Bringing UWB Indoor Localization Closer to being Universal and Pervasive

Haige Chen
hchen425@gatech.edu
Georgia Institute of Technology
Atlanta, GA, USA

Zixin Yin
zyin81@gatech.edu
Georgia Institute of Technology
Atlanta, GA, USA

Ashutosh Dhekne
dhekne@gatech.edu
Georgia Institute of Technology
Atlanta, GA, USA

ABSTRACT

Location-based services have the potentials to change how we interact with the places and things around us. UWB indoor localization is one of the most successful enabling technologies that has achieved decimeter accuracy with robustness against complex indoor multipath environments. In this work, we demonstrate a system that not only achieves high localization accuracy, but also supports infinite scalability, full user privacy, and plug-and-play infrastructure deployment, which brings localization closer to a universal and pervasive technology.

KEYWORDS

indoor localization, UWB, TDoA, anchor deployment

ACM Reference Format:

Haige Chen, Zixin Yin, and Ashutosh Dhekne. 2022. Bringing UWB Indoor Localization Closer to being Universal and Pervasive. In *Proceedings of the 2022 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp/ISWC '22 Adjunct), September 11–15, 2022, Cambridge, United Kingdom.* ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3544793.3560327

1 INTRODUCTION

Location-based services on mobile and wearable devices are transforming our daily interactions with the surroundings. Whether we are on the street, at public spaces such as museums and shopping malls, or inside our homes, knowledge of current location would allow us to navigate, locate items, interact with surrounding appliances and devices, and receive location-specific information. Whereas GPS is pervasive outdoors, in indoor settings, GPS is often unavailable or erroneous due to satellite signals being obstructed by building materials. Among many of the more recent indoor localization systems based on WiFi, BLE, ultra-sound, mmWave, etc., the ultra-wideband (UWB) technology has the advantage of cm-level localization accuracy and robustness against multipath with non-line-of-sight signal coverage.

However, there are still several gaps in bringing universal UWB localization to any public places: scalability and user privacy in large deployments. The IEEE standard Two-way ranging (TWR) protocol [3] requires any tracked device to actively transmit, which limits the number of users the infrastructure can support and exposes the users' location to the infrastructure, hindering user-privacy. In our system *PnPLoc* [1], we propose a novel Time-Difference-of-Arrival (TDoA) ranging protocol that allows any passive-listening user devices to self-localize by just overhearing infrastructure devices (also known as anchors). The anchors' communication protocol is designed such that the anchor network can be formed ad-hoc and expanded in a plug-and-play fashion. Furthermore, we recognize the dilution of precision (DoP) problem where localization precision is influenced by anchors' geometry. *PnPLoc* improves localization accuracy by selecting the set of anchors for localization.

UbiComp/ISWC '22 Adjunct, September 11–15, 2022, Cambridge, United Kingdom

ACM ISBN 978-1-4503-9423-9/22/09.
https://doi.org/10.1145/3544793.3560327

2 DESIGN

Passive-tag TDoA: To enable a localization solution that can scale to unlimited number of users and preserve users' privacy, the user devices (also known as tags) should not transmit any messages. In other words, the tags need to be passive. Among the class of existing passive-tag localization protocols, nano-second level synchronization or coordination among anchor devices is usually required, which constrains the deployment size. Therefore, we design a novel TDoA protocol, where anchors perform TWR and the tags can self-localize by overhearing the anchor TWR messages. The detail of our TDoA ranging protocol were first described in [1], and are not repeated here for brevity.

Plug-and-Play anchors: The scalability of a localization system also manifest in the deployment effort. The UWB infrastructure needs to accommodate both, small deployment such as a compact apartment, and large deployment such as a shopping mall complex. Therefore, it's important that the anchors can be simply plugged into wall power outlets and self-organize into a network, and that more anchors can be easily added to expand coverage. We take advantage of pipelined TWR communication between anchors[2] (shown in Figure 1b). For each round of TDoA ranging, one initiating anchor transmits a TDMA schedule for the neighboring anchors to follow. This TDMA schedule reserves one or two extra slots for any newly added anchors to contend for. Once the newly added anchors has been discovered by existing nodes as neighbors, the TDMA schedule will be updated to include the new anchors. Therefore, anchors can be deployed dynamically and added at any time by simply plugging them in at the desired location.

Anchor Selection: If the distance measurements have no errors, then solving for the intersection of circles or hyperbolas would provide the client's exact location. However, all practical distance measurements will have errors. This causes a naive solver to fail, since in the general case, the erroneous circles or hyperbolas do not intersect at a single point. A maximum likelihood solver (or its variants) is therefore typically used for localization. It is important to note that the final localization error is not just dependent on the distance measurement error, but also on the *geometry of the anchors*. This phenomenon is called *dilution of precision* (DoP). Thus, all

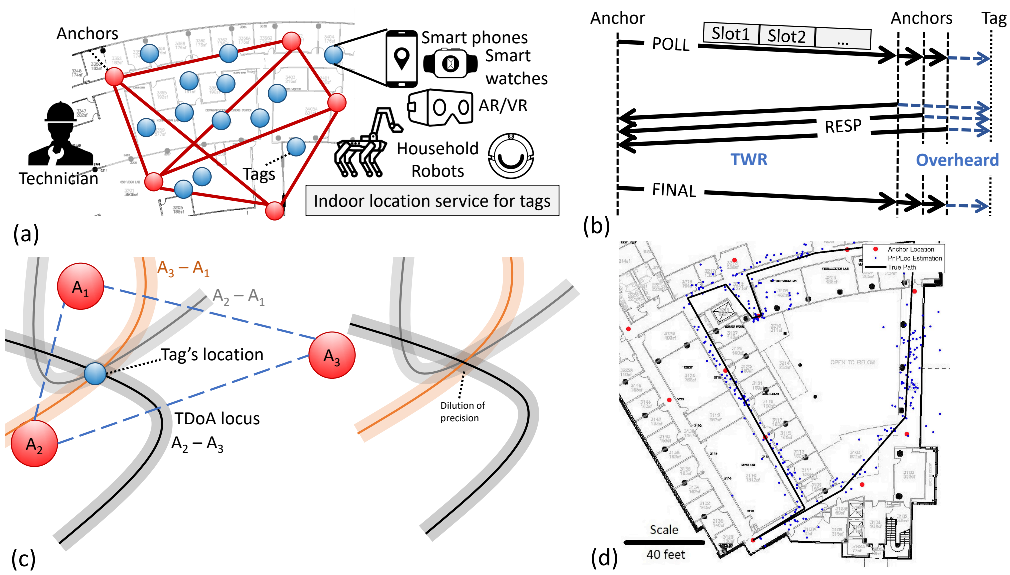

Figure 1: (a) PnPLoc enables plug-and-play, scalable and privacy-preserving indoor localization for many applications. (b) Pipelined TWR messaging between anchors follows a TDMA schedule that allows new anchors to join. The tag can localize itself by overhearing the TWR messages. (c) Example of solving for the tag location based on TDoA from various anchors, and the effect of dilution of precision which creates a region of confusion. (d) Visualization of localization result from tracking a pedestrian in a 2241 m^2 building.

locations do not have a uniform localization error. Further, intersections of circles and hyperbolas have different characteristics which lead to different extents of localization errors. Figure 1c shows an illustration of how ranging errors lead to erroneous localization (overlapping shaded area). Therefore, in *PnPLoc* tags choose the set of anchors and filter localization results based on the geometric dilution-of-precision (GDoP) metric [4].

Now consider a practical scenario. A building manager can simply place a UWB anchor, power it on, and place the next... The anchors' plug-and-play functionality allow them to discover neighboring nodes and start TWR messaging. The building manager can label these anchor locations on the building floorplan. When the visitors are inside the building, their UWB tags start to overhear the TWR messages from the anchors and localize themselves using the TDoA measurements. As the visitor moves around, the UWB tag can potentially overhear TWR messages from many anchors at the same time. The anchor selection algorithm tries to find the optimal subset of overheard anchors to compute its current location. Note that the UWB tag on the user's device never transmits, and will never expose the user's presence and location to the infrastructure, therefore protecting the user's privacy.

3 DEMONSTRATION

In the demonstration, we would like to show how PnPLoc anchors can be deployed in any indoor space. Several UWB anchors will be placed at the conference venue (see Figure 2a as an example). We will show the system is scalable to infinite number of users by keeping 10-15 UWB tags on constantly. There will also be multiple mobile phones equipped with UWB tags (see Figure 2c) performing localization and displaying the real-time location on a mobile APP that we developed. The audience can walk around with our user devices to visualize their current locations. Figure 1d shows the example setup and localization results in a 2241 m^2 area [1]. To visualize the effect of anchor selection, the mobile app has the option of turning anchor selection on and off. The audience will observe improved localization precision when anchor selection is enabled.

ACKNOWLEDGMENTS

This material is based upon work supported by the NSF under Grant No. 2145278, and by Cisco #148640_26.

REFERENCES

[1] Haige Chen and Ashutosh Dhekne. 2022. PnPLoc: UWB Based Plug & Play Indoor Localization. *2022 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*.

[2] Ashutosh Dhekne, Ayon Chakraborty, Karthikeyan Sundaresan, and Sampath Rangarajan. 2019. TrackIO: Tracking First Responders inside-Out. In *NSDI'19* (Boston, MA, USA). USENIX Association, 751–764.

[3] IEEE802.15.4z. 2020. IEEE Standard for Low-Rate Wireless Networks–Amendment 1: Enhanced Ultra Wideband (UWB) Physical Layers (PHYs) and Associated Ranging Techniques. *IEEE Std 802.15.4z-2020 (Amendment to IEEE Std 802.15.4-2020)* (2020), 1–174. https://doi.org/10.1109/IEEESTD.2020.9179124

[4] Omotayo Oshiga, Xiaowen Chu, Yiu-Wing Leung, and Joseph Ng. 2018. Anchor Selection for Localization in Large Indoor Venues. In *2018 IEEE/ACM 26th International Symposium on Quality of Service (IWQoS)*. 1–6. https://doi.org/10.1109/IWQoS.2018.8624131

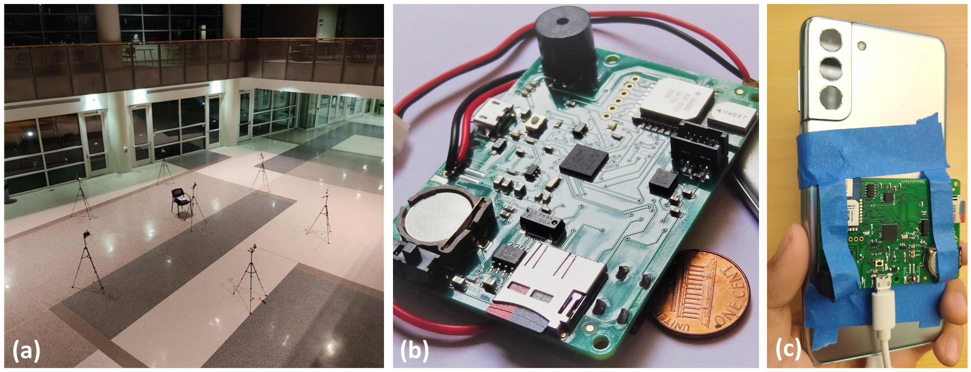

Figure 2: Example implementation of *PnPLoc*: (a) UWB anchors mounted on tripods deployed in a building atrium; (b) UWB device used in demonstration; (c) User device with UWB tag attached to a mobile phone.