OPTIMAL CHANNEL ASSIGNMENT FOR IEEE 802.11 MULTI-CELL WLANS

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ABSTRACT

In this paper, we propose a new formulation for solving the channel assignment problem for Multi-cell WLANs as a mixed integer linear programming (MILP) problem. The objective is to minimize the total interference seen by all Access Points (APs). The main advantage of the proposed algorithm is that it provides a global solution and at the same time guarantees non-overlapping channel assignment. The proposed channel assignment formulation can be used for different topologies of WLAN as demonstrated in the simulation. Simulation results show that the proposed algorithm outperforms the pick-first greedy algorithm and the single channel assignment method. The proposed channel assignment technique reduces the total interference at all APs which leads to an improved throughput.

Index Terms— WLAN, IEEE 802.11, radio resource management, channel assignment, mixed integer linear programming.

1. INTRODUCTION

Wireless LANs (WLANs) are widely used due to its ease of installation, the availability of users' mobility, the unlicensed operating frequency band, and for the cheap equipments. WLANs are available at homes, coffee shops, public hotspots, universities, airports, and large corporations, etc.

The IEEE 802.11b/g WLANs standard operates on the unlicensed 2.4 GHz Industrial, Scientific and Medical (ISM) band; this band consists of eleven frequency channels with only three non-overlapping channels. Thus, channel assignment in Multi-cell WLANs becomes a crucial point. In particular, figure 1 shows a typical Multi-cell WLAN where the objective of channel assignment is to assign a channel for each AP to maintain acceptable throughput.

WLANs use the same channel for both control and data transmission due to the nature of the IEEE 802.11 MAC protocol which is based on carrier-sense multiple-access with collision avoidance (CSMA/CA) [1], where each station must sense the medium before transmitting. A station can transmit only if the medium is free; while if the medium is busy, it should wait until the medium becomes free. Hence, interference reduces the total throughput. Thus, careful channel assignment that minimizes the interference is required.

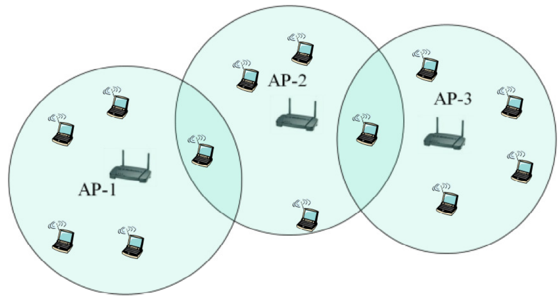

Fig. 1. A typical multi-cell WLAN topology.

There are many available channel assignment algorithms for Multi-cell WLANs [2]-[5]. In particular, the authors in [2] have proposed to solve the channel assignment problem as a graph coloring approach where they implemented a solution using an integer linear program model. Their objective was to maximize the channels' distance-sum between interfering stations; thus preserving a channel distance of at least three. However, they do not guarantee a non-overlapping channel assignment. In [3], the authors formulated the problem such as to minimize the maximum channel utilization for each AP, which resulted in higher throughput. The authors in [4] developed a mathematical model that defines the amount of interference between overlapping channels in Multi-cell WLAN systems where they have presented a dynamic channel assignment algorithm that aims to minimize the total interference at each AP. However, their proposed algorithm is a greedy algorithm which does not find a global solution. The channel allocation model presented in [5] is based on minimizing the total interference among different APs, while maintaining the Signal to Interference Ratio (SIR) higher than a predefined threshold. A recent survey on different channel assignment schemes for IEEE 802.11 WLANs is provided in [6].

The contribution of this paper lies in developing a new channel assignment algorithm as a mixed integer linear program which finds a global solution by minimizing the total interference seen by all APs and guarantees non-overlapping channels. The proposed algorithm can be applied in the initial phase of installation or after modifying the WLAN topology.

The rest of the paper is organized as follows. The channel assignment problem in WLANs is defined in section two. In section three, we describe the proposed optimization model. Simulation results are presented in section four. Finally, conclusions and future work are presented in section five.

2. CHANNEL ASSIGNMENT PROBLEM

According to the IEEE 802.11b/g WLANs standard, which operates on the unlicensed ISM 2.4 GHz band, the number of the available channels in this band varies from country to country depending on each country regulations on the radio frequency spectrum [6]. In particular, figure 2 depicts the IEEE 802.11 channels in the ISM band; where each channel has a bandwidth of about 22 MHz and every two adjacent channels are separated by only five MHz; thus, neighboring channels overlap with each other. Concurrently, there are only three non-overlapping channels (e.g. 1, 6, and 11) out of all channels. The lack of the free available channels and the overlapping among them complicates the channel assignment problem. In particular, a channel assignment algorithm attempts to assign a channel for each AP in a way that minimizes the mutual interference between the different APs.

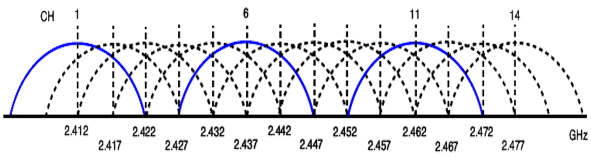

Fig. 2. Channels for the IEEE 802.11 in the 2.4GHz ISM band [6].

3. THE PROPOSED ALGORITHM

The proposed channel assignment algorithm is based on minimizing the total interference seen by all APs. The main idea is to formulate the channel assignment problem as an optimization problem and to obtain the global solution. In particular, we seek a set of channels assigned to all APs and at the same time minimize the mutual interference between all APs. The proposed model is built on the formulation given in [4]; by using transformations of variables we were able to formulate the problem as a mixed integer linear program. It should be noted that the algorithm in [4] is a greedy one in the sense that each AP is assigned a channel that minimizes the total interference received from its neighboring APs, and the selection is done at each AP separately. But the drawback of this greedy algorithm is that as an AP changes its own channel, based on the selection, the neighboring APs will be affected by interference as well. Hence, no global solution is achieved using the previous technique. On the other hand, the proposed algorithm finds the global solution in the sense that the objective function minimizes the total interference at all APs. This is achieved by modeling the problem as a mixed integer linear program whose solution is a global minimum.

Consider a Multi-cell WLAN consisting of N APs; where Pt_j is the transmitted power from AP_j and w_{ij} is the overlapping channel interference factor between AP_i and AP_j. The authors in [4] defined the overlapping channel interference factor, w_{ij}, to be the relative percentage increase in interference as a result of two APs i and j using overlapping channels.

$$w_{ij} = \begin{cases} 1 - |f_i - f_j| \times c & \text{if } w_{ij} \geq 0, \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

which can be re-written as

$$w_{ij} = \max(0, 1 - c \times |f_i - f_j|) \quad (2)$$

f_i and f_j are the channels assigned to AP_i and AP_j respectively and c is the overlapping channel factor, between any two adjacent channels, which equals 1/5 for IEEE 802.11b/g.

In order to get rid of the modulus function in (2), the overlapping channel interference factor w_{ij} can be re-written as the following linear inequality

$$w_{ij} \geq 1 - \frac{1}{5}(Z^+_{ij} + Z^-_{ij}) \quad (3)$$

Z^+_{ij} and Z^-_{ij} are auxiliary variables representing the positive and negative values of $(f_i - f_j)$ with $Z^+_{ij} - Z^-_{ij} = f_i - f_j$ [7]. This will guarantee that $Z^+_{ij} + Z^-_{ij}$ equals to the modulus of $(f_i - f_j)$. In order to ensure that at least one of the values Z^+_{ij} and Z^-_{ij} is zero, which is required for the replacement of the modulus part in (2) by $(Z^+_{ij} + Z^-_{ij})$; an EITHER-OR constraint is defined as in [7]

$$Z^+_{ij} \leq \eta\beta_{ij} \quad (4)$$

$$Z^-_{ij} \leq \eta(1 - \beta_{ij}) \quad (5)$$

β_{ij} is an auxiliary binary variable and η is a sufficiently large upper bound (e.g., 100) for both Z^-_{ij} and Z^+_{ij}. In that case, $f_i - f_j = Z^+_{ij}$ and $|f_i - f_j| = Z^+_{ij}$ when $\beta_{ij}=1$; while $f_i - f_j = -Z^-_{ij}$ and $|f_i - f_j| = Z^-_{ij}$ when $\beta_{ij}=0$.

In the simulation we have used the following simplified channel path loss model [8]

$$L(d_{ij}) = L_{FS}(d_o) + 35 \log_{10}(d_{ij}/d_o) \; dB \quad (6)$$

where d_o is the reference distance for the antenna far field, d_{ij} is the distance between AP_i and AP_j and $L_{FS}(d_o)$ is free space path loss for distance d_o, which is given by:

$$L_{FS}(d_o) = 20\ \log_{10}(\frac{4\pi\, d_o}{\lambda \sqrt{G_t G_r}}) \quad dB \qquad (7)$$

Where G_t and G_r are transmit and receive antenna gains in the Line of Sight (LOS) direction.

Let $\alpha_{ij} = Pt_j / L\ (d_{ij})$, which is the received power by AP_i from AP_j. The optimal channels can be found by solving the following integer program:

$$\mathbf{min} \sum_{i=1}^{N} \sum_{j \neq i} \alpha_{ij}\, w_{ij} \qquad (8.1)$$

subject to

$$\begin{aligned} & w_{ij} + \frac{1}{5}(Z^{+}_{ij} + Z^{-}_{ij}) \geq 1 && w_{ij} \geq 0 \\ & Z^{+}_{ij} - Z^{-}_{ij} - f_i + f_j = 0 && f_i, f_j \in \{1,2,.....,11\} \\ & Z^{+}_{ij} - \eta\beta_{ij} \leq 0 && \beta_{ij} \in \{0,1\} \\ & Z^{-}_{ij} + \eta\beta_{ij} \leq \eta \end{aligned} \qquad (8.2)$$

The previous optimization model finds the optimal non-overlapping channels, f_i, that minimize the total interference-sum at all APs. Note that, the objective function represents the sum of the total interference seen by AP_i from AP_j, which is given by the product of α_{ij}, the power received by AP_i from AP_j, and w_{ij}, the overlapping channel interference factor. The first constraint of (8.2) is a linear inequality representing the overlapping channel interference factor (2). The second constraint is provided to ensure that the first constraint is equivalent to (2) as described earlier. The EITHER-OR constraint is represented by the third and fourth constraints.

4. NUMERICAL RESULTS

In this section, we provide simulations for different topologies with different numbers of APs. For each topology we will compare the performance of the proposed channel assignment with the default settings of having all the APs assigned the same channel, as well as the pick-first greedy exhaustive search assignment [4]. It should be noted that the authors in [4] have introduced two greedy exhaustive search algorithms, namely, pick-rand and pick-first. In the comparison, we will concentrate on the pick-first algorithm. Although, for some topologies, the execution time of the proposed algorithm is more than that of the pick-first algorithm, the proposed algorithm still better as it provides an optimal channel assignment that reduces the total interference at all APs.

For the case of pick-first greedy algorithm, we have executed 100 iterations to guarantee that the algorithm will converge regardless of the number of APs. For the case of the single channel assignment we assumed that all APs are assigned channel 11. The simulation is performed on a 2.4 GHz processor. The simulation parameters are shown in Table 1. The free-ware optimization solver LP_SOLVE [9] is used for solving the optimization model of (8).

TABLE 1. SIMULATION PARAMETERS

Pt_j	20 dBm
d_o	5 m
G_t	3 dBi
G_r	3dBi

4.1. First topology

This topology consists of four APs placed as shown in figure 3. The corresponding results for this topology are shown in Table 2. It should be noted that both the proposed and pick-first algorithms provide the same performance which is better than that of the single channel. This is because both the proposed and pick-first algorithms result in only two interfering APs and the distance between these APs is the same for both cases. However, the proposed algorithm can be implemented in time which is about 1.33 % of that of the pick first algorithm.

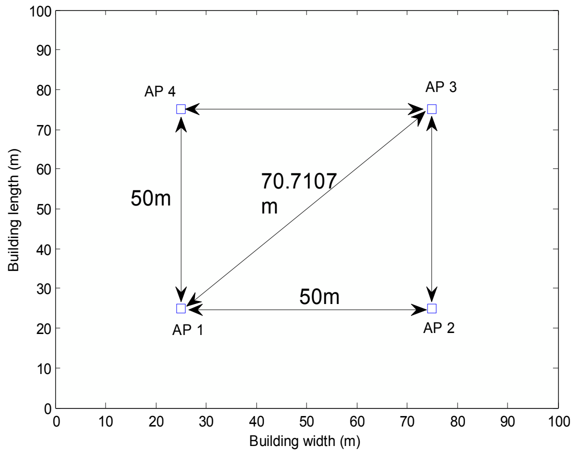

Fig. 3. Toplogy of 4 APs.

TABLE 2. RESULTS FOR FOUR APs

AP ID	Channel f_i		Interference (dBm)		
	Proposed	Pick-first	Proposed	Pick-first	Single Ch
AP_1	11	6	-Inf	-68.4263	-59.6348
AP_2	6	11	-68.4263	-Inf	-59.6348
AP_3	1	6	-Inf	-68.4263	-59.6348
AP_4	6	1	-68.4263	-Inf	-59.6348
Total interference (dBm)			-65.4160	-65.4160	-53.6142
Execution time (sec)			0.004622	0.347360	

4.2. Second topology

In this case, we have six APs deployed as indicated in figure 4. Table 3 indicates the performance of this topology. From Table 3, it is clear that the proposed channel assignment is better than both the single channel assignment and the pick-first algorithm. In particular the proposed algorithm provides reduction in the total interference of about 11.0067 dBm less than that of the single channel assignment.

Moreover, the proposed channel assignment exhibits a slight improvement in the total interference of about 0.6916 dBm compared to the pick-first assignment. Also, it is clear that the proposed algorithm provides less interference than that of the pick-first algorithm, at all APs except APs two and four. This behavior is justified because the pick-first is a greedy algorithm where each AP selects the channel that minimizes the interference seen only from neighboring APs; while the proposed algorithm provides a global solution that minimizes total interference at all APs. It is also noted that the proposed algorithm can be executed in about half the time of the pick-first algorithm.

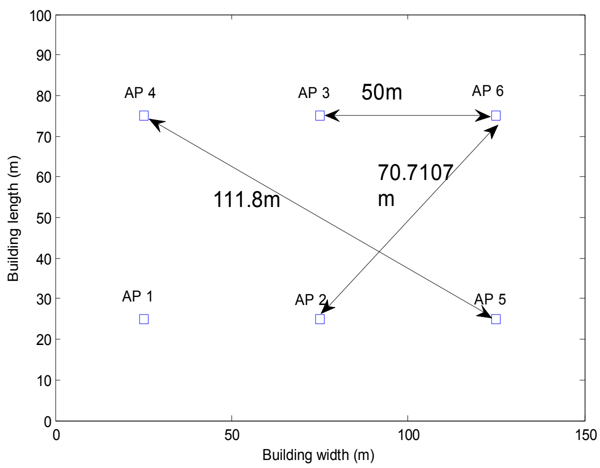

Fig. 4. Topology of 6 APs.

TABLE 3. RESULTS FOR SIX APs

AP ID	Channel f_i		Interference (dBm)		
	Proposed	Pick-first	Proposed	Pick-first	Single Ch
AP_1	11	6	-75.4789	-67.2959	-59.3632
AP_2	6	11	-68.4263	-Inf	-57.6904
AP_3	1	6	-68.3367	-65.4160	-57.6904
AP_4	6	1	-68.4263	-73.6048	-59.3632
AP_5	1	6	-68.3367	-67.2959	-59.3632
AP_6	11	1	-75.4789	-73.6048	-59.3632
Total interference (dBm)			-61.9565	-61.2649	-50.9498
Execution time (sec)			0.086650	0.169740	

4.3. Third topology

Figure 5 illustrates a topology with nine APs. The behavior of this topology is described by Table 4; that shows how the proposed channel assignment outperforms both the single channel assignment and the pick-first algorithm. Particularly, the proposed algorithm has a total interference that is 10.1565 dBm less than that of the single channel assignment. Also, the proposed algorithm exhibits better performance than the pick-first algorithm as the total interference is reduced by 0.7964 dBm. Excluding APs three, five and nine; the interference at each AP for the proposed algorithm is better than that of the pick-first algorithm.

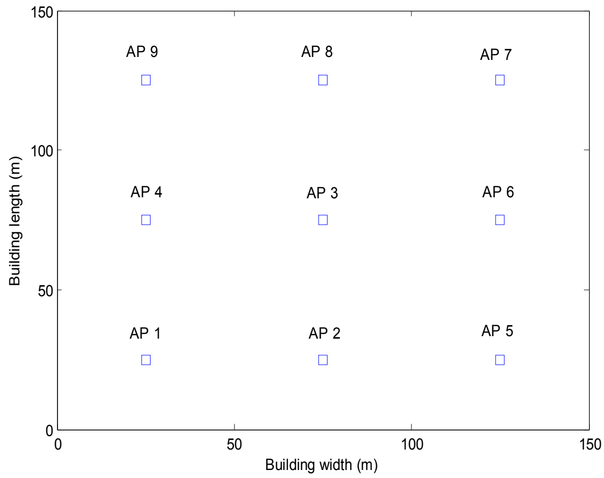

Fig. 5. Topology of 9 APs.

TABLE 4. RESULTS FOR NINE APS

AP ID	Channel f_i		Interference (dBm)		
	Proposed	Pick-first	Proposed	Pick-first	Single Ch
AP_1	11	1	-72.4686	-69.9926	-59.0639
AP_2	6	11	-67.6302	-64.9028	-57.4461
AP_3	1	6	-65.3264	-Inf	-56.0959
AP_4	6	11	-67.6302	-64.9028	-57.4461
AP_5	1	1	-67.9689	-69.9926	-59.0639
AP_6	11	11	-67.7188	-64.9028	-57.4461
AP_7	6	1	-72.3800	-69.9926	-59.0639
AP_8	11	11	-67.7188	-64.9028	-57.4461
AP_9	1	1	-67.9689	-69.9926	-59.0639
Total interference (dBm)			-58.5067	-57.7103	-48.3502
Execution time (sec)			82.484254	1.946973	

In all previous topologies, it is clear that the proposed channel assignment algorithm outperforms both the single channel assignment and the pick-first algorithm due to interference reduction. Figure 6 provides performance comparison where the total interference of the proposed channel assignment algorithm, single channel assignment, and pick-first greedy exhaustive search assignment are compared for different topologies consisting of two – ten APs.

As can be seen from figure 6, the proposed channel assignment algorithm outperforms both the pick-first greedy algorithm and the single channel assignments. In particular, the total interference in case of the proposed algorithm is less than that of the same channel assignment by values that range from 10.1565 to 12.252 dBm for the different topologies. The proposed algorithm provides the same performance as the pick-first algorithm for topologies containing two and three APs because both assign each AP a unique free non-overlapping channel, so there is no interference at any AP; also the four APs topology has the same performance for both the proposed and the pick-first algorithms because both have only two interfering APs and the distance between these APs is the same for both cases. For all other topologies, the proposed algorithm shows an improvement in the total interference over the pick-first exhaustive search. This improvement is justified; as the pick-first channel assignment is a greedy algorithm where each AP selects the channel that minimizes interference it sees from neighboring APs; while the proposed algorithm provides a global solution which minimizes the total interference-sum at all APs. This improvement ranges from 0.0734 to 0.7964 dBm according to the topology set up.

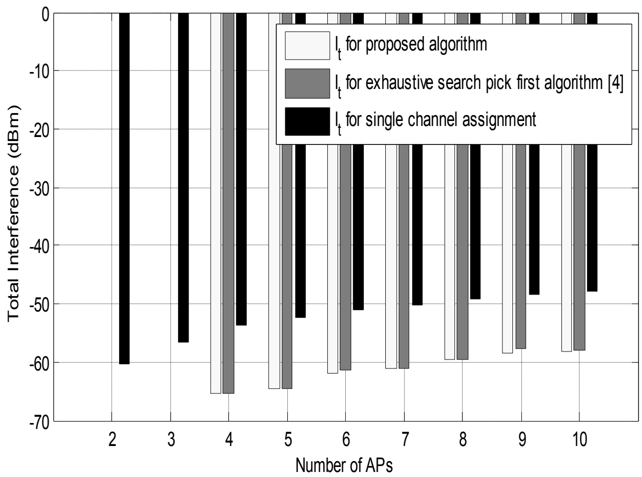

Fig. 6. Total interference comparison between the proposed, greedy exhaustive search pick-first, and single channel assignments.

5. CONCLUSIONS AND FUTURE WORK

An optimal channel assignment algorithm has been proposed that minimizes the total interference-sum between all APs. We formulated the problem as an integer program and solved it using the LP_SOLVE [9]. The proposed model is applied to different topologies consisting of two to ten APs. The obtained results reveal that the proposed channel assignment outperforms the default setting of having all APs assigned the same channel. Moreover, the proposed algorithm is better than the pick-first algorithm due to the interference reduction. The proposed algorithm finds the solution within practical time frame for small and medium sized networks; the execution time is less than five msec for WLANs consisting of up to four APs. For medium networks, consisting of up to nine APs, the proposed channel assignment algorithm can be implemented within about 1.5 minutes. For large scenarios, the size of the problem grows exponentially and the execution time increases significantly due to the combinatorial nature of the problem. In future work, we will implement the relaxation techniques in order to reduce the complexity of the integer program.

ACKNOWLEDGMENTS

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