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A New Wireless Indoor Localization Algorithm

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***Abstract*— In the recent years, the advances in localization based technologies and the increasing importance of ubiquitous computing and context-dependent information have led to a growing business interest in location-based applications and services. There are many applications like security, healthcare, location based services, and social networking use wireless indoor localization to locate or track of physical belongings inside buildings. In the art of wireless indoor localization, a lot of research works have been done, mostly classified into two categories, namely, fingerprinting-based and model-based. To take advantage of their strengths and overcome their limitations, we propose a new algorithm which can not only determine position of a device without training stage but also in-depend on hardware configurations. By using mathematical formulation analysis, we demonstrate its advantages than the other techniques.**

***Index Terms*— Wireless Indoor Localization, Fingerprinting, Radio Propagation and Received Signal Strength**

I. INTRODUCTION

LOCALIZATION refers to the process of determining an object's location in space. For localization in an outdoor environment, Global Positioning System (GPS) which is released by U.S. Department of Defense works extremely well [1]. Unfortunately, the signal from the GPS satellites is too weak to penetrate most buildings, making GPS useless for indoor localization.

Nowadays, wireless information access is widely available, it triggers a high demand for accurate positioning in wireless network, including outdoor and indoor environments [2], [3].

Wireless indoor localization has long been an active research field, and hold promise for many ambient intelligence applications which been designed to provide location information of persons as well as devices and used in many applications such as: medical, industrial, public safety, logistics, ad transport system… In wireless indoor localization, fingerprinting-based methods are widely used. This method constructs a fingerprint database and returns user's location based on similar fingerprints. Received signal strength (RSS) is the most common RF signal parameter used as location fingerprints.

Various commercially available hand-held devices and wireless access points (APs) are capable of reporting RSS. In general, the RSSs are mostly reported in dBm values. One of the problems is that these devices usually come with many different hardware solutions. As a result, reported RSS of these devices are different even for the same wireless technology. However, almost RSS based localization schemes did not address to this presence of hardware heterogeneity. As shown in [4], average RSS variation due to Wi-Fi devices heterogeneity may exceed 18 dBm. Authors compared RSS of notebook and smartphone from the same location and at the same Wifi access point. They prove that the average RSS value from notebook is -47,6dBm whereas from the smartphone is -66.2 dBm. Another experiment done in [5] also supports this result. To overcome localization error induced due to RSS variation, one of our motivation is to find the locations of unknown devices in a certain wireless area with different hardware configurations.

On the other hand, the major drawback of fingerprinting localization is dependence on training stage. It consumes more time and labor during the collection of signal strength data and a huge volume of data needs to be stored as fingerprinting. Positional accuracy of this algorithm is positively associated with the density of reference points in the database.

In this paper, we propose a method to locating an unknown device or user in indoor wireless networks not only without using training stage but also independence on radio propagation parameters.

The remainder of the paper is organized as follows: an overview of the well-known indoor localization techniques is presented in Section II. Section III presents our algorithm. Finally, in section IV we discuss some limitations, future work and conclude the work of this paper.

II. RELATED WORK

In the art of wireless indoor localization, there is a variety of well-known research directions, many methods have been proposed. These may be classified into two categories, namely, fingerprinting-based and model-based.

The concept of fingerprinting localization has the same concept as human fingerprinting. To constitute a fingerprint, several types of information can be used as the received signal strength (RSS), angular power profile (APP) and channel impulse response (CIR). Almost fingerprinting-based localization techniques consist of two stages: offline (or training) stage and online (or serving) stage. In the first stage, they build a fingerprint database by recording the signal metrics (fingerprints) received at every position of an interesting area. This process is also called site survey. During the online stage, when a device sends a location query with its current fingerprint, location positioning techniques retrieve the fingerprint database and then mapping the collected fingerprints against the database to estimate the location. The RADAR system [3] was the world's first RSS fingerprinting based indoor positioning. Bahl and Padmanabhan prove that RF fingerprinting and environmental profiling with commodity wireless LAN hardware can be used to determine user and machine location inside buildings, thereby enabling indoor location-aware applications.

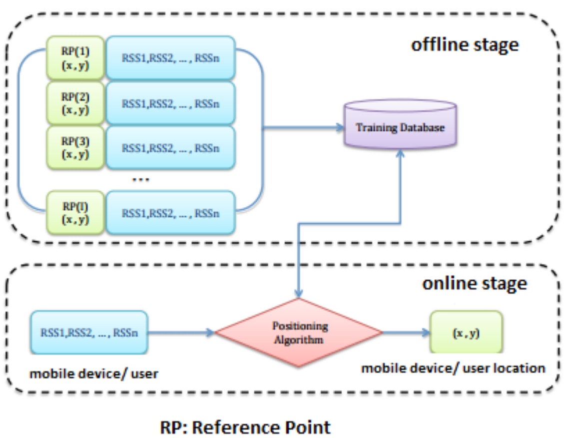

Fig. 1: The diagram of RSS based fingerprinting localization technique

Radio Camera system [4] uses multipath angular power profile (APP) information gathered at one receiver to locate the user's coordinates. Meurer [5] proposed using the covariance matrix of the CIR as a location fingerprint to locate and track mobile units. An advantage of fingerprinting localization is to obtain optimal performance in multipath environment. Using fingerprinting consumes more time and labor during the collection of signal strength data and a huge volume of data needs to be stored as fingerprinting depends on a pre-existing signal strength database for all reference points. Positional accuracy with a fingerprinting algorithm is positively associated with the density of reference points in the database. Too few features selected for the fingerprint may not give sufficient information to differentiate the various locations of interest, while too many features may include bad features that are unstable in time, causing the system to produce poor results.

To alleviate this problem, wireless indoor localization approach based on model has been introduced. This algorithm does not need an offline stage like fingerprinting. Propagation model based methods use mathematical models to predict the distance between transmitter and receiver based on the power with which a packet sent by a transmitter reaches the receiver. From this information, it is possible to estimate the position of the receiver by geometric computations (e.g., trilateration). The angle of arrival (AOA)-based positioning technique [6] measures the angles between a given node and a number of reference nodes to determine the location of a node. Upon on a path-loss model, the RSS-based localization measures the energy of the received signal at one node to calculate the distance between two nodes. Time-based positioning techniques rely on measurements of travel times of signals between nodes. If two nodes have a common clock, the node receiving the signal can determine the time of arrival (TOA) of the incoming signal that is time-stamped by the reference node [7]. If there is no synchronization between a given node and the reference nodes, but there is synchronization among the reference nodes, then the time-difference-of-arrival (TDOA) technique can be employed [8].

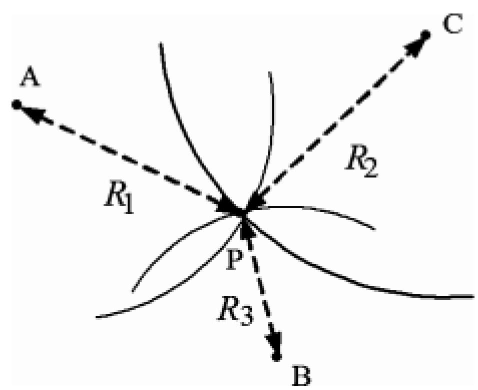

Fig. 2: The TOA based localization technique

Therefore, these techniques are more flexible as the system calculates device location in real-time (no need training stage) and the system can be more adaptable to environmental change than fingerprinting. However, in the fact, it is not easy to model the radio propagation in the indoor environment. The inaccuracy of this approach is mainly due to the propagation conditions imposed by the wireless channel as multipath and non-line of sight (NLOS) conditions, floor layout, moving objects, and numerous reflecting surfaces.

In this section, we also demonstrate the dependence of RSS on hardware configurations. If we denote $P(d)$ and $P(d_0)$ the received signal strengths at an arbitrary distance d and a close-in reference distance d_0 from the transmitter, respectively, for a particular transmitter-receiver pair. From the log-normal shadowing model [9], ignoring the variation of the received power at a certain distance, we get:

$$\left[\frac{P(d)}{P(d_0)}\right]_{dB} = -10\beta\log\left(\frac{d}{d_0}\right) \tag{1}$$

The first term on the right hand side of (1) defines the path loss component (β is the path loss exponent). Eqn. (1) can be rewritten as,

$$P(d)\big|_{dBm} = P(d_0)\big|_{dBm} - 10\beta \log(\frac{d}{d_0}) \quad (2)$$

Since the perceived power at a reference distance $P(d_0)$ varies because of antenna gains (hardware-specific parameter). Therefore, the perceived RSS at a distance d is also hardware-dependent. Although RSS is the most favorite information used in existing RSS based fingerprinting techniques, but almost these did not address this issue.

Through above brief summary, we can see that each approach has its advantages and limitations. To combine the strengths of two methods, we propose a new algorithm which can locate position of a device without training stage in independence of radio propagation parameters.

III. PROPOSED ALGORITHM

Many of the existing location fingerprinting methods lack a proper mathematical formulation and theoretical basis. In this section, we will present a new algorithm which is simple technique to estimate position of an unknown device or user in an interesting wireless area. By using mathematical analysis, we demonstrate that our method does not require training stage. Moreover, the proposed technique does not only in-depend on radio propagation parameters that such as path loss but also hardware-specific parameters such as antenna gains.

Initially, we will restrict our analysis to two dimensions using a static target that is simultaneously detected by three or more access points. We also assume that a number of access point are arbitrarily deployed in the wireless area.

If we denote the location of unknown device/ user which receives signal from access points as (x, y) in its broadcast range as described in Fig. 3.

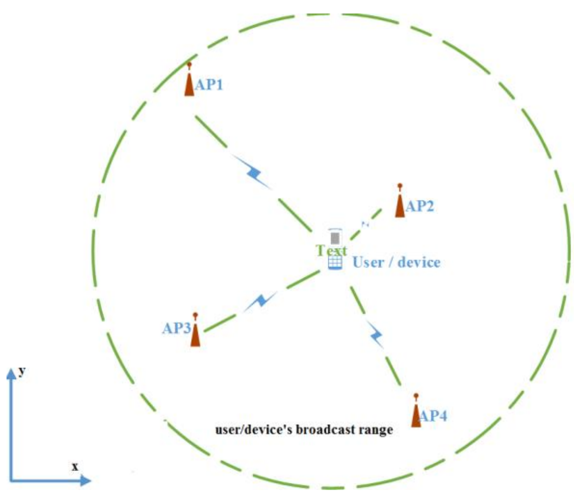

Fig. 3. Wireless Network Topology

We assume the coordinates of n access points are already given as:

$$AP_1 = (x_1, y_1)$$

$$AP_2 = (x_2, y_2)$$

$$\cdots$$

$$AP_n = (x_k, y_k)$$

Among n access points which can receive signal from that unknown device/ user, we choose k access points (k<n) with bigger RSS values:

$$AP_1,\ AP_2,\ \ldots,\ AP_k$$

Let d_i is the distance between unknown device/user and AP_i (i=1,..,k). We have:

$$\sqrt{(x - x_i)^2 + (y - y_i)^2} = d_i \quad (3)$$

Squaring both side and giving k access points, we have the following set of equations will be true with every i, assuming no estimation error for the moment:

$$\begin{cases} (x - x_1)^2 + (y - y_1)^2 = d_1^{\,2} \\ (x - x_2)^2 + (y - y_2)^2 = d_2^{\,2} \\ \ldots \\ (x - x_k)^2 + (y - y_k)^2 = d_k^{\,2} \end{cases} \quad (4)$$

Expanding the elements on the left and after that subtracting the bottom row from each of remaining rows, then moving all remaining square terms to the right hand side. As a result, above equation can be written again:

$$\begin{cases} 2(x_k - x_1)x + 2(y_k - y_1)y = d_k^{\,2} - d_1^{\,2} + x_k^{\,2} - x_1^{\,2} + y_k^{\,2} - y_1^{\,2} \\ 2(x_k - x_2)x + 2(y_k - y_2)y = d_k^{\,2} - d_2^{\,2} + x_k^{\,2} - x_2^{\,2} + y_k^{\,2} - y_2^{\,2} \\ \ldots \\ 2(x_k - x_{k-1})x + 2(y_k - y_{k-1})y = d_k^{\,2} - d_{k-1}^{\,2} + x_k^{\,2} - x_{k-1}^{\,2} + y_k^{\,2} - y_{k-1}^{\,2} \end{cases} \quad (5)$$

Equation (5) can be written in matrix form as:

$$\begin{bmatrix} 2(x_k - x_1) & 2(y_k - y_1) \\ 2(x_k - x_2) & 2(y_k - y_2) \\ \ldots & \\ 2(x_k - x_{k-1}) & 2(y_k - y_{k-1}) \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} d_k^{\,2} - d_1^{\,2} + x_k^{\,2} - x_1^{\,2} + y_k^{\,2} - y_1^{\,2} \\ d_k^{\,2} - d_2^{\,2} + x_k^{\,2} - x_2^{\,2} + y_k^{\,2} - y_2^{\,2} \\ \ldots \\ d_k^{\,2} - d_{k-1}^{\,2} + x_k^{\,2} - x_{k-1}^{\,2} + y_k^{\,2} - y_{k-1}^{\,2} \end{bmatrix} \quad (6)$$

On other hand, the relationship between RSS and distance is also described in the following equation:

$$P(d_i)\big|_{dBm} = P(d_0)\big|_{dBm} - 10n \log(\frac{d_i}{d_0}) \quad (7)$$

Moving all received signal strength to one side and getting log logarithm two both side, we have:

$$d_i = 10^{\frac{P(d_0)-P(d_i)}{10n}} \quad (8)$$

After squaring both side, resulting as:

$$d_i^2 = 10^{\frac{P(d_0)-P(d_i)}{5n}} \quad (9)$$

Applying Taylor expansion to (9), we get:

$$d_i^2 = 10^{\frac{P(d_0)-P(d_i)}{5n}} \approx C_0 + C_1\left(\frac{P(d_0)-P(d_i)}{5n}\right) \quad (10)$$

In where, C_0, C_1 is the coefficients

Combining equations (9) and (10):

$$d_k^2 - d_i^2 = \frac{C_1}{5n}(P(d_k) - P(d_i)) \quad (11)$$

From (6) and (11), we have:

$$\begin{bmatrix} 2(x_k - x_1) & 2(y_k - y_1) \\ 2(x_k - x_2) & 2(y_k - y_2) \\ ... & \\ 2(x_k - x_{k-1}) & 2(y_k - y_{k-1}) \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} \frac{C_1}{5n}(P(d_k)-P(d_1)) + x_k^2 - x_1^2 + y_k^2 - y_1^2 \\ \frac{C_1}{5n}(P(d_k)-P(d_2)) + x_k^2 - x_2^2 + y_k^2 - y_2^2 \\ ... \\ \frac{C_1}{5n}(P(d_k)-P(d_{k-1})) + x_k^2 - x_{k-1}^2 + y_k^2 - y_{k-1}^2 \end{bmatrix} \quad (12)$$

Equation (12) can be rewritten as follows:

$$\begin{bmatrix} 2(x_k - x_1) & 2(y_k - y_1) & (P(d_k) - P(d_1)) \\ 2(x_k - x_2) & 2(y_k - y_2) & (P(d_k) - P(d_2)) \\ ... & & \\ 2(x_k - x_{k-1}) & 2(y_k - y_{k-1}) & (P(d_k) - P(d_{k-1})) \end{bmatrix} \begin{bmatrix} x \\ y \\ \frac{C_1}{5n} \end{bmatrix} = \begin{bmatrix} x_k^2 - x_1^2 + y_k^2 - y_1^2 \\ x_k^2 - x_2^2 + y_k^2 - y_2^2 \\ ... \\ x_k^2 - x_{k-1}^2 + y_k^2 - y_{k-1}^2 \end{bmatrix} \quad (13)$$

Let denote:

$$z = \frac{C_1}{5n} \quad (14)$$

We achieve:

$$\begin{bmatrix} 2(x_k - x_1) & 2(y_k - y_1) & P(d_k) - P(d_1) \\ 2(x_k - x_2) & 2(y_k - y_2) & P(d_k) - P(d_2) \\ ... & & \\ 2(x_k - x_{k-1}) & 2(y_k - y_{k-1}) & P(d_k) - P(d_{k-1}) \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x_k^2 - x_1^2 + y_k^2 - y_1^2 \\ x_k^2 - x_2^2 + y_k^2 - y_2^2 \\ ... \\ x_k^2 - x_{k-1}^2 + y_k^2 - y_{k-1}^2 \end{bmatrix} \quad (15)$$

Equation (15) is a matrix equation:

$$\mathrm{AX} = B$$

In which, values in A and B have already known.

We can see that: equation (15) just depends on the coordinates of known access points and their received RSSs. In other way, estimation of unknown device/ user location doesn't depend on radio propagation parameters and hardware-specific parameters.

Through above analysis, we can see that our proposed scheme eliminates the need of acquiring reference RSS measurements and the training stage. As a result, the localization is performed quickly. The estimation of unknown device doesn't only in-depend on radio propagation parameters such as path loss but also in-depend hardware-specific parameters such as antenna gains.

IV. CONCLUSIONS

Pprevious indoor localization approaches mostly rely on labor- intensive site survey over every location or factors of wireless indoor environment. In this paper, we present a new algorithm which locates unknown device position in a certain wireless area without training stage and dependence on radio propagation parameters. By using mathematical formulation analysis, we demonstrate its advantage than the others.

For our future works, we plan to implement our algorithm in the real wireless environment or using networks simulation and investigate different estimation techniques to fide the more accurate device location.

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