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Indoor localization based on wireless sensor networks

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ABSTRACT

Indoor localization systems are becoming very popular because they enable the creation of very interesting location-based applications. This paper provides a short introduction about localization systems based on a sensor network and the actual state of the art. Important topics related to indoor localization like the necessary infrastructure, available technologies and their expected accuracy are treated. Additionally, the results of previous work referred to the performance evaluation of localization algorithms are shortly described. Finally, some ideas related to further investigations are presented.

1. Introduction and motivation

Where is the next gas station? Are my friends nearby? Are the goods in the building? Knowing the positions of persons and objects is a clear need. Thus, in the last years multiple technologies and applications were created motivated by this.

Maybe, the most used technology in this area is the well-known American Global Positioning System (GPS), which provides an accuracy level depending of the capabilities of the receiver and the used technology. By using for instance a standard GPS receiver of a cell phone, the position error can be between 6 and 15 m, which is enough for many car navigation systems. If an expensive RTK (Real Time Kinematic) GPS receiver is used, it is possible to achieve centimeter level accuracy [1].

However, GPS has an important limitation: this system works well only in outdoor scenarios. In indoor scenarios, like inside a building, the signals transmitted by GPS satellites are attenuated drastically. Thus, GPS receivers cannot be used and other alternatives have to be created for providing information about the position.

Nowadays, there are different technologies used in indoor localization systems depending on the requirements of the application, the expected accuracy and available resources. For instance, there are approaches based on infrared [2], video cameras [3], inertial systems [4], ultrasound [5] as well as radio signal [6]. There is no unique solution that satisfies all needs within the indoor localization, because each system has its advantages and disadvantages. For instance, the camera-based and infrared-based systems require Line-of-Sight condition (no obstacles between the camera and the target) and in general a powerful computer for the image processing. However, the achieved accuracy can be in the range of mm-cm. With the inertial systems, the nodes can execute localization algorithms locally, avoiding the communication with other nodes. The disadvantage of this approach is that the position error is accumulated with each iteration. The system based on ultrasound demands a dedicated receiver whose energy consumption is in general very high. The position accuracy of these systems is in the range of mm–cm. A good overview of these technologies can be found in [6].

One of the cheapest approaches is based on the radio signal, for instance exploiting the received signal strength indicators (RSSI) of transmitted packets in a WLAN network. These RSSI values can be used in a localization algorithm called “Fingerprint technique” or “Fingerprinting” [7,8] for the position estimation of a mobile node. This system is widely used in big malls or airports. The fingerprint technique consists of two phases: in the first one called off-line phase, RSSI measurements from Access Points are taken at known positions and saved in a data base as fingerprints. In the on-line phase, a node that wants to know its position, takes new RSSI measurements and compares them with the fingerprints saved in the data base. The node selects the fingerprints from the off-line phase that are similar to the measurements taken in the online phase and uses the stored positions of the fingerprints to approximate its actual position.

The fingerprint technique is able to provide a position accuracy level between 2 m and 5 m [9]. The big advantage of this method implemented in a WLAN network is its low cost and versatility, since a standard smartphone or laptop can be used as receiver. The

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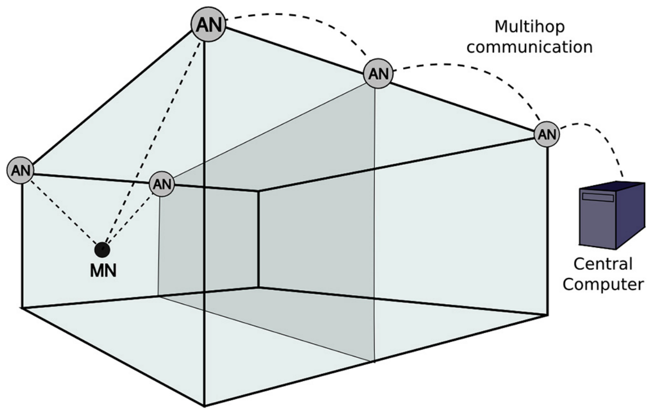

Fig. 1. Indoor localization scenario.

drawback of this system is the fact that the position estimation can suffer from large errors when changes occur in the environment. In general, the calibration of the system executed in the offline phase can be very time consuming.

2. Wireless sensor network based indoor localization

Another interesting approach used for indoor localization is based on a wireless sensor network. The sensor nodes are small devices, that consume very low energy and are able to measure environmental parameters and communicate with each other. Thus, the measurements from the sensor nodes can be associated to their positions enabling the creation of many interesting applications, for example, a localization and supervision system in a hospital. Here, the patients carry wireless sensor nodes, which can be monitored and easily located, when the patients have a problem.

Fig. 1 shows a typical indoor scenario, where a sensor network is installed for localization purposes. There are fixed nodes with known positions called anchors (ANs) which serve as reference points for the position estimations of mobile nodes (MNs). If the calculation is centralized, the MN takes measurements related to ANs, and then a multihop communication takes place to send this information to a central computer, which is in charge of the position estimation. If the calculation is decentralized, the MN can use the measurements to estimate its position. The advantage of the centralized proposal is the accuracy that a powerful computer can achieve if it executes complex localization algorithms. The disadvantage lies in the necessary communication in the resource-constrained sensor network for sending all measurements to the central computer. This can reduce the scalability of the system.

The position accuracy achieved by the sensor nodes strongly depends on the used technology and the localization algorithm. As in WLAN, it is possible to use the RSSI of the packets sent by the sensor nodes in the fingerprint technique. In one of our previous works [10], a sensor network is installed in a building of our university to evaluate the fingerprint technique as localization algorithm. The achieved average position error was shorter than 2.5 m.

There are localization algorithms that require the information about the distances between MN and ANs for the position estimation. The distance between two nodes can be approximated by using a ranging method like RSSI, time of arrival (TOA) and phase of arrival (POA).

Thus, in the RSSI method, the signal strength measurements are mapped to distance values using an attenuation model. Due to the dispersion of the RSSI measurements, this approach is not accurate and can produce large position errors. Therefore, if RSSI should be used, it is more convenient to use the fingerprint technique rather than a localization algorithm that requires RSSI-based distances directly. However, the principal advantages of this approach are that it is very easy to implement and no time-consuming calibration process is required.

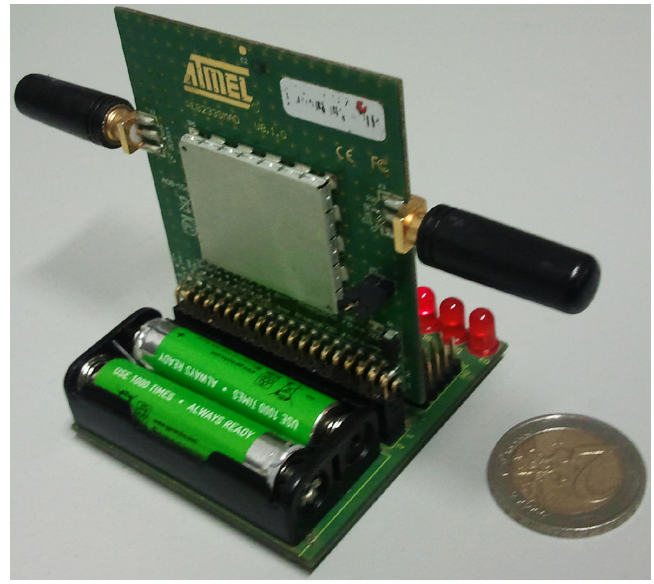

Fig. 2. Reference POA-based sensor node.

The approaches based on TOA measure the time that the signal requires to reach the receiver. With this time and the propagation speed of the signal, it is possible to calculate the distance. In general, nodes that use TOA-based methods require a dedicated hardware with very accurate clocks and they have to be synchronized. Nevertheless, in the market, there are some solutions based on TOA that avoid the use of an expensive accurate clock. For instance the nodes described in [11].

At the Chair for Telecommunications a test-bed with sensors that make use of the phase of arrival (POA) ranging method was built. Here, sensor nodes are able to measure the phase of the incoming signal. With this information, the signal frequency and the propagation speed, the receiver can calculate the distance to the transmitter. Fig. 2 shows one of the sensor nodes used in our test-bed. Technical detail about this POA-based sensor node can be found in [13,14].

Different measurements were taken by our nodes in outdoor and indoor scenarios to evaluate the distance accuracy of the POA-based and RSSI-based ranging methods [15]. Distance errors under 1m were registered in most cases by using the POA-method. In case of RSSI, distance errors as large as 20m were measured. Additionaly, we evaluate the performance of three low-complexity localization algorithms: Multilateration, Extended Min-Max (E-Min-Max) and Weighted Centroid Localization (WCL) [15]. For this, POA-based distance measurements between the MN and 4 ANs were taken in a room of dimension $14\,m \times 8\,m \times 3.5\,m$. The results show that Multilateration has the worst performance because this algorithm is not robust against distance errors. On the contrary, E-Min-Max and WCL were able to provide an accuracy level of about 1 m.

We carried out two additional measurement campaings, where POA-based distance measurements were taken in a sector of a floor ($30\,m \times 15\,m \times 3.5\,m$) and in the yard (35x35m) of our building. In these scenarios, 9 ANs were placed to take measurements with the MN. In the floor, there is non-line-of-sight (NLOS) condition in many cases, it means that the signal is attenuated by obstacles e.g. walls. In the yard there is line-of-sight (LOS) condition, where there is no obstacle between nodes.

The errors of POA-based distance measurements are principally due to the multipath effect, where the signal is reflected, e.g. in the walls or ground, and the sensor node receives the signal by more than one path producing constructive/destructive interference and phase shifting of the signal.

Our results indicate that E-Min-Max achieved a position error about 2 m in the yard. In the floor of the building, the position error was in general higher. We also evaluate a localization algorithm based on particle filter. This algorithm is not appropriate to be executed locally at a limited sensor node, because it can demand a long execution time. For instance, the particle filter algorithm takes more than 50 s to be executed in a 8-bit microcontroller when 5000 particles and 7 ANs are used in the calculation. Here, the best option is to use a centralized approach, and send the distance measurements to a central computer with a powerful processor. With the particle filter, we achieved an average position error of about 1.5 m in the indoor scenario and about 0.7 m in the yard.

3. Perspectives

In the last five years, the processing power of microcontrollers has been improved without increasing its energy consumption and cost considerably. Thus, it is expected, that sensor nodes will be able to execute more complicated and accurate localization algorithms locally. Furthermore, the trend of manufacturers is to integrate the transceiver and microcontroller in one chip reducing the size of the sensor node and improving its transmission rate.

It is important to remark that the location process requires an efficient communication between sensor nodes. Due to the fact that the used mechanisms, like routing, synchronization and ranging protocols play an important role in the achieved update rate, scalability and energy consumption of the localization system.

Many applications related to localization use the Internet for communication and visualisation of results, e.g. a remote monitoring system. The concept "Internet of Things" is becoming increasingly popular and many applications have been created based on this concept. The idea behind the Internet of Things is that all sensors (and objects) can be connected to the internet easily. The protocol 6LowPAN [16] provides each sensor node with an unique IP address for their identification in the Internet. Here, one of the open challenging issues is to create localization protocols that can work in an optimal way with the protocols related to 6LowPAN.

For the moment, there is no clear vision, if there will be one technology accepted by most developers of localization systems. There are many factors to take into consideration when selecting the adequate technology and not all technologies satisfy the requirements. Some of these factors are cost, size, coverage area, scalability, availability, maintenance, update rate, interference with other existing networks and the expected accuracy.

Recently, a low-power sensor node based on ultra-wide band and TOA was developed, which can determine the distance to another node with centimeter accuracy level [17]. Maybe, this technology together with the one proposed in [12] (TOA, chirp spread spectrum) and in [14] (POA) will share the market in the next years.

Future work will be oriented to the mitigation of the multipath effect, the improvement of ranging and localization protocols to increase the scalability of the system, the integration of localization systems in existing networks and the development and implementation of new location-based services.

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