EE5132/EE5023 - Wireless Networks

Assignment 1

Effects of Protocol and Power on Wireless Networks

Group 03

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Introduction

This study focuses on Inter-networks (802.11ac) to investigate the impact that network factors such as transmission power, distance between access point and wireless node, protocols, collision avoidance mechanisms, node density have on network performance in terms of throughput, delay and loss. Simulation is using NetSim software to obtain and analyze network performance data. The aim is to use the findings to identify some ideal and efficient configurations for wireless networks.

The study compares the network performance in terms of Throughput, Loss and Delay for the following five factors, which will be presented in the respective parts, as listed:

Part 1: Impact of TCP vs UDP

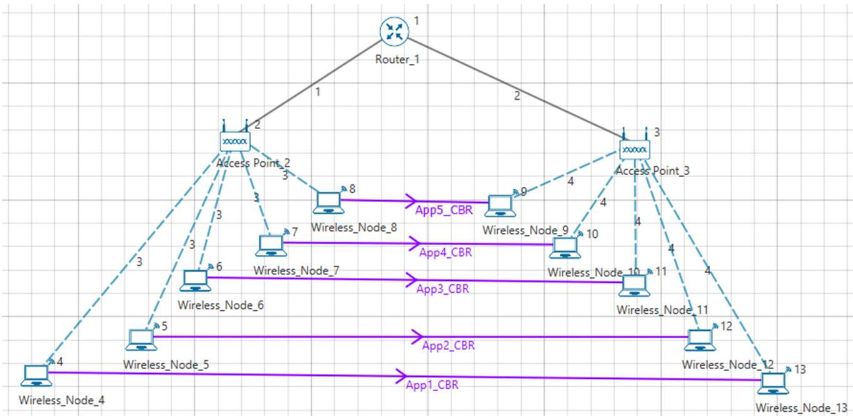
Part 2: Impact of Transmission Power and Distance between Access Point and Wireless Node

Part 3: Impact of RTS-CTS

Part 4: Impact of Access Point

Scenario

We are studying a typical network topology (as shown in Figure 1 below) that applies in environments with fixed Access Points and numerous wireless nodes that are running applications, such as offices, schools, libraries and commercial buildings. To emulate this in our simulations, we run concurrent applications (up to 5) amongst 10 wireless nodes connected to 2 access points equally.



PART I: Study delay / loss / throughput between TCP/UDP protocols by changing packet size

The maximum transmit unit MTU is 1500 bytes, if more than MTU the packet loss rate will increase. For this topic, the packet size was varied between a large range, starting from a small packet size of 750bytes and going up to 1M bytes (the maximum limit in NetSim). 4 different packet sizes were chosen within this range: 750 bytes, 1460 bytes, 150k bytes, 1M bytes. Run simulation for TCP and UDP 5 times of each condition. Do the comparison.

A. <u>Single application:</u> Connection Application TCP protocol or UDP protocol for node 1 and node 6.

<u>Multiple application</u>: 5 applications with all TCP protocol or all UDP protocol for nodes.

<table>
<tr><th>Single Application</th><th>Multiple Applications</th></tr>
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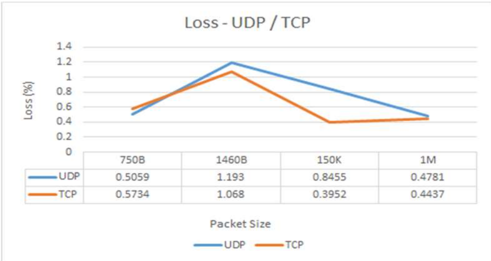

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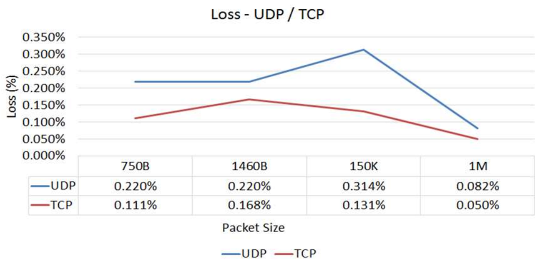

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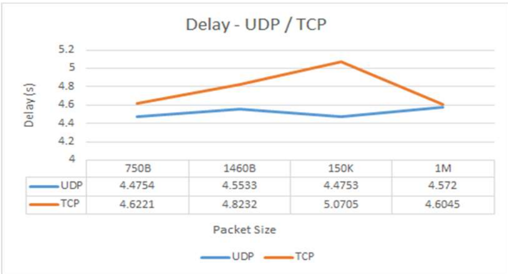

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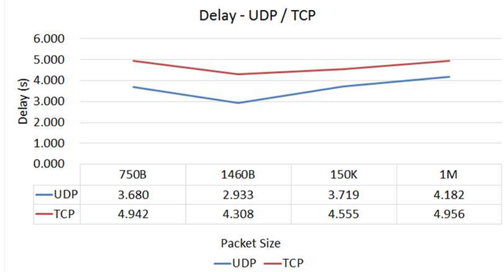

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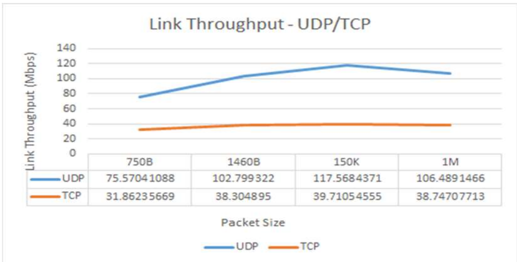

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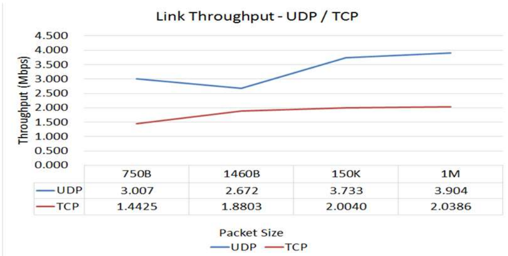

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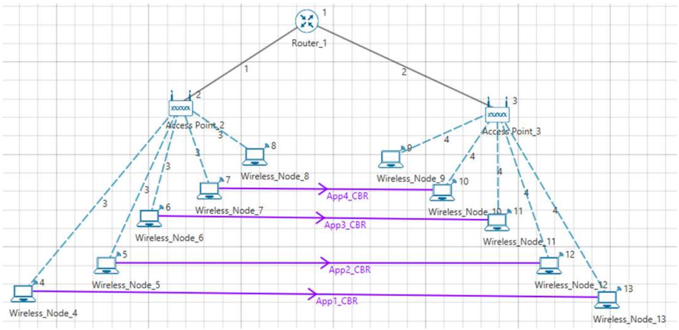
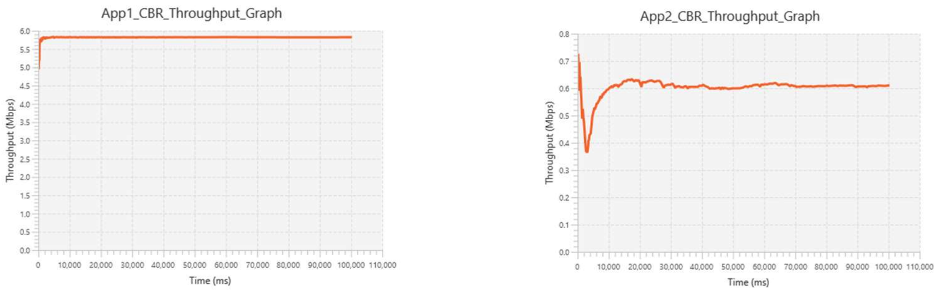
According to the data collected, we could draw the following conclusions:

- Packet Loss: UDP has higher package loss than TCP
- Delay: lower value means better performance of the protocol. So, UDP is faster than TCP
- Throughput: means the number of successfully received packets in unit time. UDP has higher throughput than TCP from the simulation result.

B. Multiple applications: Connection Application 2&3 with TCP protocol and Applications 1&4 with UDP protocol for nodes.





UDP graph (left) vs. TCP graph (right)

Throughput results shown below, calculate with variance number to get precise results:

		750 bytes		1460 bytes		**150k bytes**		1M bytes	
Application Id	Throughput plot	**Packet generated**	**Packet received**	Packet generated	Packet received	**Packet generated**	**Packet received**	Packet generated	Packet received
1	UDP	**10000**	**37638.16**	50000	18457.805	**12875**	**58575.161**	85625	12994.997
2	TCP	**10000**	**2206.114**	50000	3345.354	**10300**	**5266.509**	68500	813.043
3	TCP	**10000**	**2039.821**	50000	3007.447	**10300**	**5530.260**	68500	875.109
4	UDP	**10000**	**4587.098**	50000	2727.293	**12875**	**3307.217**	85625	3432.070

With same packet generated, it can clearly see that 2 TCP applications have similar packet received, but 2 UDP applications received packet quantity quite different. This reflects TCP working principle—equity. When congestion occurs, connected TCP have different response with connectionless UDP; TCP will send report to enter the congested network, reduce the amount of data sent into the network. Also, between TCP applications can fairly share the bandwidth, cache, etc.

CONCLUSION

TCP (Transmission control protocol) is a connection-oriented, reliable transport layer communication protocol. It is designed to provide reliable end-to-end byte streams over unreliable internetwork. it maintains the connection throughout the whole transfer processes. Once the connection is established, the protocol guarantees all the packets would be transmitted. If any packets are lost along the way, TCP would make sure the server resents the packet.

UDP (User datagram protocol) is a simple transport layer protocol for connectionless, unreliable datagrams. Compared with the three-way handshake in TCP, UDP does not establish any connection beforehand. Due to its unreliability, UDP do not take any extra actions of connection creation or acknowledge of packet loss, errors, and duplication problems, which cause UDP to have lower delay than

TCP. From the above simulation results, it clearly shows that UDP has a faster speed, but higher loss rate than TCP; these results follow theoretical information.

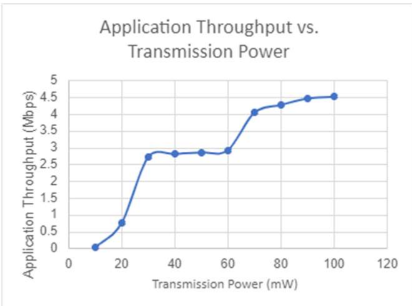
Throughput is the number of data successfully received within unit time, there are network layer throughput and application layer throughput, the Netsim software only can simulate network layer throughput. In network layer, when one file sending as many packets, how many packets sending success indicate its throughput; but in application layer, how many files sending success could count as throughput, so if one file not received all of packets, it is not counted. Thus, the simulation result shows UDP has higher throughput.

PART II – Impact of Transmission Power and Distance between Access Point and Wireless Node

In this part, we study the changes of throughput, loss and delay by varying transmission power and the distance between Access Point and Wireless Nodes. In terms of throughput, many factors contribute to the network throughput enhancement, such as transmission power, distance, interference and spatial reuse. These factors have an impact on throughput by affecting the received power.

A. <u>Throughput, Loss, Delay vs. Transmission power</u>

In this section, we study the changes of application throughput by varying transmission power. We observe both application throughput and data rate. Data rate is calculated by Bytes transmitted (bytes) timing 8 and dividing simulation time. Our simulation time is 100s. We changed transmission power from 10mW to 100mW and simulate every 10mW. For each selected power, we repeat 5 simulations for minimizing the randomness on results. Our result graphs of application throughput vs. transmission power and data rate vs. transmission power are listed as follows.



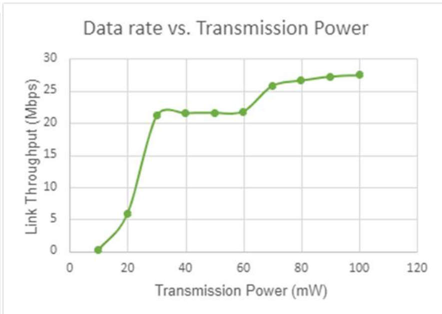


Figure 2-1 Application Throughput vs. Transmission Power   *Figure 2-2 Data rate vs. vs. Transmission Power*

From the above graphs, we can figure out that when we increase transmission power, both application throughput and data rate increase accordingly. When transmission power is less than 30mW, throughput increases sharply. This is because increasing transmitted power will lead to higher signal power obtained at the receiver, thus providing higher Signal and Interference to Noise Ratio (SNR), and consequently offering higher data rate, which intuitively enhances the network throughput. When transmission power is between 30mW to 60mW, throughput keeps stable. Then, as transmission power increases continuously, throughput increases slowly. This is mostly because high transmission power will increase the interference conducted by potential transmitters, which will result in low spatial reusing as the number of simultaneous transmission links is reduced. Therefore, we can have the conclusion that throughput has a positive correlation with transmission power.

Figure 2-3 Loss vs. Transmission Power

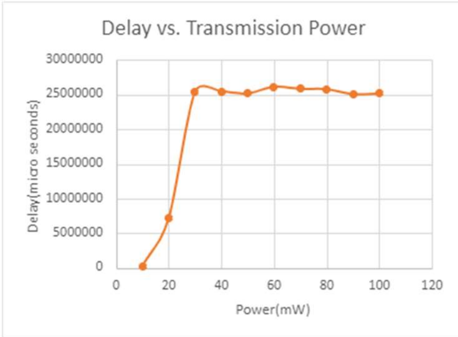


Figure 2-4 Delay vs. Transmission Power

We also study the changes of loss by varying transmission power. Loss is calculated by packet errored data divides packet transmitted data. From above graphs, we can see that delay and loss fluctuate slightly in a small range.

B. <u>Throughput, Loss, Delay vs. distance</u>

In this part, we set the transmission power as 100mW and study the changes of throughput by varying the distance between Access Point and Wireless Nodes from 10m to 130m and simulate every 10m. For each selected distance, we repeat 5 simulations for minimizing the randomness on results. Our results graph of throughput vs. distance is listed as follows.

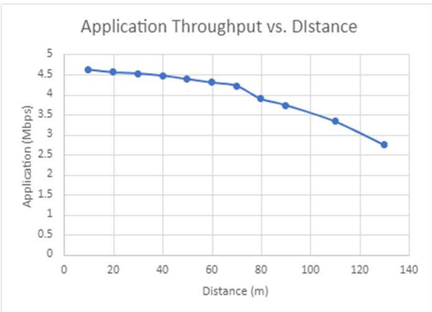


Figure 2-4 Application Throughput vs. Transmission Power

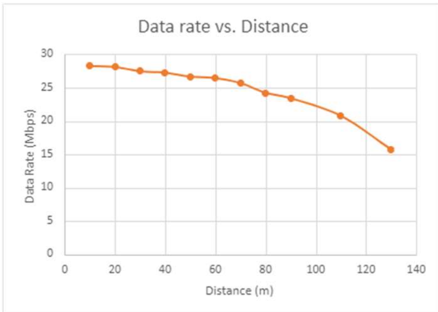


Figure 2-5 Data rate vs. vs. Transmission Power

From the above graphs, we can figure out that when the distance between Access Point and Wireless Nodes increases, both the data rate and application throughput decreases. We can conclude that the throughput has a negative correlation with distance.

We know that it is the RF loss which mainly determines the received power, as shadowing and fading are some random phenomena, we ignore them in our study. The received power is obtained by transmission power subtracting the path loss between the transmitter and the receiver. Path loss occurs when a signal propagates through space and spreads outward, and ultimately resulting in reduced power levels.

The formula of path loss is listed below, where c_0 is the path loss at the "reference" distance of 1m, η is the path-loss exponent and d is the distance between the transmitter and the receiver. From this formula, we can easily figure out that with the distance increasing, the path loss accordingly increases as well, thus resulting in a decrease in received power and lower throughput.

$$L = c_0 - 10\eta \log_{10} d$$

Figure 2-7 Loss vs. Distance

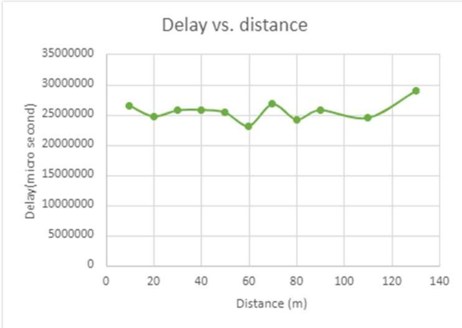


Figure 2-8 Delay vs. Distance

We also study the loss and delay by varying transmission power. Loss is calculated by packet errored data divides packet transmitted data. From the above graphs, we can see that delays fluctuate slightly in a small range. Loss changes as the data rate changes. The application throughput is dependent on the data rate and loss.

PART III – Impact of RTS-CTS

In Part 3, we study the effects of RTS-CTS collision avoidance mechanism on the throughput, delay and loss in a wireless network environment with multiple applications running on the wireless nodes. RTS (Request to Send) and CTS (clear to send) mechanism is a data flow control mechanism that is part of the RS232 standard meant to avoid frame collision introduced by hidden node problems. It involves steps to alert the sender's readiness to send data (RTS) and receiver to grant permission via CTS before data transmission occurs without collision. We want to study how this collision avoidance scheme affects the overall performance of the network.

We kept all other parameters constant, e.g., topology, distance between nodes, transport protocol (TCP), transmission power (40MW), type of application (FTP), file size (10MB). We used a larger file size of 10MB and accordingly used the FTP protocol as we know that RTS-CTS adds too much overhead to small file size. We wanted to see the impact of RTS-CTS on applications transferring larger file sizes and see how the collision avoidance scheme improves performance.

We replicated simulations with and without RTS and introduced randomness by varying seed. The number of applications running concurrently in the network was varied to understand if applying RTS-CTS framework has any impact in managing the increasing demand in the network. We ran simulations 5 times for each setting (i.e., no. of concurrent applications ranging from 1 to 5) with and without RTS and measure the performances. Based on the simulations that we ran without RTS-CTS, we confirmed that there was presence of considerable packet collisions, which increase significantly once concurrent applications came into the picture.

Findings

With the application of RTS/CTS, the following impacts are observed:

Observation	Further Assessment
Throughput in the network reduces by about 20%.	Time taken for the RTS-CTS handshaking (I.e., RTS + SIFS + CTS + SIFS + propagation delays) reduces the available time for transmission. Furthermore, the RTS-CTS management frames are sent at a basic data rate which may slow down the overall traffic. Thus, the size of data that can be transmitted with RTS is lesser as compared to without RTS.
No impact on loss performance.	Though the losses seem higher without RTS-CTS in the graph below, the difference is insignificant. Losses below 1% are acceptable and differences within 1% error margin are not of concern.

100% increase in delay without RTS-CTS vs with RTS-CTS	RTS-CTS eliminates collisions and related time delays. The reduction in delay is significant.

Based on the findings above, we realized that RTS-CTS's collision avoidance significantly reduces delays while slightly compromising on the throughput. Thus RTS-CTS would be suitable for low-latency applications in congested networks where we want to avoid retransmissions and related delays. However, the throughput must be managed, considering the slightly reduced throughput with RTS-CTS. This would be the trade-off when the key priority is to reduce transmission delays by collision avoidance.

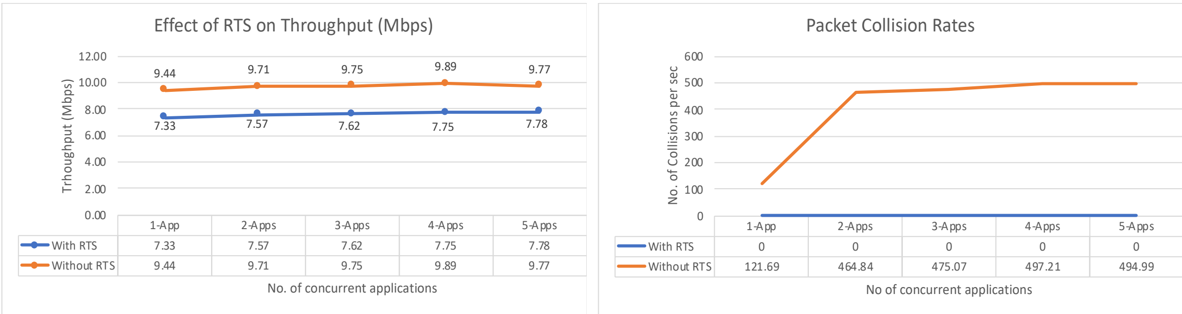


Figure 3-1 - Throughput Performance with and without RTS-CTS

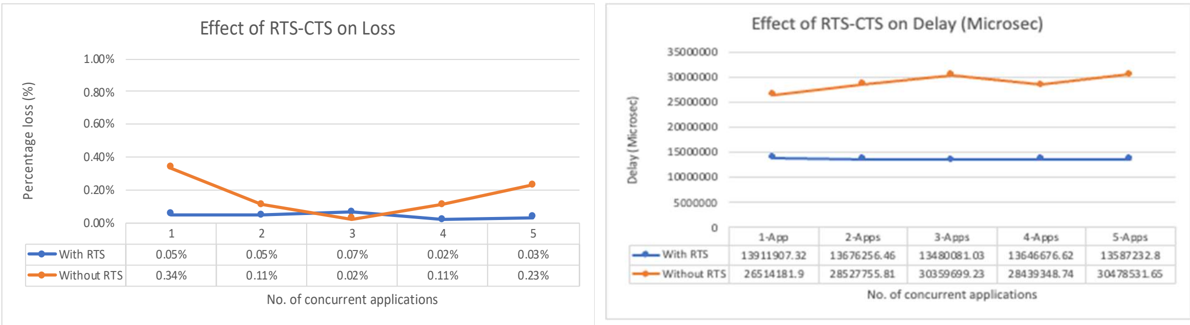
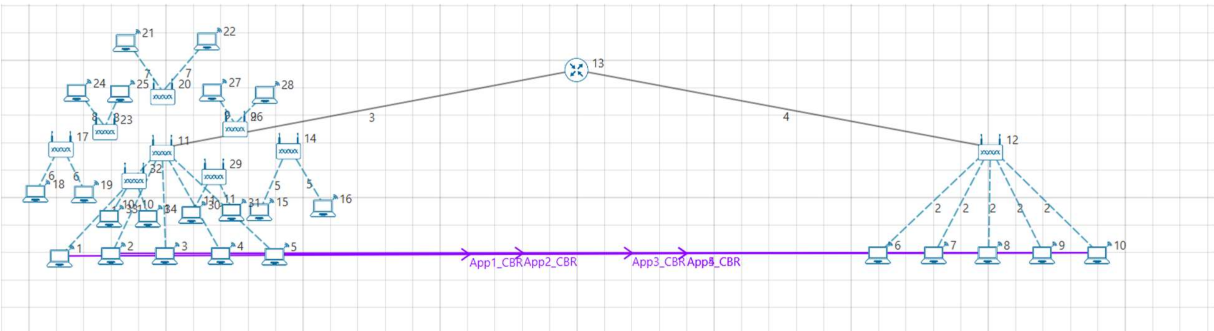


Figure 3-2 – Loss & Delay performance with and without RTS-CTS

PART IV: Impact of Access Point Density



Multiple hop wireless network is often used in extending the coverage of the network. But when the density of AP (access point) increases, the probably of interference also increases. It will affect throughout and packet delay. In this part, we will discuss the effect of AP density on end-to-end throughput, packets delay and loss. We create a scenario which contains 9 APs, 8 of which are so close that they can reach each other. And place another destination AP far away from these APs so that there will not be any interference between source AP and destination AP.

We fix all the irrelevant parameters (i.e., power, application type, etc.), and increase by adding the number of working APs between source AP. We define the AP density as the number of working APs within the coverage of source AP. AP density range from 1~9.

Findings

With the AP density increased, the following impacts are observed.

Observation	Further Assessment
Source-destination pairs throughput decrease as density increases.	All the AP working at 802.11ac, #36 channel, 20 MHz bandwidth. They will distribute the same channel resource causing a single AP throughput to be reduced.
Total throughout within the source AP coverage will increase and finally stabilize.	When the density increase, the utilization of the WiFi channel will increase and approach 100%. The upper limit data rate of this channel is 14.4 Mbps, shown in table 3-1
Source-destination pairs packet delay decrease and finally stabilize.	The distance between source AP and destination AP is $\ominus$ (1), the average packet delay can be expressed by: [2] $$\ominus\left(\frac{1}{1-\frac{1}{ne^{\frac{n}{c}}}}\right)$$
No impact on loss performance	Packet loss is very small (less than 0.1%). There is no obvious relationship between packet loss and AP density.

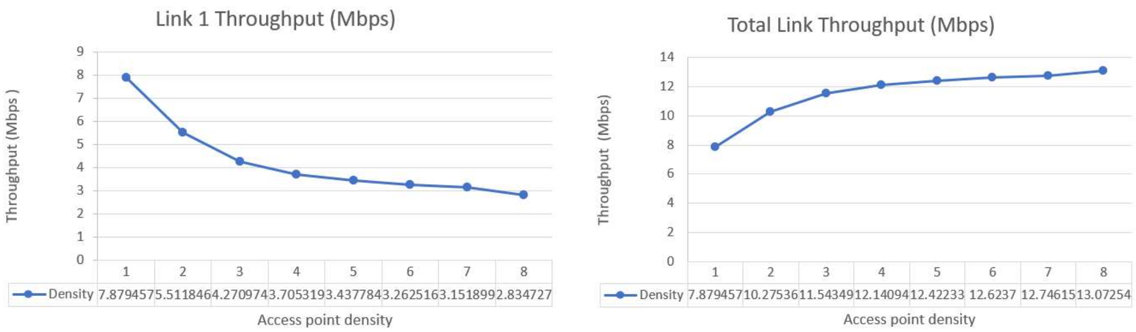


Figure 4-1 - AP density effect on Throughput Performance

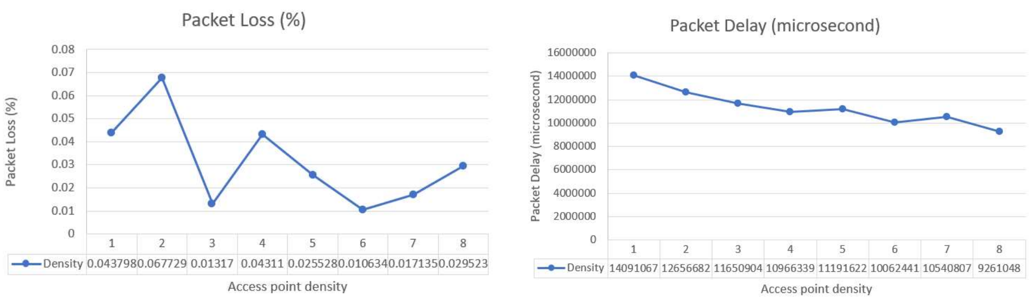


Figure 4-2 - AP density effect on packet loss and delay

Table 4-1 VHT-MCSs for mandatory 20MHz, N_{ss}=1 [1]

VHTMCS	Modulation	R	NBPSCS	NSD	NSP	NCBPS	NDBPS	NES	Data rate (Mbps)	
									800nsGI	400nsGI
0	BPSK	1/2	1	52	4	52	26	1	6.5	7.2
1	QPSK	1/2	2	52	4	104	52	1	13	14.4
2	QPSK	3/4	2	52	4	104	78	1	19.5	21.7
3	16-QAM	1/2	4	52	4	208	104	1	26	28.9
4	16-QAM	3/4	4	52	4	208	156	1	39	43.3
5	64-QAM	2/3	6	52	4	312	208	1	52	57.8
6	64-QAM	3/4	6	52	4	312	234	1	58.5	65
7	64-QAM	5/6	6	52	4	312	260	1	65	72.2
8	256-QAM	3/4	8	52	4	416	312	1	78	86.7

CONCLUSION

Based on our study, we better understood how the various factors can be considered for wireless network configurations. UDP is suitable for higher throughput and loss tolerant applications. TCP, with its connection-oriented approach, gives more reliable performance reducing losses but a diminished throughput and higher delay. The ideal transmission power is between 30-60MW, a sweet spot that provides optimal throughput considering loss and delay. RTS-CTS collision avoidance mechanism reduces transmission delay greatly favouring low-latency application but it comes with a cost - lowered throughput. We also found that increasing access point density does not adversely affect network performance, other than the fact that each node/application gets a smaller share of the bandwidth.

REFERENCE

1. "IEEE Standard for Information technology--Telecommunications and information exchange between systems—Local and metropolitan area networks--Specific requirements--Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications--Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz.," in IEEE Std 802.11ac(TM)-2013 (Amendment to IEEE Std 802.11-2012, as amended by IEEE Std 802.11ae-2012, IEEE Std 802.11aa-2012, and IEEE Std 802.11ad-2012) , vol., no., pp.1-425, 18 Dec. 2013.
2. J. Kuo, W. Liao and T. Hou, "Impact of node density on throughput and delay scaling in multi-hop wireless networks," in IEEE Transactions on Wireless Communications, vol. 8, no. 10, pp. 5103-5111, October 2009.

EE5132/EE5023 Assignment 1

Statement of Contributions

A. Joint Work, e.g., in planning and conceptualization etc. (briefly list a few specific aspects):
1. Design the simulation scenario
2. Planning and conceptualisation of the study scope
3. Write the report and make the slides

B. Li Yuxuan's Work (briefly list a few specific aspects):
1. Work on PartⅡ with Tang Chenguang: Impact of Transmission Power and Distance between Access Point and Wireless Node
2. Simulation for power from 10mW to 50mW, distance from 10m to 70m
3. Complete the data analysis and graphing of results, making slides and writing report of the effect of varying distance

C. Chen Weizhao's Work (briefly list a few specific aspects):
1. Work on Part I with Wang Rong: Impact of TCP vs UDP
2. Simulation for Single application, study the difference between TCP and UDP with 4 packet sizes, and analysis the results, make slides and report for Part I.

D. Tang Chenguang's Work (briefly list a few specific aspects):
1. Work on PartⅡ with Li Yuxuan: Impact of Transmission Power and Distance between Access Point and Wireless Node
2. Simulation for power from 60mW to 100mW, distance from 80m to 130m
3. Complete the data analysis and graphing of results, making slides and writing report of the effect of varying transmission power

E. Faisal Ahmad's Work (briefly list a few specific aspects):
1. Work on Part III: Impact of RTS-CTS
2. Complete the simulations for multiple applications and data analysis/graphing of result, make slides and write report for Part III.

F. Wang Rong's Work (briefly list a few specific aspects):
1. Work on Part I with Chen Weizhao: Impact of TCP vs UDP
2. Simulation for Multiple applications, study the difference between TCP and UDP with 4 packet sizes, and analysis the results, make slides and report for Part I.

G. Liu Weihao's Work (briefly list a few specific aspects):
1. Work on Part IV: Impact of Access Point, and design the topology.
2. Complete the simulation and data analysis/graphing of result, make slides and report for Part IV.

We agree that the statements above are truthful and accurate.
Signatures and Names:

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