Joint Optimization of Access Point Placement and Frequency Assignment in WLAN

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***Abstract*— The two relevant stages in cellular network planning process are the location selection of the transmitters and the frequency assignment. In the literature WLAN planning approach treats successively those two stages. In this article we propose a new approach where location selection and frequency assignment are tackled together during WLAN planning process. This method has two important features. 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. Firstly 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 (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.

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. 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 clients. The paper is organised in three main sections. The second section focuses on AFP problem and presents several methods to solve it. The third section introduces the unified ACP/AFP approach we propose. In the fourth section, experimentations are presented to compare different approaches and those results are analysed. Finally, we summarize our main results and go further into current 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 covering problem. For example prohibiting the selection of two close sites [3] [4] or minimizing the overlapping area between cells [5] [6] [7]. 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 detail several methods to solve AFP problem in order to understand which constraints are interesting to add to the ACP problem. Those methods are general for different wireless network contexts: GSM, UMTS, 802.11… However this article focuses on 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. It takes into account the average of interference inside the BSS. This global view has the great advantage to reduce 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 covers overlap each other. 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, assigning four or five separated channels from the bandwidth, or assigning all channels.

IEEE 802.11b/g gets 13 frequency channels overlapping each other (see Fig. 1). Frequency assignment without any interference between channels cannot use more than 3 channels such as triplets 1-6-11, 2-7-12 and 3-8-13.

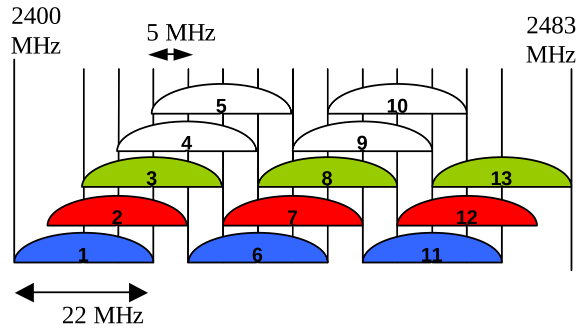

Fig. 1. The 13 overlapping channels of 802.11b/g.

The drawback of strictly non-overlapping frequency channel assignment is that the graph colouring problem becomes quickly impossible to solve with only 3 channels for some problems: open-space, huge density, large networks… As a consequence it needs to enlarge the channel assignment to some overlapping frequency channels and then to introduce interference. The objective of FAP problem becomes to minimize the number of edges using overlapping frequency channels.

The first way is to use four channels to solve the problem. Indeed knowing the four colours map theorem, we can choose channels set 1-5-9-13, which lightly overlap (only 2MHz, see Fig. 2). However the four colour map theorem can not be apply in WLAN planning because BSS are disconnected objects and BSS coverage is not always inside 2D plan but most of the time 3D. One WLAN antenna can cover several floors of a same building.

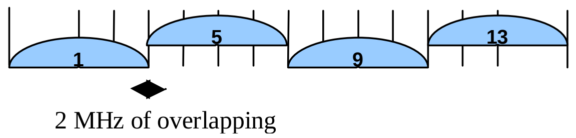

Fig. 2. Four separated channels.

But using 4 channels allows the planner to solve much more problem than with 3 channels. As well 5 channels can be used to enlarge radio resources without too much overlap: 1-4-7-10-13. Two successive channels have 7MHz jointly so they are not independent and their order is important (see Fig. 3): channels 1 and 13 have one neighbour while channels 4, 7 and 10 have two neighbours. Minimizing overlapping between frequency channels is now the main objective of AFP problem.

Now considering all 13 available channels, the overlapping amount between two channels will not be regular and will depend on their respective position on the spectrum. Computing this channel overlap for each couple of frequency we can define penalties to apply to couple of BSS using these frequencies for assignment. The penalty will increase with overlapping size. Then the graph colouring problem consists to assign one channel to each BSS while minimizing penalties amount between neighbours BSS.

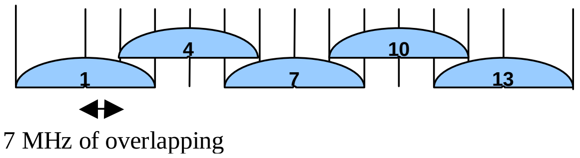

Fig. 3. Five separated channels.

As said before the AFP problem is usually solved after the ACP problem. The output of ACP is the definition of the graph used as input for AFP. For small-scale problem where the graph colouring problem can be solved with 3 or 4 channels, it is not necessary to add interference constraints to ACP problem. ACP and AFP problems can be solved independently without loss of result quality. But if graph colouring problem cannot be satisfied with 4 channels, frequency assignment needs at least 5 channels so interference appear and the separation of AFP and ACP decrease the final result quality. The global problem is under-constrained. In [1][2] the authors adopted this approach and did not take into account the AFP problem for the WLAN planning. Another approach is to add several constraints to ACP problem in order to facilitate the AFP problem. The global problem is over-constrained. In [3][4][6] a graph-based model is built to constrain the ACP problem. The results are better than without additional constraints, but when the instances are difficult (3D building for example) additional constraints severely change the problem structure and the final solution.

B. Local interference approaches

Inside BSS coverage area there is a lot of difference in quality of service. Interferences are not uniform and then clients are not getting the same QoS. A user can lose his connexion due to interference and at the same time another user of the BSS may have a very high throughput. So in the real RF world interference is a local notion.

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

$$SINR = \frac{P_{\text{best serveur}}}{\sum P_{\text{interfering transmitters}} \times \gamma(\Delta f) + N} \qquad (1)$$

where P_{best_server} is the strength of the highest received signal. It is the signal that carries the information to transmit. In 802.11 the connexion is established with the best server. $P_{interfering\ transmitters}$ are other received signals. $\gamma(.)$ is the protection factor corresponding to the coefficient attenuation between channels. It is a function of Δf, the channel distance between the carried signal and the interference signal. $\gamma(.)$ decreases when Δf increases: if Δf =0, $\gamma(\Delta f)$=1 and as seen in figure 1 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 Watt except *SINR* and $\gamma(.)$ which have no unit. In logarithmic scale the strength are in *dBm* unit and *SINR* and $\gamma(.)$ are in *dB* unit.

For any client on the network, the *SINR* determines his nominal bit rate. The real evaluation of WLAN QoS is done by the estimation of *SINR* for all users. As shown in equation (1), its computation needs to know all BSS and assigned frequency channels. It can be done at the end of ACP/AFP process but it cannot be done at the end of ACP before AFP.

There are several axis of approximation concerning the evaluation of network QoS linked to *SINR* computation.

1) The reduction of *SINR* to interfering downlink (from AP) or uplink (from clients) signals.

The interfering transmitters come either from other AP or from clients. We focus on interfering AP called downlink interference to simplify the problem. This approximation is only valid if the service used is essentially downloading; however it is not the case if the service used is VoIP for example.

2) The reduction of *SINR* to single or multiple interfering signals.

The sum of interfering signals in equation (1) shows that several transmitters influence each user in the same time. In the graph-based model (previous section) edges represent neighbourhood transmitter pairs. This model can represent single interference from one BSS to another but it cannot be used to represent multiple interferences from 2 (or more) transmitters. In WLAN, these multiple influences are essential to define the QoS. To represent them we need to define hyper-graph where BSS are vertices and multiple interfering influences (from several BSS) are represented per hyper-graph edges.

3) The number of available channels used for frequency assignment.

In *SINR* computation the term Δf is directly linked to frequency channels assignment. Then approximate *SINR* calculus may be done regarding at the frequency channels used.

Firstly, let consider that all interfering AP work on the same channel, i.e. Δf =0, then $\gamma(\Delta f)$=1. This is the worst case called *SINR co-channel* approximation:

$$SINR \simeq \frac{P_{\text{best serveur}}}{\sum P_{\text{interfering AP}} + N} \qquad (2)$$

In this case any overlapping of BSS is penalized. [5] [6] [7] use this approximation; it drives the planner to sub-dimension the number of BSS thus to reduce the network capacity.

Oppositely, it is possible to avoid all interferences with $\Delta f \geq 5$, then $\gamma(\Delta f)$=0. This approximation means to considerer the *Signal-to-Interference-plus-Noise-Ratio* equals to the *Signal-to-Noise-Ratio*, that is:

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

The highest strength received signal determines if the wireless connexion is (or is not) established. [1] [2] [7] [16] use this *SNR* approximation.

A third approach is to fix the number of channels between the carried signal and all other interfering signal. For example if we fix Δf =3, then $\gamma(3)$ =0.1. The *SINR* calculus becomes:

$$SINR \simeq \frac{P_{\text{best serveur}}}{\sum P_{\text{interfering AP}} \times 0.1 + N}$$

This approximation has not yet been tested in the literature. Both first interfering transmitters are considered on non-overlapping channel; then interference will start when there will be more than 3 transmitters on the same client (one carrier and two scramblers). It is possible to reduce *SINR* computation from the 4th interfering transmitter.

$$SINR \simeq \frac{P_{\text{best serveur}}}{3rd\ P_{\text{interfering AP}}} \qquad (3)$$

This approach corresponds to the deviation between the best signal and the 3rd one. It was introduced for GSM by [8] where the *n* first received signals are necessary for handover. Signals are interfering from the $(n+1)^{th}$ received signal. In [15] the authors applied this idea in WLAN and have as objective to minimize the strength of the $(n+1)^{th}$ received signal. Other signals are not considered.

4) The nature of the combination between ACP and AFP problems.

Wertz et al. [14] treat the AFP problem with the ACP problem but they only use 3 no-overlapping channels. In this case only the co-channel interference is considered for *SINR* evaluation: $\gamma(\Delta f = 0)$ =1 and $\gamma(\Delta f \neq 0)$ =0.

$$SINR \simeq \frac{P_{\text{best serveur}}}{\sum P_{\text{co-channel interfering AP}}} \qquad (4)$$

Prommak et al. [12] adopt the same technique with only 3 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 showed that both problems could be tackled together but with a huge reduction of search space due to the reduction of available frequency channels.

We will now define our approach which is in the category of local interference computation with simultaneous ACP/AFP problem and assignment of all frequency channels. This is a joint and full optimization of AP location and frequency assignment.

III. UNIFIED APPROACH

This approach has three major features. Firstly we treat the assignment of frequency channels in the same time than the choice of AP site location. Dealing with both problems in the same stage avoids over-constraining and under-constraining the initial problem. Secondly multiple interfering signals are taken into account to compute the SINR. Thirdly we use the 13 available channels for AFP. Let see the model.

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 signals strength received from AP. The criteria based on interference needs to estimate BSS-overlapping or to approximate *SINR*. The criteria based on capacity needs to analyse the MAC layout and to estimate the number of users per AP. The only one criterion unifying them is the real bite rate per user. However to get a good estimation of the real bit rate, we need to consider those three major components: the strength of the carried signal, the evaluation of interference and the sharing bandwidth between users of the same BSS. Both first components determine the nominal bit rate for one client and the third one estimates the sharing of BSS bite rate between clients. To estimate the real bit rate from one WLAN configuration (set of AP with their *location, antenna pattern, azimuth, emitted power and frequency channel)*, we compute the *SINR* in each client location (called now TP or *Test Point*) inside the building where the network is designed. Its coordinates, the number of located clients κ_t and their desired downlink bit rate d_t^s, define each TP *t*. On the basis of highest signal strength, we know the set of users connected to each AP. This set and AP nominal bit rate allow us to determine d_t^o, the real downlink bit rate in kbps provided by the network at each test point *t*.

From there, we only need to define a fitness function to optimize when setting all parameters of the network. This fitness includes the evaluation in Euro of network cost and client satisfaction. The cost is defined as the sum of AP installation and purchase costs (in Euro). The client satisfaction is defined as the cost (in Euro) of the deviation between the bit rate provided by the network and the desired downlink bit rate on each test point, that is: $\Delta_t = d_t^s - d_t^o$; then if $\Delta_t \le 0$, the test point request *t* is satisfied, otherwise it is not satisfied. The fitness is the following formula:

$$\sum_{a \in AP} \left(c_s + c_a \right) + \beta \times \sum_{t \in T} \max(0, \kappa_t \Delta_t) \qquad (5)$$

where the first term of the sum is composed of c_s the installation cost of chosen sites for AP location (in Euro) and c_a the purchase cost of chosen AP at each site (in Euro); and the second term of the sum is the unsatisfied bit rate (in kbit/s) weighted with β, the price of unsatisfied bit rate (in Euro).

The aim of the algorithm is to build a network that minimizes this fitness. 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.

IV. EXPERIMENTATIONS

The focus of this work is the simultaneous processing of the ACP and AFP problems. We will compare three scenarios. Both first deal with ACP and AFP problem successively and the third one tackles them together.

Our testbed is composed of one two-floor building. Each floor size is 150mx50m so there are 15000 test points for *SINR* computation. We defined 94 candidate sites for AP installation and 3384 AP configurations with different AP parameter settings. For the FAP each site must use one frequency among the 13 available. Then the WLAN design consists in installing some AP configurations among 3384 candidates and in assigning frequency channels that is $2^{3384x13}$ combinations.

The first scenario with separation of ACP and AFP is the co-channel scenario: all AP uses a single frequency channel. The hypothesis of co-channel is the strongest constraint to add to ACP problem. It is the worst case: all overlapping between BSS is considered as interference. We implement this scenario by using the local search with only one channel for ACP process. In this case we compute the *SINR* with the equation (2). When the ACP is solved (site configurations are done), we solve the AFP problem with the 13 available channels. The second scenario deals with the ACP problem and the AFP problem together but uses three no-overlapping channels. In this case the *SINR* computation given in equation (4) is considered. We implement this scenario by using the local search with three no-overlapping channels for ACP process. This is the approach followed by [11][12][14]. As for the precedent scenario after fixing the sites configuration, we also solve the AFP problem with the 13 available channels. The third scenario corresponds to the simultaneous approach we defined: the assignment of the 13 frequency channels is included in the ACP process. The frequency channel is one variable to assign among the location, antenna pattern, azimuth and emitted power. There is one single algorithmic stage for this approach.

Fig. 4 shows the coverage results of the three scenarios on the 1st floor of the building; the 2nd floor gives similar results. The blue colour represents the outside of the building. Black pixels represent uncovered test points: the best received signal is lower than the minimum threshold. Clear green pixels represent satisfied test points: the bit rate is higher than one desired bit rate. Dark green pixels represent unsatisfied but covered test points: the best received signal is higher than the minimum threshold but the bit rate is lower than the desired bit rate. White pixels represent the location of AP (locations selected among the initial candidate sites). A test point is not covered if the best received signal is too low to establish a connection (below -94dBm) or if its SINR is too low (below 4dB) resulting in significant interferences. The numerical results for the whole building are the following:

Scenario 1: 21 AP, 147 uncovered TP, 1709 unsatisfied TP.
Scenario 2: 40 AP, 4 uncovered TP, 405 unsatisfied TP.
Scenario 3: 37 AP, 0 uncovered TP, 0 unsatisfied TP.

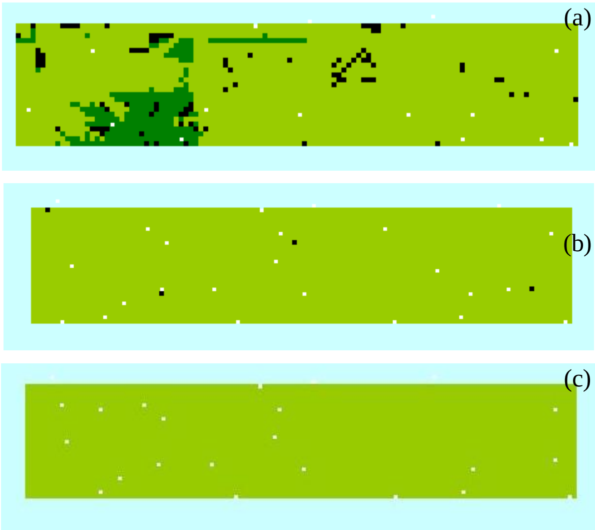

Fig. 4. 1st floor results for scenario 1 (a), scenario 2 (b), and scenario 3 (c).

test point satisfied	outsize of the building
test point unsatisfied	AP location
test point uncovered	

The 3rd scenario is the only one to fully satisfy the demand: all test points are covered and are satisfied. The scenarios 1 and 2 have uncovered test points (black) due to important interferences. The scenario 1 has unsatisfied test points (dark green) due to smaller interferences. The lack of coverage comes from the separation of ACP and AFP problems; the constraints added to the considered problem in scenarios 1 and 2 are not sufficient to guaranty the quality of AFP.

Concerning the dimension of the three networks, their sizes are different. Only 21 AP were opened in the first scenario. As explained in section II this relatively low number is due to interference limitation. In this scenario, if a new AP is added it largely interferes with the others AP inducing huge user connection losses. This result shows that co-channel constraint is too strong for WLAN design. The 21 AP are quite well distributed over floors (see figure 5a) but there is not enough AP to satisfy all users demand. Concerning the scenarios 2 and 3, assigning the 13 available channels on scenario 3 instead of only 3 separated channels on scenario 2 gives better results: less sites for better user satisfaction. Using all the available channels, even overlapping each other, leads to spread the interference impact.

V. Conclusion and Perspective

This paper proposes an original method to solve the WLAN planning. Three original features are presented. Firstly we solve channel assignment and the selection of site location simultaneously. Secondly, multiple signals are taken into account to compute the *SINR*. Finally we use the 13 available channels to process channel assignment. Three scenarios of network design methods were defined to test these features. The experimentations show that this new method gives good results to reach a given coverage and capacity on 3D building. We also showed that it enables to plan large scale WLAN with rather fine evaluation taking into account all parameters: *site, antenna pattern, azimuth, emitted power and frequency channel*. This first conclusion must be deepened with more experiments.

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