Localization of Health Center Assets Through an IoT Environment (LoCATE)

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Abstract - **The rapid advances in modern wireless technology opens the door for new applications using the Internet of Things (IoT) technology. In the medical field, staff members of a certain hospital are in need for a system that tracks where patients/medical staff/devices are at any given time. LoCATE, which is Localization of Health Center Assets Through an IoT Environment, provides a near-real time tracking tool for medical systems using the existing 802.11 WiFi infrastructure. The primary goal of this system is to track assets and personnel at any hospital (e.g., Sentara® RMH hospital) and continuously log a real-time location data on a cloud computing platform such as Amazon Web Services (AWS). Using LoCATE, administrators can view the location of doctors, patients, and assets in real-time via a web UI or a mobile app, within the organization. The collected data, stored and processes on a Cloud Storage platform, is then analyzed to expose inefficiencies in daily operations and improve the health care system.**

Low-level functionality of the LoCATE system is unlike that of typical Radio-frequency identification (RFID) technologies. The spirit of the IoT paradigm employed by LoCATE makes the system both flexible and scalable, by leveraging collaboration between embedded and cloud systems. This flexibility will allow for the future support of additional applications such as hardware integration (e.g., New hardware components). This can include data acquisition such as usage statistics and historical patient health data. Compiling this data might pave the way for future research into disease vectors or could be used to optimize care delivered for specific conditions. While implications for an IoT system such as LoCATE are wide-ranging; its primary objective is to provide an easy to use, low-cost solution to track the location of medical assets in real-time.

Index Terms – Cloud Computing, E-Health Care, Internet of Things (IoT), Localization.

INTRODUCTION

Hospitals and medical centers have been integrating technology in all aspects of medical field to improve the quality of service and efficiency. Obtaining an accurate and reliable record of patients, staff, and asset flows has historically been a challenge in the health care industry. Human error, misuse, and/or abuse are just a few of the issues that are inherent in traditional methods of resource management in health care centers. To address this challenge some health care centers have begun to adopt real-Time Locating Systems (RTLS) to gain the upper hand in asset management [1]-[2]. RTLS can provide users with both historical and real-time data. This information can be used to locate assets and can also be used as an analysis tool for process improvement. Unfortunately, there are several constraints (technical, monetary, social/legal) that are particularly obstructive to the adoption of new technologies in the health care industry [1]. For this reason, the goal of the Localization of Health Center Assets Through an IoT Environment (LoCATE) system initiative is to develop a low-cost, low-impact solution to address these issues.

Multiple technologies exist that support localization such as Radio-frequency identification (RFID) usually used for manufacturing platforms (433 MHz) [3], 802.11 WiFi (2.4 GHz, 5GHz) [4] and Bluetooth (IEEE 802.15) [5]. Several industries are currently utilizing these technologies for RTLS including manufacturing, logistics, retail, and defense. While all of these technologies have the potential to provide a tangible solution for asset management in a hospital environment; we choose 802.11 as the technology of choice. The 802.11 wireless protocol, or Wi-Fi, is a networking protocol developed to support wireless local area networks (WLAN). Using 802.11, LoCATE provides a viable RTLS solution due to widespread usage of WLANs in health care facilities and the signal loss of the cellular networks inside some areas of these facilities, due to electromagnetic interference [6]. This helps to alleviate the initial costs of an RTLS by eliminating investment in unnecessary hardware installation such as RFID readers or scanners.

An RTLS system such as LoCATE has the ability to provide significant value and utility to businesses and organizations that have already implemented a distributed WLAN network. Using the existing WLAN, LoCATE can determine the location of a tracked entity, with a reasonable level of accuracy, by monitoring beacon frames broadcasted by nearby wireless access points. Using these beacon frames, a LoCATE node can estimate its location in a building by referencing the location of the wireless access point. Using this functionality, LoCATE system can track the flow of doctors, patients, nurses, and physical assets over time. Moreover, LoCATE embedded node can communicate over the WLAN to provide a telemetry interface for medical devices to relay health monitoring data and usage statistics to a cloud computing platform; where data can be stored indefinitely and shared later.

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RELATED WORK

Indoor localization has been a hot topic for several years. Many researchers have studied the idea of using GPS signals to locate a certain place or to accurately detect a certain location [7]. In addition, the idea of leveraging the smart phone's sensor data, ubiquitously available with humans who use a building, to automatically and transparently construct accurate motion traces have been studied [8]. However, in a health center (e.g., hospitals), smartphone signal is out of service due to the infrastructure of the hospital or the interference of the signals with medical equipment. The use of WiFi signals (802.11) would be a valid solution.

Many other fields are using WiFi signals in addition to other technologies such as Bluetooth or RFID for location tracking, such as parking management system [9] or a low-cost IoT system to enhance the transit bus system [10]. Bahl et al [11] proposed the use of a radio-frequency based system for locating and tracking users, by recording and processing signal strength information at multiple base stations positioned to provide overlapping coverage in the area of interest. An industry implementation of 802.11 based RTLS system is the AeroScout system which requires the use of proprietary WiFi enabled locator tags and a "location-grade" wireless infrastructure that can support the accurate localization of tags throughout the structure. This system also requires ultrasonic emitters to increase the accuracy of the system to room-level [12].

SYSTEM DESIGN

LoCATE integrates WiFi signals (802.11), wireless networking, embedded systems, and cloud computing platforms to implement an IoT centric solution for a RTLS in health care environment. The LoCATE embedded nodes assimilate location data by evaluating the signal strength indicator (RSSI) of the 802.11 beacon frames emitted by nearby wireless access points as shown in Figure I.

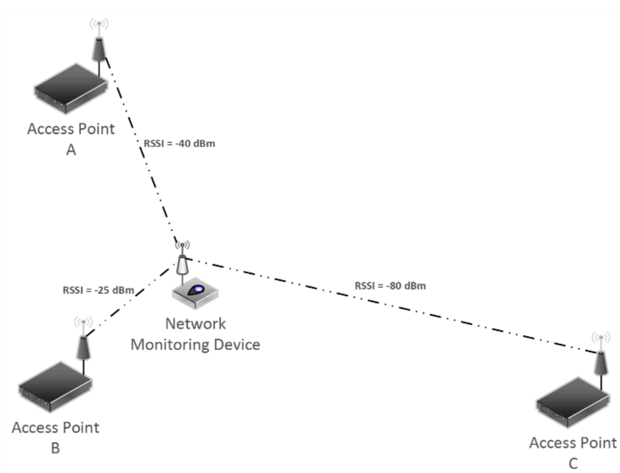

FIGURE I
LOCATE SYSTEM MODEL SHOWS A NETWORK DEVICE BETWEEN THREE DIFFERENT ACCESS POINTS IN A BUILDING

Wireless beacon frames are a subtype of 802.11 management frames that act as a preliminary communication between wireless clients and APs before any data is conveyed. Beacon frames are transmitted at specific intervals by the access point to announce the presence of a wireless LAN to a client. Management frames include information such as the EUI-48 address (Media Access Control address (MAC address)), Service Set Identifier (SSID), Received Signal Strength Indicator (RSSI), and channel number [13]. Network analysis tools (e.g., Wireshark) provide a mechanism for capturing these frames. However, it requires a compatible wireless network interface card (NIC) and driver combination. In our system, the embedded node uses TShark [14], a network protocol analyzer chosen to capture these packets of data including the arrival time, MAC address of device, strength of the WiFi signal, etc.

Received Signal Strength Indicator (RSSI) measured by the embedded monitoring device is used by LoCATE to infer a distance between the access point and the monitoring device. LoCATE stores the EUI-48 (MAC) addresses and RSSIs of the access points with the strongest measured RSSI. These addresses are then sent to a cloud computing platform where the data is aggregated, a time-stamp is applied, and prepared for viewing via web user interface (UI).

LoCATE system implements cloud-based server (AWS) to collect, organize, and compute the data from client applications running on the LoCATE tracking nodes. Several benefits can be provided by incorporation of cloud computing, including economy of scale and security and scalability on-demand. The incorporation of cloud computing provides network access to a shared pool of configurable computing resources that can be easily scaled on demand [15]. This cloud-based server is in the form of an Elastic Compute Cloud (EC2) virtual machine, provisioned from hardware maintained by (AWS). The cloud-based server instance performs a variety of functions necessary to the proper operation of LoCATE. The functions provided by the EC2 instance includes: Ubuntu (Linux, Apache, MySQL, PHP) LAMP stack for delivery of RTLS web based user interface, a python script TCP socket server used to communicate with LoCATE nodes and persistent data storage silo as shown in Figure II.

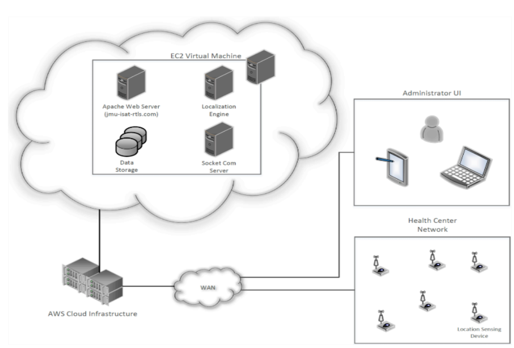

FIGURE II
NETWORK ARCHITECTURE OF LOCATE SYSTEM

HARDWARE EQUIPMENT

The embedded system used in the current implementation of LoCATE consists of a computational device (e.g., Raspberry Pi 3 Model B development board) equipped with a USB wireless adaptor capable of monitoring 802.11 wireless packets. Raspberry Pi was selected for its small form factor, low cost, flexibility, and extensive feature set. Some valuable performance capabilities of the Raspberry Pi 3 include; an on-board 802.11n wireless NIC, a 1.2 GHz 64-bit quad-core ARM CPU, 1 GB of memory, and an extensive interface options (USB, Ethernet, and GPIO). These features along with the low-power consumption of the Raspberry Pi makes it an extremely viable embedded solution. The external USB wireless adaptor connected to the Raspberry Pi is the Hawking Technologies RaLink RT3070. The wireless adaptor is capable of sniffing wireless network traffic (802.11 beacon frames emitted by nearby wireless devices) in the surrounding area. Range of Coverage: each node covers a range around 7m radius, WiFi can range between 5 and 75m [16]. Both the USB wireless adapter and on-board wireless NIC provide a dual-plane interface to simultaneously monitor the WiFi environment and communicate with the cloud-computing platform.

External power is also a necessary component for the tracking nodes. LoCATE uses an external 10,000 mAh battery that provides the tracking nodes with power. This battery pack allows the tracking devices to remain mobile so that it can be carried or attached to the entities being tracked.

SOFTWARE

There were many different types of software used to develop the LoCATE client application and the cloud-hosted web user interface. The EC2 cloud instance running on Amazon Web Services utilizes the Ubuntu Server operating system. Ubuntu is an open-source Linux based operating system. The web application framework that provides the LOCATE UI is called LAMP (Linux, Apache, MySQL, PHP) stack. LAMP is an open-source flexible web service framework that is well suited for creating interactive, dynamic web sites. A mobile-app can be provided to track each patient and staff member as discussed later in future work section.

One of the essential pieces of software used in LoCATE is the "TShark" utility. LOCATE uses TShark utility to "sniff" 802.11 wireless network traffic and export the data it observes to a usable file format called a packet capture file (e.g., pcap file). The data saved inside this file includes date, time, node id (MAC address), access point (identifier) and distance as shown in Table I.

TABLE I
EXAMPLE OF DATA ACQUIRED FROM RTLS SYSTEM

Date	Time	Node ID	AP	Dist (ft)
3/3/2017	19:33:16	64:66:B3:19:8B:13	E4:AA:5D:FF:20:A3	21.78
3/3/2017	19:33:29	64:66:B3:19:8B:13	E4:AA:5D:FF:20:A0	16.96
3/3/2017	19:33:55	64:66:B3:19:8B:13	E4:AA:5D:FF:20:A0	15.35
3/3/2017	19:34:12	64:66:B3:19:8B:13	E4:AA:5D:FF:20:A3	14.6
3/3/2017	19:34:31	64:66:B3:19:8B:13	E4:AA:5D:CA:26:20	24.07
3/3/2017	19:34:57	64:66:B3:19:8B:13	84:B2:61:0F:C6:51	16.96
3/3/2017	19:35:11	64:66:B3:19:8B:13	84:B2:61:0F:C6:51	6.9

DEVELOPMENT

LoCATE uses a Python based client application to coordinate network analysis operations on the Raspberry Pi 3. Key functions provided by the client application include; a scan of the wireless environment, temporary cache of acquired data, analysis, and transmission of data to the cloud storage. A flow diagram of the algorithm used by the client application is provided in Figure III.

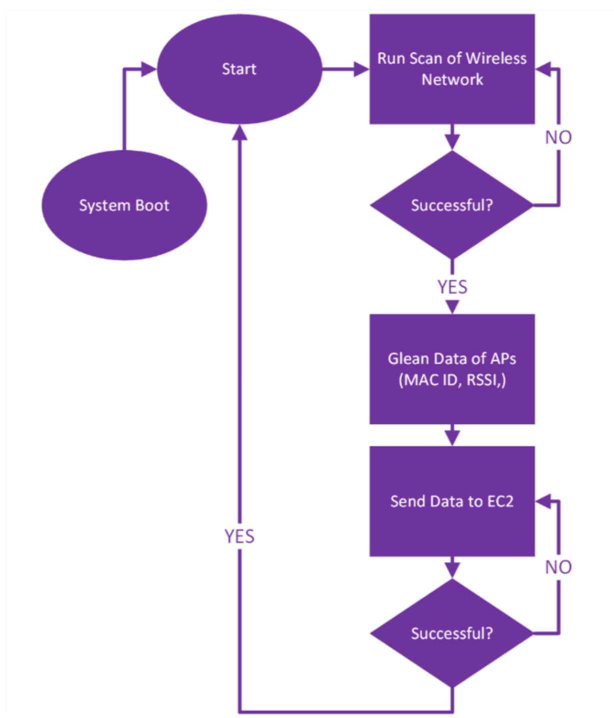

FIGURE III
LOCATE CLIENT FLOW DIAGRAM

The distance calculation uses the Friis free space propagation model given by (1)

$$P_{Rx} = \frac{P_{Tx} \times G_{Tx} \times G_{Rx} \times \lambda^2}{(4\pi)^2 \times d^2} \quad (1)$$

where P_{Rx} is RSSI, P_{Tx} is the transmit power of the wireless access point, G_{Tx} is the gain of the transmitter's antenna, G_{Rx} is the gain of the receiver's antenna, d is the distance between the transmitter and receiver in meters, and

λ is the wavelength of the propagated wave in meters [17]. This model assumes that the transmitter and receiver have direct line of sight (LOS), ignoring propagation losses that are generated from barriers and/or interference. With this model we can use P_{Rx} to estimate distance between LoCATE embedded node and Wireless Access Points, assuming P_{Tx},G_{Tx}, G_{Rx}, and λ are known as shown in (2)

$$d(m) = \sqrt{\frac{P_{Tx} \times G_{Tx} \times G_{Rx} \times \lambda^2}{(4\pi)^2 \times P_{Rx}}} \quad (2)$$

EVALUATION

After installing LoCATE, we were able to conduct several experiments, each experiment providing us with more details as to the effect of distance and barriers in the transmission of signals in a building [18]. We use the collected data to improve the accuracy and performance of LoCATE. Experiments conducted were validation of Friis Free Space Propagation Model, examination of the impact of Transmitter Power on Signal Propagation, and Wall Impact on Signal Level.

I. Experiment 1: Validation of Friis Free Space Propagation Model

In this experiment we referenced the Friis propagation model to graphically show the loss in the received signal strength as distance between the transmitter and receiver increased. Figure IV shows the theoretical data generated using the Friis model.

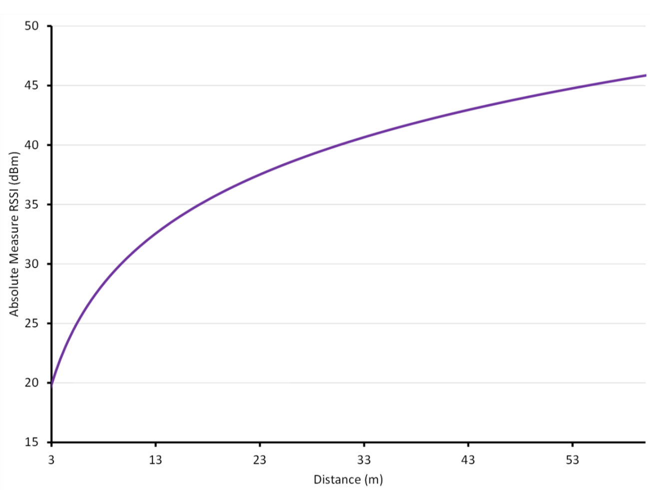

FIGURE IV
DISTANCE VS. RSSI USING FRIIS FREE SPACE PROPAGATION MODEL

The experiment was conducted by measuring RSSI at increasing distances from an access point transmitting at 100mW. The gain of the antennas used in this experiment were 4 and 3 dBi for the transmitter and receiver respectively. This experiment was repeated to ensure reliable results. Figure V shows the data acquired during this procedure. As we can see by comparing Figures IV & V, the path loss observed over distance validated the Friis model.

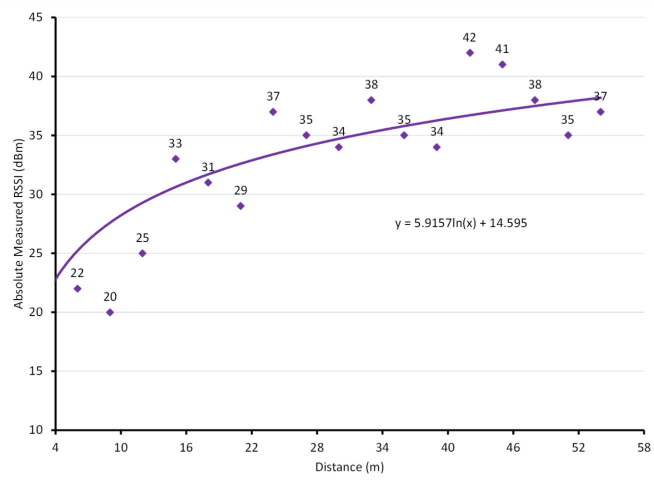

FIGURE V
DISTANCE VS. RSSI DATA VALIDATES FRIIS FREE SPACE PROPAGATION MODEL.

II. Experiment 2: RSSI vs Varying Tx Power:

There is no standard for transmit power of wireless access points, an experiment was conducted to test the effect of transmitter power on signal propagation. The methodology used in this experiment was similar to the first experiment although the transmitter's power was adjusted to reflect common manufacturer's P_{Tx} values. Three trials were conducted for this experiment with P_{Tx} values of 50, 100, and 200 mW (17, 20, 23 dBm respectively). Figure V shows the data that was acquired during Experiment II. Examination of this data shows that, as expected, transmitter power does impact the signal level observed over distance.

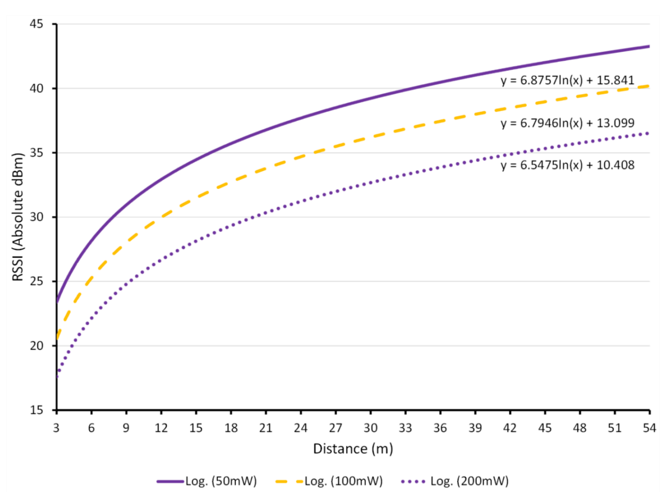

FIGURE V
DISTANCE VS. RSSI DATA ACQUIRED DURING 50, 100, AND 200 MW TESTS

III. Experiment 3: Effect of Wall on data loss:

The purpose of this experiment was to test the impact of walls and other barriers on the signal level measured at the receiver. The control of this experiment was the RSSI measured with clear line of sight at distance *d*. After gathering data for the control, RSSI was then measured at the same distance *d* with one wall as in Table II and two walls as in Table III, in the direct path between the transmitter and the receiver. Examination of the data reveals that generally the signal suffers from a fixed loss for a wall or other barriers despite the transmission power.

TABLE II
SIGNAL LOSS THROUGH WALL (2.4 GHZ SIGNAL)

Tx Power (mW)	Line of Sight (LoS)	1 Wall between (dBm)
50	-20	-28
100	-19	-30
200	-17	-20

TABLE III
SIGNAL LOSS THROUGH TWO WALLS (2.4 GHZ SIGNAL)

Tx Power (mW)	Line of Sight (LoS)	Wall between (dBm)
50	-27	-37
100	-23	-35
200	-20	-37

CONCLUSION

LoCATE is designed as an asset tracking system incorporating; cloud, IoT, and 802.11 wireless technologies to provide a low-cost alternative to traditional real time locating systems. Experimental data (II) shows that a reasonably accurate distance measurement can be attained from 802.11 wireless management frames. The ability to estimate these distance measurements between distributed wireless access points provides an opportunity to utilize 802.11 wireless network technology for more than just data transmission. LoCATE leverages this opportunity to create an IoT centric solution for health care environments. The potential benefits of the LoCATE localization system include:

- Flexibility due to the embedded processing power of client devices providing a telemetry interface.
- Scalability by incorporation of cloud infrastructure and web service.
- Improvement in health center process and asset management from historical data acquisition.

As we see in Experiments II and III, accurate localization is highly dependent on application specific variables such as P_{Tx}, G_{Tx}, G_{Rx}, and λ. Implementation of this system must deal with these variables on a site-to-site basis to obtain the most accurate tracking functionality. Similarly, the granularity of localization using this system is highly dependent on the design of the existing wireless infrastructure. Highest granularity would be achieved when being implemented on top of a, "location-grade" 802.11 wireless infrastructure. Nevertheless, LoCATE is an innovative system that incorporates embedded systems to provide both tracking and telemetry interfaces for assets in a health care environment.

FUTURE WORK

To better organize and analyze the information regarding the state of the system, a cloud-based database can be implemented that would associate LoCATE tracking device identification numbers with their respective entity in the health care network's IT system. This cloud-based database could also store information about the employees, patients, or assets that the tracking device is attached. This information may allow future analysis of the whole health system.

LoCATE references the physical location of Wireless Access Points distributed throughout a building. This allows the current implementation to approximate the general location of a tracked entity but does not provide an exact location. Therefore, LOCATE is not as well suited for applications that require room level location accuracy. To address this, a computational algorithm should be developed to gain a better estimate of the location by triangulating the location from three separate access points.

Although the system is portable, it is not ideal for someone who is constantly moving throughout the day. Therefore, in the future, it would be desirable to miniaturize the existing tracking device. This could be easily achieved by replacing the Raspberry Pi 3 with a Pi Zero; a device that is much smaller and voids of any unnecessary parts. Other pieces of the tracking device could be replaced as well; such as the USB network interface and large 10,000 mAh battery for smaller and lighter alternatives. Investigation could also take place to determine if the on-board wireless chipset found on the Raspberry Pi could support monitoring of the network which would eliminate the USB interface completely. Security is one of the most important topics that needs to be covered in LoCATE [19]-[20].

Finally, user-interface improvements could allow for a visual representation of the tracked entity on a two-dimensional model of the building. Other UI improvements would include security features such as ability to register/authorize users from an administration account, and have the ability to register/authorize LoCATE tracking nodes.

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