A Friis-based Calibrated Model for WiFi Terminals Positioning

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Abstract

Two types of applications use indoor positioning: services linked with mobility, such as guided tour or meeting systems, and the active security of wireless network which locates intrusive unauthorized mobile terminals. Indoor positioning cannot be managed by a geostationnary system like GPS. In fact, current researches are conducted to conceive indoor positioning using wireless networks such as WiFi. In this paper, we study such a mechanism and compare our accuracy results to other solutions. This positioning function is combined to a mobility prediction mechanism and constitute the mobility service in a Video on Demand system called MoVie (Mobile Video).

Keywords: *positioning, mobility, wireless LAN.*

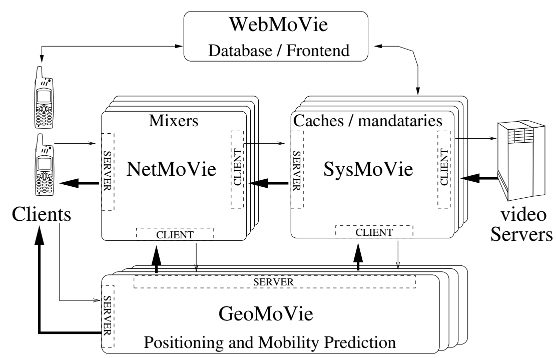

Figure 1. The MoVie modules structure.

1 Introduction

With the spreading of WiFi networks [5], that enables mobility and high data rate transfer, new problems arise. Service continuity is a recurring problem related to mobility. Indeed, mobile clients may want to change their access point. In this case, the services provided would be interrupted if nothing was done. Handover is a mechanism allowing a mobile client to change his access point transparently. Mobility prediction is a good means to anticipate the handover.

Mobility prediction aims at determining where a mobile terminal is more likely to be in the near future. To do so, the terminal location is required. It is obtained through a process called positioning. With the spreading of mobile networks, the interest in location-aware services has grown significantly. WiFi networks are commonly implanted indoors, which raises new problems with positioning. GPS [9] makes mobile terminal positioning easy outdoors, whereas indoor positioning is seriously limited.

In this article, we address the indoor positioning of WiFi terminals. Indeed, positioning is the first and most important step in mobility management. To obtain the position of a mobile terminal, we use trilateration [6]. It is therefore necessary to compute the distance between each access point and the mobile terminal. The main topic of our article is the indoor distance determination within a heterogeneous environment for which we choose to use an alternative to the Friis equation [2]. We will focus on a comparison of our technique with the existing ones through precision tests.

Our work comes within the scope of the MoVie [3] project. MoVie is a streaming platform for multimedia contents. MoVie is structured into interoperable modules (see fig. 1) where the following characteristics are gathered:

- NetMoVie integrates the RTP/RTCP protocol. It receives a few video sequence qualities and selects the most adapted one depending on the current situation.

- SysMoVie gathers ORB components and integrates the hierarchy of video caches. The strategy of video cache management is specific to the particular temporal data.

- WebMoVie represents a query interface of the MoVie platform. It is the entry point of clients where they are identified. A trader is created for each query in order to localize one or more required video sequences in SysMoVie.

- GeoMoVie tracks the mobile clients and anticipates their future moves. It contains positioning and prediction modules. It also provides the handover management.

In SysMoVie, a handover cache policy [4] ensures the continuity of the multimedia flow. SysMoVie retrieves information from GeoMoVie to determine which caches the video sequences parts will be transferred to.

GeoMoVie is split into two components. The positioning component allows to determine a mobile current position. The mobility prediction component then uses the position to guess at the future positions of the mobile terminal. Setting up GeoMoVie requires a learning period. The mobility prediction part is based on the hidden Markov model [10].

The remainder of this article is organized as follows. In section 2, we present the work related to mobile positioning. In section 3, we expound the context of our work with the related problems and their potential solutions. Section 4 describes the tests of both the related work and ours. In section 5, we analyze the results of the tests and present our conclusions.

2 Related work

In this section, we present the major positioning techniques. All of them use signal strength from the WiFi peripherals to determine the geographic location of a mobile terminal. Positioning techniques can be classified into two main categories. The first one is based on a signal strength cartography. The second category of positioning techniques aims at determining a relation between signal strength and distance. It makes the location computation possible using trilateration.

Within the RADAR system [1], the mobile terminal positioning uses a signal strength map of the covered area. The geographic coordinates, the signal strength measurements and the mobile orientation are stored in a database. The signal strength map can either be constituted by computation or by physical measurements. The signal strength measurement from each access point is compared with the reference points stored in the database. The cartography-based positioning technique has a 2-to-3-meter precision.

Wang, Jia and Lee [11] present a positioning technique based on a radio wave propagation model. This model aims at expressing the mathematical relation between the distance from transmitter to receiver and the signal strength. The mathematical expression is obtained by polynomial regression of the third degree. The advantage of this technique is the speed of positioning. However, there is a main drawback. A lot of data are required for the regression to be accurate, which involves a high cost in measurement time. On top of that, it is possible to be confronted with singularities in the buildings where the positioning technique is implemented.

The white paper of Interlink Networks [7] deals with security issues. Its first objective is to locate rogue mobile terminals and access points which try to infiltrate a network through its wireless part. The authors take signal strength measurements at many locations of many buildings. The results of these measurements are used to establish a radio wave propagation model. This model is based on the Friis relation. The Friis relation expresses the signal strength in function of distance, in a free space environment. The Friis-based model is adapted to fit the conditions of implementation. The precision observed is close to 2 meters. The main advantage of this technique is its setup speed. However, some singular geographic points were observed where the precision was worse than 8 meters. The main drawback of this technique is the unique exponent used in the Friis equation.

We focus on 5 criteria to analyse the related work: setup time, positioning time, resources used, precision and reactivity. All are summed up in the table 1.

	RADAR [1]	Interlink Networks [7]	SNAP WPS [11]
Setup time	Very long	None	Long
Positioning time	Medium	Short	short
Resources used	Many	Few	Few
Precision	Very good	Medium	Good
Reactivity	None	Total	None

Table 1. Recap of the main characteristics of the related work.

The best precision is obtained by the signal strength cartography-based technique. However, it costs lot of resources and computing time to use a signal strength map. It also requires a long setup time and it has no reactivity when topologic changes occur. These drawbacks partially affect the polynomial regression-based technique because of the need for data in order to obtain the polynomial expression of the distance. Although its precision is less accurate than that of the previous technique, the technique based on an alternative to the Friis equation is very quick to setup and use. Thus, it is well adapted to topologic changes.

Singular points are intrinsic with the topologic heterogeneity. Buildings are composed of obstacles which interfere with the radio wave propagation. The obstacles can be of various natures [8] and their layout can be irregular. When facing such unfavorable cases, the signal strength cartography shows better results because it fits the building whereas the propagation model-based techniques consider the topology uniformly.

3 Contributions

The Interlink Networks [7] approach is chosen to implement our positioning system. It has indeed the advantages of speed and simplicity. It is interesting with mobile terminals which have little computation power. We explain the drawbacks of a uniform computation in order to determine the distance according to the signal strength. We first describe the common sources of radio wave distortion and their predominance within a heterogeneous environment. Second, we highlight the radio wave distortion in indoor environment with the help of our experiments and we test the model of Interlink Networks [7], to reveal its limits in a heterogeneous environment.

3.1 Common phenomena in radio wave propagation

Radio waves are mainly subject to two phenomena affecting their signal strength or trajectory: the signal strength loss through atmosphere, and an extension of this phenomenon to every object gone through by the signal. We briefly expose these phenomena. Then, we describe their presence in the context of our work.

3.1.1 Radio wave propagation

The first source of signal strength loss is related to the distance covered by the signal. The signal strength looses power when going through the atmosphere. In a free-space environment, like our atmosphere, the loss can be determined by the Friis equation:

$$\frac{P_R}{P_T} = G_R G_T (\frac{\lambda}{4\pi d})^2$$

where:

- P_R and P_T are respectively the power available at the receiving antenna and the power supplied to the source antenna;
- G_R and G_T are respectively the receiver antenna gain and the transmitter antenna gain;
- λ is the carrier wavelength;
- d is the transmitter-receiver distance.

The Friis equation expresses the signal strength loss in function of the distance d. The radio wave absorption by obstacles is similar to the free-space loss but it is generally greater.

The radio waves are affected by the presence of topologic components altering the radio waves trajectory and therefore modify the signal strength. The phenomenon we are more likely to observe is wave reflection. The most common sources of wave trajectory distortion are metal equipment that induces huge signal reflections, preventing it from reaching areas theoretically within range. Devices functioning at frequencies close to WiFi frequencies also distort the signal by covering it with great noise.

3.1.2 Context

Our experiments take place in the context of the Numerica building (figure 2). The Numerica[1] building topology is heterogeneous. When studying the first-floor map, it is possible to distinguish two homogeneous areas. First comes the corridor which runs all along the floor and has no obstacle. Second there is the area composed of offices, separated by partition walls which alter signal strength. A load-bearing wall and a partition wall separate both defined areas. Between these two walls, there are electrical components and water pipes. Together, they considerably weaken the signal strength when the radio wave goes through them.

This characteristic of the building is recurrent on all 3 floors. It makes signal strength loss more complex than a simple distance-bound loss. A little move can indeed drastically modify received signal strength. For example, going through a door can involve the mobile being hidden by a wall, therefore having the signal strength received fall greatly with just a few steps.

On the map (see fig. 2), the triangles are the access points. The dots are the calibration measurement points and the crosses are the testing points. The origin of the coordinates is the bottom left corner on the map. The last access point is not represented because it is in a near building which is not on the map.

[1] The Numerica center is the building where ISTI and LIFC (Laboratoire d'Informatique de l'Université de Franche-Comté) are located.

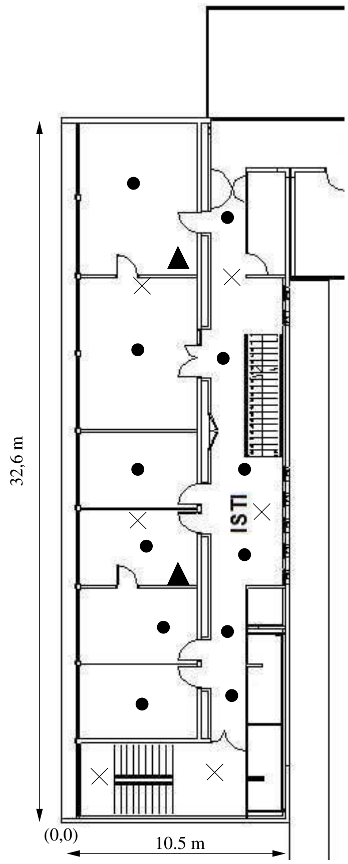

Figure 2. Numerica center first floor (ISTI area) map.

In this section, we present various phenomena interfering with radio wave propagation. These phenomena are free-space propagation loss, absorption by physical obstacles and radio wave trajectory distortion. Then, we describe the topology of the Numerica building, which includes all the types of obstacles and signal strength losses previously exposed which makes a radio wave propagation model hard to establish.

3.2 Test of the alternative to the Friis equation [7]

From now on, we call the alternative to the Friis equation the indoor Friis equation. The impact of the distance and topology being checked, a series of tests for validation of the positioning technique previously presented in [7] was carried out. To perform the test, the alternative to the Friis equation is implemented in a C program. The program makes signal strength measurements on the available access points and calculates their distance to the laptop by applying the indoor Friis equation.

The measurements are taken according to 4 directions. There are 12 points of measurement : 6 in the offices and 6 in the corridor. The results are presented in table 2.

(x;y) Coordinates	AP	Signal strength (dBm)	Real distance (m)	Computed distance (m)
(4;5,4)	1	-61.4	20.6	18.56
(4;5,4)	2	-54.6	4	8.54
(4;5,4)	3	-59.6	30.6	11.87
(5;9,1)	1	-56.2	16.6	13.18
(5;9,1)	2	-42.4	2.2	3.83
(5;9,1)	3	-59.8	31.8	12.02
(3,8;12,6)	1	-55.6	13.2	12.67
(3,8;12,6)	2	-42.4	2	3.83
(3,8;12,6)	3	-58.6	31	11.11

Table 2. A sample of measurements and distance computation (facing North).

There are 3 access points. Number 1 is the Netgear access point, the other two are from the Cisco vendor. One of the Cisco access points, number 3, is located on the first floor of a close building.

The miscalculation of the distance is significant. It can reach 20 meters in this example. Measurements at the other points produce similar errors. The experiments show that the indoor Friis equation [7] is not adapted to all types of construction work.

3.3 Distance determination

The first step in mobile positioning is to determine the distance between the known points and the point to be located. To achieve this, a valuable approach is based on the Friis equation. An alternative to the Friis equation is used in function of the nature of the area crossed. This alternative is based on the partitioning of the territory into homogeneous zones. The calibration of the model is performed for each homogeneous zone. At last, we propose to calculate the distance by an expression linked with the access point.

3.3.1 Choice of the indoor Friis equation

The variation of the propagation coefficient in the Friis equation makes it possible to express the impact of the topology on the attenuation of the signal. The propagation coefficient, when applied to the distance, explicitly materializes the difference in the absorption of the signal according to the medium it goes through. However, the alternative to the Friis equation presented in [7] has drawbacks because the medium varies from one building to another: the number of walls, spacing between the walls, the building material and other parameters have to be taken into consideration to determine the new propagation coefficient. Indeed, when the propagation coefficient, replacing the 2 in the Friis equation, is calculated, it includes to some extent an average of the media which can be encountered within the building.

Thus, the walls and all the other fixed obstacles in the building are taken into account during the calibration of the system.

3.3.2 Calibration of the Friis equation

The model presented in [11] is calibrated before use to put it in adequacy with the building where it is implemented. According to the authors of the indoor Friis equation, a coefficient of 3.5 in the indoor Friis equation is applicable to any environment of offices. However, a series of tests led in Numerica prove that this assertion is not accurate (see table 2). The model has to be calibrated so that its precision allows the use of the results in mobile positioning. The calibration has to be made after the partitioning of the building into homogeneous zones. Afterwards, each zone has to be calibrated independently of the others to obtain a suitable propagation coefficient.

Indeed, the medium surrounding the access points is not always homogeneous. For example, an access point can be in a nearby building and thus the transmitted waves go through a street. In this case, the major part of the medium they go through will be air, which means a free-space medium. Its signal strength will be different from the one transmitted by the in-building access points at the same distance. Then, a single propagation coefficient for all the access points causes a miscalculation of the distance.

To calculate the applicable propagation coefficients in the Friis equation, it is necessary to conduct measurements. For each homogeneous zone, we have to measure the power at several regularly distributed points. These measurements allow the calculation of coefficients. The calculation of the propagation coefficient is done by reversing the Friis equation in order to obtain an expression of the propagation coefficient in function of the parameters of distance and power. The coefficient c_{jk} is the coefficient at the point k for the access point j. This coefficient is calculated according to this relation:

$$c_{jk} = \frac{-SS_{jk} - K}{10.\log_{10}(d_j)}$$

where:

- SS_{jk} is the signal strength at the point k related to the access point j ;
- K is a fixed value for each access point, where $K = -37 - P_T$, and P_T is the access point current output power ;
- d_j is the real distance to the access point j, known when processing the measurements.

From now on, it is considered that p points are measured to calibrate a zone. We also consider that there are N available access points to locate the mobile terminal. pN propagation coefficients can be calculated, with p coefficients for each access point. The coefficient associated with an access point j for a given homogeneous zone z is the average of propagation coefficients c_{jk} calculated from signal strength measurements in zone z. These propagation coefficients are used in the indoor Friis equation which makes it possible to estimate the distance between an access point and a mobile terminal. We name *calibrated model* a model being based on the calibration from a concrete set of measurements.

4 Experiments

We study the precision of the calibrated model within the Numerica building. Measurements and calculations carried out allow to analyse the precision of the studied models ([11] and [7]) and that of the calibrated model (part 3.3.2).

To study the precision profit of the calibrated model, the alternatives to the Friis equation were confronted with a new set of measurements. New points were measured in random directions and calculations of the distance and position were processed.

The real coordinates and the measured power are provided to a program which computes the distances with the methods presented in [7] and [11] and according to the calibrated model. Then, the position of the mobile terminal is calculated by trilateration. The error made during the positioning process is calculated and displayed too. We use these results to analyze the models.

The measurement of the precision is done by computing the distance between the calculated position and the real position where the measurement was made. The measurements are carried out on the ground floor and on the first floor in Numerica. The results obtained are given in table 3.

In most cases, the calibrated model is more accurate than the Interlink Networks one or the SNAP-WPS. The points, where the precision of the indoor Friis equation is better, are located behind heavy topologic elements, for example a load-bearing wall. Thus, the points are excluded from the homogeneous area.

The lack of precision of our model in the absolute is explained by the use of the model calibration on the first floor, with access points placed in different positions. This series of measurements underlines the influence of the building heterogeneity in Numerica on the positioning accuracy.

Coordinates (x,y,floor)	Interlink Networks error [7] (m)	SNAP WPS error [11] (m)	Calibrated model error (m)
(3,6,12,3,0)	37,43	n/a	**33,68**
(9,5,13,0)	44,06	n/a	**30,05**
(1,6,2,0)	**30,79**	n/a	43,48
(4,4,19,7,0)	36	n/a	**27,4**
(8,1,23,8,0)	37,17	n/a	**21,87**
(3,4,26,9,0)	27,9	n/a	**23,44**
(1,6,2,2,1)	15,7	20,44	**2,72**
(7,3,1)	20,08	19,62	**7,62**
(8,6,14,5,1)	24,08	23,89	**16,86**
(7,6,25,2,1)	48,87	**17.29**	26,32
(3,6,24,8,1)	30,6	**6,58**	25,06
(12,4,11,1)	36,95	48,86	**16,56**

Table 3. Precision of the positioning models.

All the methods used, even when calibrated for Numerica, have such bad precision that it is clearly necessary to include precisely the fixed obstacles in calculations and not to distribute them on the whole building by using an average.

5 Conclusions and prospects

The lack of indoor positioning systems led us to build a positioning system whose bases are WiFi type of networks and peripherals. The complexity of the topology impact on radio wave propagation was revealed. It led us to the proposition of a calibrated model adapted to heavy constraints.

The analysis of the calibrated model tests shows that the topology should be considered more precisely. On top of that, the calibrated Friis equation is too sensitive to the distance variation from the transmitter.

The relative inaccuracy of the topology in the places where positioning is practiced is observed especially when the signal strength is either very weak or very strong. It is necessary to address the empiricism of the calibration when the peregrinations of a mobile terminal have to be tracked, especially in a heterogeneous environment. This is possible by determining the signal strength along a way for which the effects of the obstacles are taken into account. The effects must be expressed mathematically and integrated into the computation of the signal strength loss. Limited measurements could be taken in ideal conditions in order to evaluate the various phenomena separately.

Even when calibrating the alternative to the Friis equation, the results can still include great errors. These errors come from the determination of the coefficient in the formula giving the distance according to the signal strength.

We consider the possibility of determining the value of the coefficient used in the mathematical expression according to the received signal strength. The phenomena radio wave propagation is subject to are complex. Not all of them can be taken into account because the generated computations take too much time and are too frequent: the positioning has to be almost instantaneous in the perspectives of mobility prediction.

Acknowledgment

We would like to thank Damien CHARLET for his work on the handover cache policy.

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