| 3.4 | Mobile OS Market Share in Indonesia | 77 |
| 3.5 | Rasoft, online sample Size Calculator | 78 |
| 3.6 | Method of Data Collection | 80 |
| 3.7 | The Wi-Fi Networks | 81 |
| 3.8 | Deep Packet Inspection Flowchart | 84 |
| 3.9 | 5G KPIs-QoS-QoE mapping model (Berger, 2019) | 87 |
| 3.10 | The method of determining QoE with the ANN method | 90 |
| 3.11 | The structure of an ANN | 94 |
| 3.12 | The QoE model creation by using the ANN method | 96 |
| 3.13 | Chronology of Data Collection Process | 101 |
| 3.14 | Type of Measured Parameter | 103 |
| 3.15 | Controller User Guide | 108 |
| 3.16 | Subtypes of Various Forms of Validity Test | 111 |
| 3.17 | SSL/TSL Deep Inspection | 114 |
| 3.18 | The algorithm used in this research | 117 |
| 4.1 | The number of valid experimental days for each user, users are sorted in descending order of total duration | 120 |
| 4.2 | Cumulative Distribution Function (CDF) for Wi-Fi Offloading duration | 123 |

| | | |
|------|--|-----|
| 4.3 | Number of Data Offloaded | 124 |
| 4.4 | The relationship between time duration and the amount of AP traffic data | 126 |
| 4.5 | Temporal coverage of all users | 130 |
| 4.6 | Temporal coverage for Socio 1 | 131 |
| 4.7 | Temporal coverage for Socio 2 | 132 |
| 4.8 | Measurement graph of the average quality of service users in the Socio 1 group | 138 |
| 4.9 | The average QoS users in the Socio 2 group | 140 |
| 4.10 | Cumulative Distribution Function of QoS and QoE on Socio 1 | 142 |
| 4.11 | Cumulative Distribution Function of QoS and QoE on Socio 2 | 143 |
| 4.12 | Applications used based on total traffic data on Socio 1 | 149 |
| 4.13 | Applications used based on total traffic data on Socio 2 group | 151 |
| 4.14 | Applications used based on total traffic data on all data | 152 |



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 |



LIST OF APPENDICES

| APPENDIX | TITLE | PAGE |
|----------|---|------|
| A | Briefing Details on Measurement Study | 180 |
| B | Participant's Declaration Form | 181 |
| C | Application Letter from Building Management Inalum Main Office, Kuala Tanjung | 182 |
| D | Initial Survey results | 183 |
| E | Survey results on the average quality of experience | 187 |
| F | Data duration connected to Wi-Fi and Traffic Offloading | 190 |
| G | User-access application traffic data | 194 |
| H | Quality of service and QoE measurement results | 200 |

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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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.

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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.

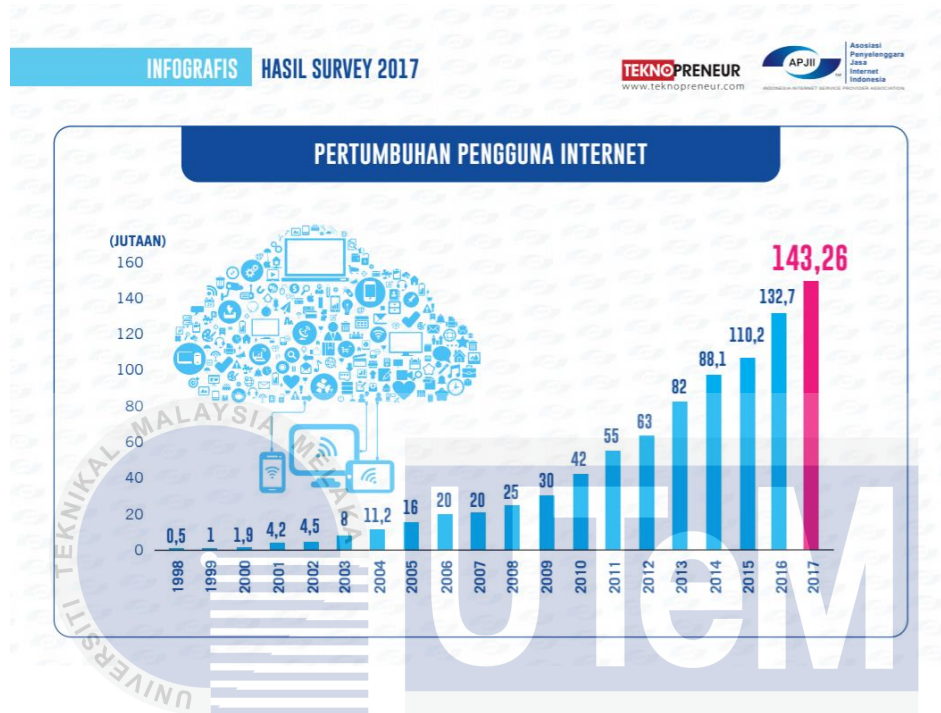


Figure 1.1: Internet user growth in Indonesia 2017

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 %.

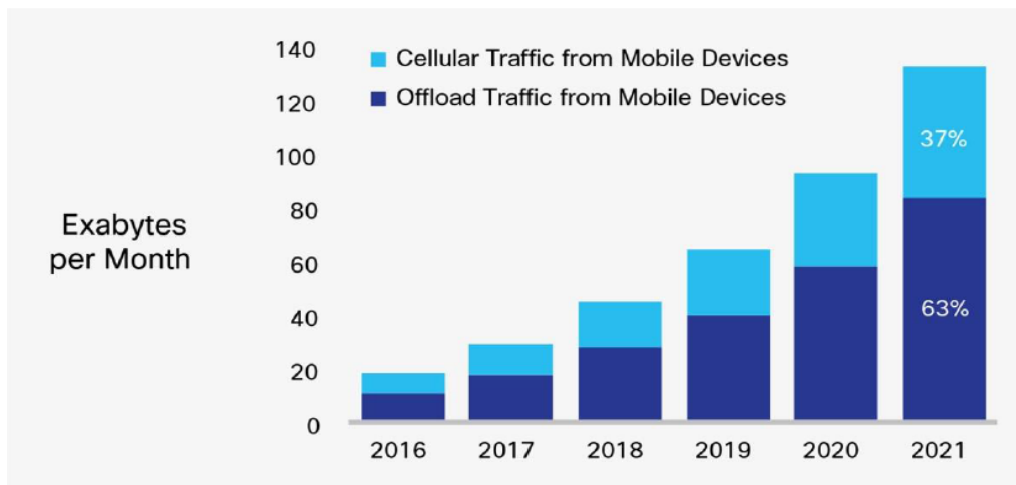


Figure 1.2: In 2021, 63 percent of total mobile data traffic will offload to Wi-Fi

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.

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