Is Addis Ababa Wi-Fi Ready?

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Abstract. As we are heading towards future ubiquitous networks, heterogeneity is one key aspect we need to deal with. Interworking between Cellular and WLAN holds a major part in these future networks. Among other potential benefits it gives the opportunity to offload traffic from the former to the latter. To successfully accomplish that, we need to thoroughly study the availability, capacity and performance of both networks. To quantify the possibility of mobile traffic offloading, this work-in-progress presents the availability, capacity and performance investigation of Wi-Fi Access Points in the city of Addis Ababa. Analysis of the scanned data, collected by travelling through the highly populated business areas of the city, reveals the potential of existing Wi-Fi coverage and capability for many application domains.

Keywords: Wireless networks · Performance evaluation · Urban areas Heterogeneous networks

1 Introduction

Currently and for the foreseeable future, there is an increasing pattern of mobile connectivity penetration [1], mobile devices usage and ownership [2], and computing capability of mobile devices like smart phones, laptops and tablets [3]. All these facts have an impact on the demand for a greater bandwidth and better ubiquitous connectivity from the existing mobile infrastructures, primarily, from cellular telecommunication networks. The increased usage and acceptance of existing and new bandwidth hungry services exacerbates the already-saturated cellular networks.

Operators, academia and the industry are working on many solutions to alleviate this global problem [1]. Among these is the idea of offloading cellular traffic to Wireless Local Area Networks (WLANs). It is attractive, mainly, because WLANs provide a cheaper, immediate and a better short-range solution for the problem [4, 5]. Nowadays, Wi-Fi Access Points (APs) are being deployed in urban areas, primarily, to extend the wired network Internet access or to avail intranet services. As the price of

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Wi-Fi devices is getting cheaper, the technical expertise to install them becomes trivial and, more importantly, since WLAN is based on the unlicensed ISM (Industrial, Scientific and Medical) band their availability is expected to sky-rocket in urban and semi-urban areas [1–3].

Therefore, exploiting these Wi-Fi hotspots for the purpose of redirecting the traffic primarily intended for the cellular infrastructure is one of the main research areas in the trade. In this work we made Wi-Fi AP scanning of Addis Ababa metropolis, the capital city of Ethiopia, using mobile devices by making many drives and walks around the main streets of the city. This is primarily done to see the potential of Addis Ababa city to use mobile offloading applications exploiting the already deployed Wi-Fi APs. We analyzed the data collected in terms of availability, capability and performance to see the possibility and potential of offloading some of the traffic intended for the cellular infrastructure. This paper is organized as follows. Section 2 briefly summarizes related works. Section 3 shades some light on how the real-time Wi-Fi traffic data is collected. The availability and capacity analysis of the collected data is presented in Sects. 4 and 5, respectively. Finally, Sect. 6 enumerates the contributions while Sect. 7 made conclusions and points future directions.

2 Related Works

Many studies are being made on IEEE 802.11 technologies as they are one of the corner stones in ubiquitous future networks having various potential application domains. Many of these studies involve in the investigation of the availability and performance of public Wi-Fi APs deployed in urban and semi-urban environments.

In [6] public Wi-Fi hotspots coverage of Paris, France, was mapped by making several bus routes for the purpose of mobile data offloading. They found that, on average, there are 3.9 APs/km^2 of public Wi-Fi hotspots on areas that have at least one AP. Moreover, they obtained 27.7% of the APs being open, there is at least one AP with in every 52 m, and −80.1 dBm as the average RSSI during reception. They concluded that up to 30% of mobile traffic can be offloaded using the exiting Wi-Fi APs. Another study for similar purpose was made in [7] at Seoul, South Korea. They found 20.6% of spatial coverage and 80% of temporal coverage concluding that the already deployed Wi-Fi APs can offload up to 65% of the mobile data traffic and can save 55% of battery power. This is achieved mainly due to the reduced transmission time via the use of Wi-Fi APs. Yet another similar undertaking was made by Balasubramianian et al. in [8] where they found out on average, Wi-Fi and 3G are available around 87% and 11% of the time across three US cities. They also studied the comparative usage of Wi-Fi and 3G across certain geographic areas of the cities which gave an insight of places where Wi-Fi is under- and over- utilized with respect to 3G.

A huge history of Wi-Fi data collected over a very long period of time through war-driving covering the entire USA was analyzed to see the availability of Wi-Fi APs in [9]. They found as high as 1800 APs/km^2 in some cities like downtown Manhattan. They also found that around 50% of the APs are unsecured. Berezin et al. in [10] tried to study the extent of citywide mobile Internet access exploiting the exiting Wi-Fi APs in the city of Lausanne, Switzerland. They found that about 40% of the APs have

−70 dBm or better signal strength during reception, around 63% of the APs use channels 1, 6 and 11 and less than 20% of the APs are open for association. They highlighted that the existing Wi-Fi coverage can be used for many applications guarantying the minimum QoS requirements. Another interesting study was made in [11] on public Wi-Fi networks deployed by Google Inc. in Mountain View, California, USA. Most locations in the city can reach at most 4 APs at any given time. Even at late night, 80% of the APs are identified being used by at least one client. They also investigated that usage depends and varies with user traffic type, mobility pattern, and usage behavior. In our study, the availability and capacity analysis of Wi-Fi APs is made on data collected by travelling around the city of Addis Ababa. We focused only on the major public areas and streets to see the extent of coverage and the possible usage of the exiting hotspots for various applications, especially for mobile traffic offloading.

3 Methodology

In this work, commercial-grade 51 mobile devices that are based on both Android and iOS systems on top of which freely available network scanning and monitoring apps are used to collect Wi-Fi AP data for three consecutive months. It's focused mainly on highly populated business areas, like market places and city centers, where more people are engaged in their daily work, streets and places like bus and taxi stations where considerable all-day traffic is present. The scanning of the city for Wi-Fi APs was made through war-driving by walking and driving through the city covering approximately 157 km of distance and quarter of the area of the whole city, which is covering 527 km^2.

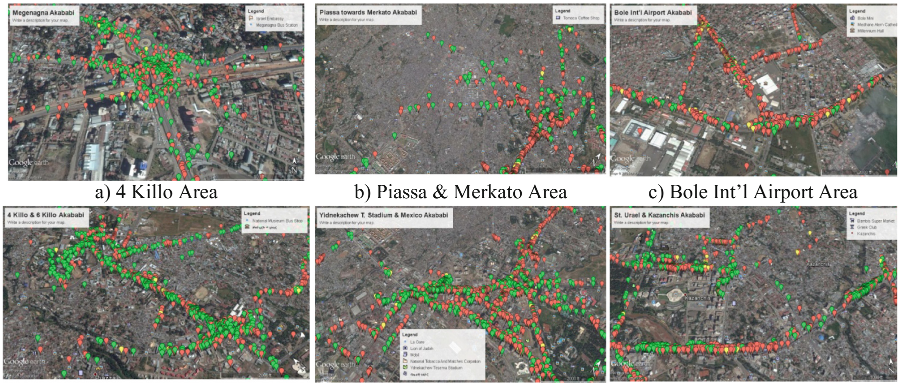
Totally, more than 15000 individual Wi-Fi APs where scanned in this process. For each Wi-Fi AP the scanned data contains, among others, the time stamp, MAC address, RSSI in dBm, location information, AP security configuration, frequency configurations, TCP and UDP uplink and downlink throughput for a given traffic load, and RTT values. Mobiperf, GMON and OpenSignal third-party apps are used to collect real-time traffic data. More specifically, default configuration of the apps is used except varying packet sizes and server addresses, whenever possible. The scanned data has three different file formats, *.csv*, *.kml* and *.txt* which are analyzed using spreadsheet applications, MATLAB and GoogleEarth.

4 Wi-Fi AP Availability

To see how much the city of Addis Ababa is populated with Wi-Fi APs, coverage heat maps for specific locations are generated from the *.kml* data set. In addition, AP densities, distance and time between APs as the mobile user travels along the streets of the city, are calculated from the *.csv* data.

4.1 AP Density and Coverage Heat Maps

The density of Wi-Fi APs in the main streets of the city is analyzed based on the number of APs within a given area. This is calculated by counting the number of APs within 1 km × 1 km area making the scanning mobile device at the center as it moves along the streets of the city. Figure 1 and Table 1 summarize the result. Figure 1 shows, as a sample, some areas of the city that are highly populated during working hours, specifically, between 8:00 AM to 6:30 PM. Each dot represents the geographic position where an AP signal is received with the maximum power (RSSI) along the route of travelling. Each AP can be seen from some meters before this location is reached and to some meters afterwards. This coverage area, among others, depends on the distance from the real position of the AP to the point where its signal was detected by the scanning devices.



a) 4 Killo Area b) Piassa & Merkato Area c) Bole Int'l Airport Area

d) Megenagna Area e) Yidnekachew Tessema Stadium & Mexico Area f) St. Urael & Kazanchis Area

Fig. 1. Heat maps of APs on the major streets/areas of Addis Ababa. On the graphics, APs are colored based on their security configurations, in *Red*, *Yellow* and *Green* pins signifying *Secure* (either WPA or WPA2), *Less Secure* (WEP), and *Open* (no security), respectively. (Color figure online)

An attempt has been made to find out the number of APs available on a given area. The measurement is done by simply counting each and every Wi-Fi AP enclosed within a given perimeter. The result is populated in Table 2. It shows that *4 Killo Area* (Fig. 1a) is highly populated with 223.84 APs per km^2 whereas; *Merkato Area* (Fig. 1b) has less number of APs per km^2 which is 48. Having these extremes, the number of APs per km^2 is found to be around 133, on average, in the main streets of the city.

The average linear density of APs on the major streets of the city has been found to be around 50 APs per km. That means someone moving along the major streets of the city can get around one AP within every 20 m, on average. In addition, the path from *Bole Int'l Airport* to *Mesqel Square* has, relatively, the highest APs/km which is 104.89 whereas; the path from *Piassa* to *Autobustera via Merkato* is less populated with only 44.67 APs/km. To have a glimpse of the above results and discussions, Fig. 1 depicts the heat maps of the available Wi-Fi APs on the major areas (avenues and streets) of Addis Ababa.

Table 1. Area density of APs found on the main streets of the city

№	Area/Akababi	Density (AP/km^2)
1	6 killo	139.80
2	4 killo	223.84
3	Piassa	94.36
4	Mexico and Yidnekachew Tessema Stadium	195.12
5	Bole Int'l Airport	123.99
6	Megenagna	187.27
7	St. Urael Church	80.65
8	Merkato	48.98
9	Kazanchis	116.28

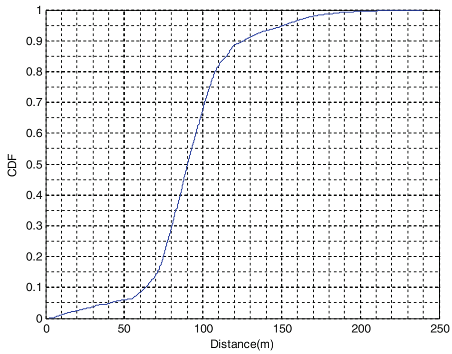


Fig. 2. Shows the cumulative percentage of distances between locations where the RSSI of scanned APs is maximum.

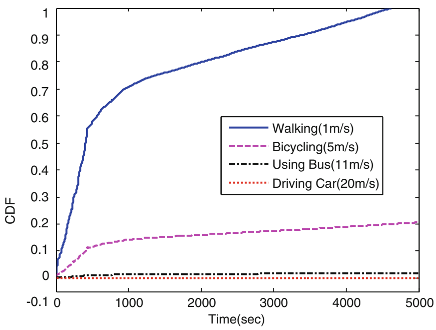


Fig. 3. Cumulative distribution of the time between Wi-Fi access points for various user speeds.

4.2 Distances Between APs

Greatest Circle Distance (GCD) is the shortest distance between two points over spherical surfaces like that of our planet. Based on the location data collected the Haversine Formula [6] is used to generate the distance between the street locations with maximum RSSI of consecutive Wi-Fi APs as shown in Fig. 2. In the same figure, around 10% and 80% of the APs are found within, approximately, 55 and 100 m of the mobile user, respectively. Moreover, it is observed that the deployment of Wi-Fi APs has no regular pattern or topology in the city.

4.3 Time Between APs

Extending the previous analysis, it's tried to generate the minimum amount of time required for a mobile user to get another Wi-Fi AP as it moves in city at various speeds. Figure 3 shows how soon a mobile user, who is either walking or using a bicycle or a bus or driving a car, gets a Wi-Fi AP to get associated with. The graph clearly shows the slowest mobile user, who is walking around, on average, at one meter per second gets the next access point within 20 s, on average. This doesn't tell about the real performance of the AP but confirms the availability of another AP to get connected with. As expected the faster the mobile user moves the lesser the time getting another AP. This effect of mobile user speed on the performance of the Wi-Fi AP should be investigated further to understand its effect on the QoS requirements of various services.

5 Wi-Fi AP Capacity

Based on the collected *.csv* and *.txt* data, further analysis was made to determine the capacity of the-already-deployed Wi-Fi APs in the city. To this end, the security configuration, the channel/frequency used, signal strength, the number of APs within a given distance from the mobile user, TCP and UDP throughput analysis, and round trip delay analysis are made and the results are presented hereafter.

5.1 Security Configurations

The security configuration of Wi-Fi APs determines their availability. In our dataset, more than half of the APs are identified as open for anyone to associate as long as the user is within the coverage area.

As presented in Fig. 4 around 40% of the APs are configured with WPA (Wi-Fi Protected Access) and WPA2 (Wi-Fi Protected Access 2) with varied combinations of the available encryption, authentication and other security algorithms. From this, half of them are configured with the strictest security configuration in the trade – 802.11i or WPA2. And, only 1 in around 10 APs are found to be configured with WEP (Wired Equivalent Privacy), the old and weakest security protocol in the realm of WLANs.

5.2 Channel/Frequency Usage

Figure 5 shows the channels together with the center frequencies assigned to the scanned Wi-Fi APs. All the APs are found to be 802.11 *b* or *g* types using the 2.4 GHz frequency band. In this standard, each channel is 22 MHz wide and channels 1, 6 and 11 are non-overlapping with 25 MHz separation between the respective center frequencies. Basically, this is what makes them the ideal choice by networking professionals during deployment of WLANs.

That is exactly what can be observed in Fig. 5. Channel 1, 6 and 11 are used approximately in the 27%, 37% and 16% respectively, totaling around 80% of the APs. That leaves only around 20% for the rest of the channels. The use of these three channels not only minimizes the inter-channel interference within a WLAN but also the interference between neighboring WLANs. However, a better way of assigning channels for wireless nodes deserves a critical analysis of channel assignments and the resulting interferences [12].

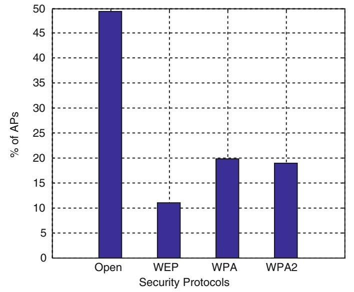


Fig. 4. Distribution of AP security configurations

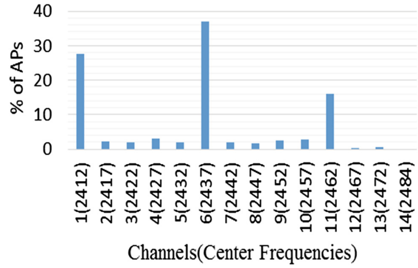


Fig. 5. Channels and frequencies used by the APs

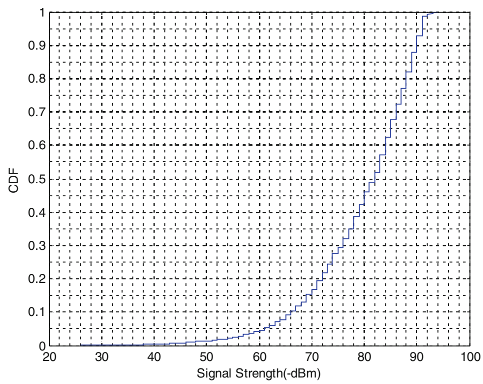


Fig. 6. Received signal strength of the Wi-Fi APs.

5.3 Signal Strength

When talking about signal strength one need to differentiate between the transmitter signal transmission power and the received signal strength. As a standard, the transmission signal power of Wi-Fi equipment, specifically, for 802.11b/g ranges from 1 mW (0 dBm) to 100 mW (20 dBm) [13]. The standard also specifies that the sensitivity will be at least −94, −89 and −71 dBm for data rates of 1, 6 and 54 Mbps, respectively [13]. The last values are only for 802.11 g.

In this work, as depicted in Fig. 6, the RSSI (Received Signal Strength Indicator) ranges from −26 dBm (2.5 mW) to −94 dBm (0.398 nW). Moreover, around 40% of the APs have RSSI value greater than −78 dBm. This value is above the minimum required to achieve full data rate for 802.11b which is 11 Mbps. The same RSSI value can be used to achieve 12 Mbps data rate for 802.11 g based networks. From the overall APs, only 754 APs have RSSI values lower than −90 dBm, which suggests that all APs can perform above the minimum data rate.

5.4 Number of APs Within a Given Distance

Here an attempt has been made to estimate how many APs are deployed in the vicinity of certain locations. The locations presented in Table 2 and two typical working distances, 40 m and 100 m, were chosen. Using a free space outdoor propagation model, for the sake of simplicity, and considering a transmission power of 100 mW at 40 m the received power is −56 dBm, and at 100 m it is −73 dBm. On this basis, Table 2 presents how many APs are received with RSSI equal or higher than −56 dBm and −70 dBm at the chosen locations. It also presents the average RSSI of the APs that are at 40 m and 100 m or closer.

Although, the aforementioned propagation model were used, further analysis should be done to obtain more precise results taking into account the fact that the variability of the signal strengths with distance depends on many factors specific to the environment where the APs are deployed and many parameters of the mobile user.

Table 2. Number of Wi-Fi APs within 40 and 100 m of the mobile device with their corresponding average signal strength values.

Main city area	40 m	Avg. RSSI (−dBm)	100 m	Avg. RSSI (−dBm)
4Killo (AAU Campus)	16	−58	48	−78
6Killo (AAU Main Campus)	14	−56	42	−78
Piassa (Cinema Ethiopia)	16	−62	52	−77
National Theatre (In front of)	19	−68	48	−76
Y.T. Stadium (Taxi Tera)	21	−70	51	−72
Kazanchis (Taxi Tera)	20	−69	43	−73
Megenagna (Kaldis Cafe)	22	−70	45	−75
Bole Int'l Airport (Bole Mini)	21	−70	52	−74
Merkato (city bus station)	9	−70	21	−80
22 Mazoria (Golagul Bldg)	16	−58	57	−72
Le Gare (Legehar)	14	−56	47	−71
Saris Abo (@ EBG)	16	−60	49	−75
Averages	*17*	*−63.9*	*46.3*	*−75.1*

As it is presented in the same table, within 40 m of the mobile device, the received power from Wi-Fi APs is much below the minimum RSSI required to achieve the maximum data rate. Moreover, even at 100 m radius of the mobile device the signal strengths of deployed APs can be used for many services and application domains.

5.5 TCP and UDP Throughput Analysis

Here, TCP and UDP throughput analysis is presented where the data is generated at selected spots of the city by initiating the data traffic from the mobile device to the servers located in Gaza and Libya which are automatically selected by the traffic data gathering app. data traffic of various bytes were generated for those APs that are openly available. The TCP and UDP throughput performances are measured for each traffic load, from smaller to larger values, repeating averagely 100 times for each location. This is done separately for both uploading and downloading scenarios. Figure 7 presents the plot of the average TCP and UDP upload and download values for each traffic load. The average TCP and UDP throughput performances obtained are, approximately, 5.7 Mbps and 6.4 Mbps for download and 7.9 Mbps and 8.8 Mbps for upload, respectively. In both cases the results show that the downstream flow of data shows more variability and, on average, lower performance when compared to the upstream flows. That could be due the uploading is mainly depends on the APs device performances while the downloading is depends on the mobile devices performances.

5.6 Round Trip Delay and Loss Analysis

Using the MobiPerf app the RTT delay were measured for three most common servers on the Internet; YouTube, Facebook and Google. Ping is initiated with 100 packets load for each of the three servers repeating 10 times almost every second. This is done for 12 selected areas of the city. As shown in Fig. 8, the overall maximum and minimum round trip delay times are found to be 257.2 and 105.3 ms, respectively. The average is 224.0, 197.6 and 161.5 ms for YouTube, Facebook and Google, respectively. It's also found that there is no packet loss in all the ping attempts. These results show that the Wi-Fi APs are reliable enough even for services like voice communication which is very sensitive for delay. It is good to remind the reader that mouth-to-ear delay of conversational voice ranges from 20 to 200 ms and for VoIP is between 20 to 150 ms.

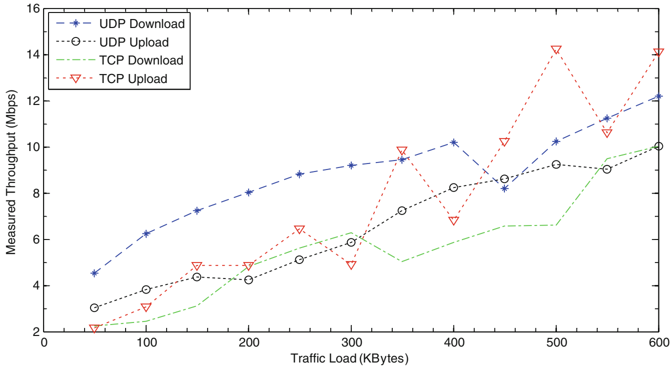


Fig. 7. TCP and UDP performances

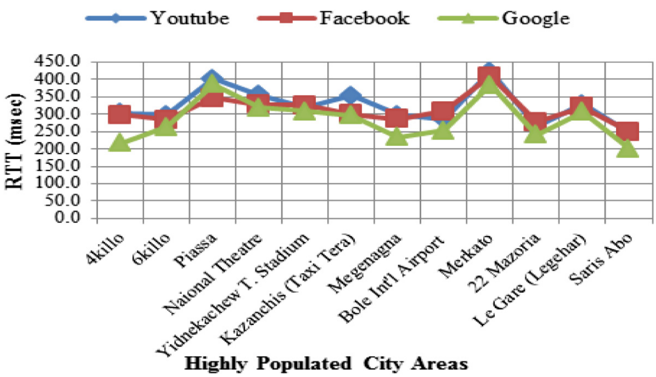


Fig. 8. Ping results of the main areas of the city.

6 Contributions

Based on the data gathered, the analysis made and the discussions presented lots of valuable and unique contributions can be harvested from this geographically pioneering, and yet preliminary, work.

First, users can delay the use of costly services using the slower cellular infrastructure for delay tolerant and non-urgent tasks like email and text messages. *Second*, AP owners may come to know the resource they owe and its economic and social potential prompting for utilizing it effectively and efficiently. *Third*, retailers and importers can pursue procuring new and improved Wi-Fi APs, like 5 GHz based ones, as long as they market based on its better performance and attractive features. *Fourth*, operators can contemplate on exploiting Wi-Fi APs systematically. *Fifth*, researchers and technologists, based on the results obtained and future works proposed, may further study the existing wireless infrastructures and pin point possible performance bottlenecks, potential solutions, and adapt technologies suitable for local situations. *Last but not least*, it is possible that the insights obtained in this work-in-progress, and future supplementary, works may have some inputs for local policy improvements and business opportunities.

7 Conclusions and Future Works

This is a work-in-progress investigation towards a fully integrated and hybrid interworking architecture for mobile traffic offloading. The commercial-grade mobile devices and the performance of the network monitoring apps employed to collect data introduced some errors and skewness of the data which are taken care of right away.

Despite all, the results obtained in this work can be taken as lower bound indicators. Therefore, it can be concluded that the major spots of the city that are highly populated during the working hours are already covered with Wi-Fi APs that can be exploited for many purposes like content sharing, advertising, accident reporting, and mobile data traffic offloading, among others.

In the future, it's planned to continue this investigation in more detail and specificity as the output can be used for operators, policy makers, and business organizations, and researchers, alike. In addition, performance evaluation of a mobile user with different speeds can be extended for vehicular applications and services. It might be required to perform a thorough performance evaluation with time-of-day analysis to further understand the behavior and capability of Wi-Fi APs. The mobility and access behavior is also another dimension that can be pursued.

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