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NATIONAL UNIVERSITY OF SINGAPORE
COLLEGE OF DESIGN AND ENGINEERING

CEG5103: Wireless and Sensor Networks for IoT

CA1 report

The Exploration of IEEE802.11ac under Different Scenarios

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Contents

1 Introduction & Background

In June 1997, the IEEE finally adopted the 802.11 protocol standards, which became the standard for wireless LANs. The 802.11 protocol standard, which became the standard for wireless LANs, focuses on the physical and media access control layers of the network. It is mainly concerned with the physical and media access control layers of the network, with a focus on the MAC layer. These standards enable wireless devices from different manufacturers to It is through these standards that wireless devices from different manufacturers can work together reliably. The 802.11 protocol works primarily on the lowest two layers of the ISO protocol, the physical layer and the data link layer (DLL). The 802.11 protocol works primarily on the lowest two layers of the ISO protocol, the physical layer and the data link layer (see diagram below), with some changes to the physical layer to The physical layer has been modified to include high-speed digital transmission and connection stability, so that any LAN application or network operating system can be used on the network. Any LAN application or network operating system can run on IEEE802.11 protocol as if it were any LAN application or network operating system can run on the 802.11 protocol as if it were running on IEEE802.3 Ethernet[1]

Since the early introduction of the IEEE 802.11 standard in 1997, the IEEE802.11 standards have evolved over the past 10 years through representative versions such as IEEE802.11a/b/g/n/ac, etc. Network throughput rates have evolved from the earliest 1Mbps and 2Mbps to the gigabit level of wireless 802.11ac has also shown its unique advantages in industrial use and development.

- Higher transmission speeds
- Wider channel technology
- More perfect backward compatibility

This report is organized as follows. We have done the literature review about some state-of-the-art WiFi protocols, and also conduct some discussion on the scenario in Section II, according to those setting scenarios, we set up the simulation case for our experiments in Section III, as we got the result, we continue to the analysis part and give the conclusion in Section IV.

2 Literature review & Scenario discussion

The IEEE802.11 protocol works on the lowest two layers of the ISO protocol, the physical layer and the data link layer (see below), with some changes to the physical layer to include high-speed digital transmission and connection stability, so that any LAN application or network operating system can run on the IEEE802.11 protocol as if it were running on IEEE802.3 Ethernet.

IEEE802.11 defines two modes, infrastructure mode, and ad hoc mode. In infrastructure mode, the wireless network has at least one wireless access point connected to the wired network and a series of wireless access points (the wireless access point, and a series of wireless end stations). This configuration becomes a basic service set, an extended service set is a single subnet consisting of two or more basic services A single subnet is formed by two or more basic service sets. Since many wireless users need to access devices or services on the wired network devices or services on the wired network, this Infrastructure model is used.

For this survey, we focus more on the 802.11ac protocol(also called WiFi5). As a new standard for IEEE wireless technology, 802.11ac draws on the various benefits of 802.11n and optimises them further. In addition to the most obvious high-throughput features, it is not only well compatible with 802.11a/n devices but also enhances a number of user experiences.

In an 802.11ac network, each wireless access point can accommodate more clients and provide more bandwidth for each parallel service stream, while offering the benefits of lower latency and reduced power consumption.

2.1 Improvement of IEEE802.11ac

As 802.11n is already excellent at the MAC layer, 802.11ac does not have many improvements at the MAC layer, mainly through the PHY layer to increase its base rate.

- Improvement on Physical layer
  1. Denser modulation patterns
  2. Wider channel bandwidth
  3. More spatial streams
  4. Beamforming
  5. MU-MIMO
- MAC layer
  1. A-MPDU
  2. RTS/CTS

2.2 Fundamental principle in experiments

This simulation tries to find out how the distance between nodes will influence the network in different aspects like throughput, delay, and packet error rate. As is well-known, the signal-to-noise ratio (SNR) is related to the received power, noise power spectral density, and system bandwidth.

$$SNR = \frac{P_received}{N_0 W}$$

In this formula, N_0 and W are fixed so the SNR depends on received power most. $P_received$ is usually given by this formula:

$$P_received = P_transmit - C_0 - 10\eta \log_{10} d$$

where η is the path-loss exponent and d is the distance between the transmitter and the receiver.

2.3 Scenario discussion

- Scenario1: It is assumed that there is a party or career fair held in the EA hall. Various wireless nodes subsequently access the rooter with various applications. Thus the performance in throughput and available connection number of the wireless network is important, which is progressed in every Wi-Fi generation. In this scenario, IEEE 802.11g/n/ac protocols are applied and their performance is evaluated.

- Scenario2: Civil network crowd structure application, given that in daily life, there is a need that uses the same network at a peak time, thus it will meet the question that what is the density(number) if we have a rigid requirement of quality about the network. It is something similar to scenario2, also given that in a rigid requirement, investigating how long can the network support, in other say, what is the scale of the network with a stable number of nodes and requirement.

- Scenario3: In some cases, the real street environment will also impact the quality of the wireless network. So the experiment also mimics the different landforms in busy streets and bay. This is also a try for the NetSim function, using the Grid environment (background) and Map environment to investigate the same network's different performance. The OpenStreetMaps of the Faculty of Engineering at NUS and Marina Bay Cruise Centre are applied.

3 Experiment & Verification

3.1 Exploration about different IEEE802.11 protocols

Until 2023, IEEE has proposed 6 generations of WiFi protocols and the 7th generation is in progress. In the process of evolution, the maximum throughput, minimum delay and maximum access device are the most significant targets that have been improved. According to the NetSim limitation, we just evaluate the maximum throughput and maximum access device in IEEE 802.11g/n/ac. A brief comparison of these protocols is shown in Figure1 [2][3].

Feature/IEEE standard	802.11g	802.11n	802.11ac
Maximum data rate per stream (Mb/s)	54	>100	>500 (Assuming 80MHz channels)
Frequency band	2.4GHz	2.4GHz/5GHz	5GHz
Channel width (MHz)	20	20/40	20/40/80/160/80+80 (last two are optional)
Antenna technology	Single-input single-output (SISO)	Multiple-input multiple-output (MIMO)	Multi-user MIMO
Transmission technique	DSSS and OFDM	OFDM	OFDM
Maximum number of spatial streams	1	4	8
Beamforming-capable	No	Yes	Yes
Approximate coverage range (indoor/outdoor)	38m/140m	70m/250m	35m/NA
Date ratified by IEEE	2003	2009	2014

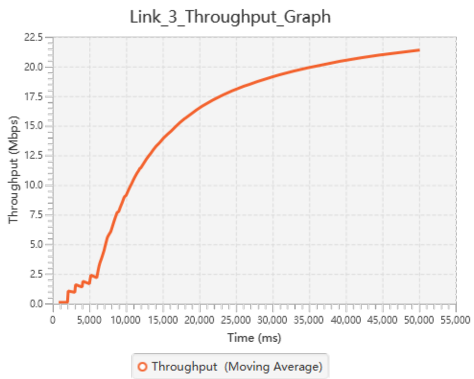
Figure 1: the comparison of IEEE 802.11g/n/ac

In the simulation, there is a total of 30 applications in 5 kinds applied in the network, which are push, HTTP, voice, video and email. To make the simulation closer to reality, they are launched one by one at 1-second intervals. Firstly, the throughput of different protocols is evaluated. The simulation parameters setting is shown in Figure2 and the result is shown in Figure3.

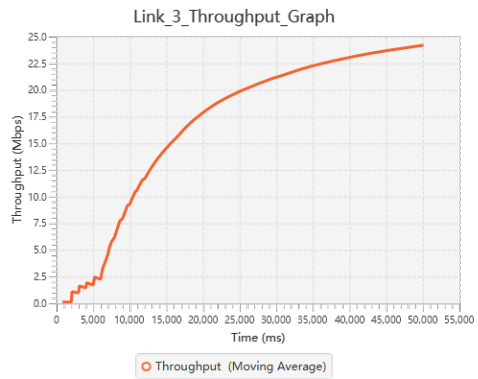
The total throughput of the wireless network is 21.5Mbps, 24Mbps and 30Mbps respectively. It is obvious that the network applied 802.11ac protocol has the largest throughput due to its widest 160Mhz bandwidth. On the other hand, the delay of 802.11ac is also the lowest. Take the application 6 video as an example, the delay in ac protocol is 243ms while it is 285ms and 333ms for n/g respectively. Besides, the average packets receiving rate of the three protocols are 69%, 63% and 59% respectively. It illustrates that the collision in ac is less than others and there are not such many packets that need to be retransmitted. There are 3 application links dead in g while 2 and 0 in n and ac, which shows the maximum capacity for access nodes in IEEE802.11ac wireless network is the largest.

Feature/ IEEE standard	Transmitting power(mW)	Frequency band	Channel width	Transmitting antenna	Receiving antenna	Wireless nodes distribution	Simulation duration
IEEE 802.11g	100	2.4GHz	20MHz	1	1	Within 50m	50s
IEEE 802.11n	100	5GHz	40MHz	1	1	Within 50m	50s
IEEE 802.11ac	100	5GHz	160MHz	1	1	Within 50m	50s

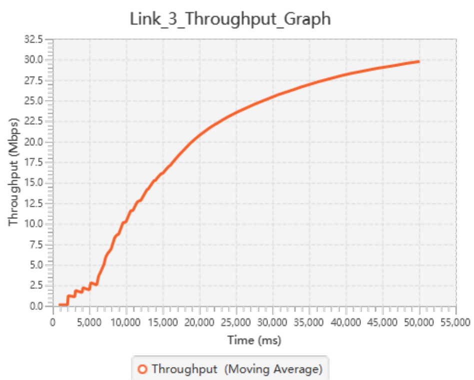
Figure 2: the parameters settings of simulation 1



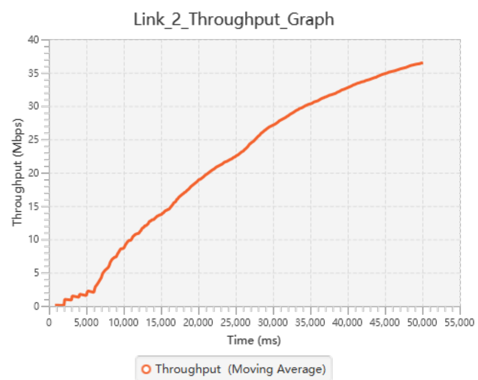
(a) Access input throughput



(b) IEEE 802.11g



(c) IEEE 802.11n

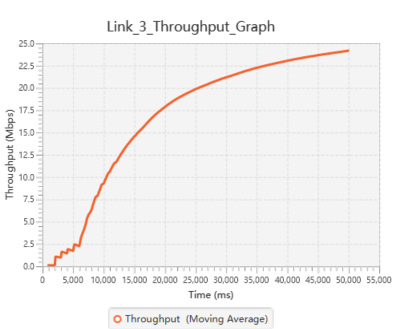


(d) IEEE 802.11ac

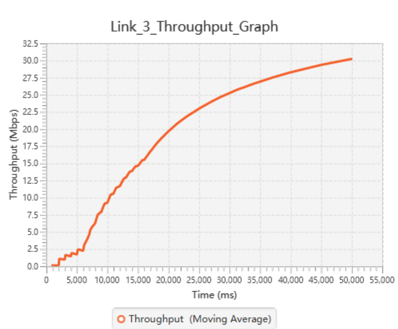
Figure 3: wireless throughput comparison

Feature/ IEEE standard	Transmitting power(mW)	Frequency band	Channel width	Antenna technology	Transmitting antenna	Receiving antenna	Wireless nodes distribution	Simulation duration
IEEE 802.11n	100	5GHz	40MHz	SISO	1	1	Within 50m	50s
IEEE 802.11n	100	5GHz	40MHz	MIMO	4	4	Within 50m	50s
IEEE 802.11ac	100	5GHz	40MHz	MU-MIMO	8	8	Within 50m	50s

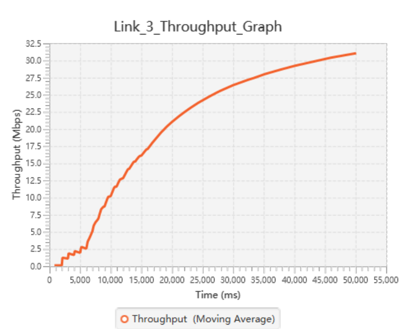
Figure 4: the parameters settings of simulation 2



(a) IEEE 802.11n SISO



(b) EEE 802.11n 4x4MIMO



(c) EEE 802.11ac 8x8MIMO

Figure 5: Antenna technology simulation result

Another advanced technology utilized in 802.11ac compared to n/g is Multi-user Multiple-input multiple-output

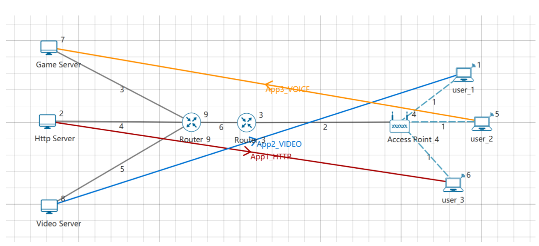
(MU-MIMO) while in 802.11n is MIMO. It allows 802.11ac to utilize a maximum of 8 transmitting antennas and 8 receiving antennas together to transmit in 8 spatial streams, which dramatically increases the throughput compared to Single-input single-output (SISO). To evaluate this feature, the simulation parameters are set as Figure4 and the result is shown in Figure5.

The throughput of antenna technology simulation is 24Mbps, 30Mbps, and 31Mbps for 802.11n SISO/4x4MIMO and 802.11ac 8x8 MIMO respectively. These simulations result shows that IEEE 802.11ac protocol is most suitable for our scenario. However, it does not mean it always performs best. If it is set to 2.4GHz frequency band and 20MHz bandwidth, the throughput of applying ac is much lower than applying g which is 21.5Mbps and 17Mbps respectively. Since the standard of ac is more complex, its efficiency of it is lower as well. In reality, the wireless router is always compatible with all low generation protocols it can choose a suitable and appropriate protocol according to the situation.

3.2 Effect of number of nodes on transmission performance

Actually, the result of the experiment is obvious the more nodes are connected to the network, the more congested the network is. The rule is considering a user watching a web page, a user watching a video, and a user playing a game as a group, and testing how many groups can be accommodated under such network settings, so that the network latency does not exceed 100ms, and the packet loss rate does not exceed 10%. 100ms latency and 10% packet loss is the limit for playing games.

As this scenario is trying to simulate an indoor situation, the configuration for the wireless channel is an indoor case. Using 802.11ac, which is WiFi 5, is closer to the current physical layer protocol settings of wireless networks in the home. Video applications can take up a lot of bandwidth. So, set the bandwidth to 160MHz.Since the page needs to be fully loaded with the information inside, the transport layer chooses TCP protocol to better reduce package loss. Playing games requires a high level of timeliness, so it is necessary to connect the local operation to the server as fast as possible. For fast communication, a small amount of packet loss is acceptable. Since the video needs to be fully loaded with the information inside, the transport layer chooses TCP protocol to better reduce package loss. Besides, Since video transmission time is usually long and takes up a lot of bandwidth time, set the Selective_ACK to TRUE to prevent multiple packets are lost from one window. The Frame_Per_Sec for video applications should be set to 20 or 30 as videos are usually more than 20 frames per second and the Pixel_Per_Frame should be set to larger than 200k as HD video is usually 1920 * 1080 pixels per second and video compression technology can generally reduce the video size by more than ten times.



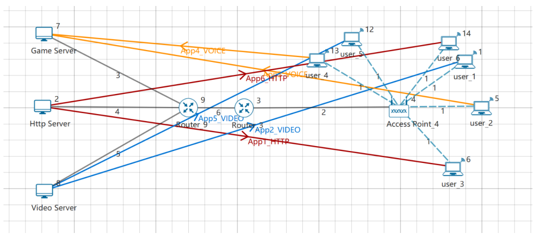
(a) model of a home networking

Application Name	Packet generated	Packet received	Throughput (Mbps)	Delay(microsec)	Jitter(microsec)
App1_HTTP	99	99	0.005940	997.135657	331.169796
App1_HTTP	1386	1380	0.157734	8680.738522	1510.989514
App2_VIDEO	29169	29165	3.230806	2814.712479	817.706885
App3_VOICE	4999	4996	0.063949	162.686105	14.288645

(b) simulation performance for the 3 APP

Figure 6: one group

These figures show the simple model of home networking(one group of users: one user is watching videos, one user is watching a web page, and one user is playing a game).the throughput for 3 applications. It is obvious from it that the throughput of HTTP is around 0.15 Mbps, the throughput of video around 3 Mbps and the throughput of Voice is stable and around 0.64 Mbps. The packet loss rate is less than 1%, with the most delay-sensitive voice (game) delay around 0.6ms. This simulation tries to simulate a scenario where a family lives in a house with a wireless router using different applications to surf online like watching videos on Netflix, calling friends using the internet, and looking through websites. It is assumed that user1 is watching videos online while user2 is playing with friends and user3 is looking at different websites simultaneously. Because there are many similarities between playing games and making phone calls, such as the emphasis on low latency, so voice applications can be a good substitute for games application. On the left of the figure above there are three corresponding servers including a video server, an HTTP server, and a game server. Both three servers are connected to the router_9. User1, user2 and user3 access the network through the access point. Server networks and home networks exchange information with each other via two routers.



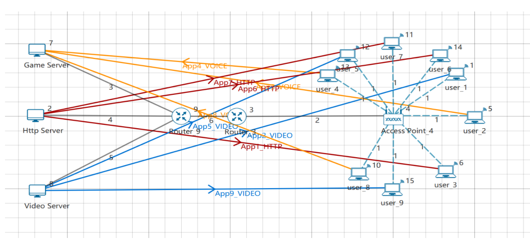
(a) model of a home networking(two group of users)

Application Name	Packet generated	Packet received	Throughput (Mbps)	Delay(microsec)	Jitter(microsec)
App1_HTTP	99	99	0.005940	1316.192424	600.827883
App1_HTTP	1386	1378	0.157536	4029.366783	867.930542
App2_VIDEO	29137	29126	3.230234	3146.822765	906.062899
App3_VOICE	4999	4998	0.063974	405.956437	214.112800
App4_VOICE	4999	4994	0.063923	408.601198	218.285230
App5_VIDEO	29085	29071	3.216477	7215.179492	1006.340449
App6_HTTP	99	99	0.005940	1560.864141	1174.694965
App6_HTTP	1386	1386	0.158400	4423.979477	1012.483723

(b) simulation performance for the 6 APP

Figure 7: two groups

These two figures show the model of home networking(two groups of users) and the throughput for 6 applications. Two users are watching TV, playing games, and browsing websites, respectively. It is obvious from it that the throughput of HTTP is around 0.15 Mbps, the throughput of video around 3 Mbps and the throughput of Voice is stable and around 0.64 Mbps. The packet loss rate is less than 1%, with the most delay-sensitive voice (game) delay around 0.4ms.



(a) model of a home networking(three group of users)

Application Name	Packet generated	Packet received	Throughput (Mbps)	Delay(microsec)	Jitter(microsec)
App1_HTTP	18	17	0.001020	180115.271176	192023.561875
App1_HTTP	238	0	0.000000	0.000000	0.000000
App2_VIDEO	29390	5815	0.644017	305752.991240	3476.367322
App3_VOICE	4999	1002	0.012826	391.742416	187.838313
App4_VOICE	4999	596	0.007629	535.287185	315.971476
App5_VIDEO	26426	17727	2.186459	19891241.873001	8880.285212
App6_HTTP	5	4	0.000240	23504073.252500	21000966.440000
App6_HTTP	56	56	0.006400	8963.854464	2070.111818
App7_VOICE	4995	524	0.006713	510.271370	305.566323
App8_HTTP	99	99	0.005945	2243.402381	2022.505628
App8_HTTP	1386	768	0.089285	8302478.608782	4434202.169151
App9_VIDEO	20147	0	0.000000	0.000000	0.000000

(b) simulation performance for the 9 APP

Figure 8: three groups

These two figures show the model of home networking(three groups of users) and when three groups of people are playing games, watching videos, and brushing the web at the same time, the network becomes seriously clogged, and the stability and effectiveness of the network decrease sharply.

3.3 Effect of distance between nodes on transmission performance

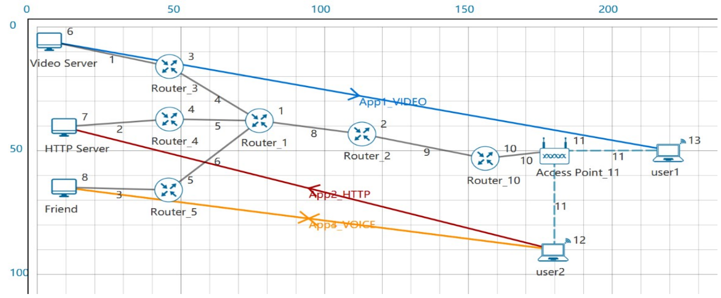


Figure 9: Overall layout of simulation

This figure shows the overall layout of the simulation. This simulation tries to simulate a scenario where a family lives in a house with a wireless router using different applications to surf online like watching videos on Netflix, calling friends using the internet, and looking through websites. It is assumed that user1 is watching videos online while user2 is calling friends and looking at different websites simultaneously. Because calling is a two-way behavior, two applications should be set to simulate calling each other. On the left of the figure above there are three corresponding servers including a video server, an HTTP server, and user2's friend connecting to 3 routers each. After the three separate routers, they follow the same path leading to the WLAN in the home.

As this scenario is trying to simulate an indoor situation, the configuration for the wireless channel is an indoor case. The PathLoss_Model should be set to INDOOR_HOME and the Fading_Model should be set to RAYLEIGH. For application configuration, the encryption for two voice applications should be set to AES as it is usually encrypted in true life. And the Frame_Per_Sec for video applications should be set to 20 or 30 as videos are usually more than 20 frames per second and the Pixel_Per_Frame should be set to larger than 200k as HD video is usually 1920 * 1080 pixels per second and there is compression in videos.

For results, three indexes are mainly considered. The first one is the packet error rate; it is the Packet_errored / Packet_transmitted in Link_Metrics in the wireless channel. The last two are throughput and delay. For video applications, it is just the value on Application_Metrics. For HTTP applications, the direction from the server to the client is used as it usually has higher throughput containing the content of the website and requires low delay reducing the time for people to wait. For voice applications, the throughput is the sum of both ways' throughput, and the delay is half of the sum of both ways' throughput.

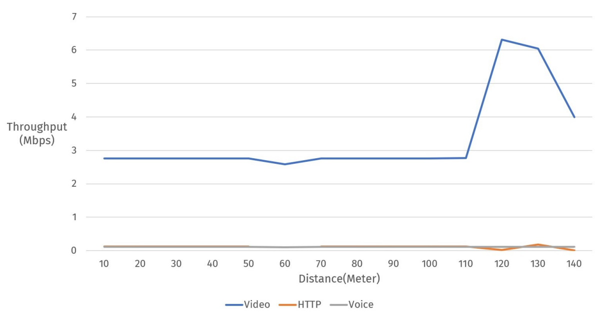


Figure 10: Throughput for three applications

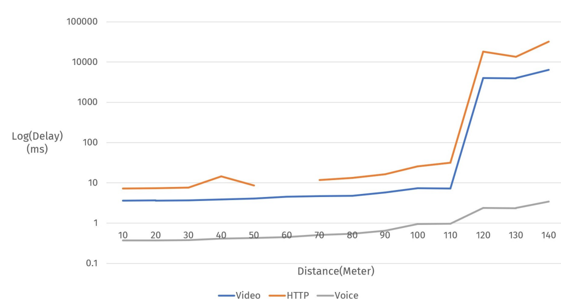


Figure 11: Delay for three applications

The first figure shows the throughput for 3 applications. It is obvious from it that the throughput remains the same for video around 3 Mbps before 110 meters. After 110 meters the throughput for video increases a lot as there are too many mistakes and losses in the transmission and it has to retransmit the packets again. After around 140 meters, the wireless channel becomes unavailable and the throughput for three applications approaching 0 as the error rate becomes too high. While the second figure shows the delay for three applications. Log scale is used in it as those delays increase too sharply after 110 meters. They increase slowly before 110 meters where the wireless channel can be used. After 140 meters it becomes unavailable. There is a gap of around 60 meters which makes the HTTP application unavailable. This is because of the error rate peak in the next figure.

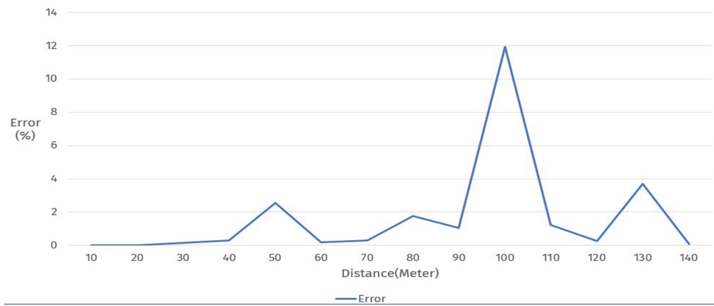


Figure 12: packet error rate for the wireless channel

This figure shows the packet error rate for the wireless channel where there are rises at 50 meters, 100 meters, and 130 meters. 50 meters rise leads to a drop of throughput and the delay gap is around 50 meters. 100 meters rise leads to a rise of throughput of around 110 meters. After 110 meters, the packets can hardly be transmitted to the receiver and verified their correctness.

3.4 Exploration on topographical conditions in NetSim

As explained in section3.3, a 20-people (wireless nodes) party scenario is taken into the investigation. The environment of Grid and OpenStreetMap is used. It is commonly used in vehicular ad hoc network (VANET) simulation [4]. 3 environments of Grid, the Map of NUS Fac of ENG, and the Map of Marina Bay Cruise Centre are tested with the same network. The layouts of simulations are shown in Figure 13 - 15. The parameters of wireless nodes in the network are shown in Table 1. Because people are assumed to arrive as time passes, the 5 voice signals will access at 0 sec (for 2 nodes), 10 sec (for 1 node), and 20 sec (for 2 nodes) respectively. The other applications start at 0 sec, and all 20 applications last until the end of the simulation in 3 experiments. To secure the high transmitting speed and successful access rate, IEEE802.11ac protocol with 160MHz bandwidth is set in these experiments. The comparison of application results is shown in Table 2 - 4.

Table 1: Parameters of wireless nodes in topographical experiments

Nodes	200m	100m	50m	Total
Voice	1	2	2	5
Video	2	1	2	5
HTTP	2	2	2	6
Email	1	1	2	4
Total	6	6	8	20

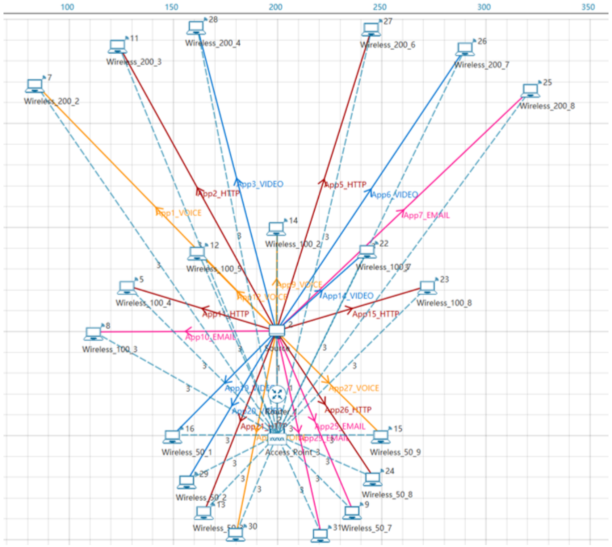


Figure 13: The layout of Grid environment simulation

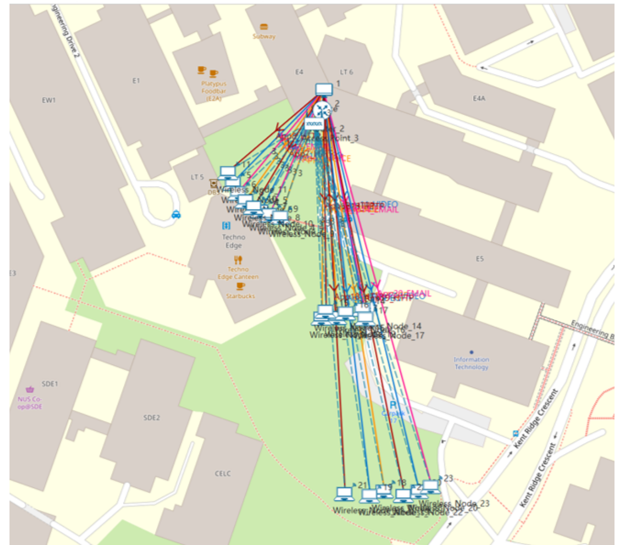


Figure 14: The layout of NUS Faculty of Engineering environment simulation

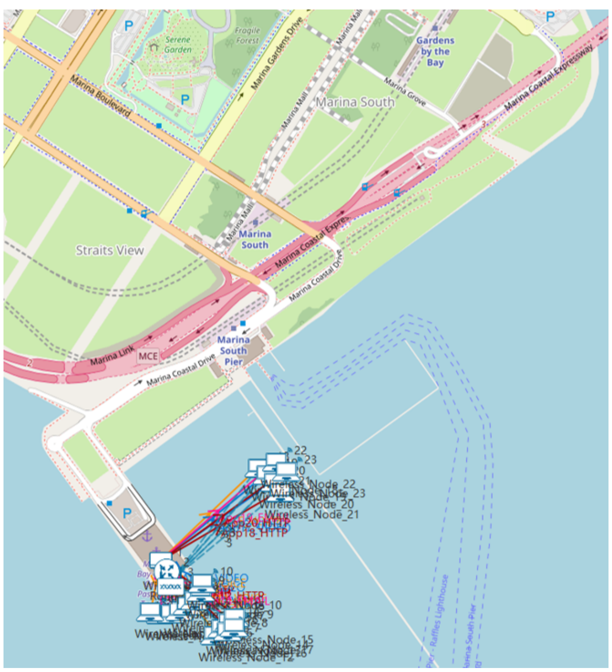


Figure 15: The layout of Marina Bay Cruise Centre environment simulation

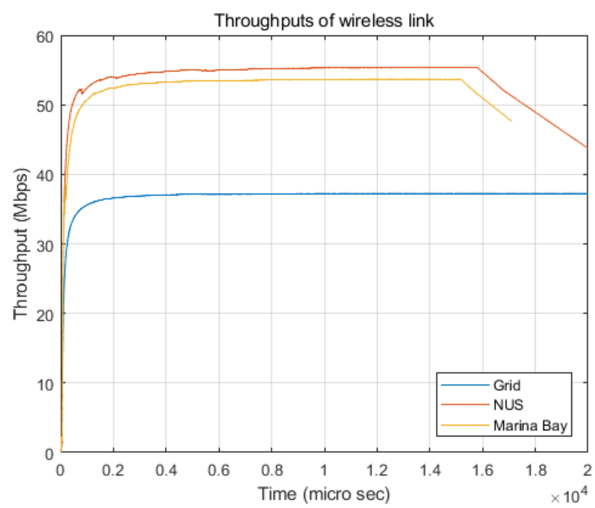


Figure 16: The throughput of 3 topographical conditions

Table 2: Delays of 3 topographical conditions

Types	**Grid**	**NUS ENG**	**Marina Bay**
Voice	<10ms	<10ms, but 2 nodes cannot receive	<10ms, but 1 node cannot receive
Video	<290ms	<150ms	<200ms
HTTP	<3.3s	<210ms	<3.4s
Email	<5.3s	<330ms	<1.8s

Table 3: Throughputs of 3 topographical conditions

Types	**Grid**	**NUS ENG**	**Marina Bay**
Voice	>0.2Mbps	>0.09Mbps	>0.05Mbps
Video	>2Mbps	>3.5Mbps	>2.5Mbps
HTTP		Acceptable	
Email			

Table 4: No. of Transmitted, Errored, and Collided packets of 3 topographical conditions

Type	**Transmitted Data**	**Transmitted Control**	**Errored Data**	**Errored Control**	**Collided Data**	**Collided Control**
Grid	114644	327890	0	0	24	92
NUS ENG	67120	67146	350	0	24	21
Marina Bay	63244	61230	2323	0	15	13

The throughputs of the wireless network in 3 topographical simulations are shown in Figure16. The performances dive when it comes to a real street map. In a Map environment, not all of the nodes can receive signals successfully.

The throughput of the NUS environment is slightly higher, and the error rate is slightly lower than those of Marina Bay, but more nodes fail to connect. So we suppose the network at NUS and Marina Bay also have different transmission performances. Based on this assumption, higher robustness happens in the Bay environment while a higher packet success rate happens in a busy street environment like NUS. The better transmission environment should be decided by cases.

4 Conclusion

4.1 Conclusion about NetSim simulation

- Therefore, for the party scenario, IEEE 802.11ac protocol is the best choice. The widest 160MHz channel band can offer a high theoretical maximum data rate. To further enhance the capacity, the access point is able to transmit 8 spatial streams by applying 8x8 MU-MIMO technology. Compared to IEEE 802.11n/g, these features improve the performance of the wireless network.

- From the number of nodes point of view, the more the nodes are connected to the network, the more congested the network is. From the distance point of view, the throughput and delay remain stable before 110 meters. Between 110 meters and 140 meters it becomes unstable. After 140 meters, the wireless network is no longer available.

- The performances dive when it comes from grid environment simulation to a real street map. It is found that the same network at NUS and Marina Bay have different transmission performances. The better transmission environment should be decided by cases.

4.2 Security issue in IEEE802.11

The performance, interoperability and manageability of wireless LANs are improving. performance, interoperability and manageability, security have become the pressing issue. Security has become an urgent issue. The security issues of wireless LANs are manifested as follows.

- Vulnerability of the transmission medium
  Traditional wired LANs use a single transmission medium, copper wire. The traditional wired LAN uses a single transmission medium - copper wire - with passive hubs or concentrators. These differences in network infrastructure result in a different level of security for wireless LANs than for wired networks. The security of WLANs is not at the same level as that of wired networks.

- WEP deficiencies
  The IEEE802.11 committees introduced WEP in recognition of the inherent security weaknesses of WLANs. However, WEP does not fully guarantee the effectiveness of encrypted transmissions.The security of WLANs is based on WEP, and if WEP is compromised, the security of such mechanisms will be lost. Once WEP is compromised, the security of such a mechanism will no longer exist.

4.3 Promise & Future development

With the increasing number of multimedia services such as video and images, how to improve the network? WiMAX is a new broadband wireless access technology that provides high-speed Internet-oriented connectivity with transmission distances of up to 50km and rates of up to tens of megabits and is used in the construction of wireless metropolitan area networks (WMANs). WiMAX has the advantages of a QoS guarantee, high transmission rate and rich and diverse services, etc. WiMAX has a high technological starting point and adopts advanced technologies such as OFDM/OFDMA, AAS and MIMO, which represent the future direction of communication technology, and has become one of the hot spots for research on wireless communication methods. In addition, the convergence of wireless LAN and 3G mobile networks and the research of security authentication is also future research topics. In addition, the convergence of wireless LAN and 3G mobile networks and the research on security authentication are also key directions for future researchers.

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