Fine-grained RFID Localization via Ultra-wideband Emulation

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ABSTRACT

This demo presents RFind, a system that enables fine-grained RFID localization via ultra-wideband emulation. RFind operates by measuring the time-of-flight – i.e., the time it takes the signal to travel from an antenna to an RFID tag. To do so, it emulates an *ultra-wide bandwidth* on today's *narrowband RFIDs* without requiring any hardware modification to the tags. It then uses the large emulated bandwidth to estimate the time-of-flight and localize RFIDs. In contrast to past RFID localization proposals, RFind can operate in multipath-rich environments without reference tags and without requiring tag or antenna motion. The demo will allow users to move RFID-tagged objects to any location in line-of-sight, non-line-of-sight, and multi-path rich settings and check that the system can accurately localize the objects.

CCS CONCEPTS

• **Networks → Cyber-physical networks**; *Mobile networks*; *Sensor networks*;

KEYWORDS

RFID, Localization, Battery-free, UWB, Smart Environments

ACM Reference format:
Yunfei Ma, Nicholas Selby, Manish Singh, Fadel Adib. 2017. Fine-grained RFID Localization via Ultra-wideband Emulation . In *Proceedings of SIGCOMM Posters and Demos '17, Los Angeles, CA, USA, August 22–24, 2017,* 3 pages. DOI: 10.1145/3123878.3132006

1 INTRODUCTION

Accurate RFID localization can be a game-changer for many industries ranging from virtual reality to factory automation. For example, virtual reality systems, like the HTC Vive [9] and Facebook's Occulus Rift [17], rely on relatively large trackers like handheld motion controllers. Accurate RFID localization would enable us to replace these handheld trackers with on-body RFID stickers that can track multiple user limbs. Another application that can benefit from fine-grained RFID localization is packaging quality control in factories and warehouses. For example, today's packaging control ends once a box is sealed. However, since many of today's packaged items are already tagged with RFIDs, accurate RFID localization would enable employees to check the number of items in a box or whether the right item is in the right box even after the box is sealed. More generally, absolute RFID localization can enable many applications in retail stores, factories & warehouses, virtual & augmented reality, and smart environments.

SIGCOMM Posters and Demos '17, August 22–24, 2017, Los Angeles, CA, USA

ACM ISBN 978-1-4503-5057-0/17/08…$15.00
DOI: 10.1145/3123878.3132006

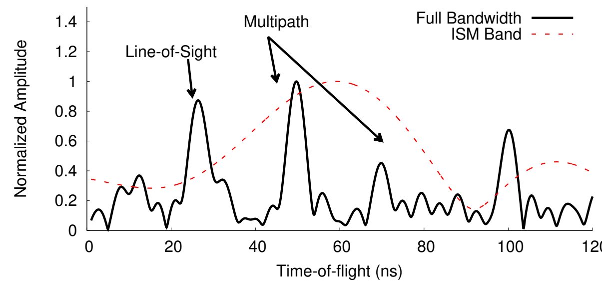

Figure 1—Delay profiles at different bandwidths. The delay profile computed with an emulated 220 MHz of bandwidth (in black) enables RFind to tease apart the different channel taps and identify the line-of-sight as the path that arrives earliest in time. In contrast, a delay profile computed only with the 26 MHz ISM band does not provide sufficient resolution in isolating the paths.

Indeed, the topic of RFID localization has gained much attention from the academic community over the past decade [10, 16, 18–20]. However, none of the past proposals can enable ubiquitous localization and deliver on the applications described above. In particular, early proposals relied on measuring the received signal strength (RSS) [5, 7, 14, 16, 21] and the angle of arrival (AoA) [4, 11, 22] and demonstrated a median accuracy of the order of tens of centimeters. Recent proposals have demonstrated finer centimeter-scale localization accuracy. However, these proposals either require furnishing the environment with a dense, surveyed grid of reference tags and localize by matching to reference tags [6, 19], or they require the tag to move on a predefined trajectory at a predefined speed [15, 20].

In this demo, we present RFind [13], a system that can achieve sub-centimeter RFID localization by directly measuring the time-of-flight (TOF), i.e, the time it takes the signal to travel between a antenna and an RFID. Accurate TOF measurements allow us to localize RFIDs without reference tags and without prior trajectory knowledge. RFind's localization works in line-of-sight, non-line-of-sight, and highly cluttered settings. As a result, it can operate in multipath-rich indoor environments. Moreover, RFind is fully compliant with today's standard UHF RFID protocol and the FCC regulations for consumer electronics.

2 RFIND OVERVIEW

RFind enables sub-centimeter localization of UHF (ultra-high frequency) RFIDs by directly measuring the TOF. The fundamental challenge in realizing this goal is that accurate TOF-based localization hinges on the ability to measure time at a very fine granularity. In particular, achieving centimeter-scale localization would require hardware that can support very high sampling rate or very large bandwidth, often multiple GHz of bandwidth [2, 8, 12].[1] In contrast,

[1] Time resolution is inversely proportional to the bandwidth.

Figure 2—An RFID-tagged object. We attach a battery-less RFID sticker to an object in order to localize it.

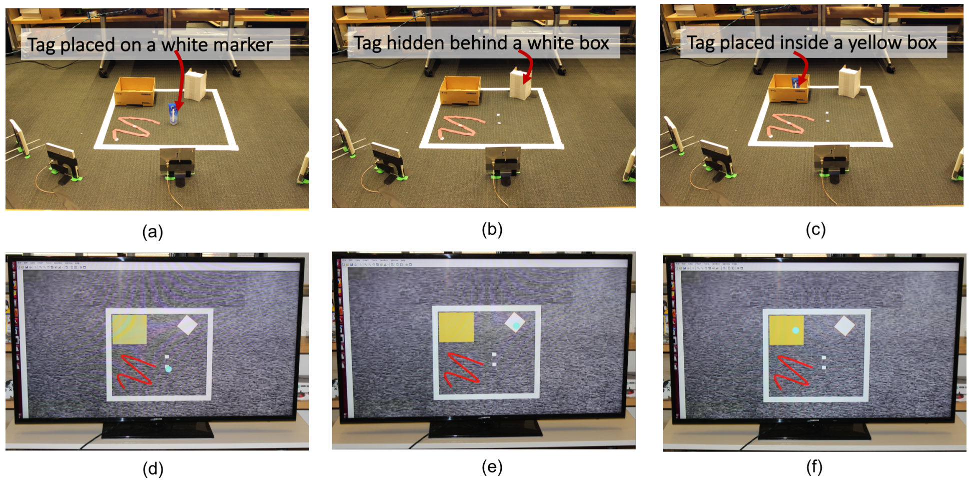

Figure 3—RFind's demo setup in a multipath-rich environment. (a)-(c) show the RFID-tagged object placed in different locations within the demo area. (d)-(f) show the output of RFind, which displays the location of the RFID-tagged object as a cyan dot on the screen. The markers on the ground are placed only to show the level of accuracy and not used as aids for localization. RFind is accurate even in non-line-of-sight settings, e.g., in (b) where the RFID occluded from RFind's antennas.

RFIDs communicate at only tens of kHz, i.e., five orders of magnitude lower than such systems. Hence, TOF-based localization with such a communication bandwidth would result in an accuracy of multiple kilometers.

To overcome this challenge, RFind leverages the underlying physical properties of today's UHF RFIDs to emulate a very large bandwidth on tags designed with a communication bandwidth of only tens to hundreds of kHz, while remaining compliant with FCC regulations. At a high level, RFind's localization algorithm operates in three stages:

(1) **Emulating a large bandwidth on RFIDs:** The first stage consists of a technique that enables RFind to emulate a large bandwidth on off-the-shelf RFIDs. To do so, RFind transmits two frequencies simultaneously: one frequency (f_p) inside the ISM band to power up the tag and communicate, and another low-power frequency (f_s) for sensing the channel. By varying f_s over a large bandwidth across time, RFind can estimate the channel at each of these frequencies. Moreover, because of the low power of the signal transmitted at f_s, RFind can use a much larger bandwidth than the ISM band while remaining compliant to FCC regulations. By stitching the channel estimates at the various frequencies f_s obtained from an RFID over time, RFind can realize a large virtual bandwidth.

(2) **Leveraging the large bandwidth to eliminate multipath and compute the Time-of-Flight (TOF):** In the second stage, RFind uses the large virtual bandwidth to compute the time-of-flight. In particular, by performing an inverse fourier transform on the channel estimates in the frequency domain, RFind can obtain the channel estimates in the time domain. This provides it with the power of the signal arriving along all the paths between the RFID tag and an RFind antenna as shown in Fig. 1. Since the direct path arrives earlier in time than all indirect paths (which bounce off reflectors in the environment),[2] RFind selects the time of arrival of the first path as the time-of-flight. This allows it to eliminate all multipath reflections. It then zooms in on the line-of-sight path through a super-resolution algorithm.

(3) **Localization from TOF measurements:** Finally, RFind uses TOF measurements from multiple antennas in order to localize a tag. Specifically, it maps the time-of-flight to distance by taking into account the propagation speed of RF signals. To perform 1D localization, RFind leverages one receive antenna. To enable 2D localization, it employs two antennas respectively and performs trilateration.

[2]The direct path arrives earliest since it travels the shortest distance.

3 DEMO SETUP & REQUIREMENTS

We implement RFind using USRP software radios [1] and off-the-shelf Alien Squiggle RFID tags [3]. These tags are batteryless and cost about 5-10 cents each. In our demo, we affix the tag to an object of interest, as shown in Fig. 2 and use RFind to localize it.

The demo setup is shown in Fig. 3(a)-(c), where the RFID-tagged object is placed at various locations. The demo is set up in a multipath-rich indoor environment. To demonstrate the accuracy of RFind's localization, we lay out several markers on the ground, including some red tape and two boxes to help with the visualization. RFind outputs the location of the RFID-tagged object as a cyan dot on a screen as shown in Fig. 3(d)-(f). The USRPs are connected to one transmitting antenna and three receiving antennas. We integrated RFind's algorithms directly into the UHD driver of the USRPs. Backend processing of the incoming packets is performed on a laptop to which the USRPs are connected.

The demo will enable SIGCOMM attendees to place RFID-tagged objects in different locations (in both line-of-sight and non-line-of-sight settings) and check that RFind can accurately localize them on its output screen.

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