Indoor Localization System Using Commensal Radar Principle

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Abstract— Indoor localization has a wide range of applicability in personal health applications. There is a need for specialized indoor localization methods [1] like Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA) and Received Signal Strength Indicator (RSSI) due to limited usability of global positioning system (GPS). The proposed work uses a novel commensal radar system (inspired by biological inter-species coexistence where one system exploits other without detrimental effect) which uses communication radiation as the illuminator, called CommSense [2]. It uses LTE communication infrastructure due to its wide availability in indoor environments. Therefore, we call this system LTE-CommSense [3]. We believe, utilization of orthogonal frequency division multiplexing (OFDM) and multiple input and multiple output (MIMO) may provide better resolution for this scenario. LTE signal provides high range resolution due to its wide bandwidth ranging from 1.4 to 20 MHz. Following this principle, the proposed system uses only passive receiver nodes that uses existing LTE communication signal. Communication receiver modules extracts information which is affected by the channel condition. It uses the same spectrum of the communication system without any detrimental influence on it. The communication signal strength between LTE (user equipment (UE)) and (eNodeB) gets affected by the span of the channel. Following the CommSense principle, we use three passive nodes (PN) for two dimensional (2D) indoor localization. These PNs determine respective distances of the (UE) by measuring incident signal power at the PNs with which it communicates with the (eNodeB). After the respective distances are calculated, we use these distances for trilateration to determine the co-ordinate of the UE. Depending on the PN placements, the trilateration algorithm is modified to have less calculation complexity. The calibration of the system to calculate the distance of the UE from a PN is performed. We setup a testbed to calculate the accuracy of our proposed method in a indoor laboratory environment. Without any loss of generality, we place the PNs at right angle to each other to reduce the computational complexity for trilateration. Use of LTE for RSSI based indoor localization and demonstration on SDR platform is a novel effort. First we evaluated the accuracy of distance calculation of individual PNs. The evaluated distance values using our proposed approach along with the actual distance values are compared with the ground truth measurements.

1. INTRODUCTION

Localization has the potential of leveraging various health-care applications. An indoor localization allows health-care personnel to localize persons or assets in the indoor environment. Many intelligent and efficient facilities may be build up using localization data. Automated nurse calling systems may find out the nearest nurse available from the current location of a patient in need. More efficient facilities can be created using this approach [4]. Finding assets in indoor environment can be a difficult task and this may require a long time. In many cases, finding an important asset quickly may save lives.

Localization at outdoor environments has been successfully implemented using global positioning system (GPS) technology. But, in indoor environments, there is a need for alternative specialized methods due to limited usability of GPS. Presently, indoor location-based systems use various techniques [1] like Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA) and Received Signal Strength Indicator (RSSI). To cater for various indoor positioning applications [1], an indoor positioning system should have the following desirable properties; the most important parameter is the accuracy of localization. As the infrastructure will be mainly battery operated mobile devices, they should have less energy consumption, less footprint and less computational complexity and minimal dedicated infrastructure.

The proposed work uses a novel commensal radar system (inspired by biological inter-species coexistence where one system exploits other without detrimental effect) which uses communication radiation as the illuminator, called CommSense [2]. It uses LTE communication infrastructure [5] due to its wide availability in indoor environments. Therefore, we call this system LTE-CommSense [3]. We believe, utilization of orthogonal frequency division multiplexing (OFDM) and multiple input and multiple output (MIMO) may provide better resolution for our scenario. Indoor localization based on Wi-Fi RSSI is a well-studied area [6]. Therefore Wi-Fi based CommSense (WIFisense) can also be proposed. But LTE signal provides better range resolution due to its wide bandwidth ranging from 1.4 to 20 MHz. Also, large frequency bands ranging from 800–3500 MHz and support of both FDD and TDD enhances the opportunity of LTE deployment in many countries.

Following this principle, the proposed system uses passive receiver nodes only that uses existing LTE communication signal. Communication receiver modules extracts information which is affected by the channel condition. It uses the same spectrum of the communication system without any harmful effect on it. The commensal principle based indoor localization is done in two phases:

1. The communication signal strength between LTE receiver (UE) base station (eNodeB) gets affected by the span of the channel. Following the CommSense principle, we use three passive nodes (PN) for two dimensional (2D) indoor localization. These PNs determine respective distances of an LTE communication receiver equipment (UE) by measuring incident signal power at the PNs with which the UE communicates with the LTE base station (eNodeB). After the respective distances are calculated, we use the distances for trilateration to determine the co-ordinate of the UE. Depending on the PN placements, the trilateration algorithm is modified to have less calculation complexity. The calibration of the system to calculate the distance of the UE from a PN is performed. We calculated the accuracy of our proposed method in a indoor laboratory environment. Use of LTE for RSSI based indoor localization and demonstration on SDR platform is a novel effort.
2. We plan to extend this work for 3D localization. To the best of our knowledge, application of LTE-CommSense for RSSI based 3D localization in practical situation using SDR platforms is never attempted before.

2. EXPERIMENTAL SETUP AND REQUIREMENTS FOR PROPOSED INDOOR LOCALIZATION

The experimental setup for *Phase*-1 work is shown in Figure 1. Without any loss of generality, we place the PNs at right angle to each other to reduce the computational complexity for trilateration as will be detailed later. For calculating distances ($d_i; i = 1(1)3$) of respective PNs (A, B, C) from the LTE UE we have adopted range based positioning algorithm with RSSI as the ranging metric. This computation depends on the channel model. An indoor channel model for indoor laboratory environment was selected [1, 7].

The log-normal shadowing model, shown in Equation (1) is used to relate the received power ($Pr_i; i = 1(1)3$) to corresponding distance [7].

$$Pr_i(d) = A - 10\alpha\left[\log\left(\frac{d}{d_0}\right)\right] - \psi \tag{1}$$

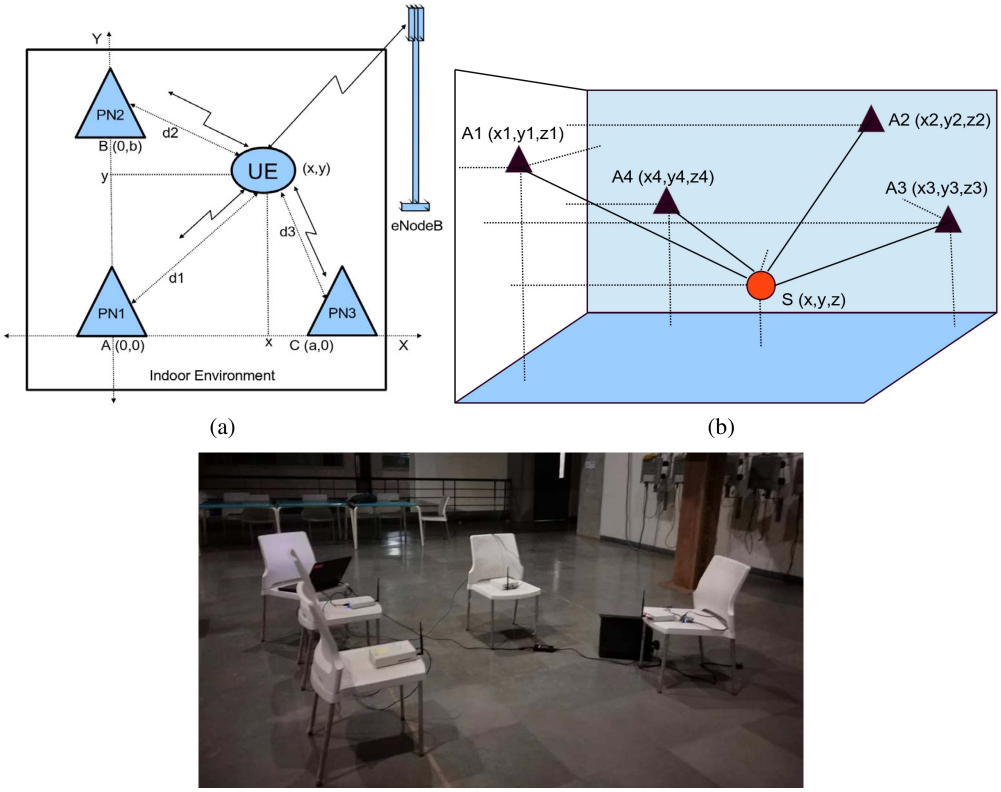
Here, α is called the path loss exponent and log-normal shadowing effect is reflected by ψ where $\psi \sim N(0, \sigma^2)$ follows a Normal distribution with 0 mean and σ as the standard deviation. The parameter A is related to the antenna gains of the transmitter and receiver antenna gains, transmission power and power loss at a reference distance d_0. At the reference distance d_0, the power loss is determined experimentally. The parameters evaluated from the practical setup and experiment are as follows. The path loss exponent α is evaluated to be 2.4, attenuation fading is 3.92 dB and at reference distance $d_0 = 1$ meter, power is -20 dB.

To evaluate the parameters of the channel model in an indoor environment, we have collected the RSSI values at multiple known distances. By using Python Script, we have calculated the constant values of the parameters (α, σ, A).

After we have evaluated the distances ($d_i; i = 1(1)3$) of respective PNs (A, B, C) from the LTE UE, we apply our proposed less computation intensive trilateration algorithm to find out the location of the UE. For the PN coordinates and their evaluated distances from the UE (Figure 1), the co-ordinate of the UE can be derived as:

$$(x, y) = \left(\frac{a^2 + d_1^2 - d_3^2}{2a}, \frac{b^2 + d_1^2 - d_2^2}{2b}\right) \tag{2}$$

We have used four SDR Platforms. Three of them are used as PN and the fourth is modeled as LTE UE [8]. Laptop is used to interface with the SDR platforms.



(c)

Figure 1: Experimental setup for indoor localization using LTE-CommSense: (a) Block diagram for 2D localization, (b) Block diagram for 3D Localization, (c) Setup snapshot in indoor environment.

For 3D localization, 4 SDR platforms should work as PNs and another is used to model LTE UE. Using Linear Algebra, the 3D trilateration quadratic equations are shown below:

$$(x-x_1)^2+(y-y_1)^2+(z-z_1)^2 = d_1^2 \tag{3}$$
$$(x-x_2)^2+(y-y_2)^2+(z-z_2)^2 = d_2^2 \tag{4}$$
$$(x-x_3)^2+(y-y_3)^2+(z-z_3)^2 = d_3^2 \tag{5}$$
$$(x-x_4)^2+(y-y_4)^2+(z-z_4)^2 = d_4^2 \tag{6}$$

Equations (3)–(6) may be simplified as below:

$$2(x_2-x_1)x+2(y_2-y_1)y+2(z_2-z_1)z = (d_1^2-d_2^2)-(x_1^2-x_2^2)-(y_1^2-y_2^2)-(z_1^2-z_2^2) \tag{7}$$
$$2(x_3-x_1)x+2(y_3-y_1)y+2(z_3-z_1)z = (d_1^2-d_3^2)-(x_1^2-x_3^2)-(y_1^2-y_3^2)-(z_1^2-z_3^2) \tag{8}$$
$$2(x_4-x_1)x+2(y_4-y_1)y+2(z_4-z_1)z = (d_1^2-d_4^2)-(x_1^2-x_4^2)-(y_1^2-y_4^2)-(z_1^2-z_4^2) \tag{9}$$

Using Cramer's Rule, we can solve for (x, y, z) co-ordinate of the target location as follows:

$$x = \frac{\begin{vmatrix} (d_1^2-d_2^2)-(x_1^2-x_2^2)-(y_1^2-y_2^2)-(z_1^2-z_2^2) & 2(y_2-y_1) & 2(z_2-z_1) \\ (d_1^2-d_3^2)-(x_1^2-x_3^2)-(y_1^2-y_3^2)-(z_1^2-z_3^2) & 2(y_3-y_1) & 2(z_3-z_1) \\ (d_1^2-d_4^2)-(x_1^2-x_4^2)-(y_1^2-y_4^2)-(z_1^2-z_4^2) & 2(y_4-y_1) & 2(z_4-z_1) \end{vmatrix}}{\begin{vmatrix} 2(x_2-x_1) & 2(y_2-y_1) & 2(z_2-z_1) \\ 2(x_3-x_1) & 2(y_3-y_1) & 2(z_3-z_1) \\ 2(x_4-x_1) & 2(y_4-y_1) & 2(z_4-z_1) \end{vmatrix}} \tag{10}$$

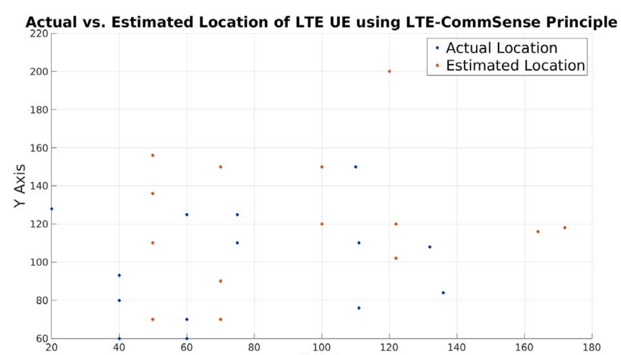
$$y = \frac{\begin{vmatrix} 2(x_2 - x_1) & (d_1^2 - d_2^2) - (x_1^2 - x_2^2) - (y_1^2 - y_2^2) - (z_1^2 - z_2^2) & 2(z_2 - z_1) \\ 2(x_3 - x_1) & (d_1^2 - d_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) - (z_1^2 - z_3^2) & 2(z_3 - z_1) \\ 2(x_4 - x_1) & (d_1^2 - d_4^2) - (x_1^2 - x_4^2) - (y_1^2 - y_4^2) - (z_1^2 - z_4^2) & 2(z_4 - z_1) \end{vmatrix}}{\begin{vmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) & 2(z_2 - z_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) & 2(z_3 - z_1) \\ 2(x_4 - x_1) & 2(y_4 - y_1) & 2(z_4 - z_1) \end{vmatrix}} \quad (11)$$

$$z = \frac{\begin{vmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) & (d_1^2 - d_2^2) - (x_1^2 - x_2^2) - (y_1^2 - y_2^2) - (z_1^2 - z_2^2) \\ 2(x_3 - x_1) & 2(y_3 - y_1) & (d_1^2 - d_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) - (z_1^2 - z_3^2) \\ 2(x_4 - x_1) & 2(y_4 - y_1) & (d_1^2 - d_4^2) - (x_1^2 - x_4^2) - (y_1^2 - y_4^2) - (z_1^2 - z_4^2) \end{vmatrix}}{\begin{vmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) & 2(z_2 - z_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) & 2(z_3 - z_1) \\ 2(x_4 - x_1) & 2(y_4 - y_1) & 2(z_4 - z_1) \end{vmatrix}} \quad (12)$$

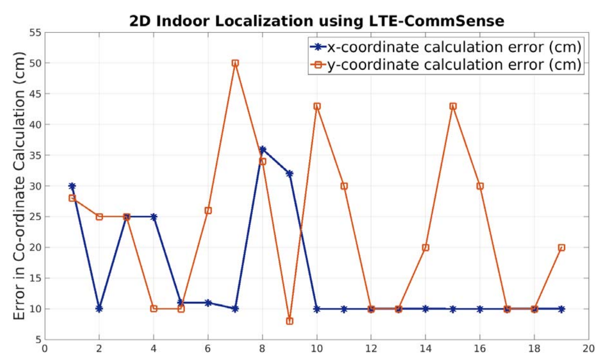
2D and 3D indoor localization methods have their own advantages and disadvantages. Adding an extra PN to the localization system will enhance the localization accuracy of the intended object in 2D. But, in case of 3D localization, the fourth PN is required to estimate the z-component of the 3D coordinate. 3D localization is less accurate and have more computation complexity than 2D localization as is evident from the derived formula of 2D and 3D localization in the preceding equations. Complex systems will consume more computational time. This is another advantage of 2D localization over 3D localization. The PNs and the LTE UE are modeled using USRP SDR platforms. The SDR board setup and GNURadio parameters are summarixed in Table 1.

Table 1: SDR board and GNURadio parameter setup for LTE-CommSense based indoor localization experiment.

SL	Parameter	Value
1	USRP Model	URSP B210
2	Bandwidth	1.4 MHz
3	Operating Frequency	2.3 GHz
4	Sampling Rate	1.92 MSPS
5	FFT Points	128
6	Modulation Scheme	QPSK



(a)



(b)

Figure 2: (a) 2D localization performance of CommSense based system, (b) Error of co-ordinate measurement for 2D indoor localization.

3. EXPERIMENTAL RESULTS

First we evaluate the accuracy of distance calculation of individual PNs. The evaluated distance values and evaluated UE coordinates using our proposed approach along with the actual distance values, actual UE coordinates by using the RSSI values at respective PN positions (A, B and C) are shown in Table 2. For the complete localization system, the localization performance of nineteen different indoor location coordinates are shown in Figure 2(a). For the indoor localization experiment, the localization performance of evaluated indoor location coordinates are shown in Figure 2(b) in terms of error between the actual and evaluated 'x' and 'y' coordinates.

Table 2: Experimental data and results for 2D indoor localization.

UE coordinate (x, y) cm	Power at PN A (dB)	Power at PN B (dB)	Power at PN C (dB)	Distances from Point A, B, C $(d1, d2, d3)$ cm	Evaluated UE coordinate (x, y) cm
(20, 128)	−11.06	−23.37	−25.125	(0.39, 1.42, 1.7)	(49.9, 156)
(60, 125)	−16.4	−21.88	−22.63	(0.686, 1.217, 1.31)	(70.0, 150)
(75, 125)	−17.24	−24.19	−24.6	(0.74, 1.5, 1.54)	(100, 150)
(75, 110)	−17.1	−24.02	−22.49	(0.72, 1.49, 1.28)	(100, 120)
(111, 110)	−20.28	−22.74	−20.75	(1.02, 1.29, 1.031)	(122, 120)
(111, 76)	−22.15	−22.53	−17.53	(1.25, 1.27, 0.75)	(121, 102)
(110, 150)	−20.94	−24.62	−26.04	(1.1, 1.54, 1.8)	(120, 200)
(136, 84)	−25.37	−22.74	−18.18	(1.75, 1.29, 0.81)	(171, 117)
(132, 108)	−20.78	−21.6	−19.99	(1.1, 1.21, 0.98)	(163, 116)
(40, 93)	−13.58	−20.05	−22.75	(0.49, 1.1, 1.3)	(49.9, 136)
(40, 80)	−13.81	−20.12	−23.83	(0.51, 1.04, 1.45)	(49.9, 110)
(40, 60)	−14.43	−16.03	−20.19	(0.55, 0.63, 1.06)	(49.9, 70.0)
(60, 60)	−19.45	−18.16	−23.39	(0.94, 0.83, 1.44)	(70.0, 69.9)
(60, 70)	−19.7	−19.15	−24.75	(0.98, 0.91, 1.51)	(70.0, 89.9)
(40, 93)	−14.4	−21.18	−23.47	(0.55, 1.2, 1.42)	(49.9, 136)
(40, 80)	−14.16	−21.43	−25.1	(0.538, 1.21, 1.7)	(49.9, 110)
(40, 60)	−15.76	−17.81	−22.95	(0.64, 0.78, 1.3)	(49.9, 70.0)
(60, 60)	−16.65	−18.84	−20.39	(0.704, 0.89, 1.08)	(70.0, 70.0)
(60, 70)	−18.7	−18.16	−20.05	(0.88, 0.83, 1.01)	(70.0, 89.9)

4. CONCLUSION

In this work we have proposed commensal radar principle based approach for indoor localization in health care application. 2D localization system comprising of passive nodes along with the LTE UE is modeled using SDR platforms and the performance evaluated. By incorporating more nodes at defined locations and by enhancing the trilateration algorithm, the proposed 2D localization method can be extended for 3D localization.

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