Building/environment Data/information System for Fine-Scale Indoor Location Specific Services

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***Abstract*— This paper describes the structure, design and implementation of a building/environment data and information system, called BeDIS for short. It is designed to support fine-scale, location-specific services provided by smart devices and mobile applications in large smart buildings. Structured as a fog, it remains responsive when overloaded and degrades gracefully when network connection is disrupted and parts of it damaged. During normal times, it enables hundreds and thousands of people to locate themselves sufficiently accurately and navigate amidst dense crowd and moving objects via their mobile phones. When triggered by a disaster/emergency alert from responsible government agencies or the building safety system, BeDIS functions as a system of micro data servers for delivering location- and situation-specific emergency response instructions to people and decision support data to active smart devices and applications within fractions of a second to seconds.**

Keywords*— *location specificity, data mist, indoor positioning and navigation, location beacon, active emergency response

I. Introduction

In recent years, increasing adoption of technologies in areas such as Internet of Things (IoT), smart sensors, and building automation systems has made our buildings and cities much smarter than a decade ago. Nevertheless, many essential indoor location-based services are still not available today. Take large public buildings (e.g., transport hubs, large department stores and major hospitals) as examples. During rush hours and on special occasions, such buildings are likely to be crowded, and views of pathways, direction signs and exits may be blocked. Scalable and responsive indoor positioning services (IPS) that can help people locate/navigate themselves and find friends can significantly improve their experiences in the building. Yet, typical modern large public buildings still do not offer such services. More seriously, when one makes an emergency call indoors using a mobile phone, the location accuracy timeline published by USA FCC says that until year 2020, the error in the caller's horizontal location can be as large as 50 meters [1]. That is half a football field long!

This observation motivated the building/environment data and information (BeDI) system [2]. Called BeDIS for short hereafter, the system intends to be a part of information technology (IT) infrastructure needed to support indoor location specific decisions and actions of smart devices, mobile applications and people indoors, especially in large public buildings. Fig. 1 shows the structure of BeDIS, its relationship with sources that provide it with data, and examples of services and applications it is designed to support.

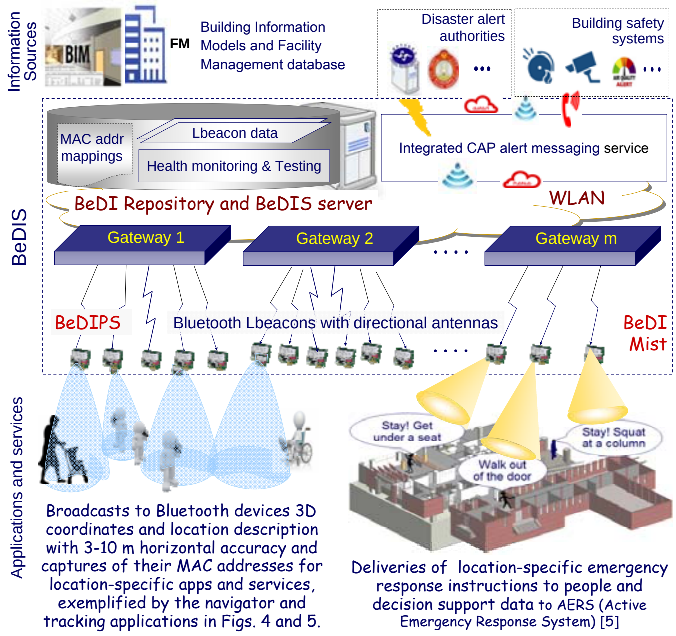

Fig. 1. Architecture, components and functionalities of BeDIS [2]

A. Functionalities and Key Components

Functionally, the system has two parts: BeDIPS and BeDI Mist. The former is a BeDI-based indoor positioning system [2][3]. It delivers to each Bluetooth enabled device in the space covered by the system the 3D coordinates and a brief textual description of the device's location: The vertical location is in terms of the floor/level on which the device is, and is error free. Horizontal location accuracy can be configured to be 3-5 meters, or 6-10 meters, or at room-level. This accuracy is

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sufficient when the coordinates are used as input to navigators for people. Section IV will describe such a navigator. For navigation of automatic guided vehicles indoors, however, on-board control, guidance, navigation and object avoidance capabilities are needed for improved accuracy.

The primary function of the BeDI mist is to deliver fine-scale (e.g., 3-10 m), location-specific decision support data to iGaDs (intelligent guards against disasters) [4] and AERS (active emergency response systems) [5] containing them. The term iGaD refers to active devices and mobile applications that can automatically process disaster alerts encoded in the standard CAP (Common Alert Protocol [6]) format and disseminated by authorized senders and then in response, take risk reduction actions. (For example, in response to a strong earthquake alert, they shut gas valves and open access-controlled doors before the ground shaking starts. Mobile iGaDs deliver location-specific response instructions to users as illustrated by Fig. 1.) Each iGaD can be effective only if it decides whether and how to respond to an alert based on not only parameters (e.g., severity) of the disaster specified by the alert, but also data on attributes of the building, interior layouts, facilities, objects, etc. in its immediate vicinity. Structured as a fog [7][8], BeDI mist is designed to deliver such data to iGaDs when triggered by a CAP alert with relative deadlines as small as fractions of a second to seconds.

As Fig. 1 shows, both BeDIPS and BeDI mist use *location beacons* (or *Lbeacons* for short) to deliver data. Lbeacons are low-cost Bluetooth smart ready devices [9] pervasively installed throughout the building. Lbeacons in each area of the building are connected via one or more Zigbee star networks for set up, initialization, and health monitoring purposes, They in turn are connected via gateways to the wireless local-area networks within the building and the BeDIS server. After initialization, each Lbeacon stores locally the 3D coordinates and a brief description of its own location and other location-specific data it is responsible for delivery. Consequently, it can broadcast the data independently during runtime.

Another key component is the *building and environment data and information* (*BeDI*) repository. This physical or virtual repository provides access to datasets selected from the BIM/FM database of the building. The Acronyms BIM and FM stand for Building Information Model and facility management (FM) [10][11], respectively. BIM are files that give a complete digital representation of functional, physical and geometrical characteristics and relevant attributes of the building and objects of interest (e.g., Lbeacons) in it. BIM/FM database integrates dynamic information on facilities and equipments with BIM to support facility management and building operation and maintenance [12]-[14]. In recent years, BIM have been adopted by AEC (Architecture, Engineering, and Construction) industries in an increasingly larger part of the world. Buildings constructed before the wide adoption of BIM are documented by blueprints. Our experience through case studies reported in [15] show that with the help of modern software tools such as Autodesk Revit [16], blueprints can be translated into BIM at an acceptably low cost. This is why BeDIS is built on the assumption that every public building of some specified size or larger has a BIM/FM database. Datasets in the database made available to BeDIS contain at least 2D-3D geometric models of the building components (e.g., stairwells and corridors) and objects (e.g., ceilings and walls) on which Lbeacons and gateways are installed.

B. *Contributions and Organization*

This paper is an extension of [2]. Its contribution includes the fog computing and network structure of the BeDI mist. As mentioned earlier, Lbeacons can function as micro data servers. When triggered by CAP alerts and during emergencies, these near-user edge devices deliver fine-scale, location-specific decision support data to the vast number of active devices and mobile applications in the building within the short time from the receipt of each alert to the time when actions must be taken in response. This paper describes the functionalities of the micro data servers, smart gateways and the BeDIS server that make the BeDI repository a scalable and responsive fog.

Other contributions of this paper include waypoint-based indoor navigation on Bluetooth Low-Energy (BLE) enabled mobile devices. According to its dictionary definition, a *waypoint* [17] is an intermediate point at a known location on a route of travel. The routes in navigation graphs [18] from any source and destination used by a *waypoint-based navigator* are made up of segments connected by waypoints. In a building served by a BeDIPS, waypoints are marked by Lbeacons. As Section IV will explain, this greatly reduce the work done by the navigator. Given the fact that there is yet no widely adopted indoor positioning standard, it would be good if one's navigator can work with different kinds of indoor positioning systems. Waypoint navigation is a way to accomplish this goal.

Each Lbeacon can capture MAC addresses of Bluetooth devices that have made themselves discoverable when they are under its coverage. Later, Fig. 3 will illustrate how this capability can be exploited for services such as tracking people wearing smart bracelets, finding family members and friends in crowds, locating equipment with Bluetooth tags and estimating crowd sizes during exhibitions, etc. The BeDIS components for these purposes are also contribution of this work.

Following this introduction, Section II first presents briefly the requirements of BeDIS for large public buildings, state-of-the-art of indoor positioning technologies, and reasons for the inabilities of IPS based on existing technologies to meet the requirements. Section III describes the structure and implementation of Lbeacons. Section IV describes the design and implementation of waypoint-based systems for navigation anywhere in general and a navigator for use in buildings with Lbeacons. Section V describes the fog structure of BeDIS, specifically, the structures of micro data servers and smart gateways and their collaborations with BeDIS server. Section VI discusses the work by Lbeacons and gateways during configuration and initialization and health monitoring. Section VI summarizes the paper and presents future work.

II. Background and Related Work

For years now, indoor positioning has been a highly contested arena filled with big companies and startups [19]-[21]. It has also been an active research area with results reported by numerous surveys and comparative studies (e.g., [22] - [26]) and technical articles (e.g., [27]-[35]). Still, none of the existing technologies have become widely accepted standards, and there are few if any large scale deployments of IPS servicing general public in large public buildings even in technologically advanced countries.

A reason for such slow progress is that any IPS for large public buildings must meet the requirements stated below. This section first presents the requirements and then an overview of state-of-the-art indoor positioning technologies, together with why systems built on the available technologies cannot meet all the requirements. In contrast, as it will become evident shortly, BeDIS meets all the requirements.

A. Requirements of IPS and BeDI mist

First of all, any system must have acceptable performance. The performance of an IPS is usually measured in terms of location accuracy. For general public indoors, horizontal errors of 3-5 meter or 6-10 meter are acceptable [19], but the system must never misinform the user which floor he/she is on. The performance of a BeDI mist is stated in terms of its *relative deadline*, i.e., the maximum allowed response time for delivering location specific data: The deadline ranges from a fraction of a second to minutes.

Second, the system must be scalable, responsive and resilient: Even when the number and density of people surge by orders of magnitude, performance deterioration of the system must remain tolerable. After setup and initialization, the system can operate without Internet and cell connections. When parts of the system are damaged, the remaining part can continue to deliver location data. Moreover, the system should be able to assess its own health automatically during operation.

Third, the system must be easy to configure, customize, install and maintain. During remodeling and renovation, the system can be updated systematically and easily. In case of BeDIS, the development environment described in [2] ease the tasks of deciding where to place Lbeacons and installing them at their chosen locations. Every Lbeacon is mounted on an object (e.g., a ceiling or wall) that is characterized by data in some datasets in the BIM. Its 3D coordinates are reliably updated during remodeling and renovation as the BIM datasets on the object are updated during the processes.

Lastly, the capabilities of user devices required to access the system are minimal: BeDIPS can serve not only Bluetooth Low Energy (BLE) enabled smart phones but also feature phones equipped with only Bluetooth BR/EDR protocol stack [9] and OBEX (OBject Exchange) protocol [36]. The navigator described in Section IV does not require any indoor map.

B. Indoor Positioning Technologies

Many techniques proposed in recent years can provide location accuracy significantly better than 3-10 meters. Examples include some of the winners of Microsoft Indoor Location Competitions [26]. They use non-standard signal(s) or make sophisticated measurements, however. The requirement that the service can be accessed via common devices prevents their use in large public buildings.

Today, the majority of indoor positioning systems in use are range based, or fingerprint based, or both using WiFi, FM and Bluetooth signals. The required 3 to 10 meter horizontal accuracy is achievable by pure range-based, triangulation systems. Such systems require only an application computing on smart mobile devices the location of the device based on received signal strength (RSS) of signals from emitters at known locations. A serious disadvantage of such systems is that their location accuracy degrades when variations in number, densities and movements of people and objects in the operating environment perturb propagation paths and cause unpredictable fluctuations in received signal strengths. This is why their location accuracy is more likely to be in 20 meter range [37] in large public buildings full of people, and their room accuracy can be less than 50% [25].

Fingerprinting is another commonly used approach to indoor positioning. A fingerprint is a set of location-specific values of received signal strengths (i.e. a signal pattern). Types of fingerprints used for indoor positioning include patterns of WiFi and Bluetooth signals, FM signals, acoustic echo patterns and background spectrum, magnetic signatures of the building and multiple types of signals (e.g., [30]-[34]). A fingerprint-based IPS has a server which maintains a database of fingerprint-to-location mappings. A mobile device determines its own location is by sending the fingerprint captured by it at its location to the server and rely on the server to find the location(s) with a matching fingerprint. Fingerprint-based systems have better location accuracy compared with range-based systems. (According to [25], room level accuracy of WiFi and Bluetooth fingerprint-based systems are 96 and 76 %, respectively. The accuracies of corresponding triangulation systems are 47 and 61 %.) Because of their reliance on Internet and the fingerprint server, such systems have longer response time, do not scale, do not degrade gracefully and can service only phones capable of capturing fingerprints.

Based on available performance data (e.g., data from [25] [35]), proximity detection systems offer a good solution for indoor positioning. In addition to being less expensive and easier to deploy and maintain than fingerprint-based systems, a proximity-based system can provide acceptable location accuracy (e.g., near 100% room-level accuracy and horizontal accuracy of 1.5 to a few meters) in large public buildings.

BeDIPS is similar to proximity detection systems. Existing IPS based on proximity detection may use of radio tags and Bluetooth low-energy beacons such as iBeacons [38] from Apple Inc. and Eddystone [39] from Google. iBeacon, Eddystones and other Bluetooth proximity marketing products (e.g., [40]) are designed to notify nearby smart devices of their own UUIDs or URLs, based on which the devices can look up their approximate locations. In contrast, each Lbeacon works alone to deliver its own 3D coordinates.

C. Fog Computing

The challenges of BeDIS arise from the fact that it needs to deliver to a vast number of embedded and mobile devices time-critical, location-specific data. The geometric scale can be as small as few square meters, and the relative deadlines can be as short as fractions of a second to seconds. These requirements cannot be met without adopting fog computing architecture, which by definition makes substantial use of near-user and end-user devices for processing, storage, communication and management than in cloud computing [7] [8].

Indeed, many IoT applications, from smart lighting to smart traffic lights to power restoration of smart grid, require low latency, location awareness and use of wireless access. Fog computing was motivated by them. Since its introduction, consensus on benefits and challenges of fog as an architecture for diverse IoT applications has grown increasingly wider (e.g., [41]-[43]). Efforts by OpenFog Consortium and similar groups are now molding system level fog architecture (e.g., [44]), identifying security risks of fogs and proposing approaches to address them (e.g., [45]), and developing testbed framework and regional testbeds (e.g.,[46] for experimentation, assessment and validation of fog platforms and applications. We will leverage the results of these efforts to address some of our critical problems. Examples include security of BeDIS and interfaces with external smart environment.

III. Structure of Lbeacons

Fig. 2 shows the structure of Lbeacons. The data delivered by each Lbeacon are downloaded during initialization and configuration and stored locally afterwards. During normal times, it continuously broadcasts the 3D coordinates and description of its own location via both BLE and BR/EDR protocol paths. The vertical coordinate provided to a user is the user's floor/level. The horizontal coordinates broadcast by every Lbeacon is its own latitude and longitude relative to the southwest corner of the building. During emergencies, Lbeacons can be commanded by gateways to broadcast location-specific emergency response instructions or building and environment data in addition to location data. Each Lbeacon logs all errors and exceptions during its operation. The content of the log will be used for system health monitoring purposes in ways to be described in Section V.

The primary users of BeDIPS part of the system are people in buildings. They access the IPS via mobile phones. Lbeacons deliver their location data to feature phones [47] via the EDR/BR data path according to OBEX protocol [36]. The protocol being widely supported, most phones can display the brief textual descriptions such as "Level 8, RM 807". Each Lbeacon also broadcasts its location data as advertising data to smart phones via the BLE path. In this case, only 26 bytes are available, constraining us to encode 3D coordinates using only 12 bytes. An alternative is to broadcast data using connectable advertising with 62 bytes of payload. This option is used by micro data servers to send decision support data.

Except for rare exceptions, Lbeacons are installed on ceilings. Typically, a complex building requires several types of Lbeacons. They all have directional antennas with conical beams, but different types differ in ranges and angles. The required location accuracy is achieved by adjusting their ranges and beam widths, thus, the shapes of their coverage areas. As examples, Lbeacons with 3 meters range and 60-degree radiation pattern can achieve 3-5 meter horizontal accuracy in a typical rooms. Zero vertical error is achieved by making the range of all beacons in the room less than the ceiling height. LBeacons with larger ranges for places with tall ceilings have antennas with narrower (e.g., 30 degree) radiation patterns to achieve the same horizontal accuracy.

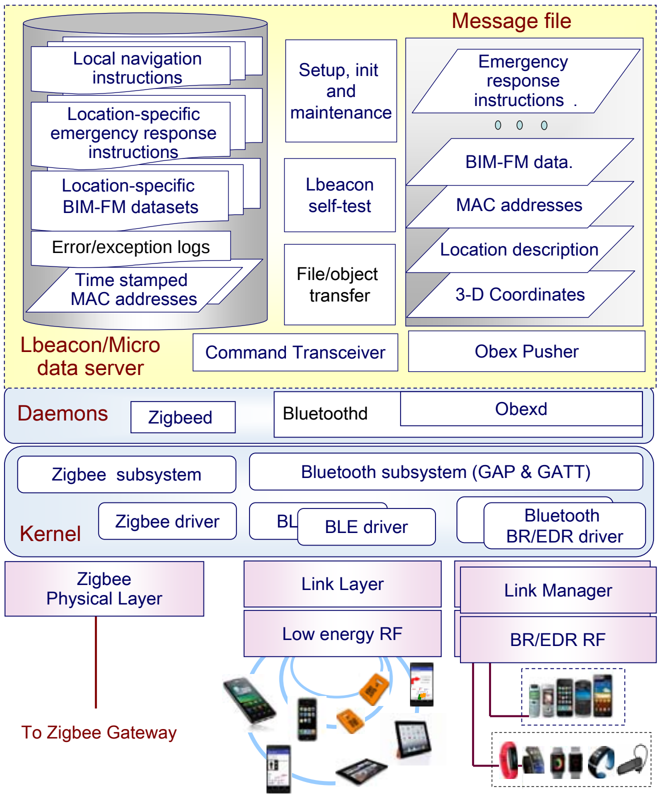

Fig. 2. Structure of Lbeacons

Fig. 3 shows a picture of the current version of Lbeacon and its interior. It is being used to support pilot studies and field trials. This type has four 60-degree antennas and dongle pairs. (The dotted square in the top left part of the picture is the outline of two 30 degree antennas.) In the performance study reported in [2], two dongles were use for pushing location data to BR/EDR devices and one dongle for broadcast to BLE devices. One dongle was used for health monitoring.

In the process of pushing data to mobile devices as they passes through its coverage area, each Lbeacon acquires the MAC addresses of the devices that are in discoverable mode and tags each acquired address with time stamps marking the start and end of each time interval during which the device with that MAC address stays under the Lbeacon. Time-stamped MAC addresses are saved locally. The Lbeacon uploads this data to the BeDIS server when it is polled. This data enables BeDIS to support location-based and personalized services as illustrated by Fig. 4.

IV. Waypoint-Based Navigation

Here, the term *navigator* refers specifically to the waypoint-based navigator described in this section when there is no ambiguity. It is for people in large public buildings. Again a waypoint is an intermediate point at a known location on a route of travel, and every route from any source and destination is made up of segments connected by waypoints.

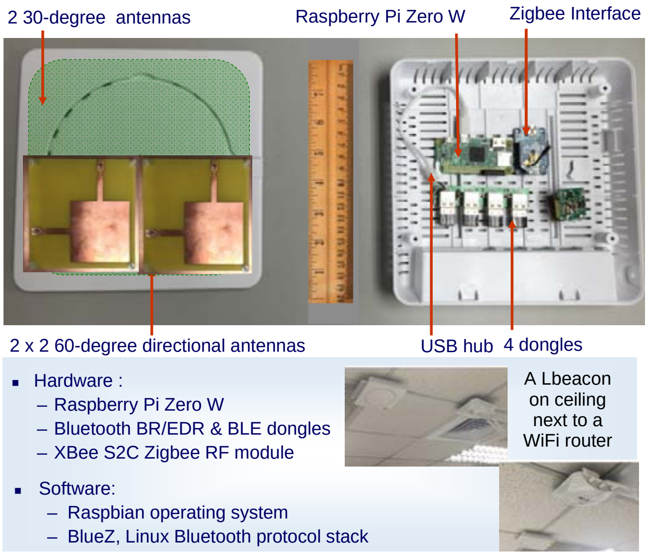

Fig. 3. Picture of a Lbeacon with 4 60-degree antennas

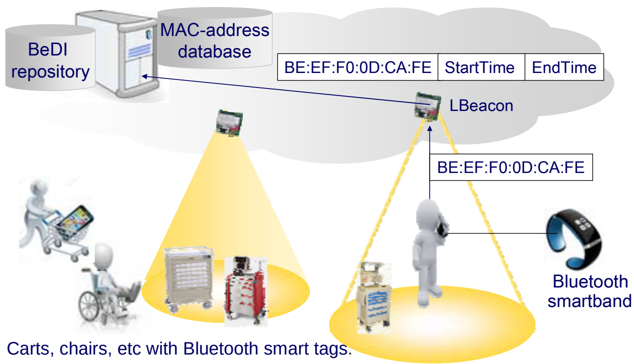

Fig. 4. Infrastructure for tracking applications

Specifically, the navigator uses as input the *navigation graph* [18] of the building. Each node in the graph represents a possible source or destination, or a place where a human is likely to require a decision or assurance, and so on. Each edge is a possible path from one node to the other traversable by people on foot, on wheelchair, etc. As examples, a path may be along a corridor, in the middle of an open space, via an escalator or elevator or stairs. When given by the user a source and destination pair, constraints and preferences (e.g., use stairs and easy-to-follow route), the navigator selects a route based on the given navigation graph and then guide the user step by step as he/she traverses the route.

In case of waypoint-based navigation, each node in the navigation graph is a waypoint where the navigator provides the user with directives and/or assurances. In a building serviced by a BeDIS, there is a Lbeacon at each waypoint. It broadcast the UID and coordinates of the waypoint to navigators as they pass by. Such waypoints are said to be *active*. Active waypoints eliminate the need for navigators to monitor their own positions continuously. In contrast, in spaces serviced by triangulation and fingerprint-based IPS, a navigator must look up or compute its own position during travel to determine whether it has reached the next waypoint. So, waypoints supported by such IPS are said to be *passive*.

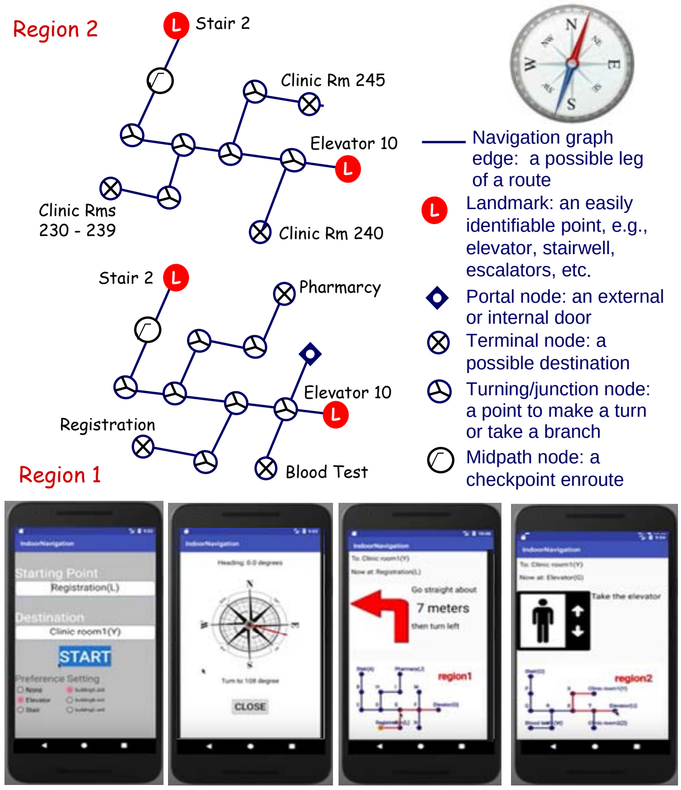

Fig. 5. Examples of navigation graph and navigator screen shots

The top part of Fig. 5 shows an example. The graph is that of a corner of a building in a university hospital visited by numerous patients daily. The figure lists the meanings of common types of nodes in the graph: Some nodes represent possible sources and destinations. Some nodes represent locations where the navigator should generate and deliver directions (e.g., “turn left here”) and assurances (e.g., “continue in this direction for 7 meters” and “you should see the stairs at this point”) to the user.

The use scenario assumes that a user new to the building can download the navigation graph of the building to his/her navigator upon entering the building. To facilitate incremental download of the graph and reduce the time the user has to wait to start selecting his/her source and destination., the entire area of the building is partitioned conceptually into disjoint regions: Here, the term *region* refers to an area on a single floor. The navigation graph is structured hierarchically with two levels. At the lower level, each region has a navigation subgraph, as illustrated by Fig. 5. The top level graph is called the *region graph*. Nodes in it are regions. The attributes of each region node include all possible sources and destinations in the region, their access information (e.g., whether accessible by general public) and other data a navigator needs to compute routes. Edges connecting two region nodes represent possible ways to go between them. In the example in Fig. 5, the region subgraph of the corner of the building contain only nodes Region 1 and Region 2. They are connected by two edges which represent Stair 2 and Elevator 10. Thus structured, only the region graph is downloaded in the first step of the download process. Then the navigation subgraph of the region containing the source node is download followed by the subgraph of the next region on the route, and so on.

The bottom part of Fig. 5 shows the screen shots of the prototype navigator. At the starting point and each time when the user may not be facing the right direction, the navigator displays a compass as shown and instructs the user to turn to the right direction. Subsequently, the navigator presents directions from waypoint to waypoint using a style similar to the style of navigators with heads-up display for drivers. The navigator also presents a part of the navigation graph for users who want to view their progress during travel. The application also provides audio instructions for users who prefer voice directives and users who do not want to look at their phones while they are walking.

V. Fog Structure of BeDIS and BeDI Micro Servers

From Fig. 1 in Section I, one can see that the major components of BeDIS are connected by two levels of star networks. The BeDIS server is at the root of the star network of gateways. Each gateway in turn contains the root of a Zigbee star network that connects Lbeacons in an area of the building. Thus connected, the server, gateways and Lbeacons manage the system collaboratively in manners to be described shortly. Under normal condition, each Lbeacon functions as an active waypoint. It switches to emergency mode when commanded to do so by its local gateway. It stays in the emergency mode until it receives a Back-to-Normal command from the gateway, While in the emergency mode, its functions as a micro BeDI server, as illustrated by the lower right part of Fig. 1.

Similar to location data and description, each micro BeDI server also stores locally emergency response instructions to be broadcast. As Fig. 2 illustrates, the micro server holds multiple sets of instructions, one or more set for each types of emergency managed by the active emergency response system of the building. Each micro data server also stores location-specific subsets of BeDI needed for decision support by devices and mobile applications under its coverage. The instructions and data were downloaded to the micro server during initialization and maintenance times so that the server can deliver them independent of the rest of the system.

Fig. 6 depicts the structure of a gateway and its connections with Lbeacons, as well as information sources and systems serving the building. In particular, the BeDIS server and gateways subscribe to a messaging service that forwards to them emergency/disaster alerts from government authorities and from building safety systems. All messages are in XML-based CAP format [6] and hence are called CAP alerts.

Like typical gateways, each BeDIS gateway facilitates the communication of Lbeacons in a Zigbee networks to and from the BeDIS server via the WLAN of the building. The gateway is smart because it has the capability of parsing CAP alerts and evaluating action activation rule(s) [4] defined for the gateway. The results generated by the CAP alert parser from an alert include the type, severity and other parameters of the emergency warned by the alert. The activation rule of a gateway is expressed in terms of these parameters and local sensor and building/environment data on the area containing the gateway and Lbeacons connected to it. The rule is an executable specification of the conditions under which the gateway is to broadcast command(s) to Lbeacons and the selection of the command(s) to broadcast. Each command specifies a message. Upon receiving a command, each micro server broadcasts the message specified by the command.

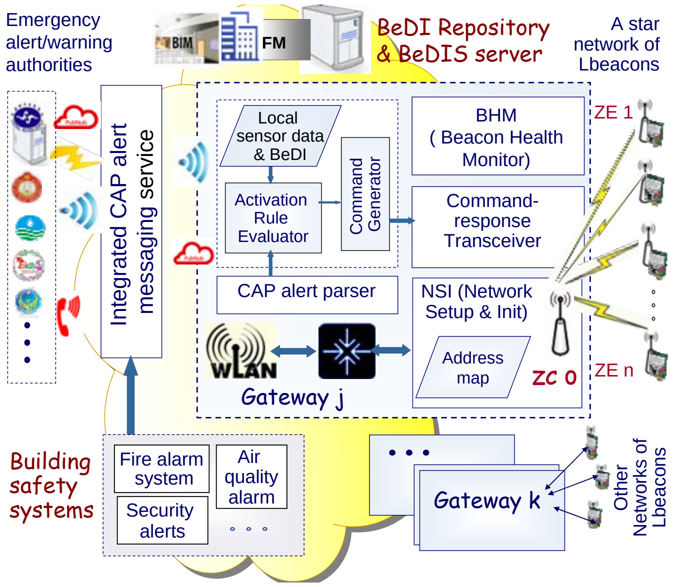

Fig. 6. Structure of smart gateway

By providing each gateway with a rule engine to evaluate the rules customized for the geographical area containing the gateway, the decisions on how to respond to each CAP alert are distributed among the BeDIS server and the gateways. With rare exception, the decision made by the server is confined to whether to forward the current CAP alert to all the gateways. Location specific choices of the commands to Lbeacons are left to the individual gateways. Finer scale than the general area of the gateway is achieved by customizing the instructions and data delivered by each micro data server .

VI. Distributed System Management

As with decision making, the management of BeDIS is also done collaboratively by the server, gateways and Lbeacons. Each gateway has a network setup and initialization (NSI) module as shown in Fig. 6. When the system is powered up, the module powers on the coordinator node (ZC) of a Zigbee star network and gets it ready to accept join requests of Lbeacons in the immediate area. Also as a part of initialization, the module creates *an address map*. It will use the map to hold the mappings of 16-bit network addresses of Lbeacons and their 3D coordinates and UIDs during operation.

During initialization, each Lbeacon within line of sight and range of the coordinator sends to the coordinator (i.e., network address 0) a join request (i.e., an association request frame). In response, the coordinator assigns and sends a 16-bit network address to the Lbeacon. The Lbeacon then sends to the coordinator its own 3-D coordinates and UID and location description. After initialization, the coordinator can address the Lbeacons in the star network individually and identify the senders of packets from them.

A requirement of an IPS for a large building listed in Section II is that the health of the system can be assessed during runtime. The BHM (beacon health monitor) module in each gateway is for this purpose. The goal is to generate a repair list containing Lbeacons UIDs to be replaced if any. Typically, the health of every Lbeacon is tested once to few times a day. Each time, the test is initiated by a request for health report (RFHR) command broadcast by the BeDIS server to the beacon health monitor (BHM) of every gateway. Upon receiving the request, the BHM broadcasts its own request-for-health-report (RFHR) command to Lbeacons on the local star network. Every Lbeacon is capable of testing for its own health and report the result to the BHM. After receiving reports from all Lbeacons on the network, the BHM generates and sends to the BeDIS server a global health report, listing the UID and location of every defective or failed Lbeacon thus identified. The report is used as input to facility management (FM) system on Lbeacons to be repaired or replaced.

The RFHR command from the gateway is received and responded by the self-test component of each Lbeacon. In the current version, the component generates the health report solely on the basis of the error/exception log maintained by the Lbeacon. The log holds all error messages generated by exception and error handlers whenever any part of object push operation encounters error or throws an exception. The health report packet of the Lbeacon contains the messages in the log generated since the previous health report was sent, together with a control code and the 3D coordinates of the Lbeacon. Some error/exception message indicate failure of some important functions (e.g., device scanning) while others are about recoverable errors. The assessment on the seriousness of error conditions are now left to the BHM of the gateway. Clearly, the reliability of health assessment of the system depends on capability of self-test component, and the self test described above is not reliable, in particular, the health of send dongles is not assessed. In the future version of Lbeacons, self test by Lbeacons will be done via receiver emulation.

VII. SUMMARY AND FUTURE WORK

The previous sections described the Building/environment Data and Information System (BeDIS) as an infrastructure for location specific services within large buildings and building complexes visited by thousands of people daily. During normal times, indoor positioning, navigation and object tracking are its primary functions. Unlike similar indoor positioning systems, BeDIS can serve devices enabled by Bluetooth 2.0 or higher, is scalable and responsive, does not require Internet to function, degrades gracefully, and can automatically assess its own health on a regular basis. During emergencies, BeDIS can provide fine-scale, location specific decision support data to hundreds and thousands active devices and mobile applications designed to enhance disaster preparedness, as well as location specific response instructions to people in the building. These design objectives are accomplished by structuring the system as a fog [7] [8] [43] [44]: The system uses pervasively deployed location beacons and common user devices to deliver and consume location specific data and smart gateways to process alerts/warnings and made decisions on whether and how to respond to the alerts. The work done by BeDIS server in the cloud is confined primarily to managing the system.

Lbeacons and gateways now run on Raspberry Pi Zero W and Raspbian operating system, and BlueZ Bluetooth Stack [48]. A waypoint-based navigator implemented on Android and iOS smart phones are now available. Three pilot studies/field trials are underway now to assess usability and effectiveness of BeDIPS in real-life operating conditions by targeted end-users. Test sites include parts of complex buildings in a teaching hospital and a part of a city government building. (The navigation graph in Fig. 5 is that of a test site in the hospital.) We expect to enhance the system and navigators in the process and make them ready for wide deployment.

The development and assessment of an alpha version of micro BeDI data server are now underway. Work to be done as soon as possible also include thorough experimentation to assess their responsiveness, as well as the development of standard format(s) for BeDI sent from micro servers to active mobile applications and a tool for extracting location specific BeDI from the repository for specified areas.

BeDIS is a mission-critical system of smart things. Dependability is of critical importance [49]. BeDIS was designed with maintainability, availability and reliability in mind. Security and safety issues are yet to be addressed, however. Structured as a fog, the system has some of the security risks mentioned in [45]: Lbeacons and gateways are numerous and pervasive. Keeping them physically secure is essential. They all store and broadcast critically important messages. Security of data in motion and at rest must be assured. We will take the approaches proposed by OpenFog Consortium and adopt solutions as they become available. Another thrust of our current work is on safety of BeDIS and AERS (active emergency response system) supported by the infrastructure. BeDIS and the AERS of a large building supported by the infrastructure contain vast numbers of active devices, mobile applications and local sensors. Even when all of them function correctly, the combinations of their actions and actions of people they serve may lead to catastrophic consequences. The AERS simulation framework [50] under development is for assessment of safety of such systems.

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