BeaCloud: A Generic Architecture for Sustainable Smart City using Bluetooth Beacons

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***Abstract*—In recent years, Bluetooth beacons have been widely used in numerous application domains, including smart cities, assistive technologies, and intelligent transportation management. Researchers or developers associated with these domains frequently require diverse systems to implement or test their prototype related innovations. They need to deploy beacons for the specific environment every time; such customized systems typically cannot often be reused. Hence, the cost of implementation increases, and multiple systems generate redundant data. In this paper, we propose *BeaCloud* – an architecture which provides a common platform of multiple beacon-based systems. BeaCloud enables inter-system communication and allows easy and secure access to data for the system administrators. The proposed architecture presents a cost-effective model that offers reduced cost and hardware. Also, BeaCloud reduces the data redundancy by up to 40%. To demonstrate the feasibility of BeaCloud, we implemented a testbed of three testing sites and evaluated the system's performance.**

***Index Terms*—Beacon, Mobile Application, Smart City, Cloud, Sustainable, IoT**

I. INTRODUCTION

Currently, more than half of the population of the world is lives in cities. According to the United Nations (UN), cities will be home to seven billion peoples by 2050 [1]. Cities are facing both environmental and infrastructural pressure for the growing demand to provide a better quality of life. City planners, including engineers, architects, and city managers are constantly boosting up the efficiency of the services and increasing benefits for the residents [2]. The goal is to provide better city services and a higher quality of life. In addition, cities are getting bigger for various reasons [3], [4]. For example, in the United States, 127 million people live in cities, and 775 cities have more than 50,000 residents [5]. There is no doubt that cities are important for economic growth and opportunity. For example, the cities on the Northeast side (from Boston to Washington D.C.) and Los Angeles, United States, holds for nearly one-third of the country's GDP; only London accounts for one-fifth of the United Kingdom's GDP [6]. However, a large population means excessive pressure on services and creates instability in environments as well as residents' physical security and safety.

The Internet of Things (IoT) has the potential to overcome the pressure of urbanization, create new experiences for city residents, and make day-to-day living more comfortable and secure. City planners are deploying IoT in infrastructure, securities, traffic management, waste management, environment monitoring, pedestrian safety, etc. For instance, Boston and Baltimore deployed smart trash bins to measure the waste levels and determine the most efficient pickup route for workers. In addition, cities are embedding smart devices to reduce fatalities (homicide, road traffic, fires, etc.) [7] and applications such as gunshot detection and smart surveillance [8] to accelerate the law enforcement's response. For example, *ShotSpotter* is a gunfire detection system used by the Birmingham, AL Police Department to provide rapid location data for gunfire in the city [9]. Currently, a plethora of applications in smart cities are using beacons.

Beacon technology with other IoT is integral now in smart cities to accomplish the goal of sustainability and accessibility. Both the industrial and public sectors are adopting this technology to ease civic life. For example, to identify the location of occurrences and report them to the police, the city authority of Columbus in Georgia, USA, installed more than 1000 beacons at the Chattahoochee Riverwalk [10]. According to a report from ABI Research (a US-based technology market intelligence company), more than 500 million beacons will be shipped by 2021 [11]. In 2013, Apple first popularized these geolocation transmitters; they are designed to interact with Bluetooth enabled devices, such as smartphones, tablets, cars, etc. There are already over 8.2 billion Bluetooth-equipped devices globally; that number does not include just tablets and smartphones. Over 90% of vehicles released in 2016 were expected to have this technology [12].

Cities are using beacon technology to solve one of the most visible consequences of urban population growth – transportation and traffic congestion. Different city entities embed these devices independently, such as in the emergency management department, traffic management, police, waste management, etc. In addition, private companies, such as Walmart, Macy's, Apple Inc., etc., installing beacons at their stores for better customer engagement, navigation, and advertising purposes. In addition, there should be an application that will receive the beacon's signal and act accordingly. Therefore, the authorities are developing various applications to receive these signals based on their necessity. It is difficult for end-users to maintain and use multiple receiver applications for corresponding different uses. In addition, even for the smart city authorities, it can be confusing to install multiple beacons and maintain them independently. For example, it is sufficient to install one beacon for all departments if there is coordination. However, communication protocols, characteristics, and work-procedure are not the same for different types of beacons. Therefore, there are several challenges associated with providing an umbrella system for all the beacons. To this end, we have presented BeaCloud – a generic architecture for the various beacons in the smart city for sustainable development.

Contributions: The contributions of this paper are as follows:

1) We propose BeaCloud, a generic architecture for BeaCloud-as-a-Service using beacons in a smart city environment.
2) We provide an access-control based mechanism which allows implementing and operating such a system in an economically feasible manner.
3) We set up a testbed with three different testing sites using BLE beacons and smartphones. The results show that BeaCloud reduces the hardware cost by more than 24%. In addition, it reduces the data redundancy up to 40%.

Organization: The rest of the paper is organized as follows:

- Section II - Background of beacons and applications.
- Section III - Details of BeaCloud architecture.
- Section IV - Test deployment; details of the testbed.
- Section V - Experimental findings.
- Section VI - Concluding remarks.

II. Background

In this section, we provide a brief overview of the Bluetooth beacons and their applications in smart cities.

A. Bluetooth Beacons

Bluetooth Low Energy (BLE) beacons, or simply beacons, are a small pieces of hardware that broadcast wireless signals in short range [13]. BLE beacons are operated using Bluetooth 4.0 [14], which has some advantages over classic Bluetooth. For example, BLE requires low energy and low cost compared to a similar communication range than the classic one. BLE beacons broadcast the signal spherically, have a specific signal transmission range, and can not receive any data from the other side. Beacons are one-way transmitters; they do not receive any signal from other devices and can not connect to nearby receivers. An example of a high-level beacon operation is shown in Figure 1.

Fig. 1. Different Bluetooth enabled devices receiving BLE signals from the beacon.

The Bluetooth enabled devices (built-in Bluetooth and turned ON) can directly receive the signals from nearby beacons. After receives the signal, it calculates the distance by the signal strength. The modern smartphone, including the Android (Android version 4.3 or upper) and iOS platform (iPhone 4 or upper version), supports BLE technology. Multiple manufacturers make beacons, including Estimote[1], RadBeacon[2], BlueCats[3], Kontakt[4], Gimbal[5].

B. Beacon Protocol

Beacons follow standard BLE communication protocols. There are multiple BLE communications standards; each standardizes the data packets structure, size, and other measures. iBeacon and Eddystone are the most popular beacon protocols:

iBeacon: iBeacon protocols introduced by Apple in 2013 at the Apple Worldwide Developers Conference [15]. iBeacon broadcast four types of information:

1) **UUID:** A Universally Unique IDentifier, in short UUID, a 16-byte string to distinguish the group of beacons in the same network from another network.
2) **Major:** A 2-byte unsigned integer values between 1 and 65535; it helps to recognize a subsect of beacons from the same network.

[1]https://estimote.com
[2]https://store.radiusnetworks.com
[3]https://www.bluecats.com
[4]https://kontakt.io
[5]https://gimbal.com

3) **Minor:** A 2-byte unsigned integer, the same value range as *Major*; it is possible to identify beacons specifically from the subset with Minor value.
4) **Tx Power:** Tx or Transmit power defined the proximity between beacons and receiver. The higher transmit power means the signal can travel long distances.

Eddystone: Google developed Eddystone as an open beacon format in 2015 [16]. The Eddystone protocol transmits these different frames-types:

1) **Eddystone-UID:** A 10-byte Namespace component and a 6-byte Instance component, the individual beacon can be identified by this value.
2) **Eddystone-EID:** similar to UID, but "encrypted". Only authorized apps and services can make use of it.
3) **Eddystone-URL:** A short URL encoded directly into the packet.
4) **Eddystone-TLM:** telemetry data such as battery voltage, uptime, etc.

Although the Eddystone follows a similar profile with iBeacon, the Eddystone can be implemented without any restriction. In 2018, the Eddystone platform came under scrutiny for various privacy issues [17].

C. Beacons in Smart City

BLE beacons can be used both indoor and outdoor for positioning in real-time. Apple Inc. installed beacons for product reviews and notifications inside the stores. They deployed the beacons in 254 apple stores in the United States in 2013. Macy's also deployed beacons in over 4000 shops in 2014. On the other hand, to provide turn by turn instructions to the visually impaired peoples, the Royal London Society for Blind People (RLSB) deployed beacons at the underground network in London. It developed an app called "Wayfindr" [18]. The application can provide audio direction and obstacle information to the users at the subway. Usually, the receiver application sends data to the server for future uses or collectively achieve better accuracy. Besides, the receiver application can store data for customized positioning. For example, the application could handle user behavior and environmental factors as input. A typical beacon-based system is shown in Figure 2.

BLE beacons have been used both indoors and outdoors for positioning in research studies [19]–[22]. Cheraghi et al. [23] developed a navigation system in large indoors. The application can provide topology and real-time notification to the users. Beak et al. [24] developed a Bluetooth beacon-based underground navigation system to facilitate mining operations. Jung et al. [25] used the Bluetooth beacon to measure the transport time of mining equipment underground. Hasan et al. [26] developed *FinderX* based on BLE beacons and smartphones to positioning amenities in the urban area. *FinderX* provides the nearby trash bins and restrooms information to pedestrians, especially those who are not very familiar with the surroundings.

III. BeaCloud Architecture

We present a high-level architecture of BeaCloud in Figure 3. The brief description of the components of BeaCloud are as follows:

A. Signal Layer

Device-level configuration, such as broadcasting power, advertising interval, beacon placement, etc., can be done in this layer. Different types of beacons can work for multiple applications based on their characteristics and application requirements. There are two factors that must trade-off between performance and energy consumption - broadcasting power and advertising interval. Strong broadcasting power means it will travel long distances but consumes more energy. In addition, the signal would be more stable if the advertising interval is smaller. However, a shorter interval would consume more power. The

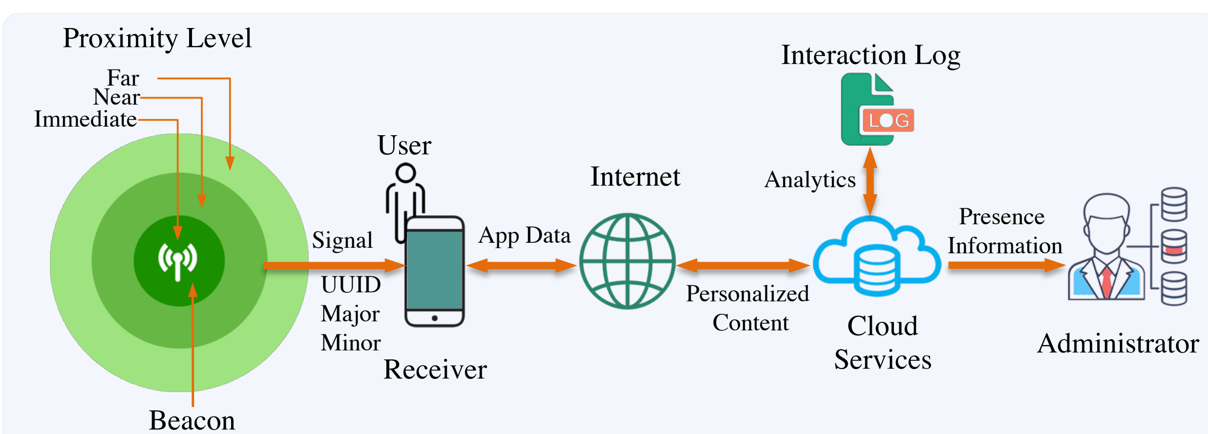

Fig. 2. The typical system architecture of beacon-based service

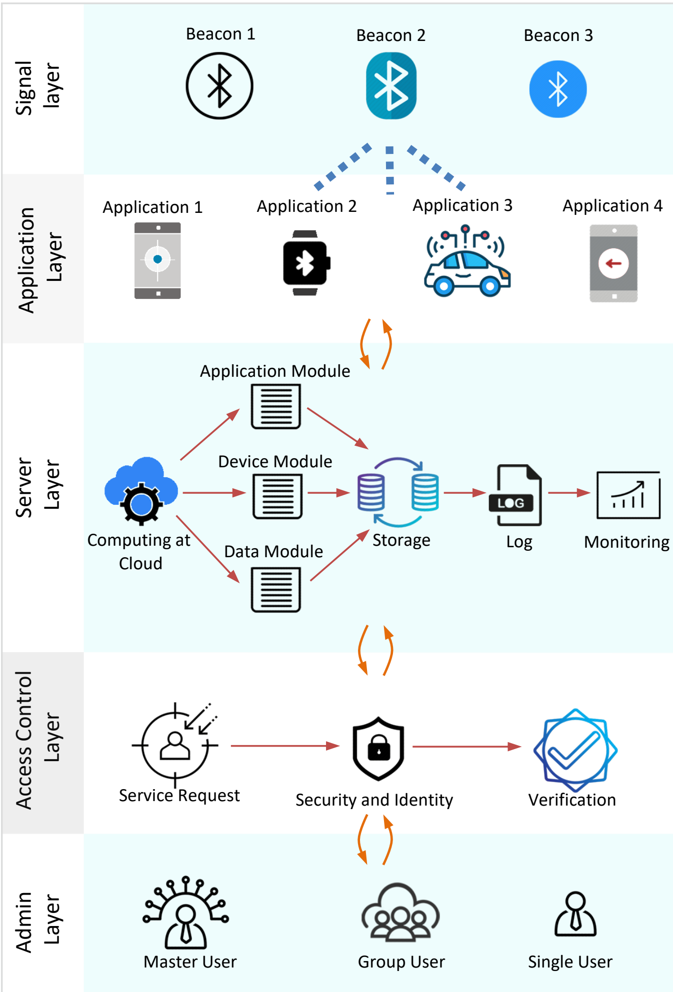

Fig. 3. Generic architecture for Bluetooth beacon-based system in smart city applications

BLE beacons transmit signals spherically both in indoor and outdoor environments in a time interval.

B. Application Layer

The application layer is the second most key layer of this architecture. The application layer basically an interface between the user and the beacons. Different application based on the service receives the signal from the corresponding beacons. Upon receiving the signal, the receiver application can determine the approximate distance from the beacon with relative accuracy using the signal strength. The applications can uniquely identify the beacon from the received signal. For example, in the iBeacon platform, the UUID, major, and Minor are the three required fields to identify a beacon uniquely. In addition, applications collect additional system-level and sensors data for personalized service. This layer can serve the user's initial purpose without the help of any other infrastructures, such as the Internet, GPS, etc. However, for better results and future analysis, applications send and/or receive data to the server. Based on the requirements, the receiver application could be any Bluetooth enabled devices, such as a smartphone, smartwatch, smart car, etc.

C. Server Layer

The application layer interacts with the server layer through web services. The cloud service is located in the server layer. The computation, storage, and monitoring part are done here and the critical component of the architecture. The Communication and Server layer launches three modules to identify and manage the incoming data from different applications and devices: *Application Module*, *Device Module*, and *Data Module*. These modules handle the diversity of the data and save it to the database accordingly. The log server stores all the user's and application's presence. Monitoring and analyzing server track the beacons life-cycle and demonstrate application data. The rule of the administrator protects access to the entire server layer. Only the master user has full access to the layer and the data.

D. Access Control and Admin Layer

The architecture accumulates the data from several applications in a common ground. From smart city perspectives, individual departments handle a specific side of the city, such as the police department enforce laws, prevent crime; the emergency management department handles the emergency, etc. The architecture confirms the segregation of data from one department to another. However, there is the superuser's probation, who can monitor and resolve if there is an anomaly. To so, the system implements the Access Control List (ACL) feature. After requesting a service from the user, the system will verify the user's identity and find the associated role. The user will able to perform what the admin has assigned.

The admin layer is the bottom part of the architecture. The master user has access to everything of the system and has the authority to add/remove it to other users. The group user is the number of people from multiple departments, suppose the emergency management and police department. The single-user access, who are from a specific department and their applications are not dependent on others.

E. BeaCloud Communication Protocol

BLE beacon-based applications communicate to the server through Application Programming Interface (API). As several beacons protocol is available, the server keeps identifiable pieces of information and signal data along with receiver sensor data. The application has to send the basic beacon data, such as UUID/EUID, Group information, distance, etc. Table I shows the required parameter to send data from the receiver application to the server:

IV. Test Deployment

We implemented a testbed for BeaCloud that runs on three types of beacon settings in an urban environment. We used the Estimote beacons in all the sites; for the backend, we used the Amazon Web Services (AWS).

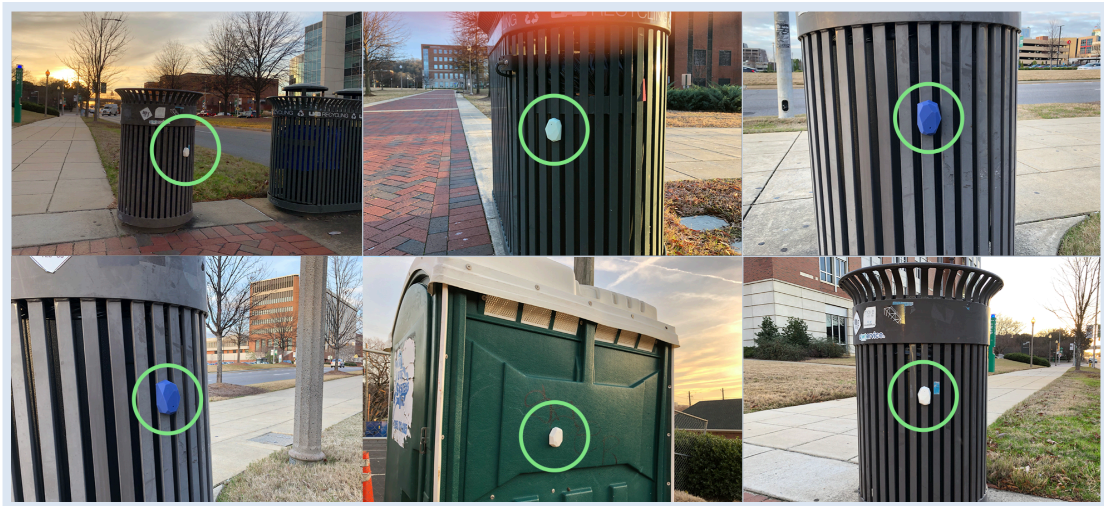

Fig. 4. Installed beacons at the amenities finder site

TABLE I
MESSAGE FORMAT FOR SEND DATA FROM THE RECEIVER TO THE SERVER

ID → [ApplicationID]
Protocol → [iBeacon, Eddystone]
Receiver → [Phone, Car, Watch, ...]
Action → [Get, Post]
FrameHeader → [EventType, Sender, TimeStamp, PayloadSize] **EventType** → [EventTypeDetails] **Sender** → [UserID, Status] **TimeStamp** → [Timestamp] **PayloadSize** → [PayloadDataSize]
BeaconData → [BeaconGroup, Subset, SpecBeacon, Distances] **BeaconGroup** → [UUID, UID] **Subset** → [Major, EID] **SpecBeacon** → [Minor, URL, TLM] **Distances** → [Distance 1, Distance 2, ...]
DeviceInfo → [Source, DeviceSpec, Status] **Source** → [Android, iOS, Windows, ...] **DeviceSpec** → [IMEI, Model, , HardwareSpec, ...] **Status** → [Orientation, in Use, Applications]
SensorData → [Motion, Regular] **Regular** → [Light, Sound, ...] **Motion** → [Acceleromete, Gyroscope, Magnetomete, ...]

A. Amenities Finder in Urban Area

To find the city's nearby amenities, such as the trash bin and restrooms, we have set up a test site in the urban university campus. There were two types of locations where we installed our pre-configured beacons [26]. We installed eight trash bin indicator beacons and three beacons for restrooms. All the trash bins are on busy roadways on the campus. Those beacons help locate the urban amenities to the users, especially those unfamiliar with their surroundings. The beacon emits the signal, and the user's carried device capture these signals to get to the nearest restrooms or the trash bin. These signals also help to provide the directions towards the location after a little workout. Figure 4 shows installed beacons at the experimental site.

B. Traffic Intersection

We choose to conduct our study at a busy intersection on our urban university campus. This intersection is one of the busiest intersections at this campus. Sampling on ten occasions over three weekdays yielded a rate of 916 pedestrian crossings per daytime hour at that intersection, and vehicle traffic of 1480 vehicles per hour on one cross-street and 548 vehicles per hour on the other cross-street. We installed Bluetooth beacons at several points around the intersection. Figure 5 shows the approximate positions of the 14 beacons installed at the intersection.

In this site, we used 14 beacons to locate each user's position and alert them at the correct time and place if they were distracted by the smartphone. Of the 14 beacons, 11 were installed on light posts or traffic signal posts. The remaining three beacons were installed on stakes hidden in surrounding shrubbery. To ensure weather conditions would not damage the beacons, we first placed them inside a waterproof and sealed plastic bag. We then used duct tape to affix the beacon in a stable position.

C. Construction Site

Construction zones are dangerous and fraught with potential hazards for all pedestrians and drivers that pass through them. It is important to pay attention to these locations and ensure safety. Injuries and death soon follow accidents within construction locations that have heavy changes to the road. According to the Centers for Disease Control and Prevention (CDC), an average of 773 lost their lives each year in traffic accidents

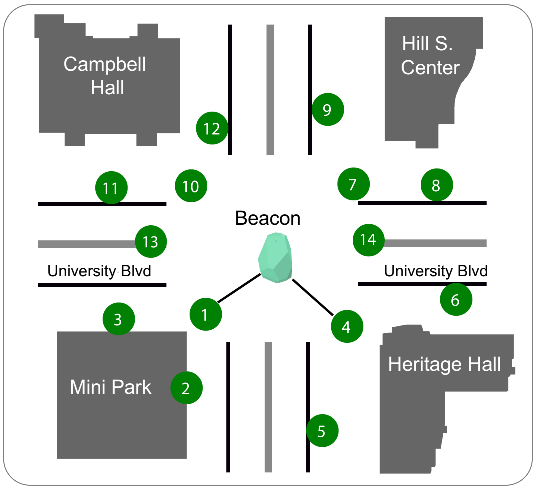

Fig. 5. Positions of installed beacons in the specified intersection

that occurred in the construction areas from 1982 - 2017 [27]. We have installed the beacons for a construction zone that is situated near a busy street. Some part of the massive construction crane was on the street. However, the traffic was not stopped. Sometimes a significant portion of the crane moving on top of the street. To warn the pedestrian and the drivers, we have installed two beacons at two end sides near the street. Figure 6 shows the positions of the two beacons that are installed on each corner of the site. The system works like a warning traffic sign, such as "*Road Work Ahead*" or "*Construction Area*".

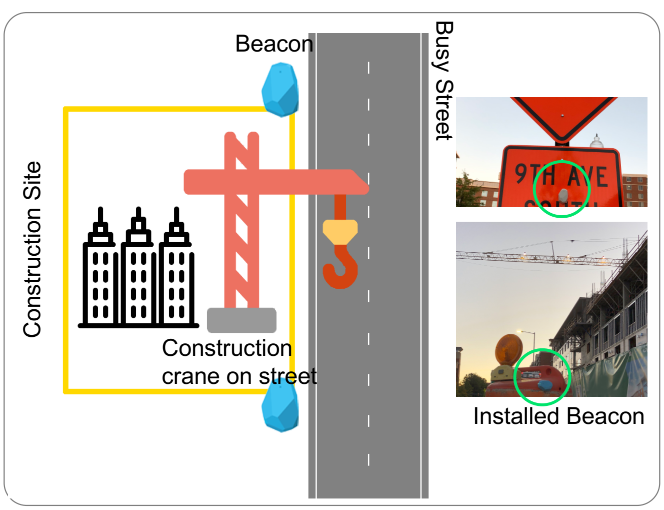

Fig. 6. Positions of installed beacons in construction site

At the first stage, we run these testing sites separately as an individual application. There were three mobile applications and three back-end servers to operate these applications. Though the working procedures of mobile applications were different, basic beacon functions were similar. After that, we combined three testing sites into a common platform.

To maintain consistency, we used the same hardware and software in every case. Table II shows the details of the used devices and hardware specifications.

TABLE II
EXPERIMENTAL DEVICE/HARDWARE SPECIFICATIONS

BEACON SPECIFICATION
TYPE → [ESTIMOTE PROXIMITY BEACON]
BUILT-IN RADIOS → [BLUETOOTH 5.0]
SUPPORTED BLE PACKETS → [IBEACON, EDDYSTONE-URL/UID, SECURE MONITORING]
BLUETOOTH RANGE → [100 METERS]
BROADCASTING POWER → [+4 DBM]
ADVERTISING INTERVAL → [100 MS]
ANDROID [RECEIVER SPECIFICATION]
VERSION → [$\geq$ ANDROID 6.0 (MARSHMALLOW OR UPPER VERSION)]
PERMISSION → [OVERLAY SCREEN, BLUETOOTH]
DEVICE → [MOTO G7, GOOGLE PIXEL 3, SAMSUNG GALAXY S10,...]
IOS [RECEIVER SPECIFICATION]
VERSION → [$\geq$ IOS 12.1]
PERMISSION → [NOTIFICATION, BLUETOOTH]
DEVICE → [IPHONE 8 PLUS, IPHONE XR, IPHONE X,...]
BACKEND SERVER
PROVIDER → [AMAZON WEB SERVICES (AWS)]
OPERATING SYSTEM → [14.04 LTS]
INSTANCE TYPE → [T2.XLARGE]
MYSQL VERSION → [5.7.22]
DB INSTANCE SIZE → [DB.T3.MEDIUM]
MONITORING SYSTEM
HARDWARE → [MacBook Pro with 2.7 GHz Intel Core i5, 8 GB DDR3 Memory and 128 GB HDD]
OPERATING SYSTEM → [MACOS MOJAVE]

Distance Calculation: To provide localization information is the main contribution of BLE beacons. The beacons platform offers an excellent opportunity to calculate the position and the distance between the receiver and source using Received Signal Strength Indicator (RSSI). The following formula is used to distance calculation -

$$RSSI = -(10n)log_{10}(d) + A \tag{1}$$

where, d = distance; A = txPower; and n = signal propagation constant. In formula 1, RSSI is the radio signal strength indicator in *dBm*. The user can get an RSSI signal from the multiple beacons at the same time. However, it is crucial to determine the difference between multiple signals. In addition, the triangulation of multiple signals is also necessary to accurately detect a user's position and direction. For that, we need to calculate the ordering of the nearest distances. Algorithm 1 shows the procedure to find the nearest beacons.

Algorithm 1 Nearest Beacons

```
Input: Beacon Information
    /*name, color, uuid, major, minor*/
Output: Nearest distances
Beacon beaconsOfInterest = filter(allBeacons, beaconIDs)
var filteredBeacons = NULL
for T in allBeacons do
    BeaconID = BeaconID.fromBeacon(T)
    if (beaconIDs in beaconID) then
        filteredBeacons.add(T)
    end if
end for
var nearBeacons = NULL
if (User in range of beaconsOfInterest) then
    for K in filteredBeacons do
        var distance = computeAccuracy(k);
        if distance > -1 and distance < CurrentNearest then
            nearBeacons.add(distance)
        end if
    end for
end if
return nearBeacons
```

TABLE III
DETAILS COSTING BETWEEN THE INDIVIDUAL TESTING SITE AND BEACLOUD

Item	Cost($)
Individual Site	
Amenities Finder	
BLE Beacons (11 x $25)	$275
Backend Server (AWS)	$20-25*
Traffic Intersection	
BLE Beacons (14 x $25)	$350
Backend Server (AWS)	$30-45*
Stationeries (Duct tape, stick, Ziplock, etc)	$30
Construction Site	
BLE Beacons (2 x $25)	$50
Backend Server (AWS)	< $10*
Total	$765**
BeaCloud	
BLE Beacons (21 x $25)	$525
Backend Server (AWS)	∼ $50*
Total	$575

* - Monthly bill
** - The lowest number has been accounted

V. EXPERIMENTAL FINDINGS

A. Cost

The cost of BLE beacons depends on multiple factors, including vendor, protocol, size, longevity, etc. We have used Estimote beacon, which is $25 each. In the individual site testing, a total of 27 beacons was used. In addition, we have used three different backend servers to store the data. However, in BeaCloud architecture, 21 beacons are sufficient; only one backend server is needed for the operation and data storage. One corner of the intersection site is also used as a construction site warning. Other five beacons interchange with the light-post and the nearest trash bins. Table III shows the details costing. We have only counted the hardware cost and bills; no human-based monitoring cost has been added. The result shows the BeaCloud reduce the cost by 24.84%.

B. Performance

We have tested the performance in terms of data points that need to handle in BeaCloud and testing sites. Figure 7 shows the detailed results. If the users' device receives any signal from the nearest beacons, we call them an event. The receiver device can get contacted with multiple beacons. We recorded that frequency on an hourly basis with data points. Suppose how much data need to be handled if there are two events in one hour, five events in one hour, eight events in one hour, and so on. As for the monitoring and access control issue, BeaCloud needs some extra overhead than the individual implementations. However, if we compare the total data (three testing sites) and BeaCloud, BeaCloud reduces more than 40% overhead and data redundancy. The redundancy varies if the receiver stays more time in an event. For example, if there are five events in one hour, the "*Amenities Finder*" site generates 331 data points, the "*Traffic Intersection*" site generates 301, and the "*Construction Site*" generates only 276 data points. Combinedly, they generate 908 data points. At the same point, the BeaCloud generate 514 points. In contrast, when there are 15 events in one hour, the "*Amenities Finder*" generates 988 data points.

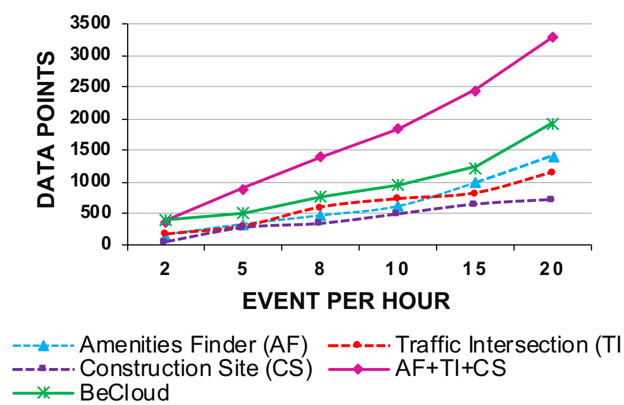

Fig. 7. Data points that need to handle in every hour in the testing sites.

Smartphones and smart devices support Bluetooth technology. However, power consumption is a major issue when the Bluetooth-enabled devices receive signals from the beacons. In BeaCloud architecture, the receiver needs to handle some extra interaction with the beacons. For that, we measured the power consumption of the receiver device (Moto G7). Figure 8 shows the results of the battery consumption of the android phone. We launched the basic individual application for the corresponding testing sites and measured the battery consumption in 45 minutes periods. Then we launched the application that followed the BeaCloud architecture and measured the consumptions for 45 minutes. The experiments ran multiple times and counted the average results. Every time, there is no difference in battery consumption for the "*Amenities Finder*" site (4%) and "*Construction Site*" (2%). However, in the "*Traffic Intersection*" site, the basic application consumes 6% battery, whereas the BeaCloud consumes 7%.

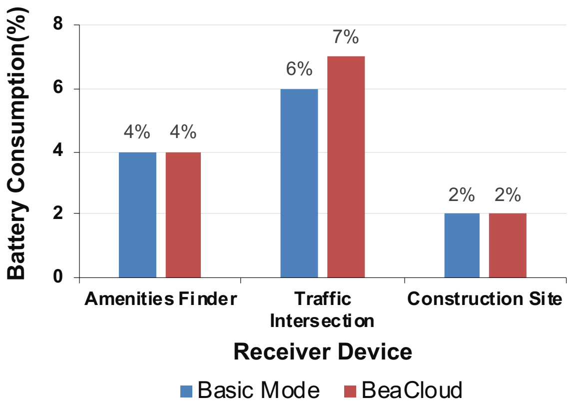

Fig. 8. Battery consumption at the receiver application (Android phone).

VI. Conclusion

Cities offer extensive facilities to enrich their inhabitants' lives by utilizing smart devices, sensors, and technologies. The uses of beacons are increasing recently to provide easy and accurate positioning in the indoor and outdoor environment. Our BeaCloud model presents a novel architecture for Beacon-as-a-Service for the distributed beacon-based systems. Such an approach provides a platform for secure communication in multiple beacon-based systems. The BeaCloud architecture also provides an economic model that offers reduced cost and fewer number of hardware. The results from our experiments show that BeaCloud reduces cost by 24% if we implement it in three individual systems. In addition, the data redundancy reduces by 40%. We therefore posit that BeaCloud can be an effective solution towards building beacon-based applications in sustainable smart cities.

VII. Acknowledgment

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