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A Building/environment Data Based
Indoor Positioning Service

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ABSTRACT

Despite years of efforts of research communities and industry on indoor position/location technologies and services, there is still no clear winner and no common standard today. By and large, existing indoor positioning services/systems (IPS) are not well suited for large public buildings/facilities such as train stations, airports, major hospitals, department stores, sports centers and theater complexes. Common characteristics of such buildings include complex and dynamic operating environment, large/fast fluctuations in density of people, criticality of IPS during emergencies and diversity in capabilities of user devices. Existing IPS do not address these challenges well enough to be easy to deploy and maintain, stay scalable in response to orders of magnitude surge in location queries, degrade gracefully to be disaster resilient, and minimize requirements of user devices to use the service.

   This report describes an IPS, called BeDIPS (Building/environment Data-based Indoor Positioning Service). It is designed to meet these high-level requirements of IPS for large public buildings. As its name implies, the service relies on a building and environment data/information cloud (BeDIC), which among other types of data, contains 3D coordinates and geometric models of every object of interest. In particular, it contains the coordinates of location beacons (called LBeacons), which the service uses to deliver location information to users. Basically, Lbeacons are a low-cost, Bluetooth Smart Ready device. At deployment and maintenance times, the 3D coordinates of every Lbeacon are retrieved from BeDIC and stored locally. Once initialized, each Lbeacon broadcast its coordinates to HereUAre, a simple messaging application on Bluetooth enabled mobile device nearby. Interferences among Lbeacons are minimized by partitioning the network of Lbeacons into subnets and having beacons in each subset transit in a time division multiplex manner. From the coordinates of all Lbeacons heard by the HereUAre on a device, the application can easily, and sufficiently accurately, estimate the coordinates of the device when the network of Lbeacons are sufficiently dense and well placed. The report presents the architecture and design of BeDIPS and discusses reasons for its feasibility.

1 Introduction

Despite years of efforts of research communities in areas on and related to indoor position/location technologies [1] and many big players (e.g., Google, Apple, Microsoft, Nokia, Qualcomm and Broadcom) racing to be leaders in the growing market of *indoor positioning service/system* (*IPS*), there is still no clear winner and no common standard [2] today. According to recent surveys such as [3, 4], many companies now offer IPS, each leveraging one or more location technologies [5-8].

Roughly, location accuracy in the 3 to 10 meter range is achievable by services (e.g., Skyhook Wireless [9]) that require only an application computing on off-the-shelf smart phones, tablets, or laptops, the location of the device based on strengths of received WiFi signals from known access points. Services aiming to provide better accuracy sometimes use non-standard signals and make more sophisticated measurements. Examples include measurements of phase differences of electric and magnetic fields of received signals in the 1-MHz range, phase differences of signals at 2.4 GHz frequencies, and visible light signals, acoustic signals and magnetic fields (e.g., [10-16].) Accuracy down to a fraction of a meter invariably require the use of *fingerprints*, each of which being a set of location-specific values of signal strength (i.e. a signal pattern). A fingerprint-based IPS has as a part of its infrastructure a sufficiently large database of fingerprints captured at different locations in the building during setup and maintenance times and a location server capable of matching the fingerprint captured and sent by each user at his/her location against fingerprints in the database. Types of fingerprints include patterns of WiFi signals from known access points, FM signals from multiple FM radio stations, acoustic echo patterns and background spectrum, and magnetic signatures of the building, etc. (e.g., [14-26]). Indoor location accuracy can be further improved by using fingerprints of multiple types of signals [27].

This report is concerned with indoor positioning within large public buildings/facilities. Examples include train, bus and subway stations; airports; large office buildings; major hospitals; department stores, large discount stores and shopping malls; sports centers and theater complexes and so on. A common characteristics of these places include that exits, direction signs and electronic bulletin boards are not within lines of sight from numerous locations, and a typical person may have difficulty finding his/her location and orientation inside the building. An IPS that can reliably provide users with sufficiently accurate location (e.g., near 0% error in floor information, approximately 3-meter horizontal location accuracy in large open halls and room-level accuracy in areas partitioned into rooms) via off-the-shelf cell phones and commonly used mobile devices can be helpful during normal times and is essential during emergencies.

Existing IPS, including the ones mentioned above, are not satisfactory solutions. Below are some of the reasons:

(1) Complex and dynamic operating environment: Some other characteristics of large public buildings are multiple floors with irregular floor plans; mobile carts carrying bags and people; and frequent remodeling, renovation and changes in interior facilities and layouts, and so on. These characteristics make fingerprint-based services expensive to set up and maintain. They may require sophisticated, adaptable fingerprint matching algorithms, and may not work reliably in many situations during emergencies.

(2) Large and fast fluctuations in density and density distribution of people: Massive crowd of people can occur regularly (e.g., during rush hours), sometimes (e.g., during holidays and special events) and unexpectedly (e.g., occurrences of emergencies). Accuracy of distance measurement based on received signal strengths may degrade. Services that rely on a server for fingerprint matching may not scale well enough to respond to large (sometimes by a few orders of magnitude) surges in location queries.

(3) Criticality of the IPS during emergencies: The positioning service is needed more than ever by victims, first responders, etc. in the building during emergencies while the support infrastructure may be damaged and location query traffic higher than normal.

(4) Diversity in capabilities of user devices: An IPS for large public buildings should be accessible by not only users with smart phones and devices but also people equipped only with dump phones and other low-end mobile devices.

This report describes an IPS that is designed to address these challenges. The service is called *BeDIPS* (*Building/environment Data-Based Indoor Positioning Service*). As its name implies, the service relies on a building and environment data/information cloud (BeDIC), which among other types of data about the building and its interior, contains the 3D coordinates and geometric model of every physical object of interest. In particular, it contains the coordinates of location beacons (referred to hereafter as *LBeacons*). Basically, Lbeacons are low-cost, low-power Bluetooth transmitters. Each Lbeacon has a small storage for storing its own coordinates (and a one-step navigation instruction for low-end devices). They are installed to provide coverage throughout the building and networked together with each other and with a server. At deployment/initialization and maintenance times, the BeDIPS server retrieves the 3D coordinates of every Lbeacon from BeDIC and loads the coordinates on the beacon. Once initialized, the server steps out of the way. Each Lbeacon broadcasts, either on a periodic basis or upon request, its coordinates to HereUAre, a simple messaging application on Bluetooth enabled mobile devices nearby. As we will show later in the report, from the coordinates of Lbeacon(s) heard by the application on a mobile device, the application can easily, and sufficiently accurately, estimate the coordinates of the device when the network of Lbeacons are sufficiently dense and beacons themselves are well placed.

We note that the approach taken by BeDIPS is proximity detection [5, 29]. Lbeacon is similar to iBeacon [30] from Apple Inc. iBeacons are designed to notify nearby high-end smart devices (e.g., iOS devices with Bluetooth 4.0 and Android 4.3 devices) of their UUID's and rely on the devices to look up their locations. In contrast, LBeacons must be able to deliver location/positioning data to a broad spectrum of device without the help from the Internet. In this way, LBeacons more closely resembles many other existing Bluetooth products for proximity marketing [31]. We will compare and contrast LBeacons with them in Section 4 where the design of LBeacon will be described. Lbeacon is also similar to the radio tag used for proximity detection in the indoor positioning system described in [32]. The difference is that their radio tags are used together with WiFi fingerprints, while LBeacons work alone to deliver location information to users.

Following this introduction, Section 2 presents the high-level requirements of indoor positioning systems for large public buildings in general and the underlying assumptions of BeDIPS specifically. The section also presents evidences to justify the validity of the assumptions, motivates the design choices of BeDIPS and presents the rationales. Section 3 presents the architecture and components of BeDIPS and elaborates the requirements of

Lbeacons. Section 4 presents the design and implementation of Lbeacons and the Lbeacon network. Section 5 summarizes the report and presents our future plans.

2. Assumptions and Motivations

From the observations on user demands and complex operating conditions of indoor positioning systems presented in Section 1, we can deduce the following high-level requirements of IPS for large public buildings, building complexes and facilities:

- *Scalability* – Degradation in performance should be acceptably small during orders of magnitude surge in crowd density and location queries. Here and hereafter, by performance of the service, we mean (average and deviation in) location accuracy and location query response time.

- *Graceful degradation* – The service should be disaster resilient, meaning that it degrades gracefully, capable of providing location information for as long as some parts of its support infrastructure are still intact.

- *Compatible user interfaces* – The IPS can support applications that exploit capabilities of smart phones and devices to provide web and GUI interfaces similar to modern interfaces to outdoor positioning services.

- *Minimal user device requirements* – More importantly, the service should minimize the capabilities of user devices required to access the service. Ideally, any, or almost any, mobile phone usable for originating an indoor emergency call can be used to get the caller's location sufficiently accurately[1].

- *Easy to deploy and maintain* – Updates in IPS infrastructure elements required to take into account changes in physical and functional characteristics of the building during its lifetime can be reliably, systematically and simply made. The health of the system, including the health of individual components such as Lbeacons, can be reliably monitored at low cost and with little or no performance overhead.

(A) Design Rationales

The design choice of using Lbeacons as the means for delivering location information to mobile user devices is motivated primarily by the scalability and graceful degradation requirements. As we will show in Sections 3 and 4, the functions of the BeDIPS server are limited to initialization, monitoring and maintenance. During runtime, Lbeacons operate essentially independently and for as long as they are powered. The load on each beacon is limited by the maximum number of user devices within its coverage area, and the beacon can be designed to produce an acceptable response time under maximum load.

To make the discussions here concrete without loss of generality, we assume here that the minimum requirements of user devices for accessing BeDIPS is the capability of supporting a low bandwidth (say around 30 kbps) application (called HereUAre earlier) for receiving 3D coordinates in a standard format via Bluetooth. The vertical coordinate provided by BeDIPS

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[1] None of the IPS described in Section 1 work well, if it works at all, for users with only dump phones. This is the reason that the US TIA (Telecommunications Industry Association) in a recent US FCC filing states that indoor location technology is not fully developed to meet the vertical location accuracy of 3 meters for 67 percent and 80 percent of wireless 911 calls originated indoors and proposes to require a horizontal accuracy of 50 meters for these calls [28].

to each user is in terms of the floor where the user is, not the actual vertical coordinate of the user or the Lbeacons nearby serving the user. In other words, the vertical coordinate (e.g., B8, G, M, 1, …, 101) can be represented by a string of 4 or fewer characters. They can be easily translated into the corresponding vertical coordinate in one of the standard formats (e.g., [33]) used by common maps and directions APIs. The horizontal coordinates broadcast by every Lbeacon is its own horizontal coordinates relative to the southwest corner of the building. Since each degree of latitude is approximately 111 kilometers and each degree of longitude is at most approximately 111.321 kilometers apart, the latitude and longitude of any point within a building down to centimeter accuracy can be specified by a string of 8 digits each. In short, the coordinates broadcast by each Lbeacon is a string of fewer than 24 characters.

Hereafter, we will say that the user device is a cell phone. How the received coordinates are used clearly depends on the capability of the phone. To serve dumb phones, the broadcast from Lbeacons may contain a one-step navigation instruction, in the form of a short text message, to be delivered to the user. On a smart phone, tablet or laptop, the coordinates, or some function of it, can be used as input to an indoor maps API and directions API [33] used by the user device.

(B) Building/Environment Data and Information Cloud

The primary reason that BeDIPS is easy to install, configure and maintain is its effective use of data and information in a BeDIC for installation and maintenance purposes. This repository of building and environment data (BeD) is created and maintained throughout the lifetime of the building for purposes from design, architect and construction of the building, to managing and control its facilities while the building is in use, and so on. The fact that it can provide the data for the indoor positioning purpose in general and support BeDIPS specifically is a benefit gained at negligible additional cost. We present now a brief overview of BeDIC to support the assumption on the existence of such repositories for large public buildings in most part of the developed world.

Specifically, BeDIC is the name used here to mean a physical or virtual repository of building and environment data. In general, the repository contains a subset of

- Data in *BIM* (*Building Information Model*) [34] of the building,
- Data on its internal facilities and layouts, and
- Data generated and used for facility management and building automation purposes.

BIM refers to files on the structures of the building; locations of its walls, doors, windows, stairwells, elevators, etc.; electricity, water and communication utilities, including locations of lights, wall plugs, and sensors; and so on. Together, the files give a complete digital representation of physical and functional characteristics of the building. Today, open national and regional BIM standards have been developed and adopted by AEC (Architecture, Engineering, and Construction) industries in an increasingly larger part of the developed world [35-43]. The growing list of BIM solution providers, the emergence of open source BIM software, and test and certification systems for ensuring seamless connections of data from different BIM solutions will further help to accelerate the rate of adoption [44-46].

BIM can also incorporate dynamic information about the building needed to support building operation and maintenance [47]. Furthermore, XML-based data exchange standards (e.g., [48, 49]) enables lightweight deliveries of subsets of BIM other than geometric models. So, it is not surprising to see the integration of BIM into facility management systems (FM)

and the emergence of BIM-based FM Services (e.g., [50, 51]) and the integration of BIM with building automation systems (BAS) based on building automation model and interchange standard [49, 52, 53].

Another important trend is the use of BIM during the lifecycle of government buildings and construction projects in developed countries. The USA has been a leader [35, 41]: Starting from 2007, submissions for final concept approvals of all federal government building projects must include spatial program BIM. Since then, the National 3D-4D-BIM Program of GSA (General Service Administration), which is responsible for space of all federal agencies in US, has established policies to phase in 3D-4D BIM adoption for all major projects and created further incentives for use of 3D-4D-BIM. GSA also developed BIM toolkits, publishing BIM guides, establishment knowledge portal community, etc. to support best practices in BIM process. Today, Canada, South Korea, and a majority of European countries require the use of BIM in public construction projects. Singapore issued its BIM implementation roadmap in 2011, and starting from 2015, BIM submission will be required for approvals of new building projects over 5,000 square meters. Similarly, UK government will require the use of BIM in all public sector projects starting from 2016. BIM has been included as part of China's 12th Five Year Plan (2011 – 2015).

In short, we can assume that in the near future, every public building/facility of some specified size or bigger in developed countries is served by a BeDIC, a virtual or physical building and environment data cloud. The cloud holds BIM, FM and BAS data on the building, as well as data on interior floor plans and layouts in some standard format (e.g., Open Floor Plan Standard [54]). In addition to providing 2D and 3D geometric models, the cloud supports digital exchange standards exemplified by the ones mentioned above for retrieving from it the coordinates of all objects of interest, including electric sockets, light fixtures, etc. In particular, the exact 3D coordinates of every Lbeacon used in BeDIPS can be retrieved from the cloud if it is mounted on a wall or a window/door frame, next to a light, etc. and hence, is represented by some datasets in BIM. Moreover, when BIM is used throughout the building lifecycle, the coordinates are kept up to date automatically during remodeling, renovation and maintenance since the underlying BIM datasets on physical and functional characteristics affecting the coordinates are updated in the BIM process.

(C) BeDIPS Development Environment

Figure 1 illustrates the keystone role of the building/environment data and information cloud (BeDIC) within a development environment that supports the design, deployment and maintenance of a BeDIPS for a large public building complex. Specifically, the lower part of the figure shows the usage of 2D and 3D geometric models of the building interior provided by the cloud and digital exchange standards supported by it.

The process of design and deployment of a positioning system starts from the selection of the types of Lbeacon for each area in the building from available types of beacons with different ranges and antennas. Graphical tools built on the geometric models can help the developer select the right type of Lbeacons for each place, experiment with the placements and orientations of the selected beacons, visualize and assess the coverage provided by them, and upon finding a satisfactory design, generate the coordinates and technical specifications of the beacons. Such a design and development tool can be built on existing 2D and 3D visualization tools similar to the tools provided by BIM-based facility management systems (e.g., [49, 50]). Similar tools for identifying and displaying malfunctioned beacons can also

be built as extensions of 2D and 3D graphical facility management tools. The design and implementation of these tools are outside the scope of this report. They will be presented in a later report.

Figure 1 BeDIC in BeDIPS development environment

3 Architecture and Key Components

Figure 2(a) shows the structure and components of BeDIPS. The workhorse of the system is the network of Bluetooth location beacons (i.e., Lbeacons) installed throughout the building. The other major component is the BeDIPS server.
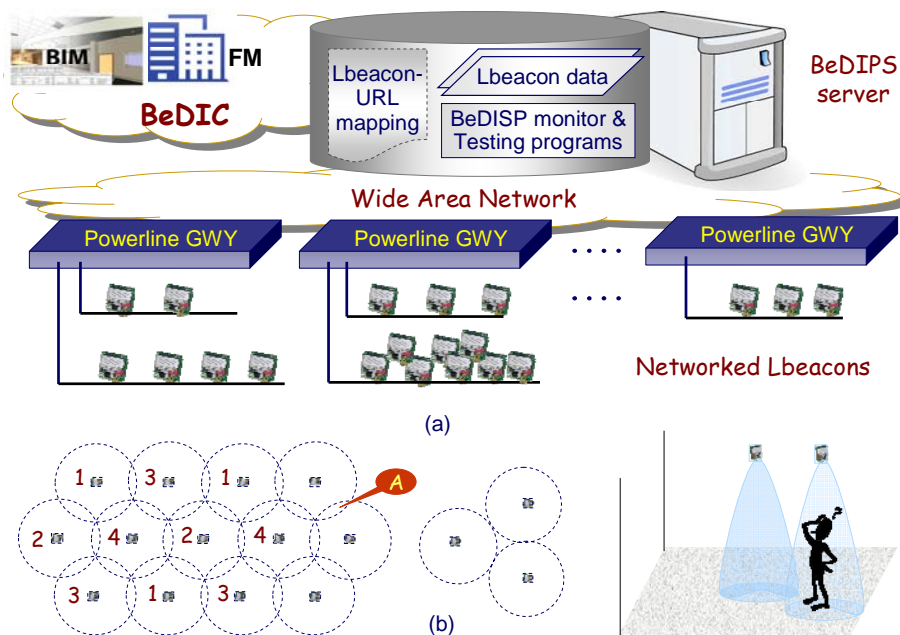

Figure 2 (a) Structure and components of BeDIPS and (b) Lbeacon coverage

(A) Operations of Location Beacons

Like smoke detectors in modern buildings, Lbeacons are AC powered. Beacons serving each area in the building are connected by a powerline sub-network and all sub-networks are connected via gateways to the building's wide area network and the BeDIPS server. Once initialized by the server, each beacon contains locally its own coordinates. It periodically, or upon request, pushes a text message containing its own coordinates to Bluetooth devices in its coverage area. Figure 2(b) shows possible configurations and placements of Lbeacons for good coverage and small position errors. Each dashed circle or oval represents the coverage area of a beacon. The beacons have unidirectional antennas with conical beams, as shown in the rightmost part of the figure. They are installed on ceilings, near where light fixtures and smoke detectors are, for example. Their antennas point downward to the floor. The range of every beacon being no more than the ceiling height, no device below the floor can hear it. This is a simple way to ensure zero error in the vertical position.

At some locations (e.g., in a big exhibition hall), Lbeacons may have overlapping coverage in patterns similar to the one shown in the left part of Figure 2(b). In this case, the horizontal position error is the radius R of the beacon beam (e.g., 2-3 meters). The middle parts of Figure 2(b) and Figure 1 show incomplete coverage patterns. Such patterns may be acceptable in some parts of the building. Take the office area shown in center part of Figure 1 for example. A reasonable design goal here is to provide room-level accuracy. By accepting small blind spots in coverage, the number of Lbeacons can be reduced[2].

It is possible to achieve horizontal position errors smaller the radius of beacon beams if devices in areas covered by multiple beacons can receive the coordinates of the beacons. For example, if phones in the area A in Figure 2(b) can receive the coordinates of both Lbeacons covering the area, the error in their positions computed from the coordinates is only a fraction (approximately 1/4) of R. This improvement can be achieved by having beacons with overlapping coverage transmit in a time-division multiplexing manner. For example, Lbeacons in a large exhibition hall may have a coverage pattern similar to the one shown in the left part of the Figure 2(b). In this case, a TDMA frame with four data slots will do.

Before moving on, we note that Lbeacons lacks the intelligence necessary to distinguish smart phones from dumb phones. It treats all of them like dumb phones and includes in its message a description of the location (e.g., "south-east corner of the lobby" and "A4", the grid index of the location), in addition to its own coordinates. The message from each beacon may also contain a one-step navigation instruction to the nearest exit. Examples of instructions include "Go out the door, turn right" and "move forward 3 meters and look for your location again". The latter intends to provide the beacons with information on user's orientation in order to enable them to provide more accurate navigation instruction. This capability would require the knowledge about the last Lbeacon visited by the user before arriving at the coverage area of the current Lbeacon. This knowledge can be provided to the current beacon without having the system actively track the user (i.e., his/her phone). A way is the one used in the campus navigation system CANPAs [55]: When invoked under the

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[2] A rough estimate of the number of Lbeacons required for 2-5 meter horizontal position accuracy is 1.5-2 times the number of smoke detectors in the building. A place such as Frankfurt airport, where there are 50,000 smoke detectors, would require almost 100,000 beacons.

coverage of the current beacon, HereUAre on user's phone sends the coordinates of the last Lbeacon received by the device. We will leave this feature to be considered at a later date.

(B) More on BeDIPS Server

As stated earlier, at deployment/initialization and maintenance times, the BeDIPS server retrieves the 3D coordinates of every Lbeacon from BeDIC, stores them locally and loads the coordinates of each Lbeacon on the beacon. Another important function of the BeDIPS server is health monitoring. Periodically, the server prompts each Lbeacon for a heartbeat message containing the coordinates of the beacon. This is done through the powerline network to the server and hence, does not interfere with the normal operations of the beacons.

We note that the BeDIPS can be easily extended to support proximity marketing and other location based services. To illustrate this point, Figure 2(a) shows that BeDIPS server stores a mapping which associates each beacon with one or more URL's. A use scenario is that the server provides stores, offices, building managers, etc. with a tool using which they can enter URL's to web pages containing information (e.g., advertisements and announcements) specific to the location at and in neighborhood around selected beacons. At initialization and update times, the server also down loads to each beacon URL's mapped to the beacon. The URLs are also broadcast to users by the beacon along with its coordinates.

4. Lbeacons and Lbeacon Network

Figure 3 shows the block diagram of a typical Lbeacon. The device has a dual-mode Bluetooth module and a powerline networking module, together with application components that work with the BeDIPS server for setup, initialization, maintenance and health monitoring purposes. It is simple enough to be implemented as a SOC (system on chip).
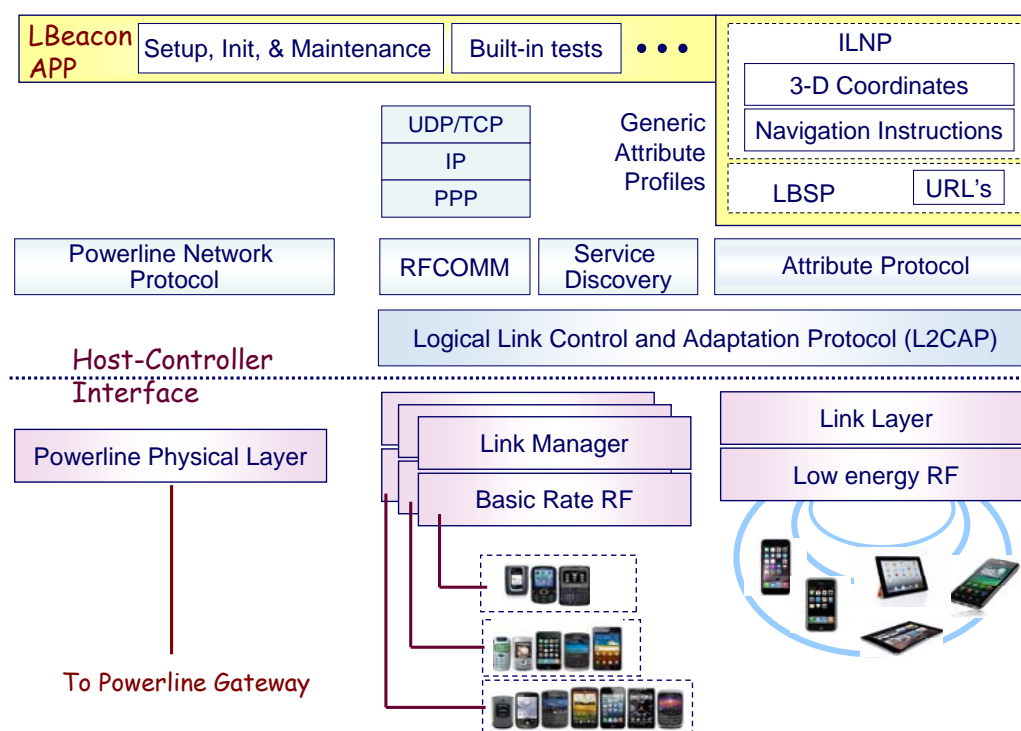
Figure 3 Location beacon with a dual-mode Bluetooth module

The primary function of Lbeacon is provided by the Bluetooth Smart Ready (i.e., dual mode) module shown in the middle and right parts of Figure 3. The discussion here assumes only features of Bluetooth 4.0 [56, 57], specifically, the coexistence of Bluetooth Lower-Energy (LE) and classic Bluetooth basic rate (BR) protocol stacks. (For our application, Bluetooth 4.1 and 4.2 offers some clear advantages: As pointed out by [58], advantages of version 4.1 include coexistences of Bluetooth and LTE, manufacturer specified reconnection timeout intervals and capability of a device to be both as a hub and an end-point simultaneously. We will investigate how to leverage these advantages at a later time.)

As shown in Figure 3, both LE transport and BR transport start from the Generic Attribute Profile *ILNP* (*Indoor Location and Navigation Profile*). ILNP is not yet defined. Roughly, it resembles the existing LNP (Location and Navigation Profile) [59]. LNP defines two roles: LN sensor and collector. LN sensor is a server device that reports location, elevation, and/or navigation data, among other data. Collectors are client devices that receive the data. The profile enables clients to connect and interact with a location and navigation server for use in outdoor activity applications. In case of ILNP, each Lbeacon is a LN sensor and server, while collectors are HereUAre applications on Bluetooth mobile devices under the coverage of the beacon. Ideally, ILNP should be defined as a version of LNP and thus enable applications implementing the profile to work both indoors and outdoors.

Also shown in the Figure 3 is the LBSP (Location-Based Service Profile) for use by proximity marketing and location-based notification applications. Support for these types of applications on Bluetooth Smart devices is provided by LNP in the form of the UUID and local name of the location and navigation service; these characteristics are additional LN Sensor requirements of the LE transport. The UUID enables the client applications to look up via Internet the location of the LN sensor and information specific to the location. The rationale behind having LBSP provide URL's directly is that the location of the sensor (i.e., the beacon) is known.

Bluetooth LE is ideally suited for exchanging tens of bytes of data between the server and a large number of client devices. Bluetooth LE only mode suffices for LN sensors (e.g., iBeacon [30]) that do not aim to serve legacy devices (i.e., devices with Bluetooth BR only protocol path). Today, the majority of mobile phones remain to be legacy devices. Being required to serve them as well, LBeacon also has the BR protocol path shown in the middle of Figure 3. The design of the bottom layer in this path is based the results of a study [60] on limitation of Bluetooth BR only for pushing messages to devices discovered on the fly. Specifically, because each dongle (i.e., Bluetooth BR interface) can only manage connections to at most 7 clients simultaneously and in the coverage area of a Lbeacon of 9 square meters there can be as many as 20 people/client devices, three dongles are used. Experiment data in [60] show that even with 3 delivery dongles, the maximum number of connections reached is only 14 when the test is done indoor. In contrast, the maximum number of connections is 21 for tests done outdoors[3].

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[3] Specifically, the data from [60] on the number of simultaneous connections reached versus the number of delivery dongles are: 7 for 1 dongle, 13 (out of 14 possible) for 2 dongles and 14 (out of 21 possible) for 3 dongles (due to interference?), Also, according to [60], typical Bluetooth-based proximity marketing products available at the time (i.e., 2009) can manage 7 - 21 connections. Some of the more expensive products are able to handle up to 28 connections,

Finally, each Lbeacon also has powerline network protocol modules which enables the beacon to be connected to the BeDIPS server and thus, enables the server to reach the beacon for purposes of health monitoring and maintenance. This is the primary reason for the network. The presence of the network also enables the coordination of Lbeacons that have overlapping coverage. We will investigate the feasibility and effectiveness of having Lbeacons with overlapping coverage clock synchronized and work in TDM (time division multiplexing) mode in order to enable the receipt of the coordinates of all the beacons by clients in areas where their coverage overlap.

5. Summary and Future Work

The proposed BeDIPS (Building/environment Data-based Indoor Positioning System/service) described in the previous sections aims to enable people in large public buildings to locate themselves sufficiently accurately via diverse cell phones and commonly used mobile devices. By sufficiently accurately, we mean no error in floor information, approximately 3-meter horizontal location accuracy in large open halls and room-level accuracy in areas partitioned into rooms. BeDIPS delivers location information using Lbeacons. They are low-cost, Bluetooth Smart Ready devices and are installed pervasively throughout the building. At deployment and maintenance times, the BeDIPS server loads the 3-D coordinates of each Lbeacon on the beacon. After initialization, each Lbeacon essentially functions standalone, broadcasting its coordinates to Bluetooth enabled devices in its coverage area. Because of this design, BeDIPS is scalable, degrades gracefully, and imposes minimal requirements on user devices to use the service. Moreover, we expect that the system is easy to deploy and maintain for reasons presented in Section 2.

In the near future, we plan to develop the ILNP either as a new GATT profile or an extension of existing LNP. We will implement and evaluate proof-of-concept Lbeacons. Specifically, we will evaluate their effectiveness and performance experimentally in terms of responsiveness and scalability[4]. The next step is to build and evaluate parts of prototype BeDIPS in two or three representative public buildings.

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