Geolocalization in Smart Environment

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Abstract: Nowadays, wireless indoor positioning systems have become very familiar, and widespread all over the world. They are successfully used in many applications including tracking objects e.g. Firemen who usually face life-threatening situations. Indoor positioning systems become critically convenient in such scenarios. This paper deals with the tracking of a group of firemen during their mission in order to have a real-time visibility of their coordinates. These firemen are armed by smart sensors and are, at the same time, active in a smart environment containing referenced nodes. This paper will propose two approaches: 'Centralized Emission', and 'Broadcast Emission' and will describe the proposed method to calculate the firemen's coordinates.

1 INTRODUCTION

Sensors have recently played an important role in monitoring objects in a specific environment. These sensors are small in size, have low power consumption, and can be easily integrated into a network to create a Sensor Network. Wireless Sensor Network (WSN), a set of distributed devices / sensors used to monitor the environment, also uses a gateway providing wireless connection. By enhancing technologies, sensors will have the ability to cooperate and exchange information between each other, so that WSN becomes Collaborative Wireless Sensor Network (CWSN). Wearable Sensor Network is a special case of CWSN, where the sensors are mounted on/worn by individuals.

Nodes cooperate to solve the problem of tracking objects and people. Many techniques and methods are used to compute the position of an object in its environment. This process is called "localization".

This paper concentrates on localization in WSN and CWSN. The localization of sensors in a WSN/CWSN faces many problems such as the complexity/topology of the network itself, the signal propagation, the reflection problems, the obstacles, etc.

The localization problem has been studied thoroughly in literature and many algorithms were proposed to resolve the complexity of the localization problem.

Our study on WSN in the localization field, can be used in different scenarios to track the localization of people or devices (firemen, policemen, soldiers, vehicles, etc.) during their works. Saving lost person or device requires locating him first and this is the aim of this work. Our study will treat the case of localizing firemen moving in an indoor environments, with emergent obstacles i.e. The obstacles' positions are predefined. Many problems faces our study to calculate the coordinates of each node/device in such a mobile, distributed, dynamic, and complex network. Because our study deals with indoor localization environment, some existing techniques like Global Positioning System (GPS) are not suitable, and that is why some other techniques will be used as described in this paper.

Our approach proposes 'Centralized Emission' and 'Broadcast Emission' used to calculate the coordinates of the mobile nodes according to a beacon (fixed node). In the 'Centralized Emission', each node sends a request to its corresponding beacon which computes the coordinates of the emitter node and sends the computed coordinates to a controller beacon. On the other hand, in the 'Broadcast Emission', each node sends its request to the beacon and all its neighbors existing in its range. Once the request is received, the beacon computes the coordinates of each node and sends it to the controller beacon.

The remaining of this paper is organized as fol-

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lows: Section II presents the computing techniques and methods used to localize a target. Section III illustrates the state-of-the-art proposals and describes the existing systems for Indoor Positioning Systems (IPS), their advantages, and disadvantages. Section IV discusses our approach to estimate the localization in a Wearable Sensor Network. Finally, Section V summarizes the paper.

2 LOCALIZATION METHODS AND TECHNIQUES

In this section, we describe various measurement methods and localization techniques used by existing CWSN indoor localization algorithms (Zhang, 2010).

2.1 Measurement Methods

2.1.1 Time-Of-Arrival (TOA)

The distance between the transmitting node and the receiving one is deduced from the transmission time delay and the corresponding speed of signals. The distance can be calculated as follows

$$R = Time * Speed$$

Where R is the distance between the sender and the receiver, Speed is the signal's traveling speed and Time is the amount of time spent by the signal traveling from the sender to the receiver. A combination of TOA and Ultra Wide Band (UWB) has been used to guarantee a higher precision (Falsi, 2006), because TOA technique has a restrict requirement of synchronization, this inefficiency can be resolved by UWB that uses short pulse duration to filter out the signals caused by reflections (Cheong, 2005).

2.1.2 Time-Difference-Of-Arrival (TDOA)

This method uses two kinds of radio transmitting signals. The time difference between these two kinds of signals is used to reconstruct the transmitting node's position. The equation is:

$$\frac{R}{C_1} - \frac{R}{C_2} = t_1 - t_2$$

Where C1 is the speed of one kind of radio signals, C2 the speed of another kind of radio signals, t1 and t2 are the time for these two signals to travel from one node to another, R is the distance between sender and receiver. The author of (Takabayashi, 2008) uses the Time Difference of Arrival (TDOA) method with Extended Kalman Filter (EKF), and this approach is suitable in environments where the number of beacons is not sufficient.

2.1.3 Round Trip Time (RTT)

This method solves the problem of synchronization incurred by the use of TOA method (Mailaender, 2007). The equation is:

$$R = \frac{(t_{RT} - \Delta t) * speed}{2}$$

t_{RT} is the time needed for a signal to travel from one node to another and back again, Δt is the time delay required by the hardware to operate at the receiving node, while speed is the speed of the transmitting signal.

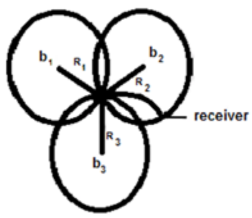
2.1.4 Angle-Of-Arrival (AOA)

The authors of (Linde, 2006) (Niculescu, 2003) determine the direction of propagation of a radio-frequency by measuring the TDOA at individual elements of the array antennas. Consequently, the AOA can be calculated. Therefore, no time synchronization between nodes is required.

2.2 Localization Techniques

2.2.1 Trilateration

It uses three fixed non-collinear reference node to calculate the position of a target node (in 2D) as shown in Fig 1. Authors of (Han, 2007) confirmed that trilateration can best demonstrate its advantages when the three reference nodes are deployed as equilateral triangle.



$$\begin{cases}(x_1 - x)^2 + (y_1 - y)^2 = R_1^2 \\ (x_2 - x)^2 + (y_2 - y)^2 = R_2^2 \\ (x_3 - x)^2 + (y_3 - y)^2 = R_3^2\end{cases}$$

Figure 1: Trilateration–based Positioning.

2.2.2 Triangulation

The position of a target node can be obtained by the intersection of several pairs of angles direction lines. Compared to trilateration only two reference nodes can track the target as shown in Fig 2. The comparison between the different measurement methods will be clearly shown in Table 1.

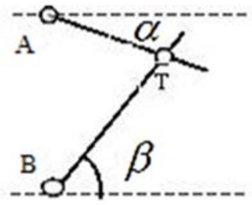


Figure 2: Triangulation-based positioning.

Table 1: Comparison Between Different Methods.

Methods	Accuracy	Cost	Energy Efficiency	Size of HW
TOA	Medium	High	Low	Large
TDOA	High	Low	High	Large
AOA	Low	High	Medium	Large
RTT	High	High	High	Large

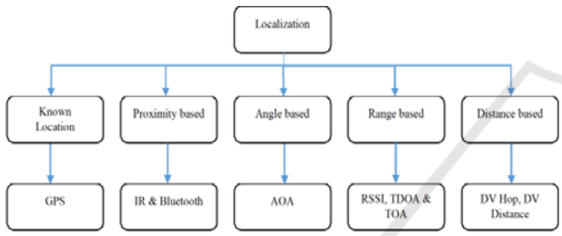


Figure 3: Localization-based Techniques.

3 RELATED WORK

Several studies tackled the problem of localization to estimate the coordinates of each node/device in a complex network. In this section, we will cover with more details the recent and existing algorithms for Indoor Positioning System (IPS) and show their advantages and disadvantages as well.

The Active badge (Want, 1992) (Harter, 1994) is used to locate individuals in a building. It estimates their location based on their badges that transmit a unique infra-red signal every 15 seconds, and each room in the building is equipped with a network of sensors which detects these transmissions. The location can be determined according to the information delivered by these sensors. The advantage of this algorithm is the privacy of the address, whereas its disadvantages are the low accuracy, long transmission period, and the influences from fluorescent light and sunlight.

Based on the IR technique, the Firefly system (Firefly Motion Capture System, 2008) (Firefly Motion Tracking System User's guide, 1999) comes with a controller tag, and other several tags in addition to one array of cameras, is used to track a person's or vehicle's motion. The tag controller which is carried by the tracked person, is small in size, light in weight, and battery equipped. Tags are IR emitters and mounted on different tracked parts of the person. The array camera receives the IR signals sent by tags fixed on different parts of the person and estimates his 3D position. The advantage of this algorithm is the small measurement delay of 3ms whereas its disadvantages are that it uses a wire to connect tags and the coverage area is limited to 7m.

The Optotrak algorithm (Optotrak, 2008) (States, 2006) uses three cameras as a linear array to track 3D position of various markers on an object. The markers mounted on different parts of a target, and emit IR light that is detected by the cameras to estimate their position. The system uses the triangulation technique to estimate the position. The advantage of this algorithm is the high accuracy which is able to manage relative motion on the different parts of an object but it is limited to line-of-sight requirement.

The IRIS-LPS approach (Aitenbichler, 2003) is an optical IR local positioning system. Stereo-Cameras receive IR signals from a tag mounted by a target object to measure the AOA, and calculate the position of the tag using triangulation technique. The main advantage of this approach is the coverage area it has, which is larger than that of Firefly and Optotrak, in addition to this, it is cheap and easy to be installed and maintained. Moreover, the IRIS-LPS is a multi-tag track approach but it is subject to interference from florescent light and sunlight.

The Active Bat system (Active Bat, 2008) (Ward, 1997) uses Ultrasonic technology and triangulation technique to measure the location of the tag carried by a person. Tags broadcast periodically a short pulse of Ultrasound that is received by a matrix of ceiling mounted receivers at known positions. The distance between a tag and three receivers is needed to calculate the 3D position of the tag based on the multilateration principle. The main advantage is that it covers a large area and provides 3-D positioning, but it is subject to the reflection of obstacles and it uses a large number of receivers on the ceiling.

The Cricket algorithm (Priyantha, 2000) (Das, 2005) uses TOA measuring method and triangulation technique to locate a target. It uses an ultrasound emitter as infrastructure, and a receiver carried on each target. The target owns its location information and decides how to publish it. The emitters also transmit RF messages in order to synchronize the TOA measurement. Its advantages are the address privacy, the low cost, and the decentralized administration, but it has high energy consumption.

The Sonitor algorithm (Sonitor, 2008) can locate people and devices in real time. In the ultrasound IPS, tags attached to people are tracked by a wireless detector fixed in various places in an indoor area. The tracked tag transmits ultrasound signals with a unique identifier; once received by a detector in the same place, the detector forwards the information through the existing LAN or WLAN to a central positioning calculation element. Its advantage is energy efficiency though it has a low accuracy level.

The WhereNet algorithm (WhereNet, 2008) is a Real Time Location Systems (RTLS). It has tags, location antennas, location processors, servers, and Ports. Tags are attached to their objects like persons/devices. Location antennas mounted on the ceiling at fixed positions receive the signals emitted from tags and forward the data to the location processor that perform location calculation and can track many tags at the same time. Finally, the location processor transmits the tags' positions to the server where ports send low frequency electromagnetic signals to the tags to indicate their behaviors. The advantage of this process is the uniquely identified equipment and person. But it needs several infrastructure components.

The RADAR algorithm (Bahl, 2000) uses the existing WLAN, signal strength and signal-to-noise ratio with the triangulation technique. It can provide 2-D absolute position information. The advantage, is the reuse of the existing WLAN infrastructure but it has a low accuracy level, and no privacy consideration. The located node needs to be equipped with WLAN technique which is difficult to be applied because the locate node is light in weight, and has a limited time energy.

The EKAHAU algorithm (Ekahau, 2008) uses the existing indoor WLAN infrastructure to monitor the motion of Wi-Fi tags. The triangulation technique is used to locate any Wi-Fi enabled device, while the RSSI values of the transmitted RF are used to determine the location of the devices. This system offers 2-D position information. The advantage is the low cost and power level of the battery but it has a low level of accuracy because it needs a lot of calibration, it can only provide 2-D location information. The comparison between the described algorithms is presented in Table 2.

In (Ahmadi, 2017), the authors mentioned that RSSI is widely used because of its availability in most wireless devices. They also mentioned that range-based localization category (e.g. AOA, TDOA, UWB) are expensive in power and delay; while range-free localization (e.g. neighborhood, and hop) have limited accuracy. So, they proposed a new algorithm that merges the learning regression tree approach with filtering method using RSSI metrics. Based on artificial intelligence, the learning tree is used to estimate the position of a mobile device, then an advanced Particle Filter (PF) is used to minimize the error of the estimated computed position. The experience shows that the proposed algorithm is accurate, and robust to environmental change. In addition, the PF is robust to noisy environment and has a low error localization.

In order to reduce the cost of Indoor Localization Systems (ILS), the authors of (Li, 2018) proposed PLILS based on a cheap and widely used commercial chip which supplies four discrete power levels. The localization employs the idea of fingerprint. PLILS consists of one reader, reference nodes, and mobile target nodes. Every reference node broadcasts a data packet (data fields, identity, etc.) periodically, the target nodes will receive, process the broadcast packets, create one specific form, and send it to the reader for positioning themselves. In addition, to avoid the large localization errors, a new algorithm called SOM is used to divide the constructed map of the target region into several sub-regions. This cost-effective approach has an accuracy of 1m. Other studies reached a minimum accuracy of 2m such as in (Gunathillake, 2016),

4 OUR APPROACH FOR LOCALIZATION IN WEARABLE SENSOR NETWORK

Nowadays, the concept of a smart building is in a perpetual progress. Many studies were done on the core of this topic. Our approach will use this concept in dealing with localization in a Wearable Sensor Network. The plan of this smart building will be composed of sensors having a defined range of capture in predefined areas/locations. Our approach on localization using Wearable Sensor Network, can be used by firemen, police, army, etc. Our used scenario represents a group of firemen during an indoor firefighting mission. The target is to have a real-time visibility of the status of each fireman specially his location, by calculating the coordinates (X, Y) of each fireman (node) in such mobile (variable node), distributed (the nodes are in many places within the environment), dynamic (many nodes can be added or removed from the network) and complex network.

Table 2: Description and Comparison Between Different Existing Algorithms.

System Name	Accuracy	Security & Privacy	Cost	Technology/ Method
Active Badge	Room Level	No	Reasonable price with cheap tag and sensors	Ultra-sound / RSS
Firefly	3.0 mm	No	A tag controller and 32 tags	Infrared / Not available
Optotrak	0.1-0.5 mm	No	Expensive	Infrared / Not available
IRIS-LPS	16 cm out of 100 m²	No	Less than Firefly and Optotrak	Infrared / Triangulation
Active Bat	3 cm out of 1000 m²	No	Expensive	Infrared / Multilateratiom
Cricket	10 cm	Yes	Cheap	Ultra-sound, RF / TOA and Triangulation
Sonitor	Room Level	No	Cheap	Ultra-sound / Not available
WhereNet	2 to 3 m	No	Expensive	RFID / TDOA
RADAR	2.26 m out of 213 m²	No	Research-oriented solution, no products	WLAN / Triangulation
EKAHAU	1 m	No	Cheap	WLAN / RS

As mentioned in the previous section, many algorithms and methods were proposed and discussed in order to track and compute the position of a target in indoor environment. Existing algorithms are based on one or more technology such as RF, RSS, UWB, WLAN, Bluetooth, etc. and many other computing methods like TOA, TDOA, RTOA and AOA, etc. These proposed algorithms had their conveniences and inconveniences according to the used network, technologies, and methods.

WLAN (IEEE 802.11) is very popular in public hotspots and enterprise locations. During the last few years, it has a high rate of 11.54 to 108Mbps, and a range of 50 to 100m, and an update rate of a few seconds. IEEE 802.11 is the dominant WLAN. Many algorithms based on WLAN (RADAR, DIT, etc.) or Bluetooth (Topaz that integrate IR with the Bluetooth positioning and communication) seems to be suitable for our approach but the limitation of these algorithms is their low-ability to overpass obstacles.

The Bluetooth (IEEE 802.15) technology is suitable for our approach because it is highly ubiquitous (embedded in many devices) and it can support many other networking services. Moreover, Bluetooth tags are small sized transceivers, and have a unique ID that can be used to locate each tag. Bluetooth was designed to exchange a lot of data at close range. In 2011, when the Bluetooth Low Energy (BLE) was developed, it had the advantage of low power consumption but with lower bandwidth, so it can be largely used for a device that exchanges a small amount of data periodically which is more suitable in our case in both proposed scenarios (Centralized and Broadcast emissions), the range of this device is about 100 m but it depends on the surrounding, radio performance, and antennas. The comparison between Bluetooth and Bluetooth Low Energy will be described in Table 3.

As mentioned by the authors of (Piwowarczyk, 2013) and (Zhou, 2010), the placement of the beacons can influence the accuracy of the localizations, that's why we suggest to use flexible beacons that can rotate around their axes in order to have a wide area of coverage, so that we reduce the repetition of signals request. As a result, this method will reduce the energy consumption, the network traffic, and the re-computation of the localization position. In fact, recent study demonstrates that the transmission power of the BLE beacons has a significant impact on the overall range of the beacons, it is assumed that adjusting the transmit power of the BLE beacon has an effect on the beacon's range and their ability to overpass obstacles such as walls. Our approach will use the following technologies:

- BLE having the advantage of low power consumption.
- Flexible beacons having the ability of rotating around their axes for better visibility.
- Enhancing the transmission power of the BLE beacon to increase its ability to overpass obstacles such as walls, but this overpass will affect the accuracy in positioning the tags.

Table 3: Comparison between Bluetooth V2.1 and BLE.

	Bluetooth V2.1	Bluetooth Low Energy (BLE)
Range	Up to 100m	Up to 100m
Max range (free field)	Around 100m (Class 2 outdoor)	Around 100m (Outdoors)
Frequency	2.402-2.481 GHz	2.402-2.481 GHz
Max data rate	1-3 Mbit/s	1-Mbit/s
Application throughput	0.7-2.1 Mbit/s	Up to 305 Kbit/s
Topologies	Point-to-point, Scatternet	Point-to-point, Mesh network
Network standard	IEEE 802.15.1	IEEE 802.15.1

The simulated environment where the armed firemen (tag holders) are acting, is composed of a room (20*20 m) having reference nodes called beacons that will be able to rotate in a horizontal plan, a Controller Beacon (CB) that memorizes the localization of every node within the range of each beacon. Many characteristics should be taken into consideration to success our implantation.

- Fast: The aim is to have a fast request and response while emission depends on the mode of transmission and the used hardware.
- Smart: The algorithm should compute and estimate the position of each node with fewer errors.

- Scalable: The number of nodes is variable so the network should be able to accept any changes (adding or removing any node).

To avoid synchronization problem with the beacons, the CB, in every lap of time, will send a request to all beacons asking them to get the position of all active firemen existing in their range.

4.1 Centralized Emission

For the centralized emission, each beacon will send a signal (RSSI, Ultra-Sound or Radio Frequency Signal) to all the nodes that are in its range. Once received, each node will reply by sending the following information to their related beacon: (Sensor ID, TOS (Time of Sending), Frequency, Sent flag, Received flag).

Once the beacon captures the signal, it estimates the coordinates of the node S (emitter) by using the Time of Arrival (TOA) and the Angle of Arrival (AOA) by applying the following formula and as shown in Fig. 4.

$D = \frac{f}{\Delta t}$ (f: frequency of transmission; $\Delta t = TOA - TOS$)

$X_S = D\cos\theta(\theta : AOA)$

$Y_S = D\sin\theta$

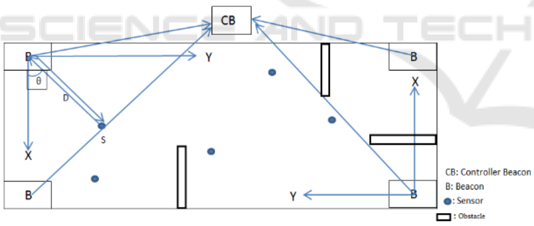


Figure 4: Centralized Emission Scenario.

The concerned beacon will send the result to the CB in order to update its routing table by saving the computed coordinates of each node referenced by its ID. Then, it sends a response to the node in question that updates from its side the flag received and sets it to 'True'. By this, it guarantees that the signal is well captured. The CB will be considered as a reference to be contacted at any time by the mission's responsible.

This scenario gives us a real-time visibility about the coordinates of each beacon with fewer errors, but on the other hand, it has an inconvenience which is: once the mobile node is not able to receive a response from the beacon upon its request because it is out of the beacon's range due to its mobility, it is obliged to resend the request to another beacon and this will cause a loss of time and energy.

4.2 Broadcast Emission

The same procedure is applied as described in the centralized emission, but the difference is after computing the coordinates of the sender, the beacon will broadcast the information to all other nodes existing in its range. This scenario will be repeated every time the beacon computes a new position of the same node or a new one. It is also repeated by every beacon. As shown in Fig 5.

This scenario is very efficient and accurate because any node at any time has the updated coordinates of all the nodes in the network. As a result, in both scenarios, the CB will have, at any time, a general overview of the coordinates of each node and their related beacon.

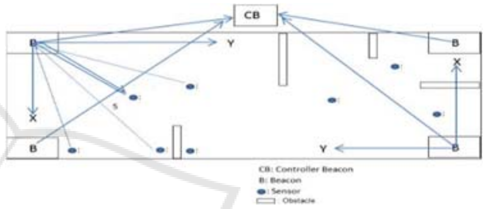


Figure 5: Broadcast Emission Scenario.

As a summary, the CB will own in its database a general table as indicated in the Table 4.

Table 4: Information on a CB about each Target Position According to each Related Beacon.

Beacon#	Tag ID	Angle	X	Y	Time
1	2	30°	10	8	t1
1	5	30°	20	16	t1
2	7	20°	30	90	t1
1	4	40°	50	70	t2
3	4	40°	60	70	t2
4	1	80°	90	70	t2
…	…	…	…	…	…

These two scenarios are suitable for the characteristics previously mentioned: 'fast', 'smart' and 'scalable' depending on the complexity of the hardware.

A Matlab simulation shows the number of nodes covered and tracked by each beacon and shows the accuracy of our approach. We suppose that we have 20 firemen that are acting randomly in a room (20*20 m) with three obstacles and four beacons as shown in Fig. 4 and Fig. 5. The beacons had a 30° angle of view and can rotate horizontally around their axes 30°each time. The Matlab simulation shows the result and compares our two scenarios in terms of delay, energy consumption, tracking, and accuracy as shown in Fig. 6, Fig. 7, Fig. 8, and Fig. 9.

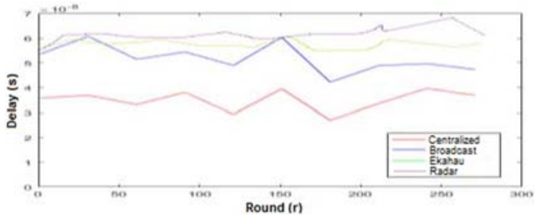


Figure 6: Delay comparison between the centralized and the broadcast emissions.

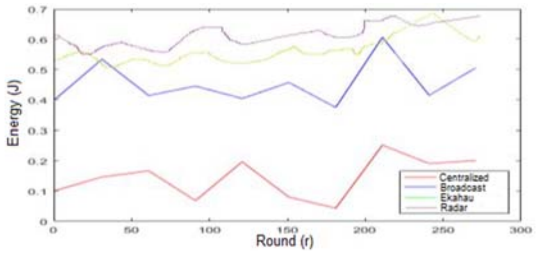


Figure 7: Energy comparison between the centralized and the Broadcast emissions.

As shown in Fig. 8, the number of targets that has been tracked is 18 whereas the number of firemen was 20. So if we change the parameter of the rotation of the angle to be 20° at a time instead of 30° and based on the “broadcast emission”, we can track all the existing firemen in the environment.

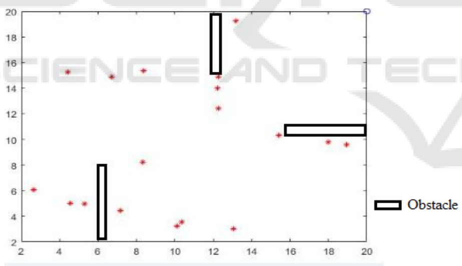


Figure 8: Tracking of the target inside the room.

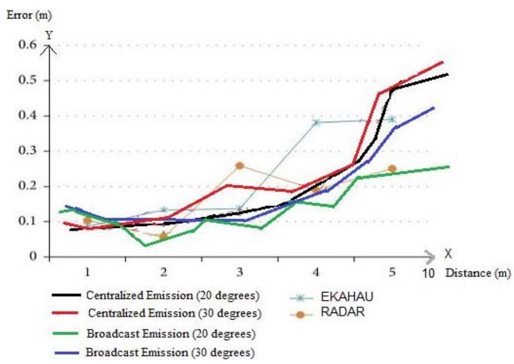


Figure 9: Accuracy of each scenario and comparison between our simulation and the RADAR and EKAHAU one.

As shown in Fig. 9, the X axis represents the distance between the beacon and the devise existing in its range. The Y axis represents the errors. We simulate the accuracy of each proposed scenario (Centralized and Broadcast). Then, we repeat the same simulation with a rotation angle of 20 degree. As a result, the accuracy will increase each time the rotation angle of the beacons is small. Finally, we compare our approach in both scenarios with the Radar’s and EKAHAU’s one. The position will be more accurate by increasing the number of beacons. Comparing our algorithm to the existing ones described in Table 1, we have shown that our algorithm is more efficient in term of delay (Fig. 6), energy consumption (Fig. 7), tracking accuracy (Fig. 8 and Fig. 9), and overpassing obstacles based on the technologies we used (BLE, flexible beacon, enhancing power transmission).

5 CONCLUSION

In this paper, we discussed indoor localization for CBSN in smart environment. We proposed 2 approaches a single-hop approach (centralized emission) and a multi-hop one (Broadcast emission). The proposed approaches were compared against existing algorithms on delay, power consumption and accuracy. Our proposed approaches are very convenient on power consumption and delay and have very good accuracy, thus providing a very competitive alternative.

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