Demo: Eavesdropping on PolyPoint – Scaling High-Precision UWB Indoor Localization

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Abstract

Recently, we introduced PolyPoint, a high-fidelity RF-based indoor localization system that achieves 28 cm accuracy indoors and tracks a fast-moving quadcopter with only 56 cm average error. PolyPoint uses ultra-wideband signals to achieve high precision RF time-of-flight estimates between nodes. To further improve accuracy, PolyPoint exploits two forms of diversity: frequency diversity, which leverages several ultra-wideband channels to improve channel response, and antenna diversity, which adds three antennas at 120° offsets to mitigate the effects of antenna polarization and nulls. To efficiently capture this diversity, PolyPoint introduces an efficient, novel ranging protocol that maximizes these diversity sources with a minimal number of packets. Unfortunately, this protocol can only locate one tag concurrently. In this demo, we explore whether passive, eavesdropping tags can also glean location information, albeit at lower fidelity.

Additionally, we demo our hardware platform that provides ranging and localization as a drop-in module. The minimal *TriPoint* integrates an ultra-wideband transceiver and microcontroller with firmware that implements the PolyPoint protocol. The *TriTag* carrier board adds Bluetooth and batteries to create a complete mobile tag, and the *TriBase* anchor platform integrates a TriPoint with an Intel Edison to act as anchors for the system.

Categories and Subject Descriptors

B.0 [**Hardware**]: General; C.3 [**Special-Purpose and Application-Based Systems**]: Real-time and embedded systems

General Terms

Design, Experimentation, Measurement, Performance

Keywords

Indoor Localization, Ultra-Wideband Communications

1 Introduction

Global Navigation Satellite Systems (GNSS) have long been the universal gold standard for the accurate navigation of outdoor spaces. Certain systems have enabled position determination accuracy better than 10 cm. Unfortunately, these RF systems break down in indoor environments due to extreme attenuation and heavy multipath, necessitating the use of local navigation aids.

To address this, we recently introduced PolyPoint [3], a new localization system that couples the DecaWave ScenSor transceiver [1] with antenna diversity and a new, efficient ranging protocol. Utilizing antenna diversity, PolyPoint shows an order of magnitude improvement in accuracy over the use of just one antenna at each node. Furthermore, PolyPoint's ranging protocol supports the aggregation of many different range estimates across different antenna and RF channel combinations while still maintaining an update rate at tens of Hz. Subsequent protocol changes improved robustness by spreading critical messages across multiple channels and added support for localizing multiple tags in a single space at the expense of update rate [2]. In this demonstration we explore the viability of recovering some of the update rate losses by eavesdropping on other transmissions during time slots when a tag is not the active transmitter. In addition, we take demonstrate our new, improved hardware platform that significantly improves the size, weight, and extensibility that can act as a drop-in localization module.

2 PolyPoint Overview

PolyPoint is a localization system that uses one-way time-of-flight measurements to derive range estimates between a mobile tag and fixed-location infrastructure (anchors) to determine a tag's position. By collecting range estimates between the tag and three or more anchors, the system is able to calculate the tag's 3D position using trilateration. The mobile tag is affixed to the object to track, and position estimates are calculated in real-time.

2.1 Precision Time-of-Flight Ranging

To derive a high-precision time-of-flight range estimate between a tag and anchor, two unsynchronized nodes, requires *three* packets. The tag sends a POLL and the anchor replies with a RESP that includes turnaround time to determine the total round trip time between tag and anchor. To compensate for crystal offsets between tag and anchor, the tag sends a REF packet at a known time offset from the POLL.

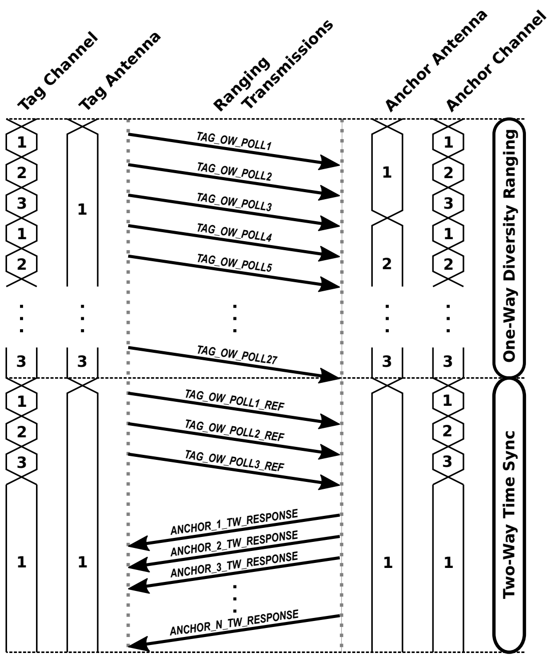

Figure 1: Ranging protocol. PolyPoint is able to leverage antenna diversity without significantly impacting position update rate. The protocol starts with a series of 27 broadcast transmissions from the tag for each combination of tag antenna, anchor antenna, and RF channel. The time-of-arrival data collected from this sequence provides information on the difference between all range estimates throughout the sequence. Finally, a two-way time-of-flight handshake is sent (on each channel for robustness) to determine the true range estimate—a total of 30 POLL messages. The offset between the first and last poll message on each channel is used to calculate the crystal frequency offset between the tag and anchor. From the first measurement, the time offset between the tag and anchor is known, leading to estimates of range for the other 26 combinations from the initial difference-based measurements.

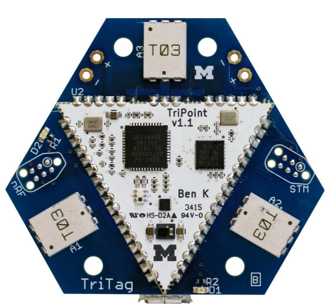

Figure 2: TriTag with onboard TriPoint module. The center triangle PCB is our new drop-on TriPoint module that integrates a UWB transceiver and microcontroller to implement the PolyPoint ranging protocol. The pictured carrier board is the TriTag, the tag to be localized, which adds batteries and Bluetooth communication with a mobile phone. The same TriPoint modules power our TriBases, an anchor solution built around the Intel Edison platform.

Comparing the sent and received timestamps for REF and POLL yield a crystal correction K. A precision range event is thus:

$$① \text{ Tag} \xrightarrow{Ref} \text{Anc} \quad ② \text{ Tag} \xrightarrow{Poll} \text{Anc} \quad ③ \text{ Anc} \xrightarrow{Resp} \text{Tag}$$

$$K = \frac{\text{Tag}_{TX\_Poll} - \text{Tag}_{TX\_Ref}}{\text{Anc}_{RX\_Poll} - \text{Anc}_{RX\_Ref}}$$

$$ToF = [(\text{Tag}_{RX\_Resp} - \text{Tag}_{TX\_Poll}) - K * (\text{Anc}_{TX\_Resp} - \text{Anc}_{RX\_Poll})]/2$$

2.2 Eavesdropping on the PolyPoint Protocol

Figure 1 shows how the PolyPoint protocol efficiently captures information from multiple antennas, channels, and anchors. While an eavesdropping tag does not have enough information to perform trilateration, if the active tag broadcasts its local time offset calculations and solved position, an eavesdropping tag can use multilateration to obtain a position estimate. The fidelity of this estimate is limited by the diversity obtained from the post-localization messages sent by the tag, which opens a new tradeoff space that this work begins to explore.

3 TriPoint Localization Module

As the ranging protocol requires precise timing operations and reasonably complex radio operations, we design the *TriPoint* drop-on module which provides ranging or location as a service. TriPoint integrates the DecaWave DW1000 ScenSor UWB transceiver for ranging, a SKY13317-373LF RF switch for antenna diversity, a STM32F031G6 Cortex M0 microcontroller for protocol operation and location reporting, and on-board power regulation. Figure 2 shows the *TriTag*, a carrier board for TriPoint that adds a nRF51822 for Bluetooth communication with a mobile phone and batteries for mobile operation. The final piece of hardware is the *TriBase*, a carrier board built around the Intel Edison platform that is used as anchors for PolyPoint.

4 Demonstration

The demonstration will affix TriTags to mobile phones that report the exact location of the phone. We will also deploy a number of TriBases around the environment to act as anchors for the localization system. Users will be able to walk around the demonstration space and observe the performance of the system. We will include a handful of labeled, measured points to give users an intuition for the system accuracy. We expect to achieve sub-meter accuracy throughout the entire demonstration space. Additionally, locations will be reported to a central server that will show traces of users walking around the space on a monitor at the demonstration table.

5 References

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