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Symbolic 3D WiFi indoor positioning system - A deployment and performance evaluation tool

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BIOGRAPHY

Nel Samama is a member of the Navigation Group of the Department of Electronics and Physics at the Institut TELECOM / TELECOM SudParis. He has been working for many years in the indoor positioning field, and more specifically on WLAN symbolic approaches and on GNSS repeater based systems.

ABSTRACT

In many location based applications there is no real need for accuracy, but rather for reliability. For example, knowing someone is in a specific room, corridor or office is often sufficient. This is the basis of the symbolic approach that gives a positioning in terms of rooms (or group of rooms). Developed algorithms have then a clear target: to provide high reliability in a typical 3D environment, together with real time indicators of both accuracy and reliability. The WLAN symbolic system has also been designed in order to provide positioning with no calibration phase and which still works even in "real telecommunication environments", i.e. with a reduced set of Access Points (it still works with only one Access Point, although the accuracy of the positioning is then really poor). In addition, the symbolic approach is scalable and easy to adapt to particular needs such as an increased accuracy in specific areas or positioning in a complex 3D building.

We have developed a tool that allows a user to evaluate the positioning performance of its WiFi network, using the symbolic method. Default values of the various parameters allow a straightforward approach, although a reduced set of initial measurements (a "not more than five minutes" calibration) is bound to provide a better positioning estimation. This tool is also useful in improving the WLAN network deployment for positioning purposes in helping to find the best locations of the Access Points. In addition, it helps in defining the location of a newly added Access Point that will improve the positioning. The tool is fully presented and described in the paper and allows the deployment and evaluation of the symbolic positioning in all environments by any user.

This paper is organized in 10 sections. Section 1 is a general introduction to symbolic positioning in

WLAN. Sections 2 and 3 detail respectively the 2D and 3D algorithms used for the current implementation. Section 4 describes the environment under consideration. Section 5 gives the way the intersection of zones is carried out (this is the basis of the approach) and in section 6 a discussion about possible real time indicators of accuracy and reliability is provided. Sections 7 and 8 give the first results on deployment and positioning. Then the paper ends with a comparison with real experimental results (section 9) and a conclusion of the work (section 10).

1 - INTRODUCTION

When dealing with WLAN positioning, one has to take into account that there is a need for a large number of "base stations" if the accuracy required has to be within a few meters (Borenovic, 2009, Eissfeller, 2004 and Heinrichs, 2003). This leads to really heavily differentiating the telecommunication network from the one needed for localisation purposes and thus to decrease significantly the potential advantage of WLAN based approaches. Furthermore, for many applications (professional centres, commercial areas, office blocks, shopping malls, etc.), there is really no need for accuracy at all, as long as one can find out the room a person is in. In such cases, one would just need to know that he/she is in corridor C or in conference room CR-23. That is enough for almost all indoor applications (except maybe in an emergency, where in some specific cases, one will need accuracy to between one and two meters).

We proposed another approach (Samama, 2005, Samama, 2006, and Chelly, 2007): the positioning is no longer concentrating on accuracy, but is working in a more symbolic way. This means that it will no longer be possible to say that you are 2 or 4 meters from such an absolute location, but only that you are within a given area, say conference room A. We showed that the global performance of a symbolic WLAN system is as good as that obtained with heavy power level database extraction methods. The idea is to define, for each access point considered, three zones of increasing size when the power level received by the mobile decreases. The three zones are associated with two corresponding power thresholds. The positioning consists then simply in intersecting zones from different access points received. The main advantage is, of course, that there is no longer the need for databases: thus the implementation could be very easy

on any mobile terminal equipped with a WLAN technology, either Bluetooth or WiFi. The other fundamental advantage is that this method applies also when only one access point is deployed, making the approach more realistic in a real environment.

The goal of this paper is to show the performance of this approach in a typical environment, such as the A building of the Institut Telecom (IT) located south of Paris. This building is a 5 storey construction with various configurations of walls and offices on different floors. Towards this goal, we designed a deployment and performance evaluation tool that allows anybody to evaluate the efficiency of the symbolic approach in its own environment. For the present paper, the tool was used in the A building environment. Both the evaluation of various deployment configurations (number of Access Points -AP- and location of the AP) in terms of global efficiency and the positioning accuracy for a random distribution of true locations were carried out.

Despite the rather good results reported, our feeling for WLAN location finding is that it is quite difficult in terms of XY absolute positioning. The developed approach of RSSI measurements is dependent on the indoor configuration and cannot easily be extended to new buildings. Thus it requires a large investment in terms of map data collection and redundancy compared to the communication network. On the other hand, results have shown that it is often relatively clear, for the experimenter, that he is entering a room by having a look at the RSSI changes of given transmitters. This leads us to believe that a symbolic type of positioning (room, corridor, stairs, etc.) may be the right way to approach the Bluetooth or Wi-Fi based location finding techniques. This would require only basic algorithms (hopefully) and could probably be a robust and repeatable method. This idea is simply presented in figure 1.

9	9	9	10	10	10	11	11	11	11	12	12	12	12	12	12	13	13	13	13	13	13	14	14	14	14	14	14	
9	9	9	10	10	10	11	11	11	11	12	12	12	12	12	12	13	13	13	13	13	13	14	14	14	14	14	14	14
9	9	9	10	10	10	11	11	11	11	12	12	12	12	12	12	13	13	13	13	13	13	14	14	14	14	14	14	14
9	9	9	10	10	10	11	11	11	11	12	12	12	12	12	12	13	13	13	13	13	13	14	14	14	14	14	14	14
9	9	9	10	10	10	11	11	11	11	12	12	12	12	12	12	13	13	13	13	13	13	14	14	14	14	14	14	14
8	8	8	8	8	8	11	11	11	11	12	12	12	12	12	12	13	13	13	13	13	13	14	14	14	14	14	14	14
8	8	8	8	8	8	11	11	11	11	12	12	12	12	12	12	13	13	13	13	13	13	14	14	14	14	14	14	14
7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
1	1	1	2	2	2	3	3	3	3	4	4	4	4	4	4	5	5	5	5	5	5	6	6	6	6	6	6	6
1	1	1	2	2	2	3	3	3	3	4	4	4	4	4	4	5	5	5	5	5	5	6	6	6	6	6	6	6
1	1	1	2	2	2	3	3	3	3	4	4	4	4	4	4	5	5	5	5	5	5	6	6	6	6	6	6	6
1	1	1	2	2	2	3	3	3	3	4	4	4	4	4	4	5	5	5	5	5	5	6	6	6	6	6	6	6
1	1	1	2	2	2	3	3	3	3	4	4	4	4	4	4	5	5	5	5	5	5	6	6	6	6	6	6	6
1	1	1	2	2	2	3	3	3	3	4	4	4	4	4	4	5	5	5	5	5	5	6	6	6	6	6	6	6

Figure 1: Symbolic positioning philosophy

Furthermore, the symbolic approach means that we decided to split the total area into symbolic areas, designating in terms of rooms, offices or corridors. In the present case, we decided to split the third level of building A of IT into 14 offices and corridors. In addition, dealing with power level measurements from a given access point at the receiver's end, there is also the need to define various location zones (depending on the power level received). This is the basis of the symbolic positioning: zones are defined for each access point and if a few access points are available, then the

resulting positioning is obtained by carrying out intersection of zones.

Following the previous discussion, it appears that the zones must not be exclusive from each other. The considered algorithm can be described as follows (note that we are dealing with three zones for each access point since it appears to be an acceptable compromise between complexity and reliability):

- For each base station, we define three sets of areas: Z1(i), Z2(i) and Z3(i);
- Z1(i) is the area in which the base station i lies;
- Z2(i) groups the surrounding areas to Z1(i), including Z1(i);
- Z3(i) groups all the areas where base station "i" can be received (whatever the power level), including Z2(i);
- For each Zone, we define two threshold values Threshold1(i) and Threshold2(i);
- If the power level (RSS: Radio Signal Strength) for base station i is greater or equal to Threshold1(i), then Z1(i) is associated to the base station;
- If the RSS value for base station i lies in between Threshold2(i) and Threshold1(i), then Z2(i) is associated;
- If the RSS value is lower than Threshold2 (i), then Z3(i) is associated;
- Given the values of the thresholds, we compute the corresponding zones for the previous set of points, taking into account all the base stations;
- We then make, for all the points considered, the intersection of the zones (if not empty) or the union of the zones (if the intersection is empty).

2 - 2D SYMBOLIC RULES

In order to define the various zones, there is a need for an "automatic" algorithm that could be used in all kind of environments. The main idea relies on the concept of adjacencies. Once the location of the AP is defined, we are going to determine the three zones as follows:

- Zone 1 is defined as being the zone where the AP lies, limited to a radius of Rz1 meters for rooms of a size greater than SurfMaxZ1. As a matter of fact, this has to be taken into account for the specific case of very large rooms, such as lecture halls where propagation is almost identical to outdoors in the vicinity of the AP. For this paper, Rz1 is taken to be equal to 4 meters and SurfMaxZ1 is 50 m2. Thus, for rooms greater than 50 m2, Zone1 is limited to a circle of 4 meters of radius. Figure 2 gives a view of Zone1 for an AP located in room "7" (see figure 1).

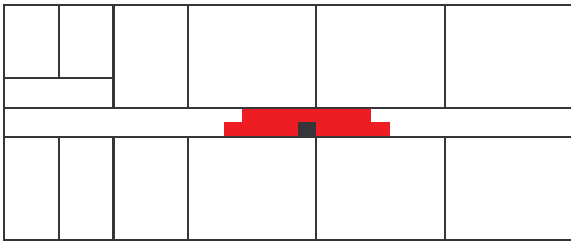


Figure 2: Zone 1 for AP in "7" (in black the actual location of the AP).

- Zone 2 includes Zone 1 and adds to it all the adjacent areas to Zone 1. See figure 3 for details. Note that similar rules apply regarding the sizes of the various rooms.

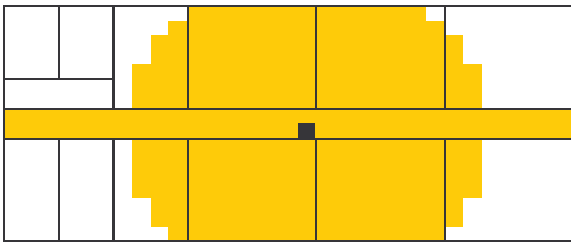


Figure 3: Zone 2 for AP in "7" (in black the actual location of the AP).

- Zone 3 includes Zone 2 and adds to it all the adjacent areas to areas in Zone 2. See figure 4 for details.

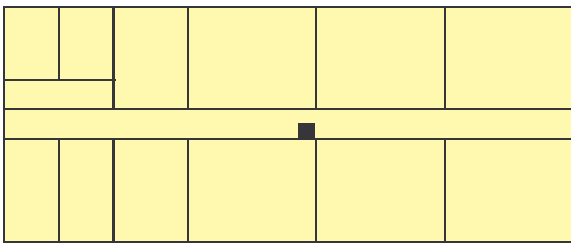


Figure 4: Zone 3 for AP in "7" (in black the actual location of the AP).

The graphical representation adopted from now is then to consider the following image for symbolic coverage for any given AP:

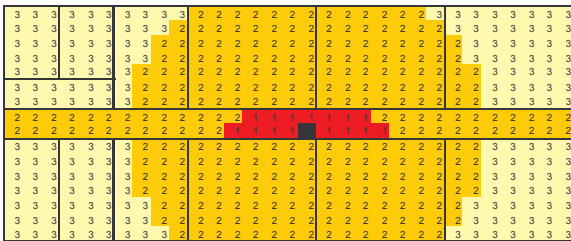


Figure 5: Different zones for AP in "7" (in black the actual location of the AP).

3 - 3D SYMBOLIC RULES

In the case of a 3D building (and it is quite difficult not to consider 3D when dealing with indoor positioning in real environments), the previous rules must be updated in order to take into account the floor levels the AP is

not on. In the case of the symbolic approach, we choose to go ahead with the "symbolic definition" of the various zones. Thus, we consider:

- Zone 1 cannot spread into another level than that where the AP lies. So, Zone 1 remains unique and the misleading of positioning is not possible.
- Zone 2 is made up of all the rooms that are adjacent to the projection of the Zone 1 of the AP. The projection has to be considered here only for the adjacent floor levels (adjacent to the one containing the AP). Thus, Zone 2 can only spread over three floor levels (this is the maximum).
- Zone 3 is made up of all the rooms that are adjacent to the projection of the Zone 2 of the AP. The projection has to be considered here for the adjacent floor levels (adjacent to the one containing the AP), and for the ones above and below. Thus, Zone 3 can only spread over five floor levels (this is the maximum, not always reached, depending on the location of the AP in the building).

In addition to these general rules, there is also a limitation in terms of distance from the access point, so the propagation is "restricted" in certain rooms because considering all the rooms would have been too optimistic. A typical situation is provided in figure 6 for three floor levels with an AP located in the middle of the corridor of the intermediate level.

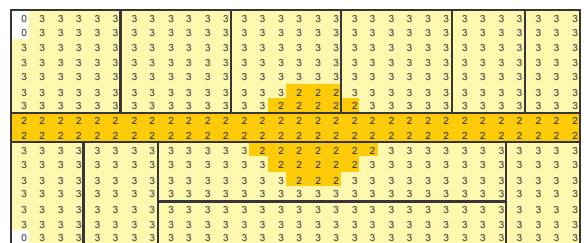
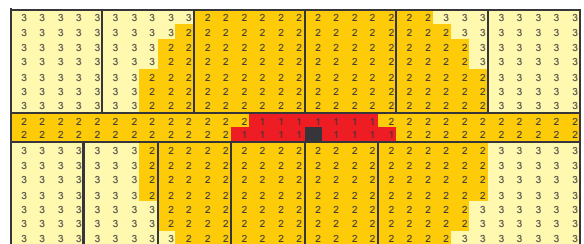
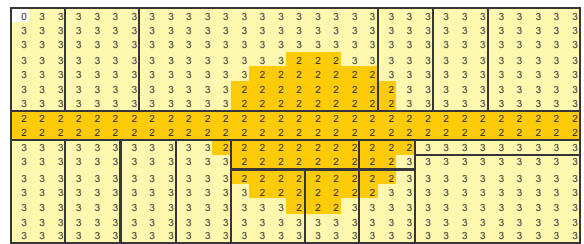


Figure 6: Resulting zones for a central AP in a corridor of an intermediate floor level (in black the AP). Above: second floor; Central: first floor; Below: Ground floor.

Note that many other "strategies" could have been imagined. The one proposed seems to match rather nicely the various experiments carried out in the A

pair of APs (on a given floor level) are located on the left and on the right hand side of the building.

In order to have an efficient way of dealing with the environment and the indoor distribution of rooms on the various floors, we decided to calculate the so-called adjacency matrices. In fact they summarise, for each floor and for each room, the other rooms that have a common wall, part of a wall or corner in common with the room. Note that it has (until now) only been implemented for a given floor, i.e. in a 2D approach. For the floor distribution given in figure 1, the corresponding adjacency matrix is as follows (figure 10).

Floor Level 3	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Surface 1	0	1	0	0	0	0	1	0	0	0	0	0	0	0
Surface 2	1	0	1	0	0	0	1	0	0	0	0	0	0	0
Surface 3	0	1	0	1	0	0	1	0	0	0	0	0	0	0
Surface 4	0	0	1	0	1	0	1	0	0	0	0	0	0	0
Surface 5	0	0	0	1	0	1	1	0	0	0	0	0	0	0
Surface 6	0	0	0	0	1	0	1	0	0	0	0	0	0	0
Surface 7	1	1	1	1	1	0	1	0	0	1	1	1	1	1
Surface 8	0	0	0	0	0	0	1	0	1	1	1	0	0	0
Surface 9	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Surface 10	0	0	0	0	0	0	1	1	0	1	0	0	0	0
Surface 11	0	0	0	0	0	0	1	1	0	1	0	1	0	0
Surface 12	0	0	0	0	0	0	1	0	0	0	1	0	1	0
Surface 13	0	0	0	0	0	0	1	0	0	0	0	1	0	1
Surface 14	0	0	0	0	0	0	1	0	0	0	0	0	1	0

Figure 10: Adjacency matrix of the third floor of the A building.

Rows and columns are the various rooms of the floor and a "1" at the intersection means that the two corresponding rooms are adjacent. This is achieved for the five floors and will be used as described in the next sections.

5 - EVALUATION OF THE INTERSECTIONS

The main idea of the symbolic approach is to carry out a sort of enhanced cell-id based on the WLAN's received power level. Instead of considering only the centre of the area of coverage (the location of the AP indeed), it implements a sort of non-exclusive "step" from each received access point. The next problem is thus to define the best way to implement the intersection of these step ranging areas when more than one AP is received. This "zone intersection" is the basis of the symbolic method. The intersection process is based on the concept of the "signature" of each point of the building.

The "point" is an item that is introduced at this stage and that has been implicitly used before: this is the elementary component of any room. When looking at figure 1 for instance, each number that can be seen is located in such a point. Note that in the present case, the point defines a 1 m2 square surface.

The "signature" is a unique number, an integer, defining the succession of corresponding zones for all APs. This means that in the case of a deployment of 2 APs, the signature of all the points is a two digit integer (and in the case of a deployment of N APs, the signature is an N digit integer). Since three zones are

considered in the symbolic approach for each AP (another choice could be made with no modification of the global philosophy), each digit is:

- 0 if the AP is not received at the point,
- 1 if the power received is higher than threshold1,
- 2 if the power received lies between thresholds 1 and 2,
- 3 if the power received is less than threshold2.

In the case of a 2 AP deployment, figure 11 shows a typical result of the signature calculation using the formula:

$$Signature(m, n) = \sum_{i=1}^{NbAP} [ZoneAP_i(m, n) \cdot 10^{(NbAP-i)}]$$

where

- m and n are indexes defining the x and y coordinates, in a local referential, of the current point,
- NbAP is the total number of deployed APs,
- ZoneAPi(m,n) is the resulting symbolic zone of point (m,n), depending on the received power,
- Signature(m,n) is the signature of point (m,n).

3	3	3	3	3	3	3	3	2	2	2	2	3	2	3	2	3	2	3	3	3	3	3	3	3	3	3	3	
3	3	3	3	3	3	3	3	2	2	2	2	2	2	3	2	3	2	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	2	2	2	2	2	2	3	2	3	2	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	2	2	2	2	2	2	3	2	3	2	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	2	2	2	2	2	2	3	2	3	2	3	3	3	3	3	3	3	3	3	3	3
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	2	2	2	2	2	2	3	2	3	2	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	2	2	2	2	2	2	3	2	3	2	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	2	2	2	2	2	2	3	2	3	2	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	2	2	2	2	2	2	3	2	3	2	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	2	2	2	2	2	2	3	2	3	2	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	2	2	2	2	2	2	3	2	3	2	3	3	3	3	3	3	3	3	3	3	3

Figure 11: Example of a signature matrix for a 2 AP deployment. The case of the basement floor.

For the A building of IT, the computations give us a total of five such matrices (one per floor) with integer lengths depending on the number of APs deployed, ranging from 3 (for configurations 1 and 1b) to 7 (for configuration 4). In the latter case, a signature can be as complex as 3202230 for example. These signature matrices are indeed a representation of the intersections for a given distribution of APs and a given environment (different floor levels and room distribution for each floor).

From these matrices, a large set of calculations can be carried out. The results available in the current version of the evaluation tool are given in figure 12 below, for the case of the underground level:

UnderGround Level															
7	2	85	11,29	8,40	4,89	0	1	0	0	0	0	4,73	5,66	7,51	7,63
3	109	4,45	8,67	5,27	0	0	1	0	0	0	0	5,32	6,35	7,80	7,96
21	16	17,00	8,44	2,12	1	1	0	0	0	0	0	2,05	2,08	3,05	3,05
22	46	15,65	8,52	9,68	0	2	0	0	0	0	0	5,68	6,18	6,67	6,68
23	14	30,00	7,71	2,18	0	1	1	0	0	0	0	1,98	2,49	2,89	3,29
32	159	20,05	8,32	5,49	0	1	1	0	0	0	0	5,67	6,45	7,60	7,92
33	67	28,22	8,94	5,57	0	0	2	0	0	0	0	5,40	5,67	6,07	6,11

Figure 12: Typical results obtained from the signature matrices.

The number in the first column (first on the left hand side) gives the total number of different signatures obtained for the floor level, here 7.

The second column gives the detail of the signatures. Thus, there are now as many lines as the total number of signatures (number in first column).

For each signature of the floor, the following columns are respectively given:

- the number of points having this signature,
- the x coordinate of the mean location of the points having this signature,
- the y coordinate of the mean location of the points having this signature (note that x and y give an indication of the centre of the area of the signature),
- the average distance separating the mean location (characterised by x and y) and the different points having the signature given in the second column (note that this gives an indication of the shape of the area of the signature),
- the five following numbers indicate the number of APs received for which the point is in Zone 1, Zone 2, Zone 3, Zone 4 and Zone ?, respectively (note that the current version of the evaluation tool takes into account the possibility of implementing up to 5 different Zones for each AP),
- the following column indicates whether the signature is present on another floor (1) or not (0) (this is very important in evaluating the ability of the deployment to determine the floor),
- finally, the last four columns give respectively the 50%, 67%, 90% and 95% distances from the mean location of the signature. This means that 50% of the points having this signature are located in a circle whose radius is the 50% distance value (and similarly for 67, 90 and 95%).

These lists have to be used in order to give an indication of the ability of the deployment under consideration to achieve accuracy or reliability of positioning. The definition of such indicators is judged as a very strong requirement in order to really deploy such a symbolic approach (or any other ...). Before describing the indicators proposed, let us show a graphical representation of the intersection results: this shows the difficulty in finding a straightforward indicator describing the efficiency of the deployment.

In the first approach (see figure 13) the calculation of the distance from a point (as defined previously) to the mean location to its corresponding signature area is calculated, as follows:

$$Distance(m, n) = \sqrt{(m - meanx(Signature(m, n)))^2 + (n - meany(Signature(m, n)))^2}$$

where

- m and n are indexes defining the x and y coordinates, in a local referential, of the current point,

- $meanx(Signature(m, n))$ is the x value of the location of the mean point of the area of identical signature "Signature(m,n)",
- $meany(Signature(m, n))$ is the y value of the location of the mean point of the area of identical signature "Signature(m,n)",
- $Distance(m, n)$ is the distance from the point (m,n) to the mean location of the area of identical Signature than (m,n).

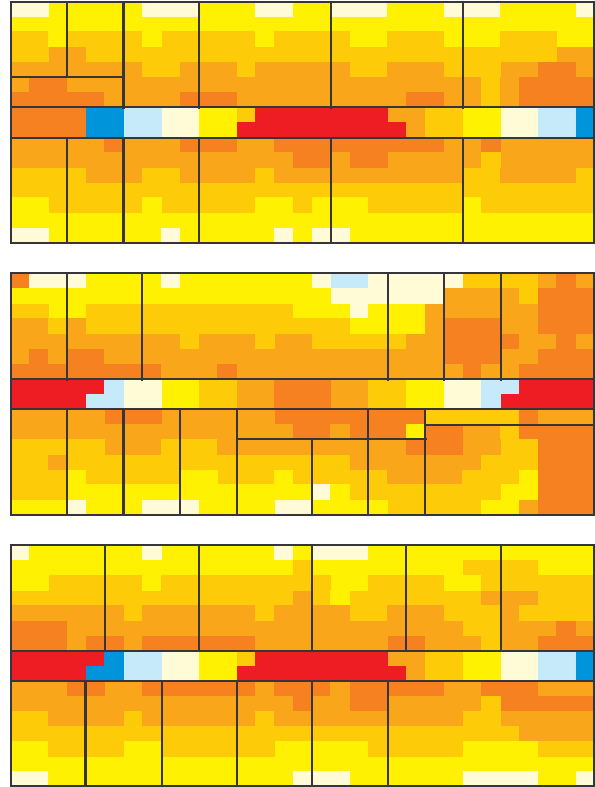


Figure 13: Graphical representation of the distance based results of intersections. The case of third, second and first floors for configuration 4. From blue to red in decreasing values (in meters).

This could be seen as an accuracy figure and shows that the potentiality of accurate positioning with this method is real (note that the orange is used for less than 2 meter accuracy and bright yellow for less than 8 meters. Thus, almost all the three storeys represented in figure 13 are in the 1 to 8 meter range). Nevertheless, this calculation (distance from the point to the centre of the signature area) cannot be obtained in real time since the location of the point is obviously not known. So, figure 13 gives only an indication of what would be the post processing results of positioning (see below for confirmation of this assertion, in the "Positioning results" section). In real time, we have to find another evaluation tool.

A number that can easily be calculated is the actual size of the signature area. This can be evaluated for all the points of the different storeys. Note that this could be given to the mobile terminal in real time and could be the "accuracy" of the symbolic approach. Figure 14 gives such a graphical representation for the same case as figure 13.

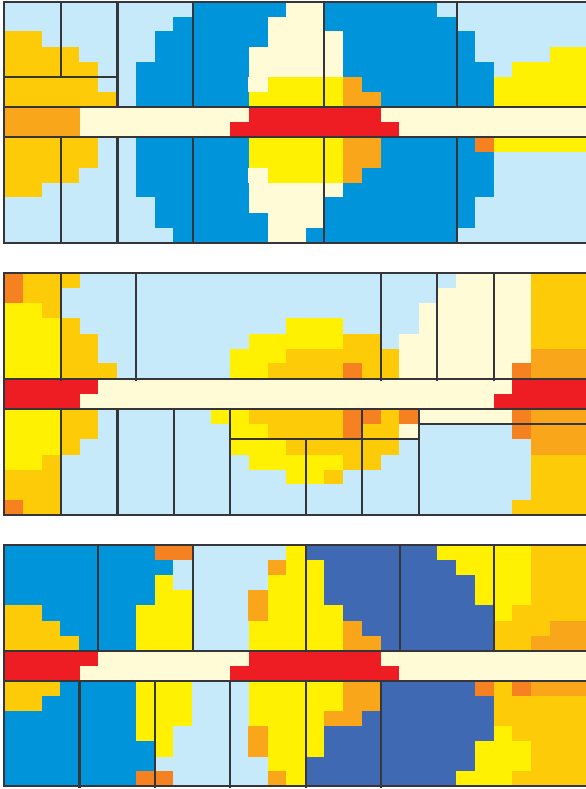


Figure 14: Graphical representation of the signature area size results of intersections. The case of third, second and first floors for configuration 4. From blue to red in decreasing values (in number of elementary points, i.e. in square meters in the present case).

The first observation is that it looks quite different from figure 13! We believe that these two figures highlight the profound difference between the classical WLAN positioning proposed approach and the symbolic one. The potentiality of accurate positioning, say typically to a few meters, is real but not yet available due to the impossibility of proposing a real-time estimated value of this accuracy. New mechanisms remain to be found to reach such a goal. On the other hand, the symbolic approach states that since such an estimation is not yet available, one has to consider a degraded mode of positioning that provides such a real time estimation. The "cost" is the large underestimated value of the resulting accuracy. Note that the orange is used for less than a 5 square meter signature area and the darker blue for less than 200 square meters. The accuracy figure could be considered as being the square root of the signature area size (assuming the area to be square, which is obviously not true). Thus, real-time estimated accuracies will lie somewhere between 2 and 14 meters. The degradation is substantial, compared to the case of figure 13, but allows for reliable indicators, which is certainly necessary for real applications.

Many other estimations can be made and the evaluation tool is an easy way to investigate new directions.

6 - THE PROPOSED INDICATORS

One major goal of the symbolic approach, and of the evaluation tool proposed in this paper, is to provide various indicators allowing an evaluation of the efficiency of the deployment for positioning. Both accuracy and reliability have to be dealt with.

Various accuracy indicators are possible, based on the calculations carried out in figure 12. The table in figure 15 gives shows how the various results are organised in the evaluation tool. The results are averaged for each floor in columns, and a global result is given in the last column for the whole building, allowing for global comparisons between configurations.

First, the distribution of the AP is recalled (upper line). Second, the various accuracy computations are summarised with mean, min and max values averaged over a whole floor. Areas, Sizes, Distances as well as 50%, 67%, 90% and 95% distances, as described above, are grouped in the table.

Deployment table			FL 3	FL 2	FL 1	GF	UGF	Building		
Access points			Nb		1	2	1	2	1	7
Accuracy	Areas	Nb	15	24	21	15	7			82
		Nb diff FL	0	0	0	0	0			0
	Sizes	Mean	33,1	20,7	23,6	33,1	70,9			30,2
		Min	1	1	1	1	14			1
		Max	98	74	103	153	159			159
	Distances	Mean	3,7	2,7	3,8	3,4	5,0			3,5
		Min	0,0	0,0	0,0	0,0	0,0			0,0
		Max	8,7	7,0	8,5	7,0	9,7			9,7
	Dist 50%	Mean	3,2	2,1	2,9	2,7	4,4			
		Min	0,0	0,0	0,0	0,0	2,0			
		Max	6,9	6,3	5,7	6,3	5,7			
	Dist 67%	Mean	3,8	2,6	3,5	3,2	5,0			
		Min	0,0	0,0	0,0	0,0	2,1			
		Max	7,4	7,2	6,5	7,0	6,4			
	Dist 90%	Mean	4,4	3,1	4,0	3,7	5,9			
Min		0,0	0,0	0,0	0,0	2,9				
Max		7,9	8,4	7,7	8,5	7,8				
Dist 95%	Mean	4,5	3,2	4,1	3,8	6,1				
	Min	0,0	0,0	0,0	0,0	3,1				
	Max	8,3	8,5	7,9	9,2	8,0				
Reliability	Adj areas	Mean Adj	5,3	5,3	5,3	4,5	3,4			4,8
		Nb diff=1	2,1	2,6	2,3	2,4	3,1			2,5
		Diff	2,3	3,3	3,4	2,3	1,0			2,5

Figure 15: Table of proposed indicators for both accuracy and reliability.

Concerning reliability, the basic idea is to propose a number that will be a real indication of the validity of the resulting positioning given by the symbolic approach. In the current version of the tool, it is based on processing the signature matrices. The first computation consists in calculating adjacency matrices for the signatures, in a similar way that was done for the symbolic areas. Three values are computed:

- the number of adjacent signatures to the signature of the current point. This is achieved for all the points of a given signature and averaged for a given floor for all the signatures appearing on this floor,
- the number of such adjacent signatures that have a difference of 1 with the current signature (and once again this is averaged over the floor),
- the average number of differences between the current signature and the adjacent signatures, for a given floor.

It is important to understand the underlying idea that has led to the use of such differences. First of all, let us explain the way this difference is calculated. For two signatures, the difference consists of the number of digits that are different for the same AP. For example, the difference between 2330030 and 3330230 is 2 since there are two differences: the first "2" of the first signature and the "2" of the second signature. Thus, a difference of 1 means that there is only one difference, for all the APs considered, between the signature allocated to the current point and the adjacent signature, i.e. a difference, for only one AP, of Zone. We have considered that depending on propagation matters, this kind of "error" is the most probable one and the one that is bound to decrease the reliability of positioning. In other words, it is more probable to make one mistake than 3 or 4!

Thus, these differences are considered as being a good indicator of reliability, either through its average value or through the number of adjacent signatures that have a difference equal to 1. The reliability increases with decreasing values of these differences. We do not propose quantitative values for reliability yet because validations in various conditions are still needed.

7 - DEPLOYMENT RESULTS

It is now time to carry out some comparisons, based on previously described indicators, of the various configurations of deployment.

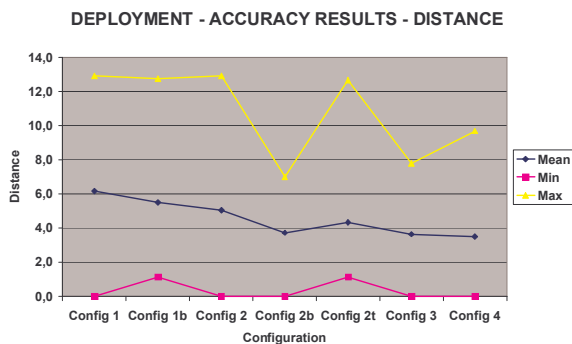


Figure 16: Accuracy results related to the "distance" parameter for deployments.

Figure 16 shows interesting tendencies:

- the average distance between the point and the mean location of its signature area is reduced when increasing the number of APs,
- the maximal distance really depends on the distribution of APs and is probably not easy to predict,
- deploying 7 APs leads to an average accuracy of less than 4 meters and goes up to 6 meters for only 3 APs. Note that this latter value should be quite close to the one really observed in a real WLAN deployment (for telecommunication purposes). It seems clear that the performance of the symbolic

approach in this case would probably have been considered as acceptable.

Of course, all this is obvious for an expert in WLAN positioning and could have been predicted. Nevertheless, the tool presented in this paper allows a quantitative description of the deployment, even for a non-expert. The proposed accuracy, resulting from the discussion of the previous section, is based on the "Size" indicator, shown in figure 17 below.

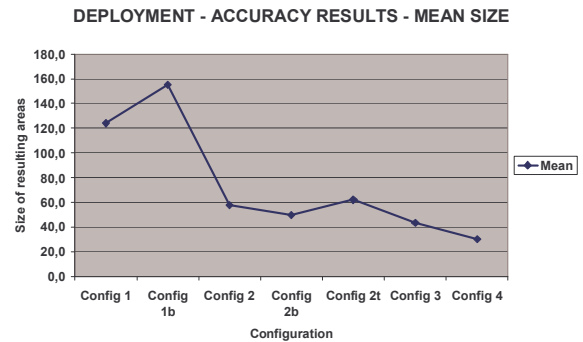


Figure 17: Symbolic proposed accuracy indicator.

Remember that the real accuracy figure which is available in real time is typically the square root of the "Size", thus leading to values ranging from 13 meters for config2b to 5 meters for config4. In addition, many other results can be obtained, for example the reliability figure (which is far less obvious for anybody), as shown in figure 18 below.

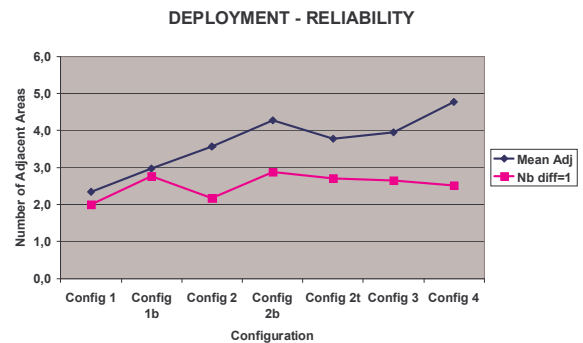


Figure 18: Reliability results related to the "1 difference" parameter for various deployments.

The interesting point is that although the average number of adjacent signatures increases when the number of APs increases, the "reliability", as defined in the previous section, does not change that much, and is even better for only three APs. This is explained by the fact that in this case, there are not a lot of signatures (compared to the case of 7 APs) and thus the number of adjacent signatures decreases "mechanically". Of course, this should be put together with the accuracy that is not as good as when the number of APs increases. Nevertheless, the fact that reliability is better with 3 APs remains.

These results confirm that the symbolic approach is valuable in a real WLAN environment and gives quite

a good positioning performance. Other classical WLAN positioning approaches are not capable of such positioning, or have really bad positioning results.

8 - POSITIONING RESULTS

Although the main goal of the simulation tool is intended to provide help for the deployment of the APs, it is also able to carry out positioning evaluation. This is based on the averaging of the symbolic positioning results of many randomly distributed locations (all over the different floors of the building). In the present case, 10 locations per storey were considered, leading to a total of 50 location estimates. Once the locations are defined (random process), the corresponding power levels for each AP are calculated in such a way that the AP Zones are respected. This is clearly an optimal case since no Zone error is thus possible (real experimental values are given in the next section). An example of locations and the associated power levels are given in figure 19.

Floor Level 3										
NbLocations 10										
	AP #1	AP #2	AP #3	AP #4	AP #5	AP #6	AP #7	x	y	Et
Location#1	-52	0	-84	0	0	0	0	24	10	3
Location#2	-44	0	-71	0	0	0	0	25	3	3
Location#3	-55	-51	-62	0	0	0	0	10	9	3
Location#4	-54	0	-89	0	0	0	0	19	2	3
Location#5	-55	0	-78	-73	0	0	0	19	7	3
Location#6	-50	-41	-42	0	0	0	0	29	9	3
Location#7	-60	-88	-75	-77	0	0	0	18	5	3
Location#8	-90	-83	0	0	0	0	0	7	6	3
Location#9	-80	-87	0	0	0	0	0	8	16	3
Location#10	-51	-77	0	0	0	0	0	14	16	3

Figure 19: Definition of the locations of the third floor with (x,y,z) and power levels received.

The results obtained from the tool are identical to those presented in section 5 concerning the Size and Distance. In addition the mean location of the signature area (Xc and Yc in figure 20) is noted and,, the actual precision is calculated. Once again, as discussed in section 7, there is no way to obtain this value in real time, but it will help to show the efficiency of the proposed accuracy indicator.

Location	Size	Xc	Yc	Distance	X	Y	Precision
1	98	22,09	8,26	5,18	24	10	2,59
2	98	22,09	8,26	5,18	25	3	6,01
3	38	18,42	8,53	8,66	10	9	8,43
4	98	22,09	8,26	5,18	19	2	6,98
5	8	19,38	7,75	2,02	19	7	0,84
6	38	18,42	8,53	8,66	29	9	10,59
7	23	16,17	7,78	2,51	18	5	3,33
8	71	5,32	8,41	6,07	7	6	2,93
9	71	5,32	8,41	6,07	8	16	8,05
10	79	11,06	8,43	4,78	14	16	8,12

Figure 20: Accuracy values for the various randomly distributed locations. The case of the third floor.

The evaluation tool also provides a graphical representation of the various positioning results, following the symbolic principles, i.e. with a shaded area. Figure 21 is the corresponding example of figure 20 in the case of config4. The black points are the locations studied and they are associated with areas of various colours, depending on their signatures. Note that it appears quite clearly that the actual symbolic areas are sometimes large and with very specific forms.

The resulting average precision really available is a little bit less than 6 meters.

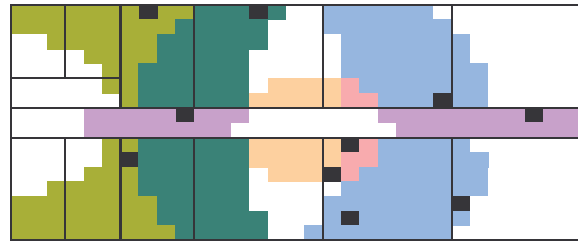


Figure 21: Graphical representation as available in the evaluation tool.

A table (see figure 22) summarizing the various results is available in the evaluation tool. For a given configuration, the averaged Sizes, Distances and Precisions are provided for each floor. This allows people in charge of positioning deployment of the WLAN network to decide the best location for a new AP, in order to optimise positioning for specific applications. For instance, one could prefer to have a better accuracy on the ground floor than on upper floors for better guiding capabilities. In addition, the table gives a global summary for the whole building (last column).

Positioning		FL 3	FL 2	FL 1	GF	UGF	Building	
Locations		Nb	10	10	10	10	50	
Accuracy	Sizes	Mean	62,2	46,8	52,3	90,2	104,2	71,1
		Min	8	6	9	25	67	6,0
		Max	98	74	103	153	159	159,0
	Distances	Mean	5,4	4,0	4,3	5,5	5,3	4,9
		Min	2,0	0,9	1,3	3,8	4,9	0,9
		Max	8,7	6,0	6,6	6,8	5,6	8,7
Precisions	Mean	5,8	4,5	4,5	5,4	5,2	5,1	
	Min	0,8	1,1	0,9	1,3	2,4	0,8	
	Max	10,6	8,7	6,9	9,4	8,3	10,6	

Figure 22: Summarising table of positioning performance over the building, detailed by storey.

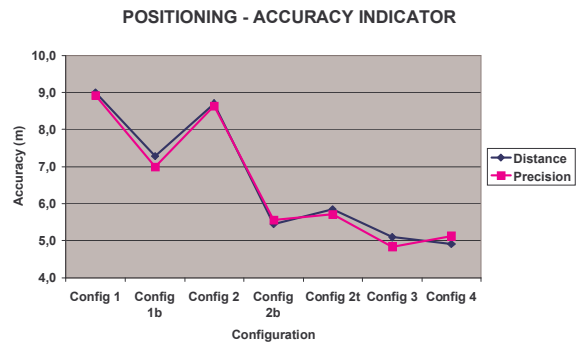


Figure 23: Comparison of the Distance indicator and real precision of positioning.

The curve in figure 23 shows the interesting correspondence between the real precision (in pink) and the "Distance" indicator (in blue). Remember that the Distance is calculated from the real point to the mean location of the signature area (corresponding to the signature of the real point). Of course, as already stated, this distance indicator is not available in real time and only a degraded version of it can be used, but for deployment purposes, one can consider that the Distance will give a valuable indication of the resulting real accuracy of positioning (although not available at the user's terminal).

9 - A FEW EXPERIMENTAL VALIDATIONS

A first experimental validation campaign was carried out in our premises, south of Paris. The basic idea is to use the algorithm of Zone allocation described in the previous sections and to evaluate the real positioning performance of the symbolic approach. One should understand that no calibration has been undertaken. The distribution of APs is comparable to that of config2t with one AP on each floor located at the left and right hand sides of the building.

Figure 24 shows the 14 tested locations (black points) together with the classical symbolic representation of the positioning result. As a matter of fact, it can be seen that only 12 positioning were carried out (see figure 25 for numerical details). The points were located on the third, second and first floors as described in figure 24.

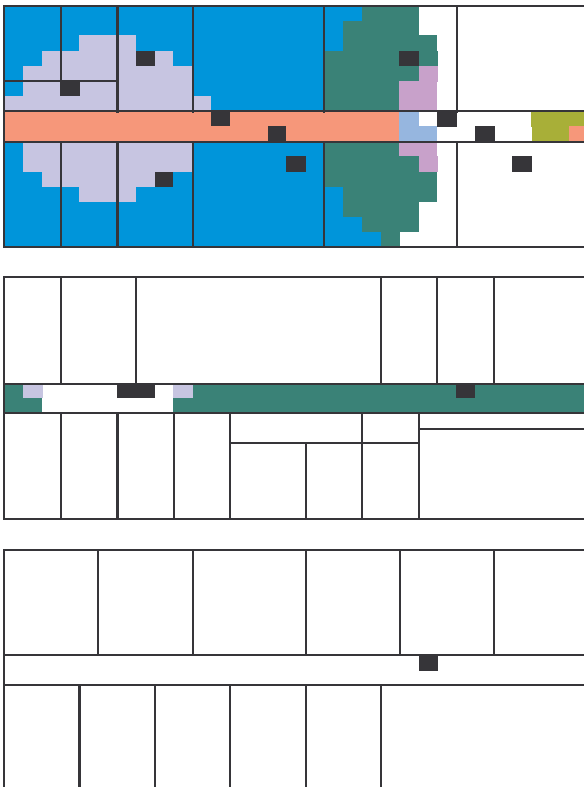


Figure 24: Real symbolic positioning results.

The Zone definition considered in the current version of the tool is not enough (usually some Zone 3 are too small compared to reality): so, in some cases, the tool is not able to match the real signature of the point to an existing one, thus leading to no location. There are two ways of fixing such a problem: either in enlarging the Zone 3 or in implementing a mechanism that still outputs a location in such a case. In the next steps of our developments, we will implement different algorithms of Zone allocation. Trials in various typical environments will then be carried out in order to define the best approach. Of course, the main goal is still not

to have any calibration phase (or a not-more-than-five-minutes one).

Location	Size	Xc	Yc	Distance	X	Y	Precision
1	43	11,47	8,49	5,64	28	6	16,72
2	67	6,00	9,16	3,76	9	5	5,13
3	182	10,68	8,15	7,30	4	11	7,26
4	3	22,33	8,33	0,65	8	13	15,07
5	8	22,63	9,25	2,02	16	6	7,38
6	8	22,63	9,25	2,02	22	13	3,80
8	5	29,80	8,60	0,85	24	9	5,81
9	5	29,80	8,60	0,85	15	8	14,81
10	59	20,36	8,93	4,46	12	9	8,36
11	2	6	9	4	7	9	1
12	46	19,48	8,48	6,33	25	9	5,55
Mean value	38,91			3,44			8,26

Figure 25: Numerical results of real positioning.

When looking at the numerical values, one can note that the averaged distance given by the tool is around 4 meters, compared to reality that is indeed around 8 meters. But please remember that the strength of the symbolic approach lies in its ability to give a symbolic positioning. In that case, the figure of interest is rather the average size of the resulting positioning. Over the 12 real locations, the obtained value is 39 square meters, leading to an average value of a little bit more than 6 meters (the square root of 39 indeed), which is rather close to reality!

10 - CONCLUSION

The evaluation and positioning tool proposed in this paper has been described. It is quite simple to use and could be available for any users in order to either evaluate the positioning performance of an existing WLAN network or deploy a specific positioning network. The basis of this tool is to exploit the so-called symbolic approach developed at the Institut Telecom. It allows for:

- estimation of accuracies depending on the deployment,
- estimation of reliability of positioning depending on the deployment.

Real time indicators are also a result of the presented study. Following the symbolic approach, these indicators are usually less accurate than reality, due to the inaccuracy of power level measurements, the basis of WLAN positioning even in this symbolic way.

Nevertheless, we showed that the "Distance" indicator, available only in the evaluation phase (while estimating the performance of a given deployment) is an amazingly accurate way to evaluate the real precision of positioning, although not available in real-time.

Positioning estimation is also possible with this tool and graphical representation of the resulting symbolic location highlights the approach by actually showing the real shape of the area the user could lie in. Real validation results have shown that with no calibration and a rough algorithm for the allocation of Zones to the various APs, the estimations given by the tool were

close to reality. Further works on these algorithms are of course needed but could be achieved by users themselves, as described in the proposed next step below.

The next step is to implement this tool in a way it could be made available to all potential users through a web based application. The current version was developed in order to set out the algorithms and the global architecture of the tool (and is implemented in Visual Basic for Applications ...), and to evaluate its performance.

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