Demo Abstract: SnapLoc: An Ultra-Fast UWB-Based Indoor Localization System for an Unlimited Number of Tags

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ABSTRACT

In this demo, we present SnapLoc, a UWB-based indoor localization system that allows decimeter-accurate self-localization of mobile tags by listening to only a single message. To this end, SnapLoc leverages (quasi-)simultaneous responses of multiple anchors. Based on these responses, the tag derives the time difference of arrival between anchors and unambiguously estimates its position. Thanks to this principle, SnapLoc carries out passive localization and supports an unlimited number of tags at high update rates. Our SnapLoc implementation runs on the off-the-shelf Decawave DW1000 UWB transceiver. The latter suffers from a limited transmit timestamp resolution that affects the achievable localization accuracy when used in conjunction with concurrent anchor responses. Therefore, in this demo we also showcase techniques to overcome these limitations and achieve nevertheless a high localization accuracy.

CCS CONCEPTS

• **Computer systems organization** → *Embedded and cyber-physical systems*; • **Networks** → Location based services;

KEYWORDS

Localization, ultra-wideband, TDOA, channel impulse response

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1 INTRODUCTION

Ultra-wideband (UWB) technology offers a high time-domain resolution, which makes it well suitable for future location-aware Internet of Things applications, especially in GPS-denied environments such as indoors. The commercialization of the first IEEE 802.15.4-compliant UWB transceiver, the Decawave DW1000, enabled UWB-based localization also for low-cost and mobile applications.

However, most existing UWB-based localization systems aim to achieve a high localization accuracy, while neglecting *multi-tag support* with *high update rates* [5]. As a result, current systems typically support only a few tags and do not scale regarding *tag density*, due to (i) the large number of messages exchanged, and (ii) the use of scheduling techniques for collision avoidance.

SnapLoc [4] aims to solve these issues by enabling localization of an unlimited number of tags at high update rates. To this end, the tags do not actively transmit messages. Instead, anchors answer to an `INIT` message with (quasi-)simultaneous responses that are separated in time by just a few nanoseconds. The high bandwidth and hence short pulses of UWB transceivers allow to extract these (quasi-)simultaneous anchor responses at the tag. Thus, within a single read operation, the tag is able to derive the anchor responses required to estimate its position unambiguously. The position-related information contained in the anchor responses is derived from the channel impulse response (CIR), which is estimated by the Decawave DW1000 upon reception of a packet. Previous work used the CIR for multipath-assisted localization [3] and for gaining information about the surrounding environmental conditions [2]. In SnapLoc, instead, the CIR is used to derive the time difference of arrival (TDOA) between the anchors.

In this demo, we present the functionality and capabilities of SnapLoc. We implement it on low-cost hardware based on the Decawave DW1000 transceiver. The latter limits the timestamp resolution of the (quasi-)simultaneous responses to 8 ns, which effectively reduces the location accuracy of SnapLoc to several meters. We will hence present techniques to overcome this limitation and show their effectiveness. Thanks to these techniques even with low-cost UWB transceivers, SnapLoc achieves a 90% error below 34 cm. We present next the principle of the proposed localization system (Sect. 2) and a detailed description of the demo setup (Sect. 3).

2 PRINCIPLE

As shown in Fig. 1, we differentiate between reference anchor (A_{REF}), anchor ($A_{1 \cdots N}$), and tag (T). The latter is located at an unknown position $p \in \mathbb{R}^2$ and estimates its position by following the procedure described next. The N anchors as well as the reference anchor are located at a static and known position $a_i \in \mathbb{R}^3$.

Initiating a position update. A position update is initiated by the reference anchor A_{REF} by broadcasting an `INIT` message. Thus, A_{REF} also determines the position update rate of the tags.

Simultaneous responses of anchors. The reception of the `INIT` message triggers the anchors to respond with the `RESP` message after a defined delay $\Delta_R + \delta_i$ (with $i = 1, \ldots, N$), where Δ_R is a common delay shared between all nodes and δ_i is unique to each anchor A_i. The individual delay δ_i ensures that the anchor responses are not overlapping in the CIR as shown in Fig. 2 [1].

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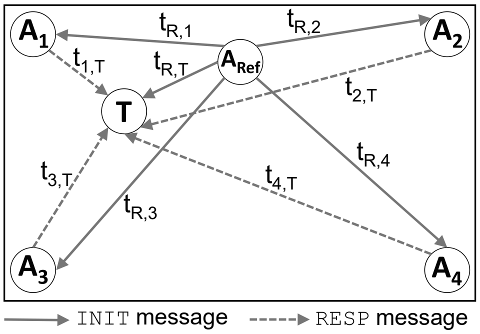

Figure 1: In SnapLoc, a reference anchor A_{REF} broadcasts an INIT message, to which all surrounding anchors reply (quasi-)simultaneously with a RESP message.

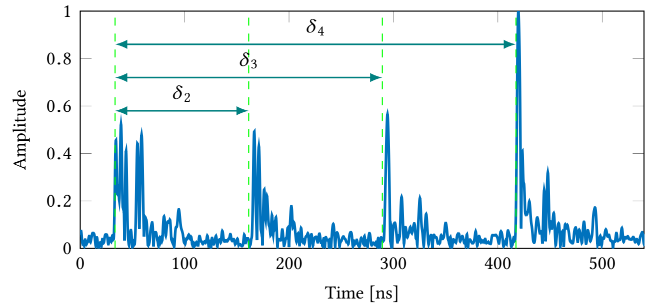

Figure 2: Introducing an additional individual delay δ_i for each responder A_i allows to identify responses and discern them from strong multipath components.

Deriving the anchors' responses using the CIR. The tags are able to derive the anchor responses by receiving only a single packet thanks to the high bandwidth of UWB transceivers and the individual delay δ_i in the nanosecond range. Fig. 2 shows a CIR read from a tag when four anchors equally far away from the tag are responding. The CIR is split up into four distinct slots, separated with δ_i. The first pulse in each slot corresponds to the first path component of an anchor. Notably, in the first slot two equally strong peaks are present, where the second pulse is a multipath component (MPC) originating from a reflecting material. Thus, δ_i must be set such that MPCs do not overlap with following anchor responses [1].

TDOA-based position estimation. The distances of the anchor responses $\Delta\tau_{i,j}$ contained in the CIR follows as

$$\Delta\tau_{i,j} = (\delta_j - \delta_i) + (t_{R,j} + t_{j,T}) - (t_{R,i} + t_{i,T}). \quad (1)$$

Thus, the CIR encodes position-related information of the tag, namely the TDOA $\Delta t_{i,j}$ between the anchors A_i and A_j $(i \neq j)$:

$$\Delta t_{i,j} = t_{j,T} - t_{i,T} = \Delta\tau_{i,j} - (\delta_j - \delta_i) - t_{R,j} + t_{R,i}. \quad (2)$$

Based on $\Delta t_{i,j}$, we build a set of non-linear equations that are then iteratively solved to estimate the position of the tags [4].

Limited transmit timestamp resolution. While the DW1000 can measure the reception timestamp with pico-seconds resolution, it can only set the transmission (TX) timestamp in 8 ns steps. Specifically, the transceiver ignores the last 9 bits of the TX timestamp. As a result, the peaks in the channel impulse response are shifted by a uniformly distributed offset $e_{tx,i}$ between 0 and 8 ns. This causes an error $e_{\Delta\tau}$ in the time difference of arrival:

$$\Delta t'_{i,j} = \Delta t_{i,j} + \underbrace{(e_{tx,i} - e_{tx,j})}_{e_{\Delta\tau}}. \quad (3)$$

where $e_{tx,j}$ and $e_{tx,i}$ are the transmission uncertainties of anchor A_j and A_i, respectively. The limited timestamp resolution and hence the error $e_{\Delta\tau}$ result in localization inaccuracies in the range of meters (an error of 8 ns translates to a positioning error of almost 3 meters). To overcome this limitation of off-the-shelf UWB transceivers, we developed several methods to correct these errors and enable SnapLoc to achieve a high localization accuracy. First, in the optimal correction we record the lost 9 bits in the transmission timestamp of each anchor. Second, in the estimated correction the reference anchor estimates the transmission uncertainty $e_{\Delta\tau}$ as the difference of the TDOA derived from the anchor responses in the channel impulse response and the expected time difference of arrival. The latter is known at the reference anchor due to the static position of the anchors and the reference node.

3 SETUP AND DEMO

We demonstrate the functionality of SnapLoc using our self-designed Decawave DW1000 evaluation boards [4] and a laptop. The latter is used to calculate and visualize the estimated position of the tag, as well as to display the received channel impulse response.

The CIR is augmented with relevant data to aid the understanding of the inner working principle, such as: detected beginning of each first path component, TDOA of each anchor pair, and the transmission uncertainties. Furthermore, we show the effectiveness of our methods to correct the limited timestamp resolution by plotting the estimated position with and without correction in real-time. While the audience is able to move the tag around freely, we mark several points on the floor and highlight them in the position plot to quantify the accuracy and precision of the localization system.

The anchors and reference node are battery-powered and communicate their transmission uncertainties via Bluetooth Low Energy (BLE) to the laptop, in order to demonstrate the optimal correction method. The positions of the anchors are known beforehand, while the tag node can be moved around on a tripod and communicates the recorded CIR of the RESP messages via BLE to the laptop. This enables the visualization of the channel impulse response at the laptop to describe the principle of SnapLoc in more detail.

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