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Experimenting Bluetooth beacon infrastructure in urban transportation

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Abstract

The research focus of this paper was to study the feasibility of Bluetooth beacons in urban transportation tracking by using mobile devices. The findings of the experimental research were discovered in autumn of 2015 and piloted in December 2015 in Helsinki, Finland. The results identify that mobile sensing of Bluetooth beacon signals can be utilized for passive monitoring and detecting significant transportation events in real-world environments. The issues discussed are designing the system, collecting and performing the statistical analysis for signal level calibration, recognizing the events, and the research findings and experiences. We propose that Bluetooth beacons can be utilized to build an infrastructure to support smart urban transportation services. It allows the mobile applications to provide essential information and guide the users in situations and places where traditional location services are not easily available.

Keywords:
Bluetooth, beacon, transportation

Introduction

Wireless location and context devices, such as Bluetooth beacons have gotten a lot of attention in indoor positioning solutions and broadcasting points of interest. Due to the increasing support of Bluetooth low energy technology in smart phones and wearable devices, there are opportunities to track the movement and position of vehicles and users by using the beacon infrastructure and mobile devices. This allows a possibility to build affordable, low-maintenance and widely adopted urban transportation services to guide mobile users in a variety of ways. Global positioning systems have been used for detecting the exact location in mobile applications, but receiving the satellite signal is often challenging in tunnels and indoor locations, such as in metro tunnels. Radio-frequency identification technologies (RFID) are also utilized for proximity sensing, but the mobile devices commonly support only “Near field communication” (NFC) protocol, which requires a very close proximity between devices. Bluetooth beacons have an advantage, when the approximate vicinity is accurate enough to make smart decisions. The recent experiments indicate that Bluetooth beacons can be used for detecting positions, passing through gates and doors and arrival of vehicles, if a proper beacon infrastructure and beacon meta-data services are available for mobile applications.

Research goals

The research focus of this paper was to study the feasibility of Bluetooth beacons in urban transportation tracking and guiding by using mobile devices. Lot of mobile navigation services are based on GPS navigation signals. The challenge of using GPS technology for location services is that receiving GPS signals may be restricted in urban architectures and indoor and underground spaces. The solution for the challenge would be a local low-energy radio network, which can be used to locate user accurately when GPS signal is not available. Related to this challenge, Siira and Heinonen [1] also identified this issue in their study. In addition, they claimed that another challenge in current navigation services is how to automatically detect if the passenger has boarded the right vehicle or a vehicle at all in indoor situations. A solution suggested was using a radio based technologies (like WLAN or Bluetooth) in the vehicles which could be detected when the vehicle is boarded.

In this study, our goal was to find a ways to improve the navigation services in challenging urban transportation environment and to build a system, which proves that the solution is feasible. To reach that goal we implemented Bluetooth beacon infrastructure and a mobile application, that together constitute a system called Beacon Open Co-sharing System (BOCS). In order to prove that the system achieves its objectives, we tested it in a laboratory and real-world environments.

Related research

Utilizing Bluetooth beacons in intelligent public transport guidance is coming more popular during the next years. Many smaller scale solutions exist, that typically provide real-time information for public transportation passengers. Mobile applications using Bluetooth beacons to notify passengers about approaching buses, timetables and waiting times are becoming more and more common. This is especially useful for assisting the visually impaired to use public transport independently. There is a list of sample cases where Bluetooth beacons are used to help visually impaired guidance:

- Bucharest: iBeacons guiding visually impaired [2]
- Barcelona: Beacons improving accessibility [3]
- London: Beacons for the blind [4]
- Oregon: Google’s BLE beacons for real-time transit information [5]

It is also possible to utilize beacons in ticketing services. Narzt et al [6] introduced a study where they implemented a system which offers so called Be-In/Be-Out (BIBO) ticketing services in public transportation systems. Their system utilizes implicit interaction and enables passengers to obtain their tickets just by being inside a vehicle.

Beacons can be also utilized for passenger guidance at larger stations and airports. The use of beacons in such spaces is often different than using them in individual stops or vehicles. Airports could utilise beacons for sensing passenger flows and to measure and inform passengers about queueing times for security checks. Since airports are large buildings and people are often in a hurry to get to their gates, location-based indoor guidance through mobile applications is becoming more common.

Other potential services for the travellers include solutions to bring up boarding passes on the user's smartphone for boarding a plane, or pushing delay or gate change information. Beacons may offer a possibility to provide a guidance for passengers to easily find the nearest customer service desk.

Example cases of utilizing Bluetooth beacons in airports:

- Helsinki-Vantaa, Finavia: Beacons for passenger tracking and security queue times [7]
- United airlinesPassengers can use the app to search for nearby points of interest within the terminal, including departure gates, restaurants and ATMs [8]
- Schiphol, Amsterdam: Passenger navigation at the airport by KLM Airlines [9]
- Hong Kong: Airport passenger guidance [10]
- Brussels Airport: BLIP systems measuring queue times [11]
- Japan Airlines: provides improved customer service through beacons and smart watches [12]
- Miami: Miami International Airport is the first airport in the world to have a complete and open deployment of beacons [13]

System design

The Beacon Open Co-sharing System (BOCS) consist of two functional components:

- The server-based repository, which manages the Bluetooth beacon context meta-data.
- Android mobile application, which demonstrates how Bluetooth beacons can be utilized for intelligent journey guidance in public transportation scenario.

In addition, we have an infrastructure of Bluetooth beacons, which consists of three types of beacons: station, vehicle and gate. The station is indicated by one or more beacons within a waiting area for public transportation. Vehicle can contain one or more beacons and the beacons are located in different sections of wagons of the vehicle. Gate is a minimum of two beacons on both sides of the passage to or from the vehicle. The beacon signals are identified by their universally unique identifier (uuid) and catalogued in a web service with their corresponding meta-data. The events are identified by the signals in range, and the change in signal strength in time. The application collects available signal strengths and compares them into previously collected signal strength samples to determine events. The goal was to identify the following events based on the collected signals:

- Arrival to a stop.
- Arrival of a vehicle.

- Entering the vehicle.
- Exiting the vehicle.
- Leaving the stop.

Particle beacons, manufactured by KS Technologies, were used for this experiment due to their low cost and versatility. Nexus 5 and Nexus 6 model Android phones were used for the mobile application because they had an up-to-date support of Bluetooth low energy technology. Java web application with web services were used for catalogue services in beacon meta-data management.

Server repository

The beacons themselves are typically only capable to one-directional broadcasting of their signature information, the responsibility to maintain the beacon data needs to be done by server-based repository. Managing the beacon meta-data in a common server-based repository service has many benefits, e.g. all beacon updates are instantly available in the subsequent searches, and the searches can be narrowed down to geographic location, time ranges and other relevant parameters.

Bluetooth beacons are identified by the 16-byte Universally Unique IDentifier (UUID) that the beacons are broadcasting. The server application manages a catalogue of beacon meta-data that are indexed by a combination of UUID and the beacon major and minor numbers. Alternatively the beacon MAC address can also be used as a unique identifier. The beacon data is maintained in a domain object model, where the beacons can have a combination of a physical location and a relative location. Relative location allows tagging beacons to places that can be constantly moving, such as a bus. Relative position describes the whereabouts within the location, such as a front door. This way the service can support multiple beacons within a limited scope and can be used to pinpoint a more accurate position or direction of movement within a vehicle or wagon. The following table lists the beacon meta-data which are stored in the system’s repository.

Table 1– Beacon metadata

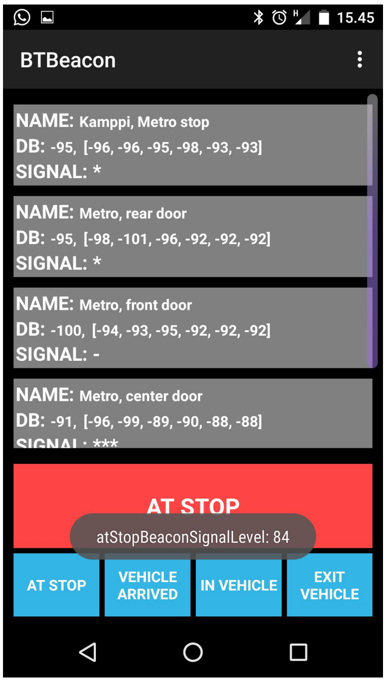
Attribute	Description	Sample data
latitude	Geographic latitude in WGS84 decimal degrees.	65.06306306306307
longitude	Geographic longitude in WGS84 decimal degrees.	25.47015498171003
relativeLocation	Location description which may not be stationary.	Metro train 73
relativePosition	Position description in relation to the location	Wagon 3, front door, upper left
description	Human readable description	Gate beacon for incoming passengers.
info	Additional information	Installed 15.08.2015. Battery last changed 11.11.2015.
uuid	Universally unique identifier code	b9407f30-f5f8-466e-aff9-25556b57fe6d

Mobile application

Mobile application demonstrates how the Bluetooth beacons can be utilized for intelligent journey guidance in public transportation scenario. The application scans available beacon signals, identifies them based on the meta-data available at the repository, and triggers appropriate events which can be used to guide user more accurately while travelling by urban public transportation

The development of the mobile application was done iteratively. In this study we call them as steps.

1. Calibrating the beacon signal levels to the suitable range, in order to establish a base line for the event triggering rules. Mobile application reports the measured signal levels to the repository server for statistical analysis.
2. Performing a field test utilizing the calibration parameters and feasibility of the rule engine in a real-world environment.
3. During the field tests, we anticipated that we may have to adjust the calibration parameters on the site, in order to improve the accuracy of the event detection mechanism. For that reason, the mobile application needs to have an administrative display to override the initial calibration values. The implementation of the administrative display was a third step.
4. Implementing an event threshold determination mechanism, as can be seen in the following figure (Figure 1). When the user presses one of the blue event buttons at the bottom of the figure, the application recognizes the beacon signal levels in a range. These beacon signal levels are used as thresholds for each event. In figure, the current state is seen in the red box. The beacon signal levels are seen in the list of grey boxes at the top of the figure. They are shown here just for additional information for the user.



NAME: Kamppi, Metro stop
DB: -95, [-96, -96, -95, -98, -93, -93]
SIGNAL: *

NAME: Metro, rear door
DB: -95, [-98, -101, -96, -92, -92, -92]
SIGNAL: *

NAME: Metro, front door
DB: -100, [-94, -93, -95, -92, -92, -92]
SIGNAL: -

NAME: Metro, center door
DB: -91, [-96, -99, -89, -90, -88, -88]
SIGNAL: ***

atStopBeaconSignalLevel: 84

Figure 1 – Event threshold analysis application

Statistical analysis

By collecting the beacon signal levels at selected locations in the laboratory environment, we were able to calculate the base line signal levels for the key events we wanted to identify. The testing required multiple entries and exits, and the data was submitted to the server for storage and analysis. The signals are negative decibel values that are rounded to the nearest integer. The smaller the negative number is, the better the signal is. In table 2 shows the signal averages, standard deviations, sample sizes and the range to cover over 95% of the statistical probability of the measured signals. These ranges were initially used as a guideline for the event threshold rules and applied accordingly. Leaving the stop-event is not statistically analysed, because we assume that it occurs when no beacon signals are received.

Table 2 – Beacon signal calibration statistics

Event / Beacon	Average Signal (-dB)	Standard deviation (-dB)	Signal range at 95% probability (-dB)	Sample size
At stop				
Stop beacon	70	10	50 – 90	11
Vehicle arrive				
Stop beacon	80	5	70 – 90	9
Vehicle beacon	90	4	82 – 98	9
Get on vehicle				
Stop beacon	95	5	85 – 105	15
Door beacon 1	72	5	62 - 82	15
Door beacon 2	70	5	60 - 80	15
Get off vehicle				
Vehicle beacon	78	5	68 - 88	12

Event recognition algorithm

The Figure 2 illustrates the rules of event recognizing algorithm, which is implemented in mobile application. The application measures the signal levels several times in a second based on user defined parameters and stores the signal levels of each beacon in range in application’s memory. With basic settings this clause is looped once in a second, and the user interface is updated accordingly. The initial values for event thresholds were identified during the statistical analysis.

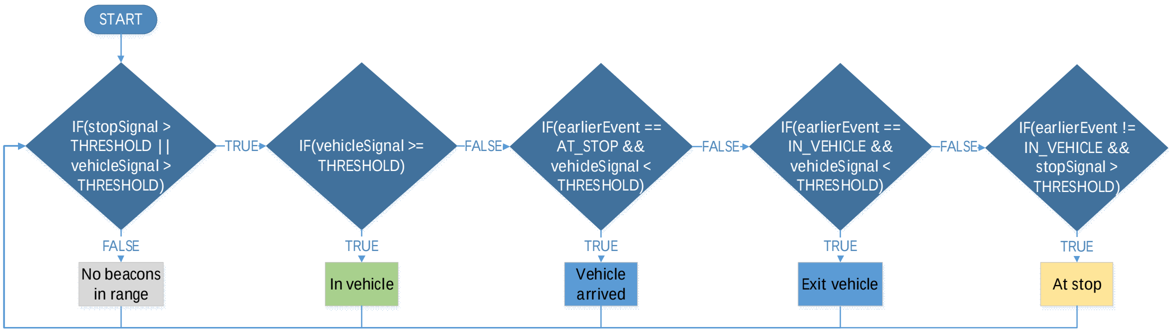


Figure 2 – The event recognition rules and flow chart.

Research findings

The received Bluetooth signals can weaken a lot if the beacon is not in a line of sight, e.g. behind the human body. This is a one specific case we need to take into account in our test case, especially during the rush hours, when there are a lot of people using the public transportation at the same time. Signals may weaken accidentally but it is never strengthening accidentally. Thus, we need to implement an algorithm which is smoothing the rapid signal changes. The smoothing algorithm is explained later.

There are events which may happen with the same signal levels, but are not logical in our case. For example, user can’t exit the vehicle before she has been inside the vehicle earlier. Keeping track on the earlier events is compulsory while determining the next event, in order that app can detect the events correctly.

The actual levels of event’s signal thresholds must be defined before app can utilize them for event recognizing. For example, entering the vehicle is recognized when mobile application notices at least one vehicle beacon, which signal level exceeds the threshold (e.g. -75dB) value.

We discovered that it should be possible to calibrate the certain parameters of the smoothing algorithm to improve the accuracy in variable environments. We implemented an administration display for adjusting the number of samples in a smoothing table, and the frequency of running the smoothing algorithm. The walls and the environment play a significant role in how the signals are received, and each environment needs to be tuned individually for the best performance. In figure 3 we illustrate the mobile application reacting to the oncoming metro beacon signal by triggering the vehicle arrived event.

Once the metro train signal is detected, the screen turns blue to indicate that the metro train has arrived.

Figure 3 – Vehicle arrived-event detected during piloting.

In our study we did not concentrate to the large-scale beacon installations and challenges which may occur in those cases. However, we are aware that the back-end system designed to be used in large-scale installations must support functions for beacon maintenance. For example, it is known that the battery power in beacons may end even in one year. It also makes sense to prepare for beacon disappearances and unexpected breakdowns.

Signal level smoothing algorithm

Smoothing the rapid Bluetooth beacon signal level drop is implemented by using the table, which stores a fixed amount of previous signal level measurements for each beacon and calculating a definitive signal level by taking an average of these signals. The table 3 illustrates how the signal level smoothing algorithm works in practice. The red cells highlight the signal level which is weaker than earlier measurement and the green cells highlight the stronger signal. The calculated average signal level is highlighted in blue. This allows the algorithm to react quickly to strong signals and adapts slower when the signal is getting weaker. The algorithm has two features:

1. Rapid signal level drops are smoothed. If the new signal level is weaker than earlier, the new signal level is stored in a table’s first cell and the oldest measurement from the last cell is deleted. After that, an average is calculated which is used as a definitive signal level.
2. Strengthening signal levels are accepted immediately as such. If the signal is strengthened, the new measured signal level is used immediately and all the table cells are filled with that stronger signal level.

Table 3 – Signal level smoothing algorithm

Time (t)	Signal at Time(t) *(dB)	Signal at Time(t-1) *(dB)	Signal at Time(t-2) *(dB)	Signal at Time(t-3) *(dB)	Signal at Time(t-4) *(dB)	Average Signal level *(dB)
1	-80	-70	-70	-70	-70	**-72**
2	-85	-80	-70	-70	-70	**-75**
3	-90	-85	-80	-70	-70	**-79**
4	-95	-90	-85	-80	-70	**-84**
5	-75	-75	-75	-75	-75	**-75**

Conclusions and Future Work

The result of our work is a system which enables us to track the movement and position of vehicles and users. With the signal levels measured from the combination of the Bluetooth beacons, we are able to detect events as the person arrives to the stop, the vehicle arrives, the person steps into the vehicle, the person steps out of the vehicle and when the user leaves the stop. Additional smoothing algorithms are needed to improve the accuracy due to the nature how the signals are received. Bluetooth beacons have the potential to enable smart tracking of people flows and all kinds of digital services, such as guidance, marketing, advertising, and billing. There are opportunities to make the beacon sensing algorithm more accurate than in our initial experiment. The beacon data services would be improved if there was a way to trigger logic based on the events detected on the mobile devices.

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