BLE Localization using RSSI Measurements and iRingLA

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***Abstract*—Over the last few years, indoor localization has been a very dynamic research area that has drawn great attention. Many methods have been proposed for indoor positioning as well as navigation services. A big number of them were based on Radio frequency (RF) technology and Radio Signal Strength Indicator (RSSI) for their simplicity of use. The main issues of the studies conducted in this field are related to the improvement of localization factors like accuracy, computational complexity, easiness of deployment and cost. In our study, we used Bluetooth Low Energy (BLE) technology for indoor localization in the context of a smart home where an elderly person can be located using an hybrid system that combines radio, light and sound information. In this paper, we propose a model that averages the received signal strength indication (RSSI) at any distance domain which offered accuracy down to 0.4 meters, depending on the deployment configuration**

Keywords— Smarthome; Localization; BLE; RSSI

I. INTRODUCTION

Medical applications over the world aim to improve the existing healthcare and monitoring services especially for the elderly persons who became increasingly numerous, mainly in Europe. In fact, in its last regional yearbook publication [1] EUROSTAT estimated that population aged over 65 years will rise from 18,2 % in 2013 to reach 28,1% by 2050 which is creating a trend appealing industrials and academics at the same time to ensure for these people appropriate assistance and healthcare services. One of the researcher's issues is to be able to locate an old person in his home perimeter at any moment.

The explosive popularity of positioning services offered by new smart phones nowadays and recent advances in sensor technology and communication networks marked a great turning in the field of indoor localization which made it possible to design smart habitations that can properly monitor these old people while maintaining their independence and their usual lifestyle as most of them prefer to stay in their own homes as long as possible. Such a concern is solved by low cost and easily deployed technologies. Indeed, the advent of Bluetooth Low Energy (BLE) technology gave opportunities for immense improvement in indoor positioning. Moreover, the availability of a Received Signal Strength Indicator (RSSI) in most of commercial off-the-shelf radio transceivers has promoted the design of several RSSI-based ranging techniques that can be largely used without any extra hardware.

This work is a part of our whole project aiming to design a hybrid localization system that combines acoustic, radio and light information in order to track the position of an elderly person in a smart home at any moment. We had already introduced the first part of this whole project which deals with indoor localization of a sound using an array of four microphones [2] [3].

In this paper, we introduce the second part of our localization system. This sub-system estimates, in a first step, the distance d between a receiver and a transmitter using only RSSI values measured by the receiver device. This step is called the "ranging phase". As a second step, we seek to derive the actual position of the receiver device using inter Ring Localization Algorithm (iRingLA) [4] [5] [6].

In our study, we worked with BLE technology for both transmitter and receiver. As receiver, we used an Iphone 5 (IOS8) and as transmitters, we used three iBeacons (developed by EALOGIC [7]- Fig.1).

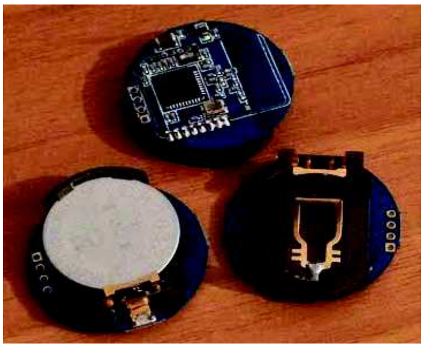

Fig. 1. Three EALOGIC ibeacons

II. BACKGROUND AND CHALLENGES

In the last decade, several indoor positioning systems have been designed. The RADAR system was one of the first developed indoor positioning systems that use radio beacons and Received Signal Strength Indicator (RSSI) measurements for localization.

Since then, many research works have been reported in the literature dealing with indoor positioning methods [8] [9] [10] more particularly those incorporating radio signal strength indicator (RSSI) measurements [11] [12] [13].

Most of these positioning techniques relying on RSSI measurements use a radio propagation model that links these values to the position of the sensor to be located. This approach needs detailed description of the propagation environment which is difficult to predict. In fact, indoor signal propagation is easily influenced by any kind of obstacles which makes it difficult to use a general propagation formula.

In this paper, we present our method which adds a first phase where the system estimates the propagation model that best fit the propagation environment we are working in, using only real time RSSI measurements. The second phase consists on computing the spatial position of the receiver device using iRingLA [4] [5] [6] which is an algorithm developed in IRIT laboratory that offers better performance while minimising the errors caused by RSSI instability. This algorithm has the advantage of being light and thus can be run on mobile devices requiring very little CPU resources and memory. Moreover, consumption is reduced, which is a major advantage to increase the life of mobile devices.

III. Bluetooth Low Energy and ibeacon technology

Around 20 billion Bluetooth enabled devices are expected to be sold by 2017 [14]. This huge number is due to the real-time characteristics and low power consumption in active mode that Bluetooth guarantees. This number had dramatically expanded in the last four years, especially after the introduction of a newly developed energy-efficient short-range wireless communication protocol [15] commonly known as BLE (Bluetooth Low Energy). BLE was introduced as a part of the Bluetooth Core specification version 4.0 [16] in June 2010, aiming to realize all the applications requiring low current consumption and low implementation complexity.

Since its creation, many studies are carried out and many systems were proposed dealing with BLE [17] [18] [19]. Many Bluetooth Low Energy-powered devices had emerged in the last few years, Beacons (referred as iBeacons by Apple [20]), for instance, are one illustration of these devices. In its report “BLE Tags and the Location of Things” released in July 2014, ABI Research focused on the big opportunities that BLE Beacons could offer in enterprises as well as the enormous potential they could have in smart homes and personal tracking.

Using BLE technology, mobile devices periodically listen for signals from ibeacons. These signals consist mainly of small packets of data emitted regularly by beacons or other BLE enabled devices via radio waves, and are called “Advertisements”.

IV. Indoor Radio Propagation Model

Several localization protocols in Wireless Sensor Networks use Received Signal Strength as an indicator (RSSI) of a radio device position.

Unlike other positioning methods based on infra-red or ultrasonic waves, RSSI measurement do not need any extra hardware. Moreover, radio signals are electromagnetic waves that propagate through a transmission media. A significant feather of radio transmission is that the signal strength decreases as the distance increases. Several research works about signals in different transmission environment [21] [22] [23] were carried out over the years. Almost all these studies concluded that there is no accurate indoor radio propagation model. Indeed, indoor propagation varies dramatically with the type of indoor environment, and the position of the transmitters within this environment; how far from walls, how high compared to the ground and to furniture... Some empirical formulas were concluded. Log-Distance Path Loss [21] is one of these model's formulas:

$$RSSI(d) = RSSI(d_0) - 10 \times n \times log\left(\frac{d}{d_0}\right) \qquad (1)$$

Where $RSSI(d)$ is the received signal strength at distance d (between receiver and emitter). $RSSI(d_0)$ is the received signal strength at distance d_0 (usually $d_0 = 1\ meter$) and n is the path loss index which depends on the propagation environment.

Using $d_0 = 1\ meter$, and solving equation (1) for d, the formula is simplified to:

$$d = 10^{\frac{RSSI(d_0)-RSSI(d)}{10\times n}} \qquad (2)$$

As n is a parameter that depends on the transmission medium, the emitter and the receiver, the value of d would depend on these factors too. The method, that we propose, is based on estimating the path loss index using only RSSI empirical values. In fact for known distances and using Eq. (1), the path loss index can be estimated as follows:

$$n = \frac{RSSI(d_0)-RSSI(d)}{10\times log\left(\frac{d}{d_0}\right)} \qquad (3)$$

V. Trilateration vs iRingLA

Trilateration is a classical method for determining location of points by measuring distances from three reference points (beacons), using the geometry of circles (2D).

Hence, as we already know the positions of the three beacons, as well as the average distances from each of them to the receiver device (from phase 1), we can generate circles around these beacons. Intuitively, the spatial position of the receiver device can be found by resolving the three circles intersection system.

With very exact distance measurements, this method will return an exact and unique position of the receiver which is the intersection of the three circles (Fig.2.a). However, due to all reasons we had already detailed in section IV, it would be difficult, even impossible to obtain perfect information on exact distances from the receiver to the three beacons. Therefore, the three circles will not intersect at only one point (Fig.2.b). They may even not intersect at all (Fig.2.c).

iRingLA (inter Ring Localization Algorithm) [4] [5] [6] is an alternative solution to trilateration problems. In fact, this algorithm draws rings around the three beacons rather than circles (Fig.3). The inner and outer radiuses of these rings are computed upon RSSI measurements already carried out during the first phase:

$$\begin{cases} R_{in} = d_{ave} - E \\ R_{out} = d_{ave} + E \end{cases} \quad (4)$$

Where R_{in} and R_{out} are respectively the inner and the outer radiuses around one beacon, d_{ave} is the average distance from this beacon to the receiver and E is the error on d_{ave}. In our case, E is computed using RSSI experimental values.

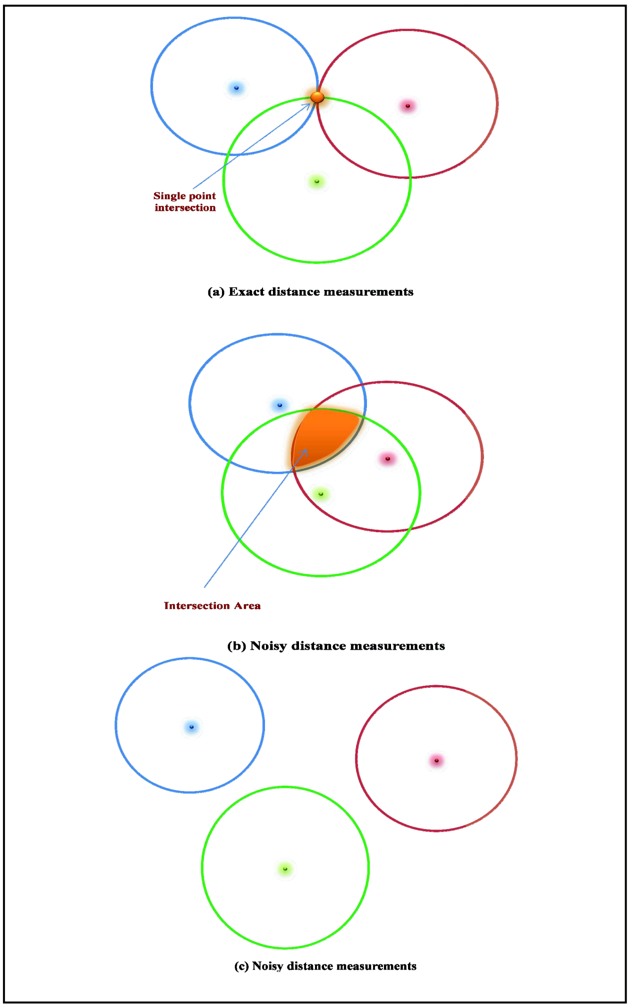

Fig. 2. Position estimation using Trilateration

The next step would be to generate a matrix containing all the intersection points of these three rings with the most likely to contain the actual position of the receiver. A matrix is then constructed, and the elements belonging to the intersection of the candidates are found. Finally, from the positions of candidates selected, an estimation of the position is performed.

VI. System Design and Implementation

As we already enounced, our goal is to estimate the actual position of a mobile like a smartphone using its received Bluetooth RSSI values and *iRingLA* algorithm. The proposed method is performed on two phases. In the first phase, called Ranging phase, the distance between each ibeacon and BLE receiver is estimated using RSSI measurements. In the second phase, the position of the receiver is estimated using iRing LA algorithm.

A. Phase 1: Ranging Phase

As we are acting in a closed-in environment, we need to model it in order to link distance (between Smartphone and ibeacons) to RSSI measurements. Equation (2) is used in our case to estimate distance. Nevertheless, we need to know the path loss index n which is difficult to predict. In fact, this index varies dramatically with any change in any environment [24] factor including building structure, room's layout and used type of construction materials. Moreover, factors like temperature and humidity can affect the propagation of the signal and hence the Path Loss Model.

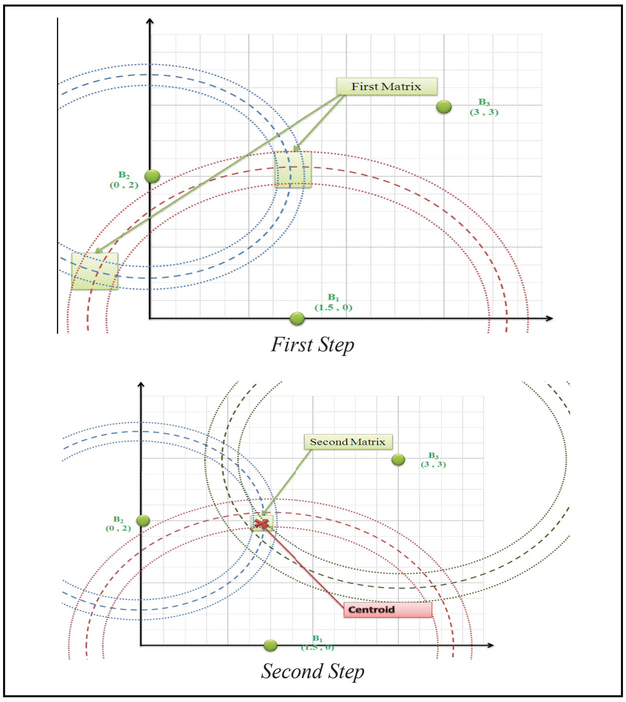

Fig. 3. Position estimation using iRingLA [*4*] [*5*] [*6*]

On the other hand, the RSSI value measured at a given time and space depends on many other factors other than the relative distance of the two devices. Indeed, as discussed in many studies, RSSI cannot be a reliable parameter to compute an accurate distance [25] [26] [27]. Indeed, in a precisely given instant and place, RSSI values obtained by a radio device in closed-in area depend of several unpredictable factors. Any little change in position could provoke dynamic variations in RSSI values. Even when the radio device is static (Fig.4), RSSI values can change due to the presence of moving objects that may interfere in the device-to-device radio propagation which makes RSSI a vulnerable parameter to strong multipath effects, especially indoors [28].

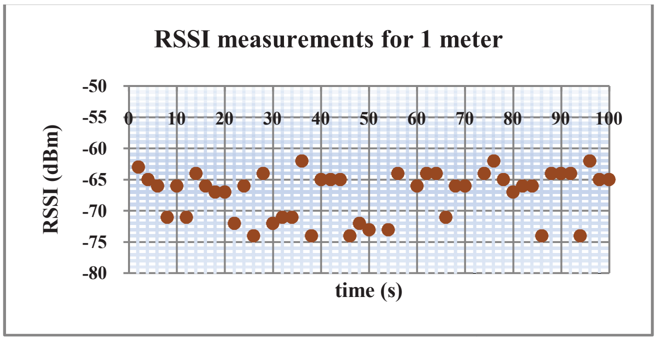

Fig. 4. RSSI measurements for a reference distance of 1 meter

For all these reasons, in order to improve the accuracy of distance estimation and to cope with the instability of the RSSI, we proceeded by taking a set of RSSI measurements instead of one instantaneous value. Using Eq. (1), $\mathrm{RSSI}(\mathrm{d}_0 = 1\mathrm{m})$ can be computed by averaging the ten maximum values of RSSI measurements for a distance of 1 meter. Path loss index can also be predicted using Eq.(3) by averaging its computed values for different average distances.

To do so, we proceeded as follows:

- Deployment stage: as a first step, we had to choose the best positions for fixing the three ibeacon transmitters considering especially two concerns: presence of obstacles and best positions for localization method. Experiments were performed in an empty room (4m by 4m). Beacons were placed as follows (Fig.5):

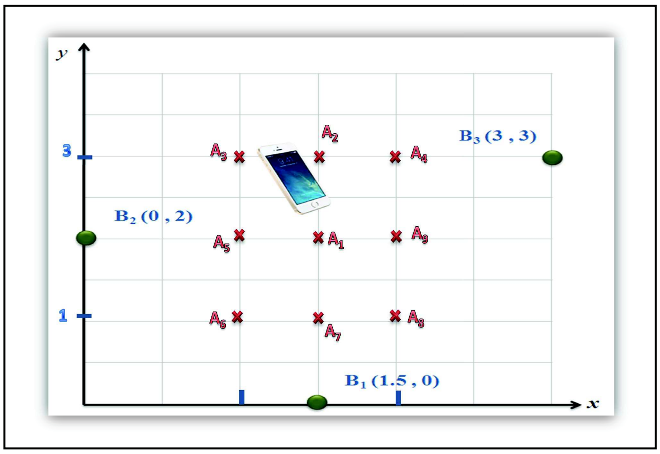

Fig. 5. Experimental deployment

- Calibration stage: As we had already installed the three emitting devices, we had to calibrate each one separately. Using an iPhone 5S running iOS 8, we measured the signal strength at a distance of 1 meter for 50 times at various distances (0.25m, 0.5m, 1m, 1.5m, 2m, 2.5m, 3m, 3.5m).
- We then picked the ten maximum values of these measurements. The average of these values is presumed to give an estimation of the real signal strength at 1 meter ($RSSI(d_0 = 1m)$). In our test bed, $RSSI(1m) = -63.8\ dBm$.
- Adjustment phase: Once we knew approximately $\mathrm{RSSI}(\mathrm{d}_0 = 1\mathrm{m})$, we calculate loss path index for different values of $RSSI$ at various distances. In our case, we obtained the following results:

TABLE I. PATH LOSS INDEX COMPUTING

Distance (m)	*RSSI Average (10 maximum values)*	*Path loss index (n)*
0.25	-44.9	1.601
0.5	-57.9	
1	-63.8	
1.5	-65.4	
2	-66	
2.5	-66.9	
3	-72.9	
3.5	-73.5	

- Ranging stage: Using Eq.(2), we obtain an equation (Eq.(5)) linking distance to RSSI measurement. We are able therefore to perform our estimation:

$$d = 10^{\frac{-63.8 - RSSI(d)}{10\times 1.601}} \tag{5}$$

B. Phase 2: Position estimation

In this second phase, our aim is to estimate the position of the BLE receiver device using *iRingLA* algorithm. Using the same steps as was stated in [4] [5] [6], position estimation can be done as follows:

- The user (Smartphone) measures the distance (denoted by d_{ave}) between him and each one of the ibeacons using RSSI instantaneous values and applying Eq.(5).
- We then apply Eq.(4). Error E was already computed using RSSI experimental readings in the first phase. Indeed, as we can see in Table.2, $E = 0.41m$. Therefore, Eq.(4) becomes:

$$\begin{cases} R_{in} = d_{ave} - 0.41 \\ R_{out} = d_{ave} + 0.41 \end{cases} \tag{6}$$

TABLE II. AVERAGE ERROR

Actual distance (m)	*Theorical distance using Eq.(2)*	*Error |act.dist - theo.dist|*
0,25	0,1	0,18
0,5	0,5	0,07
1	1,0	0,00
1,5	1,3	0,24
2	1,4	0,63
2,5	1,6	0,94
3	3,7	0,70
3,5	4,1	0,53
Average Error E (m)		**0,41**

- Eq.(6) will be used to draw a ring around each ibeacon (Fig.3). R_{in} and R_{out} are respectively the inner and the outer radiuses of this ring, d_{ave} is the distance from this ibeacon to receiver. This action is done simultaneously for the three ibeacons.

- In the next step, the receiver creates an initial search area using the intersection of the two closest rings (Fig.3). These two first rings are the smaller ones, those having the smaller d_{ave}.
- A matrix (rectangle) of dots (possible positions) is than created. Each point is tested against the initial two rings in order to reduce the number of test points for the third ring. Only the points having survived the first test will be taken into account for the next comparison when introducing the third ring.
- Finally, a small group of points will remain. At this stage, we compute their centroid. This point is considered as the position of the receiver.
- Considering the deployment as shown in Fig.5, we followed these steps and obtained the following results (see Table.III):

TABLE III. PATH LOSS INDEX COMPUTING

	Actual position		**Distance (estimated)**			**Estimated position**		**Error**	
	x	*y*	*d1_ave*	*d2_ave*	*d3_ave*	*x*	*y*	*x*	*y*
A1	1.5	2	2.11	1.37	2.11	1.3	2.5	-0.2	0.5
A2	1.5	3	3.76	2.11	0.77	1.7	3.3	0.2	0.3
A3	1	3	3.76	1.19	1.37	1.4	3.4	0.4	0.4
A4	2	3	4.34	5.01	0.28	-	-	-	-
A5	1	2	2.11	1.19	2.82	1.3	2.3	0.3	0.3
A6	1	1	1.37	1.37	2.11	1.4	1.75	0.4	0.75
A7	1.5	1	0.67	2.44	2.82	2.3	1.8	0.8	0.8
A8	2	1	1.19	3.76	5.01	-	-	-	-
A9	2	2	2.44	2.82	1.58	2.2	2.6	0.2	0.6

As we can see, the method we have stated gives an accuracy of 0.4m (the average of all the errors in Table III) which is satisfactory.

VII. CONCLUSION AND FUTURE WORK

We have introduced in this paper, a method for positioning a BLE receiver using three BLE beacons. Our method operates in two stages: averaging RSSI measurements for distance estimation and then using *iRingLA* for position computing.

Possible improvements are intended to be tested in the future, particularly in some choices we had made for the second stage of our method:

- When establishing Eq.(6), we used one error value for all ranges which is not always accurate. In fact, accuracy increases while distance (between ibeacon and BLE receiver) decreases. Therefore, we should find out the relationship between accuracy and distance. Thus, error E used in Eq.(6) will depend on $\mathrm{d_{ave}}$.
- We computed the centroid of the intersection points of the three rings in order to determine the position of the receiver. We considered that all the points have the same weight. In our future work, we intend to add weights to these points according to their proximity to the centers of the rings.

Besides, we intend to work jointly on audio and light localization methods to propose an hybrid localization system exploiting radio (BLE), light (LiFi) and audio relevant information, in order to take advantage of these systems depending on the position of the person to locate. One of our big concerns is to find the "accuracy indicator" (Dilution of Precision: DOP), for each one of these methods, beyond which we can move from one technique to another. Different DOP will be established according to the variation of the accuracy of each technique.

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