A Network Configuration Optimization Algorithm for Wireless Local-Area Network with Three Raspberry Pi Access-Points under Concurrent Communications

Mousumi Saha, Nobuo Funabiki, Rahardhita Widyatra Sudibyo, Sumon Kumar Debnath, Md. Manowarul Islam, Minoru Kuribayashi, and Wen-Chung Kao

***Abstract*—Recently, *Raspberry Pi* has become popular around the world due to the low cost, small size, yet powerful computing ability. Being equipped with an IEEE 802.11n wireless network interface card (NIC), it can be used as a software *access-point (AP)* for the *wireless local-area network (WLAN)*. Previously, we studied the *channel bonding (CB)* implementation using an external wireless NIC for *Raspberry Pi* AP, and the *throughput estimation model* for *concurrent communications* of multiple links with up to three APs under 11 and 13 partially *overlapping channels (POCs)*. In this paper, we propose the *network configuration optimization algorithm* for WLAN with three *Raspberry Pi* APs. Using the throughput estimation model, it determines the use of CB and non-CB, the channel assignment, and the associated hosts for each AP that maximizes the estimated total throughput. The effectiveness of this algorithm is verified through simulations using the *WIMNET* simulator and through testbed experiments in uniform, non-uniform, and two-crowded APs topologies.**

***Index Terms*—IEEE 802.11n, access point, Raspberry Pi, channel bonding, concurrent communication, throughput estimation model, configuration, optimization.**

I. Introduction

Nowadays, the *IEEE 802.11n wireless local area network (WLAN)* has become common as the access medium to the Internet around the world. In WLAN, a host communicates with the Internet using wireless medium through an *access point (AP)*. The *channel bonding (CB)* is one of emerging technologies to enhance the data transmission speed using the 40*MHz* channel [1]. It can increase the number of sub-carriers for data transmissions using *Orthogonal Frequency-Division Multiplexing (OFDM)*, to 108 from 52 in the conventional 20*MHz* channel [2]. As well, the CB also is able to reduce the *guard interval* time and enhance the *frame aggregation*, which further increases the transmission speed. Therefore, CB has been extensively used in 11n WLAN.

Raspberry Pi is popular as a cost-effective, energy saving, and portable computing device since it can be used as a *software AP* for 11n WLAN by running *hostapd* software with its built-in wireless *network interface card (NIC)*. This AP only supports the *non channel bonding (non-CB)* channel, because the built-in *NIC* adapter in *Raspberry Pi* does not support the CB functionality. Therefore, in [3], we studied the CB configuration for the *Raspberry Pi* AP using an external NIC adapter and confirmed that the CB AP improves the throughput performance of the single AP-host communication from the non-CB AP through experiments.

In [3], we found that the *concurrent communication* of multiple APs within the interference range provides different throughput features from the single communication, depending on the adopted NIC adapters and the assigned *partially overlapping channels (POCs)*. In POCs, the adjacent channels are partially overlapped with each other [4]. If a large number of APs are deployed in the network field, the proper assignment of POCs is important to maximize the throughput performance [5]. Our experiment results show that when three APs exist within the interference range, either configuration of 1) one CB AP and two non-CB APs, or 2) three non-CB APs, will provide the best performance.

In [6], [7], we presented the modification of the *throughput estimation model* [8] for the concurrent communication using different wireless NIC adapters and assigned channels under 11 POCs, based on the measurement results. Then, we extended this model for 13 POCs. Here, it is noted that at 2.4 GHz bands, only 11 POCs can be used in some countries [9].

The throughput estimation model estimates the *received signal strength (RSS)* at the host using the *log distance path loss model* and converts the RSS into the throughput using the *sigmoid function*. Then, to consider the interference among APs, this throughput is adjusted by multiplying a constant *reduction factor* given for each combination of APs.

In this paper, we propose the *network configuration optimization algorithm* for 11n WLAN with three *Raspberry Pi* APs by utilizing the modified throughput estimation model. For a given network field, it selects the CB or non-CB, channel assignment, and associated hosts for each AP, to maximize the throughput performance. The effectiveness is evaluated through simulations in six network topologies using the *WIMNET simulator* [10] and testbed experiments in uniform, non-uniform, and two-crowded APs topologies respectively.

The rest of this paper is organized as follows: Section 2 reviews the throughput estimation model. Section 3 proposes the network configuration optimization algorithm. Sections 4 and 5 evaluate the proposal by simulations and testbed experiments respectively. Finally, Section 6

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concludes this paper with future works.

II. Review of Throughput Estimation Model

In this section, we review the throughput estimation model for the concurrent communication of multiple 11n links.

A. Model Overview

The model estimates the throughput or data transmission speed of an 11n link. First, it estimates the *RSS* at the host by using the *log distance path loss model*. Then, it calculates the throughput from that *RSS* using the *sigmoid function*. Both functions have several parameters affecting the estimation accuracy, where the proper values depend on link specifications and network field environments.

B. Log Distance Path Loss Model

The RSS, Pd (dBm), at the host is estimated using the log distance path loss model [11]:

$$P_d = P_1 - 10\alpha log_{10} d - \sum_k n_k W_k \tag{1}$$

where P_1 represents the signal strength at 1m from the AP (source), is the path loss exponent, d (m) does the distance from the AP, n_k does the number of the type-k walls along the path between the AP and the host, and W_k does the signal attenuation factor (dBm) for the type-k wall in the environment. The estimated accuracy of RSS relies on the parameter values, which depend on the propagation environment. In the throughput estimation model, we also consider multipath effect.

C. Sigmoid Function

From the RSS, the throughput S (Mbps) of the link is derived using the sigmoid function:

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

where *a*, *b*, and *c* are the constant parameters that should be optimized.

D. Parameter Optimization Tool

The parameter optimization tool [8] is used to explore the optimal parameter values for the throughput estimation model, which uses the tabu table and the hill-climbing procedure to avoid a local minimum. This tool searches the parameter values that minimize the total throughput estimation error.

E. Modification for Concurrent Communication of Three APs

Our previous study showed that the best total throughput can be achieved in the following two configurations of the three APs for 11 POCs [3]:

1) Three APs are assigned non-CB with channels 1, 6, and 11.
2) One AP is assigned CB with channel 1+5, and two APs are non-CB with channels 1 and 11.

Then, for 13 POCs, the best total throughput can be achieved in the following three configurations of APs:

1) Three APs are assigned non-CB with channels 1, 8, and 13.
2) One AP is CB with channel 9+13, and two APs are non-CB with channels 1 and 5.
3) One AP is non-CB with channel 13 and two APs are CB with channels 1+5 and 9+13.

For all configurations, the total throughput TS (Mbps) can be estimated by the following equations [6]:

$$TS = \begin{cases} (x+y+z)\times\alpha^2 & for\ 11POCs\ 1)\ \&\ 13\ POCs\ 1),2) \\ (x+y)\times\alpha^3 + z\times\gamma & for\ 11POCs\ 2)\ \&\ 13\ POCs\ 3) \end{cases} \tag{3}$$

where *x*, *y* and *z* represent the estimated throughput of each AP by the model for the single communication. Specifically, *x* and *y* does the throughput for the two APs not interfered with each other, and *z* does the throughput for the remaining AP. α and γ are constant reduction factors, where $\alpha = 0.95$ (11POCs) or 0.96 (13POCs) and $\gamma = 0.46$ are used in this paper.

III. Proposal of Network Configuration Optimization Algorithm

In this section, we propose the network configuration optimization algorithm for concurrent communications with three APs.

A. Algorithm Formulation

This algorithm is formulated as follows:

1. Inputs:
   - locations of three APs in the field
   - locations of *N* hosts in the field
   - locations of walls in the field
   - parameters of the throughput estimation model
2. Outputs:
   - CB/non-CB assignment to each AP.
   - channel assignment to each AP.
   - set of the associated hosts with each AP.
3. Objectives:
   - to maximize the cost function *E*:

$$E = E_1 \times E_2 \tag{4}$$

where E_1 represents the minimum average host throughput and E_2 does the total throughput, which can be calculated as follows:

$$E_1 = min\left[\ k\times\frac{1}{\sum\frac{1}{TH_{ij}}}\ \right] \tag{5}$$

$$E_2 = \sum k\times\frac{N_j}{\sum\frac{1}{TH_{ij}}} \tag{6}$$

where TH_{ij} represents the estimated throughput of the link between the i-th host and the j-th AP, k does the reduction factor (α^2, α^3, or γ) in the model, and N_j does the number of associated hosts with the j-th AP.

B. Algorithm Procedure

Then, the algorithm procedure is presented.

1. Initialization

The throughput of the single link communication for each pair of an AP and a host with both CB and non-CB is estimated using the throughput estimation model. Then, for each host, the AP whose link has the largest throughput will be selected for the initially associated AP for both CB and non-CB. After that, the APs are sorted in descending order of the number of initially associated hosts, where the tie is resolved in ascending order of the average host throughput.

2. Assignment for Configuration 1)

For 11 POCs, by the sorted order of the APs, the CB/non-CB and the channel are assigned to each AP for configuration 1):

- 1st AP: CB & channel 1 + 5.
- 2nd AP: non-CB & channel 11.
- 3rd AP: non-CB & channel 1.

Then, for 13 POCs, by the sorted order of the APs, the CB/non-CB and the channel are assigned to each AP for configuration 1):

- 1st AP: CB & channel 9 + 13.
- 2nd AP: non-CB & channel 1.
- 3rd AP: non-CB & channel 5.

3. Assignment for Configuration 2)

For 11 POCs, by the sorted order of the APs, the CB/non-CB and the channel are assigned to each AP for configuration 2):

- 1st AP: non-CB & channel 1.
- 2nd AP: non-CB & channel 6.
- 3rd AP: non-CB & channel 11.

Then, for 13 POCs, by the sorted order of the APs, the CB/non-CB and the channel are assigned to each AP for configuration 2):

- 1st AP: non-CB & channel 1 + 5.
- 2nd AP: CB & channel 9 + 13.
- 3rd AP: non-CB & channel 13.

4. Assignment for Configuration 3)

Additionally, for 13 POCs, by the sorted order of the APs, the CB/non-CB and the channel are assigned to each AP for configuration 3):

- 1st AP: non-CB & channel 1.
- 2nd AP: non-CB & channel 13.
- 3rd AP: non-CB & channel 8.

5. Configuration improvement

For each configuration, the assignment for each AP is improved by repeating the following procedure in the given times:

1) Randomly select one host.
2) Randomly select one objective function among E_1, E_2, and E.
3) Find the AP such that the selected function is maximized if the host is associated with it.
4) Associate the host with this AP if E with this association is not decreased.

6. Solution selection

From the two configuration results, the one that has the larger E is selected as the final solution.

IV. Evaluation by Simulations

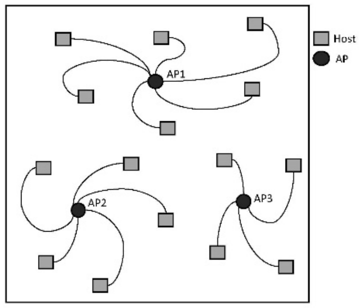
In this section, we evaluate the proposed algorithm by simulations using the WIMNET simulator [8] in one-room and three-room fields with uniformly and non-uniformly distributed 15 hosts. The number of available POCs is set 11 and 13.

A. Simulations in One-Room Field

First, the network field of one 100m × 100m room with three APs is adopted in simulations.

1. Result for uniform topology

Fig. 1 shows the one-room uniform topology. The 15 hosts and the three APs are evenly distributed, where the circle represents the AP and the square does the host. Fig. 1 (a) and (b) also suggests the associations between APs and hosts found by the algorithm for this topology with 11 POCs and 13 POCs respectively.



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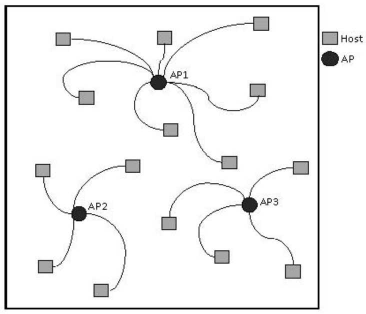


(b)

Fig. 1. (a). One-room uniform topology for simulations with 11 POCs. (b). One-room uniform topology for simulations with 13 POCs.

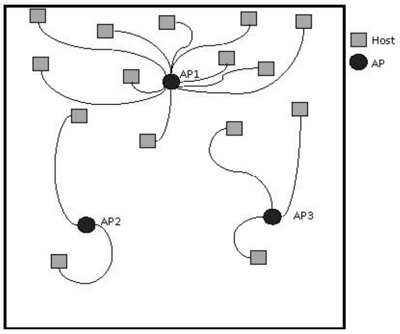
TABLE I: Simulation Results for One-Room Uniform Topology.

case	CB/non-CB (channel) (AP1, AP2,AP3)	cost function E		over. throughput (Mbps)	
		algo.	near.	algo.	near.
11 POCs	3 non-CB (1, 6, 11)	471.61	460.33	94.10	90.99
	CB + 2 non-CB (1+5, 11, 1)	380.27	371.0	91.69	90.17
13 POCs	CB + 2 non-CB (9+13, 5, 1)	767.92	767.58	112.69	110.77
	2CB + 1 non-CB (1+5, 13, 9+13)	605.42	462.42	110.85	109.74
	3 non-CB (1, 8, 13)	511.33	491.32	95.19	93.55

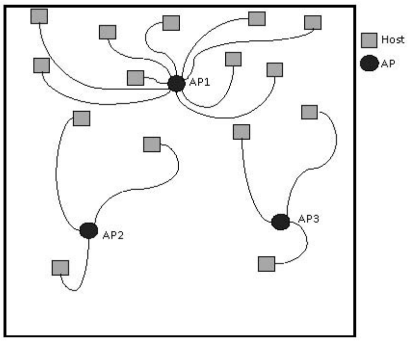
Table I shows the cost function *E* for each configuration found by the algorithm and the overall throughput by the simulator for this topology. For comparisons, it also shows the results for the configurations with the same channel assignments but the nearest host associations. It indicates that for the one-room uniform network topology, the configuration with three non-CB APs for 11 POCs and that with one CB AP and two non-CB APs for 13 POCs by the algorithm provides the highest overall throughput respectively.

2. Result for non-uniform topology

Fig. 2 shows the one-room non-uniform network topology, where the hosts are disproportionately distributed. Table II shows the simulation results for this topology. For this one-room non-uniform topology, the configuration with one CB AP and two non-CB APs provides the highest overall throughput for both 11 and 13 POCs.



(a)



(b)

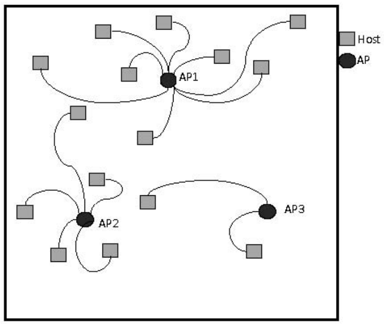
Fig. 2. (a). One-room non-uniform topology for simulations with 11 POCs. (b). One-room non-uniform topology for simulations with 13 POCs.

TABLE II: SIMULATION RESULTS FOR ONE-ROOM NON-UNIFORM TOPOLOGY.

case	CB/non-CB (channel) (AP1, AP2, AP3)	cost function E		over. throughput (Mbps)	
		algo.	near.	algo.	near.
11 POCs	3 non-CB (1, 6, 11)	296.37	245.22	85.15	84.91
	CB + 2 non-CB (1+5, 1, 11)	393.79	359.18	89.28	87.52
13 POCs	CB + 2 non-CB (9+13, 1, 5)	573.59	475.07	108.54	106.49
	2CB + 1 non-CB (1+5, 13, 9+13)	541.62	449.18	107.93	104.98
	3 non-CB (1, 13, 8)	309.04	255.71	91.53	90.04

3. Result for two-crowded APs topology

Fig. 3 shows the one-room two-crowded APs network topology. The hosts are also disproportionately distributed such that two APs can be more crowded by associated hosts than the remaining AP. Table III shows the simulation results for this topology. For this topology, the configuration with one CB AP and two non-CB APs for 11 POCs and that with two CB APs and one non-CB AP for 13 POCs by the algorithm provides the highest overall throughput respectively.



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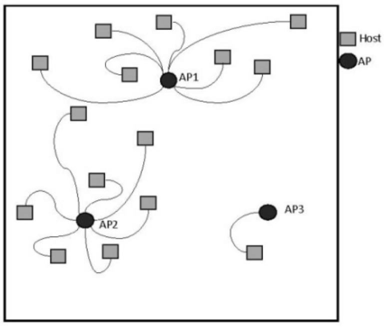


(b)

Fig. 3. (a). One-room two-crowded APs topology for simulations with 11 POCs. (b). One-room two-crowded APs topology for simulations with 13 POCs.

TABLE III: SIMULATION RESULTS FOR TWO-CROWDED APS TOPOLOGY.

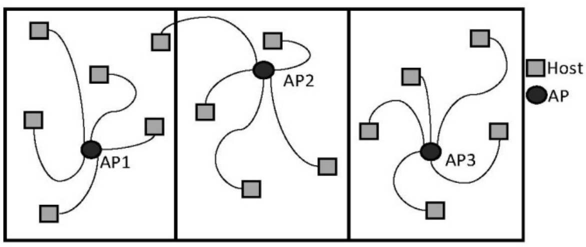
case	CB/non-CB (channel) (AP1, AP2, AP3)	cost function E		over. throughput (Mbps)	
		algo.	near.	algo.	near.
11 POCs	3 non-CB (1, 6, 11)	421.18	373.13	93.50	92.23
	CB + 2 non-CB (1+5, 11, 1)	522.86	490.83	94.16	92.51
13 POCs	CB + 2 non-CB (9+13, 1, 5)	688.73	655.29	112.37	108.75
	2CB + 1 non-CB (1+5, 9+13, 13)	755.82	670.38	112.92	109.83
	3 non-CB (1, 13, 8)	439.19	389.09	98.65	97.81

B. Simulations in Three-Room Field

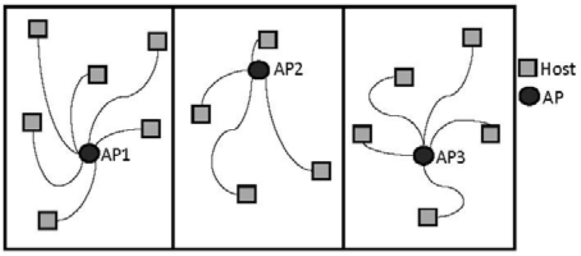
Next, the network field of three 40m × 60m rooms with three APs is adopted in simulations to investigate the performance of the algorithm in multiple rooms.

1. Result for uniform topology

Fig. 4 shows the three-room uniform network topology. Table IV shows the simulation results. For the three-room uniform topology, the configuration with three non-CB APs for 11 POCs and that with one CB AP and two non-CB APs for 13 POCs provides the highest overall throughput respectively.



(a)



(b)

Fig. 4. (a). Three-room uniform topology for simulations with 11 POCs. (b). Three-room uniform topology for simulations with 13 POCs.

TABLE IV: SIMULATION RESULTS FOR THREE-ROOM UNIFORM TOPOLOGY.

case	CB/non-CB (channel) (AP1, AP2, AP3)	cost function E		over. throughput (Mbps)	
		algo.	near.	algo.	near.
11 POCs	3 non-CB (1, 6, 11)	587.89	494.78	94.11	91.15
	CB + 2 non-CB (1+5, 1, 11)	380.59	369.59	92.53	91.03
13 POCs	CB + 2 non-CB (9+13, 5, 1)	754.95	754.95	114.51	114.51
	2CB + 1 non-CB (1+5, 13, 9+13)	609.05	461.69	110.82	108.60
	3 non-CB (1, 8, 13)	515.94	515.94	96.27	96.27

2. Result for non-uniform topology

Fig. 5 shows the three-room non-uniform network topology. Table V shows the simulation results. For the three-room non-uniform topology, the configuration with one CB AP and two non-CB APs achieves the most superior throughput for both 11 and 13 POCs.

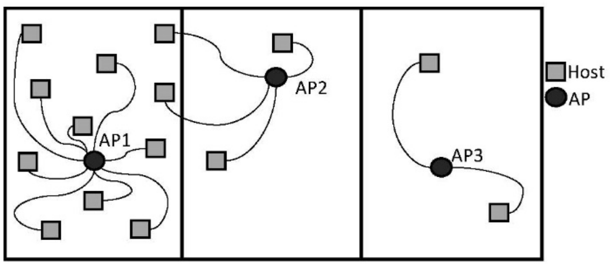


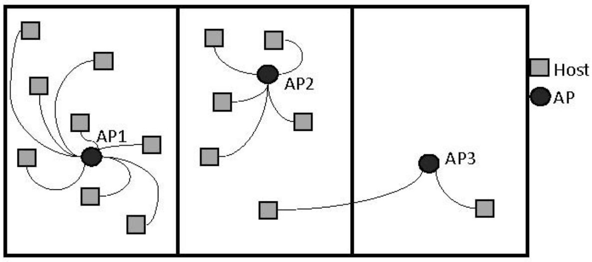
Fig. 5. Three-room non-uniform topology for simulations with 11 POCs and 13 POCs.

TABLE V: SIMULATION RESULTS FOR THREE-ROOM NON-UNIFORM TOPOLOGY.

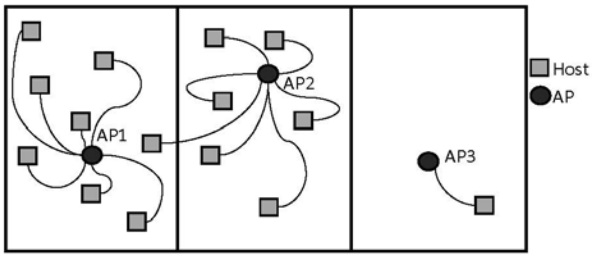
case	CB/non-CB (channel) (AP1, AP2, AP3)	cost function E		over. throughput (Mbps)	
		algo.	near.	algo.	near.
11 POCs	3 non-CB (1, 6, 11)	315.80	313.14	92.66	91.63
	CB + 2 non-CB (1+5, 11, 1)	503.69	456.86	95.58	94.33
13 POCs	CB + 2 non-CB (9+13, 1, 5)	667.87	605.04	115.22	113.50
	2CB + 1 non-CB (1+5, 9+13, 13)	612.54	557.78	109.97	107.59
	3 non-CB (1, 13, 8)	402.15	329.31	92.69	91.44

3. Result for two-crowded APs topology

Fig. 6 shows the three-room two-crowded APs network topology, where two APs can be more crowded. Table VI shows the simulation results. For the three-room two-crowded APs topology, the configuration with one CB AP and two non-CB APs for 11 POCs and that with two CB APs and one non-CB AP for 13 POCs by the algorithm provides the highest overall throughput respectively.



(a)



(b)

Fig. 6. (a). Three-room two-crowded APs topology for simulations with 11 POCs. (b). Three-room two-crowded APs topology for simulations with 13 POCs.

TABLE VI: SIMULATION RESULTS FOR TWO-CROWDED APS TOPOLOGY.

case	CB/non-CB (channel) (AP1, AP2, AP3)	cost function E		over. throughput (Mbps)	
		algo.	near.	algo.	near.
11 POCs	3 non-CB (1, 6, 11)	426.28	406.67	90.53	90.01
	CB + 2 non-CB (1+5, 11, 1)	561.94	503.39	91.57	90.85
13 POCs	CB + 2 non-CB (9+13, 1, 5)	719.82	668.01	110.48	109.66
	2CB + 1 non-CB (1+5, 9+13, 13)	771.59	724.98	113.06	111.75
	3 non-CB (1, 13, 8)	444.52	424.06	98.48	94.06

V. EVALUATION BY TESTBED EXPERIMENTS

In this section, we evaluate the algorithm through experiments using the testbed in two network fields in different buildings at Okayama University, with the uniform, non-uniform, and two-crowded APs topologies.

A. Hardware and Software in Testbed

Table VII shows the specifications of the hardware and software in the testbed.

TABLE VII: HARDWARE AND SOFTWARE SPECIFICATIONS IN TESTBED.

AP	model	Raspberry Pi 3
	CPU	Broadcom BCM2837 @1.2Ghz
	memory	1Gb LPDDR2 900Mhz
	OS	Raspbian
	AP	hostapd
	external NIC	IO-Data WN-AC433UA/TP-LINKTL-WN722N

PC server	model	Fujitsu Lifebook S761/C
	CPU	Intel Core i5-2520M @2.5Ghz
	memory	4GB DDR3 1333Mhz
	OS	Windows 7
	TCP	iperf 2.0.5
PC host type1	model	Toshiba Dynabook R731/B
	CPU	Intel Core i5-2520M @2.5Ghz
	memory	4GB DDR3 1333Mhz
	OS	Windows 7/10
	TCP	iperf 2.0.5
PC host type2	model	Lesance W255HU
	CPU	Intel(R) Core i5 2450M @2.5 GHz
	memory	4GB
	OS	Windows 7/10
	TCP	iperf 2.0.5

B. *Experiments in Building A Field*

First, the network field of two 7m × 6m closed rooms and one open room in Engineering Building 2 (Building-A) is adopted in experiments.

1. *Result for uniform topology*

Fig. 7 shows the Building-A uniform topology. Two hosts are located in D306 and D307 respectively, one host is in Refresh Corner. Each host is associated with the AP in the same room by both the algorithm and the nearest association.

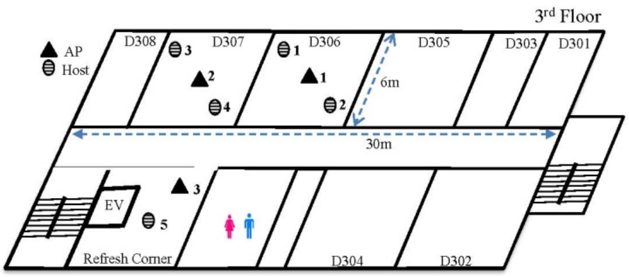


Fig. 7. Building-A uniform topology for experiments.

TABLE VIII: EXPERIMENT RESULTS FOR BUILDING-A UNIFORM TOPOLOGY

case	CB/non-CB (channel) (AP1, AP2, AP3)	cost function E	over. throughput (Mbps) simul..	over. throughput (Mbps) measure.
11 POCs	3 non-CB (1, 6, 11)	1713.81	101.12	90.9
	CB + 2 non-CB (11, 1+5, 1)	1606.34	100.22	85.47
13 POCs	CB + 2 non-CB (9+13, 1, 5)	2108.95	121.87	99.16
	2CB + 1 non-CB (9+13, 1+5, 13)	2062.74	118.91	85.6
	3 non-CB (1, 13, 8)	1787.12	103.25	83.83

Table VIII shows the cost function by the algorithm, and the overall throughput by the simulation and by the experiment for each configuration. It indicates that for this uniform topology in Building-A, the configuration with three non-CB APs for 11 POCs and that with one CB AP and two non-CB APs for 13 POCs by the algorithm provides the highest overall throughput in experiments using the testbed. However, the throughput by the simulation is much larger than that by the experiment, and the difference between the two configurations becomes smaller in the simulation. The consideration of the interference may be insufficient in the simulation, which should be improved in future works.

2. *Result for non-uniform topology*

Fig. 8 shows the Building-A non-uniform topology. Three hosts are located in D306, and one host is in D307 and refresh Corner. Every host is associated with the AP in the same room. Table IX shows the results. For the non-uniform network topology in Building-A, the configuration with one CB AP and two non-CB APs for both 11 and 13 POCs provides the highest overall throughput.

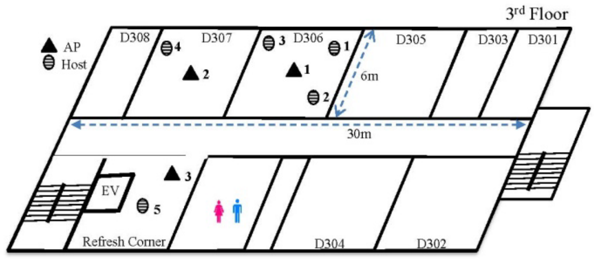


Fig. 8. Building-A non-uniform topology for experiments.

TABLE IX: EXPERIMENT RESULTS FOR BUILDING-A NON-UNIFORM TOPOLOGY

case	CB/non-CB (channel) (AP1, AP2, AP3)	cost function E	over. throughput (Mbps) simul..	over. throughput (Mbps) measure.
11 POCs	3 non-CB (1, 6, 11)	1144.68	100.75	86.84
	CB + 2 non-CB (1+5, 11, 1)	1640.59	100.86	90.3
13 POCs	CB + 2 non-CB (9+13, 1, 5)	2169.72	121.62	91.35
	2CB + 1 non-CB (1+5, 9+13, 13)	2033.39	118.59	84.48
	3 non-CB (1, 13, 8)	1193.65	102.89	80.22

3. *Result for two crowded APs topology*

Fig. 9 shows the Building-A two-crowded APs topology. Three hosts are located in D306 and D307 respectively, one host is in Refresh Corner, and each host is associated with the AP in the same room. Table X shows the results. For the two-crowded APs network topology in Building-A, the configuration with two CB APs and one non-CB AP for 13 POCs provides the highest overall throughput both in the simulation and experiment, as expected.

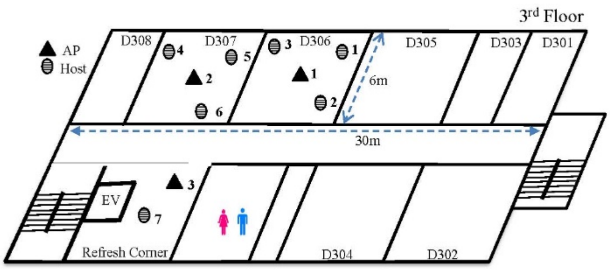


Fig. 9. Building-A two-crowded APs topology for simulations.

TABLE X: EXPERIMENT RESULTS FOR BUILDING-A TWO-CROWDED APS TOPOLOGY

case	CB/non-CB (channel) (AP1, AP2, AP3)	cost function E	over. throughput (Mbps)	
			simul..	measure.
13 POCs	CB + 2 non-CB (9+13, 1, 5)	1387.89	121.42	100.94
	2CB + 1 non-CB (9+13, 1+5, 13)	2010.67	122.55	106.4
	3 non-CB (1, 13, 8)	1175.38	102.74	94.65

C. Experiments in Building B Field

Next, the network field of a 9.5m × 6.5m room, a 4.0m × 6.5m room, and a 6.5m × 6.5m room in Graduate School Building (Building-B) is adopted in experiments.

1. Result for uniform topology

Fig. 10 shows the Building-B uniform topology. Three hosts are located in room A, and two hosts are in room B and room C respectively, and one AP is located in each room. Each host is associated with the AP in the same room. Table XI shows the results. For the uniform network topology in Building-B, the configuration with three non-CB APs for 11 POCs and with one CB AP and two non-CB APs for 13 POCs provides the highest overall throughput.

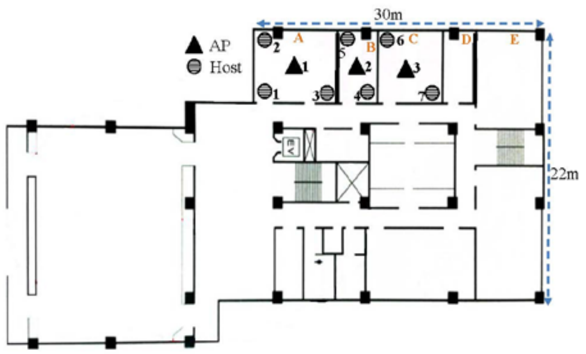


Fig. 10. Building-B uniform topology for experiments.

TABLE XI: EXPERIMENT RESULTS FOR BUILDING-B UNIFORM TOPOLOGY.

case	CB/non-CB (channel) (AP1, AP2, AP3)	cost function E	over. throughput (Mbps)	
			simul..	measure.
11 POCs	3 non-CB (1, 6, 11)	1136.51	100.91	117.77
	CB + 2 non-CB (11, 1+5, 1)	858.15	98.35	104.1
13 POCs	CB + 2 non-CB (9+13, 1, 5)	2114.18	121.69	128.68
	2CB + 1 non-CB (1+5, 13, 9+13)	1831.34	114.66	121.9
	3 non-CB (1, 13, 8)	1185.11	103.05	113.68

2. Result for non-uniform topology

Fig. 11 shows the Building-B non-uniform topology. Four hosts are located in room A, one host is in room B, and two hosts are in room C. Likewise, each host is associated with the AP in the same room. Table XII shows the results. For the non-uniform network topology in Building-B, the configuration with one CB AP and two non-CB APs for both 11 and 13 POCs provides the highest overall throughput.

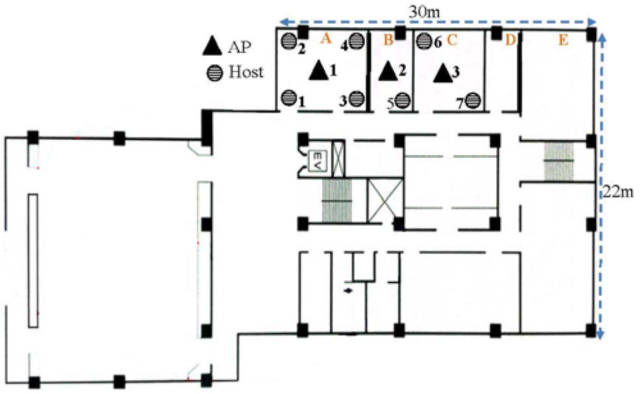


Fig. 11. Building-B non-uniform topology for experiments.

TABLE XII: EXPERIMENT RESULTS FOR BUILDING-B NON-UNIFORM TOPOLOGY

case	CB/non-CB (channel) (AP1, AP2, AP3)	cost function E	over. throughput. (Mbps)	
			simul..	measure.
11 POCs	3 non-CB (1, 6, 11)	854.96	97.58	109.23
	CB + 2 non-CB (1+5, 11, 1)	1226.69	100.07	116.47
13 POCs	CB + 2 non-CB (9+13, 5, 1)	1623.17	121.82	148.48
	2CB + 1 non-CB (1+5, 13, 9+13)	1520.24	118.73	128.96
	3 non-CB (1, 8, 13)	891.53	103.09	124.71

3. Result for Two-Crowded APs Topology

Fig. 12 shows the Building-B two-crowded APs topology. Four hosts are located in room A and room C respectively, and one host is in room B. Likewise, each host is associated with the AP in the same room. Table XIII shows the results. For the two-crowded APs topology in Building-B, the configuration with two CB APs and one non-CB AP for 13 POCs provides the highest overall throughput.

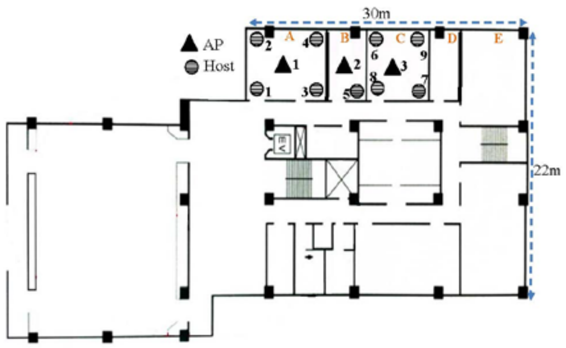


Fig. 12. Building-B two-crowded APs topology for simulations.

TABLE XIII: EXPERIMENT RESULTS FOR BUILDING B TWO-CROWDED APS TOPOLOGY

case	CB/non-CB (channel) (AP1, AP2, AP3)	cost function E	over. throughput (Mbps)	
			simul..	measure.
13 POCs	CB + 2 non-CB (9+13, 5, 1)	1054.17	121.62	136.83
	2CB + 1 non-CB (1+5, 13, 9+13)	1518.92	122.93	168.41
	3 non-CB (1, 8, 13)	890.66	102.95	133.13

VI. Conclusion

This paper proposed the network configuration optimization algorithm for IEEE 802.11n WLAN with three Raspberry Pi access-points, based on the throughput estimation model. It optimizes the use of channel bonding (CB)/non-CB, the channel assignment, and the associated hosts for each AP to maximize the total AP throughput. The effectiveness of this algorithm is verified through simulations and testbed experiments in uniform, non-uniform, and two-crowded APs topologies respectively. Our future works will involve further enhancements of the algorithm and the simulation including the extension to four or more APs, and their evaluations in various network scenarios.

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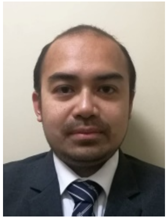

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