1. RULIYANTA[1], 2. Mohd Riduan AHMAD[2], 3. Azmi Awang Md ISA

Universitas Nasional, Indonesia & Universiti Teknikal Malaysia Melaka (UTeM) (1), Universiti Teknikal Malaysia Melaka (UTeM) (2), Universiti Teknikal Malaysia Melaka (UTeM) (3)
ORCID: 1. 0000-0002-2439-330X; 2. 0000-0001-9474-7153 3. 0000-0002-9404-5562

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Wi-Fi offloading on mobile data communication in the office, the measurement study

Abstract*. Based on gender grouping, internet use in the office is 3.82 hours per day for women and 2.53 hours per day for men. The amount of data accessed by female users is 255.61 MB, while for males, it is smaller at 221.35 MB. The research results show that the average user of offloading Wi-Fi is a Medium User. In the Male group, 2.53% of users are classified as Extreme users with an offloading capacity of more than 30 GB per month. The average amount of temporal coverage of Wi-Fi use in offices for the Female group is 14.97%, and for the male group is 14.88%*

Streszczenie. *Biorąc pod uwagę podział na płeć, korzystanie z internetu w biurze wynosi 3,82 godziny dziennie dla kobiet i 2,53 godziny dziennie dla mężczyzn. Ilość danych dostępnych dla kobiet wynosi 255,61 MB, podczas gdy dla mężczyzn jest mniejsza i wynosi 221,35 MB. Wyniki badań pokazują, że przeciętny użytkownik odciążający Wi-Fi to użytkownik średni. W grupie mężczyzn 2,53% użytkowników jest sklasyfikowanych jako użytkownicy ekstremalni z możliwością odciążenia ponad 30 GB miesięcznie. Średni czasowy zasięg korzystania z Wi-Fi w biurach dla grupy kobiet wynosi 14,97%, a dla grupy mężczyzn 14,88% (****Odciążenie Wi-Fi na mobilną transmisję danych w biurze, badanie pomiarowe****)*

Keywords: Wi-Fi, Mobile Offloading, Wireless, Internet
Słowa kluczowe: Wi-Fi, mobilne odciążanie, sieć bezprzewodowa, Internet.

Introduction

According to Cisco, Indonesia is the world's highest internet growth country [1]. Meanwhile, according to a survey conducted by the Association of Indonesian Internet Service Providers (APJII) in Indonesia in 2022, the internet penetration rate in Indonesia will reach 77.02% [2]. This value is equivalent to 210,026,769 Indonesians connected to the Internet. Based on the survey results, 67.46% of internet users have an income below Rp. 1,000,000, -. While 88.07% with income between 1-5 million, 96.83 with income between 5 million to 15 million, and 88.53% with income above 15 million rupiahs.
Still, according to APJII, 89.03% of devices used to access the Internet were recorded using smartphone devices. The most effective Internet connection method uses mobile data from cellular operators, with 77.06%, while 22.03% uses Wi-Fi installed at home. Table 1 provides a way of connecting to the Internet that was released based on a survey in Indonesia.

Table 1. Internet Connection Method

Method	Value [%]
Operator Cellular	77,64%
Wi-Fi At the Home	20,61%
Wi-Fi at Office/School	0,61%
Wi-Fi Public	0,96
Don't know	0,18%

The length of internet users based on gender is at most 1 to 5 hours, with a total of 49.59% for men and 53.74% for women. Details of the duration of internet use in a day are given in Table 2. From the table below, some use the internet for more than 10 hours per day, namely 14.16% male and 11.26% female users.

Table 2. Length of internet use by gender

Duration	Male [%]	Female [%]
< 1 hour	3.14	4.25
1 – 5 hours	49.59	53.75
6 – 10 hours	33.11	30.75
> 10 hours	14.16	11.26

In another survey, APJII released a list of smartphone brands used to access the internet in Indonesia [3]. Devices with the Android operating system dominate the list. IOS-based smartphone devices were only used by 3.4%.

Besides at home, the internet is also used in the office. Based on the survey results, only 15.3% of the internet is installed in the work or office environment [3]. In this survey, 72.2% of workers do not work in offices. The remaining 12.6% need internet in their office. The office dependency level is very high on the internet network, only 7.1%. Apart from work needs, internet use is limited in the office. The survey shows that 2.8% of companies restrict and 12.1% allow using the internet at work.

Wi-Fi offloading transfers cellular subscriber data access to a Wi-Fi network [4]–[6]. In this paper, we will measure the Wi-Fi offloading activity of 100 cellular phone subscribers who access the internet while in the office and utilize the Wi-Fi network provided by the company. The contributions of the research are measurements of the duration connected to the internet while in the office.

Related Works

The growth in data needs in the world has experienced a significant explosion in the last decade [7]. This growth is triggered by the increasing number of mobile devices that offer various applications. The increase in mobile data traffic needs is faster than the growth in cellular technology, both 4G and 5G. This gap provides an alternative for cellular telephone subscribers to take advantage of the Wi-Fi network.

5G technology offers data access speeds at high speeds. However, implementing 5G technology is more challenging than one might imagine. 5G implementation requires network densification [8]. An increase in capacity per unit area is required to achieve high speed. High speed can be reached by reducing the size of the cells used. Therefore, 5G networks are designed to use smaller cells, such as microcells with a maximum range of 100 meters [9] and pico cells with a smaller Wi-Fi range [10]. So 5G is an identification network technology that brings users closer to transmitting devices owned by cellular operators. However, it is predicted that existing cellular technology growth will not be able to cope with the explosion of existing data communication traffic growth [4], [11]. Meanwhile, the radio technology proposed to support 5G telecommunications still has several proposals. Some propose using the cellular mmWave Cellular System with unleased frequency [12]. At the same time, the 5G system carries Multi RAT (Radio

Access Technology) technology and a multi-tier 5G cellular wireless network [13].

The deficiency in the need for wireless data traffic for cellular subscribers can be overcome by switching to Wi-Fi access point services [6], [11], [14], and this is known as Wi-Fi Offloading. It is not that data traffic from operators is unable to serve customers. The main reason is the high data traffic quota offered by cellular phone operators. Figure 1 is a radio technology that illustrates the process of mobile data offloading or Wi-Fi offloading [15].

Fig.1. Mobile data Offloading

The advantage of the access point provided by Wi-Fi is that the data quota provided is cheaper than the data quota from cellular operators. Many Wi-Fi currently relies on fixed broadband access with fiber optic networks [16], [17]. Meanwhile, Wi-Fi technology continues to evolve with the latest release of Wi-Fi 6E. Wi-Fi version 6E offers high data rates supporting 5th-generation (5G) communications. This reason is possible because of the use of a new frequency spectrum. If Wi-Fi versions 4 and 5 use a single frequency, version 6 uses multiple frequencies [18]. Meanwhile, Wi-Fi 6E uses a frequency of 6 GHz [19]–[21]. While Wi-Fi version 7 has also been introduced, known as the IEEE 802.11be standard, as a preparation for the next generation of telecommunications technology that operates at frequencies of 2.4 GHz, 5 GHz, and 6 GHz [19].

According to a survey conducted in Malaysia in 2017, it was found that 89.4 percent use smartphones to access the internet [11]. The limitation of cellular operators to meet their customers' data needs at low prices is a problem. Offloading Wi-Fi seems the most viable solution due to the abundant and available infrastructure. Traffic routed to Wi-Fi networks may reduce mobile network traffic so that mobile network providers can accommodate traffic growth at a lower cost. In his research, a survey was conducted for 18 days and collected real traces of Wi-Fi users on Android smartphones. In his research, grouping was carried out based on socio-economic where Group 1 spent more time using Wi-Fi than Group 2.

Obstacles for cellular telephone operators to develop their network by increasing the number of BTS (Base Transmitter Stations) encountered many obstacles. In Indonesia, for example, government regulations of the Republic of Indonesia regulate the shared use of BTS towers for several operators at once [22]. In addition to the limited vacant land to build BTS, the costs that must be incurred to increase cellular network capacity by deploying more BTS require costly capital expenditure (CAPEX) and operating expenditure (OPEX) [5].

In his research, [11] embedding additional smartphone applications with the Android operating system, the volunteers were measured and monitored. The choice of android devices is because 83.17% of people in Malaysia use this operating system. While group 1 volunteers are a group of students, and group 2 are groups of employees and lecturers in the city of Melaka.

Meanwhile, a similar study was conducted in South Korea [23]. The difference is that the selected smartphone device is an iPhone. The volunteers selected were Iphone user communities spread across major Korean cities, and 60% were in Seoul. These volunteers have different backgrounds.

Their research measured the following statistics relevant to offloading total duration of Wi-Fi connectivity time, data rate during connection, distribution of connection time and interconnect time, and correlation of total trip length with data rate and Wi-Fi connectivity time. Temporal Coverage: Unloading performance highly depends on the portion of time the user is in the Wi-Fi coverage area, defined as the temporary coverage.

In Indonesia, the average working hours are 8 hours a day. In the initial survey, this company freed employees to use internet facilities to report their work activities.

Experimental Setup

In this study, 100 volunteers who worked in a public office building in North Sumatra Province were taken. Volunteers consisted of 21 women and 79 men from various work backgrounds. The workers surveyed included employees of banks, shipping, contractors, and mining companies owned by the Republic of Indonesia.

In previous research, user activity was monitored using an application embedded in a smartphone. While in this research, we use the Wi-Fi Server Manager to monitor all users who are offloading to a Wi-Fi network. In general, we make a research flowchart as given in Figure 2.

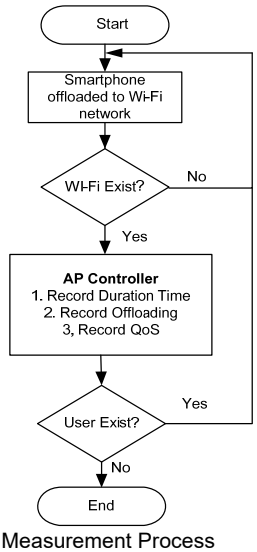

Fig.2. Flowchart of Measurement Process

The server can monitor both the duration connected to the network, data tabulation and applications accessed by the user. The server also records the quality of service for all devices. Wi-Fi Manager can automatically retrieve all user activities recorded on the server and display them on the monitor at any time. Users can be seen for a particular duration as needed, hourly, daily, weekly, or according to the wishes of the network manager.

The monitored activity was carried out for 30 days. The Wi-Fi network has the Wi-Fi 6 standard, capable of providing dual frequencies of 2.4 GHz and 5 GHz. Compared to previous versions, the advantage of Wi-Fi 6 is the ability to access data speed and the number of users that can be served [24].

Result and Discussion

We recruited 100 volunteers who own 3G/4G/5G android smartphones from the community of active phone users in the office buildings we researched in North Sumatra. We asked them to activate their Wi-Fi generally during the 20 days of the study from March 21 to April 9, 2021. The volunteers came from various occupational backgrounds, such as housekeeping, engineering, security, bank employees, and government employees. Thus, the total number of valid daily traces we collect is 1477 days. However, this number is because some volunteers need to be recorded in the server records. This is caused by various reasons, such as not coming to work or not carrying a smartphone. However, it is possible because the user does not activate Wi-Fi on the smartphone. Some volunteers work using computers or laptops. The number of valid trial days for each user is given in Figure 3. Users are sorted in descending order of total duration [23].

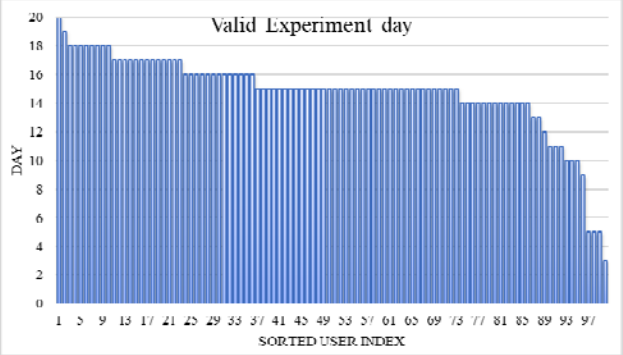

Figure 3. The number of valid experimental days for each user

According to Figure 3, the horizontal axis is the number of volunteers who have access to Wi-Fi in one day. At the same time, the vertical axis represents the number of days. This graph displays the number of days connected to the Wi-Fi of each user. For 20 days of recording, one user is connected every day. On the other hand, the smallest number connected to the server was recorded for only three days. The number of connections monitored on the server is 1477 days. If the number of volunteers is 100, the average volunteer connected to Wi-Fi is 14.77 days or about 15 days out of 20 days of monitoring. Most volunteers have a 6-day working week [25]. Regulations in Indonesia do not regulate the number of working days. But what is regulated is the number of hours worked in a week or a month [26]

Volunteers perform their work activities an average of 8 hours a day. In carrying out his work, a smartphone is needed to report work activities. For example, officers must submit hourly security situation reports to their supervisors. Documentation in the form of photos of the work environment sent through an application to superiors. Smartphones function as work support [27]. Its findings suggest that reliance on smartphones at work increases workers' perceived job performance and social capital. However, on the downside, it seems to lead to the emergence of smartphone addiction symptoms such as anxiety and uncontrolled usage behaviour.

In this study, the duration of the connection with the access point is measured. In addition to counting the connected time tabs, we are calculating the amount of unloading data. The data can be in the form of uploads and downloads. In the research location, not all areas are covered by the Wi-Fi signal, especially around the building. This area covered has to do with volunteer work positions. The landscape worker's work area is far from the AP. Security is also placed at several posts not covered by Wi-Fi access because the work is more than 100 meters from the main building. We note that the two distinct behaviours are easy to spot. On the one hand, the curve with the steepest slope is mapped for female users accessing a mean of 61.35 hours during the study with a standard deviation of 29.36. In other words, women were more active in the duration of AP use than male volunteers, which was an average of 50.26 hours with a standard deviation of 20.49. This average value is taken from 20 days of observation [28]. According to a survey conducted in Indonesia in 2017, the average internet user per day is 1 to 3 hours, reaching 43.89% [29]. We have yet to get references to the latest internet usage in Indonesia. In this observation, it was found that the average Wi-Fi user in the office is 3.59 hours a day. Based on gender grouping, internet use in the office is 3.82 hours per day for women and 2.53 hours per day for men. Detailed CDF results can be seen in Figure 4.

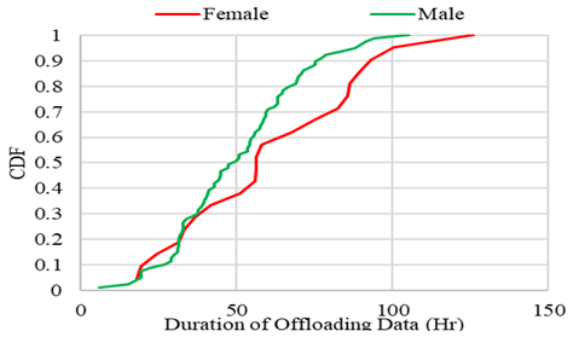

Fig.4. Cumulative Distribution Function of Wi-Fi Offloading duration

The number of data offloads of each user is measured over 20 days. The amount of data downloaded and uploaded is given on the graph. The tabulation of the duration of time connected to the access point (AP) is not proportional to the amount of data accessed by each user. Figure 5 presents a graph of the amount of Offloaded data. The graph shows the amount of data uploaded and downloaded. Data is presented in MB (Mega Byte). This value is shown on the vertical axis, while the horizontal axis shows each user who is a member of this study. The amount of data between upload and download is significantly different. Data downloads appear larger in number on the graph.

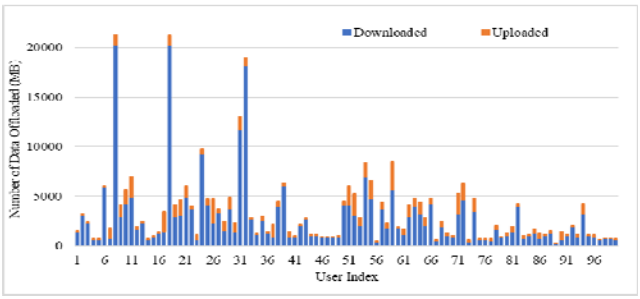

Fig.5. Number of Data Offloaded

The average amount of offloaded data is 228.78 MB per day. The amount of data accessed by female users is 255.61 MB, while for males, it is smaller at 221.35 MB. In his research [30], a comparison of the Wi-Fi offloading ratio was carried out, namely a comparison of data usage between cellular data and data from access points. We compared the amount of data uploaded and the amount of data downloaded. The average number of data downloads is 82.08%, and the remaining 21.83% is the average number of data uploads. This data gives a ratio of 1: 4.58.

In the female gender group, the average number of data downloads is 86.25%, and the average upload is 13.75%. This value provides an offloading ratio of 1:6.27. For the male gender, the amount of data downloaded is 80.74%, and the average upload is 19.26%. This value provides a demolition ratio of 1:4.19. This ratio is detailed in Table 3.

Table 3. The ratio upload and download of data group

Group	Download [%]	Upload [%]	Ratio
Female	86.25%	13.75	1:6.27
Male	80.74%	19.26	1:4.19
All	82.08%	17.92	1:4.58

Scatter diagrams are used to test how strong the relationship between the two variables is and determine the type of relationship between the two variables, namely the duration of time connected to the access point and the amount of data traffic accessed by the AP. These two variables are observed to see the correlation between the two. The amount of data uploaded compared to the data downloaded shows no relationship, and a minimal R^2 value indicates this. In addition, user habits can also affect it. The user is connected to Wi-Fi but does not perform any resulting offloading activity. Figure 6 is a graph of the relationship between the duration of the Wi-Fi connection and the amount of data offloading.

Our observations do not show a significant correlation between the two variables. This correlation is because every user connected to the access point only sometimes carries out activities with his smartphone. The user is connected to the access point but performs normal work activities. This results in the duration of time connected to the access point are not proportional to the amount of data traffic to the AP. According to Figure 6, we use a trendline liner model. The closer the data is to the trendline, the more linear the duration associated with the amount of data consumption. On the other hand, the further away, the longer the duration of connecting with Wi-Fi, the further from the data traffic consumed.

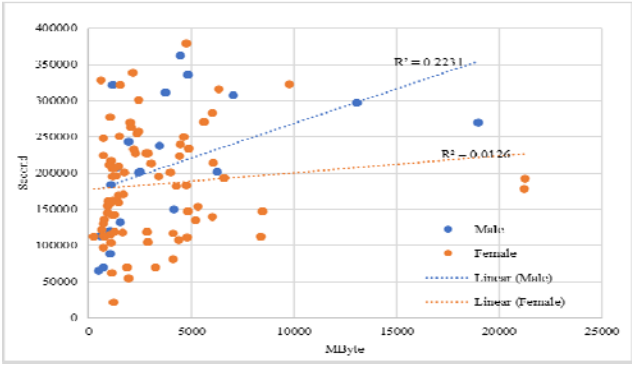

Fig.6. A relationship between time duration and the amount of data

Given the need for more consensus among researchers on categorizing smartphone users according to data traffic offloading, we decided to categorize users into five types. Five is often the number of groups selected in user segmentation research [31]. Our study data were collected for only 20 days. If it is assumed to be one month or 30 days, then the data traffic rate in a month and Wi-Fi user data can be grouped as shown in Table 4.

The research results show that the average user of offloading Wi-Fi is a Medium User. From the table, in the Male group, 2.53% of users are classified as Extreme users with an offloading capacity of more than 30 GB per month. According to [32], Indonesia had the most significant number of internet users in the world in 2014 and the country with the highest growth in internet users in 2016. At the end of 2018, internet users in Indonesia were categorized as heavy internet users, with data consumption of more than 5 GB. Per month only for internet connection from a mobile device. If data usage of more than 5 GB is categorized as heavy internet users, then in the female group, 42.86% are heavy internet users in the office, and in the male group, there is 34.18%. Meanwhile, according to Cisco's prediction [33], Indonesia's average data traffic consumption per capita in 2021 is 11.3 GB per month.

Table 4. User segmentation based on data traffic mobile offload

User Category	Data Traffic Offload [Gbyte]	Female [%]	Male [%]
Light user	<1	9.52%	3.80%
Medium user	1 – 5	47.62%	62.03%
Medium-heavy user	5 – 10	28.57%	27.85%
Heavy user	10 – 30	14.29%	3.80%
Extreme user	≥ 30	0%	2.53%

Thus, using Wi-Fi while in the office contributes to data traffic of 51.70% for women and 42.92% for men. For more details, the data is presented in Table 5. From the data we obtained, nine volunteers used Wi-Fi data in the office, totalling more than 11.3 GB.

Table 5. Traffic in the office compared to Estimated data users per capita

Group	Wi-Fi Traffic [Gbyte]	Cisco Forecast 2021 [Gbyte]	Value [%]
Female	5.84	11,3	51.70
Male	4.84	11,3	42.92

We measured the following statistics relevant to the total offload of the duration of Wi-Fi connectivity. Offloading performance highly depends on the duration of time the user is in the Wi-Fi coverage area, defined as Temporal Coverage [14]. This study measured the average duration of time connected to the AP while in the office only.

Figure 8 shows the average daily period recorded by 100 participants during the measurement study. It also displays the coverage plot recorded for 24 hours starting at 07.00 WIB or 00.00 WIB every day [11].

Yellow bars represent daily temporal coverage for each participant in the measurement study for each active day and hour. Users are numbered as shown on the X-axis and labelled as "User Index." In this survey, all participants need Wi-Fi access at home. So only access Wi-Fi at work. Even if they get Wi-Fi access to unique places like cafes, we ignore this because the number is small. As can be seen in Figure 7, the average of all users is 15.04% throughout the day. From the Temporal Coverage Graph, the average duration of a user connecting to a Wi-Fi network is 3.61 hours or 3 hours 37 seconds.

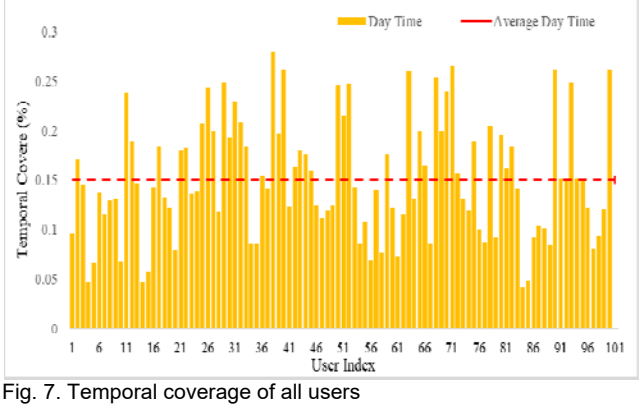

Fig. 7. Temporal coverage of all users

There is a significant difference between the data from [14], who recorded 70% temporal coverage throughout the day. According to the 2017 first-quarter report by [14], fixed broadband penetration in South Korea was 40.5%, while Malaysia only recorded fixed broadband penetration of 8%. Meanwhile, based on the World Bank 2021, fixed broadband penetration in Indonesia is only around 4% [34][11]. The report supports our findings showing an average of 15.04% temporal coverage in Indonesia compared to 70% in Korea and 8% in Malaysia [11]. Meanwhile, Figure 8 shows the results of the Temporal Coverage for the Women's group.

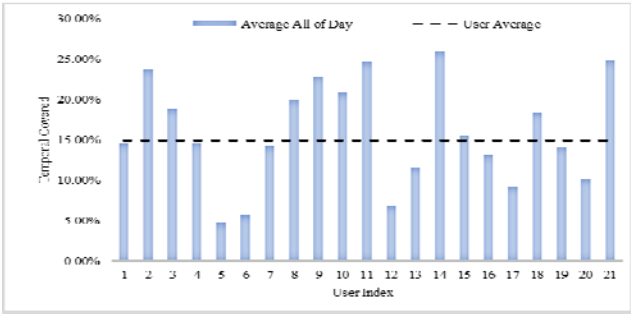

Fig.8. Temporal coverage for Female

The graph in Figure 8 shows that the female group shows a higher time coverage in using AP. The average Wi-Fi usage for connection throughout the day is 14.97%, respectively. According to the Demographic and Socio-Economic Report of Internet Users [35], 49.52% of Internet users in Indonesia come from the age group of 20-34 years, which supports the finding that group 1 generally tends to spend more time accessing the internet. Figure 9 is the Temporal Coverage of Male users while in the office.

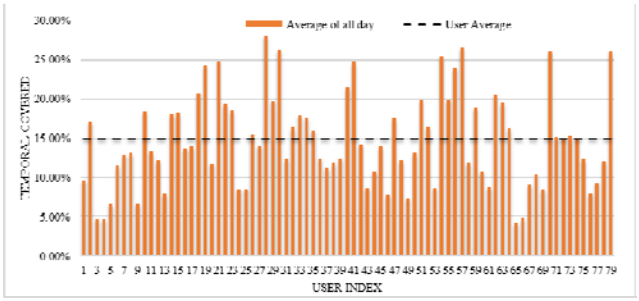

Fig.9. Temporal coverage for Male

The average magnitude of temporal coverage in the male group is 14.88%. The values obtained may have something to do with the ongoing implementation of the Covid-19 Pandemic, where the use of Wi-Fi is more to support work activities for online meetings related to the COVID-19 Pandemic policy issued by the highest authority of the Republic of Indonesia [37]. The tabulation of duration connected to Wi-Fi is not linear with the amount of data uploaded. Due to various reasons, users do not enable Wi-Fi on their smartphones. Work culture is very influential in the use of smartphones.

Conclusion

Based on gender grouping, internet use in the office is 3.82 hours per day for women and 2.53 hours per day for men. The amount of data accessed by female users is 255.61 MB, while for males, it is smaller at 221.35 MB. The research results show that the average user of offloading Wi-Fi is a Medium User. In the Male group, 2.53% of users are classified as Extreme users with an offloading capacity of more than 30 GB per month. The average amount of temporal coverage of Wi-Fi use in offices for the Female group is 14.97%, and for the male group is 14.88%.

***Authors**: Ruliyanta and Mohd Riduan Ahmad, Centre for Telecommunication Research and Innovation (CeTRI), Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer (FKEKK), Universiti Teknikal Malaysia Melaka (UTeM). Email: riduan@utem.edu.my.*

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