Indoor Localization System with Asynchronous Acoustic Beacon

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ABSTRACT

We demonstrate an acoustic indoor localization system that requires little configuration and can localize commercial off-the-shelf target devices with a microphone. Our acoustic Time-Difference-of-Arrival (TDoA)-based ranging algorithm does not require clock synchronization among infrastructure nodes (called anchors) and utilizes passive target devices. For target devices to request acoustic beacons from surrounding anchors, Bluetooth Low Energy (BLE) communication is used. With at least 4 anchors deployed, we are able to determine 3D target location. A previous proof-of-concept system using Android mobile phones as both anchors and target devices shows the 95% quantile localization errors achieved are consistently less than 7.5cm when the closest two anchors are 1 meter apart.

Keywords

indoor localization, acoustic signal, asynchronous, beacon, inaudible, time difference of arrival (TDoA)

1. INTRODUCTION

In this work, we target indoor localization using fixed acoustic anchor nodes that transmit acoustic signals in the human inaudible range but decodable by smart phone devices. Time-difference-of-arrival (TDoA) is utilized to determine the pseudo-ranges from anchor nodes to target devices and to infer locations of the latter. One main challenge in such system is the need for tight clock synchronization among the anchor nodes. To address this challenge without requiring acoustic transmission of target devices, we develop a TDoA estimation algorithm that utilizes asynchronous acoustic beacons described in Section 3. Acoustically passive target devices use Bluetooth Low Energy (BLE) communication with nearby anchor nodes to activate the acoustic beacon transmission. They listen to beacons emitted from anchor nodes and transmit the timestamps of the decoded received acoustic beacons to a location server via WiFi. The location server communicates with anchor nodes to compute the locations of the target devices.

The proposed solution has been evaluated using a small-scale testbed consisting of 4 mobile phones as anchor nodes and three different models of mobile phones as target devices at various locations. When the closest two anchor nodes are 1 meter apart, the 95% quantile localization errors is less than 7.5cm [1].

The rest of the extended abstract first introduces the system overview. Then the TDoA estimation algorithm is described. Finally we present the deployment requirements.

2. SYSTEM OVERVIEW

There are three types of devices in the system as showed in Figure 1 - anchor nodes, target mobile devices, and a location server. Each anchor is composed of a Raspberry Pi 3 Model B and our own acoustic board with ASE06008MR-LW150-R speaker and INMP411 microphone. Once being requested by a target device via BLE, the anchor transmit acoustic beacons modulated by linear chirp signals in human inaudible frequency range. The anchor itself and nearby anchors decode the

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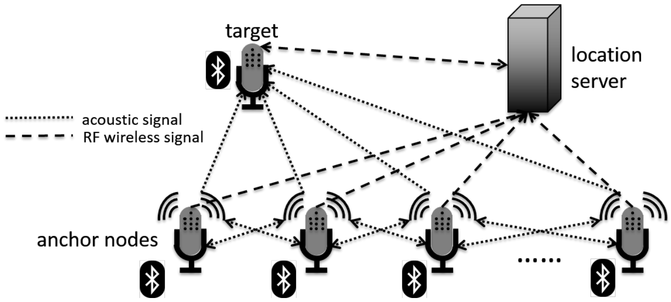

Figure 1: System architecture.

acoustic beacon and record a local timestamp at the time the preamble portion of the beacon is detected.

After requesting acoustic beacons via BLE, target mobile devices passively listen to acoustic beacons and record the timestamps of the preambles as well. Both anchor nodes and mobile devices can communicate with the location server via WiFi. Upon receiving sufficient timestamps from both sets of devices, the location server will compute the locations of the mobile devices. This design is advantageous in several aspects. First, it scales well even with a large number of mobile devices despite the limited acoustic bandwidth available on mobile phones in the inaudible range (e.g., 17KHz – 20KHz) since both the locations of anchor nodes and the frequencies of beacon transmissions are fixed. Second, our design can reduce the additional power consumption on battery-powered mobile devices compared to those that require active acoustic transmissions from user devices. Third, location updates can be done faster compared to a purely acoustic-based solution due to the higher data rate over wireless interfaces.

3. TDOA ESTIMATION

The TDoA estimation algorithm of asynchronous beacons is best understood through an example as illustrated in Figure 2, where there are two anchor nodes A and B and a target device C. Consider at time $t^s_{A_0}$ that node A transmits a beacon, which is received at time $t^r_{A_0}$, $t^r_{B_0}$, $t^r_{C_0}$ at nodes A, B, C, respectively. All timestamps are based on local clocks. At time $t^s_{B_1}$, anchor B transmits a beacon message, which is received at time $t^r_{A_1}$, $t^r_{B_1}$, $t^r_{C_1}$ at nodes A, B, C, respectively. Note that $t^s_{A_0}$ and $t^s_{B_1}$ are not known due to uncertain delays in the acoustic interfaces. To compute TDoA, we need to know the interval t_o between the transmissions of the two beacons in a common reference time, which can be approximated [1] as

$$t_o \approx \frac{(t^r_{B_1} - t^r_{B_0}) + (t^r_{A_1} - t^r_{A_0})}{2} \quad (1)$$

4. DEPLOYMENT REQUIREMENTS

The proposed solution requires at least 4 anchors deployed at different height so they are not in the same plane. For 10 anchors allowed, nearby anchors should not be deployed in the same plane. Also, anchors need to be higher than obstacles in the room but not unnecessarily high to cause signal attenuation. We will use an extra laptop server and a WiFi router to connect to anchors and target devices. The location result will be displayed on a smartphone.

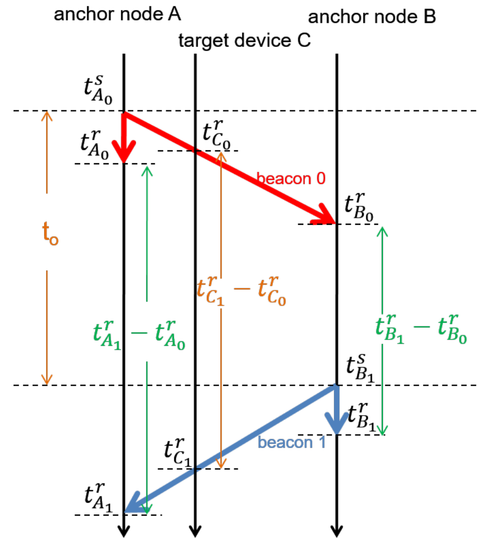

Figure 2: Two beacons sent from different anchor nodes.

5. REFERENCES

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