Measuring Auto Switch Between Wi-Fi and Mobile Data Networks in an Urban Area

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***Abstract*—To preserve consistent throughput, smartphones are equipped with a network switch feature (handover in heterogeneous networks). Frequent switching is often blamed to be a QoE downgrader in populated areas. In this paper, we measured auto switch occurrences between Wi-Fi and mobile data networks. We deployed an Android monitoring application for 89 participants and collected network status information up to 10 days long. We observed that auto switch occurred on average 2.53 times per hour and RTT decreased as the smartphone preferred to stay in Wi-Fi. Also, 68% of all users connected to Wi-Fi longer than the mobile data networks.**

***Keywords*—Wi-Fi, 4G, LTE, Cellular Networks, Measurement, Smartphones**

I. INTRODUCTION

Mobile data traffic is soaring with the rapid deployment of 4G LTE. The global mobile data traffic is expected to grow up to 30.6 exabytes per month and the number of mobile devices will reach 11.6 billion by 2020 [1].

While the performance improvements on the mobile data networks and devices deliver better user experience, monthly data caps are being reached faster than ever. A usage-based pricing policy is prevalent in most Mobile Network Operators (MNO) [2] and the higher mobile capacity is causing faster data consumption. Users tend to prefer Wi-Fi due to data cost, especially when initiating a heavy traffic download for streaming, file sharing, or app installation. More than half of the traffic generated by mobile devices was offloaded to Wi-Fi in 2015 [1].

A switch between Wi-Fi and mobile data networks can occur in two ways: auto and manual switch. The default manufacturer setting of smartphones prioritizes Wi-Fi to avoid mobile data charging issues. An advanced setting for auto switch selects one that can preserve consistent data throughput. When the Wi-Fi interface detects the registered AP nearby, it automatically connects to that AP. On the contrary, when the device detects a low signal AP or no Internet connection, it switches back to the mobile data network.

South Korea is reported to achieve 97% countrywide LTE coverage [3] and its unlimited mobile data plan costs around USD 51 monthly, an average price from country's top three MNOs. Some smartphone users manually turn off the Wi-Fi interface and connect to the mobile data networks only. There are many possible explanations, such as low signal APs in the building, unstable connection status due to AP handover, extra Wi-Fi authentication, and etc.

Auto switch enabled devices are now in place for user convenience. All TCP connections are interrupted during the switch between Wi-Fi and mobile data networks. A sudden change of IP address and path lead to disturbing user experience. The absence of Multipath TCP (MPTCP) in practice leaves the users no option but to choose either network.

By characterizing the auto switch phenomenon, we believe that better user experience can be provided. As a first step, we measured how often the network switch occurs and identified when the users turn off their Wi-Fi interface. We developed an Android monitoring application to record the network connection status every five seconds. We then deployed it to 89 users and collected usage logs for 10 days.

Our key findings are as follows:

- The switch between Wi-Fi and mobile data networks occurs on average 2.53 times per hour.
- RTT shows a decreasing trend as the device connects to the Wi-Fi networks more frequently, enabling auto switch.
- 68% of users are staying on Wi-Fi longer than the mobile data networks.

This paper is organized as follows. Section II presents the related work. Section III describes our measurement environment and collected dataset. Section IV discusses our analysis results and key findings. Finally, Section V presents conclusions and future work.

II. RELATED WORK

Smartphone usage patterns: Shafiq *et al.* collected the flow level traffic data from the MNO's core network and looked into the dynamics of mobile network traffic [4]. They concluded that the network traffic distribution was highly skewed with respect to the individual devices and constituent applications. There were several smartphone usage pattern characterization studies withness more traffic offloading into Wi-Fi [5], show feasibility in collecting information in iPhone [6], and find immerse diversity among users [7].

User experience on Wi-Fi: Bae *et al.* [8] investigated poor Internet quality at bus stops in a populated area. The Wi-Fi APs on moving buses caused frequent and unwanted AP handover, resulting in network quality degradation.

Performance comparison between Wi-Fi and mobile data networks: Several studies compared the performance of Wi-Fi and mobile data networks to understand the characteristics of both networks and assist for reliable connections. Sommers *et al.* [9] found that Wi-Fi's throughput was higher and consistent from `Speedtest.net` dataset. In terms of latency, Wi-Fi had lower latency but was less consistent than mobile data networks. Others [10], [11] also illustrated the similar phenomenon.

III. Measurement Methodology

In this section, we explain our measurement environment and collected dataset.[1]

A. Monitoring Application

We built an Android monitoring agent application reporting the status information every five seconds. The agents sent these log data to the central collecting server over a Wi-Fi connection. It could be done either automatically by default, or manually when the user presses the submit button. This approach is highly user-centric to recruit more participants to run our application. Meanwhile, we are losing the granularity to a certain extent. Since Android is the dominant mobile OS in the country (Android: 76%, iOS: 23%) [12], we felt that it was sufficient to focus on Android smartphones in this study.

Our application runs in the background in order to prevent user intervention and unexpected termination for reliable measurements. The collected categories include network type, uuid, device model, location, timestamp, round-trip time (RTT), and others. We also check whether the Wi-Fi interface is on/off whilst attaching to mobile data networks. If the device is connected to a Wi-Fi AP, then its signal strength is reported.

[1] http://dpnm.postech.ac.kr/dataset_switch/

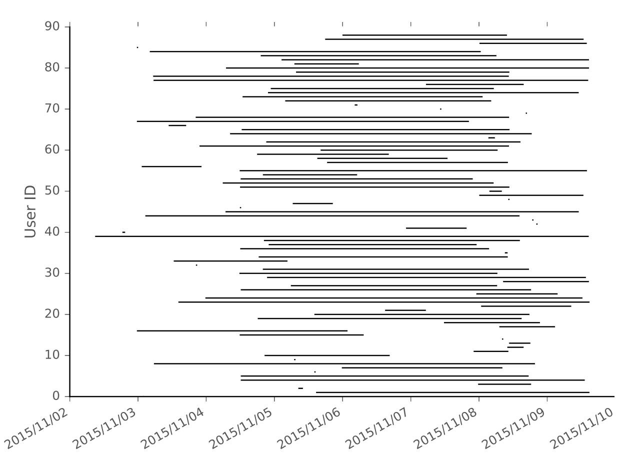

Fig. 1: Measurement durations of all participants

TABLE I: User device distribution according to carriers and manufactures; carrier A, B, and C represent the top three MNOs in the country.

	Carrier A	**Carrier B**	**Carrier C**	**Others**	**Total**
Samsung	22	18	17	4	**61**
LG	4	5	5	5	**19**
Pantech	5	2	0	0	**7**
Others	0	0	0	2	**2**
Total	**31**	**25**	**22**	**11**	**89**

The RTT is measured to estimate the quality of the network connection in use as well as checking for reachability. The device sends a single ping packet to Google's public DNS server (IP address: 8.8.8.8) to measure its RTT.

B. Dataset Description

We deployed our monitoring application to 89 participants. Table I shows manufacturer and carrier distributions of participating user devices. Samsung is the most popular, following by LG and Pantech (a local vendor).

The measurement was conducted for up to 10 days and each user's total measurement duration is depicted in Fig. 1. The average duration of all participants is 55.8 hours and 40,176 entries are recorded per user on average. For accurate analysis, we excluded 27 users' records because their durations were less than 12 hours, not meaningful enough to characterize the auto switch between Wi-Fi and mobile data networks.

Several types of mobile data networks co-exist at the moment, such as 3G, LTE, and LTE-A. Unfortunately, our application did not have access to the manufacturers' API to retrieve mobile network type. We can only speculate that the majority in this study is connected to LTE rather than 3G, which is quickly fading away now, because the number of LTE users is dominating [13].

Fig. 2 represents the measurement locations. As our monitoring application relies on the coarse-grained location provider, its information is not as accurate as that from a GPS provider. However, we can see that the measurement locations cover most metropolitan areas of Seoul.

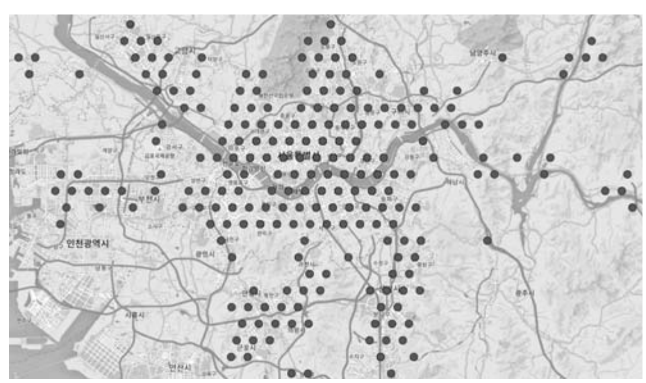

Fig. 2: Sample measurement locations in Seoul; total 291 unique cells are observed from 89 users.

IV. Characteristics of Auto Switch

In this section, we discuss the key findings of our measurement data.

A. Auto Switch Occurrences

Fig. 3 presents the number of auto switch occurrences between Wi-Fi and mobile data networks as a CDF. Since the measurement durations are different from each other, we calculated the average number of switches per hour. On average, the users change their network connection 2.53 times per hour, automatically or manually. In one case, a single user switches 7.46 times per hour.

We then picked ten users who mostly connect to Wi-Fi (user ID 1 to 10) and another ten users who mostly connect to the mobile data networks (user ID 11 to 20) (Fig. 4) to see how their usage pattern would be different for two contrasting cases. For the Wi-Fi users, the number of auto switches is higher compared to the mobile network users (3.88 times and 1.37 times on average, respectively).

We also picked another six users' data. The six users consisted of two users who mostly connect to the mobile data networks (*User A* and *B*), two users who evenly connect to both networks (*User C* and *D*), and two users who mostly connect to Wi-Fi (*User E* and *F*). As the device connects to Wi-Fi more, auto switching occurs frequently and the RTT values decrease. *User A* does not even turn on the Wi-Fi interface and connects only to the mobile data networks. While the mean RTT was highest among the six users, the variation is the smallest, showing that a stable connection is provided.

Based on the analysis results, we observed that the users are connected to Wi-Fi longer than the mobile data networks and the auto switch feature helps to reduce the average RTT.

We use a Wi-Fi to mobile ratio, the number of entries measured in Wi-Fi over mobile data networks. A user whose ratio is below 1 connects to the mobile data networks more. Fig. 5 represents the user distributions grouped by the ratio (0 to 15). Only 32% of users stayed longer in the mobile data networks and 45% of users stayed in Wi-Fi one to three times more than the mobile data networks. One user stayed 13.6 times more on Wi-Fi. Overall, Wi-Fi is twice as popular. Each group in Fig. 5 and 6 showed the number of auto switch increases as the ratio increases. In contrast, the average RTT decreases. We can say that as the device connects to Wi-Fi more, its RTT tends to decrease.

B. Manual Switch

The manual switch differs from the auto switch in the state of the Wi-Fi interface. While the interface is not turned off during auto switch, the interface is turned off in the manual

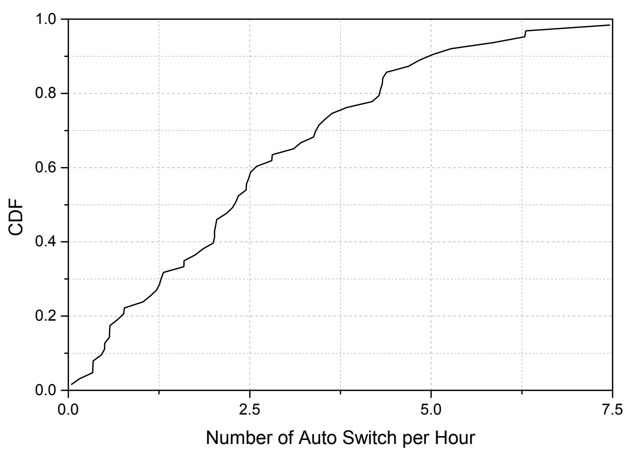

Fig. 3: CDF for average number of auto switches per hour

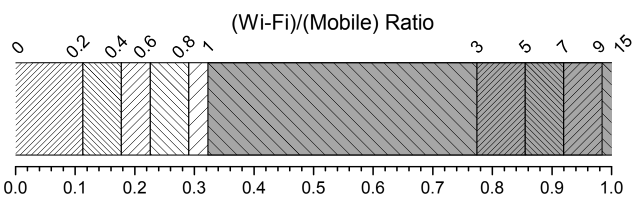

Fig. 5: User distribution for Wi-Fi to mobile ratio

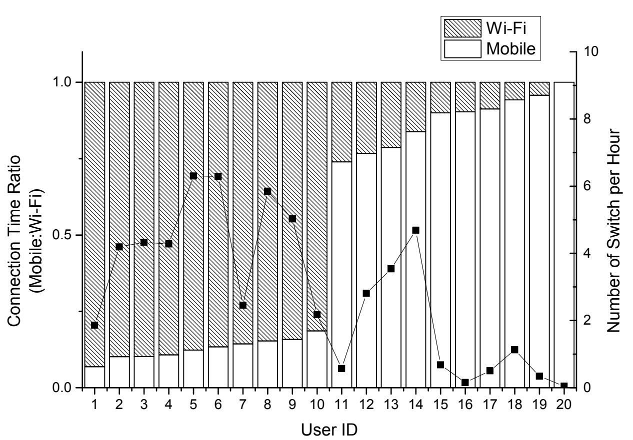

Fig. 4: 20 users' Wi-Fi to mobile network connection time ratio and number of switches

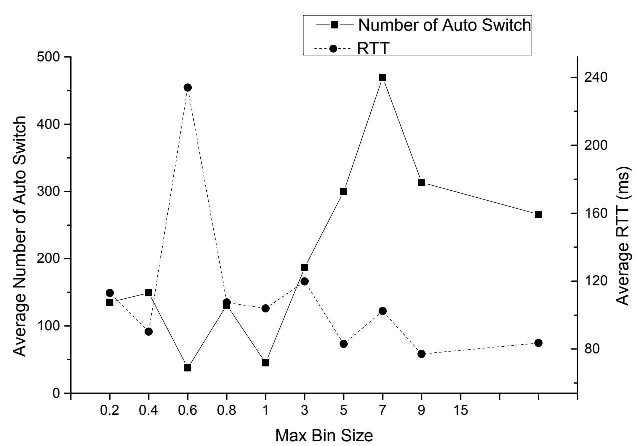

Fig. 6: Avgerage number of auto switches and RTT for each bin size

TABLE II: Selected user characteristics according to Mobile:Wi-Fi proportions in duration

	RTT (ms)		Number of Switch		Longest Duration (hr)		Measurement	Mobile:Wi-Fi
	Mean	Std.	Total	per hour	Mobile	Wi-Fi	Duration (hr)	Proportion
User A	113.448	57.935	0	0.000	22.757	0.000	22.757	1.000
User B	108.398	135.420	81	0.343	63.981	2.349	236.464	0.958
User C	108.589	192.026	104	2.015	6.347	5.419	51.613	0.499
User D	109.056	981.460	20	0.499	5.975	8.108	40.051	0.504
User E	83.596	246.230	266	1.855	3.929	37.132	143.379	0.068
User F	61.393	177.793	169	4.187	0.582	16.088	40.358	0.102

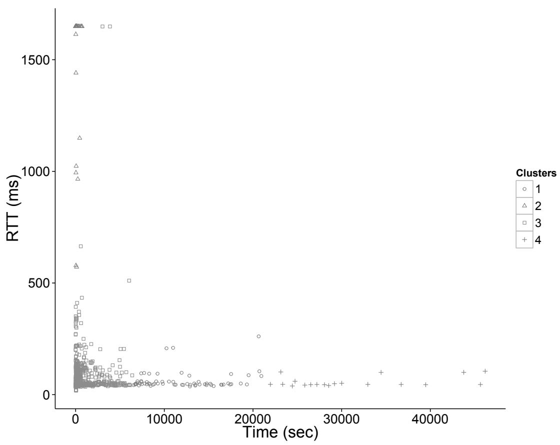

Fig. 7: Clusters for manual switch

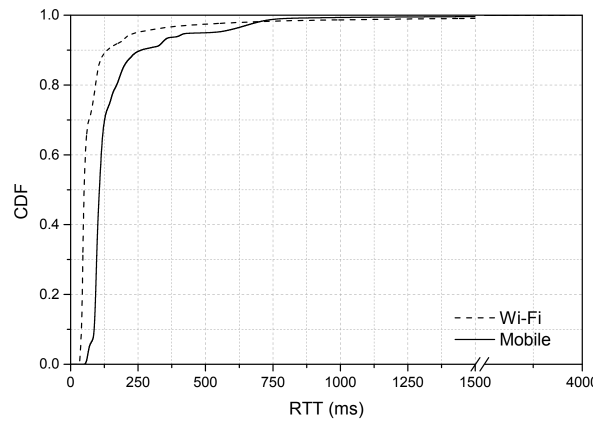

Fig. 8: RTT CDF for Wi-Fi and mobile networks

TABLE III: Clustering result for manual switch

Cluster	Size	Average Time (sec)	Average RTT (ms)	Average Signal Strength
1	59	110.509	1566.555	68.085
2	65	11867.000	63.180	86.538
3	19	31168.421	57.782	92.263
4	627	1020.335	84.909	85.052

switch. We are able to differentiate these two types based on the Wi-Fi interface status.

We found 802 cases with 55 users for manual switching in our dataset. To characterize, we applied K-means clustering with three metrics: time elapsed before the switch, average RTT, and average signal strength. The clustered result is shown in Table III. The reason for the network change in Cluster 1 is the low quality of network connection, caused by the low signal strength. In this case, the users stay less than 2 minutes on Wi-Fi. Cluster 2 and 3 stayed much longer with better network quality, 3.30 hours and 8.66 hours, respectively.

C. RTT

Fig. 8 represents the CDF of RTT values for Wi-Fi and mobile data networks. The mean RTTs are 106.92 ms and 162.76 ms, respectively. More than 95% of the measured RTT on Wi-Fi is less than those in mobile data networks. The result corresponds with our previous work [13], which measured latency in both Wi-Fi and mobile data networks.

V. Conclusion

In this paper, we focused on finding how frequently the network switch occurs between Wi-Fi and mobile data networks. We also investigated how often the manual switch occurs and analyzed its characteristics. We collected the network status logs from 89 Android phone users for the duration of up to 10 days.

We found that the switch between Wi-Fi and mobile data networks occurs average 2.53 times per hour. The RTT showed a decreasing trend overall as the device connected to Wi-Fi more frequently. Moreover, 68% of users was staying on Wi-Fi longer than the mobile data networks. The portion of manual switches was only 6.46%.

For future work, we plan to study the effect of network switching on QoE. We will improve the monitoring application to collect more metrics for user behavior.

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