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Bluetooth Beacon Enabled Mobility Services and Opportunities in Public Transit

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Abstract

Bluetooth beacon is a short-range wireless communication device emitting simple advertisement messages in regular intervals, and this data can be detected by devices like smartphones and conveyed to a backend system for further processing. Beacons are small, affordable and very easy to install nearly anywhere due to long lasting (3-5 years) battery power. As a result of these convenient properties, it has been estimated that up to 400 million dedicated beacon transmitters will be installed in our living environment, which presents challenges to the management of such a set-up. To ease this problem, this paper presents a prototype solution for open co-sharing of beacon installations between applications and services. This paper examines the requirements for management of co-shared beacon infrastructure in the highly dynamic context of public transportation and describes the related data model and experiences from a trial case.

Keywords:

Bluetooth beacon, ITS, public transit.

1. Introduction

Bluetooth (BT) is a short-range wireless technology designed to enable wireless communication between diverse devices [1]. An enhanced version of BT called Bluetooth Low Energy (BTLE, or BLE) provides considerably reduced latency, power consumption and enables machine to machine (M2M) communications and Internet of Things (IoT) applications that require a very long battery life (years) [1]. BT beacon is a BTLE transmitter device emitting simple advertisement messages (beacon identifiers) in regular intervals, and this data can be then picked up by devices like smartphones and conveyed to a backend system for further interpretations.

With the proliferation of various IoT technologies such as Bluetooth beacons, the use of multi-sensor systems is becoming more common in a variety of domains [3, 4, and 5]. A single sensor can provide only partial information and therefore more than one sensor is required to provide a comprehensive picture of the operating environment. Also, more of them are needed in contexts such as public transit where the environment is increasingly complex and dynamic.

With the advancements in technologies (e.g. BTLE), sensors are becoming smaller and cheaper. Already, a BT beacon is rather small and cost efficient (5-10 USD, and prices are dropping quickly). Beacons are very easy to install nearly anywhere and it has been estimated that 60-400 million dedicated BTLE beacon transmitter shipments will occur during the next five years. These transmitter markets alone are estimated to be worth of $2-3 billion with application markets nearly 10 times more, meaning the total value of markets related BT applications could be $20-$30 billion [6].

As the amount and the utilization of beacons is rapidly increasing, there is a clear need for management functionalities for creating and handling large scale beacon systems containing hundreds or even thousands beacons nodes. In open, shared and heterogeneous environments there may be many different applications that could utilize the information from shared sensor resources. There is a growing body of research on the utilization of BT beacons in various Intelligent Transport System (ITS) use cases, but very few, if any, provide the view of open co-sharing of beacon installations between different applications and, even more so, between different service providers.

In this paper, we describe the needs and benefits for open co-sharing of beacons in the context of ITS and related requirements for a flexible and dynamic beacon data model. The aim is to promote the use of beacons in a public transit context and reduce the cost and complexity of deployment as well as the scaling up of the services using them. We show that it will be more cost effective and easier for service developers to implement and utilise beacon networks by using a shared beacon data repository that combines a co-sharing approach with a dynamic beacon data model. We will describe a novel system for Bluetooth Beacon Open Co-sharing (BOC) that enables the creation of lightweight beacon networks. The BOC system is based on an open repository which provides support functionalities for the whole beacon life-cycle from installation to disposal. The BOC system provides interoperability with standard beacon types and data definition, support for application specific extensions to the data (e.g. dynamic and static location information) as well as an open API for managing the beacons.

The paper has been organized as follows: Section 2 presents related research and introduces Bluetooth beacon applications in the field of ITS and related needs for beacon infrastructure co-sharing as well as requirements for a beacon management system data model in the context of ITS. Then, in Section 3 an experimental beacon management system is described and first experiences from a field trial in public transit context are reported. The final section 4 concludes with the findings and challenges.

2. Related research

Co-shared beacon management has not yet emerged, but the paradigm can be found in similar domains, e.g. Internet of Things. Kibria and Chong [7] have researched how open IoT services can be implemented with interoperable Web of Object approach and virtualization of physical devices and resources.

Isomursu [9] describes how management of Near Field Communication (NFC) tags should be done and which kind of requirements there are for it. Motivation for tag management is that there is a danger of 'tag litter' when tags are placed for single purpose and the purpose may be limited in time, but they still remain in the infrastructure. This increases complexity and information overflow. First, there is an infrastructure requirement where the tags need to resist weather, wear-and-tear and vandalism. Second requirement is the creation of usage logs. From logs can be monitored which tags are being used and when. Three logs were found important: 1) logging tag usage in a mobile terminal, 2) logs generated by mobile network operator, and 3) logs generated by a back-end system. Third requirement was tracking tag placement. A management system needs to know where the tags are located. Location can be defined as a GPS coordinate or an address, but there is usually a need for even more detailed textual placement information as tags are small and may be situated out of plain sight. Moreover tags can be placed in moving objects, which makes even more difficult to track their location. Fourth requirement is the ability to detect faulty tags. Tags will get destroyed and will malfunction, and there needs to be a way to find these tags. Two ways were suggested: User reporting and monitoring the activity generated by the said tag. Fifth requirement was visual design that would guide people to understand whether the tag can be interacted with before touching it. Sixth requirement is security that would indicate which tags will be safe to interact with.

Zhao et al. [10] have been researching how Bluetooth beacons and Wi-Fi are performing in indoor location services. In their research, Bluetooth was perceived to be 27% more accurate in indoor locationing than Wi-Fi was. This suggests that Bluetooth-based systems are better suitable for location services than Wi-Fi which can be seen as a competitive technology. Geofencing is a way to create virtual areas and 'fences' to a real world and provide location-based services in that area. Garzon and Deva [8] have presented how notifications can be triggered in complex multiple area geofencing situations.

Application of Bluetooth beacons and sensors in ITS

Beacon technology allows mobile applications to understand their position on a micro-local scale and deliver contextual content to the user based on the location. Due to its limited range, Bluetooth is an ideal solution for location-aware information broadcasting. As the technology is suitable especially for indoor positioning but also applicable outdoors, it opens up vast possibilities for ITS applications.

Beacons and Bluetooth sensors have already been used in various mobility related use cases like location augmentation, passenger guidance, traffic flow monitoring, people and vehicle tracking and payment solutions, as the following examples indicate.

- Bluetooth sensors installed at the ends of a road section can be used to measure link travel times by detecting BT devices in the vehicles. While less accurate than traditional traffic counting methods (e.g. inductive loops and number plate recognition cameras), Bluetooth sensors can provide sufficient information for traffic management purposes with easier and cheaper installations. [12, 13]
- In challenging urban environments, satellite-based positioning technologies (e.g. GPS) provide unreliable information about a user's exact location. Positioning in "urban canyons" or indoors (with weak or missing satellite signal) can be augmented with beacon based solutions to improve the accuracy and reliability of navigation services. [14]
- Beacons have been used for passenger guidance and information at e.g. bus stops, interchanges and airports. The beacons typically provide real-time information for travellers, e.g. schedules and waiting time at bus stop or gate and connection information at an airport. [15]
- Mobile and wearable applications that use beacons or RFID technology to detect approaching buses and notify passengers about approaching buses are becoming more common especially for assisting the visually impaired to use public transport independently [15, 16].
- Beacons can also be used as a part of different tracking solutions – either the moving beacons can be tracked or the objects passing by beacons can be followed up. Nartz et al. [17] have studied how beacons can be used to detect when passengers board and leave a vehicle. They also conclude that the vehicle boarding detection is possible with current beacon technology for ticketing purposes.
- Bluetooth is used at airports for sensing passenger flows to, for example, measure and inform passengers about queuing times for security checks [18].
- In the UK, for example, beacons are also planned to be used as a part of payment and ticketing systems. By using a BTLE-enabled mobile application, the passengers could have their tickets automatically verified as they walk through fare gates. [19]

As these selected examples already indicate, BT beacons will become an essential part of our traffic and transportation environment. Since the transmitters only broadcast beacon IDs (although, with Eddystone, a URL could be included in the beacon message), and the interpretations of these IDs and their contextual meaning is addressed by backend systems, a single location (e.g. a small parking lot, a bus stop, a bus or a metro train carriage) can be covered with a single beacon, which can be used for many purposes.

Co-sharing of beacon infrastructure

From an economic point of view, co-sharing (like resource sharing in mobile communications, [20]) this beacon infrastructure – without a need for multiple physical replications of beacon transmitters in a single space for different purposes – would be a desirable goal for enabling a rich service infrastructure. The same environment could be used beyond just ITS applications. For example, traffic hubs equipped with a beacon constellation can serve local shops for advertising while also providing traveller information.

An open and geographically widespread and co-shared beacon infrastructure will enhance open innovations. Both commercial companies and developer communities can utilize beacons for various new application and service offerings. The incentive to share an organization's own beacons IDs with others is being relieved of investing and maintaining their own management system. The practical issues of who owns and maintains this (or these) co-sharing service(s) and what are the related business models are important questions – but beyond this study.

To utilize and manage co-shared beacon infrastructures, a common data repository with a suitable data model is required. As the public transit environment can be highly heterogeneous and dynamic, there is a need for a versatile beacon data model that could be extended by application specific data. As part of the BOC system presented in the next section, we define a basic beacon data set that always contains the basic information (UUID, type, owner, installation date, and location) common to all applications.

Public transit requirements for a beacon data model

The traffic environment is constantly evolving and highly dynamic and, respectively, beacons can be either static (e.g. attached to permanent locations like bus stops or indoor traffic hub spaces) or can move with vehicles much like Radio Frequency IDentification (RFID) tags attached to objects in logistics.

Moving beacons set new requirements beyond the simple beacon management models based on a mostly static or slowly evolving beacon infrastructure assumption. In addition to basic beacon identification information tuples (e.g. ID, type, static location description) and maintenance information (e.g. beacon status, organization responsible for the maintenance), additional information fields should be provided:

- As beacons might constantly move, there should be a link to an additional location information – most probably to a beacon’s real-time location derived from other sources like GPS or an additional beacon infrastructure (from static beacons for example).
- For navigational aid, there is a need for detecting sometimes which way a person or an object is facing or if a person has passed a gate, where the gate could be a constellation of multiple related beacons, so the data model should have a support for beacon grouping addressing these needs.

- Since the beacon id advertisement message is visible to everyone, malicious parties may capture and reproduce beacon ids at different physical locations for harmful or illegal purposes. There should be security features like countermeasures for reproducing (spoofing) of beacon ids or at least means of observing reproduction attempts. As a result of these needs, some fields might be devoted to security related purposes for utilizing cryptographic solutions like Public Key Infrastructure (PKI).
- The data model should be extendable, addition of attribute value pairs needs to be supported to enable support for different information needs emerging in the future.

The requirements list presented above is the first modest attempt to define fundamental requirements that are essential to support ITS applications based on beacons. In the next chapter a prototype system utilizing some aspects of this identified new data model is introduced.

3. **Bluetooth beacon open co-sharing in public transit environment**

The concept

Figure 1 presents use cases of how beacons can be utilised in the context of catching a bus. The aim of these use cases is to illustrate how an application that is scanning for Bluetooth signals in the background (in this case, a mobile guide for public transit) can utilize the co-shared beacon infrastructure with the help of a beacon metadata repository.

- In Case 1 (Figure 1, 1-3), the user is walking to the bus stop. When a signal is detected the application queries the back-end identification service for what metadata is attached to the encountered beacon UUID. In this case, the service responds that the beacon is a bus stop. Also other context and metadata can be added, e.g. what is the exact location, what is the stop ID, etc.
- In Case 2 (Figure 1, 4-6), the user is waiting at a bus stop as the bus arrives. The bus has its own beacon installed and, by detecting it, the application knows that the arriving bus is the one the user is supposed to board.
- In Case 3 (Figure 1, 7-10), there are several beacons inside the bus cabin so the application can detect not only that the user actually boarded the right bus, but also which door was used and in which part of the bus the user stays in.

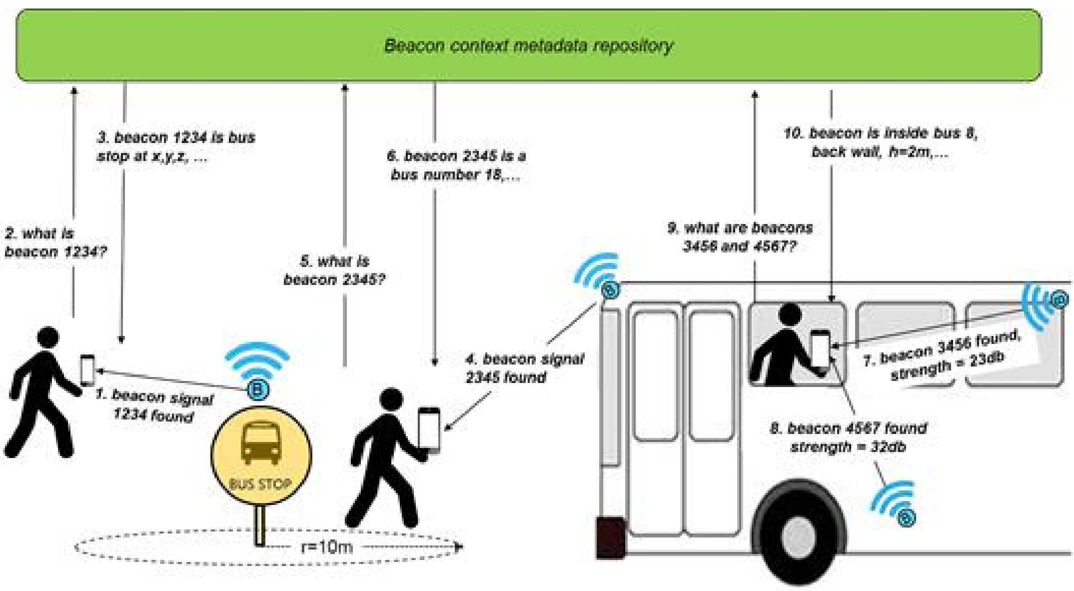

Figure 1. Three use cases of Bluetooth beacons in public transit context.

Figure 2 below illustrates an example of two separate BT beacon installations in a metro station:

- Beacon set 1 (blue) for traveller guidance: the application utilizes beacons for accurately detecting the transitions along the journey (walking, at stop, in vehicle).
- Beacon set 2 (red) for indoor navigation: the application can provide estimation of the user's location and direction of movement.

Figure 2. Example Bluetooth beacon installations in a metro station.

If both beacon sets are registered in a shared repository and use a common data model (id, type, model, location, etc.), it is possible for each application to utilize all the beacons. In addition, a third-party application, such as an advertisement service, could use the same beacons to trigger location-based notifications. Such open and shared beacon data repository can foster creation of novel services, innovation and business opportunities *BOC System*

To tackle the challenges and needs discussed in Section 2, our approach was to create a system for supporting the implementation and management of Bluetooth Beacon Open and Co-shared (BOC) installations. This experimental system is based on an open repository which provides management functionalities for the whole beacon installation life-cycle.

The BOC repository is constructed of three main components: the open beacon API, the beacon management API, and the core component, the database. The open beacon API contains interfaces for searching metadata based on the UUID key. It also enables searching for beacons in certain area or by certain parameters, such as a bus line. The beacon management API contains interfaces for registering, updating and deleting beacons. The database stores all the beacon related metadata. The high-level architecture of the BOC system is shown in Figure 3.

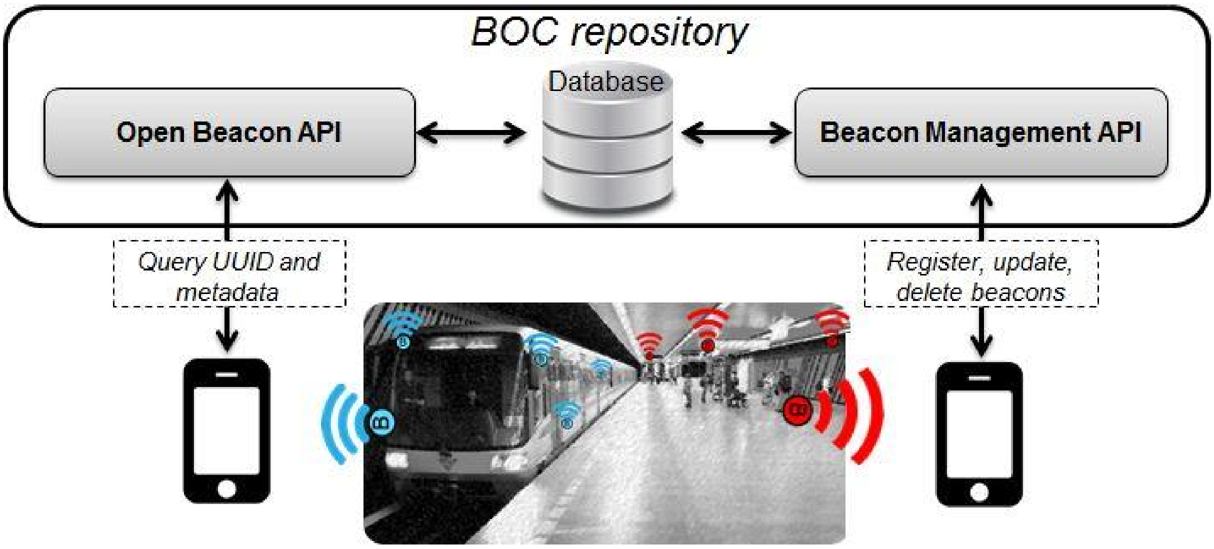

Figure 3. High-level architecture of the BOC system.

The core of the BOC is the database for storing context metadata for each beacon. Each beacon is identified by a Universally Unique ID (UUID) and the BOC manages a catalogue of beacon metadata indexed by the UUIDs. As a minimum, the metadata always contains the basic context information mandatory for all registered beacons, but it is also possible to add service specific tags. The beacon context metadata model is designed to be flexible and to enable different types of applications to utilize the same nodes. In addition, the BOC system provides management tools, e.g. for monitoring the status of the beacons by trying to automatically detect if a node runs out of battery.

For app developers who want to use these beacons for developing travel and other location-related apps, the BOC repository provides an API. For beacon owners (transport operators, advertisers, and third parties), the interfaces offer:

- managing their beacon infrastructure and tracking where they are placed.
- a simple mechanism to set the metadata associated with the beacons.
- a mobile application for installing and registering new beacons to the system.

The aim was to create a server-based repository for managing the Bluetooth beacon context metadata. Since the beacons themselves are typically only capable of one-directionally broadcasting their signature information, maintaining the beacon data is the responsibility of the server-based repository. It 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.

All the beacons registered to the repository are openly available to be used by other parties, such as third-party application developers. The Bluetooth beacons are identified by the 16-byte UUID that the beacons are broadcasting. The repository server manages a catalogue of beacon metadata that is indexed by the UUIDs.

Data model

To support the requirements of the BOC system in a public transit context, the beacon data model was designed to be both lightweight and flexible. The basic data set, mandatory for all beacons, contains only the minimum amount of data, such as owner, installation time, type, etc. For example the location is not mandatory and can be defined differently based on application needs. The beacon data is maintained in a domain object model, where the beacons can have a combination of physical and relative locations. 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.

It is also possible to easily add service specific information for the beacons. This can be simple attribute-value pairs to enable support for different information needs emerging in the future (e.g. *vehicle_type, Metro*), but this can also be used to create different layers of data objects on top of stand-alone beacon installations. As Figure 4 illustrates, the dynamic data model enables application developers to define higher level beacon node specifications, e.g. they can create *Gates* (with direction) using combinations of two nodes, or they can define different *Areas* based on multiple beacon nodes.

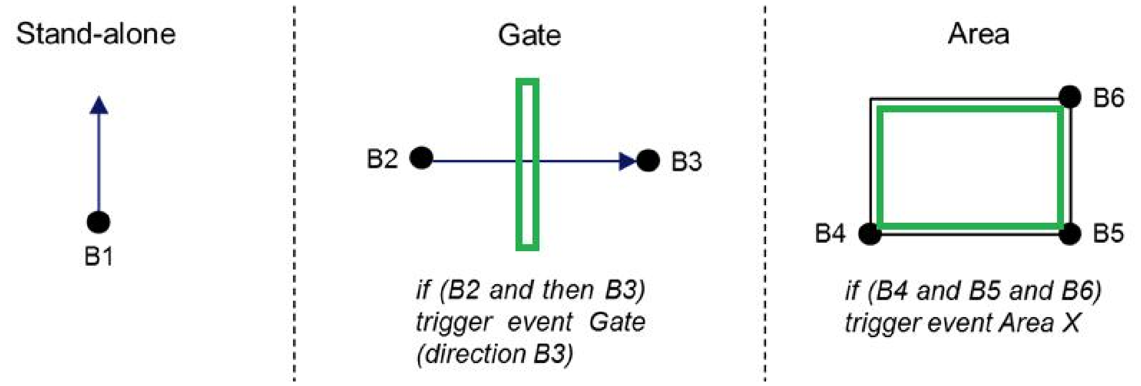

Figure 4. Beacon information layers.

Field Trial

In order to evaluate how the BOC system concept works, we conducted a small-scale pilot with an example application in real public transportation context. The aim of the pilot was to create a simple journey guidance application for the Helsinki metro system that would utilize Bluetooth beacons to offer timely and accurate guidance to the traveller. The pilot was conducted during December 2015 in Helsinki, Finland. The application developers utilized the BOC system for the beacon installations and registrations. They also created a set of metadata objects on top of the beacons to support their specific application needs.

The application scans available beacon signals, identifies them based on the UUID, queries available metadata from the repository and triggers appropriate events which can be used to guide the user more accurately while travelling by public transportation.

In the pilot, the Bluetooth beacons enabled the application to track the movement and position of vehicles and the user. With the signal levels measured from the combination of the Bluetooth beacons, the application was able to detect the following events; the user arriving to the stop, the vehicle arriving, the user stepping into the vehicle, the user stepping out of the vehicle, and when the user left the stop. Additional smoothing algorithms were needed to improve the accuracy due to the nature how the signals are received. More detailed description of the field trial setup and results regarding detection accuracy are described by Ahola et al (2016) [20].

Our experience with the application development phase indicated that with the BOC system pilot, it is easier and more cost-effective to create new applications utilizing Bluetooth beacons when the common components and their data are openly shared and well documented.

4. Conclusions

The constantly evolving and highly dynamic ITS environment sets some unique requirements to beacon management systems compared to more static application areas that utilize beacons, such as retail marketing. This paper presented a novel system for, and first field trial results of, Bluetooth Beacon Open Co-sharing (BOC) that defines a beacon data model and a shared repository to address these challenges.

The results of the pilot showed that the Bluetooth beacons have the potential to enable smart tracking of people in a public transit environment and that the method is practical for cost effective scaling of service development. While it was tested in the context of public transport, the same approach is applicable in other contexts as well.

The motivations for beacon infrastructure co-sharing are mostly economical. Unnecessary investments to both physical infrastructure and technical management can be greatly reduced when common components and data are widely available and accessible. For companies, it reduces the need to develop and maintain their own beacon management systems. For service developers, open common infrastructure can foster innovation and enable actors without their own beacons to create new solutions. For the end users, e.g. travellers, this means new services and more interoperability and coverage for existing ones.

There remain challenges and open questions related to the organisation and business models for operating the proposed beacon management repository. The value of the beacon network and related management service to the stakeholders involved varies based on their needs and usage. Other further research objectives include applying and testing the use of the beacon network and resource management model with different service providers and developers in a *Living Lab Bus* project that provides an open innovation environment by using real buses and real users in the Helsinki region as a concrete test platform for new technologies and services.

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