International Journal of Computing and Digital Systems
ISSN (2210-142X)
Int. J. Com. Dig. Sys.8 No.3 (May-2019)
http://dx.doi.org/10.12785/ijcds/080304

The Impact of Human Shadowing/Movement on Performance of 802.11ac Client-to-Server WLAN

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Received 30 *Nov. 2018, Revised 12 Apr. 2019, Accepted 28 Apr. 2019, Published 1 May 2019*

Abstract: This paper investigates the impact of human movement on 802.11ac WLAN performance using IPv4, IPv6, TCP and UDP protocols. The results show that on average, the TCP and UDP on WLAN with human movement has a lower throughput than non-human shadowing for both IPv4 and IPv6. For IPv4, the presence of human movement decreases TCP throughput by 12.76% and UDP throughput by 9.66%. For IPv6 with human movement, TCP and UDP throughput reduces by about 13.38% and 8.74% respectively.

For both IPv4 and IPv6, the presence of human movement also increases the round trip time (RTT) and CPU Utilization for both TCP and UDP.

Keywords: 802.11ac WLAN, Mobility, Performance Evaulation, IPv6

1. INTRODUCTION

One of the fastest growing sectors of the telecommunication industry is wireless communication. Having a Wi-Fi network simply creates new possibilities. It provides a cheap and stress-free way to connect more than one device with a single Internet connection and allows mobility while using an Internet connection. Wireless network has the ability to expand easily by adding extra new devices without the mess of more wires and with little additional cost.

Wireless signals can be attenuated from propagation through walls or distorted from dispersion wall materials. Signal strength and data transmission rates can be significantly decreased when radio waves are refracted by different objects in a propagation environment. Interference of radio waves occurring in a dense environment can cause network issues, increasing packets drop and delay over a Wi-Fi network. Human shadowing has a negative impact on WLAN performance in an indoor environment as it blocks part of the signal. Receiving signal strength is even influenced by the human body in some cases where the receiver gains the signals from multiple transmitters [1].

The IEEE 802.11 standard is commonly used for Wi-Fi communications. All the latest Internet devices including smartphones, laptops, and PDAs (personal digital assistant) have WLAN chipsets built-in to support this standard. The technology development of microchip and IEEE 802.11 standards have led to decreasing the cost dramatically, which has boosted user adoption of Wi-Fi network technology. In 1999, due to the increasing commercial demand, Wi-Fi Alliance (WFA) was founded. It certifies interoperability among IEEE 802.11 devices from various producers through testing [2]. With the goal of increasing the performance of WLANs compared to wired networks, the IEEE 802 standards committee formed a new Task Groups (TGs), namely 802.11ac. The 11ac standard functions in the band of 5GHz only and does not support the band of 2.4GHz. Theoretically, it is capable of allowing a speed up to 1.3 Gbps. However, our results did not show this in a testbed environment. The new provisions were assembled on the previous 11n standard. The bandwidth of 802.11ac channel was increased from 40MHz to 80 or even 160MHz. It also involves the advanced order of modulation system (256-QAM) and other improved features such as Beamforming, and better Multi-User Multiple Input Multiple Output (MU-MIMO) with up to 8 spatial streams [3,4,5].

As we note from related works in next section, there is lack of data on impact of crowds in wireless LAN environment. The motivation behind this work is therefore to investigate the impact of human movements and find new results. The results of this study can be important in

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office design when using Wi-Fi, and determine the bandwidth and delay in places where there is human blocking the wireless signal.

2. Related Works

In the literature review, the effects of propagation environment on Wi-Fi network performance is generally studied but there are few attempts to study the impact of human movement on IEEE 802.11 WLANs performance in indoor environments. Some of the related works regarding performance of IEEE802.11 are as follows:

In 2003, A. Doufexi, et al. [6] carried out a comparative examination between IEEE 802.11a and 802.11g WLANs with regards to the performance in a corporate office environment. As both of standards works at different channel bands, 802.11a (5 GHz band) had a higher throughput (26 Mbps) than 802.11g (2.4 GHz band). However, 2.4GHz extended Wi-Fi range by 10%. At 5GHz, the signal attenuation is a remarkably higher because of the increased losses linked with free space propagation and through-wall attenuation.

In 2006, N. I. Sarkar, et al. [7] carried out a performance evaluation of IEEE 802.11b in obstructed environment. Results showed that wall partition had a significant impact on file transmission time and Wi-Fi link throughput. However, the office with permanent wall partition has a higher throughput degradation (up to 10%) than the office with temporary wall partition. Signals can be lost by several office walls and corners even at a relatively short distance of 2 meters between transmitter and receiver.

In 2008, N. I. Sarkar, et al. [8] measured the performance of 802.11g network link throughput in an Indoor propagation. The received signal strength (RSS) was measured and compared with the obtained throughout. In short range coverage, RSS plays a key role in the WLAN performance. The highest throughput (10.325 Mbps) was spotted when RSS increased by 9 dBm regardless of whether the distance between the access point (AP) and the receiver (RX) was increased or not. However, increasing RSS did not raise the throughput when increasing the distance between AP and RX to over 17 meters.

In 2012, S. Japertas, et al. [9] conducted an investigation on Non-line-of-sight (NLOS) propagation on 802.11g and 802.1n Wi-Fi networks in an indoor environment. The distance between transmitter and receiver was increased gradually with each new test-bed. NLOS creates multiple signals caused by obstructions. The results showed that wall partitions absorb less signals for the 802.11n than 802.11g. Signals absorption were decreased constantly as the distance between transmitter and partitions were increased.

In 2013, N. I. Sarkar, et al. [10] carried out an investigation of people movement effectiveness against Wi-Fi link throughput using IEEE802.11g in various indoor environments by using radio propagation measurements. The measurements considered both the random and straight line patterns of people movement. This investigation showed that the human movement had a negative impact on data transfer rate. When compared to non-human shadowing, the average throughput, for fixed human and random human movement in different obstruction environments, decreased by 7.88% and 8.82% respectively. The pattern of people movement has a tiny impact on throughput degradation over Wi-Fi network.

In 2014, Demir et al. [11] did an examination of IEEE 802.11ac WLANs with regards to the power consumption of the access point during transfer data. Dianu, et al. [12] studied the impact of distance, propagation environments, and Wi-Fi interference on 802.11ac WLANs performance.

In 2015, Y. Zeng, et al. [13] studied the effect of some parameters including distance, power consumption, and interference on 802.11ac throughput in an indoor environment. Then Siddiqui et al. [14] investigated the parameters that restrict IEEE 802.11ac from achieving the maximum bandwidth beyond 1Gbps.

In 2017, Kolahi and Almatrook [15] investigated the impact of WPA2 security on bandwidth and latency in a client-server wireless network using the IEEE802.11ac standard.

As discussed in the introduction, the purpose of this research to investigate the impact of human movement on 802.11ac Wi-Fi link measuring throughput, delay, and CPU utilization in an indoor propagation environment and provide a comparative analysis to identify if there are any significant differences on Wi-Fi performance.

3. Network Set up

To measure the performance of 802.11ac for IPv4 and IPv6 on Windows 8.1 and Windows Server 2012 WLAN, the server machine is connected to the Linksys Business LAPAC1750PRO Access Point (AP) via a Cat 5e crossover cable. The client is connected to the Linksys Access Point (AP) wirelessly. The distance between the Access Point and the client was set to three metres to give a suitable space for body movement while the experiment was conducted. WPA2 encryption was set up in the Access Point security setting. In human movement experiment, three participants were standing side-by-side as a barrier (wall) in front of the Access Point and the client PC, while another participant was walking horizontally alongside the standing participants with steady movement backwards and forwards. Participants were located in the middle between the Access Point and the client PC. The movement continued until the traffic generations tools explained earlier had completed transmitting to the client workstation.

The channel bandwidth is set to 80 MHz to utilise the full bandwidth. The hardware contains an Intel Core i5 CPU 2.80 GHz processor with 24.0 GB RAM for the efficient operation of the Server and an Intel 82578DC Gigabit Network Connection on the server workstation, and an Intel Core i7-2600 CPU 3.40 GHz processor with 8.0 GB RAM for the efficient operation of Windows and an AC1750 Wireless Dual Band PCI Express Adapter on the client workstation. The client was connected to the server wirelessly by a Linksys lapac1750pro business Access Point. The test-bed setup remained constant for all experiments conducted. The test bed diagrams are shown in Figures 1 and 2.

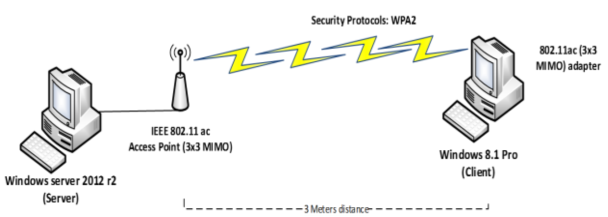

Figure 1. No human movement WLANs diagram

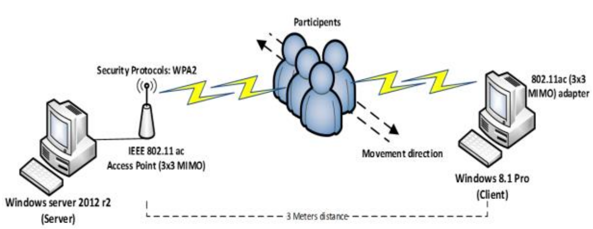

Figure 2. Human movement WLANs diagram

4. Data Generation and Traffic Measurement Tool

Jperf 2.0.2 [16] is a tool that runs as a graphical user interface (GUI) over Iperf. It performs all tests that are executed by Iperf, and generates the same output results. The Jperf front end has various text boxes and radio buttons, each of them related to one Iperf command-line [17]. The same Iperf software executes for both client and server workstations. It produces the traffic and measures the transmitted packet parameters for TCP, UDP by applying either IPv4 or IPv6 protocols. Delay, throughput, jitter and packet loss can only be measured in the network [17]. IPerf has been found to have a higher bandwidth measurement compared to other popular traffic generators in a laboratory environment [18]. In this research, Jperf was the primary tool used for generating and measuring throughputs. To run JPerf, it needed to be installed on two computers, a server computer and a client computer. The former would act as a JPerf client, while the latter would act as the JPerf server.

The Netperf [19] tool was used as a tool to measure Round Trip Time (RTT) over the Wi-Fi network. Netperf installed on both client and the server. On the server side, the tool can listen for connections from a remote host, while the tool can initiate the wired/wireless network test with the server on the client side. Netperf can be used for both TCP and UDP evaluations with IP versions 4 and 6. Netperf can be used on various operating systems such as Windows, Linux, and UNIX.

The primary tool used to collect the CPU utilisation was Typeperf [20], which is a Windows built-in tool that measures the percentage of CPU usage and exports the data to the command window screen or to a log file. The CPU usage was collected while the traffic generator tool was sending the traffic from the server to the client.

5. Results

Throughput, RTT, and CPU usage were parameters measured for transport protocols (TCP and UDP), and IP protocols (IPv4 and IPv6). The packet sizes that were tested for each scenario were 128, 384, 640, 896, 152, and 1408 Bytes. The duration of each test run on each packet was 300 seconds and number of run was usually between 10 and 15 times. The results were captured using tools explained in previous section, and recorded on a Microsoft Excel spreadsheet. The mean of these test runs and standard deviation were measured. Any irrelevant result was eliminated and the test runs were repeated until the standard deviation over mean was under 0.05.

Figures 3 and 4 show the throughput for TCP and UDP protocols for both versions of the Internet Protocol for 802.11ac WLANs in the presence of human shadowing and in non-human shadowing environments. In all scenarios, as the packet size increases, so does the throughput of TCP.

In all figures, W-MOV is an abbreviation for without human movement; MOV is an abbreviation for human movement.

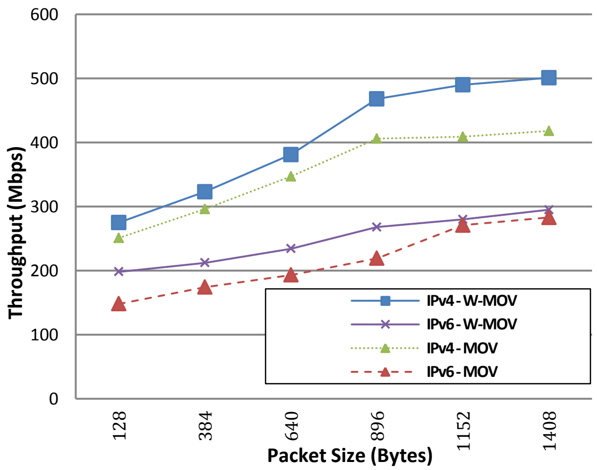

Figure 3. Comparison of TCP throughput for both versions of the Internet Protocol in 802.11ac WLAN, without human movement vs. human movement

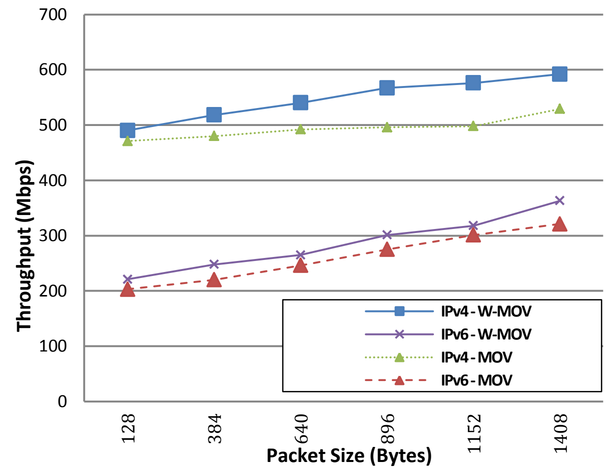

Figure 4. *Comparison of UDP throughput for both versions of the Internet Protocol in 802.11ac WLAN, without human movement vs. human movement*

Both with and without human movement, IPv4 considerably outperforms IPv6 for TCP throughput on various packet sizes. Without human movement, the maximum difference is observed at 1152 Bytes packet size, where IPv4 outperforms IPv6 by 42.86% (490 Mbps for IPv4, 280 Mbps for IPv6), or higher by 210 Mbps. With human movement, the maximum difference in throughput is observed at 896 Bytes packet size, where IPv4 outperforms IPv6 by 45.72% (406 Mbps for IPv4, 219 Mbps for IPv6), or higher by 187 Mbps.

Running 802.11ac WLAN without human movement also provides higher TCP throughput than with human shadowing. The maximum difference in throughput for TCP with IPv4 is observed at packet size 1408 Bytes, where non-human movement environment outperforms human movement by 16.77% (501 Mbps for W-MOV, 417 Mbps for MOV), or higher by 84 Mbps. IPv6 without human movement shows peak difference at packet size 128 Bytes, outperforming IPv6 with human movement by 25.25% (198 Mbps for W-MOV, 148 Mbps for MOV), or higher by 50 Mbps (Figure 3).

In Figure 4, both with and without human movement, IPv4 significantly outperforms IPv6 for UDP throughput on different packet sizes. Without human movement, the greatest difference is observed at packet size 640 Bytes, where IPv4 outperforms IPv6 by 50.93% (540 Mbps for IPv4, 265 Mbps for IPv6), or higher by 275 Mbps. With human movement, the greatest throughput difference is observed at packet size 128 Bytes, where IPv4 outperforms IPv6 by 56.90% (471 Mbps for IPv4, 203 Mbps for IPv6), or higher by 268 Mbps.

UDP throughput is also higher without human movement than with human movement. For IPv4, the maximum difference appears at packet size 1152 Bytes, where without human movement outperforms with human movement by 13.54% (576 Mbps for W-MOV, 498 Mbps for MOV), or higher by 78 Mbps. The peak difference for IPv6 without human movement is observed at 1408 Bytes, where it outperforms IPv6 with human movement by 11.26% (364 Mbps for W-MOV, 323 Mbps for MOV), or higher by 41 Mbps.

Figures 3 and 4 results showed that human movement has a negative impact on the network throughput. This is because the human movement acts as a shadowing obstacle with a strongly adverse effect on the signal, thus decreasing throughput [21]. Furthermore, using IPv6 provides lower throughput for both UDP and TCP than IPv4. This is because IPv6 adds extra overhead (40 Bytes) compared to 20 Bytes overhead of IPv4 [22].

Figure 5 shows the TCP/UDP throughput comparion with or without human movement. Figure 5 shows that UDP has a greater throughput than TCP for both versions of the Internet Protocol on different packet sizes.

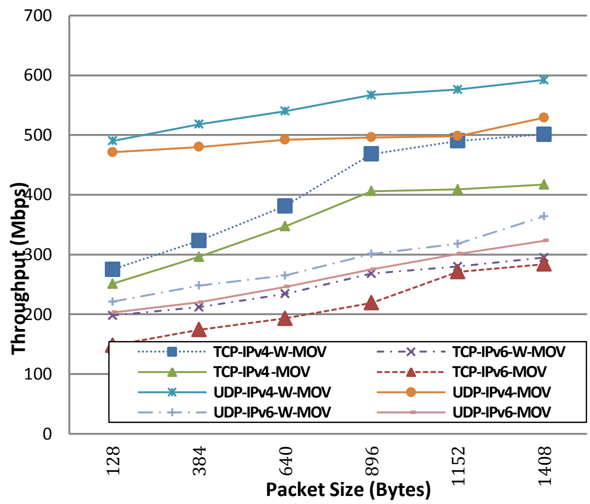

Figure 5. Comparison of TCP and UDP throughput for both versions of the Internet Protocol in 802.11ac WLAN, without human movement vs. human movement

Without human movement, the peak difference between UDP and TCP throughput for IPv4 appears at packet size 128 Bytes, with a difference of 43.88% (275 Mbps for TCP, 490 Mbps for UDP), or 215 Mbps higher for UDP. For IPv6, the highest difference of 18.96% is at 1408 Bytes packet size, (295 Mbps for TCP, 364 Mbps for UDP), or UDP is higher by 69 Mbps (Figure 5).

With human movement, the maximum difference between UDP and TCP throughput for IPv4 appears at 128 Bytes packet size, with an increase of 46.71% (251 Mbps for TCP, 471 Mbps for UDP), or 220 Mbps higher. For IPv6, the greatest change in throughput appears at 896 Bytes, an increase of 20.36% (219 Mbps for TCP, 275 Mbps for UDP), or UDP is higher by 56 Mbps.

The reason for the overall higher throughput results for UDP is that UDP has a lower overhead (8 Bytes) than TCP overhead (20 Bytes) [23].

Figures 6 and 7 show the RTT on TCP and UDP for both versions of the Internet Protocol in the presence of human movement and without human movement. In all scenarios, as the packet size increases, so does the TCP RTT.

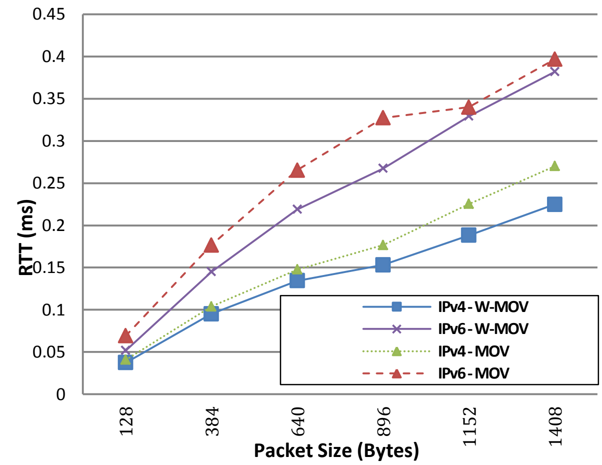

Figure 6. *Comparison of TCP RTT for both versions of the Internet Protocol in 802.11ac WLAN, without human movement vs. human movement*

With or without human movement, IPv4 outperforms IPv6 on all tested packet sizes. Without human movement, the peak difference between IPv4 and IPv6 in RTT for TCP is observed at packet size 1408 Bytes, with a difference of 41.10% (0.225 ms for IPv4, 0.382 ms for IPv6), or 0.157 ms faster. With human movement, the maximum difference is at 896 Bytes packet size, a difference of 46.18% (0.177 ms for IPv4, 0.327 ms for IPv6), or 0.151 ms faster (Figure 6).

The results show that without human movement, the TCP RTT is faster for both versions of the Internet Protocol. The highest TCP RTT difference between absence and presence of human movement is observed at packet size 1408 Bytes for IPv4, with a difference of 16.67% (0.225 ms for W-MOV, 0.270 ms for MOV), or 0.045 ms shorter RTT. At packet size 896 Bytes, implementing IPv6 without human movement results in a difference of 18.35% (0.267 ms for W-MOV, 0.327 ms for MOV), or 0.060 ms shorter RTT for W-MOV.

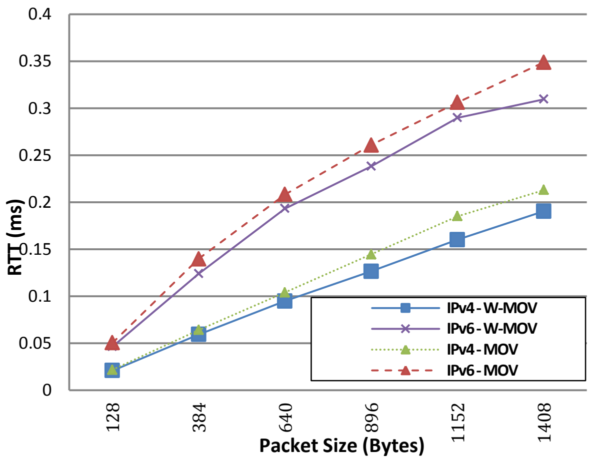

Figure 7. Comparison of UDP RTT for both versions of the Internet Protocol in 802.11ac WLAN, without human movement vs. human movement

In Figure 7, for UDP RTT, IPv4 outperforms IPv6 on different packet sizes, with or without human movement. With no human movement, the maximum UDP RTT difference is at packet size 1152 Bytes, with a difference of 44.83% (0.16 ms for IPv4, 0.29 ms for IPv6), or 0.13 ms shorter RTT. With human movement, the peak difference is at 1408 Bytes, where IPv4 outperforms IPv6 by 38.97% (0.213 ms for IPv4, 0.349 ms for IPv6), or 0.136 ms difference.

The results also show that human movement significantly slows the RTT for both versions of the Internet Protocol. The peak UDP RTT difference between absence and presence of human movement is captured at packet size 1152 Bytes for IPv4, with a difference of 13.51% (0.16 ms for W-MOV, 0.185 ms for MOV), or 0.025 ms difference. At packet size 1408 Bytes, applying IPv6 without human movement improves RTT by 11.17% (0.309 ms for W-MOV, 0.349 ms for MOV), or 0.039 ms faster.

In both scenarios, as the packet size increases from 128 to 1408 Bytes, the RTT consistently grows. Human movement has a negative impact on RTT, for TCP and UDP with both IPv4 and IPv6. IPv6 has higher overhead of 40 Bytes compared to 20 Bytes overhead of IPv4 [22], for this reason using IPv6 results in a longer RTT than IPv4 for both UDP and TCP.

Figure 8 shows the UDP with or without human movement achieves a faster RTT than TCP for both versions of the Internet Protocol on all tested packet sizes.

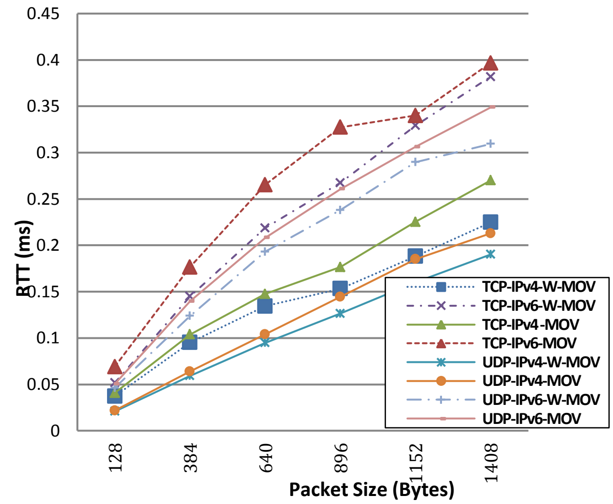

Figure 8. Comparison of TCP and UDP RTT for both versions of the Internet Protocol, without human movement vs. human movement

Without human movement, the greatest difference between UDP and TCP RTT for IPv4 is observed at packet size 640 Bytes, where UDP has lower RTT by 29.85% (0.134 ms for TCP, 0.095 ms for UDP), or 0.04 ms shorter RTT. For IPv6, the maximum RTT difference between TCP and UDP is at 1408 Bytes with a difference of 18.85% (0.382 ms for TCP, 0.309 ms for UDP), or 0.072 ms shorter RTT (Figure 8).

With human movement, the peak difference between UDP and TCP RTT for IPv4 appears at packet size 1408 Bytes, where UDP is lower by 21.11% (0.27 ms for TCP, 0.213 ms for UDP), or 0.057 ms faster. For IPv6, the maximum RTT difference is at 896 Bytes, where UDP outperforms TCP by 20.49% (0.327 ms for TCP, 0.261 ms for UDP).

UDP returns consistently faster results because UDP has a lower overhead (8 Bytes) than TCP (20 Bytes) [23].

Figures 9 and 10 show the CPU utilisation on TCP and UDP protocols for both versions of the Internet Protocol in the presence of human movement and in non-human shadowing environments. In all scenarios, as the packet size increases, the TCP and UDP CPU utilisation decrease consistently along with them. When the packet size is small, there are more packets to process and that results in higher CPU utilisation.

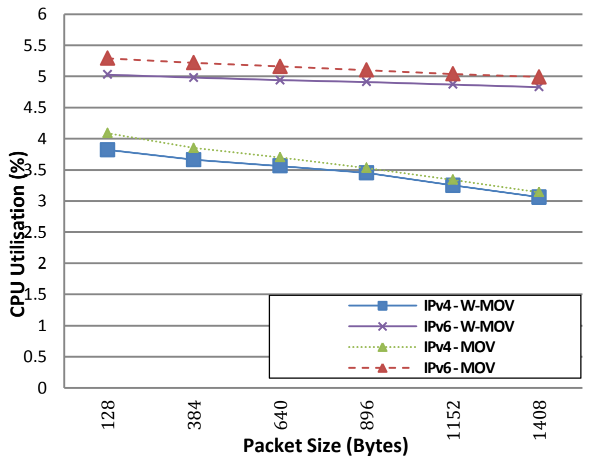

Figure 9. Comparison of TCP CPU Utilisation for both versions of the Internet Protocol in 802.11ac WLAN, without human movement vs. human movement

IPv4 consumes less TCP CPU resource than IPv6 on all packet sizes, with or without human movement (Figure 9). Without human movement, the greatest difference is at packet size 1408 Bytes, where IPv4 is lower by 1.77% (3.06% for IPv4, 4.83% for IPv6). With human movement, the maximum difference between IPv4 and IPv6 appears at 1408 Bytes, where IPv4 outperforms IPv6 by 1.85% (3.14% for IPv4, 4.99% for IPv6).

Comparing TCP CPU utilisation data shows the usage is lower for both IPv4 and IPv6 without human movement. The maximum difference is observed at packet size 128 Bytes. IPv4 achieves a difference of 0.27% (3.82% for W-MOV, 4.09% for MOV). A 0.26% lower CPU usage rate is observed for IPv6 without human movements (5.03% for W-MOV, 5.29% for MOV).

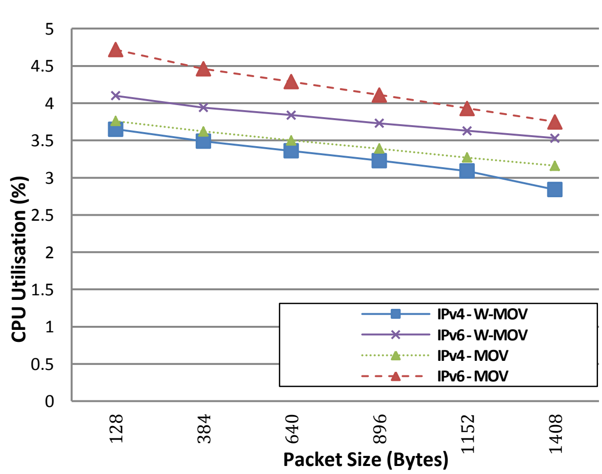

Figure 10. Comparison of UDP CPU Utilisation for both versions of the Internet Protocol in 802.11ac WLAN, without human movement vs. human movement

With or without human movement, applying IPv4 consumes less UDP CPU resource than IPv6 on different packet sizes (Figure 10). Without human movement, the greatest difference between IPv4 and IPv6 appears at packet size 1408 Bytes, with IPv4 consuming 0.69% less CPU (2.84% for IPv4, 3.53% for IPv6). With human movement, the maximum difference is at 128 Bytes, where IPv4 outperform IPv6 by 0.96% (3.76% for IPv4; 4.72% for IPv6).

The results show that with no human movement, the CPU usage is consistently lower for both versions of the Internet Protocol. The maximum UDP CPU usage difference is observed at packet size 1408 Bytes for IPv4, with a 0.32% lower CPU utilisation rate (2.84% for W-MOV, 3.16% for MOV). For IPv6, the peak difference appears at 128 Bytes, achieving a 0.62% lower rate (4.1% for W-MOV, 4.72% for MOV).

In both scenarios, as the packet size increases from 128 to 1408 Bytes, CPU utilisation generally decreases. Human movement has a negative impact on network CPU usage, using TCP or UDP and for both IPv4 and IPv6. IPv6 adds extra overhead of 40 Bytes compared to 20 Bytes for IPv4 [22], with the result that IPv6 uses more CPU resources for both UDP and TCP than IPv4.

Figure 11 shows the UDP with or without human movement has a lower CPU usage than TCP for both versions of the Internet Protocol on all tested packet sizes.

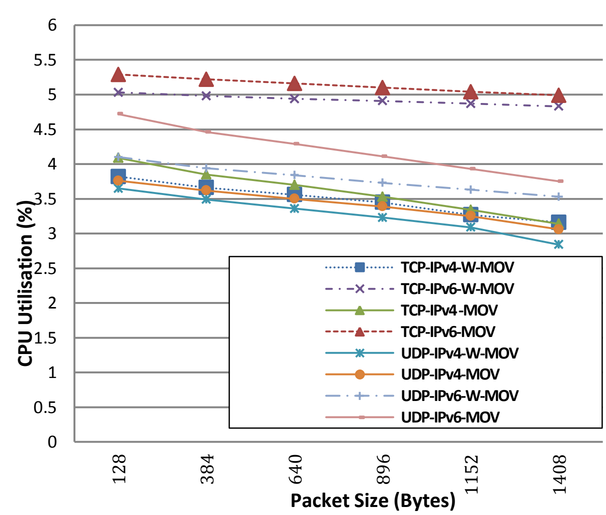

Figure 11. Comparison of TCP and UDP CPU Utilisation for both versions of the Internet Protocol, without human movement vs. human movement

In the absence of human movement, the maximum difference between UDP and TCP CPU usage for IPv4 is at packet size 1408 Bytes, where UDP has 0.32% lower CPU usage (3.16% for TCP, 2.84% for UDP). For IPv6, the peak CPU usage difference is also at 1408 Bytes, where UDP outperforms TCP by 1.3% (4.83% for TCP, 3.53% for UDP).

In the presence of human movement, the maximum difference between UDP and TCP for IPv4 is observed at packet size 128 Bytes, where UDP has 0.33% lower CPU usage (4.09% for TCP, 3.76% for UDP). For IPv6, the maximum CPU utilisation difference is at 1408 Bytes, where UDP outperforms TCP by 1.24% (4.99% for TCP, 3.75% for UDP).

UDP has a consistently lower CPU usage because it has a lower overhead (8 Bytes) than TCP (20 Bytes) [23].

6. Conclusion

We demonstrated that human movement has a negative impact on the throughput, RTT and CPU usage of 802.11ac WLANs. Both TCP and UDP had the shortest RTT and lowest CPU usage and highest throughput with non-human shadowing for both versions of the Internet Protocol. Moreover, IPv6 had a lower throughput, longest RTT, and higher CPU usage compared to IPv4 for both TCP and UDP. Also, UDP outperformed TCP for both versions of the Internet Protocol. The results showed that on average, the highest throughput (547.17 Mbps), shortest RTT (0.109 ms) and lowest CPU usage (3.277%) were measured in the absence of human movement when implementing IPv4 with UDP protocol, whereas the lowest throughput (214.67 Mbps), longest RTT (0.263 ms) and highest CPU usage (5.13%) were measured in the presence of human movement and with IPv6 and TCP protocol.

7. Future Works

The future work includes conducting the experiment in an outdoor environment, which has a different penetration loss compared to the indoor environment. There are many outdoor factors that can affect penetration loss, such as the position of the building and building materials near the experimental location, and also by effective illumination of these buildings, trees, etc. [24]. Future improvement can include providing simulation results by simulation and comparing with the set up results used here. It could also compare data for various channel sizes used in 802,11ac

Acknowledgment

The authors would like to thank UNITEC Institute of Technology for funding the research team and providing the inventory needed.

References

[1] H. Hongwei, S. Wei, X. Youzhi, and Z. Hongke, "The effect of human activities on 2.4 GHz radio propagation at home environment," in 2nd IEEE International Conference on Broadband Network & Multimedia Technology (IC-BNMT'09), Beijing, China, 18 - 20 Oct. 2009, pp. 95 - 99.

[2] G.R. Hiertz, D. Denteneer, L. Stibor, Y. Zang, X.P. Costa, B. Walke, "The IEEE 802.11 universe," *IEEE Communications Magazine*, vol. 48, no. 1, pp. 62 - 70, January 2010.

[3] Aruba Networks. (2015, Feb. 18). 802.11ac in-depth white paper [Online].Available: http://www.arubanetworks.com/pdf/technology/whitepapers/WP_80211acInDepth.pdf?_ga=1.105319942.460286927.1442720395.

[4] Bradley, M. "*What Is Multiple-In Multiple-Out (MIMO) Technology?* Retrieved March 2018 from Lifewire: https://www.lifewire.com/mimo-wifi-routers-818332.

[5] Gong M. X., Hart, B., and Mao, S., "*Advanced Wireless LAN technologies: IEEE 802.11 ac and beyond*," *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 18, no. 4, pp. 48 - 52, 2015.

[6] A. Doefexi, S. Armour, L. Beng-Sin, A. Nix, and D. Bull, " An evaluation of the performance of IEEE 802.11a and 802.11g wireless local area networks in a corporate office environment," in IEEE International Conference on Communications (ICC'03), Anchorage, AK, 11 - 15 May 2003, pp. 1196 - 1200 vol.2

[7] N. I. Sarkar, K. W. Sowerby, " Wi-Fi Performance Measurements in the Crowded Office Environment: a Case Study," in International Conference on Communication Technology (ICCT'06), Guilin, China, 27-30 Nov. 2006, pp. 1 – 4.

[8] N. I. Sarkar, E. Lo, " Indoor Propagation Measurements for Performance Evaluation of IEEE 802.11g," in Australasian Telecommunication Networks and Applications Conference (ATNAC'08), Adelaide, SA, 7-10 Dec. 2008, pp. 163 – 168.

[9] S. Japertas, E. Orzekauskas, "Investigation of WI-Fi indoor signals under LOS and NLOS conditions," *International Journal of Digital Information and Wireless Communications (IJDIWC)*, vol. 2, no. 1, pp. 126 - 32, Jan. 2012.

[10] N. I. Sarkar, and O. Mussa, "The effect of people movement on Wi-Fi link throughput in indoor propagation environments," in IEEE TENCON Spring Conference, Sydney, Australia, 17-19 April 2013, pp. 562 – 566.

[11] Demir, M. O., Kurt, G.K., and Karaca, M., "*An energy consumption model for 802.11ac access points*," in 22nd International Conference on Software, Telecommunications and Computer Networks (SoftCOM'14), Split, Croatia, pp. 67 - 71. 2014.

[12] Dianu, M. D., Riihijarvi, J., and Petrova, M. "*Measurement-based study of the performance of IEEE 802.11ac in an indoor environment,"* IEEE International Conference on Communications (ICC'14), Sydney, pp. 5771 – 5776, 2014.

[13] Zeng, Y., Pathak, P. H., and Mohapatra, P. *"Throughput, energy efficiency and interference characterisation of 802.11ac,"* Transactions on Emerging Telecommunications Technologies, 13 May 2015.

[14] Siddiqui, F., Zeadally, S., and Salah, K.,"*Gigabit Wireless Networking with IEEE 802.11ac: technical overview and challenges*," Journal of Networks, vol. 10, no. 3, pp. 164 - 171, Apr. 2015.

[15] Kolahi, S. S, Almartook A. A.,*"Impact of security on bandwidth and latency in IEEE IEEE802.11ac client-to-server WLAN."* 2017 Ninth International Conference on Ubiquitous and Future Networks (ICUFN), pp. 893-897, 2017.

[16] Google code. *Graphical frontend for IPERF written in Java* [Online]. Available: https://code.google.com/p/xjperf/

[17] R. Blum, "Network performance open source toolkit: using Netperf, tcptrace, NISTnet, and SSFNet," vol. 2, John Wiley & Sons, 2003.

[18] S. S. Kolahi, S. Narayan, D.D.T. Nguyen, and Y. Sunarto, "Performance monitoring of various network traffic generators," in 13th International Conference on Computer Modelling and Simulation (UKSim'11), Cambridge, March 30 2011-April 1 2011, 501 – 506.

[19] R. Jones. (2009). *Welcome to the Netperf homepage* [Online]. Available: http://www.netperf.org/netperf

[20] J. Gretarsson, F. Li, M. Li, A. Samant, M. Claypool, and R. Kinicki, "Performance analysis of the intertwined effects between network layers for 802.11 g transmissions," in 1st ACM workshop on Wireless multimedia networking and performance modeling (WMuNeP '05), New York, USA, 2005, pp. 123 - 130.

[21] H. Hongwei, S. Wei, X. Youzhi, and Z. Hongke, "The effect of human activities on 2.4 GHz radio propagation at home environment," in 2nd IEEE International Conference on Broadband Network & Multimedia Technology (IC-BNMT'09), Beijing, China, 18 - 20 Oct. 2009, pp. 95 - 99.

[22] S. Dutta, P. K. Mishra, G. M. Prasad, S. Shukla, and S. K. Chaulya, "Internet Protocols: IPv4 vis a vis IPv6," *Asian Journal of Information Technology*, vol. 11, no. 3, pp. 100 - 107, 2012.

[23] S. Kumar, and S. Rai, "Survey on Transport Layer Protocols: TCP & UDP," *International Journal of Computer Applications*, vol. 46, no. 7, pp. 20 - 25, May 2012.

[24] S. Stavrou, and S. R. Saunders, "Factors influencing outdoor to indoor radio wave propagation," in 12th International Conference on Antennas and Propagation (ICAP' 03), Exeter, UK, 31 March-3 April 2003, pp. 581 – 5852.

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