Least Congested Channel Recommendation for Uncoordinated Access Point

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***Abstract*— When Telekom Malaysia Berhad (TM) introduces the Wi-Fi residential gateway to its broadband customers, it faces issues related to Wi-Fi signal strength that caused degraded Wi-Fi network performance. The convenience of wireless connectivity has increased the usage of wireless devices such as mobile phones, smart TVs, tablets, wireless speakers and CCTV. The problem with wireless residential gateway arises when there are multiple access points nearby which uses the same channel or overlapping channel which caused signal interferences. Even when the signal strength is high, interference from other nearby access points which uses the same channel or overlapping channel can still cause signal interference. When an access point is using channel that is congested; channels that are used by other access points or channels that overlap with other channels that is used by other access points, network performance in terms of data transmission is degraded. In this paper, we propose a new mechanism to find the best channel in a congested channel environment. The scheme can run on client devices such as wireless laptops, tablets and mobile phones. Once the scheme has suggested the least congested channel, the TM customer will be able to switch to that channel—thus reducing signal interference and improving network performance. Results from tests show that our algorithm to find the least congested channel performed better than auto-channel selection implemented by 10 different residential gateway models provided by TM to the customer.**

***Keywords*— Least congested channel, adjacent-channel, co-channel, received signal strength indicator, Wi-Fi**

I. INTRODUCTION

Nowadays, people always access the Internet via wireless devices at home. Thus to accommodate this behavior, TM offers a Wi-Fi residential gateway, so that when a customer goes home, they can switch the Internet connectivity from 3G or 4G cellular broadband to fixed broadband via Wireless Local Area Network (WLAN) IEEE 802.11 b/g/n/ac standard. With the use of access points (AP) growing in the neighborhood, which may cause interference to wireless connectivity, the number of complaints regarding problems with the wireless connection voiced to the TM Call Center is also increasing.

Today, with the number of subscribers to fixed broadband reaching 2.34 million (or 53% of Malaysian households) [1], the neighborhood is filled with Wi-Fi TM customers using either 2.4GHz or 5GHz band, but the majority still use 2.4GHz. Thus we can see the existence of interference by the AP, especially 2.4GHz.

Based on the record of complaints [2], 4% (1374) of total Trouble Tickets (TT) per month have been categorized as 'Wireless Internet Connection' problems. To solve these issues, the TM Call Center has asked customers to reboot the residential gateway (RG) with the feature of the auto-channel selection enabled. Auto-channel selection is a method that is implemented by the RG manufacturer to switch to a new channel after RG reboot. However, the best channel selection method used is not known because it is proprietary to the RG manufacturer.

When auto channel selection fails to solve the problem, TM had to send a truck roll to the customer's premise. 1.4% (481) [2] of these sent truck rolls solved the customer problem by simply changing the customer's access point channel to another channel. The TM Contact Center struggled to reduce truck rolls because they did not understand the root cause of the problem and how to address it.

Truck roll costs are high; on–site supports costs include technicians (including travel and transition time), vehicles (fuel, depreciation, insurance maintenance, etc.) and opportunity cost. Truck rolls cost ISP, RM400 to RM800 per truck roll [3].

These costs can be reduced by delegating the task of finding the least congested channel (LCC) to the customer itself. By providing wireless troubleshooting tools that are easily accessible to the customer such as web based portals and mobile apps, TM can reduce the number of truck rolls and calls to the TM Contact Center. If at least 70% of voice calls from customers and 1.4% of truck rolls can be reduced, at least a million RMs can be saved per year. At the same time, the RG manufacturer can use the new LCC algorithm in auto-channel selection. While the RG manufacturer can undoubtedly implement the improved LCC algorithm, doing so will increase the RG manufacturing cost as it will require more resources such as memory, storage and firmware updates.

Moreover, our wireless troubleshooting tool can reduce the time it took to solve the problem. At any time, customers can quickly access and launch the tool if they believe their internet connection works slower than it should. When the tool recommends the best channel, the customer can switch to a new channel manually or automatically. For switching channels automatically, there is integration work needed to be done between the LCC apparatus and the RG configuration.

We hope that this tool will improve customer experience by reducing wireless Internet connection problems that are caused by congested channels. In addition, there is no additional cost for the customer to use this tool. After the test, if the customer needs more information regarding the result, he/she may call the TM Contact Center. Hopefully this will build a healthy relationship between TM and its customers and improve customer perception of TM.

In this paper, we will discuss the related channel allocation mechanism, propose a new LCC algorithm, experiment setup for a comparison between the new LCC and selected RG which is supplied by TM and has the auto-channel selection, and follow with a discussion and conclusion.

II. Related Work

Wi-Fi is one type of wireless communication system and has been documented by the IEEE 802.11 standard protocol specification. There are several types of IEEE 802.11 that were developed for a specific objective— namely, 802.11a, 802.11b, 802.11ac, 802.11g and 802.11n. Since 2009, TM provides a wireless router with a specification of 802.11 b/g/n/ac. According to the author [4], there are four major factors that can disrupt Wi-Fi performance, which are physical objects (such as trees, masonry, buildings, and other physical structures), radio frequency interference (such as wireless technologies including 802.11, cordless phones, microwaves that use an RF range of 2.4GHz), electrical interference (such as computers, refrigerators, fans or any other motorized devices) and environmental factors (such as fog).

Common factors that can cause degradation of the received signal strength indicator (RSSI) are the distance between access point and wireless device and the obstructions between access points and Wi-Fi device. The farther the Wi-Fi device from the AP, the lower the RSSI. Our findings based on 10 different RG models showed that the RSSI will be lower than -55 dBm when reaching a distance of 50 to 90 meters even when there is line of sight [5]. In addition, to get above -45 dBm on line of sight, the best distance is less than 10 meter all those RG. Obstruction obstacles like walls (e.g., stone, concrete, brick), glass, metal or water may also reduce the quality of radio signals between the RG and Wi-Fi devices. Thus, the customers will experience the symptoms of slow Internet experience and intermittent connection problems. It is difficult for TM to determine the obstruction obstacles or ask the customer to remove the obstacle. One way to improve the signal quality is by recommending that the customer use a Wi-Fi repeater to reduce the distance between the Wi-Fi device and the RG.

Apart from the problems of distance and obstacles, there are two types of interference: AP and non-AP. AP interference consists of three types of interferences ([6],[7]): co-channel, adjacent-channel and self. AP interference occurs when multiple access points are nearby and the channels used by the access points overlap. Co-channel interference comes from other APs that use the same channel to communicate, while adjacent-channel interference comes from APs that use different channels overlapping with each other. Self-interference occurs when one or more client devices or APs connected to an AP or AP repeater use the same or different channel.

Non-AP interference comes from electromagnetic signal by non-wireless devices such as a microwave, wireless baby monitors, cordless phones, alarm systems, etc. which mainly use the 2.4GHz frequency of channel 1 to 13 [8]. While the interference does not degrade [9] the RSSI, it does weaken data transmission performance. The effect can be observed via wireless measurable performance metrics such as loss, throughput, latency and jitters. The customer experiences slow Internet and intermittent connection problems.

There are two methods of managing the WLAN— centrally managed and uncoordinated AP [10]. TM has 2.34 million subscribers nationwide, and it seems that TM can benefit from the use of centralized management. Although each Wi-Fi AP that resides in customer premises can be accessed and controlled remotely by TM, customers also have the ability to change the channel independently. Examples of central managed schemes that have been proposed include Graph Edge Coloring [6], Centralized Loadaware ([8],[11],[12]), Genetic Algorithm [9], Conflict Set Coloring [13], Neighbor Partitioning Scheme [12], and Prioritized Approach-map [14]. These methods more likely can be used to manage multiple APs such as hot spot or in-mesh network. However, they are not suitable for an AP managed by the customer at home.

The second method, uncoordinated AP, is more suitable, as each AP can be accessed only by its owner, and the customer is not able to access other customers' APs except with the consent of his/her neighbors. However, some APs that are detected are likely to be supplied by TM, and the same RG authentication is used. There are several studies for the best channel in an uncoordinated AP system such as Least Congested Channel Search [15], Channel Scoring [16], Adaptive Channel Allocation Algorithm [7] and the Weighted Coloring Approach [17].

We proposed a method that is likely similar to Channel Scoring with methods that perform a rating on each channel. The highest score will determine the channel assignment. The difference is the method proposed by [16] uses regression analysis to estimate the performance level of each channel based on the delay and throughput, while our proposed design takes into account the RSSI, co-channel and adjacentchannel.

In reality, the eco-system of wireless connectivity is more complicated with many more APs coexisting either in the same managed or uncoordinated domains. Effective channel assignment is crucial for successful deployment and operation of IEEE 802.11-based WLANs. Whether to implement the channel assignment method inside the RG or in client devices, the ISP needs to consider the cost benefit to the customer and ISP itself. If the ISP is willing to absorb the higher cost of providing RG that can automatically choose the best channel, it might solve the problem of finding the LCC for the customer.

III. Proposed Design

We proposed uncoordinated principles to find LCC for AP, where we will observe from the client device the nearby APs and then estimate the LCC. We designed a scoring channel (Link Score) method, where the channel with the highest score will be selected as LCC. There are 5 main aspects used as input to calculate Link Score, which are the channel priority, RSSI, adjacent-channel, co-channel and weighted.

A. Channel Priority

Currently, TM provided RG have channel 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13 for the 2.4GHz frequency band, while for 5GHz RG, we consider the following channels as non-overlapping channels; 36, 40, 44, 48, 52, 56, 60, 64, 149, 153, 157, 161 and 165. Channel 1, 6, and 11 are the only channels in the 2.4 GHz spectrum that does not overlap with one another. Therefore, channel 1, 6 and 11 will be set priority higher than channel 2,3,4,5,7,8,9,10,12 and 13, whereas all channels used in 5GHz band as nonoverlapping channels. We proposed channel priority ranging from 1 to 10.

B. RSSI

The RSSI of each SSID will be taken into account by the LCC algorithm. In this case there are three RSSI values will be taken, namely, maximum RSSI, second highest RSSI and maximum RSSI of adjacent-channel. The maximum RSSI value will be significantly giving a high impact compared to that lower RSSI value in term of interference. APs with RSSI value lower than -85dBm will be removed from the Link Score calculation. For adjacent-channel we consider the channel width of 20 or 40 MHz to overlap other channel as shown in Table 1. Based on the example in Figure 1, we produce Table 2 which RSSI will be adopted in the calculation Link Score on each channel. In scenario Figure 1, the channel width is 20MHz. Therefore, interference to Channel 1 is Channel 2 and 3, while the disruption to Channel 2 is channel 1, 3 and 4 and so on according to Table 1.

TABLE 1. ADJACENT-CHANNEL IN 2.4 GHZ

Channel	Adjacent-channel width 20MHz	Adjacent-channel width 40MHz
1	2,3	2,3,4,5,6,7
2	1,3,4	1,3,4,5,6,7,8,
3	1,2,4,5	1,2,4,5,6,7,8,9
4	2,3,5,6	1,2,3,5,6,7,8,9
5	3,4,6,7	1,2,3,4,6,7,8,9
6	4,5,7,8	2,3,4,5,7,8,9,10
7	5,6,8,9	3,4,5,6,8,9,10,11
8	6,7,9,10	4,5,6,7,9,10,11,12
9	7,8,10,11	5,6,7,8,10,11,12,13
10	8,9,11,12	5,6,7,8,9,11,12,13
11	9,10,12,13	5,6,7,8,9,10,12,13
12	10,11,13	5,6,7,8,9,10,11,13
13	11,12	7,8,9,10,11,12

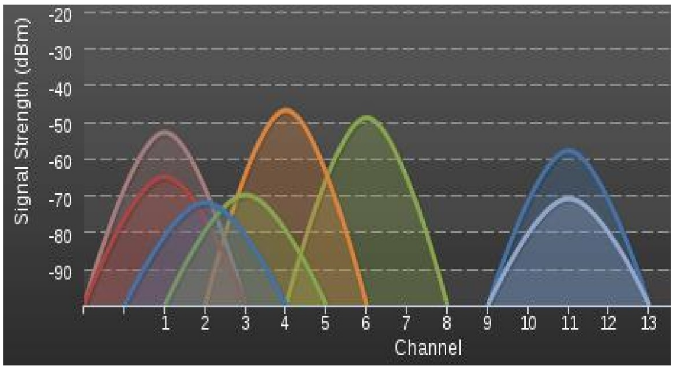

Figure 1. Eight (8) AP 2.4 GHz which occupied channel 1,2,3,4,6, and 11 and the channel width is 20 MHz

TABLE 2. RSSI OBSERVATIONS IN THE SAME CHANNEL AND THE ADJACENT-CHANNEL

Channel	Maximum RSSI per channel (in dBm)	Second highest RSSI per channel (in dBm)	Maximum RSSI adjacent-channel per channel (in dBm)
1	-53	-65	-70
2	-72	0	-47
3	-70	0	-47
4	-47	0	-49
5	0	0	-47
6	-49	0	-47
7	0	0	-49
8	0	0	-49
9	0	0	-58
10	0	0	-58
11	0	0	0
12	0	0	0
13	-58	-71	0

C. Adjacent-channel

Adjacent-channel is referring to overlapping channels as described in Table 1. In this aspect, we consider two metrics, which are RSSI and total adjacent-channel. Based on Figure 1 and Table 1, we developed Table 3. The metric 'maximum RSSI adjacent-channel' in Table 2 and Table 3, should be identical.

TABLE 3. OBSERVATION RSSI AND TOTAL ADJACENT-CHANNEL PER CHANNEL

Channel	Maximum RSSI adjacent-channel per channel (in dBm)	Total adjacent-channel per channel
1	-70	2
2	-47	4
3	-47	4
4	-49	3
5	-47	3
6	-47	1
7	-49	1
8	-49	1
9	-58	2
10	-58	2
11	0	0

D. Co-Channel

In this aspect, we will count the number of APs that use the same channel, and at the same time we also obtained two highest RSSI on each channel which has been shown in Table 2. If we refer Figure 1, the total number of APs per channel is given in Table 4.

TABLE 4. TOTAL AP PER CHANNEL

Channel	1	2	3	4	5	6	7	8	9	10	11
Total adjacent-channel per channel	2	1	1	1	0	1	0	0	0	0	2

E. Weighted

Following the aspects: priority channel, RSSI, adjacent-channel and co-channel, which metric must be emphasized. Studies shows that interference from adjacent-channel is more damaging than the interference from co-channel ([18],[19]). Thus we weighted the metrics associated with adjacent-channel lower than the co-channel. Weighted value must be in the ratio of 1 or 100 %. Table 5 shows the proposed weights.

TABLE 5. EXAMPLES OF THE WEIGHTED

	Weighted, % (ratio)
Priority per Channel (PpC)	15%(0.15)
Maximum RSSI per Channel (MaxRSSIpC)	20%(0.20)
Second highest RSSI per Channel (2ndRSSIpC)	15%(0.15)
Total Aps per Channel (TotAPpC)	20%(0.20)
Total adjacent-channel per Channel (TotAdjCpC)	15%(0.15)
Maximum RSSI adjacent-channel per Channel (MaxRssiAdjCpC)	15%(0.15)

F. LCC Algorithm

This section will elaborate the details algorithm as follows:

a. System will observe current frequency band of AP in use by customer either 2.4GHz or 5GHz. If the 5GHz frequency is used, then the system will do the calculation for 5 GHz channel assignment.
b. The system will scan all nearby AP from a wireless device. Properties which will be observed for each AP includes channel width, channel and RSSI sampling for 30 seconds period. If Step 1 state channel allocation for the 5GHz frequency, then all AP 2.4GHz will be removed from the observations. Only 5GHz only be discerned.
c. Once scanning is completed, all RSSI points will be averaged per AP.
d. System will not consider the current connected AP properties. Therefore, connected AP will be excluded from Link Score calculation.
e. The system will remove any AP with signal strength below -85dBm. Based on [20] study shows that the packet reception rate will start to degrade drastically from 0.85 (85%) to 0.0 (0%) and reach -100dBm. For the RSSI above -85dBm, the packet reception rates are all similar and near from 0.85 (85%) to 1 (100%). Another result by [21] show almost similar result which is the packet reception rate is 0.85 to 1 whenever above -87dBm. This threshold and below will not interfere with others channel. We proposed to use this filtering threshold to speed up the calculation and remove unnecessary device resource usage to calculate the Link Score.
f. For each Channel n, system will do following step
    I. declare and set Weighted, w {PpC, MaxRSSIpC, 2ndRSSIpC, TotAPpC, TotAdjCpC, MaxRSSIAdjCpC} n
    II. declare and set Priority of Channel n (PpCn)
    III. declare and set MaxRSSIpCn, if no AP use Channel n then set MaxRSSIpCn = 0
    IV. declare and set 2ndRSSIpCn, if the number of AP use Channel n is less than 2, then set 2ndRSSIpCn =0
    V. declare and set TotAPpCn, if no AP use Channel n, then set TotAPpCn =0
    VI. declare and set TotAdjCpCn, if no other Channel overlapping to Channel n, then set TotAdjCpCn =0
    VII. declare and set MaxRSSIAdjCpCn, if no other Channel overlapping to Channel n, then set MaxRSSIAdjCpCn =0
    VIII. system will calculate the Link Score of Channel n using formula (1)

Link Score = M1+M2+M3+M4+M5+M6 (1)

where,

M1 Σ *PpCn* * *wPpCn*;

M2 Σ If *MaxRSSIpCn* == 0, then M2 =1, else M2 = ((1/ *MaxRSSIpCn*) * *wMaxRSSIpCn*);

M3 Σ If *2ndRSSIpCn* == 0, then M3 =1, else M3 = ((1/ *2ndRSSIpCn*) * *w2ndRSSIpCn*);

M4 Σ If *TotAPpCn* == 0, then M4 =1, else M4 = ((1/ *TotAPpCn*) * *wTotAPpCn*);

M5 Σ If *TotAdjCpCn* == 0, then M5 =1, else M5 = ((1/ *TotAdjCpCn*) * *wTotAdjCpCn*);

M6 Σ If *MaxRSSIAdjCpCn* == 0, then M6 =1, else M6 = ((1/ *MaxRSSIAdjCpCn*) * *wMaxRSSIAdjCpCn*);

g. The channel with the highest Link Score is determined as the LCC.
h. In some cases, maybe the highest Link Score shared by two or more Channel, therefore the system will display all Channels with highest Link Score as a least congested channel.

IV. Experiment Setup

In this controlled experiment, we will compare the proposed algorithm with 10 different models of RG (supplied by 4 manufacturer) which are supplied by the TM to customers from year 2009 to 2016.

For the purposes of this experiment, we calculate Link Score using excel files only. For the purposes of AP and properties observations, we use InSSIDer Office [22]. We need to ensure that the AP used is stable in terms of signal strength and channel that does not change around the device under test (DUT) at the time of the experiment.

The DUT is a 10 different model of RG and a desktop model that ran inSSIDer Office. Observations from InSSIDer Office will be transferred to excel manually only. All AP and the DUT is set to use frequency band 2.4GHz, 20Mhz channel width, security type WPA and IEEE 802.11n protocol.

Figure 2 shows a graph channel and RSSI of AP involvement in the simulation. Based on the observation, we develop Table 6 and Link Score has been calculated and proposed Channel 6 [the Link Score is 4.573 as shown in Table 7] as the least congested channel. So our targeted channel is Channel 6.

To find out whether the RG will select the best channel if the RG channel selection set to auto, we did an experiment on ten different RG models (DUT). In this experiment, channel selection for each RG are set to auto and the RG are rebooted 6 times. Time interval between each reboot is 3-5 minutes. Selected channel after each reboot are recorded. InSSIDer tool are used to monitor the selected channel.

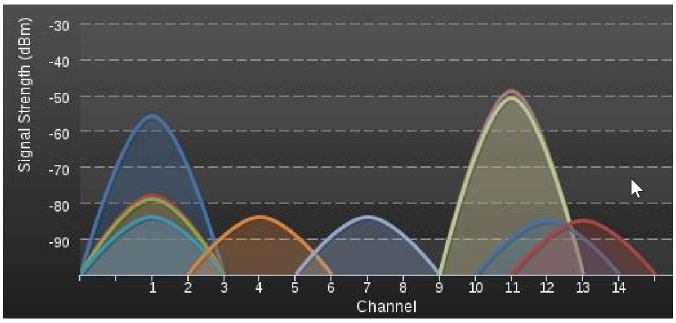

Figure 2. Channel graph shows the number of AP with RSSI

TABLE 6. To declare and set A=*PpCn*, B=*MaxRSSIpCn*, C=*2ndRSSIpCn*, D=*TotAPpCn*, E=*TotAdjCpCn* and F=*MaxRSSIAdjCpCn*

Channel	A	B	C	D	E	F
1	10	-56	-78	5	0	0
2	1	0	0	0	6	-56
3	1	0	0	0	6	-56
4	1	-84	0	1	0	0
5	1	0	0	0	2	-84
6	10	0	0	0	2	-84
7	1	-84	0	1	0	0
8	1	0	0	0	1	-84
9	1	0	0	0	2	-49
10	1	0	0	0	3	-49
11	10	-49	-51	-51	2	-85

V. Results and Discussion

From the result, all the RGs are capable of switching channels. Some of the RGs manage to change to the targeted channel (LCC calculated by our algorithm) after a few reboots. From Table 8, RG1, RG2 and RG3 only switch between two channel. For other RG, it seems that the channels are selected randomly. Unlike other RG, RG8 able to select least congested channel after a reboot. However, we have to find out how the channel selection method are devised and whether it consider co-channel or adjacent channel in its calculation. For further investigation of auto-channel selection behavior of RG8, we conducted a simple test with different scenario to get a new targeted least congested channel. In this setup only two devices involved: AP x and RG8. The distance between these two RG is less than 1 meter. The PpCn in the algorithm is set to 10 for Channel 1, 6 and 11, whereas others Channel set in 1. In the beginning the RG8 is set to Channel 1. We changed four times the Channel of AP x as follows

a. first attempt: AP x set into a fixed channel 3, then reboot RG8, the channel switch to 7; Based on proposed algorithm, the recommendation is Channel 11.
b. third attempt: AP x remain a fixed channel 9, then reboot RG8, the channel switch to 6; Based on proposed algorithm, the recommendation is Channel 1.

c. fourth attempt: AP x set into a fixed channel 8, then reboot RG8, the channel switch to 6; Based on proposed algorithm, the recommendation is Channel 1.

d. fifth attempt: AP x set into a fixed channel 3, then reboot RG8, the channel switch to 6; Based on proposed algorithm, the recommendation is Channel 11.

TABLE 7. LINK SCORE FOR EACH CHANNEL 1 TO CHANNEL 11

Channel	M1	M2	M3	M4	M5	M6	Link Score
1	10*0.15=1.5	(1/-56)*0.20= -0.004	(1/-78)*0.15=-0.002	(1/5)*0.20=0.04	1	1	3.534
2	1*0.15=0.15	1	1	1	(1/6)*0.15=0.025	(1/-56)*0.15=-0.003	3.172
3	1*0.15=0.15	1	1	1	(1/6)*0.15=0.025	(1/-56)*0.15=-0.003	3.172
4	1*0.15=0.15	(1/-84)*0.20= -0.002	1	(1/1)*0.20=0.20	1	1	3.348
5	1*0.15=0.15	1	1	1	(1/2)*0.15=0.075	(1/-84)*0.15= -0.002	3.223
6	10*0.15=0.15	1	1	1	(1/2)*0.15=0.075	(1/-84)*0.15= -0.002	4.573
7	1*0.15=0.15	(1/-84)*0.20= -0.002	1	(1/1)*0.20=0.20	1	1	3.348
8	1*0.15=0.15	1	1	1	(1/1)*0.15=0.15	(1/-84)*0.15= -0.002	3.298
9	1*0.15=0.15	1	1	1	(1/2)*0.15=0.075	(1/-49)*0.15= -0.003	3.222
10	1*0.15=0.15	1	1	1	(1/3)*0.15=0.05	(1/-49)*0.15= -0.003	3.197
11	10*0.15=0.15	(1/-49)*0.20- -0.004	(1/-51)*0.15= -0.003	(1/2)*0.20=0.10	(1/2)*0.15=0.075	(1/-85)*0.15= -0.002	1.666

TABLE 8. RG CHANNEL SELECTION AFTER REBOOT

Model	Brand	Channel after reboot					
		1st	2nd	3rd	4th	5th	6th
RG1	MAC1	4	3	3	3	4	3
RG2	MAC2	2	1	1	2	1	2
RG3	MAC3	3	2	3	2	2	3
RG4	MAC4	1	1	5	1	9	1
RG5	MAC4	8	8	8	7	8	8
RG6	MAC3	11	6	11	11	6	11
RG7	MAC3	6	6	11	9	6	11
RG8	MAC4	13	6	6	13	6	6
RG9	MAC4	10	10	1	1	9	1
RG10	MAC3	7	9	11	4	4	6

From the result, we found that for the RG8, the autochannel selection method does not really chose the least congested channel. As for the testing, we manually change the channel for the SSID named ‘AP x’ to disrupt the selected channel by RG8 to check whether the RG8’s selects the best channel at the next reboot. For example, when we reboot the RG8 for the 5th time, the RG8 should choose channel 11 where there is no overlapping channel. From here we can see that RG8 auto-channel selection mechanism is not working really well to select the best channel. From these two simple experiments we can conclude that all the RGs able to switch channels and does not consider the adjacent-channel.

VI. CONCLUSION AND FUTURE WORKS

In reality, the WLAN eco-system is more complicated, with many more APs coexisting either in the centralized management or in uncoordinated management. We proposed a new scheme to calculate the LCC by considering the RSSI, co-channel and adjacent-channel. The experiment result shows that the proposed LCC algorithm suggested a better channel comparing an auto-channel selection implemented by 10 different RG models provided by TM to the customer. Efficient channel assignment is crucial for successful deployment and operation of IEEE 802.11 - based WLANs.

For future work, we want to study and consider electromagnetic interference to be included in LCC algorithm. Beside that we want to do comparable studies between proposed LCC and paper as in ([7], [15] - [17]. To improve touch point efficiency and effectiveness for customer, we are currently design and develop the LCC algorithm on various client platforms such as Android, iOS, win 10 and webbased, to be used by the customer without the need to upgrade the RG for better auto-channel selection. In addition, we are developing a portal for TM Contact Center to view the latest result tested by customer. Wide customer touch point channels ensure customers have access to TM at all times. Positive customer experience will help retain customers, thus boosting human, social and ultimately, financial capitals.

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