A Model based Decimeter-scale Device-free Localization System Using COTS Wi-Fi Devices

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Abstract
Commodity Wi-Fi based device-free localization has attracted a great attention in recent years. Previous related work is either fingerprint-based or model-based. In this demo, we will demonstrate a generic Fresnel Penetration Model (FPM) based real-time device-free localization system called MFDL. Using only three to four commodity Wi-Fi devices, it can localize a metal plate reflector with 6cm median error in the open space and localize a moving person with 45cm median error in an outdoor space of 36m^2 and 50-75cm median error in indoor environments with a size ranging from 25m^2 to 72m^2, outperforming the state-of-the-art device-free localization approaches in similar settings.

Author Keywords
Fresnel zone model; Wi-Fi; Channel State Information (CSI); Localization.

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction
The localization of moving objects and human targets plays an important role in ubiquitous computing. Among the different technologies proposed, Wi-Fi based device-free localization has attracted a lot of attention in recent years.

Previous related works can be roughly classified into fingerprint-based and model-based. The fingerprint-based approaches [8] collect CSI measurement [1](or RSSI in earlier works [4]) at each location and build a sitemap of the whole environment. The model-based approaches [3][6] establish a geometric model to quantify the relationship between CSI measuremenst and the location of target. However, most model-based works require dense deployment of devices which is not cost effective in real life.

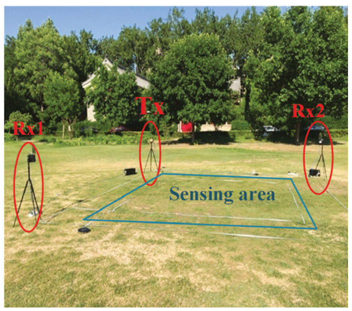

Figure 1: Environment setup

In this demo, we will demonstrate a Fresnel zone model based device-free localization system called MFDL. It is implemented based on our proposed Fresnel Penetration Model [2] which reveals the monotonous relationship between the Fresnel phase difference to its position in the Fresnel Zones of a pair of transceivers. Actually,the underlying Fresnel zone model [9] has been used in applications such as human respiration detection [5] and walking direction estimation [7]. Compared with previous work that relies either on fingerprint-based approaches or on dense deployment of transceivers, MFDL is a theoretical model based localization system that can achieve better localization accuracy ($45cm$ median error for a 36m^2 outdoor environment and 50-75cm median error in three indoor environments with sizes ranging from 25m^2 to 72m^2) with a few number of transceivers.

The core idea behind MFDL can be explained as 3 steps.

1) Knowing the monotonous relationship betweenthe Fresnel phase difference in multicarriers and the number of resided layer in Fresnel Zones as shown in Fig.2 ,we can map subject's location in one dimension in Fresnel Zones with one pair of transceivers.

2) By using two pairs of Wi-Fi transceivers, we can locate a moving subject by finding the intersection area of two Fresnel Zones as shown in Fig.3

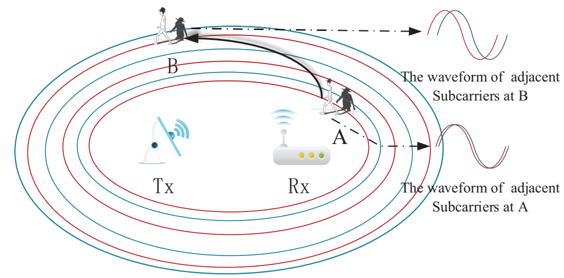

Figure 2: Conceptual illustration of the MFDL

Demonstration System

To achieve 2-D localization, we deploy two pairs of transceivers to cover the sensing area of 36m^2 as shown in Fig.1, with one Wi-Fi transmitter (Tx) and two receivers (Rx).

As shown in Fig.4, the interface of our system consists of three components: the real-time video captured by a camera as ground truth, the calculated localization output shown in a x-y coordiante system, and the cooresponding coordinates of the localization result.

The details of our demonstration process are explained as follows:

1) During the demonstration, a subject is requested to walk in the sensing area. After pre-processing of collected CSI data, MFDL will estimate the Fresnel phase difference across multiple subcarriers for each pair of transceivers, and then compute the precise layer number in the corresponding Fresnel Zones based on the Fresnel phase difference.

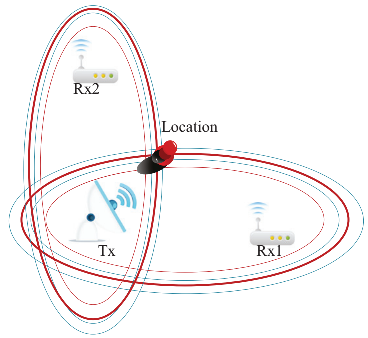

Figure 3: Locate the subject by finding the intersection area between two Fresnel Zones

2) Knowing the precise layer number of Fresnel Zones for each pair of transceivers, MFDL can calculate the intersection point of two Fresnel Zones to obtain the subject's location in the X-Y coordinate system.

3) Finally, the coordinates of the subject will be displayed with red dots in the user interface as shown in Fig.4.

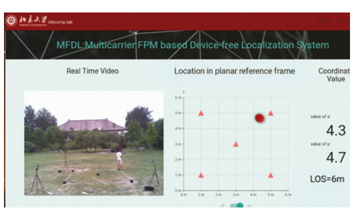

Figure 4: System Interface

Demonstration Setup

The demostration setup consists of one transmitter(Tx) and two receivers(Rx). Both receivers are mini-PCs equipped with an Intel Wi-Fi link 5300 NIC to collect Channel State Information(CSI) [1] as shown in Fig.1.

All the Wi-Fi transceivers are mounted on individual tripod with three antennas running on the 5.24GHz channel in an 802.11n Wi-Fi network. The two pairs of transceivers are placed perpendicular to each other and the length between each pair of transceivers (LOS) is set to 6 m to cover a 6m*6m sensing area.

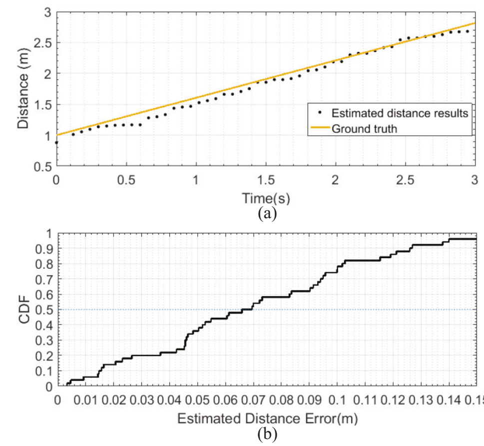

Figure 5: Localization errors with a perfect reflector in an open outspace

When a subject walks in the sensing area, a back-end server will collect the CSI datastream from the two Wi-Fi receivers and generate the localization result in real time.

Evaluation with a Perfect Reflector

We use a steel plate which is a perfect reflector for radio signals as the target object. The two transceivers are placed 4m apart. We move the steel plate along the perpendicular bisector of the transceivers from 1m to 4m in an outdoor open space. Fig.5 shows the experimental results. Fig.5.(a) compares the estimated distances based on our proposed Fresnel Penetration Model(FPM) with the ground truth, and the CDF of the estimated distance errors is depicted in Fig.5(b). As we can see the median localization error is as low as 6cm, demonstrating the great potential of FPM for fine-grained moving object localization.

Conclusion

In this demo, we have designed and implemented a real-time device-free localization system based on our proposed FPM model. Using only few Wi-Fi transceivers with simple offline calibration, our system can achieve decimeter-scale localization accuracy for a moving person in both indoor and outdoor environments, outperforming the state-of-the-art device-free localization approaches.

The demo video for the device free localization system MFDL can be found at http://wanghao13.top/wordpress/index.php/2017/07/21/mfdl/

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