Inquiry-based Bluetooth Parameters for Indoor Localisation - an experimental study

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Abstract. The ability to locate people in an indoor environment is attractive due to the many opportunities it offers to businesses and institutions, including emergency services. Although research in this area is thriving, still no single solution shows potential for ubiquitous application. One of the candidate technologies for localisation is Bluetooth owing to its support by a wide range of personal devices. This paper evaluates indoor signal measurements collected based on the Bluetooth inquiry procedure. Our goal was to establish how accurately a mobile device can be linked to the space (e.g., shop, office), in which it currently resides. In particular, we measured the Received Signal Strength Indicator and the Response Rate of an inquiry procedure for various positioning scenarios of the mobile devices. Our results indicate that the Bluetooth inquiry procedure can be successfully used to distinguish between mobile devices belonging to different spaces.

1 Introduction

The amount of information currently available in a modern society, from public transportation schedules and weather forecast to shopping discounts and cultural events, greatly exceeds one's capacity to process it and hence an appropriate content filtering is required. A major filtering criterion is one's location; a person is generally more interested in information, e.g., events or special offers, about its vicinity than in information associated with a remote location. The whole concept of Location Based Services (LBS), for example, rests on the assumption that offering one location-dependent services can increase, among others, generated profit and customer satisfaction, see [2]. Intuitively, the ability to determine one's location is crucial.

Outdoor positioning is dominated by the Global Positioning System (GPS), which offers a highly effective and affordable solution, provided on user-friendly devices. Indoor environments, however, still pose a challenge to the localisation paradigm and foster vigorous research by both academia and industry.

Various technologies have been proposed to tackle the problem of indoor localisation including infrared (e.g., [18]), ultrasound (e.g., the Active Bat system[1]) and Radio Frequency IDentification (e.g., [3]). Some authors, e.g., [7, 13,

[1] http://www.cl.cam.ac.uk/research/dtg/attarchive/bat/

16], go a step further and use combined feedback from multiple technologies. Arguably, however, the main focus of the scientific community lies elsewhere. Large number of papers, among which [6] and [19], argue that Ultra Wide Band (UWB) radio offers the excellent means to determine one's location with high precision. Equally many studies campaign for the use of IEEE 802.11, e.g., [4, 8, 11], or Bluetooth, e.g., [9, 13, 12], both a Radio Frequency (RF) technology, due to their ubiquitous support by personal devices. A taxonomy overview of the technologies can be found in [15].

The number of proposed localisation techniques is equally great, the most often used being angulation, lateration and fingerprinting, see [5]. In angulation the location is a derivative of measured angles to fixed reference points. Lateration is based on the same concept but uses distances, which can be determined by various methods among which Time of Arrival (ToA), Time Difference of Arrival (TDoA), received signal strength (RSS) and hop count. Various modifications of each method have been proposed, e.g., [4, 14], as well as combinations thereof. Finally, a fingerprinting technique compares on-line measurements to an off-line database in order to determine location. Currently there are so many localisation proposals based on the fingerprinting technique that a separate taxonomy such as [10] is appropriate.

None of the currently available solutions for indoor location estimation is mature enough to offer ubiquitous applicability. The optimal choice of technology and localisation technique still depends on the application's requirements towards accuracy, cost and ease of deployment. For example, UWB radio can provide highly accurate positioning but is costly and requires device modifications. A more cost-efficient course is to use a RF-based technology with high commercial penetration ratio, e.g., Bluetooth. RF signals, however, are more susceptible to propagation effects, which introduces estimation imprecision.

We are interested in an easy to deploy, low-cost localisation solution with rough position granularity. In particular, we wish to accurately locate persons over the spaces of a large building, e.g., an exposition centre or a shopping mall, without requesting any cooperation from their devices, i.e., non-intrusive detection. Both the IEEE 802.11 standard and Bluetooth can meet our requirements. Currently we focus on the Bluetooth technology but we are aware that the IEEE 802.11 technology can benefit a localisation solution and intend to include it in a future study. Section 2 discusses in more detail our motivation and related work on indoor localisation with Bluetooth.

This paper presents our findings on a Bluetooth-based experimental deployment in a controlled environment. Data from scenarios including in-room and out-of-room positioning, is analysed. Our purpose is to identify the Bluetooth signal parameters which can provide a successful location estimation and to determine which technology-specific and environmental factors affect the process. We aim to gain sufficient insights, which to support us in the development of a scalable method for the localisation at room level of users over large indoor areas. The presented work has been performed within the Eureka Eurostars project Location-Based Analyzer, project no. 5533. It has been funded by the

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The paper is organised in the following sections. In Section 2 we briefly summarise the state of the art in Bluetooth localisation and position our work. Section 3 describes the measurements set-up and the studied positioning scenarios. Results are discussed in Section 4 while in Section 5 we draw conclusions and identify open issues.

2 Bluetooth-based Localisation

Indoor location estimation based on Bluetooth is attractive mainly due to the large scale adoption of the technology by a wide range of devices, including mobile phones and personal assistants. Hence, a Bluetooth-based localisation system has the potential for quick, cost-efficient deployment without the need to modify the intended target devices. Any localisation algorithm requires certain input parameters from which it derives a target's position. A Bluetooth device can provide feedback on three status parameters in connection mode, namely, Link Quality (LQ), Receieved Signal Strength Indicator (RSSI) and Transmit Power Level (TPL). Methods that rely on these parameters face many challenges and showed little potential for practical application, see [12]. For example, there is no exact definition of LQ and its relation to Bit Error Rate (BER) is device-specific, see [17]. An RSSI reading is less ambiguous but unfortunately susceptible to power control mechanisms at the targets. Additionally, a general disadvantage of this group of methods is the requirement to establish a Bluetooth connection, which does not scale well as the number of targets increases, see [9].

A recent modification of the Bluetooth Core Specification[2] instigates new research on Bluetooth-based localisation. The RSSI reading returned by a Bluetooth inquiry, termed here inquiry-related RSSI, is not affected by power control and hence is a more reliable measure of a target's distance to the inquirer. Although lengthy - the inquirer needs to check all 32 Bluetooth radio channels - an inquiry procedure can monitor a larger number of targeted devices than a connection-based method. Some authors, e.g., [1], introduce as an additional measure the Response Rate (RR) of a Bluetooth inquiry, i.e., the percentage of inquiry responses to total inquiries in a given observation window.

A juxtaposition of the work done by others and our definition of the indoor localisation problem suggests that a solution based on the Bluetooth inquiry procedure fits best our needs. A short motivation follows. Our purpose is to develop a low-cost, easy to deploy system, which can locate persons with a precision at room-level. For these purposes Bluetooth offers a satisfying solution due to its ubiquitous support by personal devices. More specifically the inquiry procedure was chosen since it allows us to gather measurements without requesting active participation of the mobile devices. As a first step in the search of a localisation

[2] Available at https://www.bluetooth.org/Technical/Specifications/adopted.htm

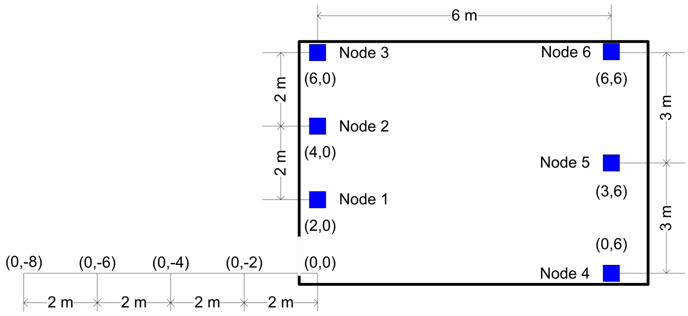


Fig. 1. Schematic of the measurements set-up.

solution we need to determine the bounds of the parameters to be used, i.e., their dependency on distance, obstacles or other factors. For this purpose we performed the experimental study presented in this paper. Since, in our opinion an optimal localisation algorithm will rely on data about both inquiry-related RSSI and RR, we monitor both parameters in the experimental measurements.

3 Experimental Set-up

In the deployed experimental set-up six reference nodes collect measurements based on the Bluetooth inquiry procedure from four mobile devices (MDs), whose position changes. Reference nodes are Bluetooth-enabled wireless sensors, whose position is fixed and known. In particular, OveroFire gumstixs nodes were used. Four smart phones were tracked - an HTC Desire (MD1), HTC Wildfire (MD2), an iPhone (MD3) and an LG e900 (MD4). All measurements are performed in an indoor controlled environment, i.e., the number and identity (MAC address) of the discoverable Bluetooth mobile devices is known. Note that the mobile devices are assumed to be in discoverable mode. We measured inquiry-related RSSI values and inquiry response rates since, as previously mentioned, their collection does not require the active participation of the monitored device.

A graphical representation of the set-up in shown in Figure 1. The wireless sensor nodes are indicated by labelled squares. Three sensors are located at the near end of the room (close to the entrance) at positions (2,0), (4,0) and (6,0); another three sensors are located at the far end of the room at positions (0,6), (3,6) and (6,6). The coordinates in a position pair (x, y) correspond to the distance in meters to the reference location (0,0).

A full grid deployment of sensor nodes may be more insightful in terms of measurements but it is in conflict with our goal to find a low-cost deployment scenario. Recall that we only want to accurately locate persons over building spaces and not precisely determine their positions.

Depending on the positioning of the mobile devices, we distinguish between *in-room* and *out-of-room* scenarios. In the former case the mobile devices were moved over positions (0,0), (2,0), (4,0) and (6,0) in circular manner; in the latter case the phones were moved over positions (-2,0), (-4,0), (-6,0) and (-8,0) outside the room. The exact moving patterns are indicated in Table 1. This specific choice of scenarios allows us to monitor the detection of subjects inside and outside a confine space, e.g., an office or a shop.

The mobile devices and the sensor nodes were positioned on the floor. In the room were present tables and chairs, which we expect to have effect on the propagation conditions. However, we have not explicitly studied the impact of the environment and the proximity to obstacles on the performance. Further, no special attention was given to the orientation of the devices towards the sensor nodes. The latter was explicitly chosen since no such awareness is yet feasible in a real deployment.

Table 1. Moving patterns for the in-room and out-of-room scenario.

	in-room				out-of-room			
MD1	(0,0)	(2,0)	(4,0)	(6,0)	(0,-2)	(0,-8)	(0,-6)	(0,-4)
MD2	(2,0)	(4,0)	(6,0)	(0,0)	(0,-4)	(0,-6)	(0,-8)	(0,-2)
MD3	(4,0)	(6,0)	(0,0)	(2,0)	(0,-6)	(0,-2)	(0,-4)	(0,-8)
MD4	(6,0)	(0,0)	(2,0)	(4,0)	(0,-8)	(0,-4)	(0,-2)	(0,-6)

4 Evaluation of Bluetooth Inquiry-based Parameters

In this section we present our findings on the inquiry-related RSSI values and RR values collected during the in-room and out-of-room scenarios. The measurements are accompanied by a short discussion. For simplicity we will use *RSSI* instead of *inquiry-related RSSI* in the rest of the discussion.

4.1 Received Signal Strength Indicator

We begin with the in-room scenario. For each of the mobile devices the RSSI values registered by each sensor node (SN) are continuously monitored while the devices are moved over positions (0,0), (2,0), (4,0) and (6,0) according to the moving patterns shown in Table 1. Each device has resided at each location for at least 1 min. Measurements were continuous, i.e., the radio channels were constantly scanned. An event can be defined as the detection of a device in a unit of time; thus multiple sensors can detect the same event time unit and one senor can detect the same device multiple times but only over different time units. Our observations show that most often there is one-to-one pairing between an event and an RSSI measurement.

First, we discuss the RSSI traces of a single mobile device, i.e., MD1, when moved over locations (0,0), (2,0), (4,0) and (6,0) in that order. As seen in Figure 2, SNs 2, 3 and 4 each registers a distinct, maximum RSSI value when MD1

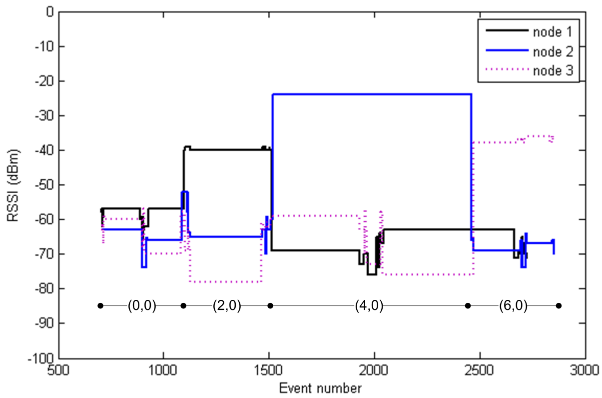


Fig. 2. Inquiry-related RSSI measurements of a single device (MD1) moving over positions (0,0), (2,0), (4,0) and (6,0) in that order.

is located next to it. However, no conclusive estimate can be derived when MD1 is at position (0,0). Hence, relying on absolute readings from a single node is vulnerable to device proximity to the node. A relative analysis of the readings of spatially disconnected nodes may be more robust. Therefore, we compare the max RSSI values measured by SNs 1, 2 and 3. Although SN1 has higher RSSI than the rest, suggesting that SN1 is closer to the target, no conclusive decision can be made. In order to increase the estimate precision we can further consider measurements from SNs 4, 5 and 6, see Figure 4(a). Clearly a SN in the proximity of an MD measures higher RSSI (-25 to -50 dBm for SNs 1, 2 and 3) than a remote SN (-55 to -70 dBm for SNs 4, 5 and 6).

In order to establish the minimalistic view of the network we take away SNs 2 and 5; the RSSI information available for localisation purposes is shown at Figure 3. The phenomenon, previously observed for MD1 at location (0,0), exhibits again for location (4,0) - it is difficult to derive precise location estimate, which is even further complicated by the higher RSSI values of SNs 4 and 6 compared to SN3.

The relative analysis proves even more efficient when applied to the out-of-room scenario, see Figure 4(b). All devices were positioned outside the room and moved as indicated by Table 1. Due to the longer signal path to the sensors and the presence of walls the maximum measured RSSI values by all SNs are lower compared to the in-room scenario. In addition to lower values, the maximum measured RSSI of an MD outside the room varies much less over the SNs.

We can conclude that rough location estimates based on the Bluetooth inquiry procedure are feasible especially with large number of sensor nodes. The results about MD1 at location (0,0) and (4,0), in the four SNs case, however suggest that fine-granularity location estimation, i.e., a meter, may be challenging. In order to investigate the issue further measurements are necessary.

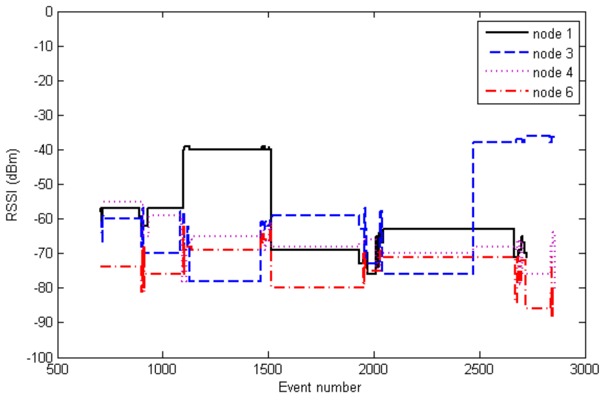
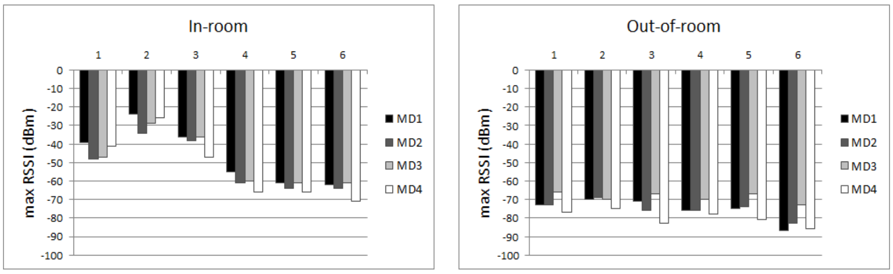


Fig. 3. Inquiry-related RSSI measurements of a single device (MD1) for four node deployment.



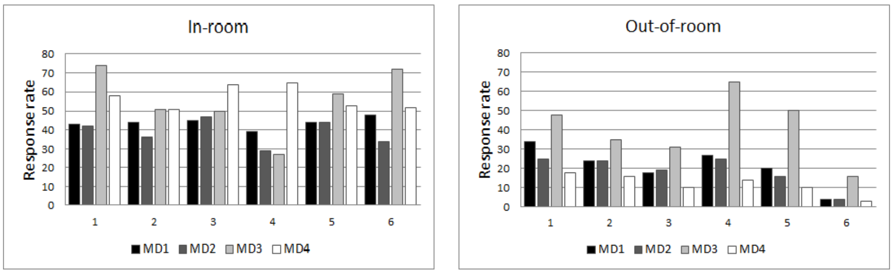
(a) in-room (b) out-of-room

Fig. 4. Maximum RSSI levels reported by the RSSI inquiry procedure for two cases: (a) in-room (MDs close to SNs 1, 2 and 3) and (b) out-of-room (MDs outside the room).

4.2 Response Rate

In addition to the RSSI values we have also collected measurements on the response rate of an inquiry again for the in-room and out-of-room scenario. The results are presented in Figures 5(a) and 5(b) respectively. It is interesting to observe a trend opposite to the RSSI measurements, namely, each MD registers only minor changes in RR from node to node for the in-room case while the differences are indicative for the out-of-room case. In the latter the RR seems to depend on the distance between MD and SN and the direction of signal propagation, i.e., SN4 (in line with the MDs) registers lower RR then SN1 but higher RR than SN3.

Another interesting observation is that the iPhone (MD3) has much higher RR than the other MDs. We explain that with the difference in how a device manages its 'discoverable' mode. In order to save battery the operation system may 'hide' the device after a pre-defined period of time. This was the case for



(a) in-room (b) out-of-room

Fig. 5. Response rate of Bluetooth inquiries for two cases: (a) in-room (MDs close to SNs 1, 2 and 3) and (b) out-of-room (MDs outside the room).

all MDs but the iPhone, which caused them to be 'hidden' during repositioning. After moved to the new location all phones were set in the discoverable mode.

5 Concluding Remarks

Based on the performed measurements we can conclude that an indoor localisation based on the Bluetooth inquire procedure is possible given that one wants to locate targets on a rough position granularity, i.e., at room-level. Finer location estimates, e.g., within few meters are in our opinion challenging. We also believe that both parameters inquiry-related RSSI and inquiry response rate should be used in combination to provide higher reliability of the estimate.

Although insightful the performed measurements introduce several concerns. The measurements suggest that both RSSI and RR may be device-specific or even depending on the particular sensor node. For example, SN2 has persistently higher detected RSSI than SN1 and SN3. These hardware oriented issues are accompanied by concerns about interference and location-specific propagation effects such as signal reflection. Further, we acknowledge the fact that higher node mobility can lead to changes in the measurements. In order to resolve these open issues we intend to perform more extensive data measurements.

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