PolyPoint: High-Precision Indoor Localization with UWB

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***Abstract*—**
We demonstrate 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. PolyPoint introduces an efficient, novel ranging protocol that maximizes these diversity sources with a minimal number of packets.

Additionally, this work showcases a new hardware platform that provides ranging and localization as a service. The minimal *TriPoint* module 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.

I. 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 [4], a new localization system that couples the DecaWave ScenSor transceiver [2] 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. This demonstration builds on our original PolyPoint work. We modify the original protocol to improve robustness by spreading critical messages across multiple channels, add support for localizing multiple tags in a single space, remove the reliance on cloud-supported computation, and introduce a new, improved hardware platform that significantly improves the size, weight, and extensibility that can act as a drop-in localization module.

II. 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.

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

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

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

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

B. Diversity and the PolyPoint Protocol

Ultra-wideband transceivers such as ScenSor still require the line-of-sight path to be unobstructed to produce accurate time-of-arrival measurements. In real-world scenarios, however, there are a variety of factors that can cause the line-of-sight path to be obstructed. While sufficient node density and careful placement can help avoid obstructions, differences in polarization between nodes can lead to significant attenuation of the line-of-sight path without the presence of any interfering objects. For this reason, we introduce multiple antennas at each node to mitigate the effects of polarization mismatch on ranging (and subsequently localization) error.

In a ranging event with the minimum 3 anchors and 3 antennas on each node, a naïve protocol requires $27 \times 3 \times 3 = 243$ packets. To reduce the total number of message exchanges, PolyPoint tags transmit a broadcast for each of the 27 different configurations. The difference in range estimates can be calculated at each anchor by observing the time differences between successive message receptions. A final two-way time-of-flight exchange is then performed between the tag and each anchor to account for any error in range due to clock

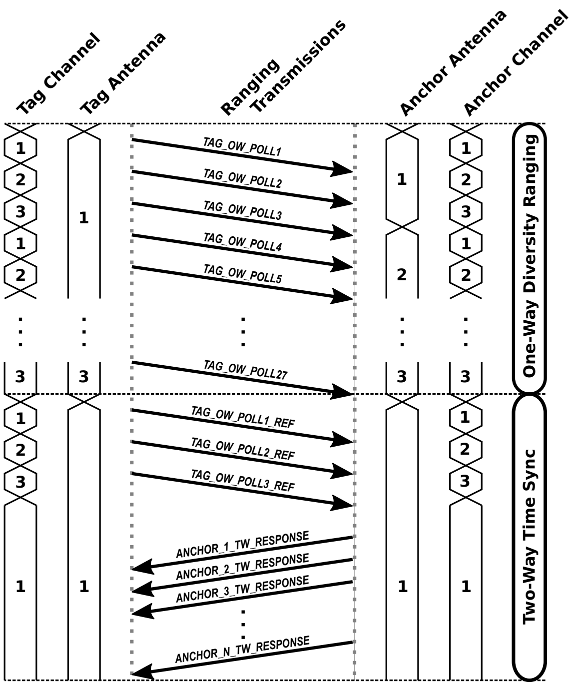

Fig. 1: Ranging protocol. PolyPoint is able to leverage antenna diversity without significantly impacting position update rate. The protocol starts with a series of 27 broadcast transmissions from the tag for each combination of tag antenna, anchor antenna, and RF channel. The time-of-arrival data collected 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.

offset. Figure 1 shows the modified two-way time-of-flight protocol used to quickly gather each of the 27 successive range estimates. For this revised protocol, 3 anchors require only $27 + 3 + 3 = 33$ packets.

III. 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.

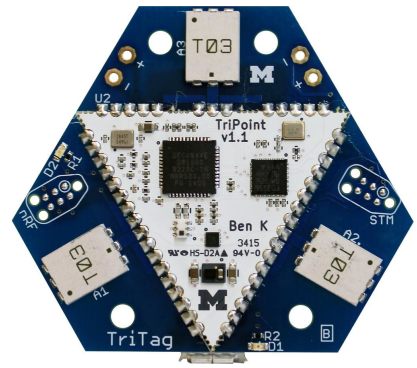

Fig. 2: TriTag with onboard TriPoint module. The center triangle PCB is our new drop-on TriPoint module that integrates a UWB transceiver and microcontroller to implement the PolyPoint ranging protocol. The pictured carrier board is the TriTag, the tag to be localized, which adds batteries and Bluetooth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

IV. 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 expect to achieve sub-meter accuracy throughout the entire demonstration space.

This work is part of a continuing project that competed and placed 3rd in the infrastructure category in the 2015 Microsoft Indoor Localization Competition [1], showcased revised performance, accuracy, and approach at HotWireless'15 [4], and demonstrated further improved reliability at usability at SenSys'15 [3].

V. Acknowledgments

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