2012 32nd IEEE International Conference on Distributed Computing Systems

Localizing Multiple Objects in an RF-based Dynamic Environment

Xiaonan Guo*, Dian Zhang† and Lionel M. Ni*
*Department of Computer Science and Engineering, Hong Kong University of Science and Technology
†College of Computer Science and Software Engineering, Shenzhen University
Email: guoxn@ust.hk, serena.dian@gmail.com, ni@cse.ust.hk

***Abstract*—Radio Frequency (RF) based technologies play an important role in indoor localization, since Radio Signal Strength (RSS) is easily achieved by various wireless devices without additional cost. Among these, radio map based technologies (also referred as fingerprinting technologies) are attractive. They are able to accurately localize the targets without introducing many reference nodes. Therefore, their hardware cost is low. However, this technology has two fatal limitations. First, it is hard to localize multiple objects, since radio map has to collect all the RSS information when targets are at different possible positions. But due to the multipath phenomenon, different number of target nodes at different positions often generates different multipath signals. So when the target object number is unknown, constructing a radio map of multiple objects is almost impossible. Second, environment changes will generate different multipath signals and severely disturb the RSS measurement, making laborious retraining inevitable. In this paper, we propose a novel method, called Line-Of-Sight (LOS) map matching. It leverages frequency diversity of wireless nodes to eliminate the multipath behavior, making RSS more reliable than before. These reliable RSS signals are able to construct the radio map, which only reserves the LOS signal among nodes. We call it LOS radio map. The number of objects and environment changes will not affect the LOS signal between the targets and reference nodes. Such map is able to be constructed easily and require no training if reference nodes are carefully pre-deployed. Our basic idea is to utilize the frequency diversity of each wireless node to transmit data in different spectrum channel. Then it solves the optimization problem to get the LOS signal. Our experiments are based on TelosB sensor platform with three reference nodes. It shows that the accuracy will not decrease when localizing multiple targets in a dynamic environment. It outperforms the traditional methods by about 60%. More importantly, no calibration is required in such environment. Furthermore, our approach presents attractive flexibility, making it more appropriate for general RF-based localization studies than just the radio map based localization.**

***Keywords*-Multiple Objects; Localization; Dynamic Environment**

I. Introduction

Localization is highly in demand and essential in many applications. Among various technologies, Radio Frequency (RF) based technologies are promising since Radio Signal Strength (RSS) can be easily measured by many wireless nodes without additional hardware support. Most off-the-shelf wireless devices support real-time RSS measurements, making the RSS nearly a free resource for localization.

There has been a large number of works based on the technologies[29][30][10][6]. Among these, radio map based technologies (also referred as fingerprinting technologies) are popular since they are able to localize target without introducing many reference nodes. In general, only several wireless nodes are required in localization [1] [28]. Therefore, their hardware cost is low. However, such technologies are faced two great challenges: The first is that it is hard to localize multiple objects. The reasons are as follows. In real environment in particular indoors, signal propagation suffers from severe multipath fading effect subject to signal reflection, diffraction and absorption by humans or structures [1]. As a result, a transmitted signal can reach the receiver through different paths, each having its own amplitude and phase. These different components are combined to reproduce a distorted version of the original signal[22][23]. Considering the scenario of multiple objects, Radio map has to collect all the RSS values when targets are at different possible positions. But due to the multipath phenomenon, different number of target nodes at different positions often generates different multipath signals. Therefore, the total received signals are usually different. So when the target object number is unknown, constructing a radio map of multiple objects is almost impossible. Second, environment changes (e.g., more target objects appear or layout changes) will generate different multipath signals and severely disturb the RSS measurement, making laborious calibration inevitable. Thus, radio map based technologies usually require a labor-intensive calibration procedure, which limit their usage in real applications.

Traditionally, usually there are two ways to handle this problem. The first is to utilize densely deployed nodes as reference (e.g., LANDMARC [20]) to localize the targets. However, this approach is costly. For example, LANDMARC [20] requires the reference nodes deployed $1m$ apart. Also, if the multiple objects are close to each other, it is very hard to find the correct nearest reference nodes and its accuracy is dramatically reduced. The second way is to localize the target based on the radio map of single object [28] [1]. As a result, the localization accuracy of multiple objects is far from accuracy. Moreover, once the environment changes, the RSS signals usually will be different. Therefore, many systems have to rebuild the

Dian Zhang is the corresponding author

1063-6927/12 $26.00 © 2012 IEEE
DOI 10.1109/ICDCS.2012.49

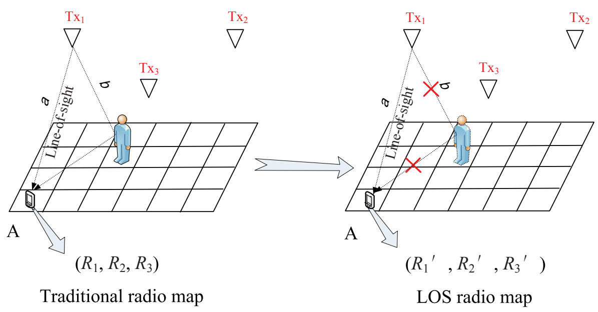

Figure 1: Illustrate basic idea by collecting RSS of LOS

radio map between RSS and distance by repeating training [1][5][21][25]. Although some works try to reduce such laborious work by using various methods, e. g., adaptive training [26], they can not fully avoid such procedure of map rebuilding.

To fully solve the above problems, we propose a brand-new approach, called Line-of-Sight (LOS) map matching. It is able to accurately localize multiple objects without rebuilding the radio map in dynamic environment (the environment often changes). Our basic idea is triggered by the following observations. The target objects or other environment changes often generate or change some non-line of sight (NLOS) paths (reflection, diffraction and absorption of the original signal). If we could build a radio map based on LOS signal, the multipath signal influence by the target objects or environmental changes will be eliminated. As Fig. 1 shows, suppose we have 3 anchor nodes acting as the receiver, A is the target object acting as the transmitter. R_1, R_2, R_3 denote the RSS value received from 3 anchor nodes, a person appearing in this environment will cause an additional signal reflection path for A, making the RSS change. If we are able to construct a radio map only reserve the RSS of LOS path, the appearing person will not affect the LOS signal. As shown in Fig. 1, R'_1, R'_2, R'_3 denote the RSS at LOS path from 3 anchor nodes. Since the LOS signal is not blocked by the person, the value of R'_1, R'_2, R'_3 will not change after introducing the person. Therefore, such map is more stable in dynamic environment, and it is denoted as LOS radio map. To the best of our knowledge, we are the first to accurately localize multiple objects by using radio map based technologies. In order to realize the LOS radio map construction and valid map matching for localization, a key issue is to identify the LOS signal from different paths. Our approach is to leverage the frequency diversity to help RSS provide phase information indirectly. We find that RSS values are significantly different when the nodes are in different spectrum channels (the other setting is the same). Such RSS difference at different channels carries the valuable phase information. By analyzing these RSS, we can identify the amplitudes and phases of signals from each path. We then may derive the RSS of LOS path by solving the optimization problem. As a result, we may eliminate the multipath behavior, making RSS more reliable than before. These reliable RSS signals are able to be leveraged to construct the LOS radio map instead. Such map only reserves the LOS signal among nodes. By careful pre-deployment (e.g., the reference nodes are deployed on the ceiling of the floor and the targets are on the ground), the environment changes and the number of objects will not affect the LOS signal between the targets and reference nodes. This LOS radio map is able to be constructed easily and require no training if reference nodes are carefully pre-deployed.

Compared with other traditional radio map based localization methods, our approach has the following advantages:

- We are able to accurately localize multiple objects in dynamic environment without calibration on the map. Traditional works utilize the raw RSS value directly, which suffer from severe multipath effect especially when multiple objects are required to localize. Our approach is based on collecting RSS of LOS path. By careful pre-deployment, we can make sure that the changing target object number only affects the NLOS paths signal between targets and reference nodes. Thus, we may achieve more reliable RSS value, and fundamentally solve traditional problem and achieve good localization result.
- Our approach is adaptive to environment changes. The LOS radio map we build reserves only the LOS signal among nodes. If the environment changes, for example, the number of targets changes or layout changes, we do not need to rebuild it. As a result, it frees the labor intensive calibration step in the traditional approach, making the radio map approach practical in real use.
- Our solution is able to eliminate multipath effect of RSS signal without additional hardware support or lower-layer protocol information. We find that the RSS difference at different channel carries the valuable phase information for signals from different paths. Through solving related optimization problem, we may identify the signal along LOS path. To the best of our knowledge, we are the first towards this goal with this constraint.
- Our work is not only suitable for the radio map based localization. Many current RSS based approaches may need a revisit. Although our work leverages radio map for localization, it is totally different from traditional approaches. We identify the LOS signal among nodes, making RSS more reliable. This presents promising

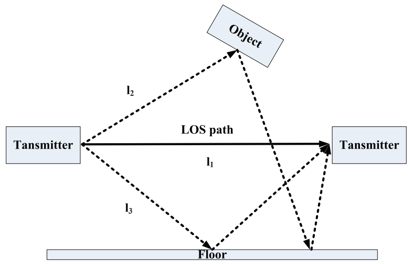

Figure 2: multipath

generality which enable it be applied in a much broader scope of application. With this new approach, many of the existing RF-based localization approaches may need a revisit.

We implement a real time tracking system based on TelosB platform [24] with only 3 anchor nodes. Experimental results show that localization accuracy of multiple objects in dynamic environments outperform the traditional approaches by 60%.

The rest of this paper is organized as follow. In the next section, we give some related work. Sec. 3 is the theoretical background. Sec. 4 will describe our methodology in details. Sec. 5 will present our localization system implementation and evaluate the performance. In the last section we conclude this work and point out some possible future work directions.

II. Related Work

There are many video technologies to track multiple objects, such as [3] [13] [12]. However, their computation complexity is high and it is hard to track object in dark area. There are also some technologies using OFDM technology [7][16] to eliminate the multipath effect of signals. However, they require physical layer information and their hardware cost is high. Our work does not need to access the physical layer and can be widely used in various wireless devices.

Significant work have been done in the area of indoor localization by using RSS information. Basically, it can be divided into two categories: radio map based technologies and non-radio map based technologies. In radio map based technologies, RADAR [1] built a radio map of RSS for each environment and localized object by using map matching on this map. However, the RSS information will change in dynamic environment. Therefore, the radio map has to be rebuilt often and accuracy will dramatically decrease. There are some adaptive learning approaches e.g., [27]. It utilized the RSS information of some reference points to help reconstructing the radio map. Thus, the calibration cost can be reduced. However, these technologies still require calibration on the map if environment changes. A large number of probabilistic approaches [28] [10] [**?**] have also been proposed. Their main idea is to construct a probabilistic model to represent the behavior of the link RSS values. Many parameters are still required to be trained in the real environments, which are also suffered from environmental changes. There are also some work [5] built multiple radio maps in advance under various environmental conditions and selected the most appropriate radio map to localize object by using sensors to identify the current environment. However, if environment often changes, e.g., the target number often changes, it is hard to construct all the possible maps. There are also some work [6] which assumes the positions of access points (anchor nodes) are unknown. Their proposed algorithm do not rely on knowledge of the placement of the access points. But this technology does not work well if environment often changes. Our work is different from all these work. All the above work are difficult to accurately localize multiple objects. We are able to accurately localize multiple objects in dynamic environments without any calibration. Furthermore, our method is able to be applied to improve all the above work.

In non-radio map based technologies, RIPS[19] [18][11] utilized the interference behavior between two nodes with slightly frequency difference to localize target. Two improved work [4] [17] used Doppler effect work to track mobile target and improve the system accuracy. Although these work have excellent positional accuracy and sensing range in outdoor environments, they are unsuitable for indoor environment due to severe multipath effect indoors. LANDMARC [20] used RFID technology to localization object inside building by finding similar RSS value between reference nodes and the target nodes. However, the accuracy of this approach relies on dense deployment of the reference nodes. Its incremental work [31] is able to localize target by using less reference nodes. However, its density is still high.

III. Theoretical Background

In this section, we first introduce the radio propagations in free space and multipath environment. In the following, we will discuss the limitation of radio map based localization on multiple objects.

A. Radio propagation in free space and multipath environment

Radio propagation is the behavior of radio wave when they are transmitted from transmitter to receiver. For radio propagation along the LOS path, it can be expressed as follows according to Friis model [2] in free space,

$$P_r = |\overrightarrow{p}| = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} \tag{1}$$

here P_r, P_t represents received radio strength and transmitted signal strength in Watts respectively. G_t is antenna gain of transmitter and G_r is antenna gain of receiver. λ is the signal wavelength. d is the path length of the LOS path

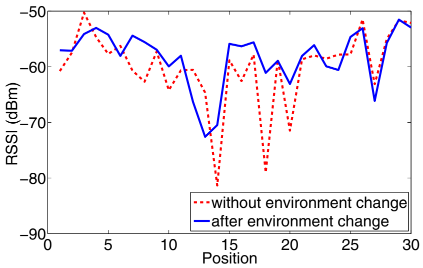

Figure 3: Impact of environmental change

(the physical distance between the transmitter and receiver). $\overrightarrow{p} = \{|\overrightarrow{p}|, \theta\}$ is the signal wave vector, $|\overrightarrow{p}|$ is its path power (amplitude) and θ is the path phase at the receiver. Suppose the sender has the phase zero, the path phase of the signal at the receiver is,

$$\theta = 2\pi \cdot (\frac{d}{\lambda} - \lfloor \frac{d}{\lambda} \rfloor) \tag{2}$$

However, in the real environments, many NLOS paths exist. Such paths are caused by the radio reflection and refraction by surroundings. In each reflection or refraction, only partial energy will be transmitted [2]. Such part can be measured by a reflection (refraction) coefficient, which is denoted as γ, $\gamma \in (0, 1)$. As a result, for a given NLOS path, the path power is,

$$|\overrightarrow{p}| = \gamma \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} \tag{3}$$

It is noted that here d is no longer equal to the physical distance between the transmitter and receiver. Eq. (3) is the same as Eq. (1) when the path is LOS path ($\gamma = 1$).

Multipath effect refer to the signal arrives at the receiver in more than one paths. For example, in Fig. 2, there are 3 paths from the transmitter to the receiver. l_1 is the LOS path, l_2 and l_3 are the reflection paths by the surroundings. As a result, the signal strength at the receiver is the signal combination of all the paths. It can be denoted as

$$|\overrightarrow{p}| = |\sum_{i=1}^{n} \overrightarrow{p_i}| \tag{4}$$

B. Radio Map Based Technology and its Limitations When Localizing Multiple Objects

The radio map technique (also referred as fingerprint technique) is to construct a mapping between the RSS (e.g., from Aps or sensors) and location information of the target in advance. The target object then can be localized by matching its received RSS information with it in the radio map. The mapping construction part is known as the *off-line training phase* and the matching part is know as the *online localization phase*.

However, this technology is suffered from localizing multiple objects and environment changes. Since in the off-line training phase, it has to arrange the target in advance to stay at all the possible locations and collect the corresponding RSS information. Once the environment changes (e.g., a new target object appears or layout changes), the RSS signal may change significantly. So we have to rebuilding the map. As Fig. 3 shows, based on 2 TelosB sensor platform [24] (one is transmitter at fixed position, the other one is the target acting as the receiver, the transmission power is fixed at 0 dBm), we test the RSS of the receiver at different labeled locations in our lab. We can see that, the RSS is very sensitive to the environment changes (we introduce a person to act as the new target object). It is easily to understand such behavior due to the multipath effect introduced by the new object.

Considering the scenario of multiple objects, it will be too costly to build such a map. For example, suppose for one object we have to build a radio map of n locations. For two objects we have to build a radio map of $n \times n$ locations. If we do not know how many objects in advance, it is almost impossible for us to build such a map. Traditional radio map based technology only localizes objects based on the radio map of single object. The localization accuracy is dramatically reduced when multiple target objects exist. Moreover, we have to rebuild to the radio map, if the environment layout changes. It is a very laborious work which limits its application in the real use.

IV. METHODOLOGY

In this section, we first explain our basic idea. In the following, we introduce how to construct our LOS radio map. Then we describe our algorithm of leveraging frequency diversity to identify the LOS signal from multipath. Finally the localization method of our LOS map matching is proposed.

A. Basic Idea

It is known that RSS is signal combination of all the paths in the real environment. If we are able to learn the phase information of signal along each path, we may easily get the LOS signal. But RSS itself have no phase information. However, we find that the RSS is different by using different operating frequency. Such difference potentially is able to give us information to infer the phase information of signal. As a result, we may filter out LOS signal from multipath signals between a pair of transmitter and receiver, based on just the RSS information.

This idea is triggered by an interesting observation from the experiment of 2 TelsoB sensors [24]. One acts as the transmitter and the other one is the receiver. The transmission power is fixed at 0 dBm. The default channel is 13. We find that if the environment does not change, the RSS is stable as shown in Fig. 4. But in such environment, if we only change the channels, the RSS is different, as shown in Fig. 5. Such difference is due to the different radio wave length on different channels. For a fixed path with

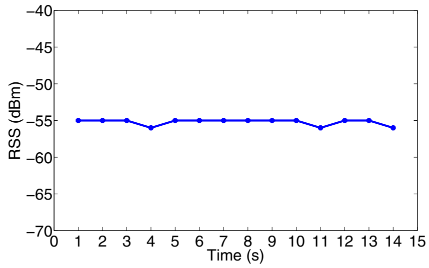

Figure 4: RSS with different time

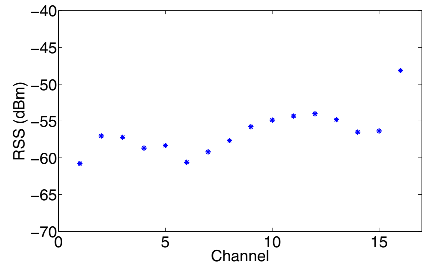

Figure 5: RSS with different channel

the same radio propagation distance, the path phase when radio arrives at the receiver will be different. Therefore Such RSS difference potentially gives us phase information. We may eliminate the multipath effect and get the LOS signal accordingly. It is noted that when the difference of radio wave length is extremely small when we change the channel (only several millimeters between different channels for TelosB nodes), the existing radio propagation paths are unlikely to change.

Our radio map and localization method are all based on the LOS signal. Since the LOS radio map only keeps the LOS signal between the transmitter and receiver, we may easily construct it through using the free space model without training. In the following localization, frequency diversity method is used to eliminate the multipath signal between the anchor nodes and target. The detail is listed in the following subsections.

B. LOS Radio Map Construction

In our system, the whole tracking area is divided into cells. Suppose we have anchor nodes acting as the receivers and the target nodes as the transmitters. The first fundamental step is to construct a LOS radio map. We offer two methods to construct such map. The first one is to construct from theory. The second one is from training results.

In the first method, we may easily construct it by using the Friis free space model. In each cell, we are able to estimate the received power by using Eq. 1. In this equation, the transmission power P_t is configured by users, the transmitter and receiver antenna gain G_t, G_r can be obtained from the hardware specification manual [14]. Also since the anchor nodes are fixed deployed, the distance between each anchor node and transmitter can be estimated. The best advantage for building such map is that we do not require the laborious offline training to construct the radio map and the LOS signal can be accurately modeled. In the second method, we build the LOS radio map from training. The procedure is similar to traditional radio map construction, except that we should measure RSS in different channels, then we may identify the LOS signal by using the frequency diversity, which will be introduced in the next subsection.

After the LOS radio map is constructed, it is able to be leveraged in localization. As long as the environment changes do not block the LOS signal between transmitter and receiver, the map does not need to be rebuilt. We may realize it by carefully deploying the anchor nodes in advance. For example, we may deploy the anchor nodes on the ceiling of the floor and the target nodes are supposed on the ground. Therefore, most environment changes will not affect the LOS signal. Only if the transmission power of the anchor nodes change (P_t changes) or the nodes themselves change (G_t, G_r change), or the anchor nodes are redeployed, the map needs to be rebuilt.

$$
\begin{aligned}
|\overrightarrow{p}| &= ((\sum_{i=1}^{n}(\gamma_i \frac{P_t G_t G_r \lambda^2}{(4\pi d_i)^2} \sin(\frac{d_i}{\lambda})))^2 \\
&\quad +(\sum_{i=1}^{n}(\gamma_i \frac{P_t G_t G_r \lambda^2}{(4\pi d_i)^2} \cos(\frac{d_i}{\lambda})))^2)^{\frac{1}{2}} \\
&= f(\gamma_i, d_i) \qquad (5)
\end{aligned}
$$

C. Eliminate Multipath Effect by Using Frequency Diversity

Suppose there are n radio propagation paths between transmitter and receiver. According to Eq. 4, we use orthogonal decomposition on each path and get the received power of the combined signal, the total received power at the receiver is

Where P_t, G_t, G_r and π are all constant values. P_t is configured by users. The transmitter and receiver antenna gain can be obtained from the hardware specification manual. We may use the parameters from TelobB datasheet [24] and calculate the gain of omnidirectional antenna.

Suppose we may measure up to m channels, the wavelength of the radio wave at these channels are λ_j,$j \in [1, m]$. Since for different radio wave length we may have different received power, we could have the following equation,

$$
\begin{cases}
\varepsilon_1 = f_{\lambda_1}(d_1 \cdots, d_n, \gamma_1 \cdots, \gamma_n) - |\overrightarrow{p_{\lambda_1}}|, \\
\varepsilon_2 = f_{\lambda_2}(d_1 \cdots, d_n, \gamma_1 \cdots, \gamma_n) - |\overrightarrow{p_{\lambda_2}}|, \\
\vdots \\
\varepsilon_m = f_{\lambda_m}(d_1 \cdots, d_n, \gamma_1 \cdots, \gamma_n,) - |\overrightarrow{p_{\lambda_m}}|.
\end{cases} \qquad (6)
$$

Here ε_i is the individual fitting error. Our goal is to find proper $d_1, \cdots, d_n$, $\gamma_1, \cdots, \gamma_n$, which can minimize such errors. As such, the problem is transferred into the following

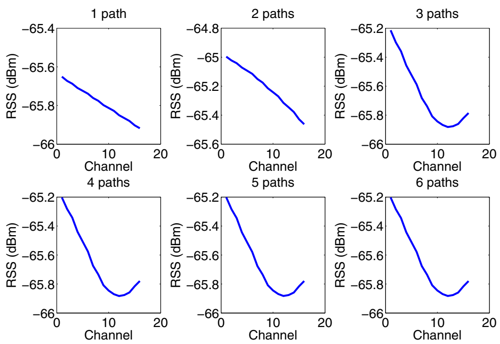

Figure 6: Simulation result of different number of paths

non-linear optimization problem

$$Min(\sum_{j=1}^{m}(\varepsilon_j)^2) \quad (7)$$

We may prove that if the number of used channels is larger than $2n$, we can solve the optimization problem and obtain the numerical result by using Newton and Simplex approach [8]. Due to the limited pages, we skip this part. Our goal is to accurately find d_1 and get the LOS path power, the accuracy of the other parameters is trivial.

D. Path Number Selection

In order to solve the Eq. 6, we have to set a path number in advance. But in the real indoor environment, it is almost impossible to know how many paths existing between a pair of transmitter and receiver. So in this subsection, we will give an analysis on the impact of multipath and conclude a reasonable result of path selection without sacrificing too much accuracy.

As introduced in the last section, given a radio propagation path between a fixed transmitter and receiver (G_t ,G_r are fixed) with fixed transmission power (P_t is fixed) and wavelength (λ_i is fixed), there are 2 parameters deciding the path power of each path: (refraction) coefficient γ_i and the distance between transmitter and receiver d_i.

The first one actually depends on the surface of the reflection (refraction) materials. For common material, this value is around 0.5 [15]. Therefore, if the radio is reflected (or refracted) for multiple times, its contribution to the total received power will be small. For example, if a reflection more than 3 times will result in only $(0.5)^3 = 0.125$ times of the original energy. For the LOS path, since there is no reflection or refraction, its value is 1. Therefore, in practice, though some accuracy is sacrificed, we may skip those signal propagation paths having many reflection (refraction) times, e.g., large than 3. Considering the second parameter d_i, the received power is in inverse proportion to $(d_i)^2$ according to Eq. 1. If the length of the multipath is large, its influence on the total received power will also be very small. For example, if the path length is larger than two times of the LOS path length, the remaining energy is smaller than $1/2^2 = 0.25$ of the original energy. So we may also skip those signal reflection paths whose path length is very large, say two times of the LOS path length.

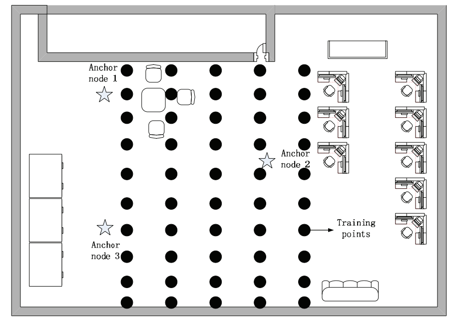

Figure 7: experiment area

Furthermore, since all the multipath signals have at least one reflection (refraction) and their length are all larger than the LOS path length, most of their influence on the total received power is limited. For example, if one path has 2 times larger than LOS path length and with one time reflection, it remaining energy will be $0.5 \times \frac{1}{2^2} = 0.125$ of the original energy.

We further verify the impact of the different number of path to the total received power at the receiver through simulation on TelosB sensor nodes. For a fixed transmitter and receiver, we set the transmission power as 0 dBm. The distance between the transmitter and receiver (it is also the length of LOS path) is $4m$. We perform 6 rounds of test to observe the signal combination effect when different number of paths combing together. They are: just one LOS path, LOS path with on multipath ($8m$), LOS path with two multipaths ($4m$ and $8m$), LOS path with three multipaths ($4m$, $8m$, $12m$), LOS path with four multipaths ($4m$, $8m$, $12m$, $16m$), LOS path with five multipaths ($4m$, $8m$, $12m$, $16m$, $20m$), LOS path with four multipaths ($4m$, $8m$, $12m$, $16m$, $20m$, $24m$). We assume each multipath signal is reflected (refracted) only once. At each round of test, all the 16 channels on TelosB are all tested. From Fig. 6, we can see that, when path length is larger than 2 times of the LOS path length, its influence on the combined signal at the receiver is very small, no matter what channel is selected. An interesting observation is that when the number of path exceed a certain value (in this example is 3), the RSS in each channel will become stable. In other words, the RSS will not change a lot with more path introduced. Thus, we could utilize limit number of path to represent the influence of the multipath without lose lot of accuracy.

Therefore, the number of paths we may use is limited through to the above reasons. We skip those paths whose path length is long or having many reflection (refraction) times, say two times of the LOS path length. So in practice, we suppose the path number is no larger than 5, though some accuracy will be sacrificed.

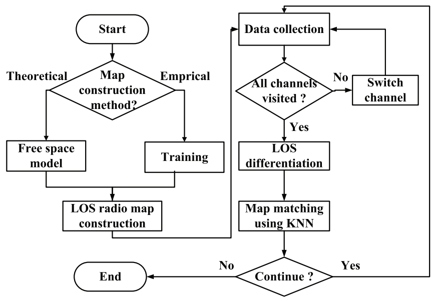

Figure 8: System workflow

E. KNN localization

After we filter out the multipath effect by using frequency diversity, we may have the LOS signal from each anchor node to the target object. In our LOS radio map, each cell stores the RSS of LOS path from three anchor nodes respectively. Base on the LOS radio map, we may localize the object by using K Nearest Neighbor (KNN) method.

Suppose each target node is the transmitter and we have q anchor nodes acting as receivers (in our experiments,the value of q is 3), and totally we have t cell in the LOS radio map. We define the signal strength vector of a target node as $S = (S_1, S_2, ..., S_q)$, where S_i denotes the RSS of the target node perceived by the ith anchor node, where $i \in (1, q)$. In each cell j ($j \in (1, t)$) of our LOS radio map we have the signal strength vector $\alpha_j = (\alpha_{j_1}, \alpha_{j_2}, ..., \alpha_{j_q})$, where α_{j_i} denotes the RSS of LOS path from the anchor node i to the cell position j. For each cell, we will calculate the Euclidean distance [20] in signal strengths to the target as

$$D_j = \sqrt{\sum_{i=1}^{q} (\alpha_{j_i} - S_i)^2} \tag{8}$$

After we calculate all the D_j, we may choose K cell positions which have the smallest (nearest) K Euclidean distance to the target. The target location (x, y) is able to be calculated from the K nearest positions, which is

$$(x, y) = \sum_{j=1}^{K} w_j (x_j, y_j) \tag{9}$$

Here (x_j, y_j) is the coordinate of the cell j in the LOS radio map. K is the number of cells selected to have the nearest Euclidean distance to the target. In general, the value of K is set as 4 [20]. w_j is the weight of the jth nearest neighbor in this algorithm. Empirically, the weight is given by

$$w_j = \frac{\frac{1}{(D_j)^2}}{\sum_{j=1}^{k} \frac{1}{(D_j)^2}} \tag{10}$$

Here those cell with the smallest vector distance value means it has the largest weight.

V. PERFORMANCE EVALUATION

In this section, we show the whole system architecture and evaluate the proposed method under different environment setting. We investigate the localization accuracy of single object in static environment and dynamic environment as well. Then we show the impact of the number of targets on our localization system. At last, we compare two different LOS construction approaches and show the latency analysis.

A. Experiment Setup

We use TelosB [24] nodes (equipped with a ZigBee-compliant CC2420 radio) as the anchor nodes and the target nodes as well. TelosB nodes are subject to $802.14.5$ Zigbee standard and support 16 different channels ranging from 2.4 GHz to 2.4835 GHz. Each channel has 22 MHz bandwidth and separated by 5 MHz from each other. The channel is easy to configure and change at running time.

All the experiments are conducted in our lab. The deployment area has a dimension of 15×10 meters, as depicted in Fig. 7. In our system, three anchor nodes are deployed on the ceiling as receiver, they are also connected to a laptop installed with Linux operating system. There are total 50 training points on the floor, forming a 5×10 grid with 1 meter apart. Each target node is a human being carrying a transmitter. The transmit power is -5 dBm. All the nodes are synchronized with each other by reference-broadcast method [9], which allow the transmitters and receivers able to switch to the same channel simultaneously. At each channel, the target node will send 5 packets continuously with, then switch to the next channel until all the channels have been visited. After that, the three anchor nodes will send the received data to the server via USB cable.

B. System Workflow

The workflow of our system is demonstrated in Fig. 8. The whole localization process is divided into two phases: LOS radio map construction phase and localization phase. In the map construction phase, we are able to construct LOS radio map either by theoretical approach or by training as introduced in the last section. Once the map is constructed, no calibration is required. When the localization phase begin, we collect RSS information from each target node at different channels. After all the channels have been visited, we differentiate RSS of LOS path by leveraging frequency diversity. Then we may apply KNN algorithm to estimate each target node's position. This procedure is repeated until users terminate it.

C. Impact of Environmental Changes on Different Maps

In this part, we investigate how the environment changes will affect different radio maps.

We construct both our LOS radio map and traditional map in the same deployed area as Fig.7 shows. At first,

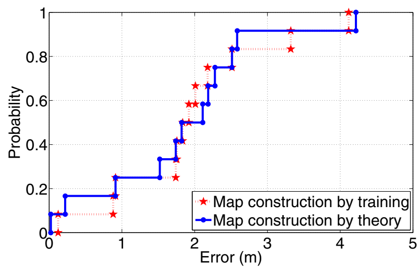

Figure 9: Localization accuracy by using two different map construction approaches

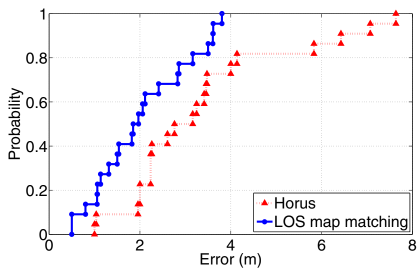

Figure 10: CDF of localization accuracy in dynamic environment

RSS data from all the 50 training points are collected. After that, we change the deployment area by introducing more people and change some layout inside the room. Then we collect the RSS data again. The RSS difference after the environmental change is demonstrated in Fig. 13. Each cell represents a training point and the cell with dark area means its RSS difference is big, otherwise it is small. This figure well illustrates that traditional radio map will be significantly affected by the environmental change. In addition, the impact is irregular and it is hard to find any pattern, making multiple objects tracking a challenge task for traditional map matching. Fig. 14 illustrates the change of the RSS at the LOS path under such environmental change. We can see that, the RSS difference is very small (more shallow color) compared with traditional one. From these two figures we find that our LOS radio map is more stable under environmental changes than traditional map.

D. Comparison of Different Map Construction Methods

In this section, we compare the localization accuracy based on different map construction methods. 24 target locations have been tested in our experiment area. The results are shown in Fig. 9. We find that, when we use training to construct the LOS radio map, the localization accuracy is slightly better than using theory to construct the map. The reason is that, different nodes may have different variance on the hardware parameters. Therefore, if users prefer higher accuracy, they may choose training to construct the LOS radio map. Otherwise, using theory to construct the map will save more cost. We will use training to construct the map in in the following experiments.

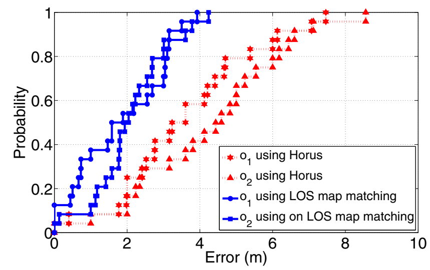

Figure 11: CDF of localization accuracy of multiple objects

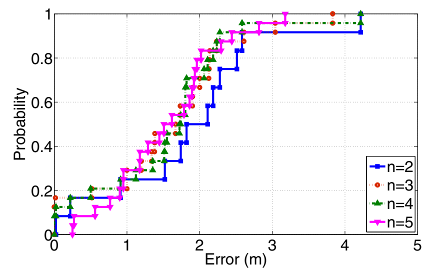

Figure 12: Accuracy of different number of path

E. Impact of Path Number Selection

In this section, we show the impact of number of path on the localization accuracy. We test different number of path from 2 to 5, based on 24 different target positions on the ground. Fig . 12 shows the experiment result, where n denotes the number of path. We find that when $n = 2$, its average localization accuracy is only about $2m$. When we take more path into consideration, say $n = 3, 4, 5$, we could obtain better localization accuracy. But we also observe that when $n \geq 3$, the accuracy improvement is marginal. Its localization accuracy is about $1.5m$. So in our later experiments, we set this value as 3.

F. Accuracy of Single Object in Dynamic Environment

In this part, we evaluate the localization accuracy of single object in dynamic environment, where we arrange some people to walking around. Based on 24 different target locations, we compare the accuracy of our algorithm with Horus [28], which has the best localization accuracy in the traditional work. The localization results are shown in Fig 10. We may see that, in dynamic environment, the localization accuracy of Horus is around $3m$ while our LOS map matching has the accuracy of $1.5m$. The localization accuracy is improved by 50%.

G. Accuracy of Multiple Objects in Dynamic Environment

In this experiment, we evaluate the system performance of multiple objects in the dynamic environment, where we arrange some people to walk around. First, we have two target objects (two persons), named O_1 and O_2. For each target object, 40 locations on the ground are tested. From Fig. 11 we can see that, if using Horus, the localization

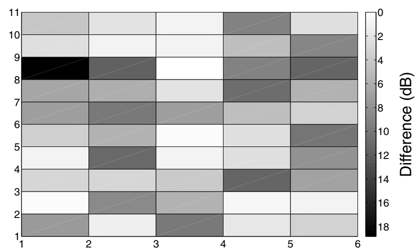

Figure 13: Change of RSS

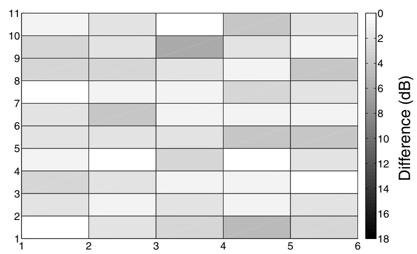

Figure 14: Change of LOS RSS

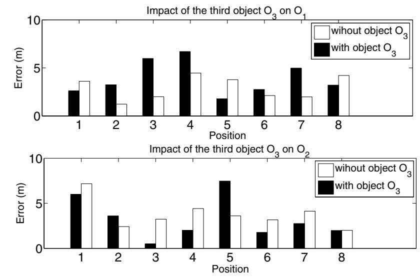

Figure 15: Accuracy with original map

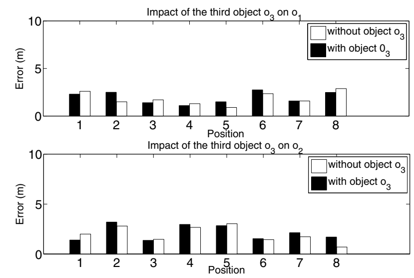

Figure 16: Accuracy with LOS map

accuracy is about $4.4m$, which is much worse than the localization accuracy of single object. Our LOS map matching method, however, has the localization accuracy to about $1.8m$. It dramatically outperforms traditional radio map based technologies by 60%. Second, To better understand the impact of multiple objects, we introduced another person named O_3 in our lab and the other environmental factors are stable. We will show the impact of the third object O_3 on the localization of the other two target objects O_1 and O_2. The experiment result by using the traditional radio map is shown in Fig. 15, the top figure demonstrates absolute localization error of O_1 with and without O_3 presents, and the bottom figure demonstrates the impact of object O_3 on O_2. However, the extra object O_3 has little impact on RSS of LOS path and the experiment result is shown in Fig. 16. By using LOS map matching, both O_1 and O_2 have average localization error around 1.8 meters. The experiment results have indicated that, without calibration, the LOS map matching is able to get high accuracy for multiple objects in dynamic environment.

H. Latency

The latency of our system mainly depends on how much time for each node to finish visiting all the channels. In our system, we will transmit beacon messages through 16 channels in total. At each channel, 5 packets are transmitted. For TelosB node, it will take approximately $7ms$ to transmit a single packet [24] and $0.34ms$ for channel switching. In order to avoid beacon collision when multiple target objects exist, the target nodes will transmit packets every $30ms$. Therefore, for each node, it will take $(30 + 0.34) \times 16 \approx 0.48s$ to visit all the channels. The total latency can be express as

$$T_l = (T_t + T_s) \times N \tag{11}$$

where T_t denotes the time interval between packet transmission, T_s represents the channel switch time and N denotes the number of channels.

VI. Conclusion and Future Work

In this paper, we proposed a novel localization approach able to accurately localize multiple targets in dynamic environments without any calibration procedure. This method is named LOS map matching. Although it is leverage radio map for localization, it is totally different from traditional approaches. It presents promising generality which enable it be applied in a much broader scope of application. With this new approach, many of the existing RF-based localization approaches may need a revisit.

Our radio map construction and localization method are both based the RSS at the LOS path among nodes. The LOS signal is identified from original signal by utilizing frequency diversity of wireless nodes to eliminate multipath behavior. During the procedure of multipath elimination, each wireless node only requires to visit different channels to transmit. Then, the elimination problem is transferred into an optimization problem. If users leverage our method, no physical layer information is needed. Only the measurement of RSS value is required, making it able to be widely used for various wireless devices. Also, the number of targets and environmental changes will not affect the LOS map and multiple object localization as well. Furthermore, no calibration is required. We verify our method in real experiments based on the TelosB sensor platform. Compared with traditional radio map based technologies, the accuracy of localizing multiple objects in dynamic environment (e.g., the target number changes or layout changes) can be dramatically improved by 60%. Our method can be widely used and benefit all the RF-based localization methods.

The future work can be conducted along following directions. First, based on this new technology, some fundamental radio map based localization problems becomes open. For example, based on the new LOS radio map, other appropriate map matching methods should be further investigated. Second, we only conduct our experiments in an area of 15×10 meters. A larger experiment area is expected in our future work. Third, in our experiment, the number of target nodes is at most three. The localization results of more target objects will be given in our following work. At last, the parameter of path number selection in the frequency diversity is from empirical results. Its theoretical foundation is calling for further investigations.

ACKNOWLEDGEMENT

This research was supported in part by Hong Kong RGC Grants HKUST617710 and HKUST617811, China NSFC Grant 60933011, 61170077, 61170076, 61033009, 61003272, 61027009 and 61103001; Science and Technology Planning Project of Guangdong Province, China under Grant No. 2011A011302001.

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