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Wireless IoT based Solution for Women Safety in Rural Areas

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***Abstract*—In today's era, women still feel scared to step out of their homes at late nights due to the fear of sexual harassment. This problem is compounded when one shifts the focus from urban to rural sector and interior areas of villages where there is erratic electric supply and poor cellular network connectivity. There are many smartphone based solutions, but the availability of smartphone and cellular network in rural areas is unreliable. This paper proposes a system, by creating a wireless network using IoT technology with a portable device for alerting the concerned authorities to prevent any mishap. Women will be provided with a beacon device consisting of a help button. In case of any emergency, the beacon information will reach the central stations and an alarm will be triggered at the prominent places of the village. One can find out the location of the victim based on her proximity to the nearest access point.**

***Index Terms*—Bluetooth Low Energy, Global Positioning System, Beacon device, Internet of Things, Solar Panels, Access Point, Central Station**

I. Introduction

Even though we live in the 21st century with much technological advancement and social awareness, women face the problem of harassment of any form and get abused physically or mentally. Areas like streets and public spaces have been the territory of such violence. This issue worsens for women living in remote and rural areas, where they might not be aware about these crimes or hesitate to report these crimes to the concerned authorities. There are many existing applications and devices for women security through smartphones. Though the smartphones have increased rapidly, it is not possible that the smartphones and cellular network will be available all the times in rural areas. Also, many people in the village do not have smartphones which can assist them in contacting the concerned authorities, otherwise. Literacy rate of villages is low and parents do not send girls to schools due to the fear of sexual harassment.

The proposed system for women safety is based on BLE (Bluetooth Low Energy) Beacon device due to their low cost, ease of deployment, ease of accessibility to the users and superior interior localization as described in [2], [3]. Kang Eun Jeon, James She, Perm Soonsawad, and Pai Chet Ng [2] specify that BLE has low energy requirements and battery life of BLE Beacon devices can be extended upto 2-3 years on a single coin cell battery if broadcast intervals are set appropriately based on the application. BLE is 60 - 80% cheaper than traditional Bluetooth and is compatible with a wide range of IoT (Internet of Things) boards, mobile phones, tablets and computers. It is ideal for the proposed system which requires small periodic broadcast of data at regular interval of 1 - 1.5 seconds.

The paper has been organized as follows - Section II describes the existing women safety systems and their demerits. An insight into the system that we proposed in Section III includes the overview of system, mathematical model, various components and the working model. The implementation of the system is described in Section IV which consists of a simulation experiment. Section V provides the results of the simulation and its analysis. Lastly, Section VI includes the conclusion and further improvements possible to the system.

II. Related Work

Majority of the approaches for providing women safety concentrate on urban areas where it becomes possible to provide immediate help for women in distress. Additionally, these systems [4], [5], [6] use smartphone and GPS (Global Positioning System) technologies which are difficult to support in undeveloped rural areas.

Implementation of Women Safety based on IoT approach by D. G. Monisha, M. Monisha, G. Pavithra and R. Subhashini [5] involves ARM Controller along with a smartphone, synchronized using Bluetooth to call the preset contacts and record audio for further investigation. It also include components like GPS Module, audio and video recorder in hardware based solution. However, using these components make the device bulky and not feasible to carry it all the time. A reliable GSM network is also required for the smartphone to alert the preset contacts. Noise can be present in the audio recording which can be misinterpreted, making it unreliable.

Another solution by G C Harikiran, Karthik Menasinkai, Suhas Shirol [6] comprises of a wearable Smart Band which continuously communicates with smartphone that has access to the GPS and Internet. The Smart Band sends emergency signal to the smartphone through Bluetooth 4.0 BLE which uses GSM messages and Internet to post on social platform provided by the mobile application. However, many remote areas in the country are difficult to be connected using Internet facilities due to latent requirements and location concerns. Also in distributed housing layout of rural areas, the cost of

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providing Internet connectivity is not viable as the subscription fee will exceed the affordability of villagers and it is not feasible to provide reduced subscription rates.

The implementation proposed by Ms. Deepali M. Bhavale, Ms. Priyanka S. Bhawale, Ms. Tejal Sasane, Mr. Atul S. Bhawale [4] provides a unified approach by designing a safety kit for women using Arduino. It consists of a handheld device for alerting and GPS component for tracking the location of victim. But GPS depends heavily on cellular network. Also it is power exhaustive and does not support indoor localization due to its inability to penetrate through the solid rock structures.

III. Proposed System

A. Methodology

Multiple solar powered street light poles are arranged in an optimized formation of triangular geometry such that each pole is within the range of its adjacent poles on either side of it. IoT boards [1] will be positioned on these street poles and will be powered using the solar energy taking into account the unpredictable electricity supply to the rural areas. It will act as an Access Point (AP) of the local wireless network through which the communication between a Beacon device and an AP will occur.

Women will be provided with the Beacon device which will consist of a help button. Based on Beacon device's UUID (Universally Unique Identifier), the user will be identified uniquely and the Transmission (Tx) Power parameter will enable us to estimate the location of the victim. The AP which sense the maximum Tx Power from the Beacon device will give us the accurate location of the victim.

For this, the street poles will be identified by a unique identifier and its pre-defined GPS coordinates in the village area. Beacon communication consists primarily of advertisement broadcast at a regular interval by Beacon device via radio waves. The communication between a Beacon device and an AP, between any two APs and between an AP and a server at central station is governed by BLE Multi-Hop routing protocol [7].

Features of the System:

- Independent of Electricity: Rural areas face the problem of frequent power cuts. To power the APs, our system makes use of solar panels mounted on the street poles. This provides dual benefit by providing power supply to both the AP and street poles. So the system will continue to function even in the absence of electricity.
- Independent of real-time GPS: For accurate tracking of the victim's location, we store pre-defined GPS coordinates of street poles in a database. Also, an offline map of the entire village is stored at the central station to accurately track these GPS coordinates on the map along with the landmark.
- Tracking victim using preset GPS coordinates of APs: Once the victim triggers the help button on the Beacon device, the message is broadcasted and routed to the central station. Based on the information stored in the central station, the concerned authorities can be sure of the victim's location based on the pre-stored latitudinal and longitudinal details of APs.
- Independent of Smartphones and GSM system: The system takes care of Internet issues based on GSM network and smartphones which are not available all the time to make a call or be in range of GSM network.
- Multiple central stations: If multiple help requests are received simultaneously, a single station will not be able to handle and process all the load efficiently. Hence, we introduced multiple stations so that help requests can be routed to the stations and alarm be triggered. This also solves the issue of single point of failure of a station.

B. Mathematical Model

The arrangement of street poles on roads or highway follow 4-in-a-rectangle placement as seen in Fig. 1 indicating that 2 poles face each other in exact opposite direction. To provide adequate visibility for the same area, we optimize the number of poles by placing them in a 3-in-a-triangle placement with each pole placed at the vertex of a triangle as seen in Fig 2. This optimizes the number of APs which need to be mounted on these street poles. Further, we place the poles at some viable distance in the transmission range of APs.

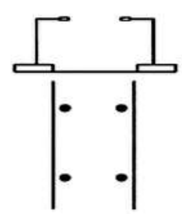


Fig. 1: Rectangular arrangement of poles

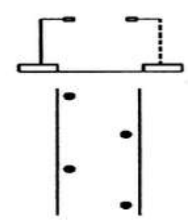


Fig. 2: Triangular arrangement of poles

The maximum transmission range of BLE Protocol is 100 meters. Taking into consideration the attenuation in signals that is caused normally due to interference or fading phenomenon, we restrict the maximum range of transmission to 80 meters. While considering the triangular arrangement, we need to take into account the blind spot, here a centroid, of triangle which is a point outside the normal range of an AP where there is unusually weak signal reception. The centroid is I as seen in Fig 3. To cover it within 3 APs, the distance of the AP to the centroid must be 80 meters which means KI is 80 meters. Based on an equilateral triangle's property, centroid bisects the median KB in the ratio 2:1. So the ratio of segment KI to IB is 2:1 and hence the distance IB is 40 meters. The height KB = (KI + IB) turns out to be 80 + 40 = 120 meters.

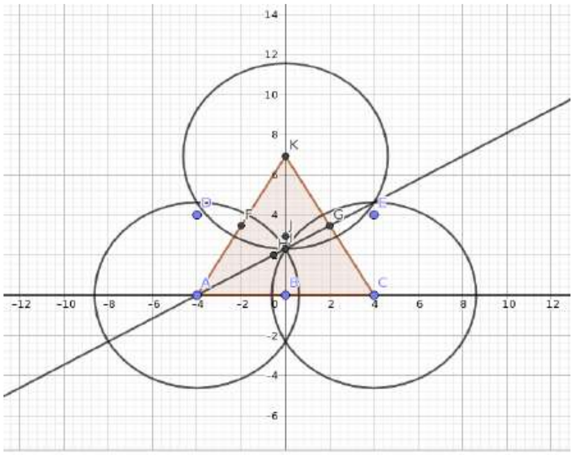


Fig. 3: Calculation of distance between 2 APs

Consider $\triangle KAB$.
Let the distances *AB, BC, CG, KG, FK* and *AF* be *r* meters.
$\implies$ The distance *AK* will be *2r* meters.

Using Pythagoras Theorem,
$(AK)^2 = (KB)^2 + (BA)^2$
$\therefore (2r)^2 = (120)^2 + (r)^2$
$\therefore 4r^2 = 14400 + r^2$
$\therefore r^2 = 4800$
$\therefore r$ = 69.28 meters

Hence, any 2 APs can be placed within a range of 130-140 meters. Thus, an area of 10^6 square meters would require 60 APs to cover the entire region without any blind spot. We can ensure that even if any victim is present at the blind spot and the help button is pressed, the help request will be received by atleast one of the three APs.

C. Hardware Description

Our system consists of five hardware components:

- Beacon device: It is a wearable and portable device [8] which is BLE enabled via radio waves [3], for alerting the concerned authorities in the village and is associated with 4 components - UUID, Major, Minor and Tx Power to uniquely identify the user. It consists of a help button that facilitates the trigger of emergency broadcast.
- AP: We performed a comprehensive review of the IoT boards [1] such as UDOO x86, Intel Galileo, BeagleBoneBlack, Edison Arduino Kit, Tessel 2 and Raspberry Pi Zero W. All of these boards are BLE enabled, have low energy requirements and can be interfaced with the solar panels. They provide efficient and a reliable platform for development of the IoT boards as an AP.
- Central Station: At each central station, a server is setup by a computer which can be powered by solar panels. It consists of a database that stores the unique mapping of AP identifiers and its corresponding colloquial village region naming. These identifiers and landmarks is plotted on a preset map stored in the server for faster tracking of victim's location.
- Solar Panel: These panels supply power to both street light poles as well as AP. The voltage supply and the electric current drawn from the source are specific to the IoT boards that will be used for APs.
- Buzzer: It is an emergency alarm device interfaced with the server at central station. For effective audibility, the loudness depends on the surrounding environment and the distance from the source. However, the recommended loudness [11] should be 80 - 90 decibels with a region coverage of 60 meters.

D. Working Model

Each woman is provided with a Beacon device. If any woman feels threatened by any perpetrator, she will press the help button on the Beacon device provided. Beacon device will send the information about its unique identifier encapsulated in a broadcast message to APs 1, 2, 3, 4 in its range as shown in Fig 4. Even though AP 4 is down, message will be broadcasted to it, but it will not be able to forward any message to other APs. The APs will route these broadcast messages amongst themselves until they reach the central station. Multiple routes are possible for the message transmission, which will guarantee the delivery of message even in case of losses.

As shown in Fig. 4, the possible paths are as follows:

AP 1 $\rightarrow$ *AP 3* $\rightarrow$ *AP 5* $\rightarrow$ *Central Station*
AP 1 $\rightarrow$ *AP 3* $\rightarrow$ *AP 5* $\rightarrow$ *AP 6* $\rightarrow$ *Central Station*
AP 3 $\rightarrow$ *AP 5* $\rightarrow$ *Central Station*
AP 3 $\rightarrow$ *AP 5* $\rightarrow$ *AP 6* $\rightarrow$ *Central Station*

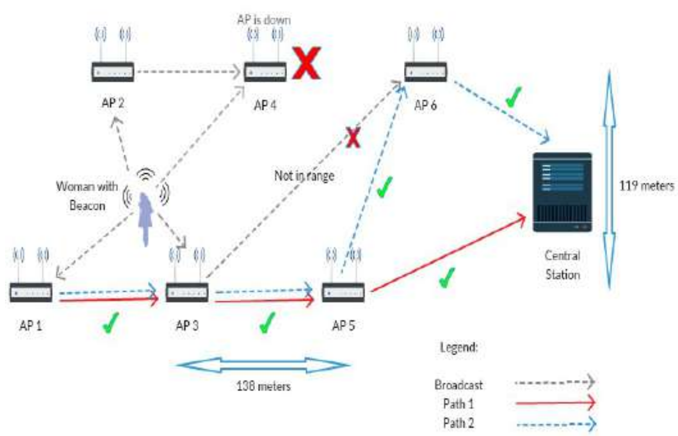
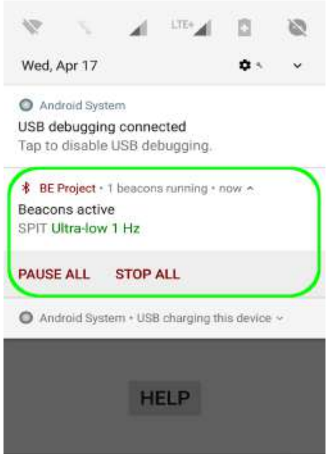


Fig. 4: Working Model of Proposed System

All these paths will route the message to the central station. As soon as the first message reaches the central station, the alarm will be triggered.

IV. Implementation

The proposed system consists of 2 aspects of implementation which are as follows:

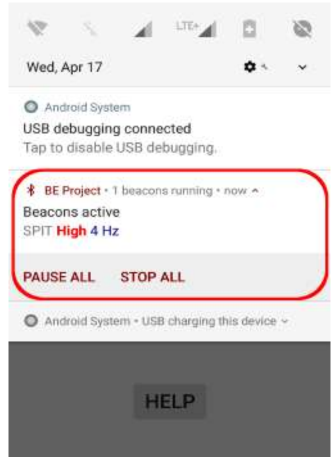


(a) Beacon Configuration

(b) Interface at Beacon device (send regular broadcast)

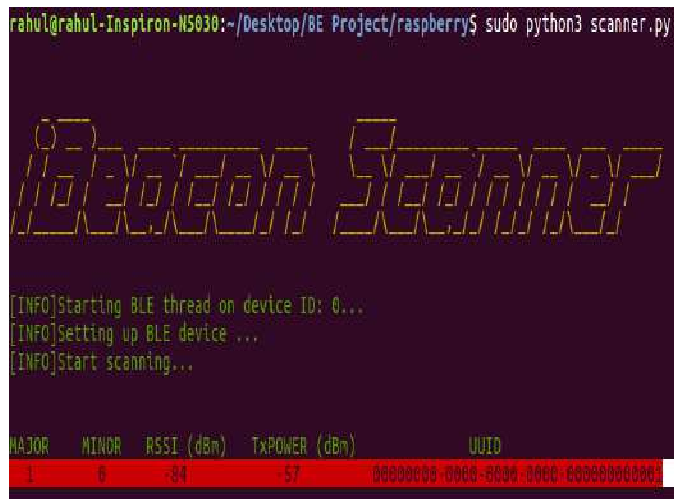
(c) Interface at AP - captured regular broadcast

Fig. 5: Regular Broadcast



(a) Beacon Configuration

(b) Interface at Beacon device (send emergency broadcast)



(c) Interface at AP - captured emergency broadcast

Fig. 6: Emergency Broadcast

A. Beacon Device - AP Communication

Communication between a Beacon device and an AP was tested by simulating the Beacon device as an Android Application and an AP device with Raspberry Pi Zero W, a single-board computer. The broadcast messages by an AP from the Beacon device is captured with the help of modules specified in [14].

Fig. 5 depicts a simulation of Beacon device, that the user will carry, for a regular use-case. Fig. 5(a) is a screenshot that shows the specification of Beacon device when it is broadcasting BLE packets at Ultra-low frequency as supported by the Android architecture. These packets are regular/normal broadcast packets that contain 4 parameters in its header frame as shown in Fig. 5(b) screenshot. The UUID name ”SPIT” is set at application layer, but at physical layer this parameter will be converted into 16 byte UUID along with Major as 0, Minor as 0 and Tx Power as integer indicating the advertisement mode. Fig. 5(c) is a screenshot that shows the regular broadcast packet captured by an AP device in the range of BLE Beacon device. Since the frequency is Ultra-low, the RSSI (Received Signal Strength Indicator) value and Tx Power are too low for any AP to capture these packets from farther distances and the calculated distance [13] gets restricted to a certain broadcast range. Thus, these packets may not even reach the AP and hence get filtered out. This benefits the system as such packets are regular broadcasts and not emergency broadcast; thus saving energy, increasing lifetime of Beacon devices, reducing load and traffic on APs.

Fig. 6 depicts a scenario for an emergency broadcast by the Beacon device that is triggered by the user. Fig. 6(a) is a screenshot that shows the specification of Beacon device when it is broadcasting an emergency BLE packet at High frequency as supported by the Android architecture. When user clicks on help button, the Beacon device increases its frequency to transmit the emergency broadcast to a larger distance.

To differentiate between a regular and an emergency broadcast, a flag or some metadata is required in the packet. As shown in Fig. 6(b), the parameter "Major" serves this purpose without increasing the size of the packet. Fig. 6(c) is a screenshot of the extracted information from the packet in a readable format with extra parameter of RSSI sensed by the AP. The broadcast at High frequency facilitates AP to capture the packet with accurate reading of Tx Power and RSSI value, determining the distance with high accuracy [13]. This information from the received packet will then be routed to the central station for further processing.

B. AP - AP Communication and Routing

For testing the efficiency and scalability of our proposed system, we designed a network simulation using ***ns3*** Network Simulator [9], [10] for the scenario described in Working Model.

1) Initial Configuration:

In accordance with the Mathematical model, the horizontal distances between 2 APs is set to 138 meters and vertical distance as 119 meters approximately. As seen in Fig. 7, it depicts the initial state of the system simulating a scenario of 12 APs (red) of which 2 constitute the central stations (black) at prominent places in the region, 3 beacon users (blue) distributed in an approximate area of 261.085×10^3 square meters. Communication between the APs is simulated based on the underlying Multi-Hop routing protocol [7].

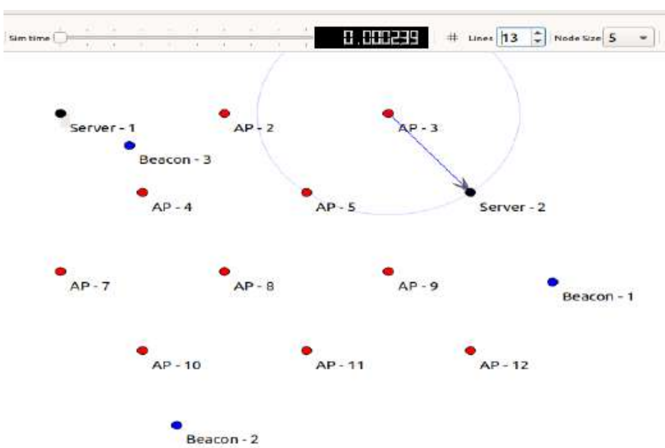


Fig. 7: Initial Configuration of Access Points and Beacons

2) Simulation of Dysfunctional AP:

If certain APs become dysfunctional the system is able to route packets to the central station. To reduce the response time for triggering the alarm, multiple stations have been incorporated so that if packets are unable to reach a particular central station, they are routed to some other central station. As shown in Fig. 8, AP-8 is labelled as 'Down' indicating that it is not in proper working condition. So packets from Beacon devices

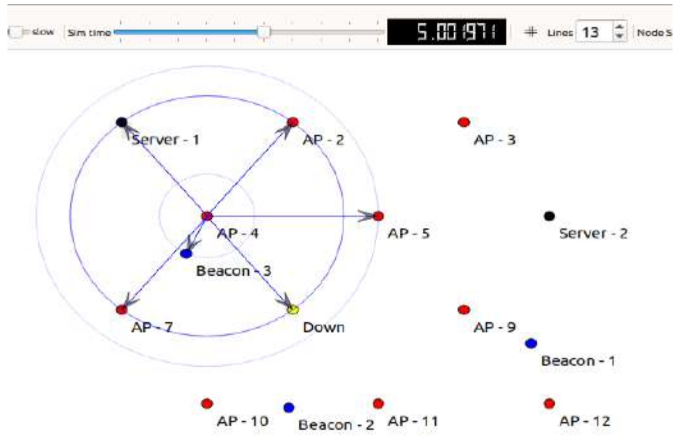
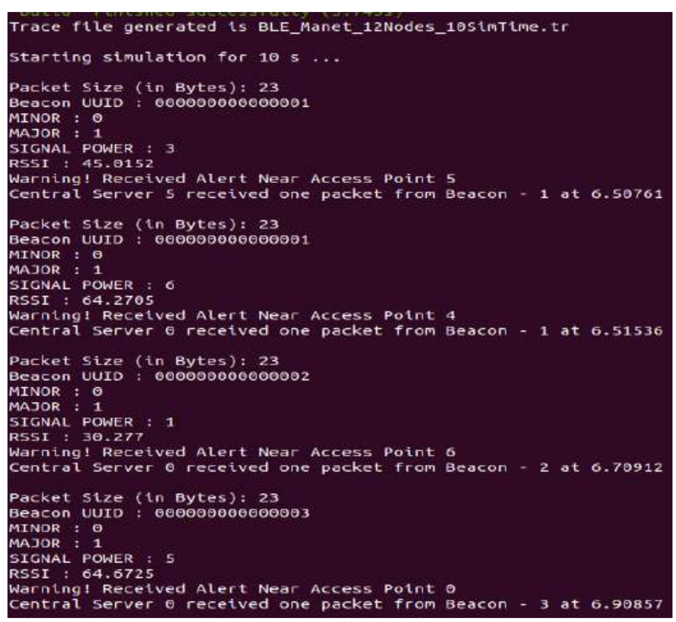


Fig. 8: Considering any random AP as dysfunctional

will be broadcasted to AP-8, but it will not be able to forward any packets.

Tx Power helps to estimate the victim location using RSSI. Fig. 9 shows each distress message packet reaching the central stations and each parameter of BLE header with its value. The message packets from all 3 Beacon devices are received indicating that system efficiently routes the packet even in case of AP failure. It also shows the warning alert - the Beacon device from which it originated and the central station where it is captured along with the time at which the message is received.



```
Trace file generated is BLE_Manet_12Nodes_10SimTime.tr

Starting simulation for 10 s ...

Packet Size (in Bytes): 23
Beacon UUID : 000000000000001
MINOR : 0
MAJOR : 1
SIGNAL POWER : 3
RSSI : 45.0152
Warning! Received Alert Near Access Point 5
Central Server 5 received one packet from Beacon - 1 at 6.50761

Packet Size (in Bytes): 23
Beacon UUID : 000000000000001
MINOR : 0
MAJOR : 1
SIGNAL POWER : 6
RSSI : 64.2705
Warning! Received Alert Near Access Point 4
Central Server 0 received one packet from Beacon - 1 at 6.51536

Packet Size (in Bytes): 23
Beacon UUID : 000000000000002
MINOR : 0
MAJOR : 1
SIGNAL POWER : 1
RSSI : 30.277
Warning! Received Alert Near Access Point 6
Central Server 0 received one packet from Beacon - 2 at 6.70912

Packet Size (in Bytes): 23
Beacon UUID : 000000000000003
MINOR : 0
MAJOR : 1
SIGNAL POWER : 5
RSSI : 64.6725
Warning! Received Alert Near Access Point 0
Central Server 0 received one packet from Beacon - 3 at 6.90857
```

Fig. 9: Distress messages received by the Central Stations

V. Result Analysis

We tested the system for response time to trigger the alarm, scalability and efficiency of the system with the observations as shown in Table I.

Table I: Scalability of the system with increase in the APs, Users and Central Stations

Number of APs	12	50	150	450
Number of Users	3	6	15	30
Number of Central Stations	2	3	7	15
Response Time (in seconds)	0.419	1.019	2.039	4.551

As seen in Fig. 10, we infer that the response time, being a critical parameter, for triggering the alarm varies in an approximate linear fashion with respect to the number of APs, but is within the acceptable range of 0.1 - 15 seconds with the increase in number of APs as described in [12] indicating that first minute during an ongoing violence is most critical and hence the response time should be within 60 seconds. It may be due to the losses and buffer limitations that the time to hear alarm increases due to queuing and processing of packets at central station. Introduction of multiple stations is able to handle the load and packet losses by routing packets to all the stations and alarm be heard. If a station is down, still packets are broadcasted to other stations and alarm is heard. The routing algorithm is able to handle the routing of packets even if multiple Beacon devices are triggered simultaneously.

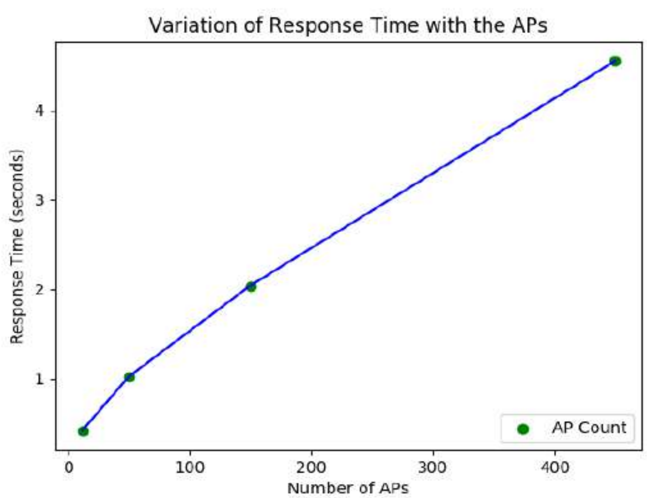


Fig. 10: Variation of Response time (seconds) with APs

VI. Conclusion and Future Scope

In this paper, we have proposed a wireless IoT based solution for women safety in rural areas by taking into account two most critical issues of erratic electricity supply and unreliable cellular network which are common in rural areas. To achieve this, solar panels on the street poles power the APs and an independent local network is created based on BLE routing protocol. Based on the Beacon signal received by an AP, location of the victim is traced out through the RSSI value and supported with a plot on preset map of the village. We introduced multiple central stations so that even if a station fails, the distress message can reach other stations to prevent any mishap.

As for future work to be done, the proposed system can be integrated with Machine Learning to identify most vulnerable and unsafe regions in the village. Thus, security in such regions can be increased by making the local network coverage more stringent. However, such computations need to be done when the system remains idle for long enough, without compromising the safety of women or else it can be done on remote systems. Also, APs can be combined with a surveillance system comprising of audio/video recorder or a camera to record the harassment incident as an evidence and to avoid false accusations. The proposed system can be extended to various emergency situations like fire breakdown, human accident, child abuse, robbery and senior citizen harassment.

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