

# WIRELESS POSITION LOCATION SYSTEM FOR INDOOR ENVIRONMENTS

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**Abstract:** Location systems are used for a variety of navigation applications. Current Location systems are designed to provide accurate distance position coordinates. There are tracking or logistic applications where actual position coordinates are not necessary. Determining the room in a building an object is located can be more useful than the actual coordinates. We present an inexpensive and robust wireless location beacon network that can track the location of emergency responders or users in an indoor environment. Location beacons are placed at predetermined positions in a building. The location beacons are used to determine the presence of the user in an area of a building. The location beacon network does not track the user's coordinates. The location beacon network uses the ZigBee/802.15.4 wireless communications protocol. Our paper examines the use of the Zigbee protocol to determine a user's location. Two realtime location tracking mechanisms are also analysed and tested. A successful prototype of the location beacon network was created and tested.

## 1 INTRODUCTION

In recent years, position locating systems such as Global Positioning (GPS) have achieved widespread use for a variety of navigation applications. Conventional location systems are designed to provide accurate distance position coordinates. Such systems often require sophisticated and expensive electronic tracking devices and an extensive infrastructure. An example is the network of satellites used by GPS systems or the cellular towers used by the GSM communications network (Otsason et al., 2005). There are tracking or logistic applications where actual position coordinates are not necessary. Determining the room in a building an object is located may be more useful than the object's exact coordinates. If accurate position coordinates are not required by the application then less sophisticated tracking devices and infrastructure can be used.

This paper presents a relatively inexpensive and robust wireless location beacon network that tracks the location of users in an indoor environment. The location beacon network is designed for use with emergency responders; operating inside a building. The location beacon network also allows a user to determine their location. Location beacons are placed at known positions throughout a building. The location beacons are only used to determine the presence of the user within a particular region of a building. An example is that a location beacon is placed within a room, any users that enter that room will be detected and their current position will be identified as that room. The location beacon network does not track actual coordinates of users.

The location beacon network infrastructure uses the ZigBee/802.15.4 wireless communications protocol. Zigbee is a low data rate wireless network communications protocol that is designed to operate on devices with limited computing resources and

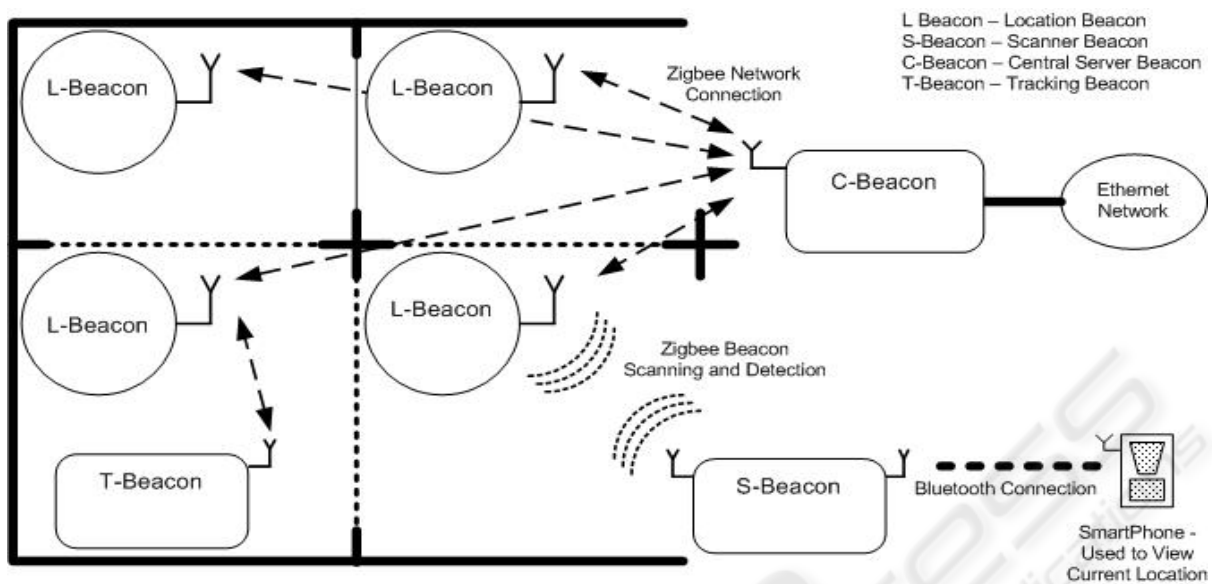


Figure 1: Location Beacon Network.

cater for large networks of active devices (ZigBee Alliance, 2006). This paper explores the use of the Zigbee protocol to determine a user's location and analyses two realtime location tracking mechanisms. Issues relating to the deployment and the integration of the location beacon network with conventional local area networks are also discussed.

This paper is organized into 7 sections. Section 2 presents a review of related work. Section 3 describes a typical scenario. Sections 4 discuss the location beacon network implementation. Section 5 presents the findings of testing conducted of the location beacon network. Section 6 provides an analysis of the location beacon network and discusses deployment issues. Conclusions and further areas of investigation are discussed in Section 7.

## 2 RELATED WORK

There are different types of wireless technologies, other than GPS, that have been investigated for location systems. Unfortunately, GPS is not suitable for indoor use and this has led to research into the use of other wireless technologies including UWB (Schwarz et al., 2005), ultrasonic and GSM (Otsason et al., 2005) platforms. Regulations are not clear for the use of UWB, and ultrasonic location detection still require the use of RF transceivers. GSM uses existing infrastructure, however accurate position resolution indoors is difficult.

Lamarca et al (Hightower et al., 2006, LaMarca et al., 2005) describe the Placelab geophysical

location system that allows users to determine their position in an urban environment. Placelab uses the received signal strength indicators (RSSI) of Wifi hotspots and GSM broadcast towers to determine a user's position. The Placelab software uses a database of known Wifi hotspots and GSM broadcast towers. The Placelab software can be used with a PDA or laptop with Wifi or GSM connectivity. Localisation accuracy is stated as being less than GPS, with 20-25m using Wifi hotspots and 100 to 150m for GSM broadcast towers. A similar technique of using RSSI is employed by the location beacon network.

A classical case of using wireless beacons for navigation is presented in (Want et al., 1992). The active badge project achieved a 5-10m accuracy using infrared. The main drawback of this platform is that it required line of sight between beacons.

An extension of the Active Badge Project was the ORL location system by (Ward et al., 1997) which developed a prototype network of ultrasonic beacons to perform realtime tracking of tagged mobile devices in an office environment. Other ultrasonic location systems such as the Cricket Mote (Priyantha et al., 2000) and the system by (McCarthy et al., 2006) describes how a network of ultrasonic beacons using time of flight analysis can determine distance position locations.

### 2.1 Zigbee Protocol

The Zigbee protocol is a wireless communications network protocol that is designed for low powered,

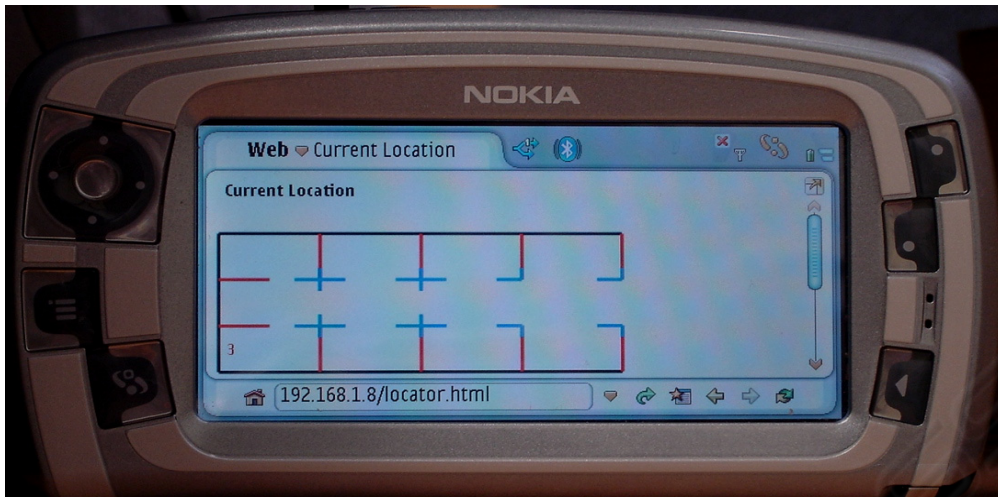


Figure 3: Scanner Beacon Locator Webpage Showing Current Location.

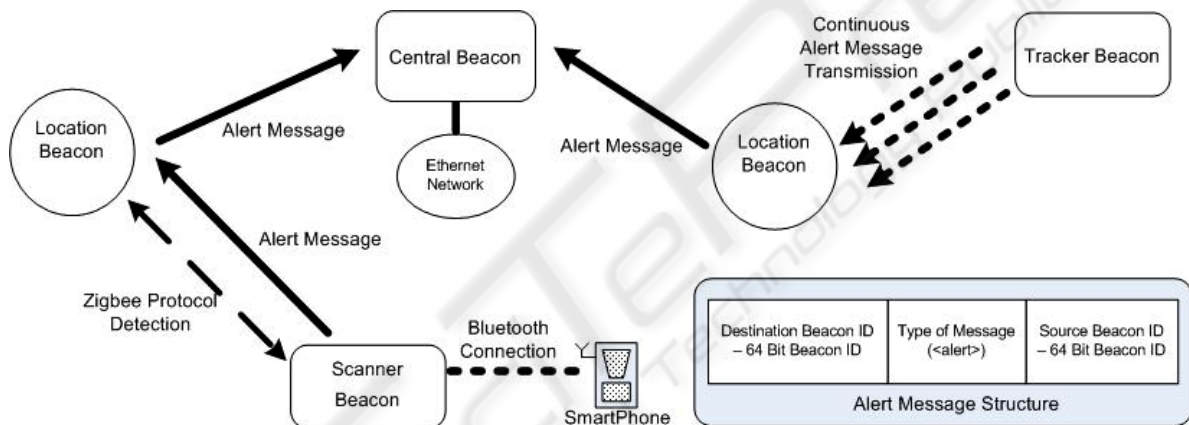


Figure 3: Location Beacon Network Message Passing Hierarchy.

low processing platforms (Baker, 2005). Its supported features are Mesh Networking, a unique 64-bit address, Low Data Rates 20kbps – 250kbps and simple application profiles. Zigbee is specifically aimed at aimed for ‘cable replacement’ applications. It operates in the unlicensed ISM 2.4GHz frequency band. Current Zigbee protocol radio chipsets have a large indoor range which can be up to 100m. The Zigbee protocol stack is divided into two sections, Zigbee and 802.15.4. The lower PHY and MAC layers are defined by the IEEE 802.15.4 protocol and the upper layers are defined as Zigbee protocol (ZigBee Alliance, 2006).

### 3 USER SCENARIO

The location beacon network was designed to track the position of users, in this case emergency

response personnel, within a building. Figure 1 shows an example deployment of the location beacon network. Location beacons are placed at known positions throughout a building.

A user carries either a scanner or tracker beacon to have their current position tracked by the central beacon. The scanner beacon allows the user to view their location as shown in Figure 3. The tracker beacon does not allow the user to view their current position. The tracker beacon is activated by the user when required.

### 4 LOCATION BEACON NETWORK

The network as see in Figure 1 consists of four different beacons, central, location, scanner and

tracker beacons. Scanner and tracker beacons are carried by users to determine their current location. The location beacons are used to determine a scanner or tracker beacon's position. The central beacon displays the current position of the scanner and tracker beacons. The location beacon network is not designed to track users with respect to distance coordinates but rather to determine their position within in a particular room or section of a building.

#### 4.1 Operation

The location beacon network uses the Zigbee protocol to provide communication links between the different beacons. Alert messages are used by the scanner and tracker beacons to report their current position to the central node. Figure 3 shows the communication message passing hierarchy between the different beacons and the structure of the alert message.

#### 4.2 Central Beacon

Each location beacon is within wireless communications range of a central beacon. The central beacon is connected to a standard Ethernet work and is used to track the current position of the user (with scanner or tracker beacon) within the location beacon network. The central beacon is accessed via a webpage interface. It displays the current locations of users.

##### 4.2.1 User Interface

As shown in Figure 4, the user interface consists of a webpage that is dynamically updated to display the current locations of users. The webpage relies on CGI scripting and an SQL database to track the last location of the user. The SQL tracking database records the details from each beacon.

##### 4.2.2 Implementation

The central beacon was implemented using an embedded Linux module connected to an XBee Zigbee/802.15.4 module (MaxStream, 2006). The central beacon is connected to the standard mains power supply and also has a rechargeable Lithium Ion battery. The battery serves as a backup power supply during a mains power outage. The central beacon has Ethernet connectivity. The architecture of the central beacon can be seen in Figure 4.

#### 4.3 Location Beacon

Each location beacon is in range of a central beacon. The position of each location beacon is known by the central and scanner beacons. The location beacons are detected by the scanner beacon. The minimum distance between the location beacons is 6m. This is required to allow the scanner beacon to use the received signal strength indicator for determining its nearest location beacon. More details are given in section 6.

##### 4.3.1 Implementation

The location beacon was designed to be simplistic in functionality, to reduce hardware and software costs. The architecture of the location beacon can be seen in Figure 5. The location beacon uses an xBee Zigbee/802.15.4 wireless transceiver module from MaxStream. Each xBee module has a unique 64-bit network address (MaxStream, 2006). This network address is used as the location beacon's identifier.

The location beacon can be connected expansion modules. Such modules consist of sensor platforms, i.e. climatic sensors such as temperature or humidity. The location beacons are plugged into mains power. Each beacon has a Lithium Ion battery to function as a power source if mains power is disrupted. The beacon was found to operate for 9 hours when powered solely from the battery.

#### 4.4 Scanner Beacon

The scanner beacon is carried by a user to determine their location. The scanner beacon detects location beacons in near proximity in order to determine a current user's position. The scanner beacon detects location beacons within a 10m range. The detected location beacon's ID and Received Strength Signal Indicator (RSSI) are stored in an SQL database. The RSSI is a measurement of the power of the received radio signal by the xBee transceiver module.

The nearest beacon is determined by the largest RSSI value detected. Once the nearest location beacon has been determined, the scanner beacon connects to it and transmits an alert message to it. The receiving location beacon then retransmits the alert message to the central beacon.

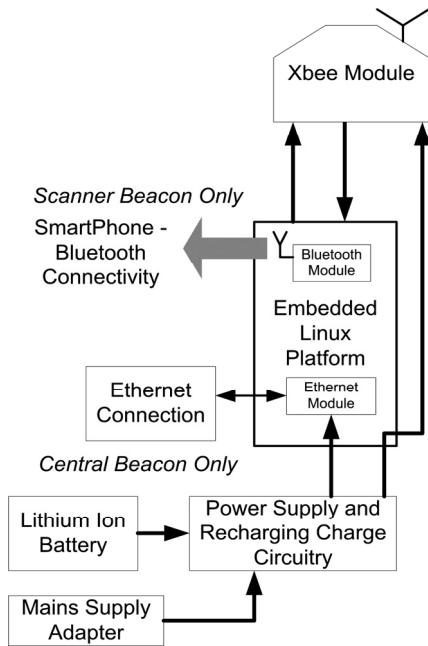


Figure 4: Central Beacon Hardware Architecture.

4.4.1 User Interface

A smartphone can be used to view the current position determined by the scanner beacon. The smartphone connects via a network point to point protocol (PPP) link via a Bluetooth connection to the scanner beacon carried by the user. The smartphone used was a Nokia 7710. As shown in Figure 3, the user interface consists of a webpage that is dynamically updated to display the current location of the user. The webpage relies on CGI scripting and an SQL database to display the current location. The SQL database records the details from each beacon.

4.4.2 Implementation

The scanner beacon has a similar hardware implementation to the central beacon except that it supports Bluetooth but not Ethernet connectivity. The architecture of the scanner beacon can be seen in Figure 4.

4.5 Tracker Beacon

The tracker beacon allows the user’s position to be determined by the location beacon network. It does not allow the user to view their current position. The tracker beacon is activated by the user when required. The tracker beacon has the same hardware implementation as the location beacon.

As shown in Figure 3, the tracker beacon continuously transmits an alert message. The Tracker beacon is designed to have a short transmission range of 1 to 3m. The minimum separation distance between location beacons is 6m. The received signal strength indicator is not required to determine the location of the tracker beacon, as required by the scanner beacon.

5 TESTING

The test setup of the beacon network consisted of six location beacons, one scanner, one tracker and one central beacon. Figure 6 shows the location beacons placed 5m apart, in a corridor and adjacent rooms. The test area was approximately 35m<sup>2</sup>.

Office walls were found to act as barriers for the Zigbee/802.15.4 transceiver signals. This was advantageous, when placing a single location beacon within a room, as this allowed the scanner determine its nearest location beacon as being in that particular room. This because the received signal strength levels is higher for location beacon in sight of the scanner compared to a location beacon that is closer in distance but is instead situated in an adjacent room. The location beacon was found to be able to communicate with the central beacon through office walls. The central beacon uses a quarter-wave antenna that is sensitive to receive transmissions from the location beacons.

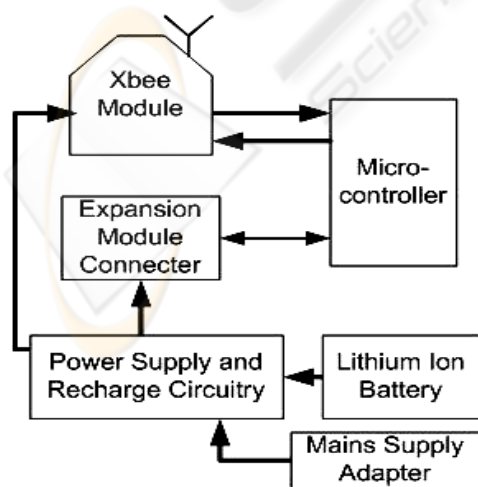


Figure 5: Location Beacon Hardware Architecture.

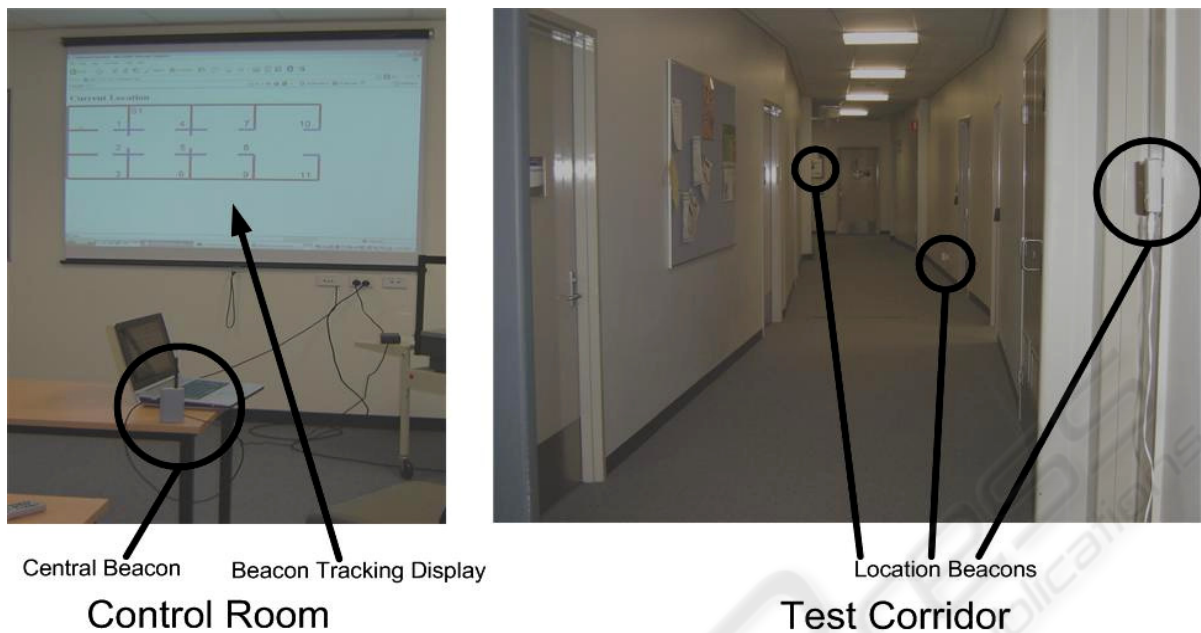


Figure 6: Test Setup of Location Beacon Network.

## 6 ANALYSIS

This section analyses the location beacon network system. The use of the Zigbee protocol and network interoperability is discussed. Issues relating to deployment and the location determining mechanisms used are also discussed.

### 6.1 Zigbee Protocol

The main advantage of using the Zigbee protocol is that it is designed primarily to provide robust and reliable wireless communications for networks containing large numbers of simple computing and battery powered devices. The location beacon network is designed to operate in during a mains power outage and hence the location beacons can operate from a rechargeable battery source.

The Zigbee lower protocol stack 802.15.4 defined PHY layer allows the location beacons to connect and disconnect quickly. Connection times are 30ms compared to 20s for Bluetooth (Baker, 2005). The use of received signal strength indicator (RSSI) allowed the Zigbee protocol to be adapted for use in the location beacon network. The RSSI measurement allows the location beacon network to approximate the location of scanner/tracker beacons within a known region but not actual distance coordinates.

Other advantages include the 64-bit ID addresses. This allows the beacon network to handle a large number of active beacons. The Zigbee communications protocol stack provides an application framework layer that allows customizable application profiles to be easily integrated with the Zigbee stack. As seen in Figure 7, each type of beacon has a unique application profile that interacts with the Zigbee/802.15.4 protocol stack. Each application profile is implemented on the embedded processor or microcontroller platform used for each beacon.

### 6.2 Location Determining

Location Determining was performed in this system using the received signal strength indicator. In this paper RSSI and transmission power levels were the main factor in calculating locations. Power control and detection features are supported by the Zigbee/802.15.4 wireless transceiver devices used. Two types of RSSI location tracking mechanisms were tested. The first mechanism involved actively scanning and detecting the RSSI levels for location beacons in near proximity. This mechanism was tested by the scanner beacon. The advantage of using this method is that the scanner can employ various techniques to determine the nearest location

beacon. One disadvantage discovered with this approach is that scanning time period is required in order to scan for beacons in proximity.

The scanning time period was approximately 100ms. This increased the time it takes to detect and issue an alert message to the central beacon. The average maximum response time was measured to be ~3s. The minimum response time estimated to be 500ms.

The second form of location determining mechanism tested, involved the continuous transmission of alert messages, over a short distance. This was tested by the tracker beacon. The tracker beacon's transmission power was limited to ensure that the only location beacons within a 2m to 3m radius could successfully receive the alert message. The advantage of this mechanism is that less time is taken for the central beacon to be aware of the tracker beacon's position.

### 6.3 Network Interoperability

The location beacon network was designed to be interoperable with standard local area networks. The central beacons were developed on embedded Linux platforms. The use of Linux in this situation was advantageous because it provided common network interface mechanisms such as sockets and SQL database functions. The central beacon's tracking database is accessible via a web interface.

### 6.4 Deployment

In order to deploy the location beacon network within a building, several central beacons and location beacons are used. Currently without the use of Zigbee mesh networking, the central beacons currently have to be within range of all location

beacons. The central beacons are currently limited in range to an average of radius of 20m inside a typical building.

To overcome range limitations, a building is divided into regions. A region is a section of floor level. A central beacon and location beacons would be deployed within a region. Central beacons would be connected via an Ethernet network to a server as shown in Figure 8. Each central beacon's tracking database can be accessed and integrated into the server's building tracking database. This allows the monitoring of scanner and tracker beacons throughout the building.

## 7 CONCLUSION AND FURTHER WORK

In this paper we presented a location beacon network system that tracks users in an indoor environment. The location beacon network consisted of location beacons placed at known positions throughout a building. Users carry scanner and tracker beacons to allow their current position to be monitored by a control centre. The location beacon network was designed to operate during a power outage and hence the location beacons can operate from a rechargeable battery source.

The requirement of the location beacon network system was to determine the position of a scanner/tracker beacon within in a region and not an exact distance position. The location beacon network used the Received Signal Strength Indicator (RSSI) as a means of determining the proximity of a scanner/tracker beacon to a location beacon. This paper analysed the use of the Zigbee protocol and RSSI as a location determining mechanism and found that the Zigbee communications protocol provided useful advantages compared to other protocols. Two mechanisms: scanning and tracking that used RSSI as a proximity detector were analysed. Both mechanisms have advantages but it was found that the tracker mechanism had a faster tracking time.

The location beacon network can be integrated with standard local area networks to allow deployment over a much wider area. The location beacon network was successfully tested over an area of approximately 35m<sup>2</sup>.

All though a successful prototype of the location beacon network was created and tested, there are further issues of investigation. Such issues include larger scale area deployments and long term reliability.

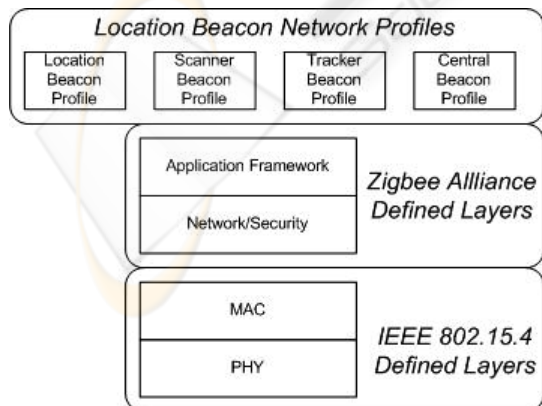


Figure 7: Zigbee/802.15.4 Communications Protocol Stack used for Location Beacon Network.

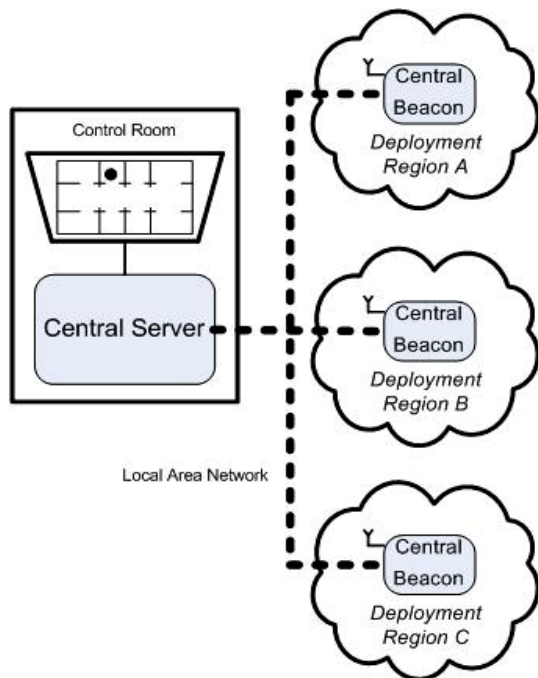


Figure 8: Location Beacon Network Large Scale Deployment.

The future addition of WLAN connectivity and the use of high antennas to the central beacons will allow the central beacons to be more easily deployed and cover a wider area.

## ACKNOWLEDGEMENTS

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