EECE 7364

MOBILE AND WIRELESS NETWORKS

WI-FI STANDARDS COMPARISON

ROMIL SHAH

NITHESH NAGARAJ

NIKITA MIRCHANDANI

INTRODUCTION

The aim of the project is to evaluate and analyze different Wi-Fi standards and compare them in terms of network throughput. The different standards run on the same basic protocol, but differ in terms of their data rates, carrier frequency, and transmission range. The next section gives a theoretical overview of these standards. We also simulate wireless networks with one access point and N clients and plot the effect of the following parameters on the network throughput:

- Number of clients N
- Number of active flows
- Constant bit rate (CBR) traffic rates

The above simulations are performed for two scenarios: with hidden terminal and without hidden terminal.

WIFI STANDARDS

This section provides a detailed analysis of the various IEEE 802.11 standards. The IEEE 802.11 is a set of specifications for the physical and MAC layers to implement WLAN (Wireless Local Area Network) to enable communication between different devices. Different standards within the IEEE 802.11 work in different frequency bands, and can have different modulation schemes and data rates. These standards are described in the following subsections.

IEEE 802.11

The legacy 802.11 was first introduced in 1997 and worked on 2.4 GHz. It supported bit rates of 1 Mbps and 2 Mbps. It used DSSS and FHSS modulation schemes at the physical layer. It also supported forward error correcting codes and employed CSMA/CA as the medium access method.

It could only support short range of communication, with indoor range not more than 20m and a maximum outdoor range of 100m. Several improvements were made to this which led to it being replaced by IEEE 802.11b.

IEEE 802.11 a

- Frequency: 5 GHz
- Bandwidth: 20 MHZ
- Data rates: 6, 9, 12, 18, 24, 36, 48 and 54 Mbps
- Modulation Scheme: Orthogonal Frequency Division Multiplexing (OFDM)
- Maximum transmission range:
  - Indoor: 35m
  - Outdoor: 120m

One of the advantages of using this standard is that it uses the 5 GHz frequency band, which is still relatively unused, and hence there is less interference. Also, devices operating at higher frequencies can have smaller antennas. However, higher frequency leads to shorter transmission range because the waves cannot penetrate walls due to their shorter wavelengths. 802.11a also supports error correcting codes.

IEEE 802.11a has 12/13 non-overlapping channels with support to add 12/13 more, increasing the overall network capacity. The use of OFDM modulation scheme ensures higher data rate at the same bandwidth. OFDM systems also have low sensitivity to co-channel interference, intersymbol interference, and multipath frequency fading.

IEEE 802.11 b

- Frequency: 2.4 GHz
- Bandwidth: 22 MHZ
- Data rates: 1, 2, 5.5 and 11 Mbps
- Modulation Scheme: Direct sequence spread spectrum (DSSS)
- Maximum transmission range:
  - Indoor: 35m
  - Outdoor: 140m

This standard is very widely used for most wireless communications. However, since it uses the 2.4 GHz band, it suffers from interference since this band is heavily used by a lot of devices. This can cause degradation of service due to frequent dropped connections.

The media access method used is CSMA/CA. This is used in a point-to-multipoint configuration with a single access points and several mobile clients. IEEE 802.11b also has the feature of Adaptive rate selection, wherein it can adaptively reduce its data rate based on the number of errors and re-broadcasts.

IEEE 802.11 g

- Frequency: 2.4 GHz
- Bandwidth: 20 MHZ
- Data rates: 6, 9, 12, 18, 24, 36, 48 and 54 Mbps

- Modulation Scheme: Orthogonal Frequency Division Multiplexing (OFDM)
- Maximum transmission range:
    - Indoor: 38m
    - Outdoor: 140m

One of the advantages of using this standard is that it is backwards compatible with IEEE 802.11b. However, this can cause the reduction of effective throughput. Also, this standard suffers from interference as it operates in the 2.4 GHz band.

The media access method used is CSMA/CA.

IEEE 802.11 n

- Frequency: 2.4 GHz, 5 GHz
- Bandwidth: 20 MHZ and 40 MHz
- Data rates: Maximum 150 Mbps in 20 MHz mode, and 600 Mbps in 40 MHz mode (with 4 antennas)
- Modulation Scheme: MIMO Orthogonal Frequency Division Multiplexing (OFDM) with maximum 4 allowable MIMO streams
- Maximum transmission range:
    - Indoor: 70m
    - Outdoor: 250m

The standard supports frame aggregation and has some improved security features. The data rates are increased by using multiple antennas in this scheme. There are independent data streams which are spatially multiplexed using multiple antennas at both the transmission and receiver side. Each antenna needs a dedicated receiver chain, which increases the hardware overhead in implementing this scheme.

The standard is backwards compatible with IEEE 802.11a/b/g.

Apart from the above explained differences, all four standards have different parameter settings which are summarized in the table below:

Standard	Frequency Band (GHz)	Data rates (Mbps)	Tx Range (m)	Physical Layer	CWmin	SIFS (µsecs)	Slot Time (µsecs)
802.11a	5	6, 9, 12, 18, 24, 36, 48, 54	100	OFDM	15	10	9
802.11b	2.4	1, 2, 5.5, 11	140	DSSS	31	16	20
802.11g	2.4	6, 9, 12, 18, 24, 36, 48, 54	140	OFDM	15;31	10 or 16	20
802.11n	2.4, 5	150	250	MIMO-OFDM	--	--	--

HIDDEN TERMINAL PROBLEM

Consider the network in Fig. 1. Nodes A and C are within transmission range of B. However, A and C cannot communicate with each other. These are said to be hidden from each other. The problem arises when both nodes A and C sense the channel, and find it to be idle. Since they cannot “see” each other, they both can start communicating at the same time, and suffer collision at B.

One solution to this problem is the implementation of the handshake mechanism along with CSMA/CA.

In this mechanism, both A and C send a RTS (Request to Send) packet to B when they want to start communicating. In case of collision, they both back off and try again after some randomly chosen back-off time. Once B hears an RTS, it can send back a CTS (Clear to Send). This CTS is heard by C too, and it defers access to the channel. This mechanism helps alleviate the hidden terminal problem somewhat. This is not a complete solution since the RTS and CTS packets can still collide, but this is not as critical since these packets are significantly smaller than data packets.

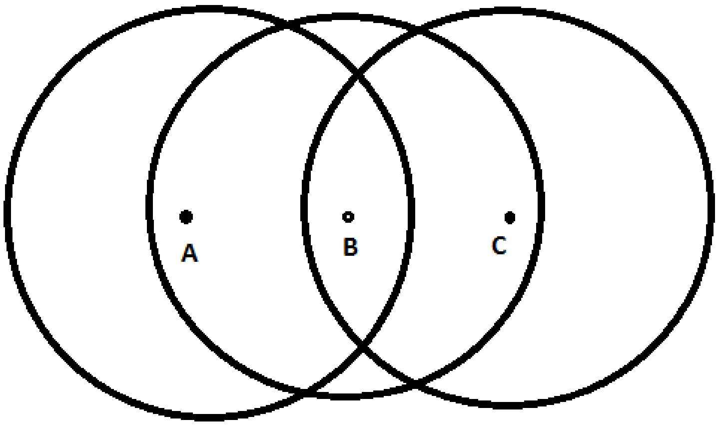

Figure 1

In this project, we compare the throughput of different standards both with and without the hidden terminal problem.

SIMULATION RESULTS

A Wi-Fi network with a single access point and a number of clients was simulated in NS3. Graphs for throughput of the IEEE 802.11 standards described above were plotted.

Here in this case we are considering N = 12 nodes and 1 AP node.

We are assuming the AP node to be at the origin (0, 0) and we create nodes around that. The structure is shown as follows:

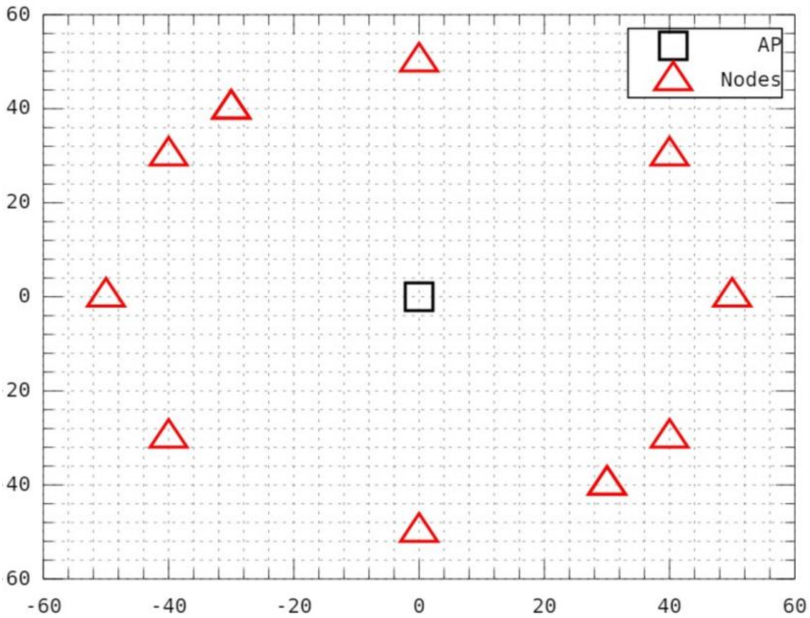

Figure 2

Node data (X, Y) coordinates:

Node	X Coordinate	Y Coordinate
AP	0	0
1	50	0
2	-50	0
3	0	50
4	0	-50
5	40	30
6	-40	-30
7	30	40
8	-30	-40
9	-30	40
10	30	-40
11	-40	30
12	40	-30

Number of Clients

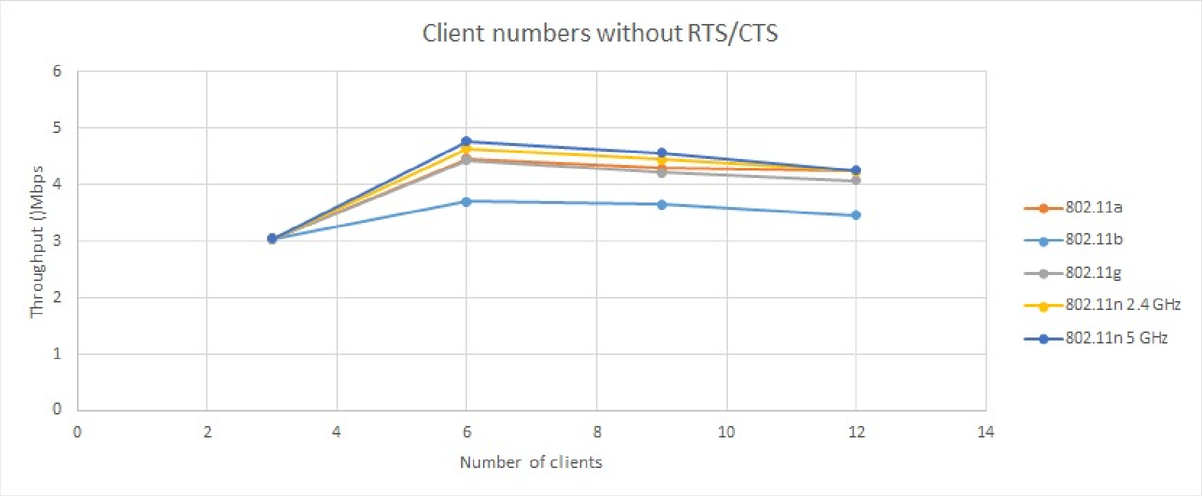

Figure 3

Fig. 3 repeats the above analysis when some nodes are hidden in the network.

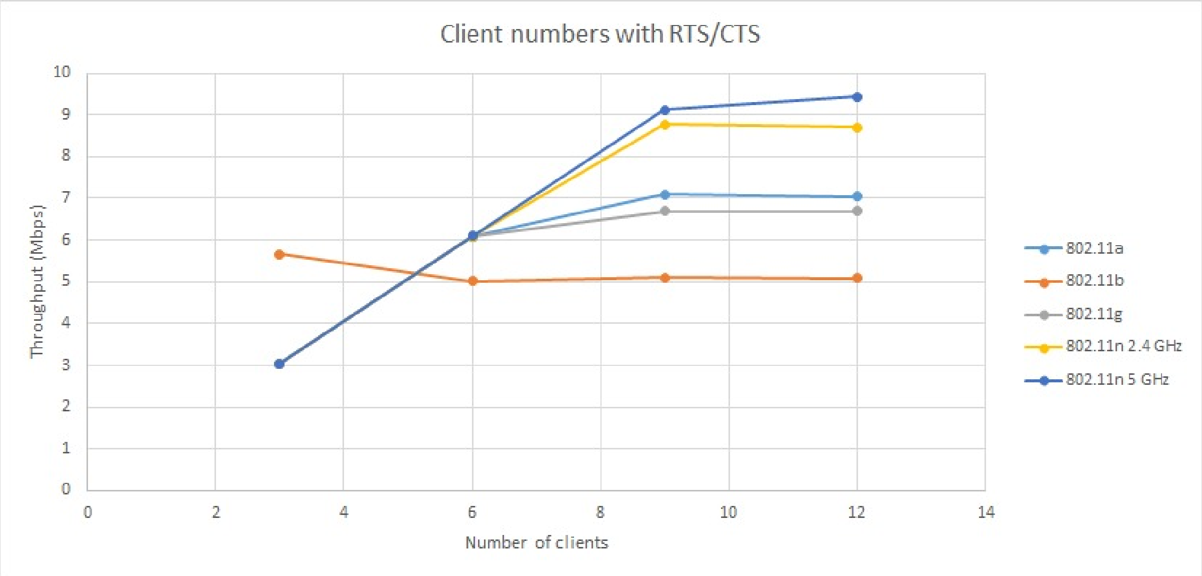

Figure 4

Fig. 4 below shows the effect of the number of clients on throughput for different IEEE 802 standards. Here, there is no hidden terminal problem.

It can be seen that the throughput increases with number of clients until a threshold is reached and the network saturates. This causes a reduction in the throughput. Also, it can be seen that 802.11n operating at 5 GHz has the highest throughput for the same number of clients. Thus, the results verify our theoretical analysis described in the previous sections.

The above graphs show the average network throughput performance of different standards as we increase the number of client nodes.

1. All the standards perform better with RTS/CTS as the number of clients increases. This is because RTS/CTs hand shaking ensures that there is less collision and more successful data transfer.
2. The throughput keeps on increasing as the number of clients increases, then reaches a saturation point beyond which the network can't perform in an ideal way. The capacity of channel is fixed to be 6Mbps. Therefore, when there are 6 nodes having a client data rate fixed at 1Mbps (saturation point), the nodes together hit the limit of the channel; performing the best at that point. Further increase in the number of clients can't be supported by the channel which results in a lower throughput.
3. 802.11n which uses 5GHz gives the best throughput at higher number of nodes even though the throughput of all standards are almost same when the number of clients are less i.e, the system has not reached saturation yet.
4. The lowest performing standard is observed to be 802.11b with a throughput which is very less than the other standards even when the RTS/CTS is enabled at higher nodes.
5. 802.11a performs a little better as compared to 802.11g. This may not always be true, as 802.11g has better range as compared to 802.11a in real time conditions. This is not exploited in this project. 802.11a can perform better under higher interference conditions as 802.11g is

susceptible to higher interferences from devices operating around the same frequency band (ISM band). The cumulative network throughput is observed to be the highest when the number of clients is 6.

Variation with CBR Rates

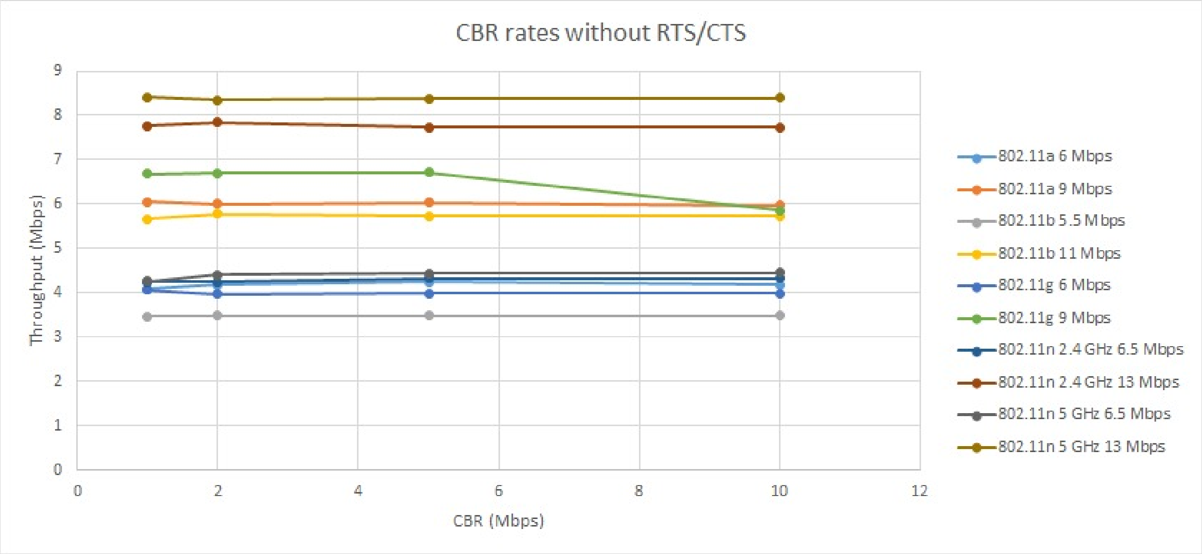

Figure 5

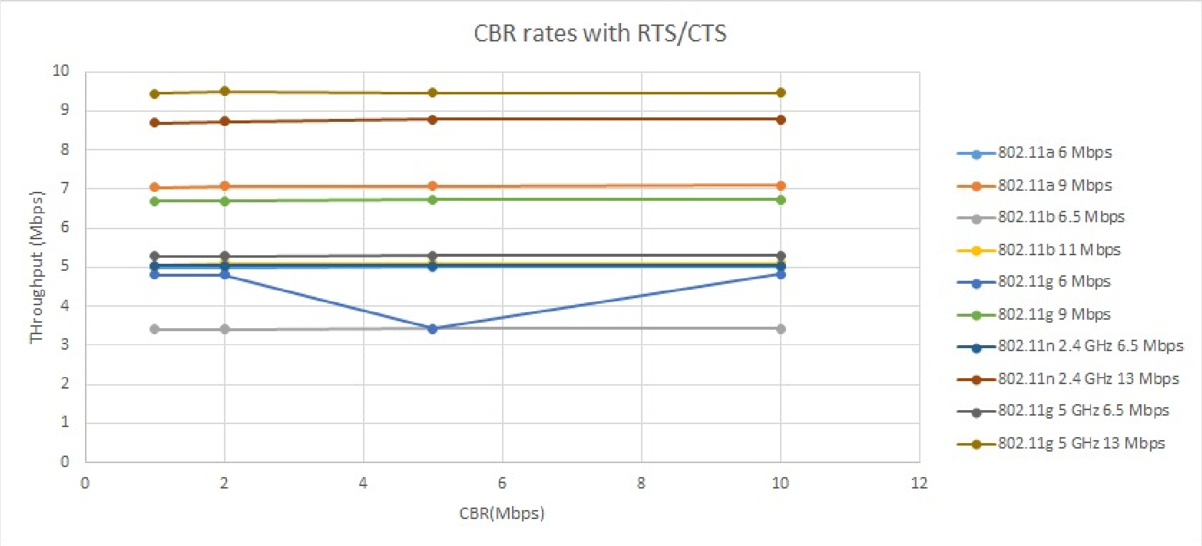

Figure 6

The graph shows the performance of the system with different Wi-Fi standards when the client CBR traffic rate is increased. Number of sender nodes is fixed as 6.

1. Better throughput when RTS/CTS is enabled.
2. The standard 802.11n provides the highest throughput of 5.08368 and the standard 802.11b provides the lowest throughput of 3.46842. That

is, there is a 1/3rd (approximately 33 percent) reduction in peak throughput when the network hits saturation.

3. As the data rate for the standard is fixed at 6Mbps, at the client data rate of 1Mbps, all the 6 source nodes adds up to give a total of 6Mbps data transmission, which is the maximum. This marks the saturation.
4. Maximum throughput is obtained at client CBR rate 1Mbps.
5. Further increase in client CBR rate reduces the network throughput due to congestion, collision and increased packet loss.

Number of Active Nodes

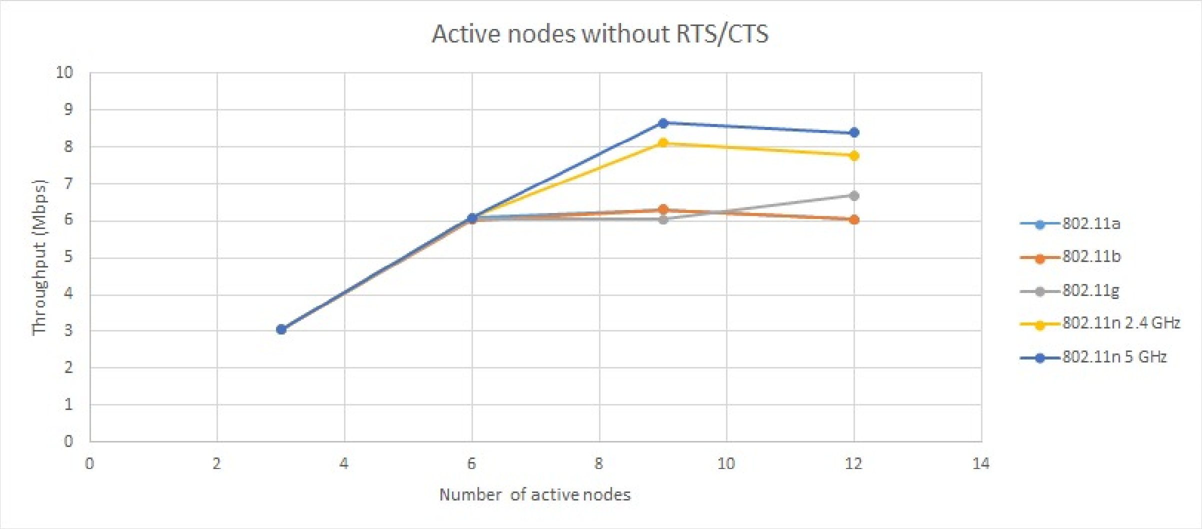

Figure 7

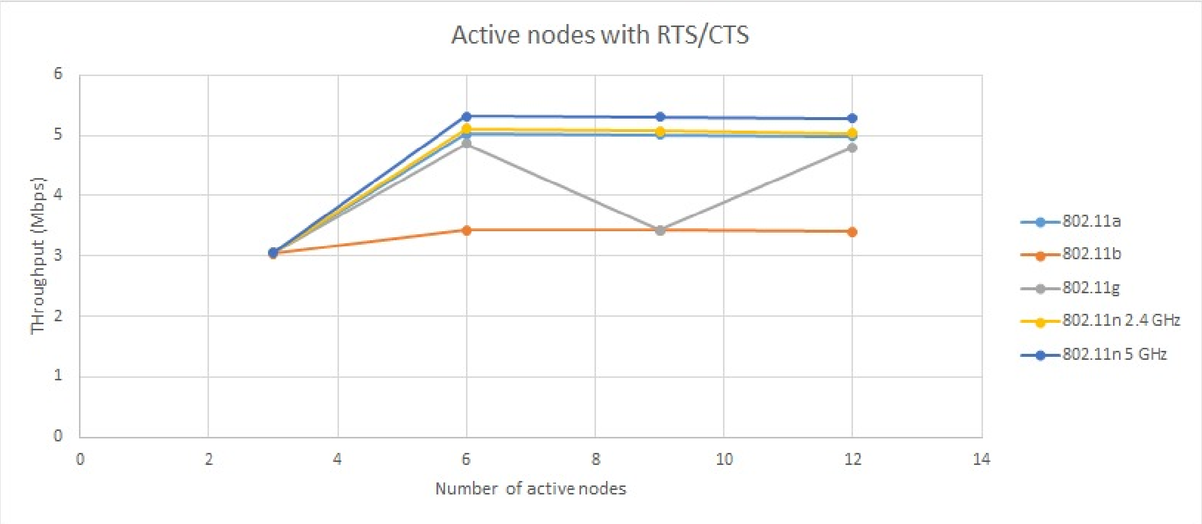

Figure 8

1. Network performs well with RTS/CTS signalling
2. Highest throughput observed when standard 802.11n is used and least when 802.11b is used which is true in a real environment too.
3. The network reaches saturation at 6 active flows as each client having 1Mbps data rate adds up to 6Mpbs which is the maximum network data rate set.

4. Again, it is observed that 802.11a performs a little better than 802.11g which can vary in real scenario.

CALCULATION

Hidden Terminal

We used the log distance path loss model to determine the number of hidden terminals.

It follows the following formulae:

$L = L0 + 10\ n \log (d/d0)$

L= path loss (dB)

L0= path loss at reference distance

n= path loss distance exponent

d0=reference distance

d= distance

We simulated a network with a single access point and a single node at 50 m. We changed the path loss exponent until the throughput became 0. The n value was found out to be 3.57 Using the value n=3.57, L0=46.67, d=50m, d0=1m, path loss was found to be L=46.67+35.7 log(50)= 107.323 With that path loss at which the throughput becomes 0, we calculated the distance at which the loss will be the same with n=3 107.32=46.67+30log(d) d= 107m This couldn't be applied in our network since the maximum possible separation between two nodes placed at the two extreme points is 100m. So we increased the n value to 3.2 and found that the distance at which the throughput becomes 0 is 78.5m. This was a good scenario as increasing the path loss exponent value to 3.5 would mean less range and lesser throughput. Using 3.2, we could still show a good number of hidden terminals while faithfully producing some good throughput.

Node Placement

Node	X coordinate	Y coordinate
1	50	0
2	-50	0
3	0	50
4	0	-50
5	40	30
6	-40	-30
7	30	40
8	-30	-40
9	-30	40
10	30	-40
11	-40	30
12	40	-30

Hidden terminal nodes of each node can be found by evaluating the distance between each node.

The range of each node is 78.5 m. Therefore, any node placed farther than the range will act as the hidden terminal to a given node.

For example, for node 1, hidden terminal nodes are:

Node 2: 100m away

Node8, Node 9: 89.4m away

Node 6, Node 11: 94.8m away

These nodes are not in range, that is, they can't hear each other. Hence, they act as hidden terminals to node1 in all the scenarios where these nodes come into play.

Throughput:

- With hidden terminal:
  - RTS/CTS Disabled: 4.45536
  - RTS/CTS Enabled: 4.86091
- Without hidden terminal:
  - RTS/CTS Disabled: 4.44394
  - RTS/CTS Enabled: 4.87234

We used 802.11g to evaluate the effect of hidden terminals on network throughput.

We placed one hidden terminal in the first case to evaluate the throughput and found that the one hidden terminal alone is contributing to a reduction of total network throughput. A clear conclusion can't be drawn from this scenario as many network conditions are affecting the throughput.

But, the RTS/CTS hand shake is pulling up the throughput of the entire network in the presence of hidden terminal to be almost same as that in the absence of hidden terminal (0.01 difference).

As the n umber of hidden terminals increase, the network performance degrades without RTS/CTS.

Finally, we repeated each observation 5 times to obtain a 98 to 100 percent confidence interval.

CONCLUSION

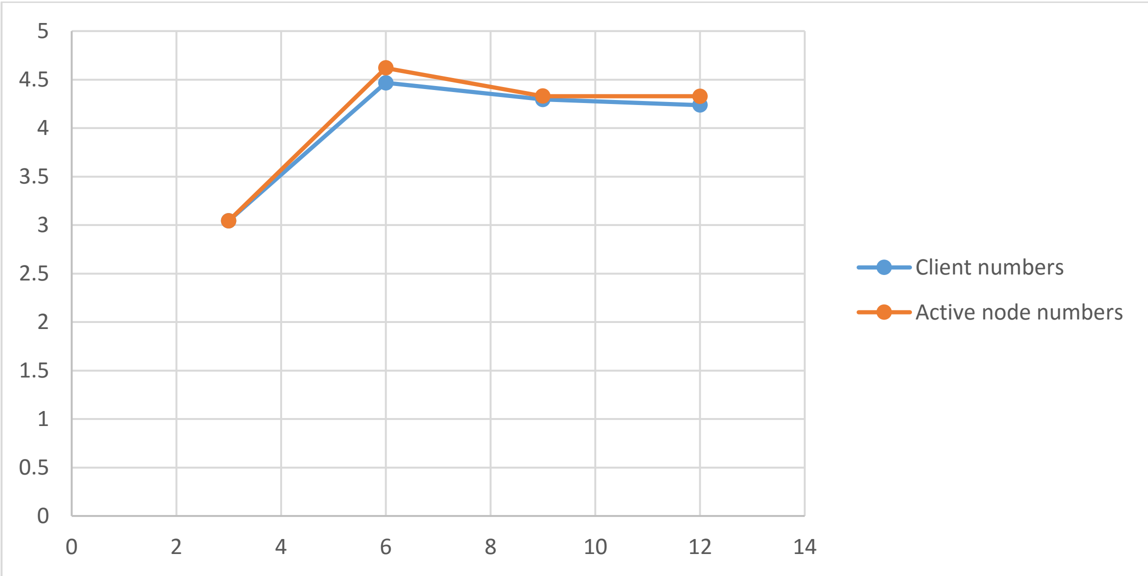

Figure 9

- As it is observed, in 802.11a standard, the network throughput considering the client nodes and the number of active flows is almost the same.
- Let us consider the point at which the node is 9. The value of throughput when considering the active nodes as 9 (stationary nodes is 12) is 4.29542 and the throughput when the total client nodes is 9 is 4.31827.The reduction in throughput is about 0.02Mbps which is only a 2 percent reduction. It can be counted as almost negligible in our scenario. This reduction may be caused due to the control packets

transmitted by other stationary inactive flows which may cause collision and packet loss.

- The same negligible difference in throughput can be observed in 802.11g and 802.11n standards.

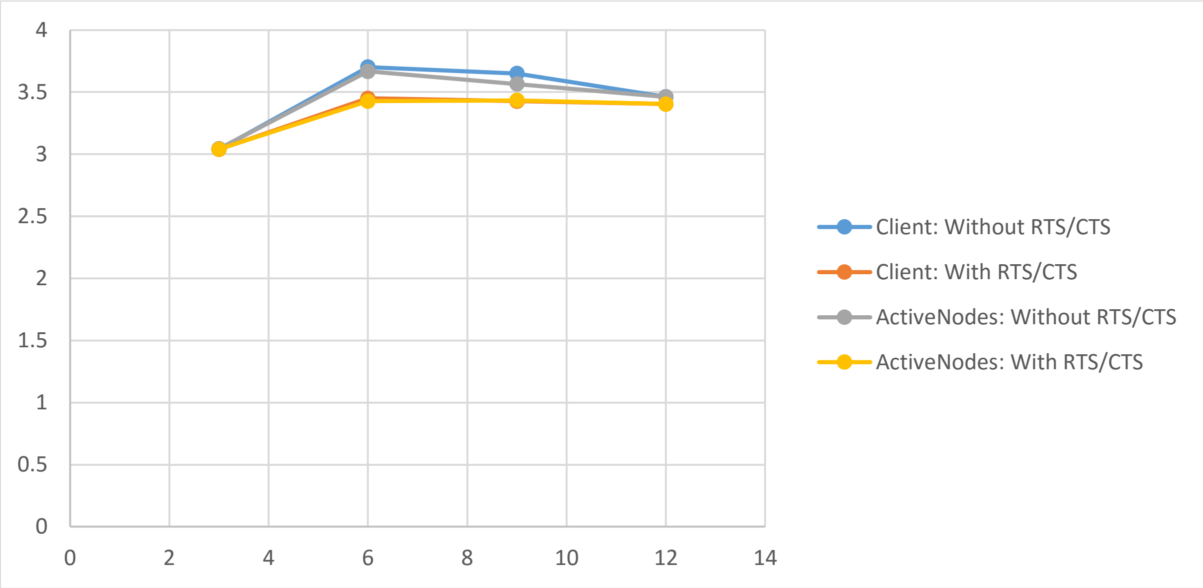

Figure 10

- The effect of control packets and the stationary inactive nodes are more pronounced in 802.11b standard.
- As the graph shows, the difference in throughput when the client node is just 6 and the active flow is 6 when the stationary node is 12 is not negligible.
- This means, the DSSS scheme again becomes a drawback when the number of stationary nodes increases and the active flows are varied.

In this project, we compared the different Wi-Fi standards and observed the network throughput with respect to varying conditions in the network. Future work could include understanding the effects of hidden terminal in detail, comparison of these standards at real time scenario within a heterogeneous network and exploiting the best capabilities of each standard. For example, 802.11b displays a poor network throughput but since it uses DSSS, could have been more secure. 802.11g has high penetration power and is not easily absorbed by the walls as compared to 802.11a. Therefore, the performance of the standards at different conditions can vary depending upon its capabilities. Currently, 802.11ac is the emerging standard with much superior capabilities like higher MIMO capability, speed and range. It is backward compatible with all the previous standards too.