Characterizing Interference in a Campus WiFi Network via Mobile Crowd Sensing

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Abstract. WiFi networks and smartphones have been penetrating into people's daily life pervasively. The increasingly dense deployments of WiFi APs have led to the severe spectrum usage overlap and channel interference. In this paper, we proposed a mobile crowd sensing method to characterize the interference experienced by a campus WiFi network by utilizing the powerful sensing capability of smartphone and users' mobility. We designed and implemented a mobile measurement App. This App can help the volunteers to sense the neighboring WiFi APs in the background on the Android mobile phones. The measurement data are then uploaded to the measurement repository server for further data analysis. Our measurement results showed that both 2.4 GHz and 5 GHz WiFi APs have been commonly deployed on campus, and 2.4 GHz APs dominate for around 80 % of total measured APs. The spectrum overlap and channel interference in the 2.4 GHz band is much severe than that in the 5 GHz band. The rising WiFi interference is due to the uncoordinated planning, random deployment and intensive density of WiFi networks at different locations. Our field measurement study may provide guidelines to design the next generation software-defined WiFi networks in order to achieve high performance with minimized interference.

Keywords: Mobile crowd sensing · WiFi · Spectrum interference · Internet measurement · Android system

1 Introduction

WiFi-based wireless local area networks are widely used for Internet access due to their advantages in three aspects: (1) simple technical implementation; (2) low-cost network construction; (3) high-bandwidth wireless links. A large number of WiFi hotspots have been deployed at various locations. Originally designed for single access point with limited number user devices, WiFi has also been increasingly used for Internet access in a large area with many clients, such as a hotzone. It has been envisioned that WiFi networks will be served as the major network components for constructing smart city and even smart country.

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Note that the rapid penetration of smartphones has been reshaping the communication and entertainment paradigm in people's daily life. Contemporary smartphones commonly integrate many sensors: Global Navigation Satellite System (GNSS), accelerometers, gyroscopes, magnetometers, light sensors, as well as WiFi and Bluetooth transceiver modules [1]. Due to the pervasive usage of smartphones, together with the cooperative sensing capability and users' mobility, can accomplish data measurement, collection, and pre-processing through powerful sensors and microprocessors while users carry them around during their daily activities [2,3].

To date, there have been emerging a number of researches and applications heavily utilizing smartphones and user mobility, such as recording physiological measure of users [4], monitoring user behavior [5], detecting the quality of the urban environment [6], and so on. The mobile crowd sensing can overcome the limited resources of the individual smartphones, and achieve real and randomized measurement experiments rather than well planned experiments [7,8]. [9,10] studied the data transmission efficiency and energy consumption problem of mobile crowd sensing. In particular, recent measurements [11,12] have shown that the wireless networks (WiFi and 3G/4G) utilized by mobile devices consumed significant energy in data transmissions. Such field measurement studies have well motivated the design and the implementation of mobile cloud transmission systems [13,14] to transfer heavy energy-hungry services up to the clouds for mobile Apps.

In this paper, we proposed a mobile crowd sensing method for characterizing the interference of a campus WiFi network. Smartphones from volunteers in the measurement can automatically probe, maintain and upload WiFi APs' information through an augmented measurement tool, namely, WiFi Tracer [15], which is an Android application running on smartphones. In order to achieve a large scale WiFi measurement, we invited many participants as anonymous users to randomly move in various ways (driving, jogging and walking) on campus with the measurement App running on their smartphones. The major results from these experiments are summarized as follows:

1. There have been considerably high-density WiFi APs running on the campus area. Over 10000 WiFi APs and more than 7000 distinct WiFi networks have been detected. It indicates that the campus is a typical area with high-density WiFi APs, and characterizing WiFi networks will help to understand the potential interference, deployment and optimization issues for high-density WiFi networks.
2. Theoretically, the usage of WiFi frequencies and channels should be distributed evenly in 2.4 GHz and 5 GHz bands that have more than 30 free channels in total. Both 2.4 GHz and 5 GHz WiFi APs are commonly deployed in measurement areas, and 2.4 GHz APs dominate about almost 80 % of the total measured APs.
3. We also measured the public campus WLAN and analyzed its characteristics. It has shown that more than 70 % measurement areas have been covered by the public campus WLAN.

2 Crowd Sensing Platform

2.1 Platform Overview

As shown in Fig. 1, our proposed mobile crowd sensing platform is an integrated platform which consists of three major components including data acquisition, collection and analysis. The first component takes the responsibility for collecting basic information of WiFi APs and storing the results locally. Smartphones serve as WiFi probes to harvest the nearby WiFi and GPS information, and they process the original data in the local database through the WiFi Tracer tool. The second component is responsible for collecting and analyzing the data as a repository server hosted on a cloud platform. When the volunteers finish the measurements, WiFi Tracer will automatically upload the local results to the server. The third component is used to share the available WiFi information as an incentive for participants.

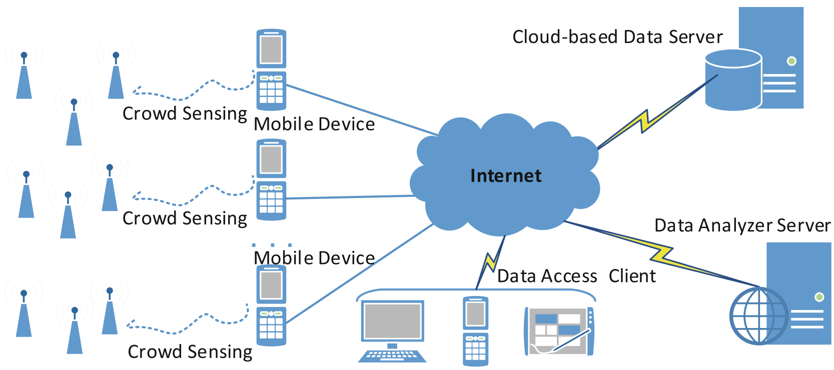


Fig. 1. WiFi measurement architecture using mobile crowd sensing

2.2 WiFi Tracer

WiFi Tracer is an Android mobile application as the terminal to implement mobile crowd sensing. In order to improve the efficiency and accuracy of measurements, we should avoid sensing the same location for multiple times unnecessarily. Hence, the tool follows a scanning procedure as shown in Fig. 2.

WiFi Tracer senses the current location of mobile device before measurement and compute the distance between the current location and the previous measurement location. If the distance between these two locations is larger than a threshold (10 m by default), the application will actively scan the WiFi APs nearby and tag this measurement with the time stamp and GPS coordinates to form the metadata of WiFi APs. The measurement results are then written into the local database through Android SQLite. WiFi Tracer tracks the

Begin: Initialization
    smartphone initialized: WiFi transceiver initialized, GPS sensor initialized.
Step 1: Default parameter configuration
    set $deviceInfo \leftarrow$ basic device information, $minDistance \leftarrow 10(m)$,
    $period \leftarrow 10(s)$, $origPosition \leftarrow$ current GPS position.

Step 2: Scanning Phase
    if $scanPeroid = peroid$ && $distance(origPosition, currPosition) > minDistance$
        Activate the WiFi scanning process; proactively scan the WiFi APs nearby.
        Record $scanResult : (bssid, ssid, frequency, rssi, capabilities)$,
        Build entity: $o^{i}_{bssid} : (scanTime, scanCount, deviceInfo, scanResult, currPosition)$,
        Store the data set O into the local database and upload to the remote server.
    else
        Keep waiting in background; then go to Step 2.
Step 3: Terminate the app, and stop all the functions.
End: Terminated.

Fig. 2. Sketch of the WiFi Tracer scanning procedure

dynamics of WiFi APs periodically (such as 10 s) if the user is moving during the measurement session.

3 Result Analysis

Mobile crowd sensing may involve many mobile devices in measurement and each device becomes a distinct end-point in experiments. User's mobility cooperating with smartphones make the whole experiment as a randomly distributed measurement process, and the data storage and computation from the server side provides convenient sharing mechanism to maintain and analyze measurement results among the measurement clients. We chose a university campus area as the main experiment area to inspect the WiFi APs and networks. We chose the well performed Android smartphones (ZTE Nubia Z7, etc.) as measurement devices which provide a well support for popular WiFi protocols such as 802.11 a/b/g/n and can work well on WiFi standard frequencies both 2.4 GHz and 5 GHz bands.

During the measuring process, participants moved on the main roads with a relatively low speed ($\leq 20\,KM/H$) and almost took 1.5 to 2 h to traverse the whole campus measurement areas. Our experiments assumed that most of indoor WiFi APs and networks were visible on the main road and could be obtained by the WiFi Tracer.

3.1 Dataset

Table 1 shows the measurement results that there are more than 10000 independent WiFi APs in measurement areas and most of the WiFi APs are private.

Private WiFi APs are WiFi networks that can share networks in small areas and require password to access successfully. Compared to the deployment of a public campus WLAN, how to reduce the interference with channel and frequency from the WiFi network has become a potential problem because there exists abundant private WiFi APs across the public campus WLAN.

Table 1. Measurement dataset

Metric	Amount
Scan times	20210
Data samples	534210
Independent areas by GPS	13065
Number of distinct WiFi APs	11380
Number of distinct WiFi Networks	7483
Number of 2.4 GHz APs	10390
Number of 5 GHz APs	1988
Number of public WiFi APs	2893

Heatmap of WiFi APs' Distribution. Figure 3 show the heatmap of the WiFi APs distribution. The red areas suggests that there are high density of WiFi APs. There are over 50 independent WiFi APs in the red area according to the parameters used in drawing this figure. When we compared the heatmap to digital maps, we found that the areas with high density of WiFi APs have a close relationship with their physical locations. The circled areas from 1 to 6 are official areas, teaching areas and living areas.

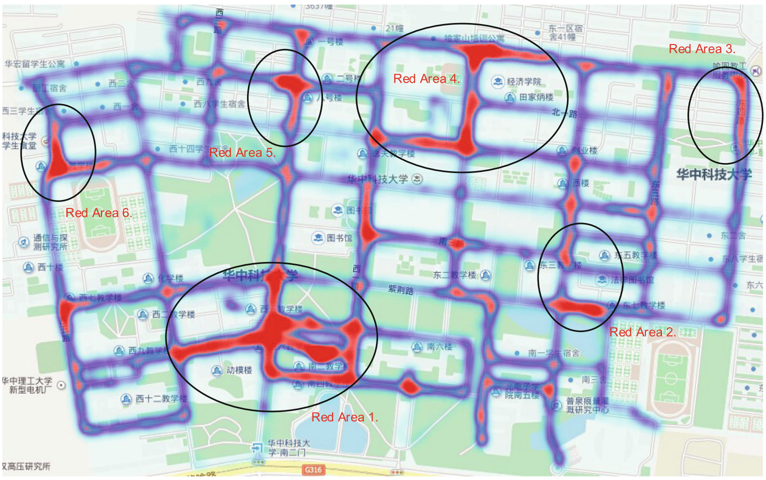


Fig. 3. WiFi AP heatmap (Color figure online)

WiFi Channel Usage. The percentage of different channels usage is depicted in Fig. 4 for both 2.4 GHz and 5 GHz WiFi APs. The results show that the 2.4 GHz band is the main working band for the WiFi networks, which dominates over 80 % over all the measured WiFi APs, while the 5 GHz band only accounts for nearly 20 %.

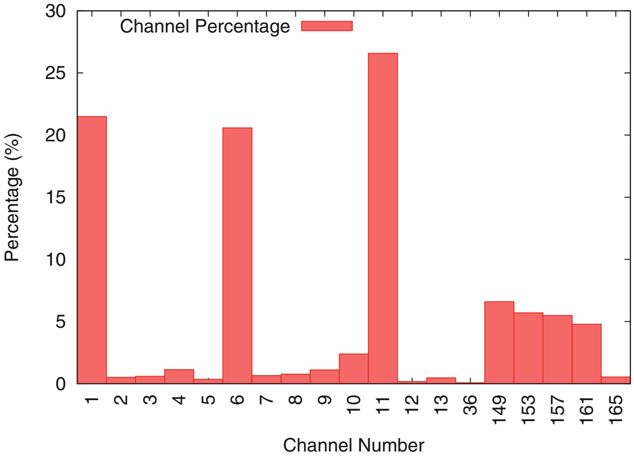
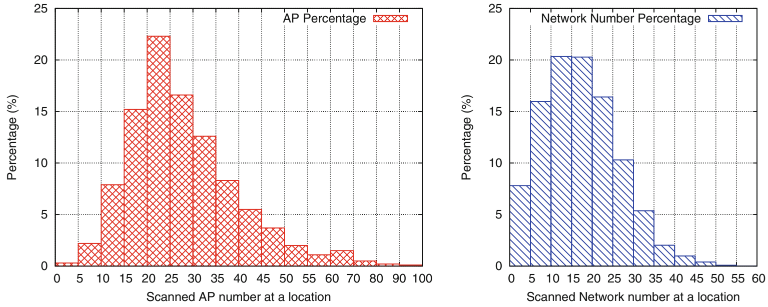


Fig. 4. WiFi channel utilization

As shown in Fig. 4, channel 1, 6 and 11 are the most popular used channels in 2.4 GHz band. WiFi manufactures normally spread the default channels of 2.4 GHz WiFi appliances in these three independent channels to avoid the adjacent channel interference in practical applications. The channels in 5 GHz band are completely isolated with each other and will not result in any adjacent channel interferences.

Density of WiFi APs and Networks. Figure 5 shows the AP density in distinct measured locations. Figure 5(a) indicates that nearly 90 % measurement areas are covered by more than 15 individual WiFi APs, and almost 70 % areas are covered by WiFi APs range from 15 to 35. At serval extremely high-density locations, the number is beyond 100. The density of WiFi networks is less than the density of WiFi APs in same areas because independent APs may work cooperatively in the Extended Service Set(ESS) model and construct a wide-range WiFi network. Figure 5(b) shows that 80 % measurement areas are covered by more than 10 independent WiFi networks, and over 65 % measurement areas are covered by 10 to 30 WiFi networks. We conjecture that both the WiFi AP density and the network density can be approximated to the normal distributions.

WiFi Channel Utilization in the 5 GHz Band. We have mainly discussed about the characteristics of 2.4 GHz WiFi APs in the previous sections. Figure 4 show that the channel utilization of WiFi APs meets the 80/20 rule, and about



(a) Density statistics of WiFi APs (b) Density statistics of WiFi Networks

Fig. 5. Density of WiFi APs and distinct networks

Table 2. Usage of 5 GHz WiFi APs

Type	Private APs	Public APs	Total
Number	100	1888	1988
Percentage(%)	5	95	100

20 % WiFi APs are working at the 5 GHz band. From these 5 GHz APs, Table 2 shows that only 5 % of them belong to private networks, and it usually suggests that 5 GHz WiFi APs are barely used as personal WiFi networks, even though they have better performance and less interference.

3.2 Characterizing a Public Campus WLAN

There are more than 4000 public campus WiFi APs found in our measurements. Figure 6 shows the distribution of a public campus WLAN and private networks. We observe that the public WLAN and private networks appear to be complementary from the visual display of Fig. 6(a) and (b).

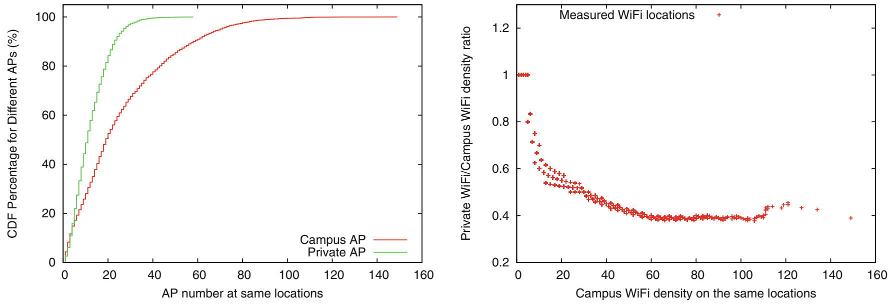
Interference of Hybrid WiFi Networks. Figure 7 presents a comparison of the density of the public WLAN and private WiFi APs in the same place under this hybrid wireless network environment. Figure 7(a) shows that 80 % areas have fewer than 20 private APs, and nearly 20 % areas are covered by private APs in the range of [20, 40]. Compared to private WiFi networks, the density of the public WLAN is almost doubled in the same location. In this hybrid network environments, the public WLAN is not only affected by the private networks, but also the network itself.

We defined the **density ratio** as the number of private APs and the number of the public APs at a spot for differentiating the network interference of hybrid networks. Figure 7(b) shows the density ratio compared with the public WLAN APs in the hybrid network areas. The results show that the density ratio in

(a) Density of public WLAN

(b) Density of private WLAN

Fig. 6. Spatial spread density statistics of WiFi networks



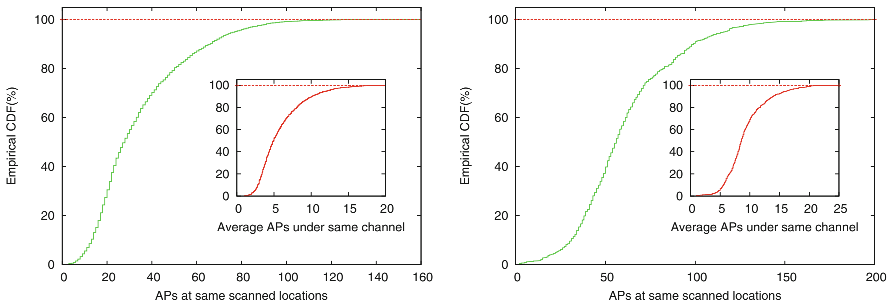
(a) CDF of private & public APs

(b) Density ratio of private/public APs

Fig. 7. Public campus WLAN vs Private WLAN

nearly 90 % areas are less than 1 which suggest that the number of public APs are larger than the number of private APs in the same measurement areas. We conjecture that the public campus WiFi network suffers from the potential interference not only from the private network but also from itself due to its high density deployment.

Indoor vs. Outdoors Interference of Public WLAN. We conducted additional experiments to gain insights into the WLAN from the outdoors to the indoors. Figure 8(a) shows that about only about 20 % areas are covered with less than 20 public APs and the main density of outdoor APs are ranged from 20 % and 80 % for almost 60 % measurement areas. The density of public WLAN (i.e., the green curve in Fig. 8(a)) only shows that the adjacent channel interference among the WLAN. However, through the measurement, we found most APs of the WLAN utilize three independent main channels(1, 6, and 11) as the default working channels in the 2.4 GHz band and part of channels in the 5 GHz band. Hence, more public WLAN APs in same areas will bring forth more co-channel interferences. The density on the same channel (i.e., the red curve in Fig. 8(a)) shows the co-channel interference in the WLAN.



(a) WiFi AP density CDF (outdoors) (b) WiFi AP density CDF (indoors)

Fig. 8. CDF of public campus WLAN density (Color figure online)

Figure 8(b) shows that there are more serious co-channel interference issues indoors than outdoors. The results show that about 20 % areas are covered with less than 40 % public APs and over 40 % indoor locations have been detected more than 10 public APs, which are almost doubled compared with the outdoor case. Figure 8 shows that the public WLAN suffers the co-channel interferences from itself rather than private WiFi networks.

4 Conclusion

In this paper, we conducted a measurement study of characterizing the WiFi APs and networks on a campus using a mobile crowd sensing method. The results show that the deployments of the current WiFi networks have various problems due to no planning, large-scale and high-density. In both 2.4 GHz and 5 GHz bands, the utilization of the channel distributions of WiFi APs satisfies the 80/20 rule in measurement areas. Those high-densely deployed WiFi APs suffer severe interference from adjacent channels and co-channels both in 2.4 GHz and 5 GHz.

We further analyzed the characteristics of interference in the public campus WiFi WLAN and private WiFi networks. The results show that the density of public campus WiFi APs is much higher than private WiFi APs in the hybrid network areas. Hence, the campus WLAN suffers from the potential interferences not only from private networks but also from itself due to its high-density deployment in the main channels.

Our measurement results also showed that the current WiFi networks deployments are not planned at all, which led to the significant performances degradation, such as interference from other network, the competition and sharing of channels, the optimal deployment of wide-area WiFi network, and so on. It may not solve these emerging problems only depending on the standard protocols of 802.11 series in current WiFi networks; therefore, we are motivated to combine the control module and the management module using a software-defined approach to manage the interference and to enhance the performance of campus WiFi networks and private WiFi networks.

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