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TafLoc: Time-adaptive and fine-grained device-free localization with little cost

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TafLoc: Time-adaptive and Fine-grained Device-free Localization with Little Cost

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ABSTRACT

Many emerging applications drive the needs of device-free localization (DfL), in which the target can be localized without any device attached. Because of the ubiquitousness of WiFi infrastructures nowadays, the widely available Received Signal Strength (RSS) information at the WiFi Access points are commonly employed for localization purposes. However, current RSS based DfL systems have one main drawback hindering their real-life applications. That is, the RSS measurements (fingerprints) vary slowly in time even without any change in the environment and frequent updates of RSS at each location lead to a high human labor cost.

In this paper, we propose an RSS based low cost DfL system named *TafLoc* which is able to accurately localize the target over a long time scale. To reduce the amount of human labor cost in updating the RSS fingerprints, TafLoc represents the RSS fingerprints as a matrix which has several unique properties. Based on these properties, we propose a novel fingerprint matrix reconstruction scheme to update the whole fingerprint database with just a few RSS measurements, thus the labor cost is greatly reduced. Extensive experiments illustrate the effectiveness of TafLoc, outperforming the state-of-the-art RSS based DfL systems.

CCS Concepts

•**Human-centered computing** → **Ubiquitous and mobile computing design and evaluation methods;**

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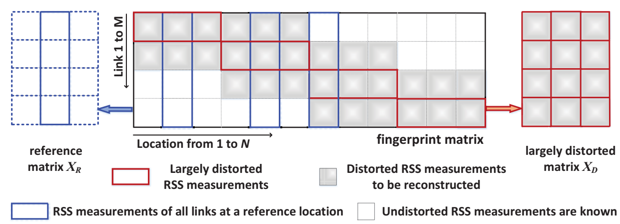

Figure 1: **Fingerprint matrix.** One row of the fingerprint matrix represents RSS measurements collected from one link, and one column represents measurements at one location from all the links. The reference matrix consists of measurements at only a few reference locations, and the largely-distorted matrix consists of measurements with large RSS decreases.

Keywords

Device Free Localization; Received Signal Strength; Time Adaptive, Fine-grained;

1. INTRODUCTION

Benefiting from the ubiquitous WiFi infrastructure, RSS based localization plays a key role in many applications, such as indoor navigation, location-based service, etc. Most existing techniques require the target to be equipped with a communication-capable device, which is detected and localized. However, in many scenarios such as elderly care, the target is usually reluctant to wear a device or hold a mobile phone. In intruder detection, it's not even possible for the target to be attached with such a device. Accordingly, device-free localization (DfL) systems [2] have attracted increasing attentions. Specifically, the fingerprint-based systems employ the RSS measurements when target is present at different locations to build a fingerprint database. Then real-time RSS measurements are compared with the fingerprints for location estimates. However, to become a practical system, one key problem still remains unsolved, i.e., *the labor and time cost for fingerprint update is high*.

It is inevitable to update the fingerprint repeatedly. The reason is that RSS fingerprints collected initially will expire over time. In fact, besides the movement of furniture, door opening and closing, even without any change in the environment, the RSS measurements still change slowly in the scale of days due to temperature and humidity changes. In our experiments, the RSS values change 2.5 dBm and 6 dBm respectively after 5 and 45 days. ***Thus, in order to maintain the fingerprint-location matching, it's a necessity to update the fingerprints whenever there are changes in the envi-***

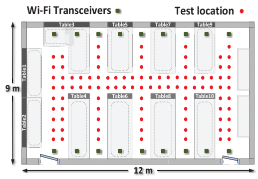

Figure 2: Experiment deployment.

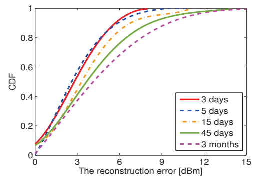

Figure 3: Fingerprint reconstruction errors after different time periods.

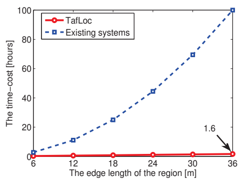

Figure 4: Fingerprint update time costs with different sizes of area.

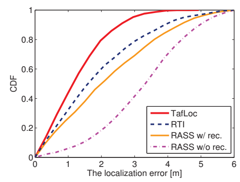

Figure 5: Localization performance comparing with state-of-the-art systems at 3 months later.

ronment, which is labor-intensive and time-consuming.

To address this issue, we propose *TafLoc*, the first RSS fingerprint-based DfL system which is able to update the fingerprint database by only collecting measurements at a few chosen reference locations. We creatively represent the database as a two dimensional matrix (Fig. 1) with the following key observations: i) the fingerprint matrix is approximate low rank and can be roughly reconstructed by the rank-minimization; ii) the fingerprint matrix can be represented as a linear combination of the RSS measurements at only a few reference locations; iii) RSS measurements at neighbor locations along a particular link are continuous, and measurements at a specific location from adjacent links are similar. Based on these key properties, we propose a fingerprint matrix reconstruction scheme to accurately update the fingerprint database with little human cost.

2. TAFLOC SYSTEM DESIGN

First, we represent the fingerprint database as a two dimensional fingerprint matrix, with each column denotes RSS measurements from different links at a specific location and each row denotes RSS measurements at different locations from a specific link. We deploy M links on the two sides of the monitoring area and divide the area into N location grids ($M \ll N$). Let x_{ij} denote the RSS measurement of link i when target is located in location grid j, where $i=1,\cdots,M$ and $j=1,\cdots,N$. By collecting RSS measurements when the target is located in each of the N grids, we construct the fingerprint matrix $X=(x_{ij})_{M\times N}$ as shown in Fig. 1. X is approximate low rank and can be roughly reconstructed by $\min\ \mathrm{rank}(\hat{X}),\quad \mathrm{s.t.},\ B\circ X=X_I$, where $\hat{X}$ is the best approximation of X. $(B)_{M\times N}$ is a binary matrix with element $B(i,j)=1$ when the RSS measurement $x_I(ij)$ of link i is undistorted by the target at location j.

To improve the reconstruction accuracy, we select $n (n \ll N)$ locations with RSS measurements corresponding to the maximum linearly independent vectors $\mathbf{x}_i$ in X as reference locations, and aggregate these measurements as a *reference matrix* $X_R=[\mathbf{x}_1,\cdots,\mathbf{x}_n]$. We use the Low Rank Representation to model the correlation between reference matrix and fingerprint matrix as $X=X_R{*}Z$, Z is the correlation matrix.

To further improve the reconstruction accuracy when the linear correlation loses efficacy due to the changes in environment, we utilize the third property described earlier. That is, when a target is present blocking the direct path of link, the RSS readings has a clear decrease. And along the path, RSS changes continuously while for the same location, the RSS readings from adjacent links are similar. We term these measurements when a target is present as largely-distorted RSS and group them as a *largely-distorted matrix* $X_D=(x)_{\frac{N}{M}\times\frac{N}{M}}$. The elements in this matrix are continuous along the row while similar along the column.

Then the reconstruction problem can be expressed as:

$$\min\ \lambda(\|L\|_F^2+\|R\|_F^2)+\|B\circ(LR^T)-X_I\|_F^2$$
$$+\|LR^T-X_R*Z\|_F^2+\|X_D*\mathbb{G}\|_F^2+\|\mathbb{H}*X_D\|_F^2.$$

To solve this non-convex problem, we perform SVD on $\hat{X}=U\Sigma V^T=LR^T$. $\mathbb{G}$ and $\mathbb{H}$ characterize the continuity (different locations along the same link) and similarity (same location from different links) properties, respectively. We propose an LoLi-IR algorithm which gets L and R in an alternatively iterative manner. By doing so, the fingerprint matrix X can be accurately reconstructed. After we reconstruct the fingerprint matrix, the real-time RSS measurements are collected as $Y=(y_i)_{M\times 1}$. Then the target location can be estimated by matching Y with X.

3. DEPLOYMENT AND EVALUATION

We implement TafLoc on Atheros AR9331 NIC in an indoor room with a time scale of 3 months. We deploy 10 links covering 96 grids with each grid of 0.6m×0.6m (Fig. 2).

Fingerprint reconstruction error. Fig. 3 shows that the average RSS errors are 2.7 dBm, 3.3 dBm, 3.6 dBm and 4.1 dBm after 3 days, 15 days, 45 days and 3 months, respectively. Since the noise is usually within 1~4 dBm, the reconstructed fingerprint matrix can serve as reliable fingerprints for localization purposes.

Time cost to update the fingerprint. For each grid, 100 continuous RSS are collected one per second. The time cost to manually update the fingerprints in an area of size 6m×6m is at least $\frac{100\times(6/0.6)^2}{3600}\approx 2.78$ hours. While for TafLoc, only 10 reference locations with time of $\frac{100\times 10}{3600}\approx 0.28$ hours are needed. Fig. 4 shows when the area size becomes bigger, TafLoc saves more time compared to existing systems.

Comparison of localization accuracy. Fig. 5 shows that TafLoc performs best when compared with the-state-of-art RASS [3] and RTI [1] systems. The results of RASS with the reconstruction scheme show that the median accuracy is also significantly improved which means the proposed method can be efficiently applied on other localization systems.

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