A MAXMIN MODEL FOR SOLVING CHANNEL ASSIGNMENT PROBLEM IN IEEE 802.11 NETWORKS

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ABSTRACT

In this paper, an optimization model for solving the channel assignment problem in multi-cell WLANs is proposed. This model is based on maximizing the minimum distance between access points (APs) that work on the same channel. The proposed model is formulated in the form of a mixed integer linear program (MILP). The main advantage of the proposed algorithm is that it ensures non-overlapping channel assignment with no overhead power measurements. The proposed channel assignment algorithm can be implemented within practical time frames for different topology sizes. Simulation results indicate that the proposed algorithm exhibits better performance than that of the pick-first greedy algorithm and the single channel assignment method.

***Index Terms*—** WLAN; IEEE 802.11; channel assignment; integer programming; maxmin problem.

1. INTRODUCTION

Wireless LANs (WLANs) are widely deployed for internet access because of the ease of installation, the availability of unlicensed operating frequency bands, the development of cheap equipments and the availability of users' mobility. WLANs are available in many places such as homes, coffee shops, public hotspots, universities, airports and large companies.

Nowadays, most of the existing WLANs follow the IEEE 802.11b/g standard which operates in the unlicensed 2.4 GHz Industrial, Scientific and Medical (ISM) band. This band consists of eleven frequency channels with only three non-overlapping channels [1]. Thus, careful channel assignment in multi-cell WLANs becomes crucial. Figure 1 shows a typical topology of a multi-cell WLAN, where multiple APs operate simultaneously. In this case, the objective of channel assignment is to assign a channel for each AP to reduce the interference and thus maintain an acceptable throughput.

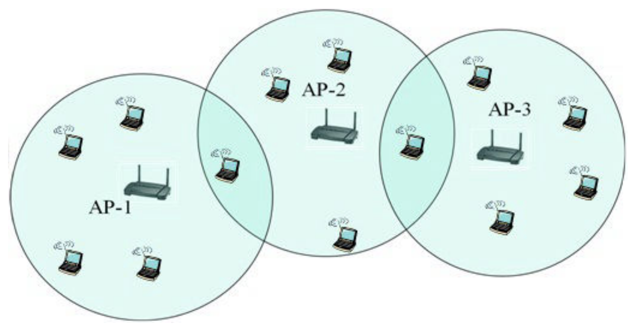

Fig. 1: A typical multi-cell WLAN topology.

Due to the nature of the IEEE 802.11 MAC protocol, which is based on the carrier-sense multiple-access with collision avoidance (CSMA/CA) [1], WLANs use the same channel for both control and data transmission. In CSMA/CA, each station must sense the medium before transmitting. A station can transmit only if the medium is free; however, if the medium is busy, it should defer its transmission until the medium becomes free. Interference may be sensed by a station as if the medium is busy and thus it should postpone its transmission. Hence, careful channel assignment, that minimizes the interference, is required in order to increase the total throughput.

Many channel assignment algorithms for the IEEE 802.11 multi-cell WLANs are available in the literature (e.g., [2–4]). A great survey on different channel assignment techniques for IEEE 802.11 WLANs is provided in [5]. The authors in [2] have 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, the proposed algorithm is a greedy algorithm which does not find a global solution. The channel allocation model presented in [3] is based on minimizing the total interference among different APs, while maintaining the Signal to Interference power Ratio (SIR) at all users higher than a predefined threshold. This may require the channel assignment algorithm to be repeated each time when a user enters, leaves or even moves within an AP service area. In this case, when the SIR at any user becomes less than the predefined threshold, the channel should be modified. The authors in [4] proposed an optimal channel assignment algorithm for multi-cell WLANs which minimizes the total interference seen by all APs in the network. To reduce combinatorial complexity of the algorithm, the authors also presented a low complexity channel assignment based on Lagrangian relaxation.

The contribution of this paper lies in presenting a new optimization model for solving the channel assignment problem where the objective is to maximize the minimum distance between APs that operate on the same channel band in order to reduce the total interference in the network. The proposed maxmin model leads to a mixed integer linear programming (MILP) formulation. Practically, the proposed algorithm can be applied in the installation phase or after any modifications in the WLAN topology. The proposed channel assignment provides non-overlapping channels. A great advantage of the proposed algorithm over other algorithms like those presented in [3, 4] is that, in the proposed algorithm, neither users nor APs have to make any overhead power measurements.

The rest of the paper is organized as follows. The channel assignment problem in WLANs is described in section 2. In section 3, the proposed optimization model is illustrated. Simulation results are presented in section 4. Finally, section 5 concludes the paper.

2. THE CHANNEL ASSIGNMENT PROBLEM

The IEEE 802.11b/g standard operates on the unlicensed ISM 2.4 GHz band; where the number of the available channels varies from country to country depending on the imposed regulations on the radio frequency spectrum [5]. Figure 2 shows 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 5 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. It should be noted that the lack of free available channels and the inherent 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 different APs.

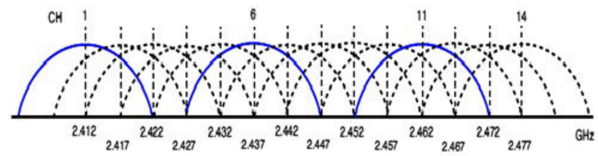

Fig. 2: Channels for the IEEE 802.11 in the 2.4GHz ISM band [5].

3. THE PROPOSED MODEL

The proposed channel assignment algorithm depends on maximizing the minimum distance among APs that work on the same channel. The main idea is that increasing the distance between APs that operate on the same channel reduces the mutual interference between these APs. In this context, we define two parameters, namely, d_{ij} and Δ_{ij}; where d_{ij} is the actual distance between AP_i and AP_j in meters, while Δ_{ij} represents the frequency channel separation between channels assigned to AP_i and AP_j. Δ_{ij} can be defined as

$$\Delta_{ij} = \min(w + c, w + |f_i - f_j|) \tag{1}$$

where f_i and f_j are the channels assigned to AP_i and AP_j respectively, c is the minimum channel separation between any two non-overlapping channels, which equals five in IEEE 802.11b/g, as shown in Fig. 2, and w is a weight that affects the execution time of the algorithm. The frequency channel separation factor Δ_{ij} in equation (1) can be written as:

$$\Delta_{ij} \leq w + |f_i - f_j| \tag{2}$$

with $w \leq \Delta_{ij} \leq w + c$.

In order to get rid of the modulus function in (2), the channel separation factor can be expressed as

$$\Delta_{ij} \leq w + Z_{ij}^{+} + Z_{ij}^{-} \tag{3}$$

where Z_{ij}^{+} and Z_{ij}^{-} are auxiliary variables that represent the positive and negative values of $(f_i - f_j)$ with $Z_{ij}^{+} - Z_{ij}^{-} = f_i - f_j$. This will assure that $Z_{ij}^{+} + Z_{ij}^{-}$ equals $|f_i - f_j|$.

In order to guarantee that at least one of the values Z_{ij}^{+} and Z_{ij}^{-} is zero, which is inherent in the modulus model (2), an EITHER-OR constraint can be defined as [6]

$$Z_{ij}^{+} \leq \eta\beta_{ij},\; Z_{ij}^{-} \leq \eta(1 - \beta_{ij}) \tag{4}$$

where $\beta_{ij} \in \{0, 1\}$ is a subsidiary binary variable and η is an appropriately large number (e.g., 100).

Hence, $Z^+_{ij} = |f_i - f_j| = (f_i - f_j)$ when $\beta_{ij} = 1$, while $Z^-_{ij} = |f_i - f_j| = (f_j - f_i)$ when $\beta_{ij} = 0$.

Consider the setting of a multi-cell WLAN containing N APs. The proposed channel assignment can be found by solving the following optimization model:

$$\begin{array}{lll} \textbf{maxmin} & d_{ij}\Delta_{ij} & \\ s.t. & \Delta_{ij} - Z^+_{ij} - Z^-_{ij} \leq w & w \leq \Delta_{ij} \leq w + c \\ & Z^+_{ij} - Z^-_{ij} - f_i + f_j = 0 & f_i, f_j \in \{1, 2, ..., 11\} \\ & Z^+_{ij} - \eta\beta_{ij} \leq 0 & \beta_{ij} \in \{0, 1\} \\ & Z^-_{ij} + \eta\beta_{ij} \leq \eta & \end{array} \tag{5}$$

In the above model, the objective is to find the channels, f_i, that maximize the minimum distance between APs that use the same channel. This can be explained as follows. In order to minimize $d_{ij}\Delta_{ij}$, we should guarantee that both d_{ij} and Δ_{ij} are minimized. It should be noted from (2) that Δ_{ij} will be minimized when $f_i = f_j$. This means that w is the minimum of Δ_{ij} and occurs when APs i and j operate on the same channel. Hence, minimizing $d_{ij}\Delta_{ij}$ depends only on the distance between APs that use the same channel. Therefore the objective is to maximize the minimum value of $d_{ij}w$. Taking into account that w is a weighting constant, the objective is to maximize the minimum distance between APs that operate on the same channel. The first constraint in (5) is a linear inequality representing the frequency channel separation factor (2). The second constraint is introduced to guarantee that the first constraint is equivalent to (2). The rest of the inequalities represent the EITHER-OR constraint.

The maxmin problem can be transformed into an equivalent form by introducing a lower bound $t \leq d_{ij}\Delta_{ij}$ [7]. When t is maximized, this lower bound ensures that t will be less than or equal to $d_{ij}\Delta_{ij}\forall ij$. At the same time, the optimal value of t will be no less than the minimum of all $d_{ij}\Delta_{ij}$ because t has been maximized. Hence, the optimal value of t will be as large as possible and is exactly equal to the minimum value of $d_{ij}\Delta_{ij}$ [6]. Thus the optimization model (5) can be represented by the following equivalent model

$$\begin{array}{lll} \textbf{max} & t & \\ s.t. & t - d_{ij}\Delta_{ij} \leq 0 & \\ & \Delta_{ij} - Z^+_{ij} - Z^-_{ij} \leq w & w \leq \Delta_{ij} \leq w + c \\ & Z^+_{ij} - Z^-_{ij} - f_i + f_j = 0 & f_i, f_j \in \{1, 2, ..., 11\} \\ & Z^+_{ij} - \eta\beta_{ij} \leq 0 & \beta_{ij} \in \{0, 1\} \\ & Z^-_{ij} + \eta\beta_{ij} \leq \eta & \end{array} \tag{6}$$

It should be noted that the objective function along with the first constraint of the optimization model (6) plays the role of the objective function in the model (5). In addition, the rest of the constraints of (6) are the same as those of (5).

4. NUMERICAL RESULTS

In this section, we provide simulations for various topologies with different numbers of APs. For all topologies, we will compare the performance of the proposed channel assignment algorithm with the default settings of having all APs assigned the same channel, the pick-first greedy algorithm [2] and the optimal channel assignment algorithm presented in [4]. In the proposed algorithm we set the weighting parameter, w, to be 100. For the case of pick-first greedy algorithm, we have executed 100 iterations to be sure 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 optimal channel assignment [4] provides a global solution that minimizes the total interference in the network. The simulation is performed on a 2.4 GHz processor. The free-ware optimization solver LP_SOLVE [8] is used to solve both the optimization model (6) and the optimal channel assignment model presented in [4]. For both the proposed and the optimal algorithms, in addition to the relative execution time, we provide additional complexity metrics, namely, the total number of iterations and the number of processed nodes. Here the total number of iterations includes both the number of iterations to find a relaxed solution and the number of iterations in the branch and bound process made by the LP_SOLVE [8]. In addition, the number of processed nodes is referred to as the number of nodes visited in the branch and bound algorithm [8] for an integer program that is successfully solved by LP_SOLVE.

In particular, the total interference sum at the APs level and the execution time requirements are used to measure the performance of the channel assignment algorithms. In order to measure the total interference sum at the APs for the different channel assignment algorithms, we have assumed the following simplified channel path loss model [9],

$$L(d_{ij}) = L_{FS}(d_o) + 35\log_{10}(d_{ij}/d_o)dB \tag{7}$$

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 the free space path loss for distance d_o, which is given by

$$L_{FS}(d_o) = 20\log_{10}\left(\frac{4\pi d_o}{\lambda\sqrt{G_t G_r}}\right)dB \tag{8}$$

where G_t and G_r are transmit and receive antenna gains in the line of sight direction, respectively. In the simulation, it is assumed that $d_o = 5$ m, $G_t = G_r = 3$ dBi and the AP transmit power equals 20 dBm.

4.1. First Example

In this case, we have six APs deployed as indicated in Fig. 3. Table 1 indicates the corresponding results for this topology. From Table 1, it is clear that the proposed channel assignment is better than the single channel assignment, the pick-first algorithm and the optimal algorithm [4]. Specifically the

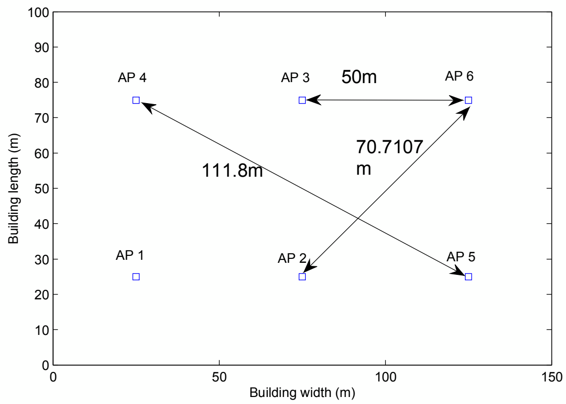

Fig. 3: Topology of 6 APs.

Table 1: Results for 6 APs.

AP ID	Channel f_i			Interference (dBm)			
	Proposed	Optimal [4]	Pick-first	Proposed	Optimal [4]	Pick-first	Single Ch
AP_1	**11**	11	6	**-Inf**	-75.48	-67.30	-59.36
AP_2	**6**	6	11	**-65.42**	-68.43	- Inf	-57.69
AP_3	**1**	1	6	**-68.34**	-68.34	-65.42	-57.69
AP_4	**6**	6	1	**-67.30**	-68.43	-73.60	-59.36
AP_5	**1**	1	6	**-68.34**	-68.34	-67.30	-59.36
AP_6	**6**	11	1	**-67.30**	-75.48	-73.60	-59.36
Total interference (dBm)				**-60.21**	-61.96	-61.26	-50.95
Relative execution time				**1**	23.38	45.86	
Total number of iterations				**100**	3777		
Number of processed nodes				**20**	1346		

proposed algorithm gives reduction in the total interference of about 9.26 dB less than that of the single channel assignment. In addition, while proposed channel assignment provides a slight increase in the total interference of about 1.05 dB as compared to the pick-first assignment; the proposed algorithm can be executed in about 2.18 % of the time required for the pick-first algorithm. Moreover, it is obvious that the proposed algorithm exhibits a slight increase in the total interference of about 1.75 dB more than that of the optimal algorithm. However, the proposed algorithm can be implemented in about 4.28 % of the time needed for the optimal algorithm at the expense of a slight increase of the total interference. This savings in the execution time is due to the reduction in both the number of iterations and the number of processed nodes in the case of the proposed algorithm relative to the optimal one. Also, it should be taken into account that the proposed channel assignment algorithm does not need any overhead power measurements.

4.2. Second Example

Figure 4 illustrates a topology consisting of 25 APs. The corresponding results are presented in Table 2. It is obvious that the proposed channel assignment provides total interference which is less than that of the single channel assignment by about 7.9 dB. In addition, the proposed channel assignment almost exhibits the same performance as the pick-first algorithm in terms of the total interference comparison. However, the proposed channel assignment can be implemented in about 6.9 % of the time required for the pick-first technique. Furthermore, the optimal channel assignment algorithm [4] can not be executed for the topology containing 25 APs using ordinary computers due to its combinatorial complexity.

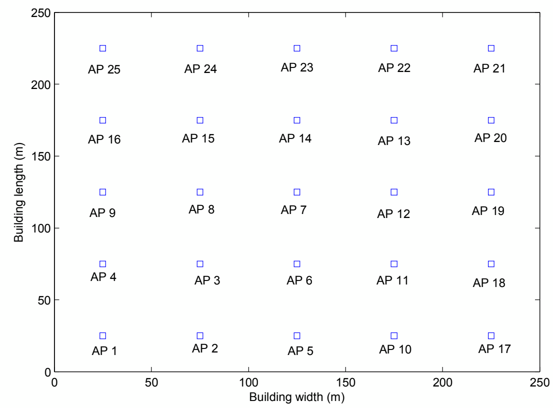

Fig. 4: Topology of 25 APs.

From the previous topologies, it is clear that the proposed maxmin channel assignment algorithm has less complexity as compared to both the pick-first and the optimal channel assignment [4]. Specifically the proposed maxmin MILP model has less execution time than that of the optimal MILP due to the reduction in both total number of iterations and the number of processed nodes. Figure 5 shows a comparison between the proposed maxmin model and the optimal model in terms of both the total number of iterations and the number of processed nodes as functions of the network size (number of APs). In Fig. 5 the dashed curves with square markers are corresponding to the total number of iterations. It is clear that the proposed maxmin algorithm exhibits a significant reduction in the total number of iterations as compared to the optimal algorithm. For instance, in the case of nine APs, the optimal MILP model requires a number of iterations which is about 5542 times the number of iterations required for the proposed maxmin MILP model. In addition, the solid curves with circle markers are corresponding to the number of visited nodes in the branch and bound process for both algorithms. It is obvious that the proposed maxmin algorithm provides considerable savings in the number of visited nodes relative to the optimal algorithm. For example, in the topology of nine APs, the number of processed nodes for the the optimal MILP model is about 10324 times that of the proposed MILP model.

5. CONCLUSIONS

A new optimization model based on maximizing the minimum distance between APs that work on the same channel

Table 2: Results for 25 APs.

AP ID	Channel f_i		Interference (dBm)		
	Proposed	Pick-first	Proposed	Pick-first	Single Ch
AP_1	**6**	6	**-70.02**	-70.45	-58.81
AP_2	**1**	11	**-66.75**	-65.66	-57.08
AP_3	**11**	1	**-63.62**	-64.45	-55.63
AP_4	**1**	11	**-66.75**	-64.31	-57.08
AP_5	**11**	1	**-66.91**	-64.58	-56.95
AP_6	**6**	6	**-62.31**	-67.95	-55.51
AP_7	**11**	1	**-64.37**	-63.04	-55.37
AP_8	**6**	11	**-62.31**	-62.29	-55.51
AP_9	**11**	6	**-66.91**	-66.25	-56.95
AP_{10}	**6**	11	**-64.21**	-65.66	-57.08
AP_{11}	**1**	1	**-64.35**	-64.16	-55.63
AP_{12}	**6**	11	**-61.37**	-62.29	-55.51
AP_{13}	**11**	1	**-67.69**	-66.56	-55.63
AP_{14}	**6**	11	**-61.37**	-61.62	-55.51
AP_{15}	**1**	6	**-64.35**	-64.62	-55.63
AP_{16}	**6**	11	**-64.21**	-63.98	-57.08
AP_{17}	**1**	6	**-66.68**	-70.59	-58.81
AP_{18}	**6**	11	**-63.85**	-64.31	-57.08
AP_{19}	**1**	6	**-65.73**	-68.48	-56.95
AP_{20}	**6**	11	**-63.80**	-63.98	-57.08
AP_{21}	**1**	6	**-69.36**	-69.71	-58.81
AP_{22}	**6**	11	**-63.80**	-63.94	-57.08
AP_{23}	**1**	6	**-65.73**	-66.44	-56.95
AP_{24}	**6**	11	**-63.85**	-63.94	-57.08
AP_{25}	**1**	1	**-66.68**	-74.41	-58.81
Total interference (dBm)			**-50.57**	-50.97	-42.67
Relative execution time			**1**	14.49	
Total number of iterations			**4946**		
Number of processed nodes			**674**		

has been proposed for solving the channel assignment problem in IEEE 802.11 networks. This model has been presented as an integer programming formulation. The proposed algorithm has been applied for different scenarios to evaluate it. The obtained results indicate that proposed channel assignment algorithm is better than the single channel assignment, the greedy pick-first algorithm and the optimal channel assignment [4]. The proposed algorithm provides non-overlapping channel assignment and does not require any overhead measurements. Furthermore, the proposed algorithm can be implemented in practical time frame even for large size networks e.g., within a second the proposed channel assignment algorithm can be implemented for a topology consisting of 25 APs.

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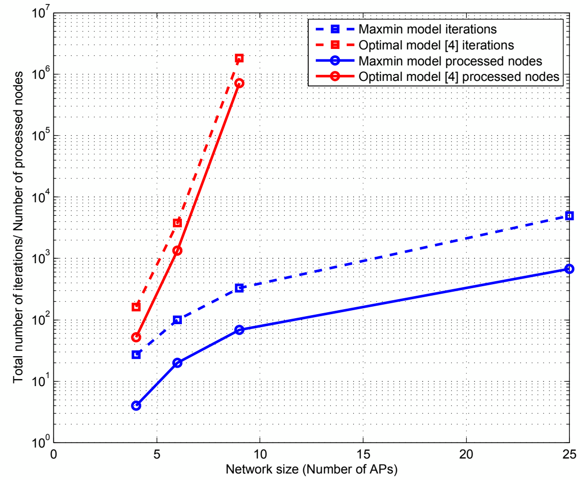

Fig. 5: Total number of iterations and number of processed nodes comparison between the proposed and the optimal [4] algorithms.

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