Augmenting Mobile Data Networks using WiFi Offloading: A Measurement Study

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Abstract*— The growing popularity and proliferation of mobile devices has resulted in an exponential growth of mobile data traffic or also known as mobile data explosion. Cellular network providers are struggling to address the challenges of bandwidth scarcity and also to meet end user's expectation of high network capacity. Due to the abundance of existing WiFi infrastructure and significantly inexpensive deployment compared to cellular network upgrade, WiFi offloading seems the most viable solution at the moment. The Malaysian Communications and Multimedia Commission (MCMC) reported in Internet User Survey 2016 that more than half (59.6%) of Internet users in Malaysia used free Wi-Fi to go online. This work presents a real trace of quantitative study on the role of WiFi networks in augmenting mobile data offloading in Malaysia scenario. The research investigated how much traffic load WiFi offloading takes away from cellular network and its utilization pattern according to a different group of users. An extensive measurement study was conducted by collecting statistics of WiFi connectivity from 100 Android platform users for 18 days. Findings from the preliminary results showed that WiFi offloaded a significant amount of data traffic in user's daily mobile data consumption. Therefore, it is an interesting alternative for cellular network operators in to accommodate and augmenting the current traffic growth as well as providing insights into their network planning or creative price plans.

***Index Terms*— Mobile Data Offloading; Delayed WiFi Offloading; Mobility; Measurement Study.**

I. INTRODUCTION

According to Cisco report [1], 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. 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 [2]. According to Internet Survey 2016 [3], it was found that 89.3 percent of internet users in Malaysia used a smartphone to access the internet. In addition, the percentage of smartphone ownership rose to 90.7 percent in 2015 compared to 74.3 percent in 2014.

The increasing trends in both mobile data traffic and mobile devices have resulted in bandwidth scarcity. Cellular network providers struggle to provide adequate and high-volume network capacity in order to cope with such demands. The major challenge lies in addressing network capacity as well as providing wider network coverage.

On the other hand, mobile broadband coverage is not universal. Broadband coverage such as 4G and 3G, usually only available at a strategic location such as metropolitan areas, offices and industrial area or location with high population. Most of the places either still experiencing slower mobile broadband service such as EDGE or does not have mobile broadband coverage at all. In addition, some of the places with good mobile broadband coverage experiencing problems like a blind spot, especially access from indoor building.

Mobile users are also experiencing slower data speed or throughput during peak hour due to network congestion, particularly at high traffic areas such as at a stadium, convention centers, and crowded airport. [3] highlighted one of the most frequent consumer complaints that are related to the speed of the service. One of the most common complaints reported by users is the signal fluctuates between 3G and EDGE, even though the area is within 3G coverage. The unstable connection is caused by the fluctuations of the receiving signals. Therefore consumers experienced slow speed during data connection activities.

The issues mentioned above highlights some limitation of mobile data service provided by cellular networks. The issues mainly are caused by the limited network capacity or also known as bandwidth scarcity. The problems are further exacerbated by the proliferation of mobile devices and rich multimedia content, video streaming and cloud services that require reliable and high bandwidth capacity. According to Internet Survey 2016 [3], it was found that 89.3 percent of internet users in Malaysia used a smartphone to access the internet. In addition, the percentage of smartphone ownership rose to 90.7 percent in 2015 compared to 74.3 percent in 2014.

There are several possible solutions to address this explosive traffic growth problem. The first is by building more cell towers and smaller cell sizes in order to scale the network capacity. The other solution is by upgrading the network to the next generation networks such as WiMAX and LTE. However, this is not a viable strategy where under the flat price structure, revenue is independent of data usage [4], while network upgrade or expansion requires high capital expenditure (CAPEX) and operational expenditure (OPEX). Moreover, upgrading the network may intensify the problem by encouraging more data utilization. Therefore, due to the abundance of WiFi infrastructure that has been widely deployed by operators and residents, Wifi offloading is a promising solution to address the need of additional network capacity and at the same time providing wider coverage.

This paper aims to provide insights on WiFi offloading roles in Malaysia and how much it could contribute to reducing cellular network's traffic load. In addition, this work has a distinctive contribution when it further analyses the user's data utilization pattern according to certain corresponding sample set. An Android-based mobile application was developed as a measurement tool to collect real data trace of user's daily-utilization pattern. Data traces obtained from the measurement study were used to study key observation parameters such as temporal coverage, spatial coverage, and an end to end data rates.

II. IMPROVING CAPACITY

WiFi offloading is a significant method of addressing mobile data explosion and enhancing network capacity. Generally, [5] classified WiFi offloading techniques into five metrics called as incentives. The five incentives are: capacity, cost, energy, rate and continuity, and has been classified according to the main area that needs to be addressed and improved.

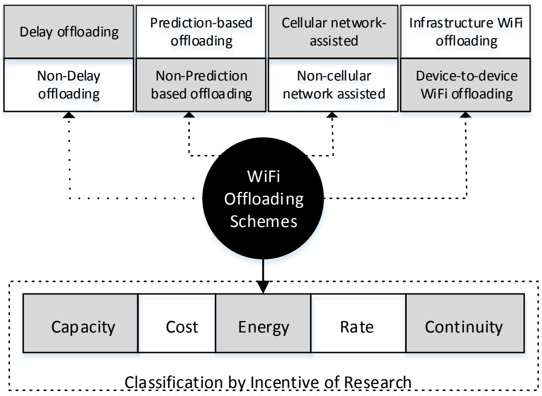

Figure 1: Incentives of Offloading Techniques [5]

This research aims to study on the incentive of capacity and WiFi roles in mobile data offloading. Capacity is the most basic incentive of WiFi offloading and is further categorized into two basic classes: Non-delayed and Delayed offloading.

A. System Description

The scenario of WiFi offloading and its procedures was described and illustrated as in Figure 2[6]. It shows the deployment of WiFi networks which is spatially overlapped in cellular network coverage.

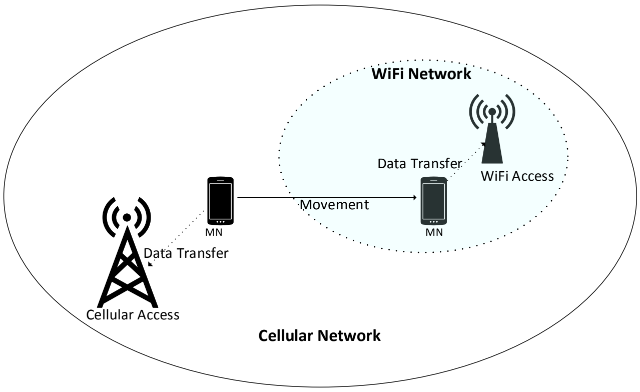

Figure 2: Description of Mobile Data Offloading

Offloading process may be described using the following scenario. Let say at time t, a MN attempts to establish a session for a data transfer. While the cellular network is always assumed available, WiFi network is only accessible when MN is close enough to the WiFi coverage. The offloading scheme uses network selection algorithm based on the Received Signal Strength (RSS).

B. Non-Delayed and Delayed WiFi Offloading

In both non-delayed and delayed WiFi offloading, MN establishes data session through WiFi network whenever WiFi is accessible, even though a cellular network is also available.

In the non-delayed offloading mechanism, MN uses cellular network immediately when WiFi network is not available. Most of the current smart-phone platforms are able to offer this simple offloading mechanism [5]. This offloading scheme uses the network selection algorithm based on RSS. MNs offload their data traffic only when the RSS access is none zero. Otherwise, cellular network will be used immediately for transactions of data traffic.

While for delayed WiFi offloading, the data session is deferred up to a certain predefined bound, D. If WiFi network becomes available within the delay bound, MN immediately starts the pending data transfer. After the expiration of the delay bound, MN will switch to the cellular network for data transfer. Data transfer is delayed with the expectation of future AP contacts [6] and is mostly useful for mobile applications that could tolerate certain delays without significantly damaging its functionality.

An application that can tolerate certain delay without significantly degrade its service can be offloaded to WiFi networks, especially when users are willing to delay their traffic. The software update, data synchronization, and bulk data transfer are some examples of delay tolerant data traffic. A mobile device can upload or download data when it is in the range of WiFi networks, but there is a pre-set time deadline for users to wait. When the delay is larger than the deadline, user switch to cellular networks for data transfer.

Delayed WiFi offloading is applicable and relevant for a scenario with low-density WiFi deployment [5], and where data services via WiFi networks are usually interrupted when users move away from the range of current WiFi. In particular, bulk data is particularly suitable for delayed WiFi offloading as far as bandwidth, energy, and cost are concerned [7].

Non-delayed offloading is most common in the current smartphones. However, delayed WiFi offloading is relatively new and has attracted many research interests. For example, John records video of his family meeting using a smartphone and would like to share with everyone using cloud storage. Since it is possible to transfer at a later time using WiFi networks, he can use delayed offloading.

There are many research that studies both non-delay and delayed WiFi offloading using the various method and design parameter, with the purpose of improving network capacity. The key performance metric is defined by the concept of offloading efficiency [5].

$$\text{Offloading Efficiency} = \frac{\text{Amount of Offloaded Data}}{\text{Total Amount of Data}}$$

The important questions are how much traffic load WiFi offloading could take off from cellular networks. How significant delayed offloading could contribute to augmenting cellular network traffic growth. By analysing and understanding both offloading techniques may provide insights to the above questions as well as possible guidance in price and cost restructuring strategies [4]. As patterns of user's movement in WiFi coverage are fundamentally tied to the above questions, this research investigates user's utilization pattern through a measurement study.

III. RELATED WORKS

Understanding the character and importance of data offloading to WiFi networks is highly depended on user's mobility and utilization pattern. However, there is limited work related to the research that uses the real-time data traces in the experimental setup.

In [8], the authors use several traces of war-driving around the cities, which resulted in shorter connection duration per contact and more frequent WiFi session. The work developed a joint offloading system called "Wiffler" to overcome poor performance. The system used WiFi connectivity prediction model, while leveraging on delay tolerance and fast switching to cellular whenever WiFi not available. The study shows that Wiffler can significantly reduce a load of cellular networks due to delayed offloading. However, the results were based on the traces from transit buses or war-driving, which might incur frequent disconnects. It did not account for the practical scenarios in users' normal daily lives.

In [4], the authors performed the first trace-driven simulation using the acquired whole-day traces in South Korea. It indicates the time portion that a user stays in a WiFi coverage area, highly influencing the performance of offloading, which is defined as *temporal coverage*. The finding shows that averages of temporal coverage across all the users are 70% for all day and 63% for the active hours (9:00 – 24:00) only.

There is a considerable difference between the data from [9] that reports only 11% temporal coverage, due to the fact that measurements were done only when users on a vehicle. Findings from [9] inaccurately described the temporal coverage as users are most unlikely spend time on a vehicle. Furthermore, since data traces were collected during driving, the record contained a lot of short connection and interconnection times with WiFi networks.

To enhance per user capacity, [11] investigated the impact of WiFi First offloading mechanism using a real digital map of Kuala Lumpur through a simulation. The results show quite a significant increase in average capacity experienced by both offloaded users and the remaining cellular network users.

IV. EXPERIMENTAL SETUP

Figure 3: Experimental Setup

There are three components involved in the experimental setup, which are the WiFi Analyzer, participants, and the file transfer protocol (FTP) server. 100 Android participants were recruited, installed the application on their phone and run it in the background for 18 days.

A. *WiFi Analyzer*

An application that runs on Android smartphone platform, called WiFi Analyzer has been developed. WiFi Analyzer tracks and records the statistics of WiFi connectivity in the background and periodically sends the recorded statistics to a FTP server. All the information recorded was accessible to the participants in advance. Mainly due to the privacy and energy concern of participants, the application excluded recording user traffic generation behaviors.

The application scans for WiFi connectivity in every three minutes interval. Once connection established, the application record details of connection in a log file located in user's phone local storage. Types of measured data recorded such as connection times and duration, the location of WiFi, data transfer rate and packet loss. The application computes data throughput and round-trip times by sending the server ping packet 10 times and measuring its average [4]. This determines the end to end data rate between the participant's phone and FTP cloud server located in Singapore.

The application was developed using Android Studio tool and compatible with minimum Android SDK 21 (equivalent to Android 5.0 Lollipop) version or newer. WiFi Analyzer starts with scanning WiFi function. The timer starts once WiFi connection is established. Otherwise, it will just keep checking the WiFi state.

SDK 21 was selected to utilize the JobService and JobInfo library which is required for the periodic task and scheduling the task once WiFi is connected. The library is only available on Android SDK 21 or newer. Under JobInfo library, the task scheduler can be configured with a various parameter. In this experiment, *NETWORK_TYPE_UNMETERED* parameter is used to start the job once the network is connected to WiFi. The period can be configured under JobInfo library under setMinimumLatency(..) function.

B. *Participants*

100 participants from Android user community were recruited and installed WiFi Analyzer on their phones. The application runs in the background and collected daily data traces of WiFi utilization for 18 days. In particular, the different sample size was selected and categorized into two groups, in order to further study the utilization pattern. This work extends (Lee et al., 2010) research, which only studied a general sample size from iPhone user community.

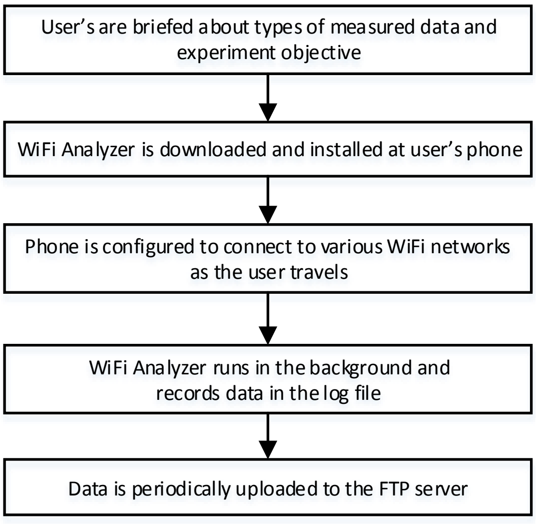

Figure 4: Real Time User's Trace Data Collection Process

Group1 represents fifty participants of higher institutional students from Universiti Teknikal Malaysia Melaka (UTeM). In order to analyze a wider array of sample sizes, students were selected from two faculties from different locations, which are from main campus Durian Tunggal and city campus Jalan Hang Tuah.

Group 2: The second group of 50 participants represents public users which comes from a diverse occupational background such as lecturers, private sectors worker, housewife, and teachers, from various locations in Melaka.

C. *FTP Server*

All data traces recorded by the application were saved in a WiFi.txt file, located in user's local storage and then were uploaded to the FTP server. Since the end to end data rates were measured in the three-minute interval, the log report is uploaded to the server in every three minutes or whenever WiFi connectivity is available. The server was set up using cloud server facility provided by Amazon Cloud Server, located in Singapore. The cloud server offers reliable service and sufficient storage for the purpose of the research.

V. Key Observation And Preliminary Results

A. *Key Observation*

The phone was configured to connect to various WiFi networks, and the following statistics relevant to offloading were recorded; the total time duration of WiFi connectivity, the data rate during connections, the distributions of connection times and interconnection times and time of WiFi connectivity time. From the measurement above, three performance parameters of offloading could be measured.

The amount of time that a user spent connected to a WiFi is defined by *temporal coverage* and has a significant impact in measuring the performance of offloading. *Spatial coverage* is defined as the fraction of an area that is under any WiFi coverage. Since the walkabout of the participants does not capture all possible WiFi in the city, the trace only gives a rough estimation of the spatial coverage.

End to end data rates represents the distributions of data rates experienced by the user. Findings from [4] show that user mobility has a weaker correlation with data rate than temporal coverage.

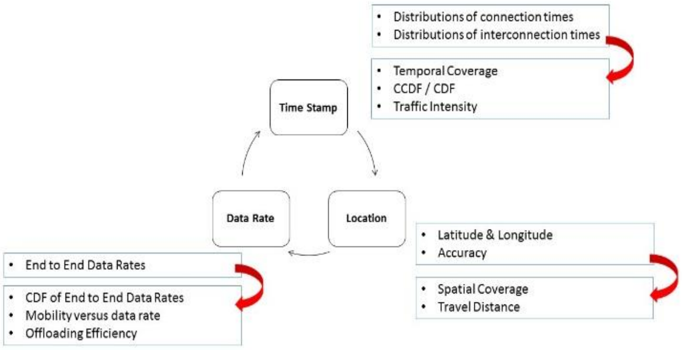

Figure 5: Key Observations and Performance Parameter

B. *Preliminary Results*

The time portion that a user stays in a WiFi coverage area, highly influencing the performance of offloading. Figure 6 shows the average of daily temporal coverage recorded by each participant. The plot distinguished the coverage during active hours (9:00-24:00) and all-day coverage. The preliminary finding shows the averages of temporal coverage across all the users are 61% for all day and 59% for active hours only. Temporal coverage for all day is higher because most participants are likely to have WiFi connectivity at home and therefore spend longer connection time.

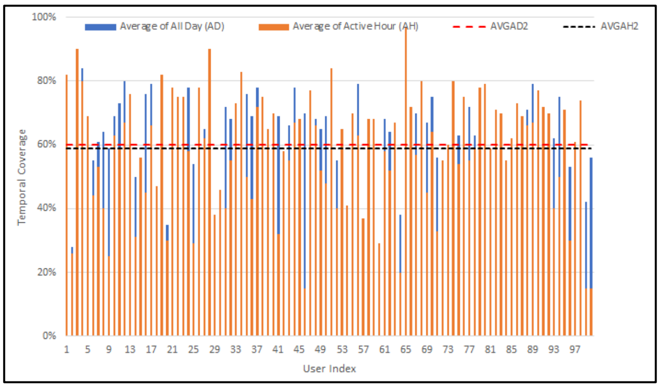

Figure 6: Temporal Coverage for all users

There is a substantial difference between the findings from (Balasubramanian, Mahajan and Venkataramani, 2010) that reports only 11% of temporal coverage. The significant difference is due to the fact that their measurements were done only when a user is on a vehicle. This type of information is unjustified as average users are not likely to spend most of their time only inside a car or bus. Users typically spend most of their time in the office and home.

Table 1:
Proportion of Temporal Coverage

	Active Hour (9:00 – 24:00)	**All Day**
Group 1	58%	61%
Group 2	59%	58%

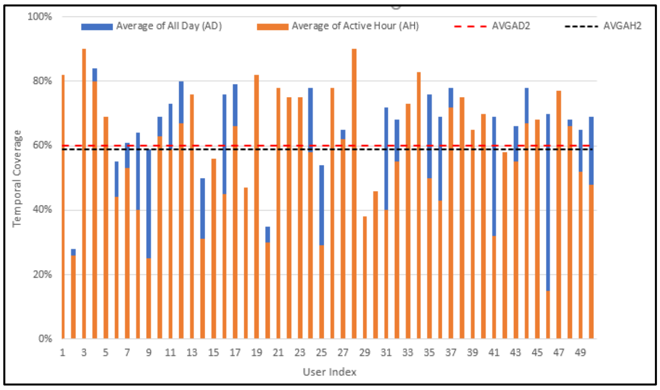

Figure 7: Temporal Coverage for Group 1

This work further investigates the utilization pattern between different group of participants. Figure 7 shows the temporal coverage for Group 1 which represents students group. The result reports average of 58% and 61% of temporal coverage during the active hour and all day respectively. Group 1 represents higher institutional students from various locations in Melaka, while Group 2 represents public users from various education and career background.

The result suggests that both groups have almost equal time spent in WiFi coverage. However, the students spent more time (all day) which means WiFi utilization is higher after active hour, compared to the other group of participants.

VI. CONCLUSION

As this paper demonstrates the method of experimental setup and measurement study of mobile data offloading using WiFi networks, the preliminary results focus on temporal coverage offloading. Assuming most mobile data are from smartphone users, roughly it implies that at any time daily, users stay almost 60% of their time in a WiFi coverage area. Typically, users spend most of their time in office and home with WiFi coverage and therefore indicates that WiFi offloading is a viable alternative in augmenting mobile data network while addressing bandwidth scarcity, as well as to provide adequate network capacity. The outcome of this research is useful to the relevant stakeholder such as mobile network provider and WiFi provider and serves as a barometer or insights to carry out enhancement measures or any potential joint venture.

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