Wi-Pi: Distributed Wi-Fi Performance Assessment using Raspberry Pi

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ABSTRACT

This paper proposes "Wi-Pi" that enables low-cost and distributed assessment of Wi-Fi performance in an enterprise network. The cost of assessment of Wi-Fi signal quality is still expensive and its continuity of the monitoring is not guaranteed. The number of monitoring devices such as spectrum analyzer is limited, and they will not stay at one place to monitor the entire Wi-Fi coverage under geographically distributed deployment. Monitoring feature of Wi-Fi signal at production-level access points does not reflect the actual situation of clients. Wi-Pi is a low-cost and stationary solution that distributes multiple Raspberry Pis in an enterprise network for monitoring Wi-Fi signal quality and network performance such as packet loss and latency. Taking the advantage of reasonable cost of Raspberry Pi, Wi-Pi collects client-side Wi-Fi performance information and visualizes it as a geographical heat map. Prototype implementation of Wi-Pi has been deployed to cover a small part of the campus network in Indian Institute of Technology Hyderabad. The aim of this paper is to make Wi-Fi monitoring to be low-cost, open source and deployable.

Categories and Subject Descriptors

C.2.3 [**Network Operations**]: Network monitoring; C.2.1 [**Network Architecture and Design**]: Wireless communication

General Terms

Design, Experimentation, Measurement, Performance

Keywords

Wi-Fi Heat map, Wi-Fi Performance Assessment, Network Quality, Low-cost System

1. INTRODUCTION

Wi-Fi is a part of core ICT infrastructure in most organizations. As wireless network grow, its complexity and operational cost also increase. Major factors that affect Wi-Fi connectivity are channel allocation, placement and transmission power of the access points. Usually, the placement of access points around the premises of organizations is mostly based on hit-and-trial method. Quality assessment and optimization of such a network after installation is heavy duty and involves a huge amount of investment, such as purchase of special monitoring equipment like a spectrum analyzer and human resources to conduct site surveys. Such network assessment and optimization fails to provide a continuous evaluation, as it is difficult to move around and cover the entire premises of the organization to get the spectrum continuously with limited equipment and human resource.

We propose continuous evaluation of large organizational network in an effective way using Wi-Pi. Wi-Pi involves a static distributed network of low cost Pis (for simplification we call Raspberry Pi as 'Pi', pronounced as 'Pie') that interacts with the access points continuously to provide a continuous spectrum analysis of Wi-Fi signal strength (RSSI), along with Packet Loss and Round-trip delay time (RTT) in getting to the specified server. Along with the information provided by Pis and the pre-existing information with the server, like geographical location of access points and Pis, Wi-Pi visualizes this information on a geographical heat map.

Most of the available network analysis tools either provide only the information about Wi-Fi signal strength (RSSI) or information about rate of data transfer between server and access points. Wi-Pi is designed to monitor RSSI, RTT and rate of packet loss simultaneously from user's perspective. The contribution of this paper is to develop a running system and making Wi-Fi quality assessment low-cost, sustainable and reliable in a feasible fashion.

Unlike the initial impression, development of such a monitoring system was not a straightforward task. Considering the Wi-Fi operations in a large-scale premise like university campus, this task became a bit difficult mainly due to a large number of access points to be monitored and their geographical distribution. Less availability of Radio Header and fluctuations in Wi-Fi signal due to change in the climatic conditions were few of the main difficulties experienced by authors. Rare cases of difficulty also include the uninformed power-cuts.

2. SYSTEM ARCHITECTURE

Wi-Pi is a collection of a server that analyses and visualizes the data and Raspberry Pis that monitor signal strength (RSSI) and channel of the surrounding access points in accessible range, which are later used to plot a heat map. Pi also has a pinger tool which monitors packet loss and delay value for reaching out to the specified server address. This information is used to evaluate network performance. Wi-Pi clearly demonstrates the gap between heat map analysis and network performance analysis in a network. The overall system architecture of Wi-Pi is shown in Figure 1.

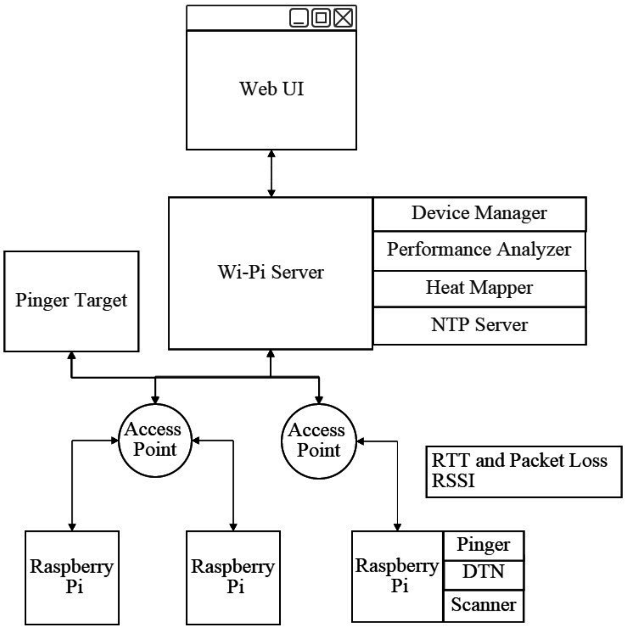


Figure 1: Overall system architecture

Wi-Pi architecture supports Delay Tolerance Networking (DTN), i.e., Wi-Pi can tackle with situations where network is down or system is not functioning. For example after power failure, Pi will automatically start to monitor the network. Also Pi is programmed to store the network information when Pi losses its connectivity with the server and later sends the information and when the connection is back again.

In order to automate the process of network monitoring, Wi-Pi automatically registers newly encountered access points. These newly encountered access points are shown on geographical heat map as soon as a server administrator provides its location through User Interface. On this system, features like notifying administrator of any problems with access points are also implemented.

Wi-Pi is so designed that the system remains flexible and easily extensible, in other words, Pi setup can be easily extended by adding new Pis or can be transferred from one place to another.

2.1 UI for Data Analysis and Visualization

Server stores all the incoming information about access points in database table, which is used by heat mapper and performance analyzer to make good and easy to understand visualization for user. This geographical heat map and performance analysis charts are displayed to users via Web Interface. **Device manager** is a medium of interaction between database table and Web Interface. Device manager stores the information related to access points and Raspberry Pis in database table.

Heat mapper plots a geographical heat map for better understanding of Wi-Fi signal distribution and performance analyzer visualizes RSSI, Packet Loss and Latency in detail against time. **Performance analyzer** can either plot all the collected data directly on the chart or can further process the data (of every 5 minutes interval) to find maximum, upper quantile, median, lower quantile and minimum and then plot this processed information on the graph. Through this User Interface, users can add, remove or relocate the locations of registered devices. All the users are allowed to analyze and study the heat map with different options, and can also control monitoring devices (Raspberry-Pi devices and mobile applications).

2.2 Database Schema

MySQL is used as the backend for Wi-Pi, 'users' table contain user details and 'users_added' table contain the list of added users by existing users. The main data for performance analysis is stored in following listed tables:

• device_info: Location, Frequency band, MAC Address, IP Address, ESSID and unique device_id for each device (covering both Pi and access point), and

• device_data: RSSI, Channel, time, conductivity factor μ[1], packet_loss percentage and latency of a particular access points detected by a Pi.

In Figure 2, the '(PK)' represents primary key attributes in all the tables. The 'device_id' is primary key attribute in 'device_info' table. 'device-id' is a unique number assigned to all the devices, which includes Pis and access points. 'mac' attribute in same table corresponds to BSSID or MAC address which is unique

[1]To be explained in section 3.2

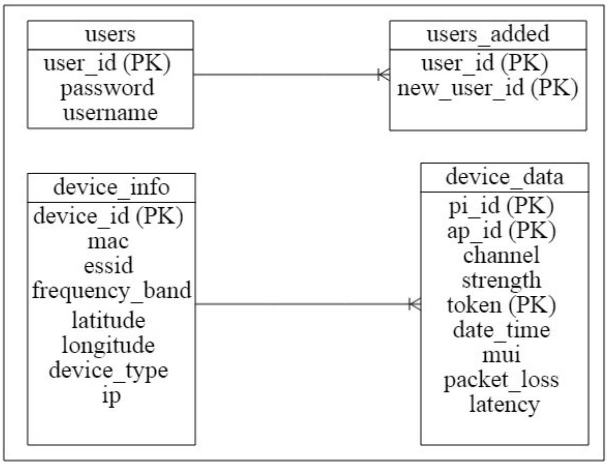


Figure 2: Database schema of Wi-Pi

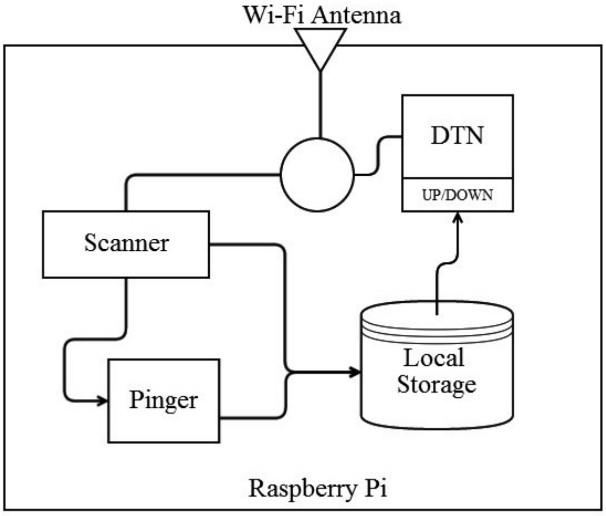


Figure 3: Pi system design

for each device. 'device_info' table also contains other information like, geographical location of each device (in terms of 'latitude' and 'longitude' attributes), 'frequency' attribute contains the frequency at which signals are being transmitted and type of device in 'device_type' attribute with IP address assigned to device in 'ip' attribute. So far 'device_type' signifies access point and Pi. Wi-Pi is open to support any other type of monitoring support.

All the raw data of monitoring results are stored in 'device_data' table. Combination of 'pi_id', 'ap_id' and 'token' is primary key attributes for 'device_data' table. Both 'pi_id' and 'ap_id' attributes are foreign key attributes to 'device_id' attribute of 'device_info' table. 'device_info' table also stored the computed conductivity factor μ, with information of packet loss and latency to reach to the best available signal access points for performance analysis of wireless signals.

2.3 Data Collection at Pi

Figure 3 describes system diagram of Pi in Wi-Pi. Pis monitor the parameters RSSI, RTT and packet loss to cover all available access points using 2.4 GHz and 5 GHz frequency band, if available. For each of the access points, RSSI is passively monitored using scanner, while RTT and packet loss is measured actively using pinger. Later as per the connectivity available Pi sends this information to the server.

2.4 Handling Disconnected Situation

Wi-Fi devices often face disconnected situation due to faulty association, power failures and malfunction of access points. To handle such situations, Pi supports Delay/Disruption Tolerant Networking (DTN) feature which stores unsent data in the local storage and retry sending after connecting to a proper access point.

2.5 Data Handling at Server

In Figure 4, Local storage is used to store all the files containing relevant data sent by the Pis to the server. Data analyzer analyzes the data contained in each file one-by-one and stores the information in the database. As soon as it ensures that the data is successfully stored in database, it deletes that particular file from local storage so as to create more space for incoming files. NTP server is used to synchronize data and time between the server and the Pis so as to avoid any discrepancy in the data. Performance analyzer queries the database for information that is used by heat mapper to plot the heat map and generate various graphs for easy visualization.

3. IMPLEMENTATION

3.1 Processing and Visualizing Data

In addition to RSSI and Pinger result, the monitored data also contains information like IP Address assigned to Pi, MAC Address of access point which it is connected to and 'device_id' of Pi to identify the Pi which has sent the data.

Web UI bridges the gap between real-world and computation that is carried out, by allowing the user to mark locations of Pis and access points directly on geographical maps which is used for computation of heat map. The UI also plots the heat map directly on geographical map, which can be visualized as per the frequency band. Also real-time charts are generated using the data received by the server.

3.2 Estimation of Wi-Fi Signal Quality

Free-space path loss formula (FSPL)[10] which is ba-

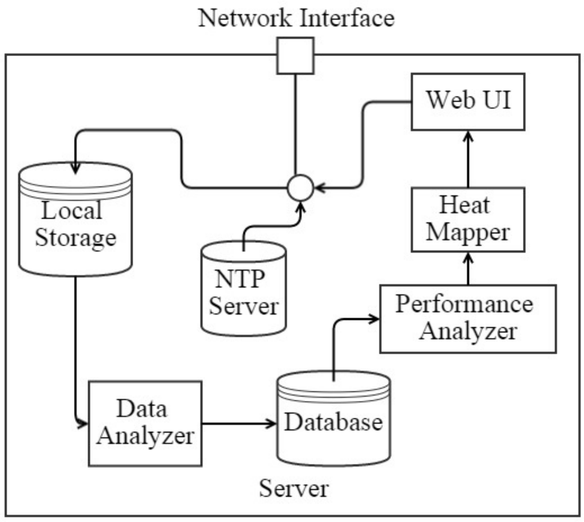


Figure 4: Server system design

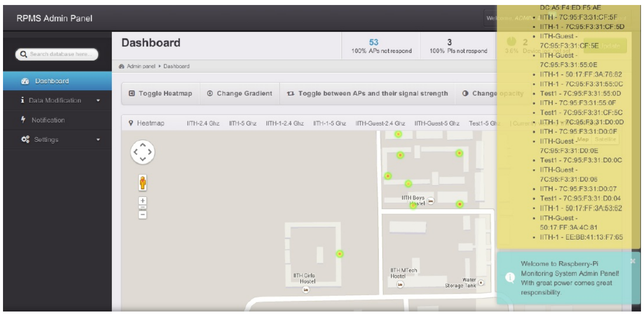


Figure 5: Working snapshot of admin panel

sically the loss in signal strength when it travel through free space (usually air). For free propagation waves in radio channel, the FSPL model is given as following.

$$L_0 = 20\log(f_c) + 20\log(d) + K \quad (1)$$

We introduced a conductivity factor term which would help us to identify how the strength decreases as it travels. This term help us to plot the heat map.

With this data, and using the formula

$$\mu * L_0 = 20\log(f_c) + 20\log(d) + K \quad (2)$$

where, d = distance, f_c = frequency and K = constant that depends on the units used for d and f. If d is measured in kilometers, f in MHz, the formula is:

$$\mu * L_0 = 20\log(f_c) + 20\log(d) + 32.44 \quad (3)$$

μ is the constant for reduction in the signal strength due to various factors, like climate, wind-speed etc.

3.3 Process of Data Collection

Pi continuously collects data and sends it to server. Figure 6 shows one round of relevant data collection process about the surrounding access points which is triggered every 35 seconds on Pi, which includes approximately 5 seconds for 1 round of packet loss and latency monitoring. But if the server doesn't receive any data pertaining to specific access points from all Pi for specified time we call it threshold, then that access points is marked as malfunctioning and notification is sent to specified user. Token is used to give a unique file name for transferred data and to identify the latest file spooled in the server.

```
procedure SCANNER
    scan Wi-Fi and list all access points available
    get BSSID of best access point signal
    ping to best BSSID and record result
    while list do
        parse all the data
        write data in file
        List ← ListEntry→next
    end while
end procedure
```

Figure 6: SCANNER (for data collection in Pi) pseudo code

To scan the available access points 'iwlist' command is used. This gives all the information related to access point like, BSSID, RSSI, frequency band and channel. Once the data is received at the server side, the data is parsed and filled in the database. The conductivity factor μ is then computed using the FSPL formula mentioned in section 3.2. Out of the all visible access points, Pi will conduct pinger only to the primary targets (the official access points in the campus network) and some unofficial targets. We may limit the number of pinger in SCANNER process to avoid spending long time at each round of SCANNER. The priority of access points and such limit of scanning target should be configurable from Web UI. Currently our implementation scans 1 priority access point which has the best signal strength at that point.

3.4 Data Transfer using DTN

Figure 7 describes pseudo code for one round of data sending algorithm used by Pi. Initially Pi checks if there is any unsent data to be send and is able to communicated with the server, then Pi sends data to the server and removes it from local storage. But if server is unreachable, Pi keeps data in its local storage and then sleeps for some time. This process keeps on repeating as long as Pi is functioning.

Table 1: Implementation Setup Detail

Device	Hardware Specifications	Software Requirements
`Pi`	Wi-Fi dongle and compatible drivers 8GB Memory Card	OS: Raspbian OS (version: July 2014) SSH, SSHPASS, SCREEN and SCP packages Python 2.7
`Server`	2GB of RAM 10GB of memory space No. of CPUs: Minimum 1 Architecture : x86_64 Network Connection: 1Gbps LAN	OS: Ubuntu 12.04.4 LTS Apache Server Python 2.7 MySQL connector module for python SSH, SCREEN, SCP packages Crontab: to automate the job of backing up the database

```
procedure SIMPLE DTN
    while files to be send && connection to server is possible do
        Send file to server
        Delete file from storage
    end while
    sleep for 30 sec
end procedure
```

Figure 7: Pseudo code of Simple DTN (data sending in Pi)

3.5 Setting up Wi-Pi

This system is already implemented and running in IIT Hyderabad on a small scale. Table 1 describes the hardware and software specifications used for implementation by Pi and server. Other than the mentioned specifications server also uses Google Maps API[5] for plotting the heat map on geographical map, and High-Charts[1] for analyzing the packet loss, latency and signal strength data by making the charts.

For setting up a Pi, memory card image[2] can be directly used. If we need to start with scratch by installing Raspbian OS on Pi and pull the code from GitHub[2] then we can follow the steps mentioned in manual. Registration of Pi can be done easily from Web UI, where the registration of access point is automatic except the location of any one of the interfaces of access point.

4. EVALUATION

4.1 Deployment in IIT Hyderabad

Wi-Pi is currently deployed and working in a part of Indian Institute of Technology Hyderabad hostel to monitor the Wi-Fi performance. A snap of the Wi-Fi heat map is shown in Figure 8. We have deployed 5 Pis. The heat map is the aggregated result of data from Pis. The detailed result of Wi-Fi performance sent by Pis can be available as graph generated using <pi_id, ap_id> as key.

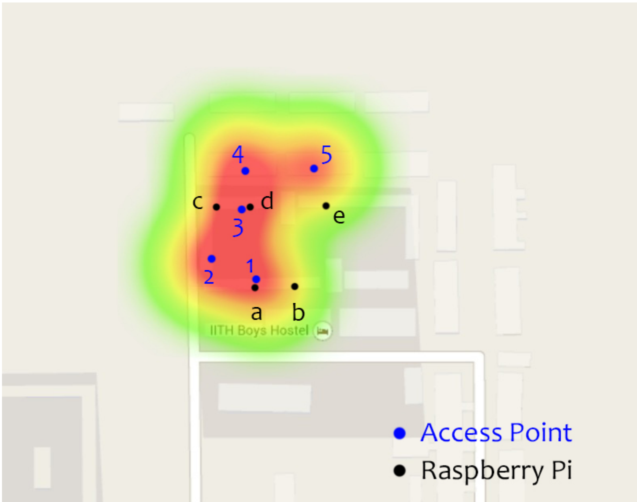


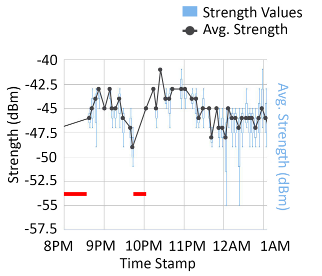
Figure 8: Wi-Fi heat map generated using Wi-Pi for 2.4GHz access points

The time taken for monitoring by Pi mainly depends on the number of access points in the surrounding environment. The size of the data is approximately 100 Bytes per access point detected by a Pi. The server is accessible internally in IIT Hyderabad providing admin control and data visualization. Wi-Pi also detects the rogue access points, and stores information related to them in database for future perspective. Monitoring rogue access points is necessary as they also hampering the network at to certain extent.

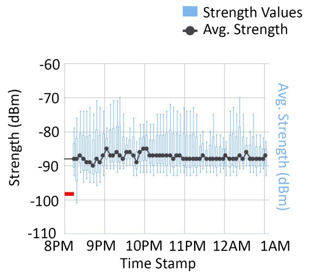
4.2 Relation between heat map and Loss/Delay

Figures 9(a) to (f) demonstrate the data which is already collected from the deployment in IIT Hyderabad. In the heat map, red colored zone indicates good/excellent signal strength, where the average packet loss rate and latency are also very low. Due to fluctuation in the signal strength, the average signal strength is used for the comparison.

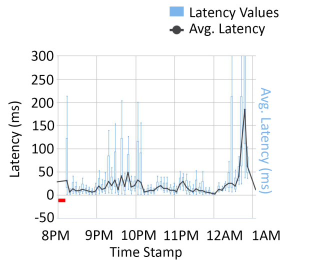
As per the Wi-Pi data visualization, some area can



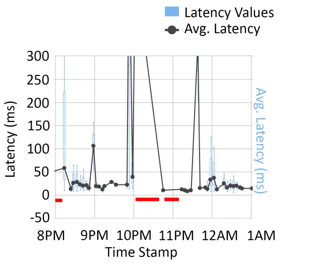
(a) Best hourly strength (per 5 minutes) result between pi(d) and ap(3)



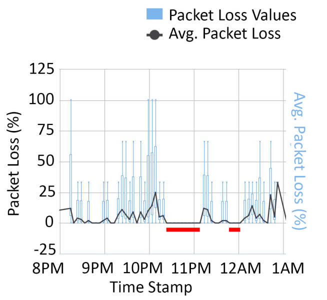
(b) Worst hourly strength (per 5 minutes) result between pi(a) and ap(3)



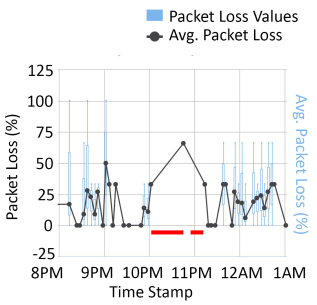
(c) Best latency rate (per 5 minutes) results between pi(a) and ap(1)



(d) Worst latency rate (per 5 minutes) results between pi(c) and ap(2)



(e) Best packet loss (per 5 minutes) results between pi(a) and ap(1)



(f) Worst packet loss (per 5 minutes) results between pi(c) and ap(2)

Figure 9: Wi-Pi monitoring results in IIT Hyderabad. Red bar in above figure represents the missing data when network is down.

be considered as a good or a bad area based on the signal strength available and the latency in that area. If signal strength is good enough with reasonable packet loss then that area can be considered as average area for network usage.

4.3 Deployment scenario of Pi

Pattern of placement of Pi in an area changes from the monitoring purpose. If the purpose of monitoring is to just to monitor the cold reasons or to locate the cold regions, Pis should be deployed at the places which are distant from access points. Similarly, if the purpose of deployment is to monitor the variation in signal strength and latency during a time span, then Pis need to be either deployed at particular locations or nearby the access points. If users are not satisfied with the accuracy of heat map in any particular area/location, then this is the best place to deploy a new Pi. More the Pis covering an area, better and more accurate results it generates.

The deployment in IIT Hyderabad is tested in all the situations and program is made to give the best possible assumption according to the data that is available. Installing a new Pi is just flashing the memory card with the iso image of Wi-Pi. After that the registration of Pi can be completed on Web UI.

5. RELATED WORK

In today's market, there are other Wi-Fi heat-mappers available like Wi-Spy[6] and Ekahau[4]. These software products also plots the heat map of Wi-Fi signal but procedure is completely different. Unlike Wi-Pi, some of these are commercial software products and some needs proprietary hardware. Most of these software products does not provide a continuous evaluation and real-time analysis of Wi-Fi signal strength. This is mostly because they require human resource to walk around the area that needs to be analyzed to collect the data, but if the area is very large then the cost of maintenance and analysis increases.

Few software like Ekahau requires a map of the area as input. Cisco Spectrum Expert Wi-Fi[3] is a Cisco proprietary software that works with Cisco network cards. This software is also similar to other software mentioned, with some additional features like, locating video camera or rogue Wi-Fi devices. Most of these software products take in consideration obstacles in path of signal propagation and accordingly reflect the same in the heat map.

Wi-Pi is unique in terms of visualizing the network on Google maps, i.e. plot using latitude and longitude. Wi-Pi is a stationary and distributed approach that also gives the performance analysis of network. Wi-Pi also monitors the network even if network is down, but storing the data. Unlike these products, we need to think about floor-wise visualization of heat map.

6. CONCLUSION AND FUTURE WORK

This paper introduced Wi-Pi which is a simple, static and cost efficient method of assessing Wi-Fi performance based on the actual feedback from Wi-Fi clients. We choose Raspberry Pis because they are low cost devices that used for carrying out computations and have the potential to be customized easily to capture extra information like Wi-Fi signals, GPS location, temperature and environmental information, etc. The small deployment has been done in IIT Hyderabad's campus network and generating geographical heat maps with detailed per-device monitoring results including RSSI, packet loss rate and latency of Wi-Fi network at various locations.

Future plans includes a large-scale deployment of Wi-Pi system in IIT Hyderabad campus with making Wi-Pi more efficient and extending the system to multi floor structure. Visualization can be made more effective in future by time stamp based heat map generation. Currently monitoring of only target access points is taking place, which can be extended to all the access points and to estimation of location of unwanted access points. Being a stationary network monitoring system, Wi-Pi monitors rogue access points efficiently.

FSPL formula is being used for estimating distance between Pi and access point but it does not take in consideration to reflection and absorption of signals from walls and other obstacles. In future a better method can be used to determine distance between Pi and access point with taking in consideration all the factors affecting signal transmission. A long-term vision is to implement Pi functions on mobile phones. They have additional benefits of covering areas that Pis cannot monitor and are also cost efficient.

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