InSight: A Bluetooth Beacon-based Ad-hoc Emergency Alert System for Smart Cities

Raiful Hasan
Department of Computer Science
University of Alabama at Birmingham
Birmingham, AL 35294, USA
raiful@uab.edu

Ragib Hasan
Department of Computer Science
University of Alabama at Birmingham
Birmingham, AL 35294, USA
ragib@uab.edu

Tanveer Islam
Department of Emergency Management
Jacksonville State University
Jacksonville, AL 36265, USA
tislam@jsu.edu

***Abstract*—The purpose of alerts and warnings is to provide necessary information to the public that will lead to their safety in emergencies. The nation's alerting capabilities need to evolve and progress with the extensive use of smartphones, and newer technologies become available, especially to be more precisely targeted to sub-populations at risk. Historically, this has been a challenge as the delivery of alerts and warning messages to the public is primarily through broadcast media and signs. However, deploying such signs takes time and may not be visible to people imminent of natural hazards. Especially for road closing, marking hazards, emergency evacuation, etc., it would be beneficial to have an easy-to-deploy and automated alert/warning system that requires no line of sight. To this end, we have developed *Insight* – a Bluetooth beacon-based system that uses a smartphone application to sense signals from beacons marking hazard zones. The system does not require any Internet or communication infrastructure and therefore, it is resilient to breakdowns in communications during disasters. To demonstrate the feasibility of *Insight*, we conducted a study in an urban university campus location. The system demonstrated adequate usability and feasibility.**

***Index Terms*—Smart City, BLE Beacon, Emergency Management, Alert, Hazard**

I. Introduction

During natural disasters and in an emergency condition, it is essential to disseminate messages/warnings to people who are approaching a specific location. It is crucial to warn them about potential hazards or to direct them to a safe zone through evacuation routes. During natural disasters, such as earthquake strikes, tornadoes, hurricanes, etc., warning dissemination could be needed without the aid of mainstream communication infrastructure. If the communication breaks down, the cellular network and internet connection may be lost. Localization of any dangerous spot and give warning to the community are challenging tasks in this situation. Often, updates and alerts arrive in the form of verbal messages, which are inconvenient to circulate. Even during normal conditions, the traffic control department may need to close a road by putting a sign ahead to warn the drivers. Police may need to mark a location as dangerous and need to circulate the message to avoid this area. However, multiple studies found that pedestrians and drivers do not notice such signs [1], [2]. Also, it takes time to install a warning sign, which is inconvenient when immediate action is needed. To resolve these issues, we need an automated warning system for road safety and hazardous area that can be deployed quickly and will work despite network breakdowns and lack of visibility.

Public safety is a significant component of the smart city [3]. The smart city refers to the implementation of pervasive and ubiquitous computing in urban environments through the use of wireless networks, sensors, and digital infrastructure [4]–[7]. These cities are often characterized as locations where sensors and wireless networks enhance the efficiency, security, and sustainability of the community [8]. Smart cities must also respond promptly to the community's needs for public safety [9]. Thus, cities must implement intelligent systems to ensure the safety of pedestrians, drivers, allowing them to navigate the roadways safely.

One effective strategy is to warn the neighborhood within the context of a smart city would be to alert via smartphone during unsafe conditions. However, as stated earlier, any such system should be robust enough to function during natural disasters, even when communications break down. Also, the lack of visibility should not hamper such a system. To this end, we have developed *InSight* – a system that uses low energy Bluetooth beacons [10] as external hardware and a smartphone-based app. Bluetooth beacons provide a platform for marking locations and detecting the marked locations. *InSight* can operate even in the absence of any communications infrastructure such as cellular networks or the Internet. The low-cost of Bluetooth beacons make the system economically feasible to implement. The *InSight* mobile application incurs low energy consumption because the app runs in the background, emerging to the foreground only when it detects the user in a range of a predefined Bluetooth beacon placed at the targeted position. The beacon is portable, and it can be placed and removed quickly and easily .

In this paper, we aim to demonstrate the feasibility and usability of the *InSight* system by demonstrating that: (a) *InSight* can correctly identify when users are about to enter a hazard zone; (b) The system is capable of working in extreme situations without the help of any other infrastructure as well as in normal condition; and (c) *InSight*'s warnings cause the users to stop approaching the hazard zone, and in consequence, reduce the risk of injury/death and improve mobility. To this end, we implemented a mechanism to identify user's locations based on the signal from Bluetooth beacons and to provide appropriate interventions to their smartphone.

Contributions: The contributions of this paper are as follows:

1) We demonstrate an automated alert dissemination system using BLE beacons and smartphones.
2) We deployed *InSight* at multiple locations in an urban environment to demonstrate the feasibility.
3) *InSight* gives a warning from 65 meters to the pedestrian and 48 meters to the bicyclist.

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

- Section II – Background on Bluetooth beacons and emergency alert applications.
- Section III – Motivation of this research.
- Section IV – System design of *InSight*.
- Section V – Test deployment; Experiment.
- Section VI – Experimental findings.
- Section VII – Concluding remarks.

II. Background

A. Bluetooth Beacons

Bluetooth beacons are a one-way wireless communication medium that can broadcast messages in the short-range. In the Bluetooth Low Energy (BLE) protocol, a part of Bluetooth 4.0 [10], batteries power them and transmit low-energy signals. These devices are used where energy consumption is more important than data transfer speed. BLE enabled devices can receive signals from the beacons. Bluetooth technology is most often implemented for applications that require continuous streaming of data, such as headphones. However, this technology is also well-suited for applications that transmit data periodically. Given their capacity to broadcast signals in close proximity, they offer many valuable uses. BLE technology is now supported by most smartphones, including all Android phones since version 4.3 and all iPhones newer than iPhone 4.

B. Emergency Alert Applications

Several studies use Bluetooth beacons for indoor location positioning [11]–[13]. Supporting efficient alert dissemination has been investigated in the context of multiple applications, namely, distribution of alerts, warnings, or general information [14], [15]. Some conventional technology to disseminate the alerts are VANET [16], mobile devices/networks, wireless sensors, etc. Seo et al. [17] proposed *UAV-EMOR*: Beacons and UAVs based emergency response systems for building fire hazard. However, the system needs that the user will carry a sensor device, which is not feasible. Some systems use the Global Positioning System (GPS) of users' smartphones for location, but GPS-based location information cannot be calculated accurately indoors [18]. Wu et al. [19] propose a framework for an intelligent evacuation guidance system for large buildings. They combine fire detection, video surveillance, mobile terminal, and passive RFID tags to create an evacuation guidance system. Choi et al. [20] propose a monitoring system for emergency responses. Their system consists of both an aerial and a ground component. The aerial aspect includes a UAV platform, sensors, and supporting modules, while the ground aspect includes vehicles and a receiving and processing system. However, these systems need an infrastructure to emit the alert messages or signals. Marking a danger zone, building an evacuation route to a safe place, and disseminating this information are major concerns for emergency management agencies.

III. Motivation

Communication is one of the most important lifelines in emergency management [21]. Emergency alert and warning system is an integral part of risk communications. Historically, alert and warning systems have evolved very slowly over time, moving from various television and radio broadcast technologies to now include cell broadcast. Following a series of natural disasters, including Hurricane Katrina, the United States Congress passed the Warning, Alert, and Response Network (WARN) Act in 2006, which encouraged the adoption of much newer technologies, including the dissemination of alerts and warning messages via mobile devices. That was the first significant changes to national alerting systems since the mid-1990s [22].

The WARN Act created the Integrated Public Alert and Warning System (IPAWS) to integrate various alerting systems, Emergency Alert System (EAS), National Warning System, Wireless Emergency Alerts (WEA), and NOAA Weather Radio All Hazards—into one modern network. Although WEA added important capabilities to IPAWS, it has not been deployed widely, and the current WEA system is not sufficient to yield a quick public response [22]. As of August 8, 2016, only 387 wireless emergency alerts have been originated by state or local governments compared to two million alerts by the National Weather Service [23]. The WEA alerts disseminate to the entire population within an area instead of precisely targeting sub-populations at risk. Fine-grained Geo-targeting is important to ensure that those who are not at risk do not receive alerts that do not apply to them [22]. This is possible with our new Bluetooth system and will add great benefit if it is integrated into the IPAWS. Also, WEA was developed prior to the extensive use of smartphones, and its shortcomings (such as cellular network congestion or failure) could be addressed with newer technologies, such as Bluetooth beacons. With 96 percent of American adults owning a smartphone [24] and with one in five households no longer having cable television subscriptions [25], it is essential to develop a new smartphone-based alert system to ensure public safety in emergency situations.

IV. System Design

In this section, we present the design of *InSight*. We begin by discussing the general requirements for such a system.

A. Requirements

The desired characteristics of this system are as follows:

1) The system should be able to locate the user accurately to provide warnings at the right moment near the hazard.
2) The system should be portable. It would be deployable anytime by the authority with the minimal human cost and it should be removable when the danger is gone.
3) The system should detect correctly whether a user is approaching the zone or not. The users should not get a warning if they are not going toward the zone.
4) The system should work without the help of any other communication medium in basic mode, on top of that, it can provide an additional message with the aid of the internet in the normal condition.
5) No special skills needed to deploy it, the responders, such as police, firefighter, etc., can keep a bag of beacons in their emergency vehicles and deploy them in seconds.

B. *InSight* Components

There are three components in *InSight* – pre-configured beacons, *InSight* mobile application, and a backend server. Figure 1 shows the high-level system design of *InSight*. For each type of sign such as road closure, hazards, evacuation route markers, etc., we assign a specific beacon. The beacons of a specific type are pre-configured with some unique identifier strings; the mobile app is pre-installed with the knowledge of such strings and beacon types. The backend server stores the beacons list with their warning types and details of the hazard areas (i.e., reason, time to resolve, location, etc.). The authorities can add, modify, and delete the hazard points and beacons configurations from the server.

C. Operational Model

At a high level, *InSight* operates as follows: when specific locations need to be marked for the purpose such as road closure or hazards, emergency responders or police would drive by such locations, turn on the beacons and deploy them. A beacon can be attached to any roadside surface. They can even be thrown from a car window for quick deployment. When users with *InSight* mobile app on their smartphones approach such locations, the app will detect the Bluetooth signal broadcast by the beacon and identify the type of beacon based on the identifiers. The app would then show the appropriate warning message (for example - hazard beacons), or show the evacuation route marker. When the location marker is no longer needed, the beacons can be located (based on their signals), retrieved, turned off, and stored for later reuse during other scenarios.

D. User Direction Using Beacon Signal and Time

We have calculated the direction of the user using the beacon signal and time. If the distance decreases with respect to the time, then the user is going toward the hazard zone. The direction will be opposite if the distance is increasing. The system used multiple beacon signals when necessary. We have divided the 100-meters radius of the beacon signal into two portions. The first 70 meters radius is the *hazard zone*. If the system detects the user within this zone, the user will get a warning from the system. This basic warning will work in

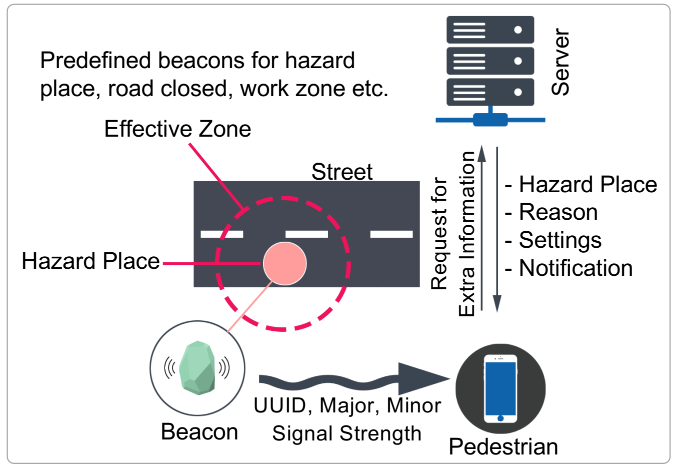

Fig. 1. High-level system design of the *InSight*

any environment. There could be an additional message for this hazard zone or the warning on the server. The user will be able to see this message in the normal situation through the internet. The outer 30-meter radius is the *activation zone*. The user will not get a warning in this zone. However, the system will keep track of the user movement in this area in a time interval. Figure 2 illustrates the procedure of finding the direction and the zone definition.

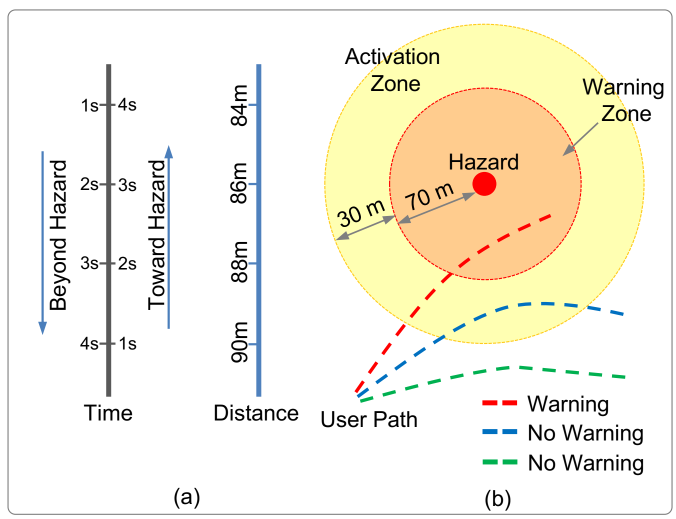

Fig. 2. Determine the user direction and path using beacon signal, in (a) shows if the distance decreases with time then the user is going toward the hazard zone, the direction is opposite if distance increase with time. (b) shows who will get warning based on the path.

E. Mobile Application

We developed *InSight* mobile application for both android and iOS platforms to receive beacon signals and calculates the distance. The mobile application shows the warnings based on the beacons and the user's relative position. The android version shows an overlay alert. However, due to the restriction in the iOS platform, it gives the alert in the notification panel. *InSight* app runs in the background as a service and only starts the calculations within a beacon radius. The application fetches the updated beacon configuration list and stores the event details to servers when necessary. Figure 3 shows some interface of *InSight* mobile application.

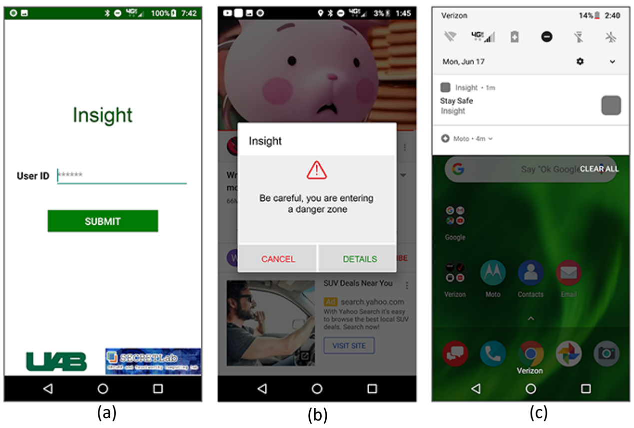

Fig. 3. Mobile app interface. (a) User login page. (b) A basic alert from the system while the user entering a danger zone on an Android phone. (c) Alert notification.

V. Test Deployment

When emergency management personnel, such as police, firefighters, etc., wants to designate a location as a hazard, they can place a beacon outdoors to mark the hazard. To study the feasibility and usability of the system, we have set up three testing sites: construction site, a busy traffic intersection, and 900 meters long evacuation route. We had prior permission from the authority and police departments. All these sites were in an urban university campus.

A. 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 substantial 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 that occurred in the construction areas from 1982-2017 [26].

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 the 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 ends of the zone near the street. Figure 4 shows the positions of the two beacons that are installed on each corner of the site.

B. Traffic Intersection

In the United States, an estimated 6,480 pedestrians were killed in traffic crashes in 2017, according to the Centers

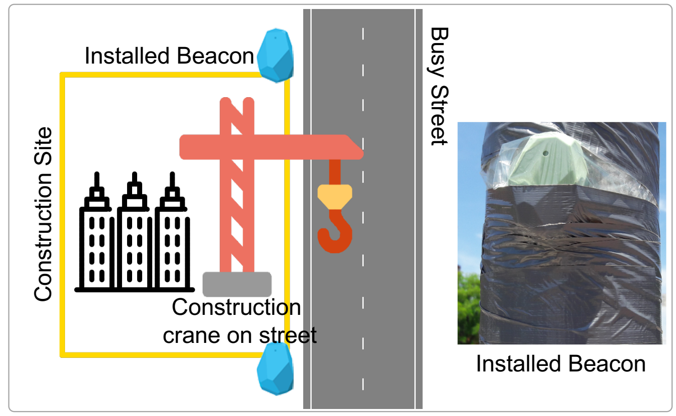

Fig. 4. Positions of installed beacons in construction site

for Disease Control and Prevention [CDC] [27]. Research suggests that distraction by smartphones may be a primary reason for the increasing number of pedestrian injuries and deaths. Timely interruptions could alert distracted pedestrians and prevent injuries. To warn the distracted pedestrian, we choose to conduct our study at a busy intersection on our urban university campus. We installed four beacons at each corner of the intersection. Pedestrians are often get distracted during walking and crossing the street. Each beacon will transmit the signal on the corresponding side to warn the pedestrian. If the user approaching the intersection while using the smartphone, such as listening to music, talking, texting, etc., then the system will identify this as distracted. The mobile applications will calculate the distance from the road crossing during that time. If the user is within a certain radius, the system will automatically send an alert.

C. Evacuation Route

There is a growing demand for evacuation planning in urban areas due to an increasing number of natural and human-made disasters. In an emergency, there is a need to transport people from the affected disaster area to safe places, such as schools, stadiums. The final setup is an emergency evacuation route. Affected people can reach these safe locations in several ways, such as by car, by bus, or on foot. Disseminate the message is the primary concern in this situation, especially when the major communication structure is broken down. We have installed six beacons in the 900 meters long street toward the University recreation center. This beacon, along with the system, can work without the help of other communication media. We affixed the beacons on the sticks and installed them on the roadside. In this setup, the distance between the two beacons were around 140 meters. The system can able to identify each beacon with its unique numbers (UUID, Major, and Minor). We have assigned number 1-6 to the beacons in increasing order toward the recreation center. Figure 5 shows the setup of the evacuation route. The system gives an alert when the user enters any beacon zone and directs the user to follow the evacuation path. The installment time is low for these pre-configured beacons. The emergency management personnel need to install a beacon approximately 120 to 140 meters.

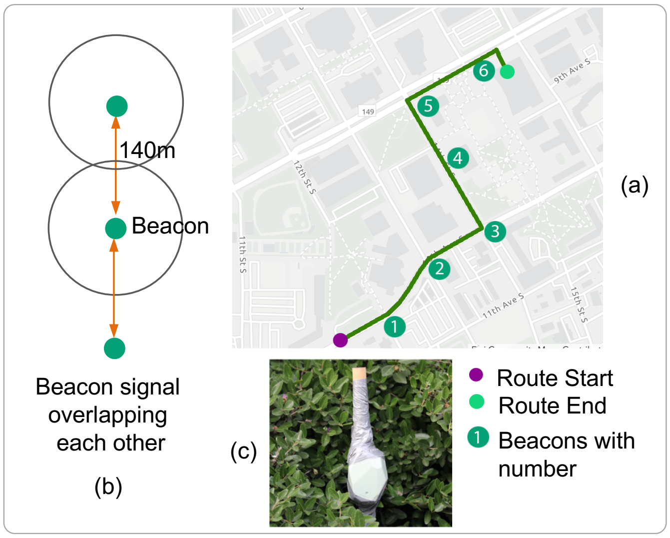

Fig. 5. Evacuation route setup. (a) shows the 900 meters route in urban campus with the beacon's position. (b) shows that each beacon signal overlapping signals in neighbor beacons. We have set the distance between beacons 140 meters. (c) beacons affixed on the stick

D. Beacon Settings

Each beacon transmits radio signals, and the mobile application calculates the distance based on signal strength. We used Bluetooth proximity beacons developed by Estimote[1]. Broadcasting power for all of the beacons are set at +4 dBm, a power that is effectively expected to transmit signals at a distance of up to 100 meters. This distance is sufficient for our setup. We have set the advertising interval to 100 ms because we need the most stable signal possible. We used Amazon Web Services (AWS)[2] to store the data collected from users. We created an AWS Elastic Computer Cloud (EC2) virtual machine instance and implemented all the necessary Application Programming Interface (APIs) for communication between the smartphone and server. For storing data, we used the AWS Relational Database Service (RDS).

VI. Findings

To see if *InSight* can successfully provide alerts and to test the feasibility and usability, we performed some experiments in our real-life deployment of the system. *Insight* mobile application has tested in our three testbed sites in various conditions.

Though the effective beacon radius was 70 meters, in the real experiments, the data showed different scenarios. The detection of the user's position depends on the speed. Figure 6 (a) shows the highest and lowest distance in meters from the beacons, where the users first received the alert form the system, a.k.a. what is the earliest distance when the system could able to detect that the user is in the danger zone. The users received an alert between 49 meters to 65 meters when they were on foot. The distance was between 25 meters to 48 meters when users were in a bicycle, and 15 meters to 30 meters in the vehicle. All the experimental sites were on the university campus, where the driving speed limit was 15-30 MPH.

It took only a minute to install a beacon normally as the system is ready. To test the taken time to install a beacon, we have installed 20 beacons by foot and by vehicle. During the installation, we calculate the time between the intervals of the two installations. If we use the vehicle and throw the beacon during the emergency situation, then the average time to install a beacon is 48 seconds. The average speed of the vehicle was 15-20 MPH. It took 380 seconds to install the next beacon on foot. Figure 6 (b) shows total time to install the beacon in the testing site and (c) the average time interval to install beacons. On the other hand, the total time to install the beacon in the full testing site is also calculated. We have added the overhead of 20% as this time needs to observe the emergency situation and need to make a decision where the responder installs that beacon. The traffic intersection took only three minutes to cover the sites. The overhead time is small, as it is easy to install four beacons on each side. The evacuation route took 8 minutes, and the construction site took a total of 5 minutes to install the beacons. We have set the advertising interval of 100 ms. Theoretically, the receiver device should get ten signals per second near the beacons. However, there is some delay in receiving the signal. For the first signal packet, it took an average of two seconds to get the signal. After that, the receiver gets updated every second. we removed the beacons from a designated location and installed it in another place after the experiment. The system timely gave warning to the pedestrian and the drivers every time.

VII. Conclusion and Future Work

In this paper, we have presented *InSight* – a low-cost and easy-to-deploy solution for urban environments. *InSight* can provide warnings to alert the community people in an emergency, even in the absence of any communication infrastructure. We have deployed our system in a busy intersection and a construction site and also marked an evacuation path. Experiments demonstrate the effectiveness, usability, and feasibility of our system. The results of our study suggest that our system was able to provide timely warnings to pedestrians and drivers. In the future, we plan to deploy the beacons with the minimal workforce, such as with the help of drones in order to automate the process.

VIII. Acknowledgment

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[1]https://estimote.com
[2]http://aws.amazon.com

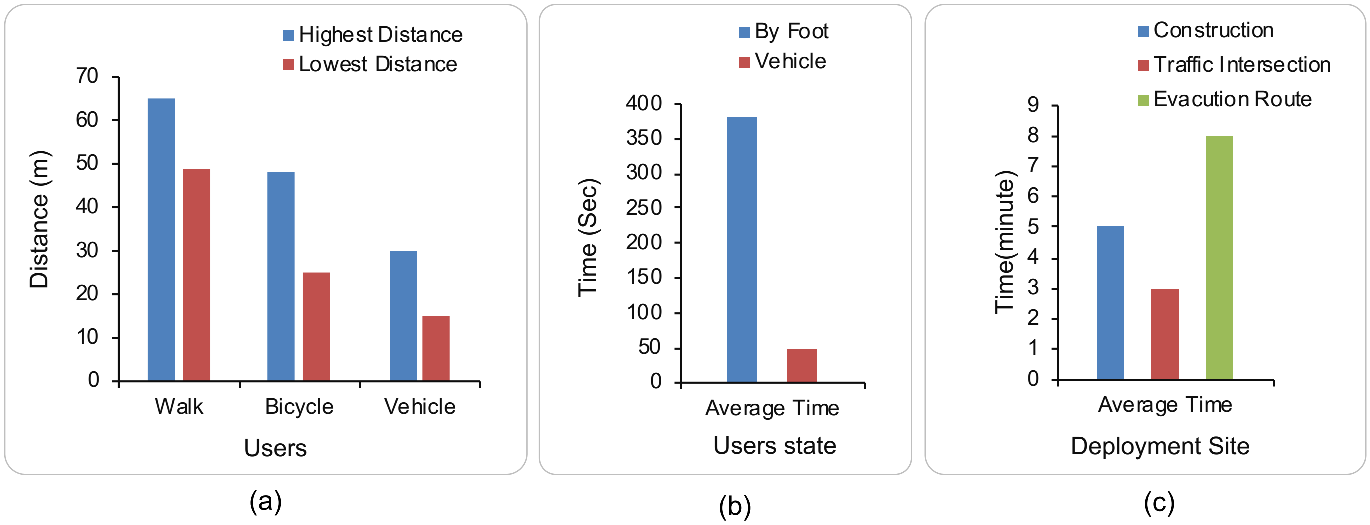

Fig. 6. (a) Highest and lowest distance in the meter when the user receives alerts from the beacon. (b) Average time interval to install two beacons. (c) Shows the total time to install the beacon in testing site.

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