Performance Analysis of Smartphone-based Mobile Wi-Fi Hotspots Operating in a Congested Environment

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***Abstract*— In this work, we address the ubiquity of internet connections in smart cities by analyzing mobile Wi-Fi hotspots in terms of speed and energy efficiency in a congested Wi-Fi environment. We consider state-of-the-art consumer smartphones in our work since they are the major devices in establishing mobile Wi-Fi hotspots nowadays. There are two main wireless connections in mobile Wi-Fi hotspots, the cellular connection and the Wi-Fi connection. It has been known that the speed of Wi-Fi connections enormously supersedes the speed of cellular connections with the use of present technologies of each. In this work, we show that this well-known fact becomes controversial when establishing mobile Wi-Fi hotspots using smartphones in a nowadays typical congested Wi-Fi environment.**

Keywords – Energy Consumption, Energy Efficiency, IEEE802.11, Mobile Wi-Fi Hotspots, LTE, Wi-Fi

I. INTRODUCTION

Mobile Wi-Fi hotspot is a wireless network that is established to share internet connection between two mobile devices which operate more than wireless technology. The most common technologies used in tethering are Wi-Fi and 3G/LTE. The use of mobile Wi-Fi hotspots is nowadays essential for many users and it ensures the ubiquitous provision of internet connection everywhere and whenever needed. It is also one of the promising technologies for providing internet in smart cities [1]- [4]. The wireless chipset of the internet capable mobile device acts as a mobile software access point (softAP). Vendors such as Atheros, MediaTek, Realtek, Broadcom and many others have been supporting the softAP, known as master mode, through the Linux drivers of their chipsets which are implemented in many Wi-Fi wireless adapters from many years ago. This mode has not really spread much for its lack of practical applications on fixed devices such as PCs or low-mobility devices such as laptops. Recently, the use of mobile Wi-Fi hotspot has increased tremendously with the implementation of softAP in most mobile smart handheld devices such as smartphones. A smartphone is capable of sharing its internet connection which is provided by a non-Wi-Fi technology such as 3G/LTE with other devices such as laptops, tablets, phablets and other smartphones through their Wi-Fi interfaces. Therefore, Mobile Wi-Fi hotspot comes out as an appropriate solution to bridge the gap between the unavailability of a ubiquitous and/or an accessible Wi-Fi network in one hand and the unavailability of a cellular data plan in some devices in the other. Thus, the most typical deployment scenario of a mobile Wi-Fi hotspot occurs when only one device creates a mobile Wi-Fi hotspot on the fly and share its cellular-based internet connection with other surrounding devices. Hence, hypothetically, mobile Wi-Fi hotspot is a solution for the on-the-fly use of internet whenever needed. Unfortunately, the performance of a mobile Wi-Fi hotspot is dramatically affected by many factors which may shrink its delivery of pervasive, ubiquitous and efficient internet connections in smart cities. We addressed in [5] many performance anomalies of smartphone-based mobile Wi-Fi hotspots. In this work, we further analyze the performance of smartphone-based mobile Wi-Fi hotspots by addressing and analyzing the speeds of both Wi-Fi and LTE which are the present wireless technologies used in mobile hotspots for providing internet connections as mentioned earlier. In spite of the well-known fact that the speeds of contemporary Wi-Fi technologies are much higher than the speeds of the contemporary cellular technologies, we show in this work that with the current implementations of Wi-Fi and cellular technologies in modern smartphones, the bottleneck of the connection speed, from the wireless domain perspective, is the Wi-Fi connection and not the cellular connection when Wi-Fi hotspots are established in nowadays typical congested Wi-Fi environment where other Wi-Fi networks exist. We also analyze in this work the energy efficiency of smartphones which are used in mobile Wi-Fi hotspots in a congested environment since energy efficiency is the main concern of mobile networking using smartphones.

It is worth mentioning that we consider the full functionality of the wireless technologies and not just the wireless link. Therefore, we consider the impact of both the MAC and the PHY layers on the wireless connection speed and not just the link speed. We also only consider the wireless part of the internet connection and not the backbone wired part.

The rest of the paper is organized as follows. In Section II, we deliver a literature review and provide discussions about the works that tackled the performance of Wi-Fi hotspots. We then perform experiments and provide discussions about the obtained results in section III. Finally, we conclude the paper in Section IV.

II. LITERATURE REVIEW

Since energy consumption and draining the battery is the main concern in mobile networking using smartphones, most of the works in the literature focused on analyzing and/or suggesting solutions to reduce the energy consumption of smartphones which use Wi-Fi connections [6]-[17]. The majority of these works addressed the energy consumption of a smartphone when it is connected to infrastructure networks [10]-[17] while very few work addressed the energy consumption of the smartphones involved in mobile Wi-Fi hotspots [6]-[9]. Note that the energy consumption of the smartphone that runs the mobile Wi-Fi hotspot is much more than the energy consumption of the mobile which receives the service since the former runs both a cellular connection and a Wi-Fi connection and it also does not apply the power save mode like the latter. Hence, the former is the crucial device to consider in mobile Wi-Fi hotspots. We will discuss in the following only the works that considered the tethering smartphone.

The authors of [7] proposed an algorithm named DozyAP for reducing the energy consumption of a tethering smartphone. Their algorithm is based on the idea of making the tethering smartphone sleep when the Wi-Fi network is idle. The power efficiency is only enhanced with a long packet inter-arrival time which is not applicable for many applications such as file sharing and video streaming. In these types of applications, the packet inter-arrival time can be very short.

The authors of [6] proposed a system named POEM which reduces the energy consumption of a tethering smartphone by allowing its Wi-Fi interface to sleep even during data transfer. The system utilizes the asymmetrical bandwidth of the cellular connection and the Wi-Fi connection by buffering the packets received over the cellular connection and thus making the Wi-Fi interface sleep.

The authors of [8] proposed a hybrid approach to reduce energy consumption of a tethering device. The first approach is based on adjusting the transmitting power of the tethering device to a value that all connected smartphone may operate without degrading the quality of the provided service. This approach only reduced energy consumption by less than 5%. The second approach is based on putting the tethering smartphone on sleep mode to save Power in idle periods as the two works mentioned previously.

The authors of [9] proposed E-MAP, which is an energy saving algorithm for a tethering smartphone. E-MAP introduces a sleep cycle which is similar to the Wi-Fi power save mode. E-MAP prevents the wireless stations from transmitting when they sleep.

It can be deduced from the description of all the mentioned work, the proposed approaches are based mainly on a single idea which is putting the tethering smartphone on a sleep mode whenever possible. While their approaches are efficient in some operating scenarios, they are inefficient in the mostly common scenario where the Wi-Fi channels are congested with competing Wi-Fi networks. The works in [6]-[9] did not consider the co-existence of Wi-Fi networks which operate at the same channel of the mobile hotspot that may lead to channel congestion. We show in this work that in case of congestion, which is actually the dominant case, the Wi-Fi connection can be the bottleneck of achieving high data rates on the end-to-end connection and not the cellular connection as claimed by the authors of [6]. We show that by the operation of just few devices of other Wi-Fi networks at the same channel which a mobile Wi-Fi hotspot use, the Wi-Fi throughput decreases below the speed of an LTE cellular connection. Therefore, in a typical on-the-fly hotspot where data is transferred greedily in order to utilize the established connection, the tethering smartphone is always busy either by transmitting data or trying to access the channel to transmit data. So introducing a power saving mechanism may not work efficiently in reducing the energy consumption in these typical scenarios. Moreover, from our findings in [5], the state-of-the-art smartphones can only run, during a mobile Wi-Fi hotspot session, the legacy IEEE802.11n standard at the heavily congested 2.4GHz frequency band with a 20MHz channel bandwidth which is also relatively slow when compared with the currently used IEEE802.11ac standard. The congested band and the speed of IEEE802.11n severly affect the performance of the mobile Wi-Fi hotspot. To the best of our knowledge, the work presented in this paper is the only one which considers the congestion that occurs because of the co-existence of other Wi-Fi network(s) in studying and analyzing the performance of smartphone-based mobile Wi-Fi hotspots.

III. PERFORMANCE ANALYSIS

We evaluate the performance of smartphone-based mobile Wi-Fi hotspots by conducting experiments in a very common environment where other Wi-Fi networks exist. We first setup a wireless connection on a smartphone using LTE technology and record the actual provided speed. We repeat this operation twenty times to have valid statistical samples and record the average. The average speeds are almost 18Mbps for the downlink and 2Mbps for the uplink. We then establish a Wi-Fi hotspot to connect smartphones and conduct further experiments. Henceforth, we call the smartphone which receives the internet service through its cellular interface and provides it through its Wi-Fi interface the AP Smartphone (APS) and we call the smartphone which receives the internet service through its Wi-Fi interface the STA Smartphone (STAS).

In the upcoming conducted experiments, we measure the following network performance metrics:

- Wi-Fi throughput, in Mbps, which is the rate of the successfully transmitted and received data through the Wi-Fi connection. This is a measure of the actual speed of the Wi-Fi connection which is lower than the link speed because of the overhead introduced by the PHY and MAC layers of the Wi-Fi standard.
- The end-to-end throughput, in Mbps, which is a measure of the actual speed of the internet connection running on the STAS where the data passes over the cellular connection and through the APS and then over the Wi-Fi connection to the STAS.

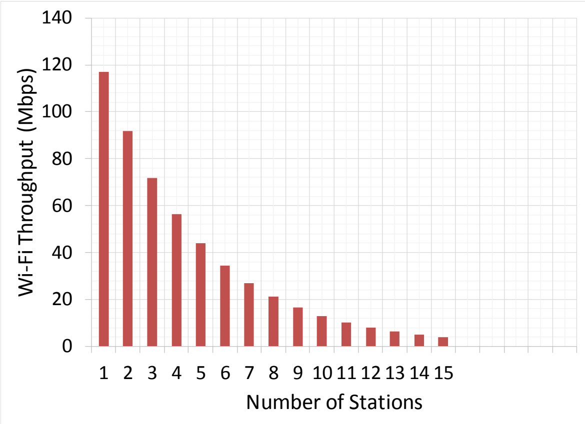

Figure 1. Wi-Fi throughput obtained by the smartphone that receives the service.

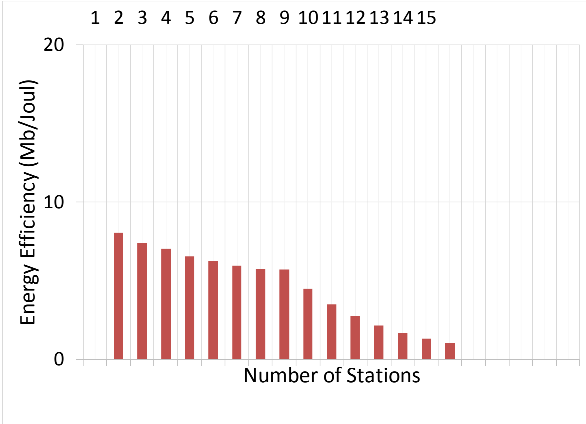

Figure 3. Energy Efficiency of the smartphone that provides the service.

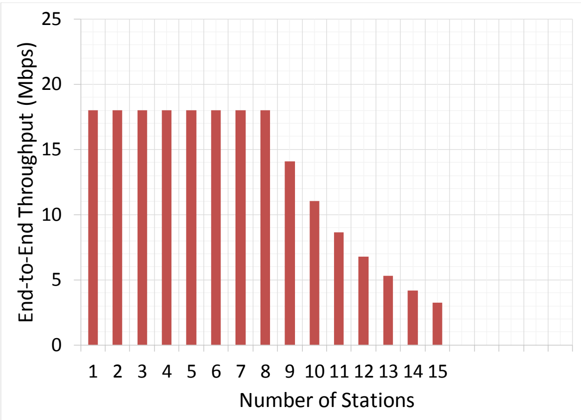

Figure 2. End-to-End throughput obtained by the smartphone that receives the service.

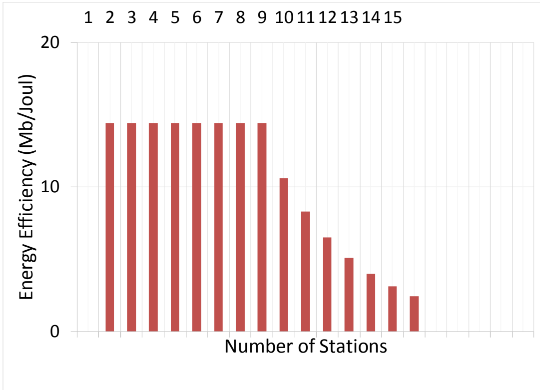

Figure 4. Energy Efficiency of the smartphone that receives the service.

- The energy efficiency, aka energy utility, bits/Joule, which is the total average number of bits successfully conveyed from/to an APS/STAS per Joule consumed energy. We consider energy efficiency and not energy consumption because the former measures the performance of the network better than the latter given that the aim of the network in the first place is to deliver information efficiently.

We establish a Wi-Fi hotspot with only one STAS in an indoor environment. We also setup an infrastructure Wi-Fi network and make it operate at the same channel of the established Wi-Fi hotspot to act as a co-existing competing network with our hotspot. We put all the involved devices in close proximity of each other to eliminate the effect of week signals since we want to concentrate only on channel congestion. We also make this co-existing network always busy in data transmissions over the wireless channel to create a congested environment.
It is worth mentioning that whether we establish only one co-existing network or many co-existing networks, the performance of the mobile Wi-Fi hotspot would be the same because the key concern is the number of the co-existing Wi-Fi stations and not the number of the networks they belong to. Whether these co-existing Wi-Fi stations belong to only one network or many networks, the competition with the mobile Wi-Fi hotspot is almost the same due to the operation of the access mechanism of the MAC layer of the IEEE802.11 standard [18].

We now perform the following experiments:

- We generate a rapacious downlink traffic via the Wi-Fi connection of the hotspot without involving the cellular interface to measure the actual speed of the Wi-Fi connection by tracing the Wi-Fi throughput. We vary the number of active wireless stations of the co-existing network increasingly and record the values of the throughput obtained by the STAS. Figure 1 shows the throughput as a functions of the number of competing stations. It can be noticed that it decreases with the increasing number of competing active stations. This is due to the access mechanism of the MAC sub-layer of the IEEE802.11 standard.

- We setup a webserver on an Ubuntu Linux operating system running on a PC to generate a rapacious downlink traffic over the established internet connection to keep a good download speed over twenty Mbps and abolish the effect of a congested host. We adopt this setup to measure the end-to-end throughput as a function of the number of active wireless stations which belong to a co-existing network. The obtained results are recorded as shown in Figure 2. It can be noticed from the figure that the end-to-end throughput is bounded by the speed of the cellular connection as long as the speed of the Wi-Fi connection is greater than the former. The end-to-end throughput starts to decrease with the decreasing Wi-Fi speed because of the congested channel. Note that, with just only few competing stations, the Wi-Fi speed went below the cellular speed. We also measure the energy consumption and calculate the energy efficiency for both the APS and the STAS as a function of the number of competing stations. Figure 3 shows the energy efficiency for the APS and Figure 4 shows the energy efficiency for the STAS. We realize that the energy efficiency of the APS is much lower than the energy efficiency of the STAS. This can be reasoned to the operation of both the Wi-Fi interface and the cellular interface on the APS while only the Wi-Fi interface operates on the STAS. Notice the considerable amount of energy consumption by APS because of the congested channel.

IV. CONCLUSION

In this work, we analyzed the performance of smartphone-based mobile Wi-Fi hotpots in terms of Wi-Fi and LTE speeds as well as the energy efficiency of the used smartphone in a congested Wi-Fi environment. Although the congestion was relatively slight, we showed that with only few competing Wi-Fi stations which belong to other co-existing network(s), the Wi-Fi limits the speed of the internet connection of the mobile Wi-Fi hotspot and not the LTE connection. We also showed that the energy efficiency is very low in a congested environment especially for the smartphone which provides the hotspot service since it runs both a Wi-Fi connection and an LTE data connection while the smartphone which receives the service only runs a Wi-Fi connection. It is worthy to concentrate on the fact that with nowadays' extensive use of Wi-Fi networks everywhere, the congestion is very considerable especially on the 2.4GHz frequency band.

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