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Open Wireless Positioning System: a Wi-Fi-Based Indoor Positioning System

Matteo Cypriani — Frédéric Lassabe — Philippe Canalda — François Spies

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Open Wireless Positioning System: a Wi-Fi-Based Indoor Positioning System

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Abstract: Wireless network positioning is the main pillar of the continuity of rich and mobile multimedia applications. Good position accuracy is particularly difficult to obtain in urban or leafy areas and indoors or in mixed (both indoor and outdoor) environments. A system proposing such positioning must localize any mobile terminal accurately within hostile environments and ideally be low-cost and easy to deploy.

We propose an indoor positioning system, based on the IEEE 802.11 wireless network. This system, named OWLPS (*Open WireLess Positioning System*), implements several of the major mobile position computation algorithms and techniques: fingerprinting location, topology-based and viterbi-like algorithm, propagation models. These algorithms result from community work and our personal researches.

Key-words: Wi-Fi, IEEE 802.11, Indoor positioning

Laboratoire d'Informatique de l'Université de Franche-Comté,
Antenne de Montbéliard — UFR STGI,
Pôle universitaire du Pays de Montbéliard,
25200 Montbéliard Cedex (France)
Téléphone : +33 (0)3 81 99 47 43 — Télécopie +33 (0)3 81 99 47 91

Open Wireless Positioning System : un système de géopositionnement par Wi-Fi en intérieur

Résumé : Le géopositionnement dans les réseaux sans fil est le premier verrou à ouvrir pour permettre une continuité des applications multimédias riches en mobilité, au sein de zones bâties, en intérieur comme en extérieur. Il est donc nécessaire d'être capable de bien se localiser au sein d'environnements hostiles, tout particulièrement à l'intérieur des bâtiments. Un système permettant ce géopositionnement serait dans l'idéal peu coûteux et facile à déployer.

Nous proposons un système de géolocalisation en intérieur, fondé sur le réseau sans fil Wi-Fi. Ce système, baptisé OWLPS (*Open WireLess Positioning System*), met en œuvre différents algorithmes de calcul de la position du mobile provenant des travaux de la communauté, et nos propres algorithmes.

Mots-clés : Wi-Fi, IEEE 802.11, Positionnement en intérieur, Géolocalisation

Laboratoire d'Informatique de l'Université de Franche-Comté,
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I. INTRODUCTION

Since the scientific community focuses more and more on indoor positioning, the goals and the considered parameters differ. If positioning accuracy remains obviously the most important goal, other factors are important too. The material cost comes first: is the equipment involved normalized hence low-cost or very specific hence expensive? The second important element is the deployment time that can be very short (a few hours) or require several days or weeks. A real-time position computation is also generally expected, allowing instantaneous mobile tracking, a location-aware service, etc.

The purpose is then to find a compromise between all these parameters, depending on the focused application. In the case of an indoor positioning system, the accuracy has to be sufficient to determine the room the person is in. The positioning service must also cover the totality of the deployment area. The IEEE 802.11 data network (Wi-Fi) offers good support for a positioning system: it is already widely deployed for other services (Internet connection, multimedia applications, IP telephony, etc.) and the equipment is quite inexpensive. Moreover, if large-scale deployment is envisaged, the deployment time should be as short as possible; this is facilitated by the use of a pre-existing infrastructure.

Such a positioning system, providing the base for an indoor mobile position computation, will allow positioning service continuity, involving multiple positioning solutions and efficient transitions between them. This means that in a given place, among the available solutions, the one offering the best accuracy will be chosen: a satellite-based system (GNSS [1]) in clear areas, a cellular telephony-based system in urban areas, a wireless computer data network in dense urban areas and indoors, or combinations of several of these systems.

This is a first step toward the construction of a global positioning network, because many obstacles still remain: the use of several types of wireless networks (notably ad-hoc), changing-environment adaptation (climate, mobile obstacles that can modify wave propagation) in order to keep sufficient accuracy, etc.

Section II introduces some concepts and questions in order to understand the issues and a synthetic state of the art. The OWLPS software components are presented in section III and in section IV we give the results obtained in our experiments, an accuracy comparison of the implemented algorithms.

II. CONCEPTS

A. Position computation techniques

Indoor positioning systems use various techniques in order to compute the mobile position. The two main techniques are signal strength (SS) cartography[1] and multilateration; multilateration is based either on the caught SS or on the time of flight. It is also possible to combine multilateration with cartography. In the cartography-based systems, the positioning accuracy is correlated with the mesh granularity. In the SS-multilateration-based systems, the accuracy is dependent on the propagation models used. To refine the computed position, one can take into account the mobile past positions, eventually taking into account the building topology to estimate the distances.

B. Mobile-centred or infrastructure-centred computation

In each infrastructure-supported[2] positioning system with bidirectional communication, there are two ways to operate. The first one is for the mobile itself to compute its position. In that case, the mobile listens to information transmitted by the infrastructure and computes its position. This information can simply be the Wi-Fi beacons transmitted by access points (APs), in such a case it is simple to add APs to refine the position computation (however we need to beware of the mutual jamming of the APs). The counterpart is the mobile need to embed software which includes an up-to-date list of the APs and their positions.

The second possibility is that the mobile may request the infrastructure to compute and send back its position. The advantages of this solution are multiple. First, the mobile only needs a small program to contact the infrastructure and request its position. But the main interest resides in the flexibility provided to the infrastructure for computing. Since the “APs” listening for the mobile requests do not have to transmit themselves, they can be entirely passive and this way avoid polluting the signal environment[3]; we can then multiply and deploy them without any effect on the wireless network service quality. Infrastructure elements can also easily communicate, coordinate themselves, and we can imagine that the system would be able to adapt itself to environment evolutions.

This second solution, which we retained for most of our experiments, also offers the possibility to treat each mobile emission as a positioning request, in order to localize even mobiles that do not send positioning requests. We address this processing mode in section III-C.

C. Related works

Table I compares several positioning techniques based on the Wi-Fi network, published within the scientific or industrial communities. The *Cartography* and *Attenuation* columns describe the experimental system core – the way the SS is employed: to realize cartography, to evaluate the distance in order to multilaterate, or both. The next two columns, *History* and *Topology*, give information about the use of complementary data to refine the computed position and the distance estimation. Finally, the last two columns, *Centred* and *Deployment*, give more general information about the system.

The RADAR [2] system uses only SS cartography, its accuracy is dependent on the meshing granularity of the cartography realized during the deployment. Depending on the expected accuracy, it is possible to devote more or less time to deployment: a one-meter meshing is very long to realize, a four-meter or five-meter meshing (corresponding to about one point per room in an office environment) is far

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[1] SS cartography results from a fingerprinting location process applied to the deployment area.

[2] In opposition to systems where the autonomous mobile deducts its position from its environment observation, for example mechanical-based systems (gyros, accelerometers). [3] Being passive, such APs do not provide network access to mobiles.

Publication name	Uses SS cartography	Uses SS attenuation model	Mobile itinerary history	Building topology	Centred[a]	Deployment duration
RADAR [2]	Yes	No	No	No	I	medium / long[b]
RADAR + VL [3]	Yes	No	Yes	No	I	medium / long[b]
Interlink Networks [4]	No	Yes	No	No	I	short[c]
FBCM [5]	No	Yes	No	No	M or I	short[c]
Basic FRBHM [6]	Yes	Yes	No	No	M or I	medium[d]
Discrete FRBHM [7]	Yes	Yes	Yes	Yes	M or I	medium[e]
Continuous FRBHM [7]	Yes	Yes	Yes	Yes	M or I	medium[e]

[a] Indicates if the experimental system, as described by the technique authors, measures and computes the position on the mobile ("M") or on the infrastructure ("I"). [b] For a pure cartography-based system, the deployment time depends on the meshing, on which will depend the accuracy. [c] The deployment consists only in putting the APs in the rooms and determining their coordinates. [d] The deployment consists in a minimal fingerprinting (like in RADAR in the case of a large meshing) and in the placement of the APs. [e] The building topology description lightly increases the deployment time in comparison to the Basic FRBHM.

Table I
WI-FI-BASED POSITIONING TECHNIQUE COMPARISON.

less tedious. RADAR is a first technique whose accuracy is adaptable, depending on the deployment time and means. The combination of such a system with other techniques (requiring a fast fingerprinting process) and other algorithms (taking into account the context: prediction, topology) would appear a major contribution in this domain. The RADAR system was extended by probabilistic methods in order to improve its accuracy: Ekahau [8] considers the SS distribution as a Gaussian curve; HORUS [9] uses a histogram representation. These methods allow better accuracy than that obtained using the cartography calibration measurement mean.

Other positioning techniques exist based on wireless networks (GSM, Wi-Fi, Bluetooth). The way to determine the position is generally based on a distance computation by SS attenuation or time differential of arrival (TdoA), or on the network cells (in this case, the error is dependent on the cell size). The works of Interlink Networks [4] are based on the SS, modifying the Friis equation [10]. The principle is the same with the SNAP-WPS [11] that establishes a relationship between the SS and the transmitter-receiver distance; this relationship is obtained by a 3-order linear regression on the calibration data. Other systems use entirely different technologies: infrared sensors, ultrasound, gyroscope and accelerometers [12], etc.

Ongoing works merge indoor Wi-Fi positioning with outdoor satellite positioning to offer a positioning and rich media application continuity in every place where the mobile can be, indoors and outdoors.

III. CONTRIBUTIONS & ACHIEVEMENTS

The major contribution presented in this paper is the realization of a system that implements several positioning techniques and algorithms, allowing to combine and compare them, even in a real-life experimentation way. This evolving system offers an adequate platform for the conception and validation of new techniques, propagation models and for the development of hybrid techniques combining existing algorithms.

The FRBHM algorithm [6], [7], conceived by F. LASSABE, is an example of such a hybrid technique. It combines minimalistic SS cartography (about one point per room) with the FBCM [5], a dynamic attenuation model adapting itself to a given environment (cf. section III-D). In its two last variants (Discrete and Continuous FRBHM), this technique includes an *a posteriori* mobile itinerary estimation (cf. section III-D2), taking into account the building topology to compute the distances in order to be closest to reality[4].

A. Infrastructure-centred system architecture

The configuration where infrastructure executes all the processing needs several elements:

- **Mobile terminals**, which are equipped with Wi-Fi cards: laptops, PDA, cell phones, hand-held game console, etc.
- **Access points**, which capture the frames transiting on the Wi-Fi network, listening for any positioning request transmitted by the mobiles.
- **The aggregation server**, to which the APs forward the received positioning requests; its task is to gather and format these requests.
- **The computation server**, which computes the position of each mobile from information forwarded by the aggregation server.

At least four APs are dispatched in the deployment building and at least one of them is placed in a different vertical plan; it is the minimal configuration to compute the mobile altitude.

A software module that performs the needed computation and communicates with the next module (cf. section III-B) corresponds to each architecture element. The same computer can run both the aggregation and computation server.

B. System operating process

Figure 1 summarizes the four steps of the mobile position resolution:

1) The mobile submits a positioning request to the infrastructure. In our experiments, this request is a UDP packet containing the local time; it contains more information when the mobile is used to calibrate the system (Fig. 2).
2) Each AP capturing the positioning request extracts the corresponding received SS[5]. Then it transmits a UDP

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[4] If obstacles, especially walls, are present between two points, the euclidean distance between them is generally far less than the real distance the mobile has to cover. [5] This is done using the *radiotap* header added by the AP Wi-Fi interface.

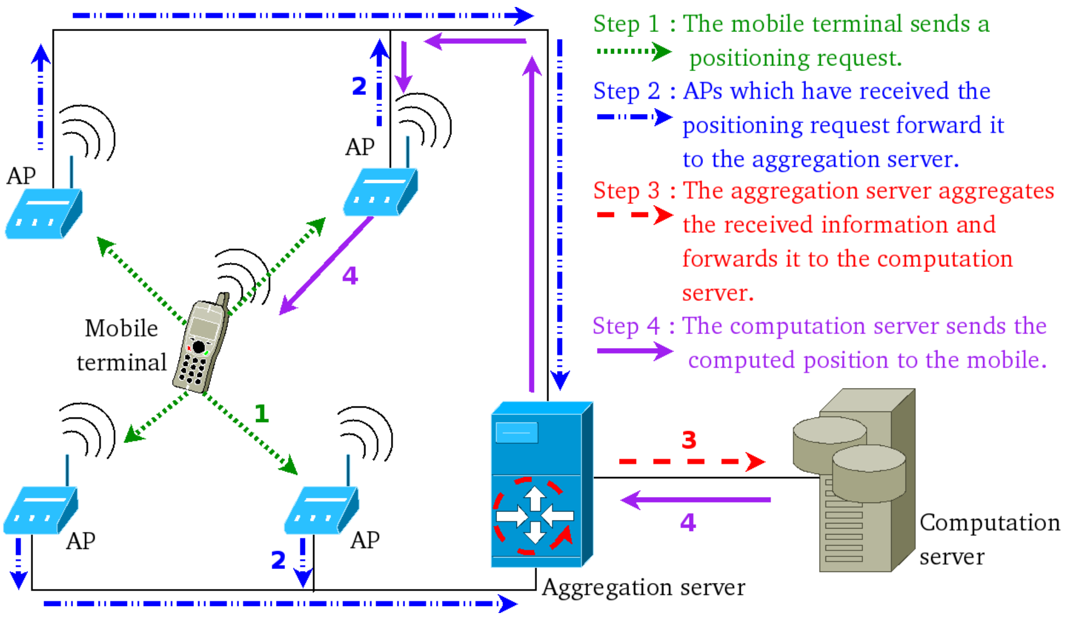

Figure 1. Four-step process of the infrastructure centred positioning system.

packet containing the received mobile information, the received SS, the reception hour on the AP and the mobile and AP MAC addresses to the aggregation server.

3) The aggregation server receives the positioning requests forwarded by the APs. It gathers those corresponding to the same couple (mobile MAC address, request hour) and forwards them to the computation server.
4) The computation server analyzes the information received from the aggregation server and computes the mobile position (using accurate and contextual algorithms, see section III-D); the computed position is then sent to the mobile (or processed in another way).

	Byte:	0	1	2	3	4
	0	Request type	Request time (16 Bytes)			
	4					
	8					
Field:	12					
	16		Direction	Position X		
	20	(4 Bytes)		Position Y		
	24	(4 Bytes)		Position Z		
	28	(4 Bytes)				

Figure 2. Positioning/calibration request packet format, sent by the mobile. *The grey fields are always present; they correspond to a positioning request. If the packet contains all the fields, it is a calibration request.*

C. Explicit to implicit positioning requests

In most cases, the mobile transmits a specific packet, the positioning request; it is an *explicit* request to the infrastructure. Please note that actually, the only information needed to compute the mobile position is the SS (that the APs get from the mobile), so the infrastructure may make use of any packet transmitted by the mobile; hence, all such packets could be considered as *implicit* positioning requests: the mobile sends a packet, without explicitly requesting its position, but the infrastructure can make use of it to compute the position. The only missing information in these implicit requests is the time of emission, which could be replaced by a hash sum.

D. Position computation algorithms

The computation server implements several mobile position computation algorithms: (1) those that compute the position from the instantaneous data and (2) those that take into account the mobile itinerary in order to adjust the computed position or select the most pertinent one. The computed position is expressed by X, Y, Z axis[6], and the temporal dimension. Some of these algorithms use SS cartography, some others a propagation model, or a mix of them.

1) Instantaneous algorithms:

- **RADAR** [2] uses SS cartography; in the SS space, it maps the reference point having an SS close to the one received from the mobile.
- **Interlink Networks** [4], adapts the Friis formula to a heterogeneous environment like a building. The computation is done by multilateration, taking the AP coordinates as reference points.
- **FBCM** [5] (*Friis-Based Calibrated Model*) dynamically adapts the Friis formula to match a given building or even a given room better.
- **Basic FRBHM** [6] (*FBCM and Reference-Based Hybrid Model*) combines SS cartography with the FBCM. As in RADAR, the nearest point in SS space is selected. It is used to calibrate FBCM, which recomputes coordinates.

2) Itinerary-aware algorithms:

To take into account the mobile itinerary, we conceive and implement a Viterbi-like (VL) algorithm: at each computed position, we refer to the potential anterior positions to select, between pertinent possibilities, not the point that instanta-

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[6] We had to adapt the original literature algorithms, conceived and experimented in a planar environment.

neously seems the best, but rather the one corresponding to the shortest route.

- **RADAR with VL**, based on [3] and improved with an optimized VL [7].
- **Discrete FRBHM** [7] first elects the most pertinent point according to VL, taking into account the building topology in the distance computation and second adjusts the elected point by the room-calibrated FBCM.
- **Continuous FRBHM** [7] operates like previously, except that the most pertinent points are all altered by the room-calibrated FBCM, before one of them is elected by VL.

IV. EXPERIMENTS

A. Hardware

For the experiments realized with the infrastructure-centred system, we used the following hardware:

- Five mini-PCs (800 € each): Intel Celeron M processor (1,50 GHz), 512 MB SDRAM, Intel BG2200 Wi-Fi card with a 5 dBi antenna; the OS used is Debian GNU/Linux *Etch*, the Linux kernel version is 2.6.23.16.
- A Linksys WRT54GL access point (60 €).
- An IBM Thinkpad R40 laptop, also with an Intel BG2200 Wi-Fi card.
- A desktop computer running the aggregation and positioning server: AMD Athlon 2000+ processor, 1 GB SDRAM; the OS used is Debian GNU/Linux *Lenny*.

The cost of this experimental infrastructure is about 5000 €.

B. Experimental protocol

Various experiments have been conducted on the first two floors of the three-floor west wing of the Numerica building (a multimedia development center). This wing is 33.50m long by 10.30m wide; the concrete slabs and load-bearing columns are 20 to 80cm wide. Most of the rooms are 3.60×5m offices with glass walls, aligned on the building west side and served by a corridor on the east. Each floor includes two stairs, a water room, electricity and water columns. This space is occupied by about 30 people and is quite busy.

The five mini-PCs, used as APs, were dispatched and positioned accurately, two on the first floor and two on the second one, slightly misaligned, and the last one located outside the experiment area (in the north wing building), so as to form a geometric figure in space encompassing the majority of potential mobile positions.

First, we fingerprinted the experiment area in order to build the SS cartography, with a one-meter meshing (one measurement per meter, in the four cardinal point directions); this took about 3-4 days (more than 1200 measurements). Then, we measured a mobile terminal, tracking its itinerary through the two floors, with a minimal delay of one second between positioning requests (86 measurement points).

For each measurement, we compared the real position (written down during the measurements) to the one computed by each algorithm. We varied the SS cartography meshing from one meter (base meshing) to four meters (which corresponds to about one measurement per room, plus one measurement in the corridor in front of each room).

C. Results

The main results obtained are presented in table II. The algorithms offering the best accuracies are RADAR and RADAR with Viterbi-like; we can observe that the advantage derived from the itinerary memorization with VL is not significant. The FRBHM algorithms are a little less accurate (the error overtakes by about 1m those of RADAR); the Discrete and Continuous FRBHM results confirm the fact that VL does not improve the accuracy: in most cases, the Basic FRBHM remains more accurate. Certainly, the building topology suffers from a lack of corridor and chaining halls. Last come the attenuation-based techniques, Interlink Networks and FBCM, suffering from a far bigger error; please note that the error of Interlink Networks is fixed because it does not at all depend on the meshing (no calibration is used), while those of FBCM vary because it uses calibration points to modify the used SS attenuation formula.

We can observe that cartography-based algorithm accuracy varies only lightly according to the meshing granularity. Furthermore, the densest meshing (1m) does not have the best results: all the algorithms are more accurate with a 2-meter meshing. This is probably due to the environmental dynamic variations compared with fingerprinting process.

These observations lead to several analysis elements. Firstly, to demonstrate the pertinence of an algorithm such as VL and its adequacy to a given environment (building topology, exposure to reflection, refraction, absorption in multi-path, interference), it is necessary to introduce a topological accuracy criterion and to apply it to different types of buildings. Secondly, there does not currently exist a satisfying attenuation model in heterogeneous and hostile environment, while in close and obstacle-free spaces effective models do exist. It is then necessary to evaluate alternative approaches: TdoA, phase analysis… Finally, the accuracy does not grow linearly with the meshing density; we think that this can be imputable to the mobile peregrination, the calibration points and the considered building topology. All this analysis needs further validation to understand the complex links unifying each approach to an environment better.

V. CONCLUSIONS

OWLPS [13] is an experimental platform designed to evaluate various positioning techniques in a 3-dimension space; the tested techniques are placed in an identical situation, in order to obtain comparable and objective results. The implemented techniques are based on SS cartography, SS attenuation models, a dynamic mobile itinerary history and the building topology. The most accurate of them makes an error of about 5 meters in a very heterogeneous indoor environment, requiring a limited calibration (a little more than one reference point per room) and a density of 5 APs for 600 m^2 on two floors.

Meshing	Interlink Networks		RADAR		FBCM		Basic FRBHM		RADAR + VL		Discrete FRBHM		Continuous FRBHM	
	Avg.	Std. d.	Avg.	Std. d.	Avg.	Std. d.	Avg.	Std. d.	Avg.	Std. d.	Avg.	Std. d.	Avg.	Std. d.
1m (308pts)	11.63	5.3	4.74	3.24	10.75	5.69	4.95	2.72	4.85	2.55	5.09	2.57	5.13	2.7
2m (113pts)	11.63	5.3	4.48	3.2	10.1	5.13	4.79	2.6	4.52	2.52	5.03	2.38	5.01	2.74
3m (62pts)	11.63	5.3	5.26	3.35	13.56	6.02	5.09	2.77	5.3	3.13	5.25	3.31	5.25	3.28
4m (35pts)	11.63	5.3	5.03	3.31	7	3.36	5.94	2.3	4.77	2.92	5.78	2.29	6.07	2.53
4m (% best)[a]	6.98 %		45.35 %		24.42 %		11.63 %		8.14 %		1.16 %		2.33 %	
4m (% worst)[b]	72.09 %		10.47 %		10.47 %		4.65 %		1.16 %		0 %		1.16 %	

[a] Percentage of the algorithm occurrences in first place (smallest error), on the 86 points of the mobile itinerary, with a 4-meter meshing. [b] Percentage of the algorithm occurrences in last place (biggest error).

Table II
EXPERIMENTAL RESULTS WITH A MOBILE TERMINAL: AVERAGE ERROR (“AVG.”) AND STANDARD DEVIATION (“STD. D.”).

It has been observed that the building inner environment, is not only very heterogeneous but also evolves constantly. For instance, the number of people depends on the time of day; furniture can be moved, electricity can be turned on or off, water may run or not in the pipes… All these factors influence the signal behavior and will be included in the parameters of our future models.

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Laboratoire d'Informatique de l'université de Franche-Comté
UFR Sciences et Techniques, 16, route de Gray - 25030 Besançon Cedex (France)

LIFC - Antenne de Belfort : IUT Belfort-Montbéliard, rue Engel Gros, BP 527 - 90016 Belfort Cedex (France)
LIFC - Antenne de Montbéliard : UFR STGI, Pôle universitaire du Pays de Montbéliard - 25200 Montbéliard Cedex (France)

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