Interference Management in IEEE 802.11 Frequency Assignment

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***Abstract*—In this article we address the frequency management during WLAN planning. Frequency management refers to channels interference and *SINR* computation. We propose a new approach where location selection and frequency assignment are tackled together during WLAN planning process. Two steps characterize this approach. Firstly we use all the available channels for frequency assignment. Secondly multiple signals are taken into account to compute the SINR. Several experimental results show the benefits of this new approach.**

Keywords- WLAN planning; access point placement; frequency channel assignment; optimisation

I. INTRODUCTION

Wireless Local Area Network (WLAN) planning consists in selecting a location for each transmitter and setting the parameters of all sites in order to provide users a wireless access to their local network. The objective is to respect financial requirements and to guaranty a given **Quality of Service** (QoS). There are two relevant stages in WLAN planning. First we have to select a set of installation sites from a list of candidates that have been identified as potential location. For each site we must choose the antenna pattern, as well as its azimuth that indicates the main propagation direction, and the emitted power of the antenna. The 4-uplet (*site, antenna pattern, azimuth, emitted power*) is called **Access Point (AP) configuration**. Selecting a set of AP configurations from a list of candidate AP configurations is a location problem usually called ACP problem for ***Automatic Cell Planning*** in cellular system. In GSM or UMTS networks the coverage area relative to a transmitter is called a *cell* instead this is called a *base station service* (BSS) in WLAN. The second important stage is to allocate one of the available frequencies to each AP configuration in order to minimize interferences. The frequency set depends on the standard (IEEE 802.11 a, b or g) and also on specific restriction on spectrum usage in each country and environment. This problem is called AFP problem for ***Automatic Frequency Planning*** and becomes very famous for designing GSM/GPRS/EDGE cellular network [19] [20].

In this paper, we evaluate the difference of QoS between networks that have been design using ACP and AFP stages successively as in current strategies, and networks designed using ACP and AFP as a joint optimisation problem to optimise [17]. The main issue of this unified approach is the on-line computation of *Signal-to-Interference-plus-Noise-Ratio* (SINR) during the selection of site for installation of transmitters without additional constraints linked to frequency channel assignment. The direct estimation of SINR might drive the process to a better network design offering a larger throughput to network users. The paper is organised in three main sections. The second section focuses on AFP problem and gives some methods to solve it. The third section presents four optimisation strategies tackling ACP problem and AFP problem successively or together. In the fourth section, experimentations are presented to compare different strategies and those results are analysed. Finally, we draw the conclusions and give some future work.

II. AUTOMATIC FREQUENCY PLANNING

Usually the design process begins choosing antenna sites then allocating the available frequencies to the selected sites. The first studies on ACP problem were defined as a covering problem [1] [2] without link with AFP. Later, various constraints were added to the ACP problem in order to ease the AFP problem. The ACP problem became over constrained. A large variety of constraints are described in the literature. The most current constraint consists to add some cell overlapping to the covering problem. For example prohibiting the selection of two close sites [3] [4] or minimizing the overlapping area between cells [5] [6] [7] or selecting BSS according to its geometrical shape [16] as in cellular [18]. More sophisticated approach is to evaluate the deviation between interfering transmitter [8] [9]. Another approach is to estimate the capacity of channel frequency reuse [10].

Now we present two different approaches to tackle AFP problem: one global view focuses on interferences at cell level, another local view focuses on interferences at user level. Those methods are general for different wireless network contexts: GSM, UMTS, IEEE 802.11… However this article focuses on IEEE 802.11g wireless networks in order to put in practice our approach.

A. Global interference approaches

The simplest approach of frequency planning is to consider each BSS like an indivisible entity. This approach considers the average of interferences inside the BSS. This global view has the great advantage of reducing BSS to single point. The network can then be represented as an undirected graph where vertices are BSS and edges connect pairs of BSS if they are neighbours that is their coverage areas are overlapping. In this case, the AFP problem becomes a constraint satisfaction graph colouring problem: frequencies are colours to assign to graph vertices or BSS. In this graph context there are several different approaches to use frequency channels in WLAN design:

assigning only non-overlapping channels or assigning all available channels.

IEEE 802.11b/g has 14 overlapping frequency channels (only 13 channels are available in France). Owing to the standard definition, only 3 channels are not overlapping. In the case of assigning non-overlapping channels, AFP is a 3-graph colouring problem. The main drawback of strictly non-overlapping frequency channel assignment is that the graph colouring problem becomes impossible to solve with only 3 channels especially for open-space, huge density, large networks… Indeed close BSS using the same channel create interferences resulting in uncovered areas.

Therefore it is necessary to enlarge the channel assignment to overlapping frequency channels and then to introduce interferences. The objective of this approach is to spread interferences over all cells. In this case AFP problem is a T-colouring problem with 13 channels. The objective of AFP problem becomes to minimize the number of edges using overlapping frequency channels.

B. Local interference approaches

Inside BSS coverage area the quality of service perceived by the user is of different level because interferences are not uniform. A user can loose his connexion due to interference while another user of the same BSS may have high throughput.

One indicator to measure interference is the *Signal-to-Interference-plus-Noise-Ratio*. Its definition is local for each user, that is:

$$SINR = \frac{P_{\text{best RSS}}}{\sum P_{\text{others RSS}} \times \gamma(\Delta f) + N} \tag{1}$$

where $P_{best\ RSS}$ is the highest Received Signal Strength (RSS). In IEEE 802.11 standard the connexion is usually established with the best RSS. $P_{other\ RSS}$ are other received signals with smaller values than the best RSS. $\gamma(.)$ is the protection factor corresponding to the attenuation coefficient between channels. It is a function of Δf, the channel distance between the carrier signal and the interfering signal. $\gamma(.)$ decreases when Δf increases: if Δf =0, $\gamma(\Delta f)$=1 and if $\Delta f \geq 5$, $\gamma(\Delta f)$=0. All intermediate values depend on the receiver equipment features. *N* is the noise strength. Its value is around *-100dBm* in surrounding air.

Equation (1) is valid for all values in mWatt except *SINR* and $\gamma(.)$ which have no unit. In logarithmic scale the signal strength is in *dBm* unit and *SINR* and $\gamma(.)$ are in *dB* unit. The evaluation of WLAN QoS is done by the estimation of all users *SINR*. The *SINR* determines the user nominal bit rate.

The interfering transmitters come either from other AP or from users. We focus on interfering AP called downlink interference to simplify the problem. This approximation is valid only if the service used is essentially downloading. However it is not the case if the service used is VoIP for example. This approximation will be used in the strategies presented in the next section.

III. OPTIMISATION STRATEGIES IN WLAN PLANNING

In this paper, all presented strategies will adopt the local interference approach. The SINR computation as defined in equation (1) needs to know the selected BSS and their assigned frequency channels. This can be done only at the end of ACP and AFP process. If ACP and AFP problems are tackled successively, an approximation of the *SINR* is needed to solve ACP problem. In the following we present four strategies. The two first tackle the ACP and AFP problems successively and use approximations of *SINR*. The third treats ACP and AFP problems simultaneously using only non-overlapping channels. The last one is our approach and uses all available channels.

A. Strategy 1: Δf =0

In equation (1) the term Δf is directly linked to frequency channels assignment. Then approximate *SINR* calculus may be done regarding the frequency channels used. Firstly, let us consider that all AP use the same channel, i.e. Δf =0, then $\gamma(\Delta f)$=1. This is the worst case:

$$SINR \simeq \frac{P_{\text{best RSS}}}{\sum P_{\text{others RSS}} + N} \tag{2}$$

The hypothesis is the strongest constraint to add to ACP problem. Here any overlapping between BSS results in interference. Authors in [5] [6] [7] use this approximation. It drives the planner to decrease the BSS number thus reducing the network capacity. Strategy 1 treats only the ACP problem without frequency assignment.

The opposite strategy is to avoid all interferences by fixing $\Delta f \geq 5$, then $\gamma(\Delta f) = 0$. This approximation considers that SINR equals to the Signal-to-Noise-Ratio, that is:

$$SINR \simeq \frac{P_{\text{best RSS}}}{N} = SNR$$

The highest RSS determines if the wireless connexion is (or not) established. The problem becomes a set covering problem [1] [2] [7] [15].

B. Strategy 2: Δf =3

A second strategy is to fix to three the difference between the assigned channels leading to $\gamma(3) = 0.1$. The SINR calculus becomes:

$$SINR \simeq \frac{P_{\text{best RSS}}}{\sum P_{\text{others RSS}} \times 0.1 + N} \tag{3}$$

This kind of approximation is not yet studied in the literature. For this strategy the only step is to solve the ACP problem using *SINR* approximation. The AFP problem is not considered.

C. Strategy 3: 3 non overlapping channels

Wertz et al. [14] treat the AFP problem together with the ACP problem but they use only three non-overlapping channels. In this case only co-channel interferences are considered for SINR evaluation: $\gamma(\Delta f = 0) = 1$ and $\gamma(\Delta f \neq 0) = 0$.

$$SINR \simeq \frac{P_{\text{best RSS}}}{\sum P_{\text{co-channel RSS}}} \tag{4}$$

Prommak et al. [12] adopt the same technique: channel assignment using only three channels. Ling et al. [11] have a similar approach but instead of computing the SINR they directly estimate the throughput with collision probability. These works show that both problems could be tackled together with considerable reduction of search space due to the reduction of available frequency channels.

D. Strategy 4: all available channels

This strategy corresponds to the simultaneous approach we defined: assigning the 13 available channels is part of the ACP process. The frequency channel is one variable to assign among location, antenna pattern, azimuth and emitted power. This is a joint and full optimization of AP location and frequency assignment. In this case the *SINR* calculus is based on the equation (1).

As we unify the problems we need to use a unique network evaluation criterion. In the literature there are almost as many evaluation criteria than papers. We classify them in three main categories: coverage, interference and capacity. The criteria based on coverage needs to compute the RSS from AP. The criteria based on interference needs to estimate BSS-overlapping or approximate *SINR*. The criteria based on capacity needs to analyse the MAC layout and to estimate the number of users per AP. The only criterion unifying them is the real bit rate per user. However to get a good estimation of the real bit rate, we need to consider those three major components. The computation model of the real bit rate from one WLAN configuration (set of AP with their *location, antenna pattern, azimuth, emitted power and frequency channel)* follows these principal steps:

1) Connecting each user location (called *Test Point* or TP) to the best server. On the basis of highest signal strength, we know the set of TP connected to each AP. For each candidate site, a propagation model computes the RSS on the whole building. The propagation model takes into account the shadowing, reflexion and diffraction effects.

2) Computing the SINR in each TP. It determines the nominal bit rate of each association of TP with its AP server.

3) Computing the real capacity of each server (AP) by taking into account its users load and the nominal bit rate of each user. It determines the real downlink bit rate in kbps provided by the network at each TP.

4) Evaluating the TP satisfaction corresponding to the deviation between the bit rate provided by the network and the desired downlink bit rate on each TP.

A complete description of the model can be found in [13]. The algorithm we used is a single local search method based on iterative neighbourhood exploration. Firstly it finds one of the best WLAN configurations that covers all TP (i.e. provides a minimal real bit rate to all TP), then it minimizes the unsatisfied TP.

	ACP/AFP together	ACP step: SINR approximation	AFP step
strategy 1	NO	YES, $\Delta f = 0$	YES with 13 channels
strategy 2	NO	YES, $\Delta f = 3$	YES with13 channels
strategy 3	YES but only 3 non-overlapping channels	NO	YES with 13 channels
strategy 4	YES with 13 channels	NO	NO

Table 1. Strategies description

Table 1 summarises the four strategies. The performance strategies have to be evaluated in the same condition i.e. using the 13 available channels. To compare strategies with each other we need additional steps. For strategy 1 and 2 we add a second step in order to solve the AFP problem using the 13 available channels. For strategy 3, once the site configuration fixed using only 3 non-overlapping channels, we add another step to solve again the AFP problem using the 13 available channels.

IV. EXPERIMENTATIONS

Some experiments were realized with the objective to evaluate these different strategies of ACP and AFP problems resolution. The experiments were held in the environment described by the figure 1. The testbed is composed of a two-floor building. Each floor size is 120m x 40m. We defined 94 candidate sites for AP installation. To focus on the different optimisation strategies, we reduce the combinatory of this testbed: AP parameter settings are reduced to one type of AP with an omnidirectional pattern and 2 possible values of power. As well optimisation strategies does not take into account financial requirements. Indeed, the AP purchase cost and installation site cost are not taken into consideration for QoS evaluation. However we fix at 30 the maximum selected AP for a solution.

In order to define the traffic demand, we use several *service zones*, which are represented by polygons covering parts of the building. Each of these zones is characterised by a number of users and a throughput demand by user of this zone. One service zone (in green on figure 1) is defined on each floor of the building. 300 users are uniformly distributed on each service zone and each user demand is about 500 kbps real bit rate. Then the global demand for the whole building is 300 Mbps. Those 2 service zones correspond to 7728m², and then 7728 TP are defined for *SINR* computation.

Figure 1. a/b. description of the first and second floor of the building test.

For each strategy we run our algorithm 3 times during one hour. Here we present the best solution of the 3 runs. Results of the four strategies are depicted by figure 2. For each strategy we compare the number of selected AP, the number of uncovered TP and the number of unsatisfied TP.

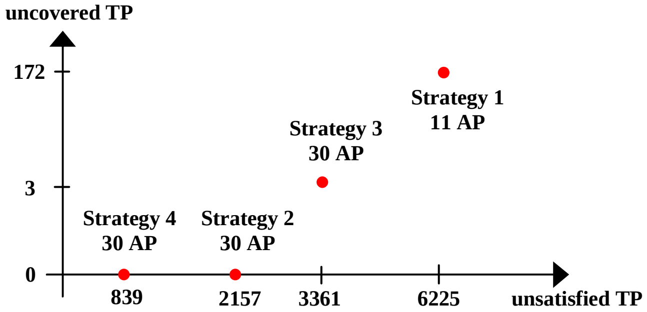

Fig. 2. Results of the four strategy: number of selected AP, number of unsatisfied TP, number of uncovered TP. There are 7728 TP in total.

One TP is not covered if the best RSS is too low to establish a connection (below -94dBm) or if its *SINR* is too low (below 4dB) resulting in significant interferences. One TP is not satisfied if it is covered but its real bit rate is lower than its desired bit rate (500kbps).

Let us consider the networks dimension given by solutions. Strategies 2, 3 and 4 select 30 AP which is the allowed maximum size of network. Only 11 AP are selected in strategy 1. As explained in section III this relatively low AP number is due to interference limitation. In this strategy, if a new AP is added it widely interferes with other AP inducing huge user connection losses. This result shows that this strategy is over constrained for WLAN design. The 11 AP are not enough to satisfy all users demand. Moreover strategy 1 gives the worst results in term of uncovered TP and unsatisfied TP.

Fig. 3 (respectively fig. 4) shows the coverage results of the four strategies on the 1st floor (respectively 2nd floor) of the building. Light blue represents outside the building. Black pixels represent uncovered TP. Light green pixels represent satisfied TP: the bit rate is higher than the desired bit rate. Dark green pixels represent unsatisfied but covered TP. White pixels represent the AP location (locations selected among the initial candidate sites).

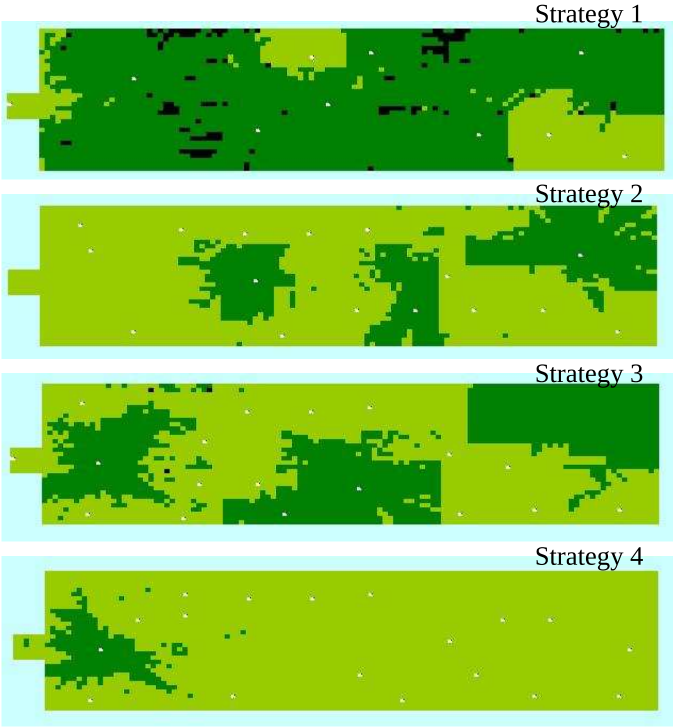

Fig. 3. 1st floor results for strategy 1 (a), strategy 2 (b), strategy 3 (c) and s strategy 4 (d).

Strategies 1 and 3 have uncovered TP due to important interferences. Broadly all strategies have unsatisfied TP due to smaller interferences.

Regarding strategies 3 and 4, the lack of coverage does not come from dissociation of ACP and AFP problems. Using only 3 non overlapping channels concentrates interferences in some areas of the building. Assigning the 13 available channels (strategy 4) instead of only 3 non overlapping channels (strategy 3) gives better results: same number of sites for better user satisfaction. Using all available channels, even overlapping each other, leads to spread the interference impact.

Strategy 2 gives better result than strategy 3 as strategy 3 tackles ACP/AFP problems together and strategy 2 tackles them successively. This means that it is interesting to tackle ACP/AFP problems together only if all available channels are used. Strategy 2 consists in some way to average out at all interferences. This is a good approach if we want to tackle ACP problem before the AFP problem. But our approach (strategy 4) gives best results thanks to two major features. First we treat the assignment of frequency channels in the same time than the AP site location. Second we use the 13 available channels for AFP.

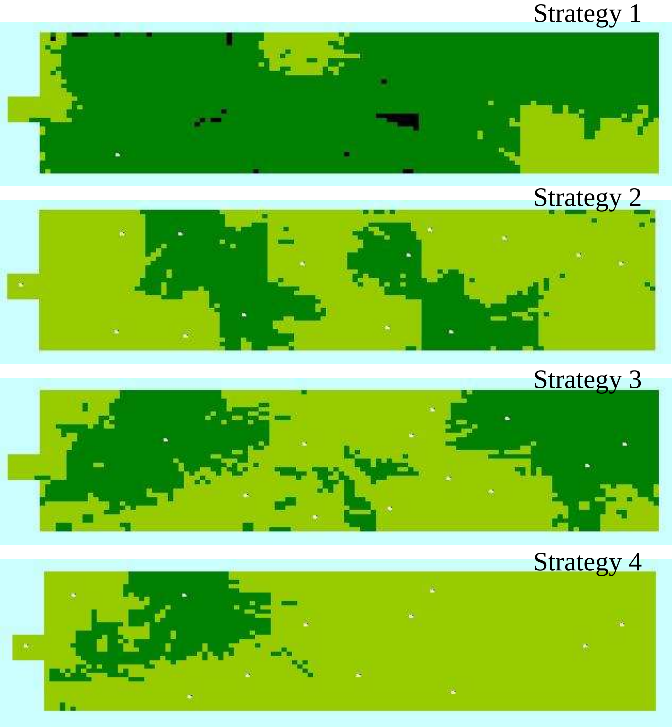

Fig. 4. 2st floor results for strategy 1 (a), strategy 2 (b), strategy 3 (c) and s strategy 4 (d).

🟩	satisfied TP	🟦	outside the building
🟩	unsatisfied TP	⬜	AP location
⬛	uncovered TP		

V. CONCLUSION AND PERSPECTIVE

Frequency management is a major stage in WLAN design process. Channels management refers to channels interference and *SINR* computation. This paper proposes an original method to solve the WLAN planning. Two original features are presented. First we solve channel assignment and location selection of sites simultaneously. Second we use the 13 available channels to process frequency assignment. Three other strategies of WLAN planning were defined to test these features. The experimentations show that considering both features gives good results to reach a full coverage and a desired capacity on a building. As a conclusion these two features have to be used simultaneously to get the best results. In this paper all presented strategies are based on user interference and *SINR* computation takes into account multiple interfering signals. This approach could be validated in future works to show that an optimisation focused on *SINR* computation will give best results than optimisation focused on cell interference and graph modelling.

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