A Building/environment Data Based Indoor Positioning Service

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***Abstract*—In addition to being able to provide accurate location information, indoor positioning services/systems (IPS) for large public buildings/facilities should be easy to deploy and maintain, stay scalable in response to surges in crowd density and location queries, minimize the capabilities required of user devices to use the service and degrade gracefully to be disaster resilient. This paper describes an IPS with these attributes. It is called BeDIPS (Building/environment Data-based Indoor Positioning System). Location beacons used by the system to deliver location information to users are simple Bluetooth Smart Ready devices. The paper describes the architecture, design and proof-of-concept prototypes of BeDIPS and the development tools to support its design, deployment and maintenance.**

***Keywords*— indoor positioning; location beacons; Bluetooth Smart Ready devices**

I. Introduction

Despite years of efforts of research communities on indoor positioning/location technologies [1,2] and many big players [3,4] (including Apple, Google, Microsoft, and Qualcomm) and over sixty startups [5,6] racing to be leaders in the growing market of indoor positioning services/systems (IPS), there is still no clear winner and no common standard today. As an evidence of the dismal state of the art, a goal stated in the road map published by USA FCC (Federal Communication Commission) earlier in 2015 is to find, over the next four years, indoor mobile locating methods that can pinpoint a caller's location within about 50 meters if the call is made indoors via a mobile phone [7].

A reason is that existing IPS typically do not work well within complex, large public buildings/facilities, such as transport hubs, major hospitals, and large department stores. In such buildings, exits and direction signs are often not insight. IPS that can reliably help people to locate and navigate themselves are essential, during normal times and emergencies. For this purpose, IPS for large public buildings should have the four attributes presented below, in addition to being able to provide sufficiently accurate location information. Fig. 1 illustrates the environment in which the systems operate and why these attributes are essential.

First, the system must be scalable. Orders of magnitude surges in crowd density and location queries may occur daily and during holidays, special occasions and emergencies. Degradation in performance when surges occur should be small. Here, we measure performance of the service by the average and standard deviation of location accuracy and average response time of location queries.

Fig. 1. Operating environment and requirements of IPS for public buildings

Second, the system must be easy to configure, deploy and maintain. Spatial, physical and functional characteristics of large public buildings and building complexes often change due to repairs, renovation and reconfiguration. It is important that updates of the IPS required to take into account the changes can be made systematically and easily. Moreover, the health of the system can be reliably monitored at low cost.

Third, graceful degradation is an essential attribute. The system should be capable of providing location information even when large parts of it are severely damaged. In particular, it should function without Internet and cell phone coverage.

Fourth, most importantly, the capabilities required of user devices to use the service should be minimal. Ideally, any cell phone usable for originating an indoor emergency call can be used to get the caller's location sufficiently accurately. BeDIPS is short of being ideal in this aspect: It requires Bluetooth enabled mobile phones and devices. However, it works for both feature and smart mobile phones.

By and large, existing IPS built on a wide range of technologies do not have the above mentioned attributes for

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reasons presented in the next section. In contrast, the indoor positioning system described in this paper does. The system is called *BeDIPS* (*Building/environment Data Based Indoor Positioning System*). 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 3D coordinates and geometric models of every physical object of interest in the building. In particular, it contains the coordinates of location beacons, referred to as *Lbeacons* hereafter. Section V will describe them in detail. For now, it suffices to note that Lbeacons are low-cost Bluetooth transmitters. They are installed to provide coverage throughout the building and networked together with the BeDIPS server. Each Lbeacon stores its own coordinates. At deployment and maintenance times, the server retrieves the 3D coordinates of every Lbeacon from BeDIC and loads the coordinates on the beacon. Once the system is initialized, the server steps out of the way. Each Lbeacon broadcasts its coordinates either on a periodic basis or upon request. The intended receivers are simple applications on Bluetooth enabled mobile devices nearby. We refer to the applications as *HereUAre* when there is no need to be specific. From the coordinates of Lbeacon(s) heard by HereUAre on a mobile device, the application can easily and accurately estimate the coordinates of the device when Lbeacons are sufficiently dense and well placed.

The contribution of this work is a practical approach to providing indoor positioning services for large public buildings and places. An enabler of the proposed BeDIPS is building information models (BIM) [8]: BIM of a building refers to files on the building and objects of interest in it (e.g., windows, doors, elevators, electric outlets and, if the building has a BeDIPS, Lbeacons). Together, the files give a complete digital representation of physical, functional and spatial characteristics of the building and the objects. BIM and associated data exchange standards have been adopted increasingly widely in developed regions of the world in recent years.

BeDIPS is made possible by using BIM data innovatively. To illustrate, we consider Frankfurt Airport as an example: The transport hub has approximately 50,000 smoke detectors. It will need two or three times more Lbeacons to achieve 3-5 meter and room-level location accuracy. The tasks of selecting the location of each beacon, determining the coordinates of the location and placing the beacon at the coordinates would be prohibitive without the BeDIPS development tools described in Section III. With the tools, however, the tasks are only slightly more demanding than the task of deploying RFID tagged smoke detectors [9] throughout the facility.

Following this introduction, Section II presents an overview of indoor positioning technologies, examples of systems built on the technologies, and the reasons preventing the systems from having the above mentioned attributes. Section III presents the motivation, assumptions, and design rationales of BeDIPS, together with a BIM-based development environment that supports the configuration and deployment of BeDIPS. Section IV presents the architecture and key components of BeDIPS. Section V presents the design and implementation of Lbeacons and the Lbeacon network. Section VI summarizes the paper and presents our future plans.

II. Related Work

Roughly, location accuracy in the 3 to 10 meter range is achievable by pure RSS (Received Signal Strength) and triangularization based systems. Such systems (e.g., Skyhook Wireless [10]) 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 access points at known locations. This type of IPS can be expensive to maintain when the number and locations of WiFi access points change frequently [3]. Moreover, their location accuracy may degrade when large variations in numbers and densities of people and objects they carry and carry them cause significant and unpredictable fluctuations in received signal strengths.

Systems aiming to provide significantly better accuracy (e.g., down to a fraction of a meter) often use non-standard signal(s) (e.g., low frequency signals, ultra-wideband signals, visible light signals, acoustic signals, and magnetic fields) and/or make more sophisticated measurements (e.g., measurements of phase differences of electric and magnetic fields of received signals in the 1-MHz range, near field of low frequency signals, and phase differences of signals at 2.4 GHz frequencies) [11-19]. A disadvantage of these approaches is that special user devices are required. Systems that use visible light signals clearly do not work during fire emergencies.

Fingerprinting offers another way to improve location accuracy. The term *fingerprint* refers to a set of location-specific values of signal strength (i.e. a signal pattern). Types of fingerprints used for indoor positioning include patterns of WiFi signals from known access points, FM signals from multiple radio stations, acoustic echo patterns and background spectrum, and magnetic signatures of the building [17-29]. A fingerprint-based IPS has as a part of its infrastructure a large database of fingerprints captured at different locations in the building during setup and maintenance times and a location/fingerprint server. To determine its own location, a mobile device sends the fingerprint captured by it at its location to the server and relies on the server to find the location(s) with matching fingerprint(s). Location accuracy can be further improved by using fingerprints of multiple types of signals [30]. In addition to requiring user devices with the capability of capturing fingerprints and high cost of maintaining a database of fingerprint-to-location mappings, scalability is a serious shortcoming with all fingerprint-based systems.

In essence, the approach taken by BeDIPS is proximity detection [2, 31]. Lbeacon is similar to iBeacon [32] from Apple Inc. iBeacons are designed to notify nearby smart devices of their own universally unique identifiers (UUIDs), based on which the devices can look up their approximate locations. In contrast, Lbeacons are designed to deliver location data to a broad spectrum of devices without the help from the Internet. In this way, Lbeacons more closely resembles many other existing Bluetooth products for proximity marketing [33]. We will compare and contrast Lbeacons with them in Section VI 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 [34]. The difference is that their radio tags are used together with WiFi fingerprints, while Lbeacons work alone to deliver location information to users.

III. Motivation, Assumptions and and 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 IV and V, 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.

A. Assumptions

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 simple application (called HereUAre earlier) for receiving 3D coordinates in an internal geo-coordinate format via Bluetooth. Moreover, we assume that the user devices are cell phones hereafter except for where it is stated otherwise. The vertical coordinate provided by BeDIPS to each user is in terms of the floor/level 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 are B8, G, 1, 2 …, 101 or -8, 0, 1, 2 and so on, for example. 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 characters each. In short, the coordinates broadcast by each Lbeacon is a character string that can easily fit in a 128-byte Bluetooth packet [35].

What the HereUAre application is and how the received coordinates are used by the application clearly depends on the capability of the phone. On a smart phone, the application can easily translate the coordinates received from the beacon into the corresponding coordinates in the WGS (World Geodetic System) standard coordinate system or an indoor coordinate standard and use them as input to APIs of the indoor maps (e.g., Google Indoor Maps [36]) used by the phone.

The internal coordinate format aims to minimize the need for translation by HereUAre on low-end mobile devices: To serve feature phones, for example, the broadcast from Lbeacons also contain a short text description of the location (e.g., Level 2, RM 201 and Lobby, south-west corner). It may also contain a one-step textual navigation instruction to be delivered to the user. Indeed, by letting Lbeacons stores and broadcast such textual descriptions, the need for feature phones to have HereUAre can be eliminated.

Fig. 2 illustrates these assumptions: What the user of a smart phone may see on his/her phone is illustrated by the left half of Fig. 2. The image of Google indoor map is from [36]; it can be easily generated by HereUAre from the coordinates received from a Lbeacon. What the user of a feature phone may see is illustrated by the left half of Fig. 2. We will elaborate how the navigation instruction to the nearest exit of the building can be generated in Section V.

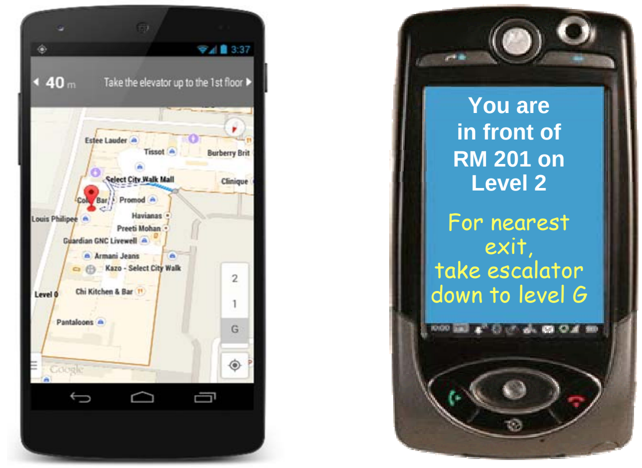

Fig. 2. Examples of displays generated by HereUAre on a smart phone and on a feature phone. Image on the left is from [36]

B. Building/Environment Data and Information Cloud

The primary reason that BeDIPS is easy to install, configure and maintain is its use of data and information in the *Building/environment Data/Information Cloud* of the building for configuration, installation and maintenance purposes. This repository, called *BeDIC* for short, contains selected parts of the database that is created and maintained for purposes from design, architect and construction of the building and managing its facilities while the building is in use. 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 justify the assumption on the existence of such repositories, or that they can be easily made available, 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) [8] of the building, data on its internal facilities and layouts, and data used for facility management and building automation purposes. Again, BIM files of a building give a complete digital representation of physical, functional and spatial characteristics of the building and objects in it. Today, open BIM standards have been developed and adopted by AEC (Architecture, Engineering, and Construction) industries in an increasingly larger part of the developed world [37]. 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 further help to accelerate the rate of adoption [38-40].

BIM can also incorporate dynamic information needed to support building operation and maintenance [41]. Furthermore, XML-based data exchange standards (e.g., [42]) enables lightweight deliveries of subsets of BIM. So, it is not surprising to see the integration of BIM into facility management systems (FM), the emergence of BIM-based FM Services (e.g., [43, 44]) and the integration of BIM with building automation systems (BAS) [45].

Another important trend is the mandated use of BIM during the lifecycle of government buildings and construction projects in developed countries. These facts leads us to assume that now and in the near future, every public building/facility of some specified size or larger in developed countries is served by a BeDIC. The virtual or physical building and environment data 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 [46]). In addition to providing 2D and 3D geometric models, the cloud supports digital exchange standards for retrieving from it the coordinates of all objects of interest (e.g., electric sockets, light fixtures, and smoke detectors). In particular, the exact 3D coordinates of every Lbeacon can be retrieved from the cloud if the beacon is mounted on a wall or a window/door frame, next to a light, etc. and hence, is characterized by some datasets in BIM. The coordinates are kept up to date during remodeling, renovation and maintenance since the BIM datasets on the characteristics affecting the coordinates are updated in the BIM process.

C. *BeDIPS Development Environment*

Fig. 3 illustrates the key 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 Fig. 3 shows the usage of 2D and 3D geometric models of the building interior provided by the cloud and digital exchange standards supported by it.

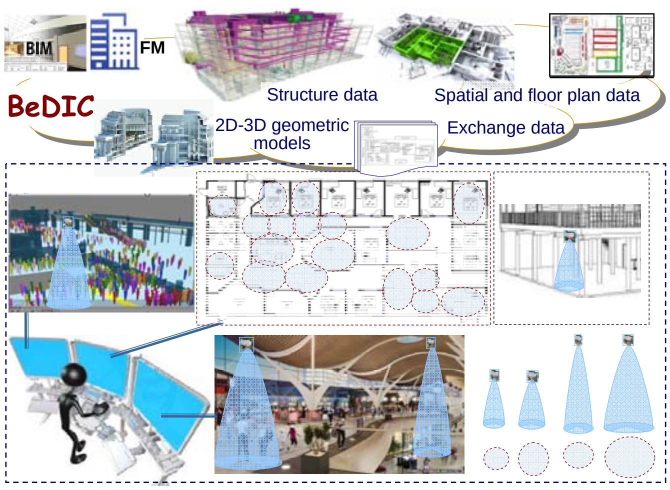

Fig. 3. BeDIPS development environment

With rare exception, Lbeacons are installed on the ceilings. Different types of Lbeacons differ in their ranges and antenna radiation patterns. The lower right corner of Fig. 3 shows four types as examples. Each dashed circle or oval represents the coverage area of a beacon. A complex building such as large shopping malls and transport hubs is likely to require several types as illustrated by Fig. 3. While Lbeacons with range around 3 meters are suitable for typical rooms, beacons with range 20 meters or more may be needed for multi-level halls. All of them have directional antennas with conical beams. For 3-meter location accuracy, beacons with 3-meter range have 60-degree coverage, while beacons with larger ranges need to have antennas with narrower radiation patterns.

The process of design and deployment of a positioning system in a building starts from the selection of the types of Lbeacon for each area in the building from available types. Graphical and visualization tools built on the 2D-3D geometric models of the building such as the ones shown in the lower half of the Fig. 3 aims to help the developer to select the right type of Lbeacon for each location, experiment with the placements and orientations of the selected beacons, and visualize and assess the coverage provided by them. Upon finding a satisfactory design for an area (e.g., a room, a corridor, and a large hall), the developer can have the tool generate, for each beacon in the area, its 2D barcode, type and coordinates. In addition, the tool also generates the coordinates of a reference point for the area. The reference point is a location in the area that can be easily pinpointed by the installer. Examples include the south-west corner of the room or the left inside frame of a specified door. This information will help the installer locate the position of each Lbeacon in the area accurately with the help of the installation tool described in the next section.

We have prototyped a BeDIPS development environment as an extension (i.e., a plugin) of Autodesk Revit [40]. A tool for identifying and displaying malfunctioned beacons can also be built as a Revit plugin. We will build this tool in the future.

IV. Architecture and Key Components

Fig. 4(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.

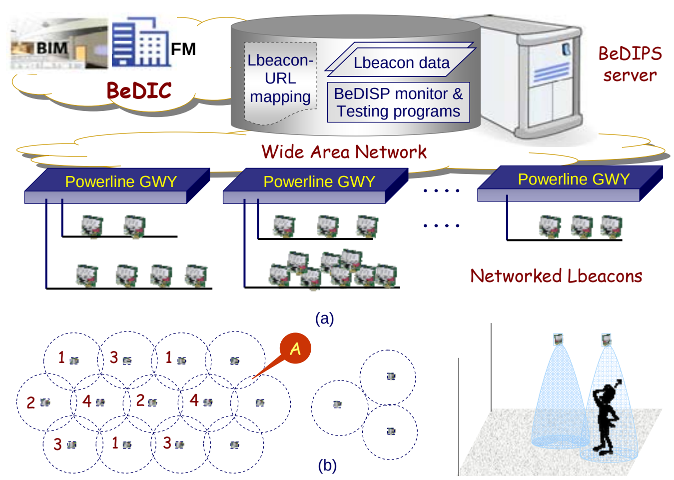

Fig. 4. (a) Structure and components of BeDIPS and (b) Lbeacon coverage

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 installed and initialized, each beacon contains locally its own coordinates. It periodically, or upon request, broadcasts the coordinates to Bluetooth devices in its coverage area.

Fig. 4(b) shows possible configurations and placements of Lbeacons for good coverage and small position errors. As stated earlier, the beacons are installed on ceilings. Their antennas point downward to the floor. The range of every beacon being less than the ceiling height, no device below the floor can hear it. This is a 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 Fig. 4(b). In this case, the horizontal position error is bounded from the above by the diameter D of the beacon beam (e.g., 3-5 meters). Fig. 3 and the middle parts of Fig. 4(b) show incomplete coverage patterns. Such patterns may be acceptable in some parts of the building. For example, in an office area illustrated by the middle part of Fig. 3, a reasonable design goal is to provide room-level accuracy. By accepting small blind spots in coverage, the number of Lbeacons can be reduced.

It is possible to achieve horizontal position errors smaller than the diameter 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 Fig. 4(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 D. This improvement can be achieved by having beacons with overlapping coverage transmit in a time-division multiplexing (TDM) 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 Fig. 4(b). In this case, a TDM frame with four data slots will do, when beacons transmit in the slots indicated by the numbers next to them in the figure. In general, one can tradeoff between the number of Lbeacons required to achieve the required location accuracy and the capabilities required of the user device. Currently, our design choice is to keep the capabilities required of the user devices and HereUAre application at a minimal at the expense of Lbeacon density.

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 broadcast a textual description of the location (e.g.,“A4”, the grid index of the location on the map) 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 the one shown in Fig. 2 or "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 [47]: When invoked under the coverage of the current beacon, HereUAre on user's phone sends the coordinates of the last Lbeacon received by the device. We 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 3D coordinates and 2D barcode of every Lbeacon are retrieved by the BeDIPS server from BeDIC and stored locally. To prepare each Lbeacon for installation, the installer downloads its coordinates and fixes its barcode on the beacon. The installation of Lbeacons in each area of the building is done with the help of an installation tool that has a barcode scanner, a servomotor controlled laser pointer and network connection to BedIPS server. To install Lbeacons in an area, the installer places the tool at the reference point of the area and has the tool retrieve from the BeDIPS server the coordinates of the reference point and 2D barcodes of the Lbeacons to be installed. To install a Lbeacon, he/she then has the barcode of the beacon scanned by the tool. After verifying that the Lbeacon is indeed intended for the area, the tool reads the coordinates of the beacon and direct the laser pointer to point to the spot on the ceiling where the beacon should be placed based on the coordinates of the reference point and the beacon. In this way, the tool enables the installer to easily locate the point with the beacon's coordinates. Fig. 5 illustrates this scenario, showing that the tool points to the location on the ceiling where the beacon on the right should be installed.

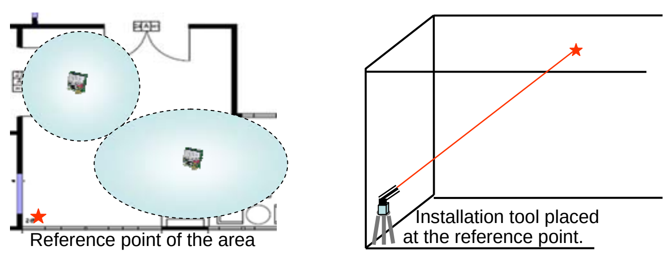

Fig. 5. Summary of installation process.

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. The message is sent 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, Fig. 4(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 of web pages containing information (e.g., advertisements and announcements) specific to the location at and in the neighborhoods 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.

V. LBEACONS AND LBEACON NETWORK

Fig. 6 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 system on chip.

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 Fig. 6. Thus far, we have assumed only features of Bluetooth 4.0 [35], 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 [48], advantages of version 4.1 include coexistences of Bluetooth and LTE, manufacturer specified reconnection timeout intervals and the 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.

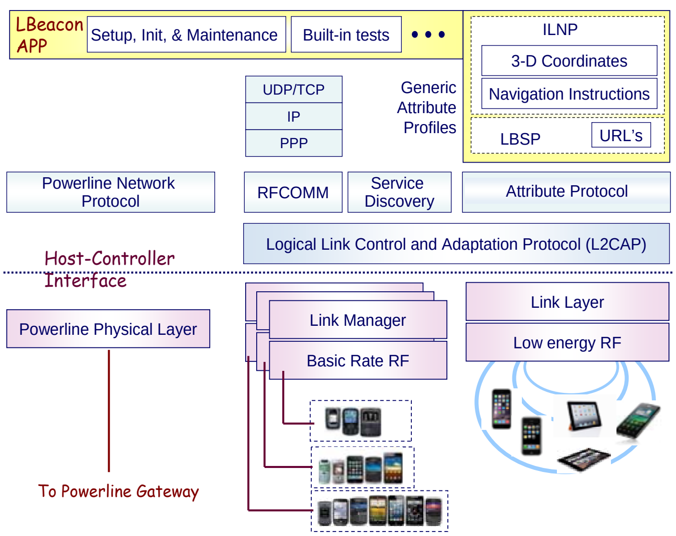

Fig. 6. Location beacons with dual-mode Bluetooth module

As shown in Fig. 6, both LE (Lower-Energy) transport and BR (Basic Rate) transport start from the Generic Attribute Profile ILNP (Indoor Location and Navigation Profile), which is to be defined. Roughly, ILNP resembles the existing LNP (Location and Navigation Profile) [49]. LNP defines two roles: LN (Location and Navigation) 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 mobile devices under the coverage of the beacon.

Also shown in the Fig. 6 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 [32]) that do not aim to serve legacy devices. Today, a large number of mobile phones remain to be legacy devices, however. Being required to serve them as well, Lbeacon also has the BR protocol path shown in the middle of Fig. 6. The design of the bottom layer in this path is based the results of a study [50] 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 approximately 9 square meters, there can be as many as 20 people/client devices, three dongles are used. Experiment data in [50] 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. (Specifically, the data from [50] 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 possibly. Also, according to [50], 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 a powerline network protocol module 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 effectiveness of having Lbeacons that have 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.

VI. SUMMARY AND FUTURE WORK

The proposed building and environment-data based indoor positioning system (BeDIPS) 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/level information, approximately 3-5 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 Bluetooth Smart Ready devices and are installed pervasively throughout the building. At deployment and maintenance times, the BeDIPS server loads the 3D 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 III.

We have been experimenting with prototype Lbeacons, focusing primarily on their functionality. The BR (Basic Rate) module of the prototype uses only one dongle. The coordinates and textual location description are sent in vMessage format according to the Bluetooth OBEX protocol [51]. Object Push Profile being widely supported, all of the feature phones we experimented with can display location descriptions such as the one illustrated by Fig. 2 without HereUAre application. As expected, the implementation of the LE (Low Energy) module and HereUAre on smart phones are straightforward.

The next step is to evaluate the performance of Lbeacons experimentally in terms of responsiveness and scalability. To determine how scalable the Bluetooth BR part of Lbeacon is, we will perform simultaneous connection tests similar to the test reported in [50] to determine the maximum number of legacy Bluetooth devices reachable by a beacon as a function of acceptable response time interval. In addition to experimentation with different ways to use of multiple BR dongles, we will experiment with tradeoffs between Lbeacon density/coverage versus user device requirements. Also, in the near future, we plan to develop the ILNP. Ideally, ILNP should be defined as a version of LNP and thus enable applications implementing the profile to work both indoors and outdoors.

We have implemented a prototype BeDIPS development environment as a Revit plugin. We plan to build and evaluate parts of prototype BeDIPS in two or three representative large public buildings selected as test sites. An ideal choice of a test site is a sports center under construction in New Taipei City, as the building is large and complex and the parts of BIM needed for our purpose will be available. One of the test site is the Institute of Information Science (IIS) Building at Academia Sinica. It is office building in which this work is done. Built in the mid 90's before BIM become widely adopted, only blueprints on the building were available. We have constructed the BIM files needed by BeDIC from the blueprints of the building using Autodesk revit and AutoCAD [52]. Fig. 7 show two of the 3D models generated from the resultant BIM. By doing so we have validated the assumption on the availability of BIM stated in Section III.

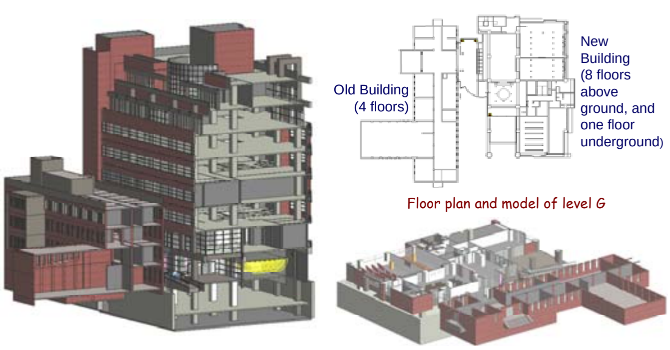

Fig. 7. 3D model of a test site generated from blueprints of the building

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REFERENCES

[1] Indoor positioning systems, http://en.wikipedia.org/wiki/Indoor_positioning_system (Last retrieve: August 2015)

[2] Z. Farid, R. Nordin, and M. Ismail, “Recent advances in wireless indoor localization techniques and systems,” Journal of Computer Networks and Communications, Volume 2013, 12 pages,

[3] D. Schneider, “New indoor navigation technologies work where GPS can’t,” IEEE Spectrum, November 2013.

[4] D. Dodge, “Leaders in indoor location positioning technology,” http://dondodge.typepad.com/the_next_big_thing/2013/04/leaders-in-indoor-location-positioning-technology.html, April 2013, (last retrieved: August 2015)

[5] D.Dodge, “Indoor location startups innovating indoor positioning,” http://dondodge.typepad.com/the_next_big_thing/2013/06/indoor-location-startups-innovating-indoor-positioning.html, June 2013, (last retrieved: August 2013)

[6] Indoor positioning startups, https://angel.co/indoor-positioning (last retrieved August 2015).

[7] “Wireless E911 location accuracy requirement,” FCC PS Docket No. 07-114, Feb 2015, https://www.fcc.gov/document/fcc-adopts-new-wireless-indoor-e911-location-accuracy-requirements-0, (last retrieved: August 2015).

[8] BIM, Building Information Models/Modeling, http://en.wikipedia.org/wiki/Building_information_modeling, (last retrieved: August 2015).

[9] "RFID lands at Frankfurt Airport," RFID Journal, 2005, http://www.rfidjournal.com/articles/view?2121 (Last retrieved: August 2015).

[10] Skyhook Wireless, http://www.skyhookwireless.com/about-skyhook (Last retrieved: August 2015)

[11] Q-TRACK, http://q-track.com/ (Last retrieved: August 2015)

[12] 2015 Microsoft Indoor Location Competition, http://research.microsoft.com/en-us/events/indoorloccompetition2015/, (last retrieved: August 2015)

[13] Information technology -- Real-Time Locating Systems (RTLS) -- Part 5: Chirp Spread Spectrum (CSS) at 2.4 GHz Air Interface. ISO/IEC 24730-5:2010.

[14] A. Bestmann and R. Reimann, “EasyPoint – indoor localization and navigation,” The first place entry, 2014 Microsoft Indoor Location Competition, 2014, http://research.microsoft.com/en-us/events/ipsn2014indoorlocalizatinocompetition/ (last retrieved: August 2015)

[15] L. Li, C. Zhao, G. Shen, and F. Zhao, “Indoor localization with multi-modalities,” Second place entry, 2014 Microsoft Indoor Location Competition, 2014, http://research.microsoft.com/en-us/events/ipsn2014indoorlocalizatinocompetition/ (last retrieved: August 2015)

[16] S. Robarts, "Supermarket indoor "sat-nav" guide users to discounts," Electronics, May 21, 2015, http://www.gizmag.com/carrefour-philips-indoor-positioning-system/37631/ (Last retrieved: August 2015)

[17] “An indoor positioning system based on echolocation,” MIT Tech. Review, Emerging Technology From the arXiv, July 25, 2014.

[18] J. Chung, M. Donahoe, C. Schmandt, I.-J. Kim, *et al*., “Indoor location sensing using geo-magnetism,” Proc. of MobSys, 2011, pp. 141-154.

[19] Indoor Atlas, http://venturebeat.com/2013/11/15/indoor-atlas-uses-magnetic-sensors-to-the-great-indoors/ (last received: August 2015).

[20] A. Farshad, J. Li, M. K. Marina and F. J. Garcia “A microscopic look at WiFi fingerprinting for indoor mobile phone localization in diverse environments,” Proceedings of International Conference on Indoor Positioning and Indoor Navigation, October 2013.

[21] P. Bahl and V. Padmanabhan, "RADAR: an in-building RF-based user location and tracking system," Proceedings of IEEE INFOCOM, 2000, pp. 775—784.

[22] M. Youssef and A. Agrawala, "The Horus WLAN location determination system," Proc. of ACM MobiSys, 2005, pp. 205-218.

[23] S. Sen, B. Radunovic, R. R. Choudhury, and T. Minka, "You are facing the Mona Lisa: spot localization using PHY layer information," Proceedings of ACM MobiSys, 2012, pp. 183-196.

[24] K. Wu, J. Xiao, Y. Yi, M. Gao, and L. M. Ni, "FILA: fine-grained indoor localization," Proceedings of IEEE INFOCOM, 2012, pp. 2210 – 2218.

[25] Y. Chen, D. Lymberopoulos, J. Liu, and B. Priyantha, "FM-based indoor localization," Proceedings of ACM MobiSys, 2012, pp. 169-182.

[26] A. Popleteev, "Indoor Positioning Using FM Radio Signals," PhD Dissertation. University of Trento, Italy, 2011.

[27] A. Matic, A. Papliatseyeu, V. Osmani, and O. Mayora-Ibarra, "Tuning to your position: FM radio based indoor localization with spontaneous recalibration," Proceedings of IEEE International Conference on Pervasive Communication, March 2010, pp. 153 – 161.

[28] A. Varshavsky, E. Lara, J. Hightower, A. LaMarca, and V. Otsason, "GSM indoor localization," Pervasive and Mobile Computing, Vol. 3, No. 6, 2007, pp. 698–720.

[29] S. P. Tarzia, P. A. Dinda, R. P. Dick, and G. Memik, "Indoor localization without infrastructure using the acoustic background spectrum," Proceedings of ACM MobiSys, 2011, pp. 155-168.

[30] S.-H. Fang and T.-N. Lin., "Cooperative multi-radio localization in heterogeneous wireless networks," IEEE Transactions on Wireless Communications, 9(5), 2010, pp. 1536-1276.

[31] X. Hu, L. Cheng, and G. Zhang, “A Zigbee-based localization algorithm for indoor environments,” Proceedings of the International Conference on Computer Science and Network Technology (ICCSNT ’11), December 2011, pp. 1776 – 1781.

[32] iBeacon, http://en.wikipedia.org/wiki/IBeacon, (Last retrieved : August 2015)

[33] Proximity marketing, http://en.wikipedia.org/wiki/Proximity_marketing (Last retrieved: August 2015).

[34] P. Wawrzyniak, P. Korbel, P. Skulimowski, and P. Poryzala, "Mixed-mode wireless indoor positioning system using proximity detection and database correlation," Proceedings Federated Conference on Computer Science and Information Systems (FedCSIS), September 2014, pp. 1035 – 1042.

[35] Bluetooth Core Specification 4.2, Specification Adopted Documents, Bluetooth Special Interest Group, https://www.bluetooth.org/en-us/specification/adopted-specifications (Last retrieved: August 2015)

[36] K. Hong, “Google’s indoor maps arrive in India so you don’t get lost in shopping malls,” http://thenextweb.com/google/2014/03/05/googles-indoor-maps-arrive-in-india-so-you-dont-get-lost-in-shopping-malls/, also Google Maps: "go inside with indoor maps," http://www.google.com/maps/about/partners/indoormaps/ (Last retrieved: August 2015).

[37] W. Jung and G. Lee, "The status of BIM adoption on six continents," International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering Vol:9, No:5, 2015, pp. 444-448.

[38] CAD Addict, List of BIM software and providers, http://www.cad-addict.com/2010/03/list-of-bim-software-providers.html

[39] xBIM Toolbox, http://www.openbim.org/ (Last retrieved: August 2015)

[40] Autodesk Revit, https://en.wikipedia.org/wiki/Autodesk_Revit, (last retrieved: August 2015)

[41] BIM for Facility Managers, Paul Teicholz, Ed., Wiley, March 2013.

[42] N. Nisbet and T. Liebich, "ifcXML Implementation Guide," version 2.0, 2007, http://www.buildingsmart-tech.org/downloads/accompanying-documents/guidelines/ifcXML%20Implementation%20Guide%20v2-0.pdf, (last retrieved: August 2015)

[43] YouBIM, http://www.youbim.com/about-youbim.html (last retrieved: August 2015).

[44] FM: Systems, http://www.fmsystems.com/company-overview/ (last retrieved: August 2015).

[45] "Integrating BIM with building automation systems," http://www.tradelineinc.com/reports/2012-4/whitepaper-integrating-bim-building-automation-systems , April 2012

[46] Open Floor Plan Display/Exchange, http://www.nibs.org/?page=bsa_openfloorplanex, June 2010 (last retrieved: August 2015).

[47] T. S. Chou, *et al.*, "CaNPAs: A campus navigation and parking assistant System," Proceedings of IEEE International Conference on Systems, Man and Cybernetics, Volume 1, 2006, pp. 631 – 638.

[48] G. Kelly, “Bluetooth 4.1: What is it and why should you care?” Trusted Reviews, http://www.trustedreviews.com/opinions/bluetooth-4-1-what-is-it-and-why-should-you-care (Last retrieved: August 2015).

[49] LNP version 10, Location and Navigation Profile, Document No. LNS_SPEC, April 2013, https://www.bluetooth.org/en-us/specification/adopted-specifications (last retrieved: August 2015)

[50] M. Aiello, R. de Jong and J.de Nes, “Bluetooth broadcasting: how far can we go? An experimental study,” Proceedings of the 9th International Joint Conference on Pervasive Computing , December 2009, pp. 471 – 476

[51] Object Exchange Protocol (OBEX) and Object Push Profile (OPP), https://developer.bluetooth.org/TechnologyOverview/Pages/OBEX.aspx (last retrieved: October 2015)

[52] Autodesk AutoCAD, https://en.wikipedia.org/wiki/AutoCAD, (last retrieved: October 2015)