Application of IEEE802.11ac/n Link Throughput Estimation Model in Holding Access-Point Assignment Algorithm for Wireless Local-Area Network

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Abstract —Currently, various types of *access-points (APs)* and hosts can be used in *IEEE802.11n/ac wireless local-area networks (WLANs)*. Previously, we have studied the *holding AP assignment algorithm* to find an optimal assignment of the holding APs into the network field. Here, the *11n* link throughput is obtained by using simple equations, and the *11ac* link throughput is obtained by multiplying it with a constant value larger than 1, assuming the former link is faster than the latter one. Unfortunately, our experiments found that the 11ac link throughput is more quickly decreased as the link distance increases than the 11n. Thus, our algorithm may produce incorrect solutions in some cases. In this paper, we adopt the *throughput estimation model* for the 11ac/n link as the accurate estimation method in the holding AP assignment algorithm, and confirm the effectiveness of improving the total throughput performance through simulations in three instances using the *WIMNET simulator*.

***Index Terms*—**Wireless local-area network, holding access-point, assignment algorithm, throughput estimation, IEEE802.11ac

I. INTRODUCTION

Recently, various *access-point (AP)* devices are available providing higher performances and advanced functions in *wireless local-area networks (WLANs)*, as the rapid developments of the technologies for device manufacturing, wireless communications, and supporting software. Some AP devices implement faster communication protocols and adopt *multiple-input-multiple-output (MIMO)* with more antennas.

Besides, the variation of client hosts in WLANs has been increased as new mobile devices such as smartphones and tablets have appeared. Traditionally, laptop Personal Computers (PCs) have been mainly used as client hosts. These hosts support different protocols and have the different number of antennas for MIMO.

Currently, *IEEE802.11n* and *11ac* protocols have been practically used in WLANs, which allow the use of MIMO antennas to increase the communication capacity by realizing plural streams between the source node and the destination node [1]-[6].

Basically, the highest communication speed of a wireless link between an AP and a host can be confined by the lower specification of either device of the link. For example, when the AP supports IEEE802.11ac with three antennas and the host does IEEE802.11n with one antenna, they can communicate with the lower specification of 11n with one antenna. In this case, the lower-spec AP supporting 11n with one antenna can be assigned there to provide the same speed, while the higher-spec AP supporting 11ac with three antennas should be assigned at other places where hosts supporting 11ac should be connected.

As a result, the proper assignment in the network field of the holding APs of an organization becomes the important task in designing high-performance WLANs, so that the wireless links between APs and hosts can perform with the highest specifications as best as possible. Therefore, we have proposed the *holding AP assignment algorithm* to find an optimal assignment of the holding APs into the network field [7].

In IEEE802.11 WLAN, a limited number of frequency channels are available. For example, in Japan, 13 channels can be used for 2.4 GHz bands, and 19 channels can be for 5 GHz bands, when 20 MHz band is allocated for one channel. The frequency spectrum of one channel is actually partially overlapped with the neighboring four or five channels, because the difference between the adjacent channels is only 5 MHz. Then, the channel is often called the *partially overlapping channel (POC)*. As a result, the proper channel assignment to each assigned AP is also important to improve the performance of the WLAN by reducing the interference between the APs. Thus, our algorithm finds the channel assignment together, assuming that only one channel can be used for any AP for simplicity [8].

In the previous algorithm, we adopt a simple throughput estimation method. Here, the *11n* link throughput is obtained by using simple equations. Then, the *11ac* link throughput is obtained by multiplying the *11n* link throughput with a constant value larger than 1, assuming the former link is faster than the latter one. However, our throughput measurement experiments for 11ac and 11n links found that the 11ac link throughput is

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more quickly dropped as the distance between them increases than the 11n one [9]-[12]. Actually, when the distance exceeds 45m, the throughput of the 11ac link will be lower than that of the 11n link. Thus, our algorithm using this incorrect throughput estimation may produce incorrect solutions in some cases.

In this paper, we adopt the throughput estimation model for the 11ac link and the 11n link in [9] in the holding AP assignment algorithm. We evaluate the effects in throughput performances through simulations using the WIMNET simulator.

Advantages of this throughput estimation model are as follows: 1) it is possible to describe differences in throughput characteristics coming from the difference of the frequency, 2) it is possible to consider influences of obstacles such as walls along the transmission path, and 3) it is possible to express differences of adopted devices and protocols by parameters of the model.

Some related studies discussing the difference of the frequency in the wireless communication have been reported in literature. In [13], Lu et al. proposed an AP placement method for the passenger car with high speed transmissions using a millimeter wave system. The transmission characteristic of the millimeter wave communication is different from 2.4GHz or 5GHz wireless networks because of the great degradation of the path loss. In [14], Hashim *et al*. proposed a new path loss model for wireless sensor networks using ZigBee.

The rest of this paper is organized as follows: Section II reviews the holding AP assignment algorithm for WLAN. Section III presents the correction of the throughput estimation model for 11ac link. Section IV shows simulation results for evaluations. Section V provides concluding remarks with future works.

II. Review of Holding AP Assignment Algorithm

In this section, we review the holding AP assignment algorithm in our previous study.

A. Background

An organization usually holds various types of AP devices that may offer different performances. A commercial AP device supporting 11ac with four antennas may realize the throughput up to 1.3 Gbps. On the other hand, a soft AP using a low-performance computer supporting 11g with one antenna may realize the throughput only up to 54 Mbps. There is a large difference in the throughput performance among them.

However, to use this high speed communication of 11ac with four antennas, the client host must also support the protocol and the same or more antennas. If the host only supports 11g, the AP also communicates with this host using 11g as the *backward compatibility* in IEEE 802.11 devices. Thus, the holding AP devices should be properly allocated in the network field to improve the performance of WLAN. For example, the holding AP that can offer the high performance should be assigned to the place in the network field.

In our study, we introduce *types* to describe the difference of the combination of the protocol and the number of antennas in a device. Each type is associated with the maximum communication speed. A larger type indicates the combination that offers the higher maximum speed. To allow the backward compatibility, the maximum speed is determined by the smaller type of the devices between the source and destination nodes in a link.

B. Algorithm Formulation

The holding AP assignment algorithm is defined as followings:

- Inputs:
  - Ha_k: the number of holding APs with type k,
  - Hh_k: the number of hosts with type k in the field,
  - La_i: the *i*-th AP location,
  - Lh_j: the *j*-th host location,
  - ht_j: the type of the *j*-th host,
- *Output:*
  - af_i : the assigned type to the *i*-th AP location La_i
  - Ah_j: the connecting AP location of the *j*-th host Lh_j.
  - hf_j: the assigned type to the *j*-th host.
- Constraint:
  - The number of assigned APs with type k must be equal to or less than H_{a_k}.
  - Every host must be connected to one AP placement.
- Objective: to minimize the cost function E in equation (1).

$$\boldsymbol{E = A\sum_{i}\sum_{j\in AP_i}\frac{1}{sa_{ij}} + B\max_{i}\left[\sum_{j\in AP_i}\frac{1}{sa_{ij}}\right]} \quad (1)$$

where A and B represent the constant coefficients ($A = 5$ and $B = 1$ in this paper), AP_i does the set of hosts connected to La_i, $\max_i[\,]$ returns the maximum value on i, sa_{ij} does the link speed between AP La_i and host Lh_j that can be calculated by equation (2):

$$\boldsymbol{sa_{ij} = \begin{cases} \max(S_{ij}^{ac}, S_{ij}^{n}) & (i,j \in 11ac) \\ S_{ij}^{n} & (otherwise) \end{cases}} \quad (2)$$

where S_{ij}^{ac} represents the link speed between La_i and Lh_j by 11ac, and S_{ij}^{n} does the link speed by 11n. The A-term in E represents the total delay time and the B-term does the maximum delay time of one AP when all the hosts are communicating at the same time.

C. Algorithm Procedure

The two-stage heuristic algorithm that is composed of the greedy method and the Simulated Annealing (SA) is presented for the holding AP assignment problem.

1. Initial solution by greedy method: In our algorithm, first, the initial solution is constructed by assigning the currently available AP with the highest performance or type index to the most congested unassigned AP location in the field.
   1) Calculate the standard link speed (sd_{ij}) for every pair of the AP location and the host, assuming the standard-type AP and host, by using the formula in [8] from the layout information of the network
   2) Sort the holding APs in descending order of the maximum link speed.
   3) Calculate the actual link speed (sh_{ij}) for every pair of the AP location and the host considering their types by:

$$\boldsymbol{sh_{ij}} = \begin{cases} \mathbf{max}(\boldsymbol{S_{ij}^{ac}}, \boldsymbol{S_{ij}^{n}}) & (\boldsymbol{i}, \boldsymbol{j} \in \mathbf{11}\boldsymbol{ac}) \\ \boldsymbol{S_{ij}^{n}} & (\boldsymbol{otherwise}) \end{cases} \quad (3)$$

   4) Select the AP location that provides the largest maximum link speed in 3) for each host and associate the host to the corresponding AP location.
   5) Count the number of hosts associated with each AP location in 4) and sorts the AP locations in descending order of this number.
   6) Assign a holding AP to each AP location sequentially:
      a) Select the first unassigned AP location in the sorted list.
      b) Assign an unassigned AP whose type is equal to or larger than the type of any host associated with the selected AP location.
      c) If no such AP exists, assign an unassigned AP whose type has the minimum difference from the type of any host associated with the selected AP location.
   7) Calculate the real link speed sa_{ij} for each pair of an assigned AP and a host by equation (2).
   8) Calculate the cost function E in equation (1).
   9) Save the solution as the best solution S_{best} and the cost E as the best cost E_{best}.
2. Solution improvement by SA: Next, the initial solution is iteratively improved by SA, where the following parameters are used:
   – L_{max} : the local minimum convergence parameter ($L_{max} = 10{,}000$ in the paper)
   – RN : the number of iterations ($RN = 8{,}000{,}000$)
   – T_p : the SA temperature ($T_p = 0.00013$).
   1) Initialize the iteration counter I_{cnt} and the local minimum counter L_{cnt} by 0.
   2) Generate a neighbor solution from the current one.
      a) If $L_{cnt} < L_{max}$, change the associated AP of a host by:
         i. Randomly select one host that can be associated with two or more APs.
         ii. Randomly select one AP that is not currently associated but can be newly associated with the host.
      b) Otherwise, swap the assigned APs between two AP locations by:
         i. Randomly select one AP location.
         ii. Randomly select another AP location that is assigned an AP with the different type.
         iii. Swap the assigned APs between the two AP locations.
   3) Calculate the cost function E^{new} for this neighbor solution and the increase of the cost function $\Delta E = E^{new} - E$ if the new solution is accepted.
   4) If $\Delta E < 0$ or rand1< $\exp\left(-\frac{\Delta E}{T_p}\right)$, accept the neighbor solution as the new solution, where *rand1* returns a 0-1 random number. Otherwise, discard it.
   5) If $E^{new} < E_{best}$, update S_{best} and E_{best} . Otherwise, increment L_{cnt} by 1.
   6) If $I_{cnt} = RN$, output S_{best} and terminate the algorithm. Otherwise, increment I_{cnt} by 1 and go to 2).

D. Channel Assignment

Channel assignment algorithm is applied to the network for which AP placement has been determined in [7].

III. Application of Throughput Estimation Model in Holding AP Assignment Algorithm

In this section, we present the application of the throughput estimation model for the 11ac/n link in the holding AP assignment algorithm.

A. Previous Throughput Estimation Method

In the previous study, we adopted the third-order liner function of the link distance in [8], to estimate the throughput sd_{ij} of the 11n link between AP_i and $Host_j$ using one antenna:

$$\boldsymbol{sd_{ij}} = \begin{cases} -\mathbf{0.0022}\boldsymbol{d_{ij}^3} + \mathbf{0.1853}\boldsymbol{d_{ij}^2} - \mathbf{5.3348}\boldsymbol{d_{ij}} + \mathbf{117.43} \\ \qquad (\mathbf{0} \le \boldsymbol{d_{ij}} < \mathbf{40}) \\ -\mathbf{0.00006}\boldsymbol{d_{ij}^3} + \mathbf{0.0095}\boldsymbol{d_{ij}^2} - \mathbf{1.732}\boldsymbol{d_{ij}} + \mathbf{117.17} \\ \qquad (\mathbf{40} \le \boldsymbol{d_{ij}} < \mathbf{75}) \\ \mathbf{0.000438}\boldsymbol{d_{ij}^3} - \mathbf{0.10955}\boldsymbol{d_{ij}^2} + \mathbf{8.477156}\boldsymbol{d_{ij}} - \mathbf{189.48} \\ \qquad (\mathbf{75} \le \boldsymbol{d_{ij}} < \mathbf{100}) \\ \mathbf{0} \ (\boldsymbol{otherwise}) \end{cases} \quad (4)$$

where d_{ij} represents the distance between AP_i and $Host_j$.

Then, the estimated throughput sd_{ij} is used as the *standard link speed* to estimate the speed of a link between an AP and a host of arbitrary types by the following equation:

$$sa_{ij} = sd_{ij} \frac{\min\left(m_{at_i}, m_{ht_j}\right)}{m_k} \quad (5)$$

where sd_{ij} represents the standard link speed between the AP at La_i and the host at Lh_j, m_{at_i} and m_{ht_j} do the maximum link speed of the assigned AP type at La_i and of the assigned host type at Lh_j, and m_k does the maximum link speed of the standard type (11n in this paper).

B. Throughput Estimation Method

In this paper, we adopt the throughput estimation model in [9]-[10] in the holding AP assignment algorithm for both 11ac and 11n links. The 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.

The model has two steps. In the first step, it estimates the RSS at the host using the *log-distance path loss model* [15], which considers the distance and the obstacles between the AP and the host. In the second step, it converts the RSS to the throughput using the *sigmoid function*.

C. Signal Strength Estimation

The RSS at a host from an AP is calculated by the *log-distance path loss model*:

$$P_d = P_1 - 10\alpha \log_{10} d - \sum_k n_k W_k \quad (6)$$

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 1 m 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 (dBm) 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 [16].

D. Throughput Conversion

Then, the estimated RSS is converted to the throughput or the data transmission speed using the *sigmoid function*:

$$S = \frac{a}{1 + e^{-\left(\frac{(120+P_d)-b}{c}\right)}} \quad (7)$$

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. Table I shows the parameter for 11ac and 11n using in this paper.

E. Model Parameters

The two functions in the throughput estimation model have several parameters whose values affect the throughput estimation accuracy critically. Thus, their values are optimized by applying the *parameter optimization tool* in [11]. Table I shows the obtained parameter values of the model for the 11ac link [9] and for the 11n link [11].

TABLE I: MODEL PARAMETER VALUE

Parameter	11ac	11n
P_1	-34.5	-20.0
α	2.2	2.85
α_{inc}	0.8	0.0
d_{thr}	45.0	0.0
a	442.0	205.0
b	51.0	49.0
c	7.0	4.8

Fig. 1 illustrates the throughput results for 11ac and 11n by the measurements and the new model.

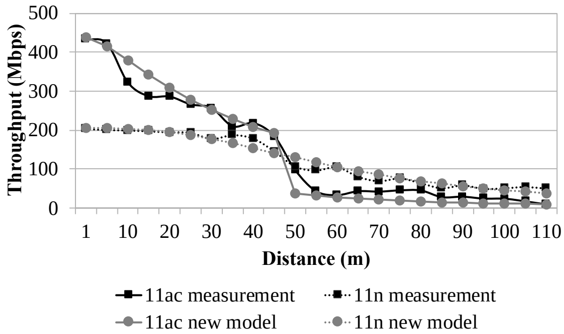


Fig. 1. Throughput result as link distance.

F. Application to Holding AP Assignment Algorithm

The throughput estimation model for the 11ac link and the 11n link is used in equation (2) and equation (3) in the holding AP assignment algorithm.

IV. EVALUATIONS BY SIMULATIONS

In this section, we evaluate the effectiveness of the use of the throughput estimation model for the 11ac/n link in the holding AP assignment algorithm through simulations using the WIMNET simulator [17].

A. Simple Topology Instance

TABLE II: TYPES AND THROUGHPUT RESULT IN SIMPLE INSTANCES

Distance (m)	New		Previous	
	type	throughput (Mbps)	type	throughput (Mbps)
10	ac	371.57	ac	371.57
20	ac	300.80	ac	300.80
30	ac	251.85	ac	251.85
40	ac	209.10	ac	209.10
50	n	128.53	ac	22.58
60	n	105.39	ac	16.50
70	n	85.80	ac	12.58
80	n	68.61	ac	9.92

A pair of an 11ac AP and an 11ac host are prepared for this simple topology. The distance between the AP and the host are changed from 10 m to 80 m with the 10 m interval. Table II shows the obtained link protocol type and the simulated throughputs by applying the proposed algorithm and the previous algorithm.

By the proposed algorithm, the link type is changed from 11ac to 11n after 50 m, because the link speed for 11ac becomes smaller than the link speed for 11n when the link distance is over the 45 m in the new throughput estimation model. As a result, the decrease of the throughput becomes smaller as the link distance increases than the previous model, which is more similar to measured results.

B. Random Topology Instances

Three instances in Table III are considered in the simulations. A square plain field with 150m × 100 m is used, where six AP locations are selected at the field boundary assuming the wall with the same interval. The number of hosts is varied among the instances, where their locations are distributed randomly over the network field. Table III shows the adopted types of the APs and the hosts and their numbers.

TABLE III: TYPES AND NUMBERS OF HOLDING APS AND HOSTS IN INSTANCES

Instance	AP: type (number)	Host: type (number)
1	11ac(3), 11n(3)	11ac(10), 11n(10)
2	11ac(3), 11n(3)	11ac(20), 11n(10)
3	11ac(3), 11n(3)	11ac(30), 11n(10)

Figures 2-4 illustrates the obtained network topology results by the algorithm for the three random topology instances. In each figure, (a) does the result when the previous 11ac link parameters, and (b) does the result when the new parameters are used for the comparison. The *gray circle* represents the *11ac AP*, the *white circle* does the *11n AP*, the *gray square* dose the *11ac host*, and the white square does the *11n host*. The straight line represents the 11ac link, and the dot line does the 11n link.

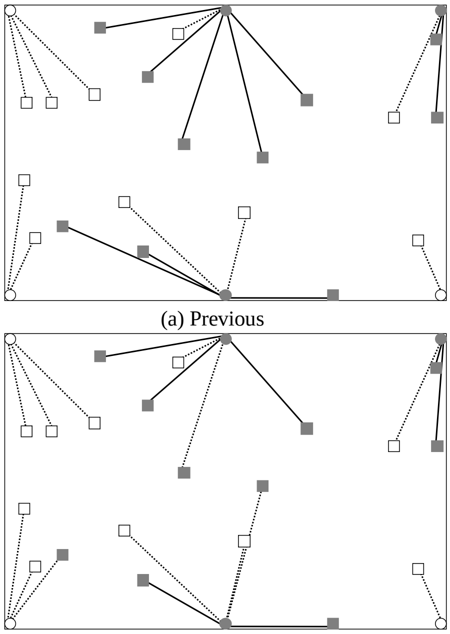
In any instance, the protocol of some hosts with long distances from the associated APs is changed from 11ac to 11n. For example, in Fig. 1, the third host from the left boundary at the bottom side of the field changes the protocol from 11ac to 11n by associated with a different AP. This new AP only supports 11n.

Table IV shows the total throughput results for three instances that are obtained by using the WIMNET simulator. It is noted that the WIMNET simulator uses the throughput estimation model for the 11ac link and the 11n link, because they are correctly reflecting the measured throughput results.

TABLE IV: THROUGHPUT RESULT

Instance	New	Previous
1	364.20	320.25
2	377.55	249.91
3	328.44	220.02

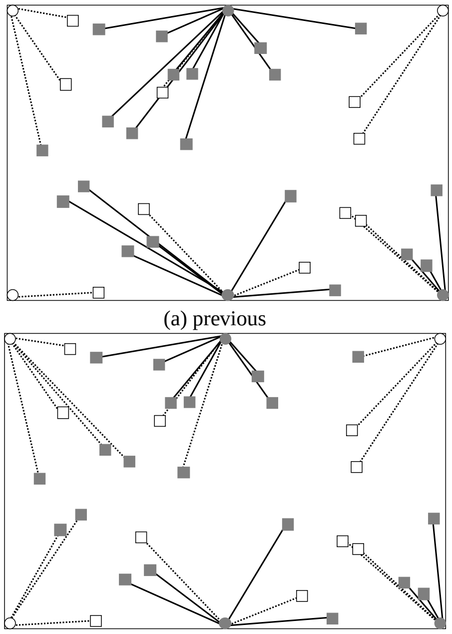
Table IV indicates that the correction of the model parameters improves the throughput by 1.1-1.5 times from the comparison. With the new parameter values, the 11ac link speed becomes smaller than the 11n link speed when the distance between the AP and the host exceeds 45 m. Thus, 11n is used for such links including the links in Fig. 2-Fig. 4 instead of 11ac.



(a) Previous

(b) New

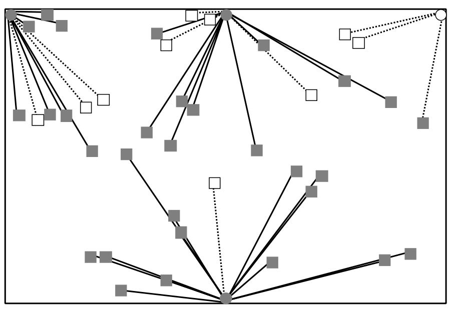
Fig. 2. Algorithm result for *instance 1.*



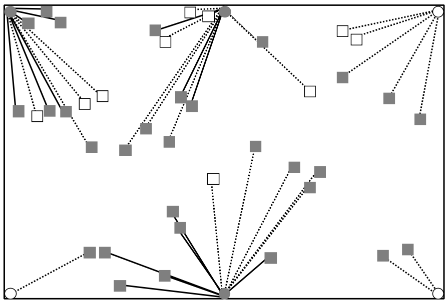
(a) previous

(b) new

Fig. 3. Algorithm result for *instance 2.*



(a) previous



(b) new

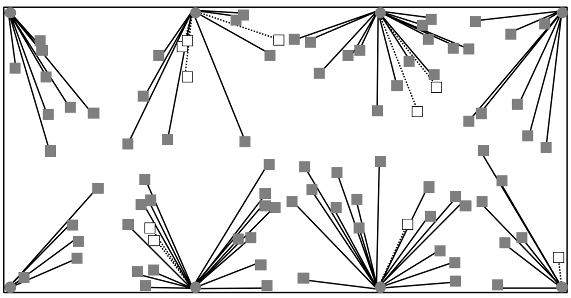
Fig. 4. Algorithm result for *instance 3*.

C. Large Field Topology Instances

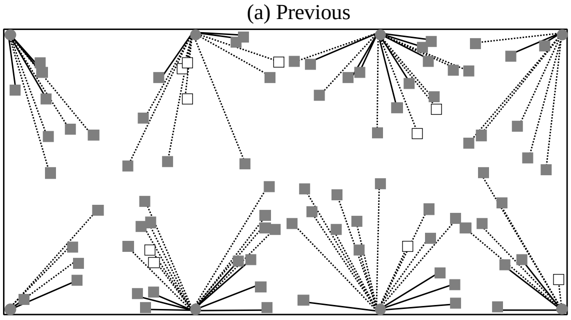
Four instances are considered for simulating large field instances. Here, a square plain field with 300 m × 150 m is used, and eight AP locations are selected at the field boundary assuming the wall with the same interval. The number of hosts is varied among the instances, where their locations are distributed randomly over the network field. Table V shows the adopted types of the APs and the hosts and their numbers.

TABLE V: TYPES AND NUMBERS OF HOLDING APS AND HOSTS IN INSTANCES

Instance	AP: type (number)	Host: type (number)
4	11ac(8)	11ac(50), 11n(10)
5	11ac(8)	11ac(60), 11n(10)
6	11ac(8)	11ac(70), 11n(10)
7	11ac(8)	11ac(80), 11n(10)



(a) Previous



(b) New

Fig. 5. Algorithm result for *instance 7*.

TABLE VI: THROUGHPUT RESULT

Instance	New	Previous
4	414.67	371.58
5	347.71	289.49
6	363.62	353.66
7	427.97	360.06

Fig. 5 shows the algorithm result for instance 7 where the host that is more than 45 m away from the AP is assigned to 11n. Table VI shows the throughput result, where the throughput is improved by using the new throughput estimation model from the previous one.

V. CONCLUSIONS

In this paper, we adopted the two-step throughput estimation model for the 11ac/n link in the holding AP assignment algorithm, and confirmed the effectiveness in improving the total throughput performance through simulations in three instances using the WIMNET simulator. In future works, we will evaluate the algorithm adopting the throughput estimation model through simulations and testbed experiments in various network fields.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

S. Tajima and N. Funabiki conducted the research; S. Tajima and N. Funabiki analyzed the data; S. Tajima, N. Funabiki and T. Higashino wrote the paper; all authors had approved the final version.

REFERENCES

[1] E. Perahia and R. Stacey, "Next generation wireless LANs: throughput, robustness, and reliability in 802.11n," Cambridge Univ. Press, Cambridge, Aug. 2008.

[2] M. Gast. 802.11ac: A Survival Guide. [Online]. Available: http://chimera.labs.oreilly.com/books/1234000001739/index.html

[3] R. V. Nee, "Breaking the gigabit-per-second barrier with 802.11ac," *IEEE Wireless Commun.*, vol. 18, no. 2, pp. 4–4, Apr. 2011.

[4] O. Bejarano, E. W. Knightly, and M. Park, "IEEE 802.11ac: From channelization to multi-user MIMO," *IEEE Commun. Magazine*, vol. 51, no. 10, pp. 84–90, Oct. 2013.

[5] Q. H. Spencer, C. B. Peel, A. L. Swindlehurst, and M. Haardt, "An introduction to the multi-user MIMO downlink," *IEEE Commun. Magazine*, vol. 42, no. 10, pp. 60–67, Oct. 2004.

[6] T. Hiraguri and K. Nishimori, "Survey of transmission methods and efficiency using MIMO technologies for wireless LAN systems," *IEICE Trans. Commun.*, vol. E98-B, No. 7, pp. 1250–1267, Jul. 2015.

[7] S. Tajima, N. Funabiki, and T. Higashino, "A holding access-point assignment algorithm for IEEE802.11 wireless local-area networks," *Int. J. Space-Based and Situated Compu.*, vol. 8, no. 1, pp. 50–58, 2018.

[8] N. Funabiki, W. Maruyama, T. Nakanishi, and K. Watanabe, "An extension of routing tree algorithm considering link speed change in IEEE 802.11n protocol

for wireless mesh network," in *Proc. MENS2012*, Sep. 2012, pp. 600–605.

[9] Z. Wang, K. S. Lwin, N. Funabiki, and M. Kuribayashi, "A study of minimax access-point setup optimization approach in IEEE802.11ac WLAN at 5GHz," *IEICE Technical Report SRW2018-12*, Aug. 2018.

[10] I. M. Kwenga, N. Funabiki, M. Kuribayashi, and R. W. Sudibyo, "A throughput estimation model under two-link concurrent communications with partially overlapping channels and its application to channel assignment in IEEE 802.11n WLAN," *Int. J. Space-Based and Situated Compu.*, vol. 8, no. 3, pp. 123–137, 2018.

[11] K. S. Lwin, Z. Wang, N. Funabiki, M. Kuribayashi, and W. C. Kao, "Applications of minimax access-point setup optimization approach to IEEE802.11ac WLAN at 5GHz," in *Proc. ICAIT2018*, 2018, pp. 132–138.

[12] K. S. Lwin, N. Funabiki, S. K. Debnath, I. M. Kwenga, R. W. Sudibyo, and M. Kuribayashi, "Enhancements of minimax access-point setup optimization approach for IEEE 802.11 WLAN," *Int. J. Space-Based and Situated Compu.*, vol. 9, no. 1, pp. 47–59, 2019.

[13] F. Lu, A. Yamaguchi, K. Takeuchi, and H. Shinbo, "Topographic allocations of MmWave access points inside the passenger car of high speed trains," *J. Commun.*, vol. 14, no. 8, pp. 647–655, 2019.

[14] H. A. Hashim, S. L. Mohammed, and S. K. Gharghan, "Path loss model-based PSO for accurate distance estimation in indoor environments," *J. Commun.*, vol. 13, no. 12, pp. 712–722, 2018.

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

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

[17] N. Funabiki, ed., *Wireless Mesh Networks*, InTech - Open Access Publisher, 2011.

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