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Smarttag: An Indoor Positioning System Based on Smart Transmit Power Scheme Using Active Tags

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ABSTRACT There are no large-scale deployments to navigate the people indoor environments as the GPS for outdoor environments. For this reason, the development of high-performance systems of indoor localization has been considered the potential research areas by both academia and industry in last decade. These indoor localization research studies are divided into two groups in the literature which are reader-based and tag-based systems. Most of these studies are reader-based. These readers and tags can determine the received signal strength levels of the signal using the radio frequency technology. We present a tag-based and cost-effective indoor localization system using NRF24L series radio modules. Different from the available tag-based systems, we propose a smart transmit power scheme run in the tags called SmartTag. The SmartTag provides communication with the nearest reader using different power levels. However, the existing tag-based methods require the received signal strength indicator (RSSI) information to achieve high localization accuracy. Our proposed system eliminates RSSI information with the SmartTag. We have developed a simulation of the prototype system, and we used Monte Carlo simulations in many different scenarios. We have also implemented the system prototype and conducted in an actual indoor environment to demonstrate the performance of the SmartTag by comparing with the Monte Carlo simulations. From the indoor experimental results, we confirm that the detections of room and objects are accurate and positioning accuracy is improved thanks to the SmartTag localization. If we briefly summarize our work, we have determined the position in indoor environments by communicating with the nearest reader in the medium thanks to the scheme on the SmartTag.

INDEX TERMS Indoor localization, Monte Carlo methods, NRF24L radio modules, path loss model, smart tags, trilateration.

I. INTRODUCTION

Location detection systems for indoor environments, determine the locations of the people or the objects using the perceptual information transferred by radio waves and magnetic-fields [1]. In recent years, indoor localization techniques have been widely discussed and researched. However, a sophisticated solution has not been recognized at present [2]. In these studies, location detection systems are divided in two different categories which are reader-based [3] and tag-based [4] systems. First, a reader-based system detects the strength of the signal whose sent by tag. The tag does not have any information (ACK) about whether the reader has received this signal. Also, the tag's signal output power and beacon message content are always the same [5]. In tag-based systems, the situation is different. The tag can update the run status at runtime (RX, TX), change the signal output power and change the message content [4].

There are many studies about a location detection for indoor environments in the literature. For example, Suvil Deora and his colleagues developed a Sequence-based localization system. In their work, they tried to locate the tags using different signal output powers. Also, they consider beacons with unequal transmit power for sequence-based localization and present heuristic algorithms for joint transmit power optimization and beacon placement. As a result of the work, they detected the location of the tag with an error between 2 and 5 meters [6]. R. Beuran and his colleagues developed a tag-based system. They have proposed a simulation tool to determine performance analysis of active tag systems [7]. As a result of the study, they stated the development phase is much more flexible and versatile than real-world experiments [4]. Subbu *et al.* [8] developed a tag-based location system using sensors on smartphones. They pointed out that smartphones are very efficient devices for positioning in indoor environments [8]. Ahmed and Avaritsiotis [9] and others developed a reader-based system used Radio Frequency Identification (RFID) tags. The system minimized the distance between the exact locations and the estimated locations of the tags using Multidimensional Scaling (MDS) algorithm [9]. Hossain *et al.* [10] recorded the Wi-Fi signals collected from the smart mobile devices in a database. Using this data, they realized the location detection operation using the Weighted Neighborhood (WKNN) and the Nearest Neighborhood (KNN) algorithms with a location error in 2-2.5 meters [11]. Almaaitah *et al.* [12] and his colleagues developed a reader-based 3-D working simulation interface using the multi-lateration method to estimate location in indoor environments. In the study, they tried to determine the positions of RFID tags using different signal output powers of RF readers. As a result of the work, they detected the location of the tags correctly with an error of 0.48 m^3 [12]. Wendlandt *et al.* [13] detected location by classifying the Bluetooth signals according to their strength levels. In their study, the Bluetooth signal strengths data are used KNN and Support Vector Machines (SVM) algorithms. As a result of the study, SVM algorithm categorized the data with less margin of error compared to the KNN algorithm [14]. Peng *et al.* [15] and his colleagues created a new solution by developing a mobile application using IBeacon-based BLE technology for positioning in emergency rooms. The cost of this BLE device is around ten dollars. In their work, RSS-based [16] algorithm is esmphasized using Time of Arrival (TOA) [17], the Angle of Arrival (AOA) [18] and Time Difference of Arrival (TDOA) [19] techniques. As a result, they stated that devices and patients' location in the emergency room determined correctly by 97.22% within 5 meter error [20]. Subaashini *et al.* [21] developed a reader-based system using the ZigBee module. In their study, they measured RF signals in three different ways. First, they measured the signal strength level between the tag and the reader without any obstacles. The second measurement was made in the area where the glass, the wood, and the wall were located. Finally, the level of signal strength in the area where there are people measured and compared with other measurements. As a result of the study, they pointed out that the signal strength of the locator, the environmental factors and the number of readers are necessary for indoor positioning [21]. Gandhi *et al.* [22] realized a reader-based system. They developed this system to detect locations in indoor environments using the RF and Field Programmable Gate Array (FPGA) technologies in a 100 × 100 meters square area. The RF readers transmit the tag signals they receive to the FPGA and collect data for the indoor positioning operation. In addition, they performed position detection in indoor environments using the triangulation algorithm in FPGA. As a result of the study, it was stated that they detected the location with 3 to 5 meters error [22]. Xu and Gang [23] used RFID technology [23] in 2009 and examined the relationship between the KNN and the Landmark [24] approach, which makes use of the topology of reference tags. They analyzed the layout of the reference labels used in the Landmark approach and figured out triangle mesh topology advantages. As a result of the simulation, reference tags placed according to triangle mesh topology presented better results [25]. Kaseva *et al.* [26] and his colleagues worked on a tag-based system. They have presented an RF-based indoor localization design targeted for the wireless sensor networks. In their prototype setup configuration, they used four different output power to communicate between sensors. They also stated that the system has low power consumption. As a result of the work, they said that the prototype network reaches accuracies ranging from 1 to 7 meters. Also, they stated that with one anchor node per a typical office room, the current room of the localized node is determined with 89.7% precision [26]. This last study is very similar to our work but it is different from our architecture. We have also seen better results when we work with our system.

In our study, a tag-based system is proposed to detect the location of objects in indoor environments. The proposed system consists of a server, a tag, and a reader module. In the proposed system, we have designed smart transmit power scheme in active tags called SmartTag. This scheme is run in the active tag and can update transmit power level. Thus the communication between the SmartTag and the reader is continuously ensured through different power levels. The tags send the beacon messages to the reader at specific time intervals. These messages consist of a unique tag number and the strength level information of the message. The readers send their messages to the server. They are used to implement the detection of individual location operations using the trilateration method [27]. We also provide a simulation tool to enable the performance analysis of the proposed system. This tool is used to determine different reader numbers, room numbers, environment parameters and signal output powers. Also, we have designed and implemented the SmartTag prototype and system. The SmartTag, the reader module, and the server are implemented by Nordic Semiconductor NRF24L series radio modules [28]. NRF24L is explained in Section IV. The NRF24L radio module is more cost-effective than the BLE. The prototype system is tested in the experimental environment. Also, Monte Carlo simulations and experimental results are presented.

In short, we have described the main contributions in four parts:

- We have designed smart transmit power scheme to control and manage various signal output power. We also identify the nearest reader using the SmartTag and determine the position of the objects.
- We provide a simulation tool to enable the efficient development phase and determine performance analysis of the proposed system as real experiments.
- We have designed and implemented the SmartTag prototype and system using NRF24LE1.
- We have used NRF24LE1 modules because it is low-cost than other technologies and devices like BLE, Wi-Fi, etc.

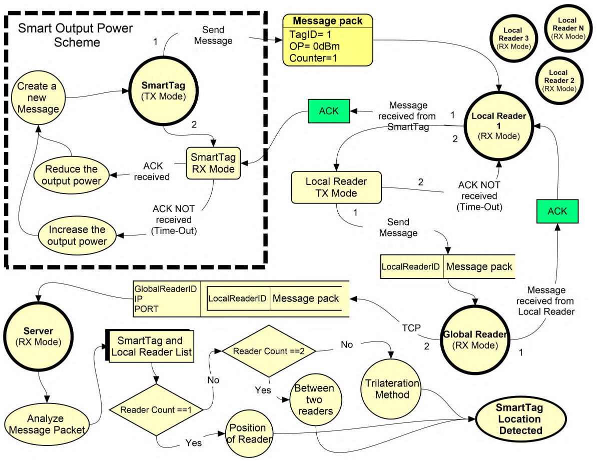


FIGURE 1. State diagram of the system components.

This paper is organized as follows; the localization procedure is briefly explained in Section II. Then, system components are presented in Section III. After that, the implementation of the SmartTag in Section IV. Then, simulation and experimental results are discussed in Section V. Finally, the paper conclusion is discussed in Section VI.

II. LOCALIZATION PROCEDURE

In Figure 1, the indoor positioning system consists of the components of the SmartTag, the local reader, the global reader, and the server drew bold black circles.

- The SmartTag is a component that allows beacon messages to be sent at different power levels determined by the signal transmit power scheme.
- The local reader encapsulates the beacon message from the SmartTag and sends it to the global reader.
- The global reader re-encapsulates the local reader messages from the local reader and sends it to the server.
- The server examines the global reader message packets and determines the appropriate procedure for estimating the location of the SmartTag.

The indoor positioning procedure starts with the SmartTag becoming active as shown in Figure 1. When the SmartTag runs, the beacon message is sent with the highest signal output power in the TX mode by the SmartTag. If the beacon message is detected by the local reader, then the reader sends an acknowledged (ACK) message to the SmartTag regarding the received beacon message. If the SmartTag receives the ACK, a new beacon message is transmitted by decreasing the signal output power. If the beacon message is not received by the Local reader, a new beacon message is transmitted by increasing the signal output power by the SmartTag. The local reader creates a new local reader message and writes its LocalReaderID inside this message in TX mode. Then it transmits this local reader message to the global reader. If the global reader receives the local reader message, it sends the ACK message to the local reader. If the local reader does not receive the ACK message until the timeout, the local reader message is retransmitted again by the global reader. Then it runs in RX mode and captures the new beacon message. The global reader receives a local reader message; it generates a new global reader message by re-encapsulating it with the GlobalReaderID. Then this message is transmitted using a TCP connection. The server analyzes on received global reader messages and creates the SmartTag and local reader list with TagID, output power indicator, and message counter. The server uses this list to determine how many local readers is known inside the SmartTag communication region. If the SmartTag signal is received only from a local reader, it is assumed that the SmartTag location is in the position of the local reader. If the signal is received from two different local readers, it is in the coverage area of both readers, and if the number of readers is more than two, the location of the SmartTag is estimated by using the trilateration intersection model. The server refreshes this list every received global reader message and estimates the SmartTag position.

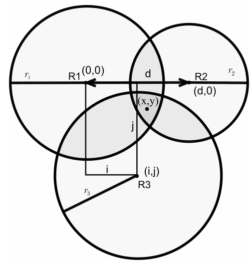


FIGURE 2. Coordinate system for trilateration method.

A. TRILATERATION METHOD

Trilateration is a method that is used to estimate the unknown point [27]. In this study, trilateration method is used to find the intersection point (x, y) of at least three circles whose radiuses are known (1) and (2).

$$x = \frac{r_1^2 - r_2^2 + d^2}{2d} \tag{1}$$

$$y = \frac{r_1^2 - r_3^2 + i^2 + j^2}{2j} - \frac{ix}{j} \tag{2}$$

R1, R2, and R3 are the centers of the local readers. r_1, r_2, and r_3 represent the radius of these readers. It means the radius of visibility of the SmartTag at a given signal level. d is the distance between the centers R1 and R2. i is the signed magnitude of the X-axis, in Figure 2 coordinate system, of the vector from R1 to R3. j is the signed magnitude of the Y-axis of the vector from R1 to R3. x represents the X-axis in the coordinate system of the intersection point. y represents the Y-axis in the coordinate system of the intersection point.

This method is used when the server detects that the SmartTag is communicating with 3 or more local readers. In Figure 2 the intersection point found is accepted to be the horizontal location of the SmartTag.

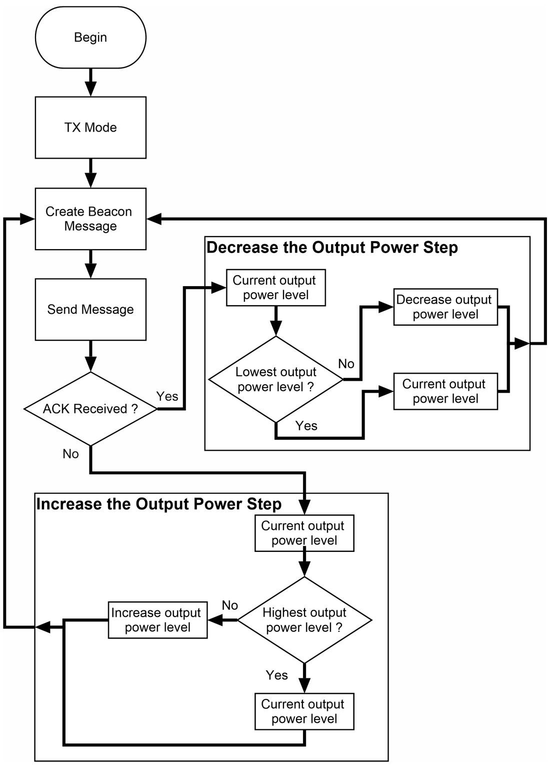


FIGURE 3. Flowchart of the smart transmit power scheme.

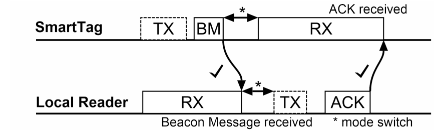


FIGURE 4. The SmartTag and the local reader modes in case the ACK message is received.

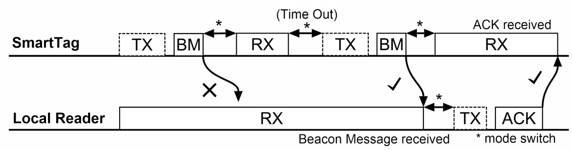


FIGURE 5. The SmartTag and the local reader modes in case the beacon message is lost.

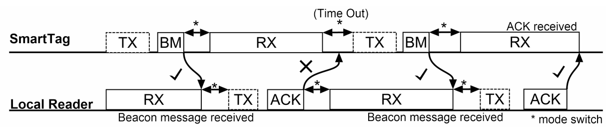


FIGURE 6. The SmartTag and the local reader modes in case the ACK message is lost.

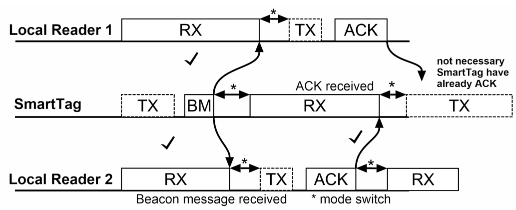


FIGURE 7. The SmartTag and the local reader modes in case the multiple ACK messages are received.

III. SYSTEM COMPONENTS

A. SMARTTAG

Firstly, the SmartTag is mounted on the people or objects and defined with a unique number. The SmartTag uses smart transmit power scheme to manage output power level. Initially, the SmartTag runs TX mode. Then it creates a beacon message with the preamble, address, packet control, and payload. Figure 3 presents a flowchart of the proposed smart transmit power scheme runs on the SmartTag. The SmartTag module sends the beacon messages at the highest output power level. The SmartTag knows whether the local reader has received the signal with the ACK message. If the SmartTag receives the ACK message, the signal output power is reduced. If not received, the signal output power is increased.

The main purpose of the SmartTag is to update the signal output power level according to the received ACK message information. This information of ACK message provides exact information about received beacon message. The basic auto acknowledgment case is shown in Figure 4. If the local reader receives a beacon message, it sends back the ACK message. The asterisk indicates the transition from TX mode to RX mode or from RX mode to TX mode. Figure 5 shows a retransmission scenario due to the loss of the first beacon message transmitted. The SmartTag is sent the beacon message and switches to RX mode. If the SmartTag does not receive the ACK message until the time-out, the beacon message is re-sent. Figure 6 shows that the beacon message is received by the local reader, but the ACK message is not received by the SmartTag. In this case, the SmartTag re-sends the beacon message. The SmartTag consider to receive multiple ACK messages. If the SmartTag receives only one local reader's ACK message, the SmartTag updates the signal output power as shown in Figure 7.

B. LOCAL READER AND GLOBAL READER

The local reader is located on the ceilings of the rooms. This module is set to RX mode at initial configuration. The local reader module receives the beacon messages as shown in Figure 8(a). The local reader is converted to the TX mode when the beacon message is received. Then, it sends the ACK message to the SmartTag. The received beacon message is converted to the local reader message format. This local reader message format consists of LocalReaderID information and beacon message. The local reader module sends the local reader messages at the highest output power level in the TX mode to the global reader. Then, the message send operation is completed and the local reader switch to the RX mode.

The global reader is located in the corridors to cover all local readers. This module is set to RX mode at initial

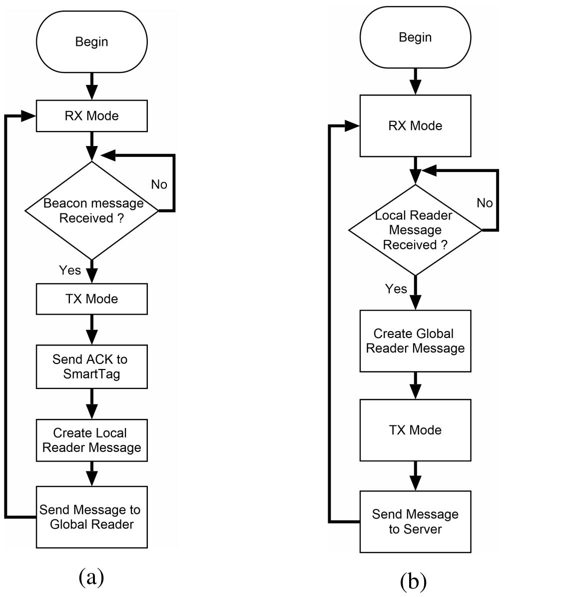


FIGURE 8. **Flowchart of the local reader Module and the global reader module. (a) Local Reader. (b) Global Reader.**

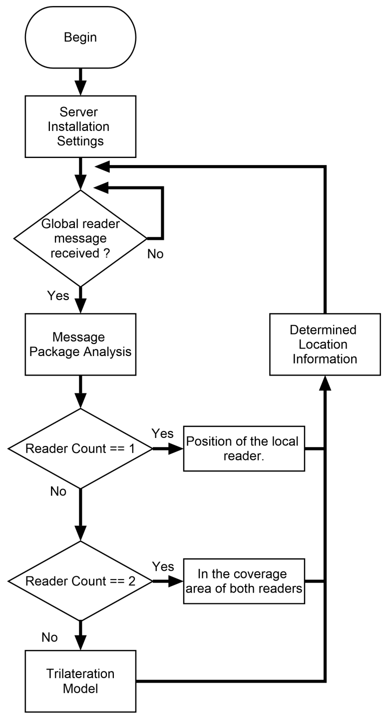


FIGURE 9. **Flowchart of the server module.**

configuration. The global reader module receives the local reader message as shown in Figure 8(b). The received local reader message is converted to the global reader message format. This global reader message format consists of GlobalReaderID information and local reader message. By establishing a TCP connection to the IP and port addresses of the server module the global reader message is sent. Then, it continues to wait for the global reader messages that will come from the local reader module.

C. SERVER

The server is located in the coverage area of the global readers. The server analyzes the global reader messages and estimates the location by using the trilateration algorithm, check system errors, control the elements, etc. Figure 9 shows the flowchart of the server. The server analyzes the received global message. Then, the server detects from which global reader and local reader this message is sent. Also, the SmartTagID, output power indicator and message counter information in the message are reached to the server. Server lists all of the local and global readers received according to their SmartTagID. The server uses this list to determine how many local readers is known inside the SmartTag communication region. If the SmartTag beacon message is received only from a local reader, it is assumed that the SmartTag location is in the position of the local reader. If the beacon message is received from two different local readers, it is in the coverage area of both readers, and if the number of readers is more than two, the location of the SmartTag is estimated by using the trilateration intersection model. The specific window size is defined within the server. The window size indicates the number of beacon message packets for the start of the positioning process. The window size is used to determine the distance between the SmartTag and local reader. This window size should be selected to guarantee the smart transmit power scheme steps. The server refreshes its lists for every selected window size and estimates the SmartTag position.

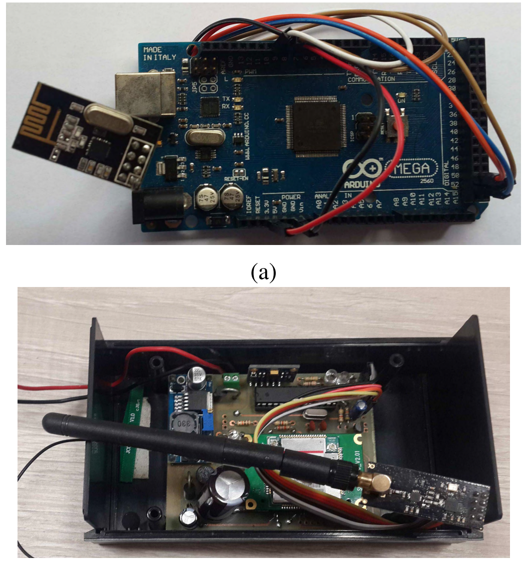
IV. IMPLEMENTATION OF SMARTTAG

In this section, we present the hardware implementation for the indoor positioning system. Firstly, the Nordic Semiconductor NRF24LE1 hardware is chosen for the SmartTag. This equipment has a system on chip (SoC). It communicates within 2.4 GHz RF. It can also be programmed with four different signal output powers which are 0 dBm, −6 dBm, −12 dBm and −18 dBm at runtime. This SmartTag is programmed to constitute a beacon message within 1 second. The format of the beacon message is described in Figure 10. The beacon message contains a preamble field, address field, packet control field, payload field and a CRC field. The preamble is a bit sequence used to synchronize the receiver's demodulator to the incoming bit stream. An address ensures that the correct beacon message is detected by the receiver. The packet control field contains a 6-bit payload length field, a 2-bit PID (Packet Identity) field, and a 1-bit NoACK flag. This 6-bit field specifies the length of the payload in bytes. The length of the payload can be from 0 to 32 bytes. The 2 bit PID field is used to detect if the received beacon message is new or retransmitted [28]. The 1-bit NoACK flag indicates the ACK request of the SmartTag. The payload is the user-defined content of the beacon message. It can be 0 to 32 bytes [30]. The SmartTag payload field contains 1-byte SmartTagID, 1-byte signal output

			Payload 0-32 byte	
Preamble 1 byte	Address 3-5 byte	Packet Control Field 9 bit	SmartTagID 1 byte Output power indicator 1 byte Message counter 1 byte	CRC 1-2 byte

FIGURE 10. SmartTag beacon message format.

FIGURE 11. The implemented SmartTag prototype.



(a)

(b)

FIGURE 12. The implemented (a) local reader and (b) global reader prototype.

power indicator, and 1-byte message counter. The CRC is the error detection mechanism in the message. The implemented SmartTag prototype is shown in Figure 11. In the SmartTag design, the power board for the NRF24LE1 chip is implemented with the CR2032 battery [29].

The local reader is also developed using NRF24L01+ [30]. The developed hardware also communicates with 2.4 GHz RF. The local reader can work as both receiver and transceiver. The local reader message sent from the local reader to the global reader consists of 1-byte LocalReaderID and 3-byte MessageContent information. The Arduino Mega 2560 [31] is chosen to implement this local reader prototype as it provides power supply. The implemented local reader prototype is shown in Figure 12a. Another hardware that is implemented is the global reader. This hardware has been developed with the NRF24L01+ integration as well as with the local reader. The difference between the global reader and the local reader is the use of an antenna. The Raspberry Pi [32] is chosen to implement this global reader prototype as it is to transmit the global reader message to the server that it has received from the local reader. Global reader message sending is accomplished by establishing a TCP connection to the server of the global reader which Raspberry Pi has an embedded Wi-Fi module. The implemented local reader prototype is shown in Figure 12b. A standard laptop computer is used as a server. The server is equipped with Intel Core i5 (2.4 GHz, Dual Core) processor, 802.11a Wireless adapter, and 1 TB HDD.

V. SIMULATION AND EXPERIMENTAL RESULTS

A simulation environment is developed for performance testing of the proposed system by using Matlab. In this section, two different cases are realized. The first case concerns the detection of the communication region relative to the four different signal output powers of the SmartTag. The second case the SmartTag performance is tested using many different rooms and local readers. In these simulations, the SmartTag, local reader, and server are used. All local reader messages transmitted by the local reader are assumed to be received by the general reader without message loss. It is assumed that the global reader transmits all message to the server without message loss. For this reason, the global reader is not used in the Monte Carlo simulations. Log-Normal Shadowing Model is used to provide causes fluctuations in the signal strength by adding some noise on the signals in the simulation. This model is used by adding on the Free Space Path Loss Model (FSPL). FSPL model is written in the Equation 3. The Log-Normal Shadowing Model is depicted in the Equation 4 and Equation 5 [33].

$$\begin{aligned} FSPL(dB) &= PL_0 \\ &= 20log_{10}(d) + 20log_{10}(f) + F - G_t - G_r \quad (3) \\ X_g &= e^{\mu+\sigma Z} \quad (4) \\ PL(dB) &= P_{Tx_{dBm}} - P_{Rx_{dBm}} \\ &= PL_0 + 10\gamma log_{10}\frac{d}{d_0} + X_g \quad (5) \end{aligned}$$

PL_0 is the path loss at the reference distance. d is the length of the path in meters. f is the signal frequency in megahertz. As the operation is carried out with the units, meter, and MHz, the constant F value in the path loss model. G_t and G_r are transmit and receive antenna gains in dBm. PL is the total path loss measured in dB. P_{Tx} is the transmitted power in dBm. P_{Rx} is the received power in dBm. d_0 is the reference distance. γ is the path loss exponent. X_g is a random shadowing effects.

The parameters used in these Monte Carlo simulations are determined according to the NRF24LE1 integration [34]. The constraints of this device are used as simulation parameters. Parameters utilized in the simulation are listed below:

- The SmartTag module communicates at the 2.401 GHz central frequency with the speed of 1Mbps. The SmartTag output power is used to be 0 dBm, −6 dBm, −12 dBm, and −18 dBm. The antenna gains are 2 dBm.
- The local reader module communicates in the 2.401 GHz central frequency with the speed of 1 Mbps(the other data rates are 256 Kbps, 2 Mbps). The signal output power is 0 dBm. RX sensitivity of the local reader is −82 dBm. The antenna gain is 2 dBm.
- The global reader modules communication frequency is the same with the local reader. The global reader module on-air data rate is 256 Kbps (Communication range around 1000 meters). It is accepted to be in the global reader module simulation area. It is assumed that the local reader message sent by the local readers to the global readers are lossless.
- Carried out transceiver-receiver separation are LOS and NLOS, the path loss exponent is taken 1.8 [33].
- Gauss random variable variance is taken 7 dB for Log-Normal Shadowing Model [33].
- The wall effect is assumed as 6.9 dBm [35].
- We have placed the SmartTag within the grid (1x1 meter) for each reference point.
- Each case is performed Monte Carlo simulations (100.000 runs) in order to assess the performance of the proposed system.

In the first case, the communication areas of the SmartTag's signal output powers are determined. The SmartTag is run without the smart transmit power scheme. In this case, beacon messages are sent with four different signal output powers. The distance of communication with the local readers is determined for each signal output power. The simulation area is set to 6 meters horizontal length (X), 7 meters vertical length (Y), and 3 meters depth (Z). The local reader (LR) is positioned hanging in the middle of the environment. The local reader is positioned at LR1 (4,4,3) point. We simulated within the grid for each reference point of the SmartTag. Virtual radius and communication region distances are determined when the results of Figure 13 are examined. Figure 13a shows the communication region with a standard deviation of 1.8763 and mean 10.5 meters. Figure 13b shows the communication region with a standard deviation of 1.3476 and mean 8.3 meters. Figure 13c shows the communication region with a standard deviation of 1.1515 and mean 6.1 meters. Figure 13d shows the communication region with a standard deviation of 1.1135 and mean 3.1 meters. These communication distances can be changed according to the data rate. For example, around 1000 meters at an on-air data rate of 256 Kbps. This demonstration informs us the local readers should be placed at least 5 meters away. Also, the global reader must be placed to cover the local readers.

Second case consists of five subsections. These are Sim A, Sim B, Sim C, Sim D and Sim E. Each section has different rooms and local readers. In the simulation environment,

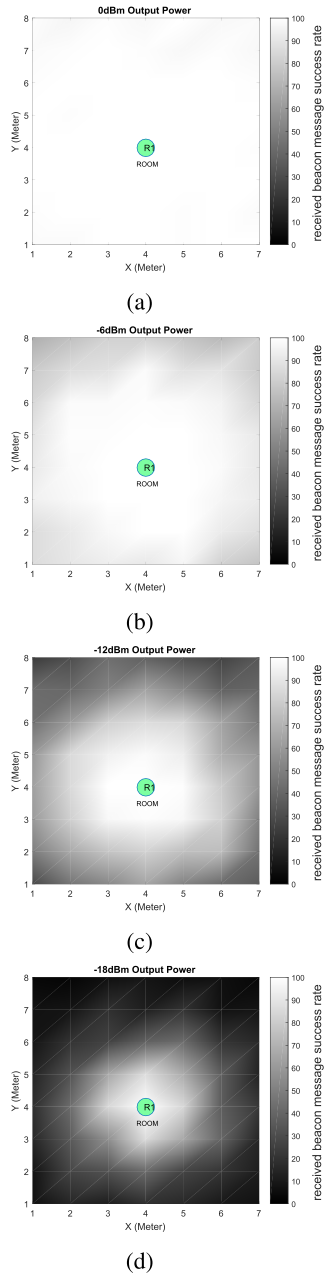


FIGURE 13. Communication region of the SmartTag with different output power levels (a) 0 dBm, (b) −6 dBm, (c) −12 dBm and (d) −18 dBm.

we have implemented within the grid for each reference point of the SmartTag. Simulation A has five local readers as shown in Figure 14a; one in the corridor and four at the corner of the room. Simulation B has two local readers as shown in Figure 14b; one in the corridor and one in the middle of the room. In Simulation C, there are ten local readers as shown in Figure 14c; four in the corners of the first room, four in the corners of the second room and two in the corridor. Simulation D has three local readers as shown in Figure 14d; one in room 1, one in room 2 and one in the corridor. This simulation also has twelve local readers as shown in Figure 14e;

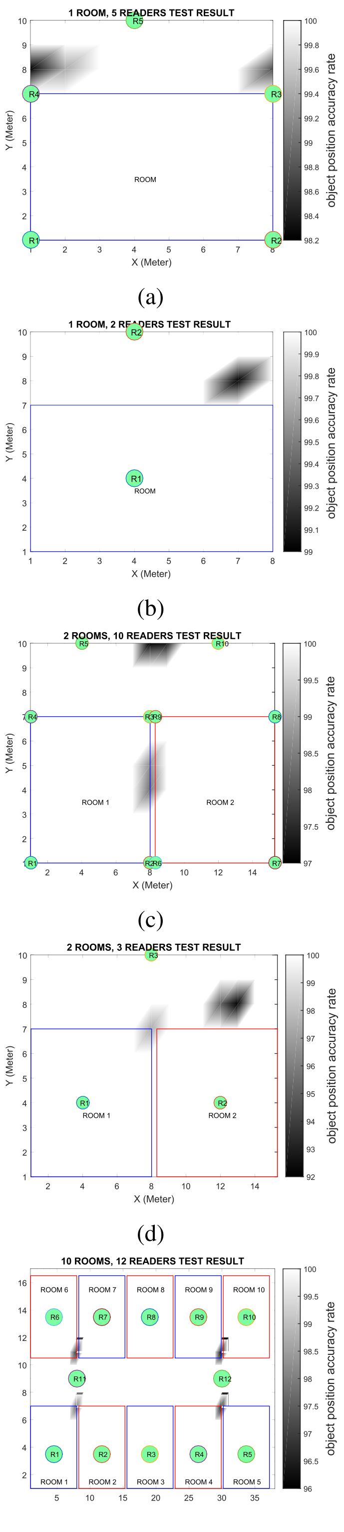


FIGURE 14. Localization performance of the SmartTag based localization technique for simulations (a) Sim A, (b) Sim B, (c) Sim C, (d) Sim D and (e) Sim E.

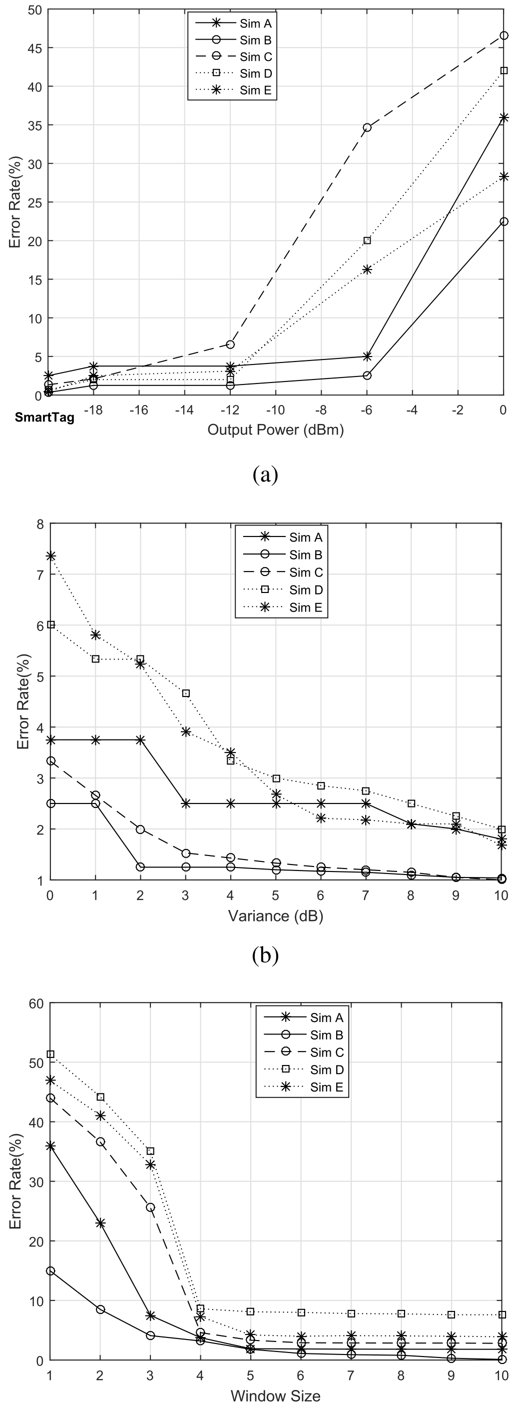
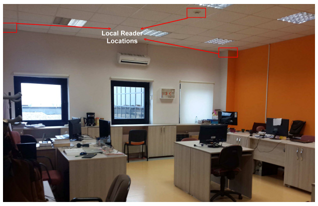


FIGURE 15. Localization error of smart transmit power scheme for simulation environments (a) different output powers, (b) different variances and (c) different window sizes.

one in each room and two in the corridor. Figure 14 presents the accuracy of the estimated location of the SmartTag for each subsection. This figure shows that two local readers are getting better localization performance for one room. As we seen Figure 14 localization error increases if the number of local readers decreases and when the number of rooms increases. The maximum and mean values for the localization errors for second case are tabulated in Table 1.

TABLE 1. Statistics of locations error.

	Simulation	Maximum (%)	Mean (%)
Localization Error	SimA	1.8	1.2
	SimB	1.0	0.8
	SimC	3.0	1.5
	SimD	8.0	6.8
	SimE	4.0	2.8



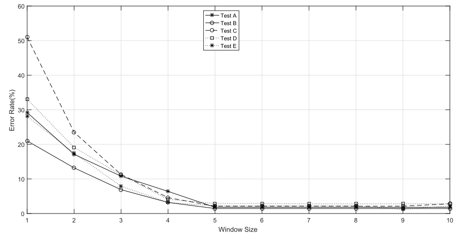
(a)

(b)

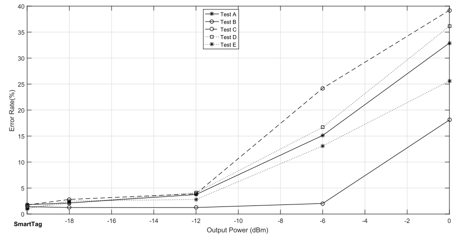
FIGURE 16. Experimental test environments used for (a) Sim A and Sim B, (b) Sim C, Sim D, and Sim E.

Figure 15a presents the comparison between constant signal output power and the SmartTag about the object position in the room or not. The error rates are observed by performing scenarios with constant signal strength levels. The object position error rate is too high compared to 0 dBm output power. It is noted that when the simulation is run with the smart transmit power scheme, the error rate is lowest. When the Log-normal shadowing variance is used between 0 and 10 dB, the error margin is observed as in Figure 15b. As a result, it is observed that increasing the variance level decreases the error rate. The noise on the signal increases, when the variance level increases. In the noisy environment, the SmarTag is starting to send messages with higher signal output power. This situation increases the accuracy of the position by communicating with more readers. In Figure 15c the simulation is run according to all values of window size 1 to 10 the number of beacon message packets. As a result, it is observed that the window size has the lowest error value between 5 and 10.

The proposed system is also tested in the experimental environment. Figure 16a, experimental environment is used for Sim A and Sim B. Figure 16b, experimental environment is used for Sim C, Sim D, and Sim E. The local readers used in the experimental environments are placed as the simulations environment. The developed system is run for 10 hours in the test environments. As a result, it is observed that the window size has the lowest error value between 5 and 10 as shown in Figure 17a. After this, the window size is set to 5. In the second test, we compared four different output power levels with smart transmit power scheme. As a result, it is understood that smart transmit power scheme algorithm performs position estimation with less error margin than other signal output powers as shown in Figure 17b. Accordingly; it has been observed that the error rate of the position detection with 0 dBm constant signal output power is the highest. The smart transmit power scheme has correctly detected the position with 98.2%.



(a)



(b)

FIGURE 17. Localization error of smart transmit power scheme for implemented system (a) different window sizes and (b) different output powers.

VI. CONCLUSION

In this paper, we newly developed an indoor positioning system based on the smart transmission power scheme run NRF24L radio modules as the SmartTag. This scheme ensures that the SmartTag communicates with local readers at the lowest signal output power level. The proposed system is implemented by using different NRF24L modules as the tag, the reader, and server components, and the performance of the system is experimentally evaluated in a real indoor environment. The SmartTag based localization system performance is also compared with the Monte Carlo simulations. The result of experiments indicates that the proposed indoor localization system has correctly detected the object position with accuracy 98.2%. As a result of all simulations tests, it is observed that the proposed system is depending on the conditions indoor environment, the 96% accuracy rate is achieved in Monte Carlo simulations. The server module estimates the location of the SmartTag with 0.1% to 2% margin of error in case where the SmartTag module communicates with the only one reader module. It estimates the location with 1% margin of error when the SmartTag module communicates with two local reader modules and with a 0.5% margin of error while the SmartTag module communicates with more than two local reader modules. In addition, the strength of the proposed system is that the accuracy of localization improves when the window size is chosen as five with the SmartTag.

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