IV. BLE BEACONS FOR IOT APPLICATIONS

Bluetooth low energy (BLE) beacon, a low power wireless device, has showed its promising ability for IoT applications because of the wide spread of Bluetooth-compatible devices. The BLE Beacon paper provides with a through investigation into the BLE Beacon technology, and it gives insights to research challenges and opportunities.

A. Focuses and Overview

The BLE beacon paper discusses five aspects of the BLE beacon technology including IoT applications, BLE protocols and RF signal characteristics, BLE beacon hardware, BLE beacon software, and research challenges and opportunities.

a) Applications:

*Indoor Localization:* The cheap production, easy deployment, and readily accessibility to users of BLE beacons make it suitable for indoor localization. A research [a] described 19 BLE beacons deployed in an indoor office area and achieved an error of less than 2.6 m for 95% of the time when one beacon was deployed every 30 m2. This example worked better than the existing Wi-Fi networks that had at most 8.5 m error.

*Proximity Detection and Interaction:* A typical technology used for proximity detection is the QR code, which needs to be installed and is not pleasing to generate. Another technology called near-field communication (NFC) is only available within very short distance of 10-20 cm. BLE beacons can deal with these problems such as the AirDrop application, which scanned for iBeacon signals from other iOS devices to make connections [b].

*Activity sensing:* The use of BLE beacons for activity sensing can improve the knowledge of the device on the user activity and its micro-location. A system [c] was developed to monitor the activity information of senior citizens by wearing a BLE beacon tag embedded with an accelerometer.

b) BLE Protocols:

As shown in Table I, the channels of BLE are less than classic Bluetooth, and the advertising of BLE is constrained in only channels 37–39, which are the typically called beacons.

Machine generated alternative text:
TABLEI
CLASSICBLUETOOTHVERSUSBLE
Feature
Symbolrate
Powerconsumptlon
Throughput
ConnectionLatency
Channels
ChannelBandwidth
PeakCurrent
ClassicBluetoothBLE
1一3Mbps
1(normalized)
0．7一2彐Mbps
100+ms
79
1MHz
<30mA
IMbps
0．01-0，5
305kbps
<6ms
40
2MHz
<巧mA

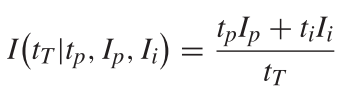
Table I Classic Bluetooth And BLE Features

BLE devices are connectionless and periodically broadcast their signals. These characteristics of BLE devices make it preferable to use BLE devices because they do not require device pairing to receive the BLE beacon signals. The data payload transmitted by BLE beacons are commonly called an advertising protocol data unit (PDU), and different profiles make use of this PDU in different ways. Apple and Google both developed their own BLE beacon protocols.

Apple's iBeacon [d] consumes less power because its advertising PDU has a smaller data size. This protocol only uses universally unique identifier (UUID) in its data payload. Eddystone [e] provides direct connection to the Chrome browser in any mobile devices, and it can switch between URL and TML frames and UID for the data payload.

c) Hardware

*Power Consumption*: BLE beacons send signals periodically, and it is sufficient to evaluate its power consumption in one period. As shown in Fig. 1, the initialization stage happens once for a device startup and should not be considered in the periodic behavior. Each signaling period consists of an advertisement event that consumes a fixed amount of power and an idle state that uses less power. Using Ip and Ii to represent the average current drawn during the advertisement event and the idle state respectively, the average current drawn during an advertising period can be expressed as:

 (1)

Machine generated alternative text:
InitializationStage
Advertisement
event
Fig.6．
《Idlestate《
Time
ElectricalcharacteristicsOfBLEbeaconincludinginitializationstate.where tp is the advertisement time, ti is the idle time between each advertisement, and tT is the advertisement period.

Fig. 1. Current characteristics of a BLE beacon over time.

Average current draw during advertisement state can be used to estimate the power consumption, and thus guiding the design of the battery.

*BLE Chipset:* The standards for choosing a BLE chipset include the power consumption, flash capacity, RAM capacity, and the internal voltage regulator. Table II shows three representative BLE chipsets with their supported BLE versions and average current. The nRF51 series have 128KB and 256 KB flash storage choices, and 128 KB is usually sufficient in simple applications. In the authors’ experience, 16KB RAM is enough for BLE, and larger ones do not aid the performance or development [BLE beacon]. Current draw from the radio is most significant for BLE because there are little CPU computations done in the BLE chip. Therefore, it is sufficient to analyze the current for power evaluation. The authors proposed that future research could integrate external voltage regulator in the BLE chipset to increase battery lifetime and to avoid complications [BLE beacon].

Machine generated alternative text:
TABLEIll
COMPARISONOFREPRESENTATIVEBLECHIPSETS
FROMLEADINGMANUFACTURERS
BLEChipset
CC2541
nRF51822
PSoC4BLE
SupportedVersion
SingleModeBLEv4．0
SingleModeBLEv4.1
SingleModeBLEv4.1
Current
18．2一14．3mA
9．7mA
15．6mA

Table II Representative BLE chipset comparison

*Energy Storage*: Coin-cell batteries are widely used in BLE beacon devices because of their low-profile form factor and yet sufficient power delivery. The disadvantage of coin-cell is that it requires frequent battery replacement due to low battery life. The use of larger alkaline batteries like AA and AAA batteries can increase the batter lifetime, but the heavy weight and large size reduce the advantages of BLE beacons.

*Energy Harvest:* Outdoor energy harvest technology for BLE beacons includes motion and light harvesting. More complicated than outdoor energy harvest, an indoor energy harvest architecture for BLE beacon includes three parts: photovoltaic energy harvesting, a power management unit, and a BLE unit.

*Casing and Installation:* Two major purposes for BLE beacon casing is the look and protection. Good casing makes the BLE beacon less noticeable and protects it from dust, water, or electric influences. However, one common issue is that the casing needs to be cut to replace batteries, which makes the casing less protective. Design of the casing depends on the material and orientation of the surface it attaches to. Magnetic casing is suitable for metal surfaces and double-sided adhesive tape is suitable for wood surfaces. In installation process, it is better to clear obstacles between the beacon and the receiver device by setting the beacon at a height.

d) Software

*Battery Monitoring:* The drawback of BLE beacon is the large fluctuation in RSS and a finite battery capacity, but these can be overcome through the software design including battery monitoring. The iBeacon protocol utilizes the flexibility of BLE beacons to collect battery information through communication with the beacons. The iBeacon protocol can be customized to include battery information in the transmitted packet [f].

*Proximity Estimation:* Proximity estimation is essential for may BLE applications, and while being cost-efficient, BLE also has fluctuation in the RSS that affects the accuracy. The authors experimented on an iBeacon software to estimate the distance of 60 points taken each for 0.2m using BLE beacons. As Fig. 2 [BLE beacon] suggests, the estimation is relatively accurate for the first 0.5 m but does not provide useful estimation for distance above 0.5 m. Another method [g] that measures the path loss index by referencing the RSS at 1 m to the unknown distance has 0.4 m error within 3.5 m.Machine generated alternative text:
groundtruth
℃
1000
500
80
160
coreLocationFramework(iOS)
240320400480560
ActualDistance(cm)
640
720
800

Fig. 2. Estimated distance versus actual distance using RSS measurements.

*Security:* Due to its simplicity, BLE beacon is easily attacked or abused by unwanted users such as thievery and cyber-attack. The security of a BLE beacon can be protected mainly through two methods: geological validation and cloud-based token authentication.

1) Geological Validation:

For this method, each beacon's location information is first stored in the server, and the user's location information is sent to the server to make sure the physical presence of user near the beacon. This can deal with the beacon spoofing attack which copies the advertisement packet of a beacon and uses it outside the designed range. The drawback of geological validation is that the storing of location information takes up a lot of storage space, and this is restricted for outdoor use because GPS is unavailable indoors.

2) Cloud-Based Token Authentication:

This method generates a unique token for each beacon on the firmware layer that can only be verified by the server. However, the disadvantage is that if the algorithm of generating a token is discovered, the BLE beacon still can be attacked. Also, this is difficult to be deployed to an existing beacon network because it requires firmware updates in each beacon.

*System Scalability:* Beacon communication is dependent on the network requests sent to the corresponding cloud servers. The number of requests is the product of the total number of users and the total number of beacons. Therefore, it is necessary to have a scalable server that sustains the successful connection rate when the number of requests and the size of packets increase.

B. Challenges and Problems Solved

The challenges for BLE beacons mainly lie in three sections: protocols, hardware, and software. By analyzing these challenges, the authors [BLE beacon] proposed some promising research opportunities of BLE beacons.

*BLE Protocols:* The two major protocols iBeacon and Eddystone are incompatible to each other. Thus, it is important for a mobile device such as a smart phone to support both protocols, so that it can connect to most of the Bluetooth devices. Upon the compatibility challenge, BLE protocols also face the signal interfering challenge because usually there are many-to-many Bluetooth connections within a region. To account for this challenge, RSS-comparison [h] is designed such that only the beacon with the strongest RSS will be connected. The RSS-comparison technology is not suitable in every condition, and more decent algorithm for selecting connection should be developed. Moreover, there are different interaction interfaces that cause development challenges if beacons do not use the same interfacing technology.

*Hardware:* The major challenge for BEL hardware is the energy harvesting technology. Although energy harvesting has been studied for wireless sensor networks, it is not sufficient for BLE beacons for two reasons: wireless sensor networks are mostly outdoors while the BLE beacons are used both indoor and outdoor; the electrical characteristics of BLE beacons are different from wireless sensors. Therefore, future research can focus on developing hardware specifications for BLE beacons to suit different scenarios. Besides energy harvesting, there are three challenges for BLE hardware:

1) Robustness: BLE beacons should preserve its protection for inner circuit parts after battery replacement, while sticking to the IEC standard 60529 or standard 250-2003 [85].

2) Energy Harvesting: BLE beacons need higher energy harvesting efficiency and its adaptability.

3) Installation: It is essential for the development of special installation techniques and casing for convenient installation, strong protection, and easy replacement.

*Software:* The software challenges for BLE beacons include battery monitoring, distance estimation, system scalability, and security.

1) Battery Monitoring: The challenge is that the BLE beacon cannot update battery information frequently with low user traffic nearby, and error can exist in the retrieved battery level because each beacon may have different battery information packet offset. Therefore, the battery information style should be considered to get accurate battery data.

2) Distance estimation: The identification of beacons by measuring RSS in a dense environment is challenging because there is interference among close beacons. Future research can study the algorithm to improve the RSS measurement accuracy.

3) System Scalability: Many network requests are generated by multiple devices at the same time, which require proper management. A possible approach to improve the server performance is by reducing the number of requests needed.

4) Security Issues: The geological validation and cloud-based token authentication are more like precautionary systems rather than security systems, for they prevent beacon abuses, but cannot detect or react to potential attacks. The research of security issues in BLE beacon infrastructure is still at its starting up stage and there is little research done. There is urgent call for a more scalable attack detection method with less computational load, as well as a security protocol to fully control the beacon network.

C. Strategies Used

The BLE beacon paper used three strategies to study the BLE beacon technology: survey on existing works, comparison between different approaches, and small-scale experiments [BLE beacon].

For example, the authors conducted an experiment on CR2450 battery with a nominal voltage of 3 V (2-3.6V working range) to show that the CyPhy Media iOS application can provide approximate battery information. In Fig. 3, comparing the actual battery voltage and the percentage provided by the mobile application, it can be concluded that the behavior of CR2450 is consistent to its theoretical characteristics [70].

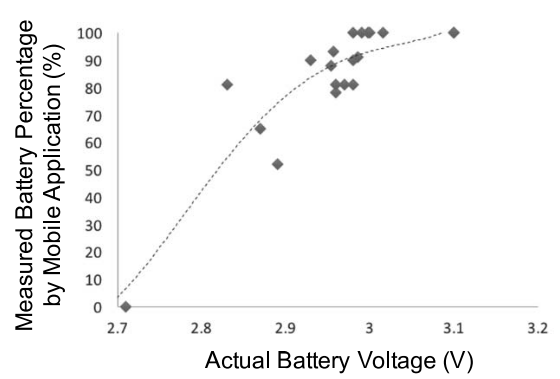


Fig. 3. Mobile application reported battery level versus actual voltage of the CR2450 battery.

V. IOT FOR SMART CITIES

The objective of this paper is to discuss a general reference framework for the design of an urban IoT, supported by an example of large scale IoT system that was deployed in real world. It focuses on the communication between edge IoT nodes and the server systems [Smart Cities].

A. Focuses and Overview

This paper offers a detailed survey on enabling technologies and architecture for an urban IoT, before finally discussing the technical solutions and best-practice guidelines adopted in the Padova Smart City project [Smart Cities].

a) Services:

There are nine services surveyed in the paper, and those are of particular interest because they improve the quality and the service for citizens while offering advantages to local government by reducing operational cost [6]. However, those services are not widely used because there are few accepted communication and architecture models to work in a harmonized way between different services. Here three services are introduced.

*Structural Health:* Urban IoT can collect building structural integrity measurements using sensors in or around the buildings and store them in a public database, which saves the human work for structural checking [11]. This approach may require an initial investment to install sensors and connect sensors to a control system.

*Traffic Congestion:* Using the sensors and GPS on modern vehicles and possibly noise and air quality sensors, a traffic congestion monitoring service can be implemented to aid the city authorities as well as citizens on route planning [15].

*Smart Lighting:* By including streetlights in the smart city plan, energy can be saved by adjusting city lighting according to the environment change. This has potentials for improve WiFi connection and fault detection because the number of connection spots dramatically increases.

b) Architecture:

There are two main characteristics of an urban IoT infrastructure. The first characteristic is its ability to interoperate between different technologies using the existing communication infrastructures. The second characteristic is the necessary accessibility of the collected data for authorities and citizens [9]. These characteristics are satisfied by appropriate combination of the web service, link layers and devices.

*Web Service Approach:* As presented in Fig. 4, the web service consists of three layers: data layer, application and transport layer, and the network layer. The three layers are needed for the communication between the more common unconstrained protocols and the less complex constrained protocols, as the communication between IoT nodes and the Internet requires easy access and interoperability.

1) Data Format:

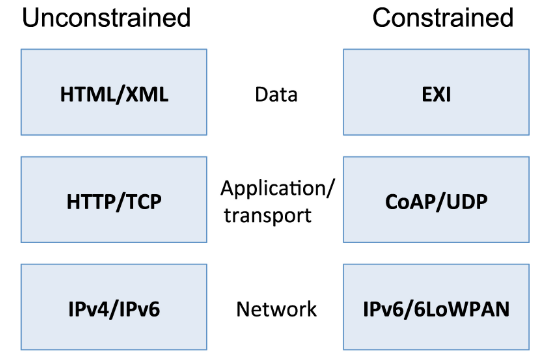
It is preferred to use EXI format to describe the messages sent in an IoT system because even constrained devices can natively support and produce messages in an open data format that is compatible with XML [19]. The integration of multiple XML/EXI data sources in an IoT system can be achieved by high-level databases that control nodes using data and the application.

Fig. 4. Layers of protocols for constrained (right) and unconstrained (left) IoT peripheral nodes.

2) Application and Transport:

CoAP [22] can be used for IoT because it enables the transportation of data in a binary format over UDP, and a reliable service is based on the correct retransmissions. CoAP can also interoperate with HTTP well with a cross-proxy which provides straightforward translations of the requests and responses between the two protocols to enable transparent interoperation between native HTTP devices and the application [23].

3) Network Layer:

IPv6 addresses are redundant for constrained nodes to process. The 6LoWPAN compression format [25], [26], designed for IPv6 and UDP headers over constrained networks, can ease the computation load for constrained nodes through the conversion between IPv6 and 6LoWPAN format using a border router.

*Link Layer Technologies:* An IoT system needs a link layer to cover a wide geographical area and to digest large amount of data flow. Unconstrained technologies are not suitable for IoT because of its high power consumption and complexity. Constrained technologies are used for IoT because of its lower power consumption, although having lower data transfer rate which is usually lower than 1 Mbit/s.

*Devices:* There are three kinds of devices needed for an IoT system. The first is the backend service in the control center for data collection, storage, and processing to perform added-value services, interfacing with data feeders. The second device is the gateway that interconnects end devices to the main communication infrastructure by providing functional mapping and protocol translation. The third device is the IoT peripheral node to produce data such as RF tags and mobile devices.

c) Padova Smart City

The Padova Smart City deployed at the University of Padova [31], [32] was designed to collect environmental data and to monitor the streetlighting by the collection of CO level, benzene level, air temperature and humidity, vibrations, and noise, while checking the operation of lighting system by monitoring light intensity at each post.

Each streetlight was identified by an IoT node attached to it, which was equipped with photometer sensors, humidity sensors, and temperature sensors. There was also one benzene sensor deployed. The IoT nodes were sealed inside transparent plastic shields to prevent environmental influence and were powered by small batteries.

This example is representative for an urban IoT design because it involves various of devices and link layer technologies. IPv6 addresses compressed through 6LoWPAN standard were assigned to each node to form a 6LoWPAN multihop cloud using IEEE 802.15.4 technology. A sink node was used to gather all data and to interface with the external nodes, which was enabled by the WAN technology gateway. Data were collected by the database server through the communication with the HTTP-CoAP proxy server, and data could be accessed from traditional web programming.

B. Challenges and Problems Solved

This paper [Smart Cities] introduced an entire IoT system for Smart City application, but also surveyed on the difficulties that slowed down the application process of a Smart City IoT system and provided possible solutions.

*Political Obstacles:* One problem of the Smart City is the administration power attribution to different stakeholders. This may be solved by institutionalize the decision-making process into one department to prevent the attribution of decision-making power to different stakeholders [7].

*Technical issues:* There still exists noninteroperability of the current heterogeneous technologies, which shall be solved by building a unified urban-scaled ICT platform based on IoT vision [8], [9].

*Financial problems:* The market still lacks a clear business model of a Smart City [10]. To account for this, the investors can first try smart city services that have clear and direct return on investment such as smart parking, and then aid the deployment of other added-value services [10].

C. Strategies Used

This paper [Smart Cities] used three strategies to present the IoT system for Smart City applications: literature review, comparison between different methods, and field experiment.

For the data collection of the field experiment of the Padova Smart City, temperature, humidity, light, and benzene readings over a period of 7 days were provided in the paper. Red dots are the raw data, and the lines stand for the moving average value within one hour.

From figure 7 (a), it can be observed that the light peaks at daytime and reaches minimum at night. The light intensity value is noisy at night because of the influence form car lights. The Benzene level in figure 7 (b) is lower at night because of lower traffic congestion.

Machine generated alternative text:
4000 
3500 
3000 
2500 
2000 
1500 
1000 
500 
10/24 
• 
Raw data 
Filtered data 
10/25 
10/26 
Raw data 
Filtered data 
10/27 10/28 
Date 
(a) 
10/29 
10/30 
10/31 
101 
10 
10 
10/24 
10/25 
10/26 
10/27 
10/28 
Date 
(b) 
10/29 
10/30 
10/31 

Fig. 5. Data collected in the Padova Smart City: (a) light and (b) benzene.

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