3-D BSS Geometric Indicator for WLAN Planning

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Abstract: **Optimal planning of wireless networks is one of the most fundamental problems in WLAN design. This paper discusses the organisation of BSS in WLAN extended service set planning for large-scale deployment. We take advantage of a new geometric criterion to evaluate the coverage quality and apply them to WLAN planning. The obtained results show that using such criteria facilitates WLAN planning and improves the WLAN QoS.**

1. INTRODUCTION

WLAN network planning consists in selecting a location for each transmitter and setting the parameters of all sites in order to supply 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 network planning. Firstly we have to select a set of sites from a list of candidates that have been identified as potential sites; 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 **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 network context.

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 environment. This problem is called AFP problem for ***Automatic Frequency Planning*** and becomes very famous in the context of cellular GSM/GPRS/EDGE systems.

Usually these two problems are treated successively in WLAN: 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].

Till in WLAN, some other constraints not connected to frequency allocation may also be added to the ACP problem in order to improve the QoS like the estimation of the throughput [9] [11], of the network capacity [12] or the evaluation of the impact of hidden nodes [7]… Each constraint concerns a particular aspect of QoS which is directly linked to interference management that is the number and amplitude of scrambling signals on carrier.

This paper introduces a new constraint based on **Basic Service Set** (BSS) geometry to ease frequency allocation in WLAN planning. Considering all BSS composing a network our innovative work consists in defining a 3 dimension performance indicator of BSS shape in two contexts: used separately for each BSS and used globally for best server BSS inside an Extended Service Set.

In the literature, there are few works which take into account the cell (in cellular network) or BSS (in WLAN) shape as criteria and study its impact on the network QoS. *Reininger et al.* defined a notion of cell connectivity [8]. *Hao et al.* used this concept during a pre-optimization phase of network design [15]. *Jedidi et al.* introduced cell criteria measuring the distortion from the disk [13]. *Mabed et al.* [14] deepened those criteria and study their impact on interferences in GSM. In this paper we adapt and apply this category of criteria in WLAN context to study their impact on QoS. The environment is specific as the transmitter and the receiver are inside building and the signal propagation is in 3 dimensions to take into account building floors.

The paper is organized as follows. The second section introduces the geometric criteria and shows how we define them in WLAN planning. The third section explains and presents early experimentation results. In the fourth section we apply geometric criteria to the whole network and show that it improves the WLAN design process. Finally, we summarize our main results and go further into current work.

2. GEOMETRIC CRITERIA

2.1 Definition of cell

In GSM or UMTS networks the area to be covered is defined as a 2-D grid of pixels. Then a cell relative to one antenna is a set of pixels associated to a given base station.

We define a cell C as a set of pixels where the signal received from the station exceeds a given quality threshold q.

$$C = \{b_{i,j} / F_{i,j} > q, \forall i, j\} \quad (1)$$

Where $b_{i,j}$ represents the pixel of co-ordinates (i, j) and $F_{i,j}$ is the signal strength received at pixel $b_{i,j}$ from the antenna.

2.2 Reference geometric model

In a 2-D space, all pixels have 8 neighbours except pixels on space borders. In cellular network *Jedidi et al.* [13] evaluate the convexity of a cell by counting for each pixel of the cell the number of pixel neighbours that belong to the same cell. For a given pixel $b_{i,j}$, the function V computes this number of neighbours. *Jedidi et al.* defined then the geometrical quality of a cell by the following criteria:

$$G(C) = \frac{\sum_{b_{i,j} \in C} V(b_{i,j})}{8 \times |C|} \quad (2)$$

The term in denominator is necessary to compare cells having different sizes. The function G value is between 0 and 1. The closer G is to 1, the closer the cell geometry is to a disk.

Mabed et al. [14] brought some corrections to the original geometric criteria. They clearly normalized the criteria in order to compare it with the ideal cell shape which is a disk. So they replaced the denominator by a better evaluation of one disk in a grid space. Knowing the cell size $|C|$ they estimated the value of one disk by: $8 \times |C| - 6 \times \sqrt{\pi \times |C|}$, taking into account that bordered pixels do not have 8 neighbours. So *Mabed et al.* define the function:

$$G'(C) = \frac{\sum_{b_{i,j} \in C} V(b_{i,j})}{8 \times |C| - 6 \times \sqrt{\pi \times |C|}} \quad (3)$$

This criterion G' is between 0 and 1. G' gives a better measurement of cell distortion from the disk. This value equals to 1 if the cell shape is a disk and decreases as the cell geometry defers from it. This result improves interference management so QoS in GSM network [14].

2.3 Geometric indicator for WLAN

To evaluate and compare the AP configurations in WLAN context, it is necessary to adapt the formula to the specific indoor environment. The area to be covered while deploying a WLAN is generally a building. Each floor is defined as a 2-D grid of pixels, so we have globally a 3-D grid of pixels. In WLAN the same AP can cover several floors at the same time then it is not correct to compare a WLAN BSS which is in three dimensions with 2-D cell in cellular network. Consequently we defined for each floor k a 2-D BSS C_k as a set of pixels at the same floor k where the signal received from the AP exceeds a given quality threshold q.

$$C_k = \{b_{i,j,k} / F_{i,j,k} > q, \forall i, j\} \quad (4)$$

Where $b_{i,j,k}$ represents the pixel of co-ordinates (i, j, k) and $F_{i,j,k}$ is the signal strength received at pixel $b_{i,j,k}$. Then the real BSS (in 3-D) is defined as the union of all 2-D BSS, we get: $C = \bigcup_{k=1}^{k=K} C_k$ where K is the number of floors.

It is necessary to adapt the geometric measurement to take into account the 3-D space. We choose to keep the same definition of G' for each floor as if they were independent. $G'(C_k)$ is the value of the geometric indicator of the configuration in the floor k.

$$G'(C_k) = \frac{\sum_{b_{i,j,k} \in C_k} V(b_{i,j,k})}{8 \times |C_k| - 6 \times \sqrt{\pi \times |C_k|}} \quad (5)$$

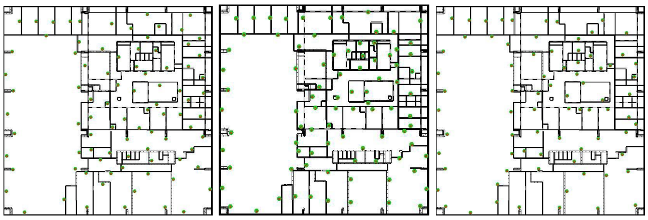
We regroup floor-indicator inside a unique indicator defined by the following equation:

$$G_{WLAN}(C) = \sum_{k=1}^{k=K} \frac{|C_k|}{|C|} G'(C_k) \quad (6)$$

Where each 2-D indicator is normalized on the basis of its percentage of coverage in 3-D. In the further section we will evaluate two networks with this performance indicator.

3. EARLY EXPERIMENTATIONS

Our testbed is composed of one three floor building (figure 1). Each floor is a 45m square. We defined 252 candidate sites for AP installation. For each site we can choose between 2 antenna patterns: one omnidirectional antenna (without azimuth) and one directional antenna with 8 possible azimuths. The two antennas are able to transmit the signal at 4 different powers. Then for each site we may choose between 36 configurations. So globally we get 9072 candidate AP configurations. A WLAN consists in the installation of some AP configurations among these 9072 candidates that is 2^{9072} combinations.



a. floor 0 *b. floor 1* *c. floor 2*

Figure 1 – Topology building: candidate AP locations

The histogram depicted by figure 2 represents the distribution of those AP configurations according to G_{WLAN} value. We see that G_{WLAN} values follow a Gaussian distribution centred on 0.9 mean values. This geometric indicator denoted **isolated geometric indicator** concerns each AP configuration.

We fixed the threshold value q at *-80dBm*. It is about *10dBm* higher than the minimum power necessary to establish a connection given by constructors which is more realistic.

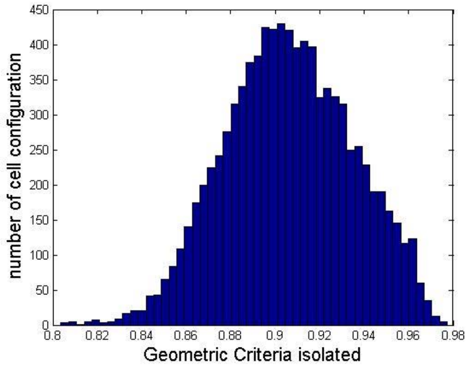
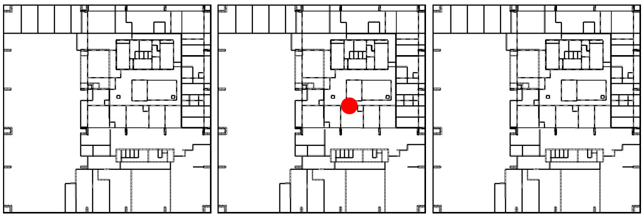


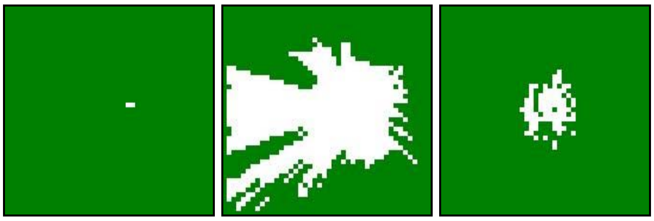
Figure 2 – AP configuration distribution according to the isolated geometric indicator: G_{WLAN}

Figures 4 and 6 show representative values of this indicator on a 3-D building for 2 different AP location and compare them to the corresponding BSS shape.



a. floor 0 *b. floor 1* *c. floor 2*

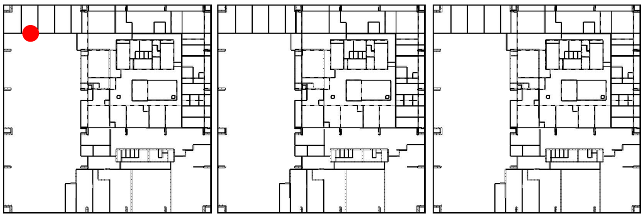
Figure 3 – Topology building: AP location



a. floor 0 *b. floor 1* *c. floor 2*

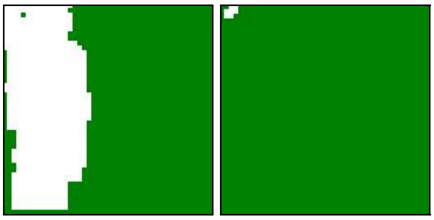
Figure 4 – BSS of the AP configuration with G_{WLAN} = 0.86

In site configuration described by figure 4 we installed the antenna on floor 1 (see spot on figure 3). Figure 4.b represents the coverage area of the floor 1 corresponding to pixels receiving at least *–80dBm* signal. We see that the BSS shape is slightly dispersed. The floor 0 and floor 2 are also covered by the same antenna but their respective areas are less wide than that of floor 1. The BSS shape depicted by figure 4.c is also slightly dispersed. That dispersion creates isolated pixels where the BSS overlapping and neighbourhood are poorly managed driving to interference problem.



a. floor 0 *b. floor 1* *c. floor 2*

Figure 5 – Topology building: AP location



a. floor 0 *b. floor 1*

Figure 6 – BSS of the AP configuration with G_{WLAN} = 0.95

Figure 6 corresponds to another site configuration. Here we installed our antenna on floor 0 (see spot on figure 5). Figure 6.a describes the coverage area of floor 0 and the coverage area of floor 1 is described by figure 6.b. Floor 2 is not covered at all. However we can clearly see that the BSS shapes are more compact than those of figure 4.

We observe that the BSS of figure 6 has a greater G_{WLAN} value than the BSS of figure 4. In our case study, the higher is G_{WLAN} the more compact and convex is the BSS. This compacity is good for interference management between the BSS of the extended service set.

4. NETWORK GEOMETRY

In WLAN, when a client receives several signals from different AP, he establishes the communication with the AP from which he receives the highest signal. Such AP is called the Best Server of the client. For each AP *l* we define his Best Server cell BS^l as the set of pixels where the signal received from the AP *l* exceeds a given quality threshold *q* **and** is the highest. Similarly to the definition of the simple BSS *C* and C_k we defined for each floor a Best Server BSS BS_k^l as:

$$BS_k^l = \left\{ b_{i,j,k} / F^l_{i,j,k} > q \text{ and } F^l_{i,j,k} > F^m_{i,j,k}, \forall m \in A - \{k\}, \forall i, j \right\} \quad (7)$$

Where $F^l_{i,j,k}$ is the signal power received on the pixel *(i,j,k)* from the AP *l*. In the same way, we define: $BS^l = \bigcup_{k=1}^{k=K} BS_k^l$.

Now, we evaluate for each Best Server BSS the geometric indicator $G_{WLAN}(BS^l)$. To evaluate the geometric quality of the entire WLAN network, we proposed to compute the weighted average according to the size of each Best Server BSS i.e. the respective pixel number of each Best Server BSS.

$$G_{Network} = \sum_{\forall l} \frac{\left|BS^l\right|}{\sum_{l} \left|BS^l\right|} G_{WLAN}(BS^l) \qquad (8)$$

To make our tests we considered two networks each one composed of 12 AP distributed over the three-floor building (see figures 7 and 9).

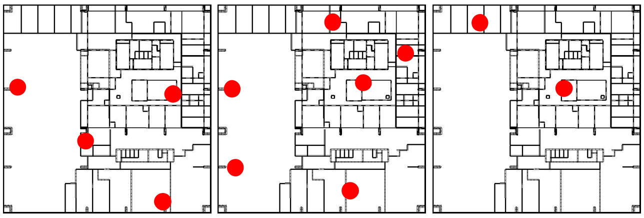

a. floor 0 *b. floor 1* *c. floor 2*

Figure 7 – Topology building and AP location

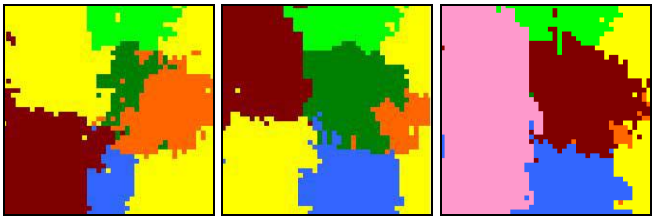

a. floor 0 *b. floor 1* *c. floor 2*

Figure 8 – Network 1 Best Server cartography ($G_{Network}$ = 0.94)

These networks result from an optimization process which try to cover the building at a given data rate in each pixel. Figures 8 and 10 describe Best Server cartography for each network. Each colour corresponds to a different Best Server BSS. Figure 8 describes the Best Server BSS of the first network having a $G_{Network}$ value of 0.94. Figure 10 describes the Best Server BSS of the second network having a $G_{Network}$ value of 0.91.

Best Server BSS of the first network are less dispersed and so more convex than those of the second network. We notice that the number of cell neighbours in figure 8 is smaller than that in figure 10. As a matter of fact, the ***Automatic Frequency Planning*** (AFP) problem will be easier to solve for the first network than for the second network. As for cellular systems, the $G_{Network}$ indicator seems quite suitable to evaluate the AFP problem feasibility in WLAN.

Our next step is to show how this geometric performance impacts on interference performance. At the moment, a comparative study from expert on WLAN immediately concludes on a better design involving a better QoS management with network 1. There is a clear identification of BSS distribution and borderlines on the 3 floors. This is not the case on network 2.

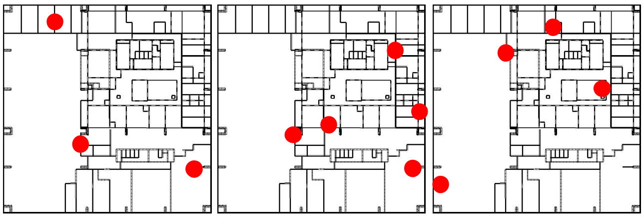

a. floor 0 *b. floor 1* *c. floor 2*

Figure 9 – Topology building and AP location

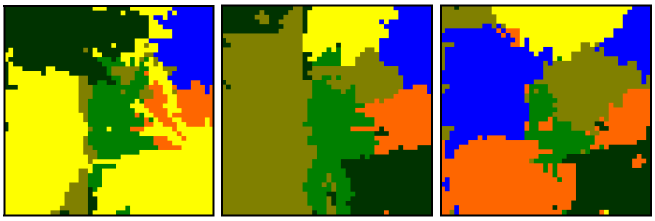

a. floor 0 *b. floor 1* *c. floor 2*

Figure 10 – Network 2 Best Server cartography ($G_{Network}$ = 0.91)

5. CONCLUSION

WLAN planning is a crucial problem for large-scale deployment. In this article we considered geometric criteria used in cellular networks context and adapt them in WLAN context. Our results show that the higher is the function value the more convex is the BSS shape. Then we defined two geometric indicators for WLAN: an isolated one which characterizes the shape of a unique BSS and a Best Server one which characterizes the average value for the global network. In our case study, we notice that there is a relationship between both geometric indicators and BSS convexity.

Using those criteria during WLAN planning seems very interesting to improve the frequency planning process. A network having a "good" value of the $G_{Network}$ has real facility for frequency assignment. Ongoing work aim to validate those conclusions on much more samples and determine what is a "good" geometric value. More over we have to study the relationship between the isolated geometric indicator and the Best Server indicator in order to define how to use them during optimization phase of WLAN design process.

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