ESTINDOOR: IEEE 802.11 Mobile Device Location Algorithm in Indoor Environments

Jeandro de M. Bezerra, Filipe Maciel, Joaquim Celestino Jr and Marcial P. Fernandez
Laboratório de Redes de Comunicação e Segurança (LARCES)
Universidade Estadual do Ceará (UECE)
Av. Paraíbana 1700 - Itapéra - 05508-900 - Fortaleza, CE, Brazil
Email: {jeandro,filipe,celestino,marcial}@larces.uece.br

Abstract—The wireless networks have been obtaining success, allowing user’s connectivity anywhere. However, almost all communication systems do not make available the physical location of the users, which turns security administration complex, and also difficults the use of location-aware applications. Hence, it becomes interesting the creation of a system that identifies the position of mobile devices in the environment. This paper introduces an algorithm that calculates the physical location of a mobile WLAN terminal in indoor environments using signal strength, avoiding the use of special customized equipment. As the measurement of WLAN signal strength has some imprecision due to the environmental conditions, it is necessary to apply a statistical treatment to improve the precision of the calculated positions. It was built a prototype that demonstrated promising results in mobile device location.

I. INTRODUCTION

The popularization of IEEE 802.11 (WLAN) standards has increased the use of wireless networks in companies, universities, airports and other environments. Equipments, such as notebooks and PDAs, are incorporating wireless interfaces and increased their use anywhere. Then, it is useful for network administrators the knowledge of mobile devices location to provide security and Quality of Service. However, because most of WLAN usage is mainly in indoor environments, where the satellites based GPS (Global Positioning System) system does not work, indoor location systems are necessary.

Nowadays, there are several location systems, most of then referenced in [1], showing benefits and limitations of each system. Another reference is the work from Schiller that shows some mobile applications based on location[2].

The objective of this work is to present a new algorithm and a prototype of a location system for indoor environments, improving the location precision to make possible location-based applications development. The goal is to implement a system based only on software and usual WLAN infrastructure, without additional hardware in mobile device or customized equipment. In this way, the signal power strength technique was used, together with statistical processing of the data, in order to improve the results precision.

This paper is organized as following: the section II shows some location techniques and related works; the section III shows the ESTINDOOR algorithm used to calculate the location of mobile devices; the section IV shows the system prototype and the results of experiments; and finally, section V presents the conclusion and suggestions for future works.

II. INDOOR LOCATION SYSTEMS

In spite of the progresses in GPS technology and its large use, million of square meters of indoor environments are out of coverage of Navstar satellites. Their signals are not able to cross the ceiling of buildings. Some systems were developed to compensate this limitation, providing the location of devices in indoor environments, generally known as LPS (Local Positioning System).

A. Location Techniques

The three main techniques of location are: triangulation, scene analysis and proximity. We present a summarized description of each technique[1].

1) Triangulation: It considers the triangle properties to calculate object location. That technique is divided in two categories: lateration and angulation.

   a) Lateration: The lateration technique is based on position calculation related to multiple reference points. To calculate the position in two dimensions are necessary distance measurements of three not-collinear points. In three dimensions, distance of four points are required. There are three approaches to measure distances for lateration technique:

      Direct: Measure of physical distance using action or movement. For instance, a robot can extend a arm to find something solid. Direct measures are easy to understand, but difficult to obtain due to complexity of mechanical devices.

      Time of propagation: Measure of the signal propagation time means the time that a signal takes "traveling" from one point to another at a known speed. Measures of propagation time of light or radio waves are possible, but require higher precision clocks and detectors then used in sound waves.
Attenuation: The intensity of a signal decreases with the distance with a proportional factor $1/r^2$, where $r$ is the distance. Given a function that relates attenuation and distance, it is possible to estimate the distance of an object measuring the signal attenuation. In environments with many obstacles, measuring distance using attenuation is usually less precise than time of propagation. Events like reflection, refraction and multi-path cause imprecise signal strength measurements, leading to inexact distance estimations.

b) Angulation: Angulation is similar to lateration, but instead of distances, it uses angles to calculate the object position. The problem to measure angles is that it demands the use of multiple directional antennas, which is complicated to make and expensive.

c) Scene analysis: The scene analysis technique uses scene observation to deduce the object location in an environment. Usually, the observed scene is simplified to obtaining the relevant characteristics easy to compare. In a static scene analysis, a fingerprint of observed scene is analyzed to deduce object location. The advantage of this method is that the object location can be deduced using passive observations. The disadvantage of the scene analysis is the need to rebuild the dataset if there are changes in environment. The scene can be visual images, captured by a camera, or other physical measurement, like magnetic field intensity.

d) Proximity: The proximity location technique uses comparison of known positions to define the object position. There are three approaches of proximity detection: detecting physical contact, monitoring wireless cellular access point and observing automatic ID systems.

B. Problems of Indoor Location Systems

Building a system that provides the location of devices in indoor environments is a difficult task. In spite of different possible solutions, using hardware and software, some difficulties should be considered.

1) RF Signal Propagation: The use of radio frequency for data communications in indoor environments is very frequent because it does not need a direct line for signal propagation, like infrared light. The RF technologies suffer random influence from the environment. Events like loss, which is the "signal dispersion"; reflection, which happens when a wave finds an obstacle; refraction, when a wave pass through different density media; diffraction, when the wave deviates around a obstacle.

2) Space Interference: As indoor environments are inside constructions, each space (an office, a room, etc) has its own administration, where the physical and logical limits are not clear, producing electromagnetic interference.

C. Related Works

A work that uses signal power to locate mobile devices in indoor environments is RADAR[3], using own WLAN IEEE 802.11b infrastructure to locate the devices. The RADAR system works storing and processing the signal power information of several base stations positioned to cover the working area. It uses a combination of empiric measurements and a model of signal propagation to define the device location. The data collection phase is very important in that methodology, because this information is used to create a power map used to compare the mobile measurements to define its position. The algorithm implemented was the closest neighbor.

The work of Lionel[4] uses the RFID (Radio Frequency Identification), technology based in reference tags and RFID readers. The LANDMARC (Location Identification based on Dynamic Active RFID Calibration) system uses reference points to improve calibration and reduce the costs, reducing the number of tags. LANDMARC does not use precise signal power measure, but only a fixed number of power level (1 to 8). A preliminary measurement is used to know the correspondence between power level and distance. This work also used the closest neighbor algorithm.

A work based on an analytical model was developed by Kaemarungsri[5], which developed a framework to analyze a simple positioning system using Euclidean distance between a signal power vector and the average of powers vector of an area stored in a database. The analytical model proposes the use of two vectors of power of the signal to estimate the user’s location and each random variable of the vector assumes that they are mutually independent and fall in the normal or Gauss distribution.

Another interesting approach was proposed in [6], which includes algorithms to locate stationary and mobile users based in different RF technologies, for instance, IEEE 802.11b and Bluetooth. Two algorithms were proposed, SELFLOC (Selective Fusion Location Estimation) and RoC (Region of Confidence), that can be used with classical location techniques, like triangulation. The SELFLOC algorithm supposes that user location is a combination of information about several wireless technologies with or without classic algorithms of location. The RoC algorithm tries to solve the problem when several areas have similar radio-frequency characteristics. Results show that SELFLOC gives errors less then 1.6 m for stationary users, while RoC gives errors less then 3.7 m for mobile users.

In this work the technique used was the static scene analysis and triangulation of signal power. We take a fingerprint of environment measuring signal power in some calibration points. When a mobile device wants to find its location, the system collects a series of signal power measurements to define the three nearest calibration points, with known position. Then, it calculates the relative position based on these points, using signal attenuation equation.

III. ESTINDOOR ALGORITHM

We presented in this section the ESTINDOOR (Estimation Indoor) algorithm, a mechanism to estimate the
physical location using scene analysis and power measurements with statistical treatment. As the power signal measurements vary in different environments, it is necessary to accomplish a calibration stage to define the signature of signal power values.

A. Statistical Analysis

RF signals may suffer interferences of environment objects, due to reflection, refraction and diffraction. As the method used in this work uses the signal power, path loss equation, proposed by Rappaport[7], was used:

\[ P_l(d_{j,k}) = P_l(d_0) + 10\alpha \log_{10}(d_{j,k}) \] (1)

The equation 1 could be applied for two propagation ways. The first way is known as LOS (line-of-sight), which is the direct line between transmitter and receiver. The second way is known as NLOS (non-line-of-sight), where obstruction between transmitter and receiver is considered. The term \( P_l(d_0) \) identifies the signal loss in a reference distance, for instance, for \( d_0 = 1 \text{m} \) in a propagation environment LOS the reduction is of 41.5 dBm and 37.3 dBm for an environment NLOS[8]. The variable \( \alpha \) denotes the exponent of path loss, which for indoor environments in 2.4 GHz frequency, is indicated to be 2 for LOS propagation and 3.3 for NLOS propagation[8]. In figure 1 we show the frequency of signal power measurements during a 5 minutes period. This was important to define the type of statistical distribution to be applied.

![Fig. 1. Frequency of signal power measurements](image)

Analyzing the variability of the signal power, a statistical treatment was applied to adjust the powers measurements to statistical models based on the equation 1. The objective is to use Continuous Statistical Laws to adjust the power measurements obtained to a known probabilistic continuous model. Studies in the last years show that power measurements in indoor environments follows a log-normal distribution[7]. Measurements in indoor environments show that the standard deviation \( \sigma \) has a value of 2.13 dBm.

The Kolmogorov-Smirnov (K-S) adherence test was applied because it is used for continuous variables; although the Chi-Square (Chi2) test, used for discrete variables, can also be applied for consecutive contiguous intervals[9]. The samples picked after the adherence test is adjusted to a Gaussian model. We shows in figure 4 the adjustment of the equation 1 in measures.

B. Geometric properties

The positioning system was created using the IEEE 802.11b wireless infrastructure. The mobile position can be represented by a tuple \((x, y, z)\), where \( x \) and \( y \) are coordinates of two dimensions in a plane while \( z \) represents its height. In this study it will be considered that \( z \) is zero in all \((x, y)\) coordinates.

There were chosen calibration points in the area to create a database of power means in each point. Each entrance in database includes the actual location in the plan \((x, y)\) and a vector with power means for each Access Point (AP). In function of variance and sample deviation, the best adjustment curve is chosen. The vector is built with the mean of signal power in calibration point \( C_X \) received from all AP’s and stored in the database as \( \overrightarrow{C_X} = (P_{AP1}, P_{AP2}, \ldots, P_{APN}) \).

When we want to calculate the position of a point \( M \) we need to collect a serie of power measurements of all reachable AP’s. The vector \( \overrightarrow{M} = (P_{AP1}, P_{AP2}, \ldots, P_{APN}) \) is built with samples of measured signal powers of mobile station in relation to the \( N \) AP’s in the area. This vector is compared with all \( C_X \) registers in database. To obtain the position of a mobile device, is necessary information of, at least, three APs simultaneously. The metric used to calculate the distances among two vectors \( \overrightarrow{C} \) and \( \overrightarrow{M} \) is the Euclidean distance showed in the equation 2:

\[ \overrightarrow{E}_j = \sqrt{\sum_{i=1}^{n} (\overrightarrow{M} - \overrightarrow{C_i})^2} \] (2)

C. ESTINDOOR Pseudo-Code

The ESTINDOOR algorithm is divided in two phases: the Calibration phase and the Location phase. We presented in algorithm 1, the description of ESTINDOOR algorithm in calibration phase. Starting from the knowledge of the real position, we extract a series of signal power measurements and apply the appropriate statistical treatment according to sample profile. Then, we save the vector of signal power for this calibration point. The vectors of several calibration points will form the power signatures matrix from a specific environment.

We show in algorithm 2, the description of ESTINDOOR algorithm in Location phase, i.e., calculating location of mobile device \( \overrightarrow{M} \). Initially, it takes a series of power measures in desired point. From the sample profile the appropriate statistical treatment is applied. The \( \overrightarrow{M} \) parameters is compared against power signature matrix to find the nearest three calibration points, at least. With the
Comparing NLOS/LOS attenuation in environment

In NLOS environment a test was done comparing the laboratory showing the variation of LOS/NLOS signal power. In regard to all APs, additional equipments should help to eliminate inconsistent measurements. In spite of this imprecision, we can observe that the results are better than results presented in many references, demonstrating the validity of this proposal.

V. Conclusions and Future Works

We presented in this paper a survey of location techniques for WLAN mobile devices and a algorithm to locate located in the central room, points 5 to 7 are located in left room and points 8 to 10 are located in right room. We can observe that all the position estimates had errors below 1.00 m, and 40% of then, below 0.50 m. We can see that for larger distances, the attenuation and multi-path effects interfere in precision. Besides, there were used only three APs, additional equipments should help to eliminate inconsistent measurements. In spite of this imprecision, we can observe that the results are better than results presented in many references, demonstrating the validity of this proposal.
a mobile device in WLAN environment. The focus was to discover the appropriate techniques suitable to indoor location, where GPS signal are not received. Another objective was to identify the techniques that does not need additional hardware, to be used with commercial WLAN device, without modification. The results showed algorithm validation, allowing a good precision even with signal variations due interferences of the environment.

A natural way for future work is the extension of the proposed method to environments with more interference factors. New experiments and adjustments in the algorithms, or even in the methodology may be necessary to obtain reliable results. Another suggestion would be the analysis of the system in an environment with more APs. Our prototype used only three APs, but Youssef showed that the increase of number of APs allows better precision in the estimation[10]. Other important point is to improve the calibration process including Artificial Intelligence techniques. This procedure should be applied only in the calibration stage to maintain low complexity of location algorithm.

ACKNOWLEDGMENT
This work was partially supported by CNPq and developed in collaboration with HP Brazil R&D

REFERENCES