Applications of Minimax Access-Point Setup Optimization Approach to IEEE802.11ac WLAN at 5GHz

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Abstract

Previously, we have studied the minimax access-point (AP) setup optimization approach to improve the throughput performance of a wireless local-area network (WLAN) with IEEE 802.11n at 2.4GHz. Recently, IEEE802.11ac at 5GHz has become popular due to the much higher data rate, using a larger number of antennas for multiple-input-multiple-output (MIMO), the larger frame aggregation size, the beamforming, and the multi-user-MIMO(MU-MIMO). In this paper, we present the application of the minimax AP setup optimization approach to WLAN for 11ac at 5GHz. First, the throughput performance of this WLAN using MIMO links is investigated and compared with the one for 11n at 2.4GHz. Then, the minimax approach is applied with slight modifications. The effectiveness of our approach for 11ac at 5GHz is confirmed through extensive experiments in three network fields.

Keywords-Wireless local-area network, access-point setup, MIMO, IEEE 802.11n/ac, throughput estimation model

1. Introduction

Nowadays, *IEEE 802.11 wireless local-area network (WLAN)* has become common in daily life as the high-speed and cost-effective Internet access network. Previously, we have studied the *minimax AP setup optimization approach* to improve the throughput performance of WLAN [1]. In this approach, the *bottleneck host*, which receives the weakest signal from the AP in the field, is detected using the *throughput estimation model*. Then, the AP setup is optimized by changing the height, orientation, and coordinate, such that the throughput of this bottleneck host is maximized.

This throughput estimation model consists of two functions. First, the *received signal strength*(RSS) at the receiver is estimated by the *log-distance path loss model* [2]. Second, this RSS is converted to the throughput using the *sigmoid function*. The parameter values of these functions are optimized using the *parameter optimization tool* with the throughput measurement results at the WLAN.

However, in this previous study, we only considered WLAN with *IEEE 802.11n at 2.4GHz* although *IEEE 802.11ac at5GHz*has become popular due to the much higher data rate than 11n, using a larger number of antennas for *multiple-input-multiple output (MIMO)*, the larger *frame aggregation* size, the *beamforming*, and the *multi-user-MIMO (MUMIMO)* [3]. For example, the maximum throughput of a commercial AP *NEC WG2600HP* can be 1,733*Mbps* for 11acat 5GHz and 800*Mbps*for 11n at 2.4GHz [4].

In this paper, we present the application of the minimax AP setup optimization approach to WLAN with IEEE 802.11ac at 5GHz. First, the throughput performance of this WLAN using MIMO links is investigated and compared with the one for 11n at 2.4GHz. Then, the minimax approach is applied to 11ac at 5GHz with slight modifications. The effectiveness of our approach for 11ac at 5GHz is confirmed through extensive experiments in three network fields.

The rest of this paper is organized as follows: Section 2. presents the related works to this paper. Section 3. reviews the previous minimax AP setup optimization approach for 11n at 2.4GHz. Section 4. introduces the application of the minimax approach to 11ac at 5GHz. Finally, Section 5. concludes this paper with future works.

2. Related Works

Several related works have been reported in literature. In [5], Kriara et al. studied the performance characterization of IEEE 802.11ac in terms of the throughput, the jitter, and the fairness using real testbed deployments. The authors reported that 11ac WLAN with wider channels can be fairer in dense environments with high interferences.

In [6], Simić et al. studied the combined impacts of the channel bandwidth, the traffic profile, and the AP density and placement on the overall network-level throughput

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and the fairness in IEEE 802.11ac. The authors evaluated the performance of 11ac Wi-Fi in a large 24-node indoor testbed. They addressed that wide 80MHz channels are only beneficial in very dense deployments with extreme offered traffic volumes, due to the significant adjacent channel interference (ACI) which couples narrower channels.

In [7], Newell et al. carried out the performance evaluations of IEEE 802.11n and 11ac to characterize the effects of the distance and the interference between different channels. The authors concluded that throughput performance of 11ac decreases at an extremely faster rate with the increasing distance from the client to the AP when compared to 11n at 5GHz.

A variety of studies have been addressed to the radio wave propagation regarding positions, polarizations, and radiation patterns of transmitting and receiving antennas [8]-[11]. It is revealed that different antenna configurations and orientations have significant impacts on performances of MIMO links.

3. Review of Minimax AP Setup Optimization Approach for 11n at 2.4GHz

In this section, we review the minimax AP setup optimization approach for IEEE 802.11n at 2.4GHz.

3.1. Overview

In the minimax AP setup optimization approach, first, the throughput is measured for each link between the target AP and a possible host location in the network field. Next, the parameters of the *throughput estimation model* are tuned based on the throughput results using the *parameter optimization tool*. Then, the *bottleneck host* in the field is found through simulations using the model. After that, the AP setup is optimized by changing the height, orientation, and coordinate such that the throughput of this bottleneck host is maximized against the AP. Finally, we evaluate the overall throughput improvement among the hosts by the AP setup optimization.

3.2. Throughput Estimation Model

The throughput estimation model has been developed to accurately estimate the throughput of a wireless communication link between an AP and a host in WLAN from the network field information. First, this model estimates the RSS at the host using the *log-distance path loss model*, which considers the distance and the obstacles between AP and the host. Next, it converts the RSS to the throughput using the *sigmoid function*. Both functions have several parameters whose values can affect the estimation accuracy.

3.2.1. Signal Strength Estimation. The *RSS* at a host from an AP is calculated using the *log-distance path loss model* [2]:

$$P_d = P_1 - 10\,\alpha\log_{10} d - \sum_k n_k W_k \quad (1)$$

where P_d represents the RSS (*dBm*) at the host, α does the path loss exponent factor, *d* does the distance (m) to the host from the AP, P_1 does the RSS (*dBm*) at the host at the 1m distance from the AP when no obstacle exists between them, n_k does the number of *type k* obstacles along the path between the AP and the host, and W_k does the signal attenuation factor (*dB*) for the *type k* obstacle. P_1, α, and W_k are parameters to be tuned. To consider the multipath effect, the *indirect path* is also considered by selecting a *diffraction point* for each AP/host pair and select the larger *RSS* between the direct and indirect signals for sigmoid function. It is noted that α can be replaced by α_{inc} (enhanced path loss exponent factor) for $d \geq d_{thr}$ (distance threshold) to improve the estimation accuracy [13].

3.2.2. Throughput Conversion. The *RSS* is converted to the throughput or the data transmission speed from the AP to the host using the *sigmoid function*:

$$S = \frac{a}{1+\exp\left(-\frac{(120+P_d)-b}{c}\right)} \quad (2)$$

where *S* represents the estimated throughput (Mbps) when the RSS (dBm) at the host is P_d. a, b, and c are parameters to be tuned.

3.3. Parameter Optimization Tool

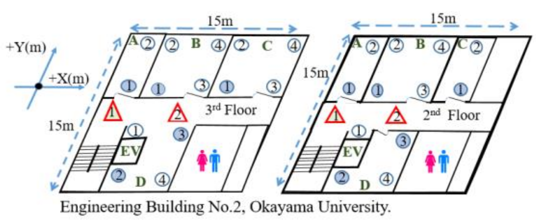
The throughput estimation model has a number of parameters whose value determines the estimation accuracy. These values are optimized by use of the *parameter optimization tool*, which adopts a local search algorithm that combines the tabu table and the hill climbing procedure to avoid a local minimum. This tool has normally been implemented in the general form, so that it can be used for a variety of algorithms/logics that have parameters to be optimized. The program for the tool has been independently implemented from the program with the throughput estimation model. It runs the model program as its child process. The optimality of the current parameter values in the model program is evaluated by the throughput estimation error that is given in the output file.

3.4. Evaluation Results

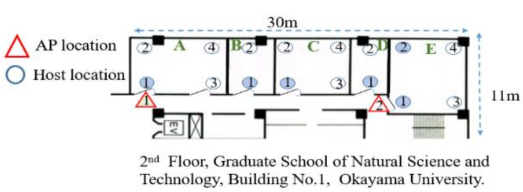
In this section, we present the evaluation results of the minimax approach for 11n at 2.4 GHz in three network fields.

3.4.1. Network Fields and Devices. The outdoor network field in Figure 1 and three network fields in Figure 2 are considered. In each indoor field, the triangle represents the AP location and the circle does the host location. One NEC WG2600HP with four internal antennas is used for the AP. Two laptop PCs with Windows OS for the server and the client host, where the host PC has dual-band Wireless-AC 8260 wireless adapter. Two-stream IEEE 11n MIMO links with the 40MHz channel at 2.4GHz are generated in measurements. *iperf* [12] is used for throughput measurements by generating TCP traffics for 50*sec* with 477*Kbytes* window size and 8*Kbyte* buffer size. It is noted that all the experiments were conducted on weekends to reduce the interferences from other wireless devices and human movements.

Figure 1. Outdoor network field



(a) Network field#1and field#2



(b) Network field#3

Figure 2. Three indoor network fields

3.4.2. Throughput Estimation Results. For the outdoor network field, Figure 3 shows the throughput measurement results when the distance between the AP and the host is changed from 0m to 170m with the interval of 5m. The estimated throughput by the model is also illustrated there.

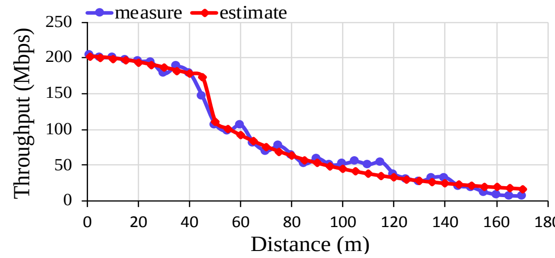


Figure 3. Throughput results in outdoor network field

For the three indoor network fields, we follow the throughput measurement minimization procedure in [13] to reduce the labor cost of throughput measurements. It selects the limited host locations for throughput measurements to optimize the parameter values while keeping the accuracy. Then, five host locations are selected in field#1 and field#2, and six host locations are in field#3. For example, the shaded circle in Figure 2 indicates the selected host location for AP1 respectively.

After throughput measurements, the parameter values of the throughput estimation model were optimized by applying the tool to the results in each field. Table 1 displays the parameter optimization results for 11n at 2.4GHz. The parameter optimization tool [1] is applied to the measurement data in each field. To verify the accuracy of the model, the throughput estimation errors (Mbps), given by the difference between the measured throughputs and the estimated ones, are calculated.

Table 1. Parameter optimization results for 11n at 2.4GHz

Parameter	Out.	field#1	field#2	field#3
P_1	-20	-35.6	-35.2	-34
α	2.4	2.09	2.20	2.10
α_{inc}	2.9	2.19	2.40	2.20
d_{thr}	45	5	5.2	5
corridor wall	~	7	7	7
partition wall	~	8	8	5
intervention wall	~	7	7	~
glass wall	~	~	2	~
elevator wall	~	2	2.8	~
Door	~	3	3	2
diffraction point	~	2	2	1.9
a	202	190	190	194
b	49.5	46.5	50	40
c	6	7	8	6.5

Table 2 summarizes the average, the maximum, the minimum, the standard deviation (SD), and the coefficient of variation (CV) of the estimation errors for all the links between the host locations and each AP. Table 2 indicates the high accuracy of the model. It is noted that the bottleneck host providing the lowest throughput by the model is coincident with the one found by the measurements for any A Plocation. Specifically, in field#1, C4 is the bottleneck host for AP1 and A2 is for AP2. In field#2, C2 is for AP1 andA2 is for AP2. In field#3, D2 is for AP1 and A2 is for AP2.

Table 2. Throughput estimation errors (Mbps) for 11n at2.4GHz

field	AP	Mea.	Estimation errors				
		Avg. TP	avg.	max.	min.	SD	CV (%)
Out.	AP	88.34	6.35	27.44	0.27	5.87	6.64
#1	1	139.63	11.83	36.58	2.11	8.65	6.19
	2	155.36	8.61	24.82	0.39	6.94	4.47
#2	1	141.28	15.78	24.64	3.98	6.34	4.49
	2	166.00	12.29	20.46	2.58	6.65	4.01
#3	1	147.17	12.18	20.32	0.01	5.59	3.80
	2	161.56	9.69	24.80	0.24	7.54	4.67

3.4.3. AP Setup Optimization Results. In the three indoor network fields, the setup condition for each AP is optimized to maximize the throughput of the bottleneck host. To evaluate the effectiveness of the optimization, the average throughput improvement of all the hosts is investigated for each AP. The average throughputs of three cases, 1) the original setup, 2) after the height and orientation optimizations (after H&O), and 3) after all the optimizations (after ALL), are compared, where the improvement rates from 1) to 2), and those from2) to 3) are also calculated.

Table 3 reveals the results which indicate that the height and orientation optimization can improve the average throughput for any AP, while the coordinate shift does not improve it for specific APs, because the multipath effect is not sensitive to the link environment for MIMO.

Table 3. Average throughput improvements of 11n at2.4GHz

field	AP	1)orig. setup (Mbps)	2) after H&O (Mbps)	imp. Rate From 1) (%)	3)after ALL (Mbps)	imp. Rate From 2) (%)
#1	1	139.63	145.94	4.51	145.94	0.00
	2	155.36	179.86	15.77	182.00	1.19
#2	1	141.28	155.59	10.13	160.33	3.05
	2	166.00	174.92	5.37	174.92	0.00
#3	1	147.17	156.38	6.26	156.38	0.00
	2	161.56	169.43	4.87	171.00	0.93

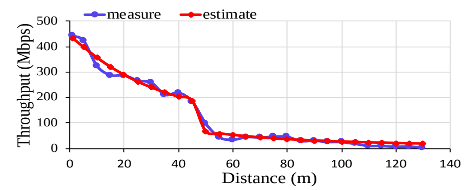
4. Minimax AP Setup Optimization Approach to 11ac at 5GHz

In this section, we present the application of the minimax AP setup optimization approach to WLAN with IEEE 802.11ac at 5GHz.

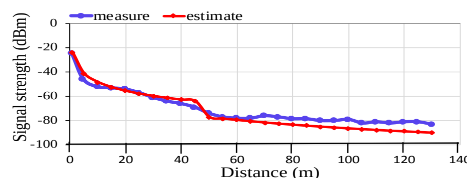
4.1. Throughput Measurement Results

To investigate the performance of IEEE 802.11ac at 5GHz with the 80MHz channel, firstly we conduct the measurements in outdoor and indoor network fields using the same devices and software tools as in Section 3. 4. 1. It is noted that the wireless devices support 11ac. That is, the 80MHz channel is used as the default setting for this commercial AP.

4.1.1. Outdoor Network Field. Figure 4 exhibits the outdoor field measurement and estimated results for the throughput and RSS at the host. It is observed that they sharply drop at around 50m distance, and the throughput is lower than that of 11n at 2.4GHz. Besides, the signal at the host is lost at 140m or larger.



(a) Throughput results



(b) RSS results

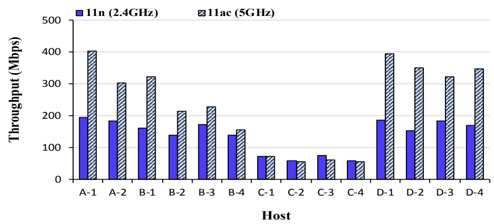
Figure 4. Measurement results in outdoor network field

4.1.2. Indoor Network Fields. Figure 5 shows indoor measured throughput results for AP1 in field#1 and in field#3 in Figure 2. These results demonstrate that when the host is near the AP such as A-1 in both fields, the throughput by 11ac becomes more than double of that by 11n due to the wider channel bandwidth. However, as the distance between the host and the AP becomes larger, the throughput advantage of 11ac will turn out to be smaller due to the higher frequency. Furthermore, at certain host locations such as C-2, C-3 in field#1 and D-2, E-2, E-4 in field#3 where several walls exist along the line-of-sight from the AP, the throughput for 11ac is smaller than that for 11n.

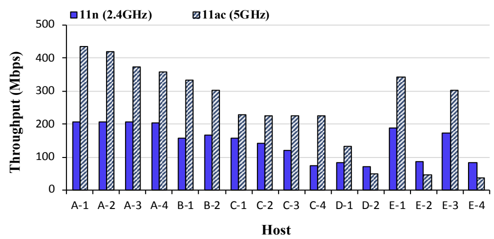
4.2. Throughput Estimation Model

Next, we present the throughput estimation model for the IEEE 802.11ac link at 5GHz.

4.2.1. Exclusion of Slow Host Locations. With the IEEE 802.11ac at 5GHz, the *log-distance path loss model* in the throughput estimation model may not be accurate for a slow link that has a small throughput, because the RSS at the receiver becomes too small due to the larger path loss at the higher frequency. Besides, the throughput range of the 11ac link at 5GHz can be much larger than the11n link at 2.4GHz.



(a) Throughput results for AP1 in field#1



(b) Throughput results for AP1 in field#3

Figure 5. Throughput measurement results for two APs in indoor environments

Therefore, in this paper, any host location whose throughput is smaller than 100*Mbps*, where the big drop of the throughput is observed in Figure 4 (a), is excluded from the scope of the throughput estimation model and the bottleneck host selection in the AP setup optimization. For instance, C-1, C-2,C-3, C-4 for AP1 in field#1 and D-2, E-2, E-4 for AP1 infield#3 are excluded. It is noted that $100Mbps$ is selected from the results in Figure 5.

4.2.2. Model Parameter Optimization Results. The parameters of the throughput estimation model for 11ac at 5GHz are optimized by using the parameter optimization tool with the remaining throughput measurement results in each field. Table 4 shows their values. It is observed that α (path loss exponent factor) becomes larger to α_{inc} at shorter distance threshold $d \geq d_{thr}$ than 11n at 2.4GHz, because of the larger path loss for 11ac at 5GHz. The value of a in the sigmoid function becomes more than double due to the larger throughput range.

Table 4. Parameter optimization results for 11ac at 5GHz

Parameter	Out.	field#1	field#2	field#3
P_1	-24	-35.1	-34	-34
α	2.4	2.00	2.00	2.00
α_{inc}	3.1	2.50	2.50	2.50
d_{thr}	45	5	4	5

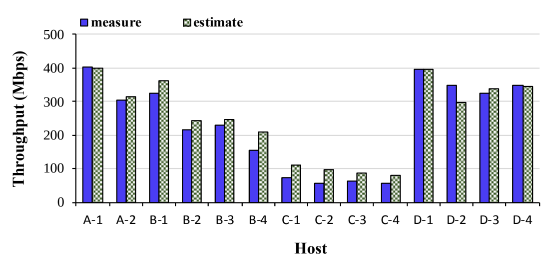
corridor wall	~	8	8	7
partition wall	~	8	8	6
intervention wall	~	7	6	~
glass wall	~	~	2	~
elevator wall	~	2	2	~
Door	~	2.6	2.5	3
diffraction point	~	2	1	1
A	442	445	437	452
B	59	53.5	51.85	42.0
C	9	9	8	9

4.2.3. Throughput Estimation Results. To verify the accuracy of the throughput estimation model, the estimated throughput results are compared with the measurement results. Table 5 summarizes the average, the maximum, the minimum, the standard deviation (SD), and the coefficient of variation (CV) of the throughput estimation errors (Mbps) for each AP. The CV is similar between 11ac at 5GHz and 11n at 2.4GHz for most of the APs. Thus, similar estimation accuracy is maintained for 11ac at 5GHz. Figure 6 shows the measured and estimated throughput results for AP1 in field#1 and field#3. It indicates that the estimation error for the slow host whose throughput is smaller than 100*Mbps* is large.

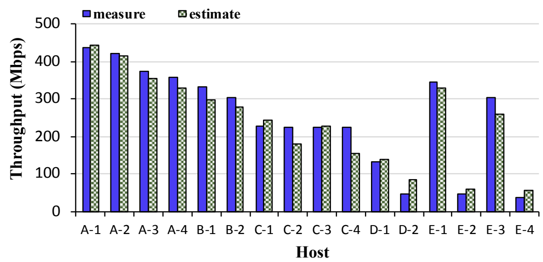
Besides, it is found that for any AP, the bottleneck host found by the model is coincident with the one of the measurements. Specifically, in field#1, B-4 is the bottleneck host for AP1, and A-2 is for AP2. In field#2, C-2 is for AP1, and A-2 is for AP2. In field#3, D-1 is for AP1, and A-2 is for AP2. These results justify the use of the throughput estimation model in the minimax AP setup optimization approach for 11ac at 5GHz.

Table 5. Throughput estimation errors (Mbps) for 11ac at5GHz

field	AP	Mea.	Estimation errors				
		Avg. TP	avg.	max.	min.	SD	CV (%)
Out.	AP	126	11.90	35.64	0.13	9.81	7.79
#1	1	305.20	22.49	53.91	1.88	20.04	6.57
	2	305.43	25.26	66.49	0.02	17.81	5.83
#2	1	298.42	24.91	66.68	2.82	16.31	5.47
	2	319.92	19.63	41.90	4.12	12.16	3.80
#3	1	302.85	23.57	69.73	2.15	20.51	6.77
	2	349.25	33.64	62.33	5.00	15.69	4.49



(a) Throughput results for AP1 in field#1



(b) Throughput results for AP1 in field#3

Figure 6.Measured and estimated throughput results for 11ac at 5GHz

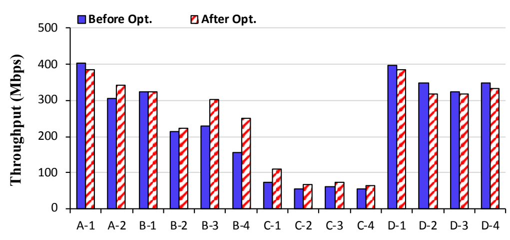
4.3. AP Setup Optimization Results

Finally, we apply the minimax AP setup optimization approach to IEEE 802.11ac at 5GHz in the three indoor net-work fields. Table 6 shows the results of each of the six APs in the three network fields. This table indicates that our approach can improve the average throughput in any field. To elaborate, for AP2 in field#2, the average through- put is improved from 319.92Mbps to 350Mbps, which means 9.4% improvement. Thus, the eff ectiveness of the minimax approach for IEEE 802.11ac at 5GHz is confirmed.

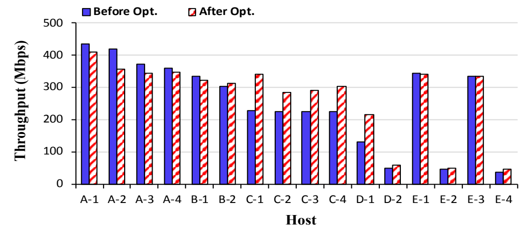
Figure 7 compares the measured throughput results for AP1 in field#1 and field#3 before and after applying the optimal approach. It can be noticed that throughputs after optimization become more averaged among the host locations than those before optimization.

Table 6. Average throughput improvements of 11ac at5GHz

field	AP	1)orig. setup (Mbps)	2) after H&O (Mbps)	imp. Rate From 1) (%)	3)after ALL (Mbps)	imp. Rate From 2) (%)
#1	1	305.20	315.40	3.34	318.60	1.01
	2	305.43	317.29	3.88	317.29	0.00
#2	1	298.42	310.33	3.99	317.75	2.39
	2	319.92	350.00	9.40	350.00	0.00
#3	1	302.85	317.38	4.80	323.31	1.87
	2	349.25	354.13	1.40	354.13	0.00



(a) Throughput improvement results for AP1 in field#1



(b) Throughput improvement results for AP1 in field#3

Figure 7. Throughput improvements by setup optimizations for 11ac at 5GHz

5. Conclusion

In this paper, we presented the application of the minimax AP setup optimization approach to WLAN for IEEE 802.11ac at 5GHz. First, the throughput performance of this WLAN using MIMO links was investigated and compared with the one for 11n at 2.4GHz. Then, the minimax approach is applied with slight modifications, where the effectiveness is confirmed through extensive experiments. In future works, we will apply this approach to various network fields.

6. References

[1] K. S. Lwin, N. Funabiki, C. Taniguchi, K. K. Zaw, M. S. A. Mamun, M. Kuribayashi, and W.-C. Kao, “A minimax approach for access point setup optimization in IEEE 802.11n wireless networks”, Int. J. Netw. Comput., vol. 7, no. 2, pp. 187-207, July 2017.

[2] D. B. Faria, “Modeling signal attenuation in IEEE 802.11 wireless LANs”, Tech. Report, TR-KP06-0118, Stanford Univ., July 2005.

[3] M. S. Gast, 802.11ac: a survival guide, 1st ed., O’Reilly, 2013.

[4] NEC Inc., “WG2600HP manual”, http://www.aterm.jp/ support/manual/pdf/am1-002673.pdf.

[5] L. Kriara, E.C. Molero, and T.R. Gross, “Evaluating 802.11ac features in indoor WLAN: an empirical study of performance and fairness”, Proc. ACM Int. Work. Wireless Netw. Testb. Exp. Eval. Char., pp. 17-24, 2016.

[6] L. Simić, J. Riihijärvi, and P. Mähönen, “Measurement study of IEEE 802.11ac Wi-Fi performance in high density indoor deployments: are wider channels always better? ”, Proc. IEEE Int. Symp. World. Wireless, Mobil. Multi. Netw. (WoWMoM), pp. 1-9, 2017.

[7] D. Newell, P. Davies, R. Wade, P. Decaux, and M. Shama, “Comparison of theoretical and practical performances with 802.11n and 802.11ac wireless networking”, Proc. IEEE Int. Conf. Adv. Inform. Netw. Appl. Work. (WAINA), pp. 710- 715, 2017.

[8] Z. Sun and I. Akyildiz, "Channel modeling and analysis for wireless networks in underground mines and road tunnels", IEEE Trans. Commun., vol. 58, no. 6, pp. 1758-1768, 2010.

[9] D. Kong, E. Mellios, D. Halls, A. Nix, and G. Hilton, "Throughput sensitivity to antenna pattern and orientation in 802.11 n networks", Proc. IEEE Int. Symp. Person. Indoor. Mobil. Radio Commun. (PIMRC), pp. 809-813, 2011.

[10] P. Y. Qin, Y. J. Guo, and C. H. Liang, "Effect of antenna polarization diversity on MIMO system capacity", Proc. IEEE Antenna. Wireless Propa., vol. 9, pp.1092-1095, 2010.

[11] H. C. Lo, D. B. Lin, T. C. Yang, and H. J. Li, "Effect of polarizationon the correlation and capacity of indoor MIMOchannels", Int. J. Antenna. Propa., 2012.

[12] ACD.net, Iperf Speed Testing, http://support.acd.net/wiki/index.php?title=IperfSpeedTesting.

[13] K. S. Lwin, K. K. Zaw, and N. Funabiki, "Throughput measurement minimization for parameter optimization of throughput estimation model", Proc. Chugoku-Branch J.Conf., Oct. 2017.

[14] S. K. Debnath, M. Saha, N. Funabiki, and W.-C. Kao, "A throughput estimation model for IEEE 802.11n MIMO link in wireless local-area networks", Proc. Int. Conf. Comput. Commun. Syst. (ICCCS), pp. 327-331, April 2018.