Dense WiFi: Challenges and Performance Measurements

M. Tech. Seminar Report
Submitted in partial fulfillment of the requirements
for the degree of
Master of Technology
by
Ratheesh K V
Roll No: 153050057

under the guidance of

Prof. Kameswari Chebrolu

Department of Computer Science and Engineering
Indian Institute of Technology, Bombay
Mumbai
Contents

1 Introduction 2

2 Problems in Dense Network, and methods for performance enhancement 4
  2.1 Issues and challenges in dense WiFi networks[10] 4
  2.2 Understanding channel selection dynamics in dense Wi-Fi networks [1] 6
  2.3 Per-node throughput enhancement in Wi-Fi densenets [9] 8
  2.4 TCP download performance in dense WiFi scenarios [3] 10

3 Wireless performance measurements from access point 12
  3.1 Observing home wireless experience through WiFi APs [5] 12

4 Wireless performance measurements and crowdsourcing using smartphones 14
  4.1 MCNet: Crowdsourcing wireless performance measurements through the eyes of mobile devices[7] 14
  4.2 Pazl: A mobile crowdsensing based indoor WiFi monitoring system [6] 15
  4.3 Crowdsourcing access network spectrum allocation using smartphones [8] 16
  4.4 Understanding 802.11 performance in heterogeneous environments [2] 18

5 Wireless performance measurements from AP and using smartphones 19

6 Summary 22
  6.1 Parameters of performance measurement 22
  6.2 Current limitations on performance measurement 23

7 Conclusion 24
Abstract

A wireless network deployment with multiple access points and stations termed as Dense WiFi network, also called Overlapped Basic Service Set (OBSS) [10], since their coverage areas are in overlap. The wireless technologies are using the same unlicensed ISM band, because the available channels are less in this band the channel reuse is common in dense deployment. The reuse of channel results in different co-channel interference problems and it significantly affect the wireless performance received at the client. Proper placement of access point and channel allocation are the common challenges in dense deployment.

There are different proposals and implementations to enhance the throughput achieved in dense networks, like dynamic channel allocation, changing access point’s transmit power etc. In order to do these changes the network administrator or the entity who is managing these functionalities need to know the wireless performance in the network. Wireless performance measurements can be done in different ways, the most common among are deploying sniffer, measurements from access point’s perspective, user crowdsourcing the performance measurements using smart devices etc. User side performance measurements represent actual wireless usage experience. The increased popularity and high availability features of smartphone make it as suitable platform for client side wireless performance measurement. Different smartphone applications are available to make this process easy.

From experiments and simulations it was observed that dynamic channel allocation by a central controller, increasing the transmit power of access point based on the information obtained from crowdsourcing helps to improve the throughput.

The performance problems in a simple wireless network is get amplified in dense scenario. Understanding performance problems and methods to enhance performance are the motivations to study about dense network. It is import since the dense deployment is costly and complex and is used to serve a large crowd, a better performance is expected with all these costly and complex deployment.
1 Introduction

A wireless network deployment with large number of access points (AP) and associated stations termed as Dense wireless network. Shopping malls, airports, large classroom etc. are examples of such deployment. Dense network deployment intended to serve a large crowd to access the network.

Wireless technology uses the unlicensed band with less number of channels. In dense deployment there is high probability of reusing the channel, so neighbouring access point may came to use the same channel. Overlapping common channel create different types of interference issues, which leads to degrade the client’s received throughput.

Channel reuse is the main source of performance degradation in dense network. Experimental studies in a dense environment indicate that some channels are reused multiple times and some are not used at all [9], so leveraging the unused channel can reduce the interference problems to some extend. AP-AP interference, AP-station interference, hidden terminals, exposed terminals, interference amplification etc. are the most common performance problems arrived in dense network[10].

In a single Basic Service Set (BSS) itself stations will compete for accessing the channel, the access point serve some set of client and they respond with acknowledgment, but in real time in addition to these acknowledgment clients like smartphones generate small amount of upload traffic (in terms of Kbs). Experimental results shows that this small amount of traffic is sufficient to increase the contention and reduce the TCP download performance further[3].

The objective of dense wireless deployment is to serve a large crowd with better performance, so it very important to understand how much performance is actually receiving. The dense network deployment and management is costly and complex, since it involve multiple AP installation. There are proposals and deployment exist to measure the dense network performance in different ways. These collected measurement need to communicate with the network administrator or an automated mechanism who is managing the whole network. The common categories of performance measurements methods are [7],

- Deploying sniffers in various places in network
- Performance measurements from access point
- Performance measurements from client side

The sniffers have specialized performance computation logic embedded with it. It capture the packet in the network and apply it’s logic of measurement and sent these data to a central controller. The controller collect these type of data from multiple sniffers and try to identify the network condition. The network administrator take decision based
on these data to improve the network performance. But this methods have the following drawbacks[7],

- For covering the whole network, more number of sniffers are required which increases the cost
- Less control and configuration freedom for changing any measurement parameters
- They are passive, they may not capture all the packet
- Measurements are not actual representation of performance achieved at the client.

Measurements from access point involve AP with two radio, one radio is used for associating with client and the other for measurements. Using the second radio it is possible to track all the packets to and from each clients, details like channel airtime utilization, local contention, RSSI of received packet etc. can be collected. This information either passed towards a central controller or it is used by access point itself to understand about the network condition, and come up with strategies to improve the network performance. These approach of measurements from access point have the following drawbacks[7],

- Access point which are proprietary in nature, there is less control for measurement configuration
- Measurements are not actual representation of performance achieved at the client.
- Increases the cost of access point, since it require two radios one from serving the client another for performing measurements.

Another approach for performing measurements are from client side and it can be categorized in to two,

1. Taking manual site survey by going to different part of network area and perform measurement using available tools, this methods have following limitations,

   - This process is tedious and time consuming
   - Network situation changes dynamically, the amount of clients contend for channel is different at different time, so measurement taken at a particular time will not represent varying network condition and cannot help much to enhance the wireless performance due to this dynamic nature.

2. Measurements using devices like smartphones, tablets etc. that contains measurement applications running in background to collect measurement at regular interval of time. This informations are pushed towards a central server in an energy efficient way, this method is more automated compared to manual site survey. But the amount of information that can be collected are restricted.
Because of the increased popularity, always on, mostly idle, easy development and deployment of software makes smartphones and tablets a suitable platform to conduct wireless performance measurement. These devices occupied with different interfaces like wireless, cellular that also helps to crowdsource these measurement to central server. The measurement application better to run on the background so that it will not disturb the active user session and crowdsource the collected information to a center controller in an energy efficient manner. So performance measurement and crowdsourcing using smartphones is easy and better approach since it measure the actual user achieved wireless performance.

This seminar report is organized in the following way, section 2 deals with problems in dense network and methods to enhance the performance, section 3, 4 and 5 discuss wireless performance measurement from access point side and using smartphones, section 6 collect parameters used for measurements from discussed papers and section 7 conclude this report.

2 Problems in Dense Network, and methods for performance enhancement

As mentioned earlier the main reasons for throughput degradation in dense network is due to reuse of channel by different access points with overlapping coverage area in the network, and small amount of upload traffic generated by email, dropbox, facebook applications in mobile devices which further increase the contention. This section discuss about different issues and challenges in dense network because of channel reuse, experimental analysis of performance in dense network, and methods to enhance throughput in dense wireless network are also discussed.

2.1 Issues and challenges in dense WiFi networks[10]

This paper identify reasons for throughput degradation in dense network, also knows as overlapped BSS(ObSS). ObSS provide good coverage but because of overlapping range of access point results in different types of interference problems. Common problems which affect performance in traditional network is amplified in dense scenario, especially when there is common channel between neighbouring access points. The access point placement are important, because if the distance between access points is short then interference will be higher in the case of co-channel. In a managed network if there is a provision to change the channel of access points dynamically and remotely, then by changing the interfering channel helps to reduce the problem. But for an unmanaged network this is not applicable.

The factors affecting the network performance in co-channel scenario are,

- Presence of hidden terminal

  In an overlapping dense scenario, RTS/CTS may not be sufficient for tackling hidden
node problem, if a particular client didn’t receive CTS due to increased interference it will not set SIFS, so it may collide with other transmission.

- **AP-AP interference**
  If neighbouring access points are using the same channel then, only one client to access point communication will be succeeded.

- **Station-access point interference**
  One station-access point communication set the other access point in idle state which is also using overlapping co-channel.

- **Deadlock effect on access point**
  When two access points are using the same channel and if there is non interfering hidden nodes common in each, when one client sent RTS to it’s access point, other access point set NAV, before responding with a CTS to it’s client’s RTS request the second client also send RTS, which is also heard by these two access points, because of these RTS the first access point also set NAV, both access point wait till other client-access point communication to finish. The situation continue till the next time when both sense the channel.

- **Interference amplification effect**
  There can be a situation like colliding signals combined to form a single stronger signal with more power, which can potentially affect existing client-access point communication.

- **STA-AP link suppression**
  Client within the range of an access point, but communicating with other access point cause the original access point unable to use this link

- **Exposed node problems in dense network**
  This will prevent a station to connect or transfer data to an accesspoint, due to an active station within it’s coverage area.

These problems can be reduced in a planned network, where access points are separated with specific distance away so that the density of access points and interference can be reduced, if the network support dynamic selection of channel which further improve the throughput. But in an unplanned network these situations are difficult to manage.

**Experiments and Evaluations**

The experiments are done in simulation. Simulations include to study about above problems and to understand the effect of placement of access point to the network performance. And the result shows that increase in the number access point will not increase the overall performance, the placement of access point is important.
Positives

- Issues related with co-channel in dense network explained well
- Simulation results shows that placement of AP is important than increasing number of APs.

Negatives

- Only talks about issues associated co-channel scenarios
- Realtime experiment is not conducted, since the simulations are conducted in restricted condition with artificial traffic. Which may not represent the real time situation.
- Methods to resolve above issues are not mentioned.

2.2 Understanding channel selection dynamics in dense Wi-Fi networks [1]

This paper addressing the problem of performance of unmanaged residential wireless network, which exist together with a managed service provider network and using the same spectrum.

In residential network, the access point’s channel are always fixed or it rarely got changed, they are having less management control, less costly and their coverage area is also less. But service provider access points are composed of costly hardware and software, have larger coverage area and they are configured to adapt channel dynamically by centralized channel allocation.

When these two network comes together i.e coverage areas are overlapped, since both are using different channel selection methods, simulation study shows that with increase in the number of managed access point create performance problem to residential access point.

The throughput is the measure of performance and is calculated by constructing contention graphs as follows, the vertices represent the AP, edge between AP will present if both are using the same channel.

Then calculated all maximum independent set(MIS) found out by approximation mechanisms, from this the throughput formula was derived as follows,

\[
\text{The throughput at a node} = \frac{\text{number of MIS in which the node is present}}{\text{total number of MIS}}
\]

The metrics of measurements considered are,
Throughput at AP: It is the combined throughput received by the clients

Starved nodes: The nodes which are not getting any channel share, so their throughput is nearly zero.

i.e more the number of starved node means the overall throughput at AP will be reduced.

The experiments are conducted for identifying the impact of different channel allocation algorithm on the received throughput achieved by the client. Simulations are used for testing the following channel selection schemes at each access point,

1. Random channel: Random channel will be chosen from available channels
2. Local selection: Least congested channel from local viewpoint will be selected
3. Centralized assignment: Single central entity will manage the channel allocation

In simulation testing are conducted in the following two different environment,

- Homogeneous setting: Here all APs use the same scheme for channel selection
- Heterogeneous setting: Here all APs use the different scheme for channel selection

From simulation it is observed that,

- In homogeneous setting with increase in number of access points per square kilometer the throughput at access point which are using random and local channel selection is getting decreased, where centralized channel allocation scheme is getting more throughput compared to others. Also the number of starved nodes are less for centralized channel allocation compared to other channel selection algorithm.

- In heterogeneous setting with increase in the number of centralized access points compared to residential and independent access points, the number of starved nodes are getting reduced

- But further increase in the number of managed access point, the throughput obtained at access points are getting reduced.

The reason behind reduction in performance can be explained as initially the residential AP make some selection on channel, then the managed AP have choices for selecting channel and maximize it’s performance, but when the number of managed AP increases, the available free channels reduces, and there need to reuse the same channel after some point, which will cause co-channel interference as mentioned before and that will reduce the performance.
Experiments and Evaluations

The experiments are done in simulation. The simulation results are validated using conducting experiments on eight nodes, each consists of Atheros cards, and choose some connection topologies, channels are selected from 0-8. In the first experiment there is only one centralized access point, and the rest are using same channel and obtained a throughput of 20Mbps, in the second experiment all are using centralized scheme and obtained a throughput of 15Mbps, the results are in agreeing with simulation results.

Positives
- The impact on performance due to different types of channel allocation schemes are explained well

Negatives
- Per node throughput calculation may not be much accurate. Since throughput depends on amount data send or received, impact of interference are not taken care.

2.3 Per-node throughput enhancement in Wi-Fi densenets [9]

The goal of 802.11ax task group was, to improve the per-node throughput in a dense network. As part of it’s goal the 802.11ax standard came up with proposals that can be used to improve the client achieved throughput. One of the important suggestion they made was dynamic sensitivity control(DSC) and transmit power control (TPC).

The problem addressed by this paper is, which all methods can be used to enhance the degraded performance in a dense network. They made following suggestion including the one suggested by 802.11ax standard.

- Use of cellular technologies in wireless

The idea is to offload traffic from dense network to cellular technology, which can reduce the contention and traffic in the free wireless band.

- Increase spectral efficiency

Increase spectral efficiency, by employing non-orthogonal multiple access scheme, which is having better spectral efficiency compared to OFDM. The following non-orthogonal multiple access schemes are suggested,

  - NOMA

    Access point use different transmit power for different stations based on the distance from AP. More power to farther station, less to nearby stations. These power levels are superposed in single transmission in the power domain. The receiver need to do recover it accordingly.
- **SE-FDM**
  This method uses constant inter sub-carrier gap, which is less than that used in OFDM, so that they can use more sub-carrier and improve the data rate compared to OFDM. But it can cause inter channel interference, receiver need to use better decoding techniques for recovering original data.

- **OFDMA-VTS**
  Uses variable length inter sub-carrier gap, here inter symbol and inter channel interference are possible to occur. The spacing should use in such a way that to reduce these interference.

- Control overall interference level using DSC and TPC

  DSC is used to dynamically change the threshold values for clear channel assessment (CCA), based on these value the station access the medium aggressively or passively. TPC is to control the transmit power so that the receiver will receive the signal with specified transmit power.

Experimental evaluation of dynamic sensitivity control (DSC) and transmit power control (TPC) conducted practically in the following dense deployment,

1. Residential scenario
   Involve a multistorey building, APs are randomly placed in a unit, which is of dimension 10x10x3 meter and each AP handle N stations. About 20 units are considered.

2. Indoor enterprise building
   Involve eight offices each with 20x20 meter, each office have four APs, one office have 64 cubes, and each cube have four stations. One AP serve 16 cubes

3. Indoor small BSS/outdoor large BSS
   Involve BSS with hexagonal cell coverage, distance between APs are 130 meter outdoor, 12 meter for indoor. APs are managed by enterprise and some standalone APs are present in the network.

**Experiments and Evaluations**

Experiments are conducted in the above dense deployment, the results shows that usage of DSC and TPC mechanism improve the per node throughput around 50 to 100 percent in residential areas with different number of nodes. About 40 percent improvement in enterprise building, 20 percentage in small BSS and around 200 percent in large BSS compared with throughput achieved without using DSC and TPC.
2.4 TCP download performance in dense WiFi scenarios [3]

Earlier simulation study on TCP download performance in dense setting shows that TCP download performance is good and contention is less, here the traffic are generated in a controlled environment, and are artificial.

This paper summarize the results of TCP download performance experiment conducted in real time dense network and the result shows that the TCP download performance is poor.

Experiment are conducted in a classroom where about 94 students are required to attend a quiz, for that they need to connect and authenticate with the web server using their laptops or tablets and download a variety contents like reference material, and quiz. The clients are spread roughly equally among three APs. The quiz data size is 200KB, and the additional reference material is around 4MB.

The network traces are collected from the following for supporting the later analysis,

- At the WiFi AP, to collect per-frame MAC layer statistics like idle time, airtime spend for transmission and reception
- A sniffer running tcpdump at the server side, to collect TCP and HTTP logs

The metric used for analyzing the performance was completion time of request. The 802.11g physical data rate is 54Mbps, and after all overhead it will provide a data rate around 24Mbps at the application level and with this rate when it scaled to all users, it was expected to complete the download after 54 seconds.

But the actual time for downloading those files were 229 seconds for the quiz material was 229 sec and 478 sec for reference material[3]. Based on the analysis from log statistics of experiment it was concluded that,

- Some client suffered from TCP segment loss, and timeout and leads to re-transmission
- There is small amount if extra upload traffic besides TCP ACKs, the traffic is generated by email clients, Dropbox like applications.
- TCP handshake packets were present for multiple connection opened by browser
- GET request for various embedded objects of course page

But the amount of small upload traffic was in terms of 8Kbps, and it is shown that that is sufficient to increase the contention and collision. The rate adaptation algorithm consider collision losses are due to poor signal on channel, as a result it reduce the rate which leads to increased completion time.

Following experiments are also conducted to identifying reduced performance,

- Experiment was conducted in simulation and small scale real time scenarios to understand the effect of contention on rate adaption algorithm. It is observed that the
rate adaptation algorithm reduce rate for collision losses, and it took time in terms of tens of second to recover. Long recovery time of rate adaptation and effect of contention persist for a period of time which further magnify the effect of small amount of upload traffic.

- Experiment was conducted to study impact of collision losses on TCP performance. It is observed that a mix of upload and download traffic created enough contention and slow down the TCP download, the contention leads to variable delay which affect the TCP retransmission timeout estimation, leads TCP to timeout unnecessarily which leads to retransmission of packets.

The solution proposed was modification to AP’s MAC layer scheduling policy, called as WiFiRR. WiFiRR uses both FIFO and round robin scheduling, it is required to modify the AP driver code and buffer management. With WiFiRR a subset of K out of N clients are considered as active. The features of these modification are,

- Access point will serve those clients in round robin fashion so that each client get a chance.
- AP will skip packets from non-active clients.
- Broadcast and management frames are also send according to round robin to active clients
- If there is no packet for active client, it will send packet to non-active client to prevent the channel to become idle.
- Non-active clients will stall for this duration.
- This method is benefited when there is large traffic and leads to improvement in overall performance
- Not suitable for interactive or short traffic, since it non-active client will reduce the overall performance for short traffic.

Experiment was conducted using linux laptop with Atheros wireless adaptor for the evaluation of WiFiRR with varying slot duration shows that WiFiRR achieved 3.2 times reduction in completion time, and outperform 2.25 times compared to WiFox, which is another solution to improve TCP download performance in dense scenario.

**Positives**

- Practically verified and collected logging from different levels helps to understand the degraded TCP download performance
- Separate experiments are conducted to identify the effect of contention on rate adaptation
• Choice of completion time as performance metric, which represent wireless performance at client side.

3 Wireless performance measurements from access point

AP level measurements is one of the approach for wireless performance measurement. There are several proposals and implementations exist which follow this approach. But these measurements may not reflect actual user wireless experience, because these evaluations are conducted using the information obtained from NIC of access point. One of the method using this approach is discussed here,

3.1 Observing home wireless experience through WiFi APs [5]

This paper addressing a problem of implementing a measurement infrastructure that gives a better estimate on wireless performance than existing sniffer like approach from access point side.

The infrastructure called Wise, which contain a set of access points which are openWrt based. These APs are configured with specialized measurement and monitoring software that collect measurement and communicate with a central controller through an open API. Each AP contain 2 NICs, one in Atheros for measurements and other is for serving the client request.

The components of Wise architecture are,

1. OpenWRT based access point, this AP can collect following informations,
   • All traffic to and from client, overheard packets and beacons
   • Measure CRC error, busy time etc.
   • Packet level information like length, physical rate, rssi etc.
   • Non-WiFi device detection by running a Airshark tool

2. Management API, it’s features are,
   • OpenAPI with set of exposed interface
   • Controller used to specify type of measurement needed to access point
   • Used for remote management and configuration by controller

3. Linux server central controller
   • Use openAPI to configure the access point remotely.
   • It can install of software on AP, since it was openWrt based.
From the calculated informations a metric value is calculated called Witt, which represent the likely throughput in the present environmental conditions. Its value depend on client, AP, wireless protocol used. Following informations are used to predict the value of Witt,

- Airtime utilization, CRC error rate, signal strength
- Local contention It indicate the relative amount of other client traffic
- Effective rate It is the weighted average of number of successful packets with different physical rate

The calculated metric value is benchmarked with actual ground truth measurements, and it is observed that this metric is giving better prediction on TCP throughput, since it is considering above mentioned parameters.

The calculated Witt value is used to classify wireless experience into following categories,

- Very good Witt value greater than 16Mbps
- Good for Witt value between 8-16 Mbps
- Moderate for Witt value between 4-8 Mbps
- Poor for Witt value between 1-4 Mbps
- Very poor for Witt value less than 1Mbps

The infrastructure deployed in two apartment area, one is having 5 floor, 12 flats per floor and 14 AP are used. Other deployment was in 2 floor dormitory type area with 6 APs, a central AP is used to serve more number of clients, third deployment was in suburban area. Based on the experiment conducted on these deployment it was noted that there exist poor and very poor performance in the first two deployment scenarios,

Based on the value of Witt and associated measured parameters, following conclusions are made to reason about poor performance,

- The first deployment is a dense one, higher packet loss due to congestion, presence of non-WiFi sources and other near by transmitter with low physical rate increase the airtime utilization leads to very poor performance.
- Second one was more centralized AP approach, where a single AP serve more clients, weak signal strengths with increase in distance from AP interference from non-WiFi devices, presence of near by transmitters using low physical rates leads to increased airtime and reduce the throughput, and increased the latency.
- Interference from hidden terminals
• Some APs reported significant increase in airtime utilization in the presence of microwave oven

• Static channel allocation on AP, cause th APs unable to adapt to interference problems.

Negatives

• Paper is not talking about any solution to improve the degraded performance.

4 Wireless performance measurements and crowdsourcing using smartphones

The wireless performance measurement in large complex network like universities, enterprises etc. are difficult and challenging, crowdsourcing is a better solution, because it is easy and cheap and it uses user equipment like smartphone which is installed with corresponding performance measurement software. By crowdsourcing we can collect the actual user wireless experience and create a global view of network from input from a large crowd. This further helps the network manager to take necessary actions to improve the network performance. This section discuss some of the suggested crowdsourcing approaches,

4.1 MCNet: Crowdsourcing wireless performance measurements through the eyes of mobile devices[7]

McNet is a crowdsourcing solution to measure wireless performance in complex network like universities, corporation etc. It is an android application which need be run continuously on background to perform measurements. So McNet is associated with a scheduling algorithm, which trigger the measurement calculation at regular interval of time, that makes about 15 minutes per day and it consumes around 1 percentage of battery. Some scheduling features are given below,

• Turnoff throughput measurements when battery is less than 50 percentage

• Turnoff all measurements when battery is in power save mode

• During charging measurements are taken in every 5 minutes and upload the traffic to server

• Stop taking measurements when user leaves out of network, and starts when user comes back.

As part of the design the power consumption for each measurements are calculated and it is found that throughput calculations by downloading large file are consuming more power, and the latency measurement done by using pinging a destination consumes only
less power. So McNet scheduling algorithm will disable the throughput calculation when the device battery is low.

Performance measurements using McNet involves collecting the following informations,

- Metrics and reflect user experience like throughput, latency
- Rssi, data rate, access point info, access point handover
- Use passive data for collecting performance parameters to minimize power consumption
- Use active traffic when passive data are not possible

**Experiments and Evaluations**

Experiment is conducted in two different enterprise WLANs, all smartphones and tablets are using 802.11a/g/n 2.4Ghz band. One deployment is on a one floor of a large corporation, contain open space, low wall cubicles etc.

Second deployment was in a multi-storey building from there it found out the latency related issues.

From the measurements collected in the first deployment leads the network manager to increase the transmit power of AP, which helps to increase the performance by 37 percentage.

4.2 Pazl: A mobile crowdsensing based indoor WiFi monitoring system [6]

This paper is addressing the problem of developing an automated solution for indoor wireless performance measurement. Existing tools like Ekahau survey tool are manual site surveying approach, measurements using this tool is tedious and time consuming. Pazl is a crowdsourcing system to measure the wireless performance in indoor environment. In indoor environment like shopping malls, classrooms etc. the environment conditions vary with time, some time they are crowded and some times not. In crowded situation the usually the access point is also crowded, and in other case the network utilization is very low. There will be more interference in indoor environment, and also the wireless performance vary based on location inside. Presence of walls and other obstacles degrade the received signal strength at a particular location compared with an open space inside a building. So in indoor performance measurement localization information is also needed to track the problem easily.

The features of Pazl are following,

- Pazl is an automated indoor wireless performance measurement tool
- It is having crowdsourcing mobile app, which collect performance measurements,
• Passive monitoring via scanning, that is used to diagnose most coverage and performance orient WLAN problems

• Push the measurements to backend cloud

• Use localization techniques to identify the location and movement of person, which is also added along with crowdsourced information, localization method combine the Pedestrian dead reckoning, WiFi fingerprint approach.

The crowdsourced information pushed to the cloud are collected and using that the Pazl system create a network view of wireless performance after mapping with it’s location information. This map view can be used by network administrator to make decision to improve the network performance.

Experiments and Evaluations

Experiments are conducted inside an enterprise indoor environment using smartphones. The final network view is compared with Ekahau Mobile survey tool which is used for measuring indoor wireless performance manually. The results obtained by Pazl are matching with manual surveying tool. The goal of Pazl is to automate the process of performance measurement.

4.3 Crowdsourcing access network spectrum allocation using smartphones [8]

The POCKET-SNIFFER is prototype for a smartphone application which can be used to crowdsource information from passive clients, which will help it’s neighbouring active client to receive a better wireless performance. The idea was not to disturb active client session, and use nearby passive client for measurements.

Here the mobile app perform performance measurements based on the request it receive from access point, i.e there is no measuring algorithm which is running in the app. Access point can give either of following types of request for collecting performance parameter from client,

1. Asynchronous request
   • It involve long running measurement request
   • Client supposed to publish measurements to a subscription
   • There can be delay in the response to this request

2. Synchronous request
   • Expecting a fast response from client after measurements.
• Request is created on demand
• Corresponding measurements are short

The above requests also involve information about the type of data collected, which all device to participate, time of measurements etc.

Based on these request client can perform two types of measurements,

• Wireless scan result
  – The process of doing is inexpensive
  – Collect visible access point list and signal strength information

• Spectrum utilization information
  – The measurement is expensive
  – It will give detailed view of spectrum usage
  – It is required to disable power save mode, so consume energy
  – The capacity of WiFi chipset varies among devices for this purpose

Based on the experiment results the central controller can perform,

• Move active clients to different channel
• Adjust AP power level
• Change the associate of client to different AP

Active clients will ignore the requests, since the goal of the application is to do not disturb active client. Because of these there can be selfish clients which provide incorrect data for improving it’s own performance. For spectrum utilization measurements we need all packet level information, for that it is required to sniff the channel by moving into monitor mode, still smartphone network cards are not yet ready to support monitor mode operation.

**Negatives**

• Didn’t specify how to find a neighbouring passive or active client
• For major measurement details, the smartphone need to support monitor mode operation, nowadays technologies didn’t reach there
• If there is not passive client nearby, and an active client still continue to receive less performance
4.4 Understanding 802.11 performance in heterogeneous environments [2]

Since the ISM band is used by different wireless technologies it is important to understand the effect of interference and performance impact on WiFi. The problem addressed by this paper is in identifying non-WiFi interference in a heterogeneous wireless network from Bluetooth, microwave oven etc.

This paper deals only with measuring interference in this environment and provide a framework for measurement, WiMed framework is the result which is a client side solution to identify the performance in heterogeneous environment. For the measurement it is require to have two NICs, one for getting wireless service, other for sniffing the channel, Atheros NIC required for this purpose.

The WiMed solution involve the following steps

- **Passive Monitoring**
  - Sniff the channel using monitor mode
  - Collect kernel level statistic using registers in NIC, along with timestamp, it helps to identify medium busy time, MAC busy time etc.

- **Trace merging**
  - By using the timestamp, merge the kernel traces with sniffer data

- **Analysis**
  - Identify time instances where channel is busy and there in no 802.11 packet present, this indicate the presence on non-802.11 sources.
  - Identify the total packet errors, the peaks in bit error rate indicate the presence of interfering sources
  - Bit Error timing analysis is used to identify presence of interference from non-802.11 sources
  - It involve bluetooth, microwave and other non-802.11 detecting algorithms for finding it’s presence from trace input
  - It output the confidence level of non-802.11 interference from the trace inputs.

- **Time allocation**
  - Mark the presence of interference and packet transmission events etc, in time scale

**Experiments and Evaluations**
The WiMed system takes input from sniffing the channel and kernel level statistics and outputs a confidence value from 0 to 1 for indicating the presence of any non-WiFi interference.

Experiment is conducted to measure the correctness of kernel traces captured using NIC registers. Whether it capture the correct medium utilization information with various signal strength values. The results indicate that the mean error in only 0.5%.

Experiment is conducted using a laptop with two NIC one is Atheros NIC for sniffing other for connect with access point. In the presence of bluetooth and microwave oven etc. the system is able to categorize the type of interference present in the environment successfully.

Negatives

- Here the smartphone need to support monitor mode operation for sniffing, nowadays technologies are not supporting this feature.
- Collecting kernel level statistics may required to root the application.

5 Wireless performance measurements from AP and using smartphones

So far discussed about conducting measurements from either from AP or smartphone, but these two measurements can be combined to resolve some ambiguity in measurements while using only one approach. It can give a better estimate for performance. Dyson is one of the performance measurement solution using this approach.

5.1 Dyson: An Architecture for Extensible Wireless LANs [4]

Current WLAN architecture are not designed to incorporate changes. Because it require modification at each of wireless network nodes. This paper proposing a solution for this problem as Dyson, which is the first software architecture for extensible WAN. Dyson is a solution for extensibility problem. It require the client and access points are Dyson aware, means configured with Dyson software solution. Dyson also support non-Dyson aware legacy clients also, but the performance measurement can not be conducted on it.

Dyson builds upon existing 802.11 standards, including CSMA MAC and the format of the data and management frames. Dyson defines set of APIs through which the clients, access points can communicate performance measurement to central controller and central controller can issue some commands based on management policies.

The main components of Dyson architecture are,

1. Clients
Dyson aware clients can be used to perform performance measurement based on the command issued by central controller. Legacy client can also exist in the network, but the level of manageability is less.

2. Access points

It is used to perform performance measurement based on the command issued by central controller, also it collect the measurements from client at regular interval of time and pass these details to controller.

The Dyson nodes are client and access points. The following informations can be collected from these nodes,

- Number of packets received
- RSSI
- Airtime used by packets
- Channel airtime utilization
- Number of retransmissions

The following are the components of Dyson architecture,

3. Single central controller

Controller collect the measurement from Dyson nodes and create a global map of network status. It issues some commands to Dyson APIs to control the Dyson nodes as part of policies. The types of commands the central controller can issue are,

- set Physical rate
- set channel
- set transmission level
- Handoff client from one AP to other
- Associate a client to an AP
- Disassociate a client from AP etc.

4. Policy Engine

It is used to define policies to customize and manage the network. The policies are designed with Python-based scripting API so they can be modified or extended as per requirements. Sample policies are,

- Customizing association
- User specific airtime reservation
- Uplink downlink load balancing
- VoIP aware handoff
Dyson use both client and access point measurements. Client-side information can be used to resolve some sources of ambiguity that would arise with access point only observations, like

- Detection of hidden terminals
- Awareness of mutual connectivity between APs and clients
- Mapping channel airtime utilization

For managing the access point and client came up with customization policies. There can be different types of policies as per the requirement. Following are some sample customization policies are,

- Customized association
  On receiving association request from client to multiple APs, the AP with maximum available capacity selected for that client.

- Interference aware association policy
  While choosing an AP for association, interference effect also considered like co-channel effect. From testbed experiment it is observed that this policy improve the throughput of client compared to without using interference information.

- User-specific airtime reservation
  The controller throttle the transmission rate of clients in such a way to incorporate the request of a high priority client. Here the goal is to give a guaranteed airtime to higher priority clients.

- Uplink/Downlink load balancing
  Controller throttle the transmission rate of clients to balance the upload and download traffic through an access point

- VoIP aware handoff
  Handoff command issued by controller to handover non-VoIP client to separate access point, such that a VoIP clients can be associated with particular AP and can served better

Dyson was implemented on a 28-node testbed, and distributed over one floor of an office building, and evaluated using range of policies.

All policies demonstrate the configuration and manageability provided by Dyson, these policies are evaluated using testbed. But it is important to note that in this deployment we can configure access point as well as clients to change their current association, handoff client to less congested AP, throttle transmission rate to reduce the contention, change channel to reduce co-channel interference. These are really helpful in a dense network and all above commands of central controller can be used to get a better performance in a dense deployment.

Dyson management facilities can be utilized to provide better overall performance in dense network.
6 Summary

It is important to know what all parameters can be collected from network nodes that represent the received wireless performance. It helps to support to debug the network issues and also helps in designing new application for measurement with better features. The parameters which are mentioned in across the above discussed papers are listed below.

6.1 Parameters of performance measurement

The following parameters can be measured from a smartphone[7][5],

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Measurement type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Received signal strength</td>
<td>Passive</td>
</tr>
<tr>
<td>Link speed</td>
<td>Passive</td>
</tr>
<tr>
<td>List of available access points (WiFi Scan result)</td>
<td>Passive</td>
</tr>
<tr>
<td>Location information</td>
<td>Active information</td>
</tr>
<tr>
<td>Latency</td>
<td>It can be calculated by pinging a destination, It can be active measurement</td>
</tr>
<tr>
<td>Throughput</td>
<td>It can be calculated by downloading large file. It can be active or passive</td>
</tr>
<tr>
<td>Client movement information using accelerometer</td>
<td>Active</td>
</tr>
<tr>
<td>Response time for a request</td>
<td>It can be calculated by issuing GET/POST request on URL. It can be active or passive</td>
</tr>
</tbody>
</table>

An active measurement required to generate a live data request. For passive measurement we can use already completed (not too old) resource request information. Collection of information like airtime utilization, physical layer information are required to set smartphone in monitor mode, current smartphone technologies are not supporting those features. Expecting those features can be supported by future technologies that make smart devices a best platform for wireless performance measurement and crowdsourcing tool.

Using a secondary NIC cards like Atheros, it is possible to collect channel utilization information, which will give much more details about network performance. An access point which is having this facility can collect the following performance parameters[5][4],
Table 2: Parameters can be measured from access point

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Measurement type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of packet received</td>
<td>Active or Passive</td>
</tr>
<tr>
<td>Total byte received</td>
<td>Active or Passive</td>
</tr>
<tr>
<td>Total RSSI of received packet</td>
<td>Active or Passive</td>
</tr>
<tr>
<td>Physical rate of each packet</td>
<td>Active or Passive</td>
</tr>
<tr>
<td>Total airtime used by packets</td>
<td>Active or Passive</td>
</tr>
<tr>
<td>Number transmission failure</td>
<td>Active or Passive</td>
</tr>
<tr>
<td>Number of retransmission</td>
<td>Active or Passive</td>
</tr>
<tr>
<td>Channel airtime utilization</td>
<td>Active or Passive</td>
</tr>
<tr>
<td>Overheard beacons information</td>
<td>Active or Passive</td>
</tr>
<tr>
<td>Packet count with CRC errors</td>
<td>Active or Passive</td>
</tr>
<tr>
<td>Local contention</td>
<td>Active or Passive</td>
</tr>
<tr>
<td>Effective physical rate</td>
<td>Active or Passive</td>
</tr>
</tbody>
</table>

If future technologies to allow to use these NIC with smartphones, these measurements can also be calculated from client side, which can provide more client side received performance statistics.

6.2 Current limitations on performance measurement

The smartphone based approach of performance evaluation have the following drawbacks,

- The amount of information that can be collected from smartphones or tablets are limited as per the current technology.

For collecting channel utilization measures like airtime utilization require the smartphones need to setup in monitor mode and need to sniff the channel. Current smartphone technologies are not developed to support monitor mode.

- For accessing kernel level information like registers of NIC, we need to root the application

- Difficulty in identifying correct measurement input, because there can be selfish or malicious client

A selfish user can crowdsource wrong information for improving their WiFi performance, or reduce the whole network performance, or it can cause problems at the central controller level also[8].

- The values of received signal strength, link speed measurements depends on the hardware of device, we may not get uniform values for these parameters at the same location.
• The participation of client should be large, because usually people refuse to install these types of applications. The network manager may require some threshold of performance values for make decision on changing the network configuration.

The problems with sniffers, other legacy measurement methods and access point side measurements are already discussed.

7 Conclusion

The amount of measurements that can be collected from smartphones are less compared with access points. But the smartphone based client side measurement provides the actual wireless experience in the network. Measurements from client and access points can be combined together to get much more accurate information about network performance. Access points in dense network with automatic channel adaptation feature can help to improve the degraded performance.

Different types of problems and types of performance measurement techniques in dense network are studied. The placement of access point to reduce the level of interference is more important than deploying more number of APs in dense network. More accurate measurement helps the network administrator to make changes in the network configuration for improving the network performance. Expecting future technologies will allow the smartphone to work in monitor mode to sniff the channel, that helps to collect much more client side information that helps to provide a large set of input for better network performance.

References


