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The design and development of a smart building access management and visitor tracker system

Literature Survey

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January 2022

MEng in Electronic and Computer Engineering

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Declaration

I hereby declare that, except where otherwise indicated, this document is entirely my own work and has not been submitted in whole or in part to any other university.

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Indoor wireless location tracking for use in a smart building access management system

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***Abstract*— This document will investigate wireless communications technologies and their suitability for use in the application of real time indoor location tracking for the purpose of access management. This paper serves to compare and contrast the features of Bluetooth Low Energy (BLE), Ultra-Wideband (UWB) and WiFi technologies to determine the feasibility.**

Keywords— Indoor location tracking, Wireless devices, Bluetooth, UWB, WiFi, RSSI, ToA, TDoA, Triliteration

I. Introduction

A. *Indoor Location tracking*

Demand for indoor wireless real time location tracking services has significantly grown in the last number of years. At present it is estimated that indoor wireless real time location tracking market is worth in excess of $7 billion [1] that many high-profile companies have begun to venture into the space. The demand can be seen in the 2019 foundation of the FiRa Consortium specifically focusing on the implementation of IEEE 802.15.4 also referred to as Ultra-wideband (UWB) [2]. The range of applications for indoor wireless real time location tracking services is extremely vast, from tracking of resources in a smart warehouse, navigation assistants to building access management.

While location tracking is not a new concept, popular technologies like GPS require line of sight and are susceptible to complete signal degradation when a user enters a building. The resolution to this problem is to implement a method which can be installed indoors and execute the tracking locally..

B. *Selection methodology*

There are a number of wireless technologies in use for data transmission that can be co-opted for location tracking as well as some more recent protocol developments. The selection of the most appropriate technology will vary based on use case. For this paper it is proposed the device will be carried by a person through a property to be integrated with a system which would control access and egress within a building. The following protocol and device characteristics selection criteria have been identified as primary concerns for such a system:

1) Accuracy

Within the aforementioned scenario accuracy as to pinpointing a user's location is crucial so as to ensure actuation of doors appropriately as per design use cases and not restrict or grant unwarranted passage. Resolution as well as tolerances will be considered.

2) Power efficiency

As the on-person device would be required to transmit data for the full extent of a person's presence in a building, avoidance of high-power consumption methods is crucial to ensure the device doesn't require daily charging/battery changes. Observation of the mitigation/trade-offs for other characteristics will be taken into consideration.

3) Scalability

It is important in any systems future proofing to be able to scale a solution. In this case analysis of a solutions capability to add more users and extend area of coverage are the primary factors as well as any hardware overheads required.

4) Real Time

Is real time tracking achievable and is there a risk of time slippage to account for

5) Reliability

An assessment of transmission error rates as well as how susceptible the protocol is to interference and attenuation from the likes of cross talk and the physical properties of a rooms structure.

6) Measurement Methods available

There are a number of methods which will be analysed later in this paper ranging in degrees of accuracy and processing required to determine a location. The availability or lack thereof, of these various methods will also be an influencing factor

II. Wireless Techniques Review

A. *Protocols*

There are a number of wireless communication protocols already available and implemented in off the shelf end user devices. As part of the development of indoor location tracking and the readily available devices these have been co-opted for application. For the given scenario 3 protocols have stood out and will be analysed:

1) Bluetooth Low Energy

Bluetooth Low Energy (BLE) is a protocol which operates within the 2.4GHz band with is regulations specified in IEEE standard 802.15.1 . In Europe the ETSI (European telecommunication standard institute) regulations for BLE comes under ETSI EN 300 328 V2.2.2 (2019-07). BLE operates at a range of 50m in air with a 0dBm (1mW) power output. It works best sending small discrete packages with a maximum data rate of 1Mb/s [3] and a net through put of 260kb/s. BLE has been shown to have high tolerance to noise and channel interference due to its use of channel hopping and guaranteeing data delivery however with a trade-off of latency

2) *Ultra-Wideband*

Ultra-Wideband (UWB) permits data transmission across a wider spectrum of 3.1GHz to 10.6GHz compared to other protocols. The ESTI UWB standards in ETSI TR 103 181-3 V2.1.1 (2019-01) specify 6GHz – 8.5 GHz as its operation band . As per IEEE 802.15.4-2011 it is defined as having a transmission rate of 110kb/s up to 27.24Mb/s depending on the structure of the data symbols transmitted. A transmission power -45dBm/MHz which equates to roughly 0.07mW. Decawave an established producer of UWB devices reports transmission ranges of up to 250m when in line of sight, and with most devices operating optimally within 70m. UWB is more effective against multipath propagation and narrowband interferences and is also better able to propagate through materials. Due to the broad spectrum UWB is susceptible as well as posing a risk of interfering with a greater range of devices that communicate within its given frequency range.

3) *Wi-Fi*

Wi-Fi is regulated under 802.11 and its various revisions. As with BLE and UWB is transmits within the 2.4GHz, 5GHz. As of 802.11ad in 2012 that now also includes 60GHz band. The data rates can vary based on which protocol is being implemented, 801.11ax dubbed Wi-Fi 6 by the Wi-Fi alliance allows up to 2.4Gbps and power consumption of 1W during transmissions [4]. Nominal transmission ranges for Wi-Fi vary on device, antennas etc however the nominal range for most devices the optimal range is 0- 50m with greater distances being achievable as long as there is clear line of sight. While Wi-Fi has greater data rates the paired devices must contain a Wi-Fi transceiver.

B. *Measurements*

1) *Received signal strength indication*

Received signal strength indication (RSSI) is a metric which can be used to measure distance of a device by evaluating the signal strength at the receiver. The distance can be obtained by calculating the power present in the signal which has been sent to an access point (AP) from an end users' device. Due to the nature of the signal degradation a log-normal model must be used to correlate the signal attenuation to a linear distance. One mathematical representation of which is as follows:

$$RSSI(d) = RSSI(d_0) + 10nlog\left(\frac{d}{d_0}\right) + X_\sigma$$

Where $RSSI(d_0)$ is the reference RSSI in dBm at the AP of distance d_0, n is the path loss exponent, and X_σ is the zero-mean gaussian noise with a variance of σ^2 [4]. The advantage of utilising RSSI is that it can be identified in any wireless communication system protocol thus it could be implemented with all of the aforementioned. Since it is a fundamental within a system there is no extra hardware required making it the least expensive metric to implement. Due to the nonlinear relationship between signal strength decay and distance, this requires post measurement processing to ensure the distance calculated is representative. Further error is introduced when we try to implement RSSI where line of sight is obstructed, or other devices are communicating on the same channel frequency. These environmental variations can often cause RSSI peaks and valleys which can misrepresent the location of the target device. As a result of the above the signal variation, latency due to packet interruption and lacking direction vector this results in poor precision.

2) *Trilateration*

Trilateration is the method of using 3 or more access points to locate an end user. It is achieved by identifying the distance of the end users from an access point and using that to establish a transmission radius. Once the radii of the 3 access points have been drawn, based off of their intersection, the end user's device can be located. This provides a greater degree of accuracy when to all of the aforementioned methods. It is extremely affective in locating with higher degrees of precision that it is the method implemented between satellites in GPS.

1) *Time of Arrival*

Time of arrival (ToA) and often referred to as time of flight is a linear method of calculating distance based off of the time taken for a message to travel from the end user's device to the access point. This method can be implemented over any range but requires the transmitter and receiver to be synchronized.

2) *Time Difference of arrival*

Time difference of arrival (TD0A) is an expansion on time of arrival however only the access points are required to be synchronized. Received values are then compared much like in trilateration to decipher the devices' location by using hyperboloids.

III. ANALYSIS AND COMPARISON OF EXISTING SOLUTIONS

A. *Case studies*

1. *Bluetooth*

Within the case study of utilizing BLE for indoor IoT system [5] we see the requirement of implementing a post measurement model when working with RSSI to extrapolate a location. With the model within this paper, they were only able to achieve accuracy to within a $2m^2$ area.

2. *UWB*

Within the case study of implementing UWB for tracking sports players [6] it was identified an optimal positioning of the UWB anchor points in an array around an area to identify location with an accuracy within 31cm.

3. *WiFi*

Within the case study of Wi-Fi versus BLE for performance using RSSI measurements [4] we see that BLE outperformed Wi-Fi. The higher performance of BLE can be contributed to the frequency of sampling (50Hz BLE versus 1Hz Wi-Fi) the previously discussed channel hopping of BLE. This means error is more likely when using Wi-Fi and also required more power by comparison for lower accuracy.

B. Proposed solutions

For distance calculation implementing trilateration will afford the greatest degree of accuracy if RSSI is used to find the distance from access points to end users as it is more resilient due to the leveraging of multiple access points but is still susceptible to the same errors due to the metric used. If ToA is used it resolves the non-linearity issue of RSSI however requires significant synchronization effort across the system which will increase as it is scaled. From the analysis TDoA is the most optimal as it provides a linear model, it only requires the access points to be synchronized which can be facilitated by their connection back to a central system.

The device which best permits implementation of TDoA and has the highest resolution of accuracy is UWB

IV. Conclusion

There are significant challenges to overcome when implementing an indoor location tracking system however due to the wealth of choice of devices there is an appropriate selection for most scenarios. As the wireless research working groups continue to expand on current and develop new standards the selection will grow as will the capabilities of existing devices. It is anticipated that the IoT market specifically the indoor location tracking market will continue to grow at an accelerated rate and thus continued work in the area is required to overcome the challenges covered in this paper as well as many others. For a real-time indoor location tracking system which will expect a fluctuating end users base of which it will be integrated with an access management system UWB and TDoA has emerged as the best solution for this use case.

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