Locating the Information: Applications, Technologies and Future Aspects

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In today's world, the demand for information is growing rapidly with respect to the human curiosity to explore the inside and the outside of our planet. In a simple analogy, the human body has thousands of sensors called receptor neurons to obtain information such as temperature or pressure from the environment. Similarly, recent developments in electronics and wireless communications lead engineers to the design of small-sized, low-power, low-cost sensor nodes which have the ability to communicate with each other over short distances and collect the information that is gathered.

As introduced in [1], these sensor nodes consist of sensing, data processing, and communicating components and leverage the idea of sensor networks. In our group, one of the principal research areas is *Short-Range Radio*, in which we research current and new wireless sensor network standards (e.g Ultra-Wide Band (UWB), Bluetooth, Zigbee, Wibree) regarding low power consumption, robustness to interference, integration on chip and overall costs. One of the projects we are working on is *Physical layer in body area networks (BANs)* in which we deal with challenges such as the low power consumption of the nodes, the efficient support of a large number of nodes (up to 1000) with different data rates (between kbps and several Mbps), the difficult propagation channel around the human body, interference mitigation and coexistence of the network. Another project in our group is *Localization in smart dust sensor networks*, in which we aim to design a robust and highly-accurate localization system that is capable of handling problems in harsh indoor and outdoor environments using wireless sensor networks. The latter project is the main topic of this paper.

There are many application areas of sensor nodes for military service such as command, control, communications, computing, intelligence, surveillance, reconnaissance and targeting. Furthermore, sensors nodes can be deployed for environmental applications such as animal habitat monitoring, water quality monitoring and precision agriculture. And also recently sensor networks have become very popular in application areas like road traffic and patient monitoring. In most of these wireless sensor network applications, information is meaningless without accurate and precise location information. For instance, wireless sensor networks can be deployed to detect and localize unauthorized targets in an indoor environment by means of collaborative tags, or to localize a box in number of other boxes for logistics as shown in Figure 1a and Figure 1b, respectively. In addition to these application examples, the WHERE [2] project was established recently to use the position information for the benefit of future mobile radio systems.

In the 1990s, the cellular communication infrastructure was used by 911 services in the U.S. to locate people who are in emergency situations. However, the localization accuracy was in the order of the several hundreds of meters in rural areas, where the base station density is low. Meanwhile, in urban areas, microcells and picocells, which have

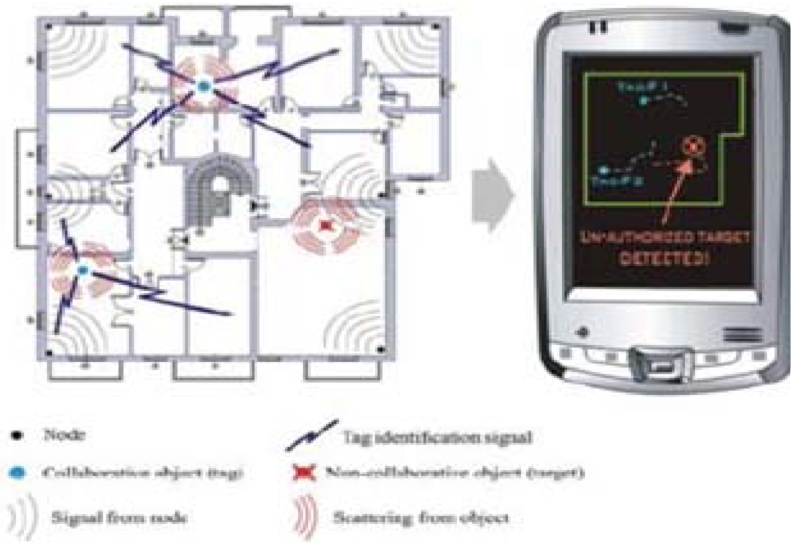

Figure 1a Application areas of wireless sensor networks: Target detection

Figure 1b Application areas of wireless sensor networks: logistics

lower coverage area, are widely used. So then the localization accuracy was better, but still about 100m because of the reflections and scattering in the environment.

Since the beginning of the 21st century, GPS (Global Positioning System) has been a widely used localization technique in commercial areas. GPS is based on satellite communications, requiring at least three satellites for positioning and one satellite for clock synchronization. The position is determined by measuring the time-of-arrival (TOA) between the GPS receiver and the satellites. As long as we get the signal propagation time between the transmitter and the receiver, under the assumption that the signal propagates with the speed of light, we can derive the distance information simply by multiplying the speed of light ($3 \cdot 10^8$ m/s) with the signal propagation time (i.e the time difference between the signal transmission from each satellite and reception at GPS receiver). With the knowledge of the distance to the each satellite, the position is derived using the tri-lateration technique as shown in the Figure 2. In Figure 2, each sphere in the center of the circles represents a satellite, of which we know the position in a priori, and the location of the GPS receiver is determined by the intersection of these circles. GPS offers about 10 m accuracy, which is sufficient for many purposes, but GPS signals cannot propagate through obstructions (e.g walls, floors) which makes GPS useless for indoor applications.

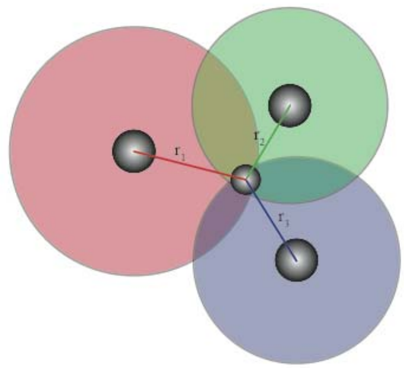

Figure 2 Tri-lateration method

Recently, Wi-Fi (IEEE 802.11) is used for localization purposes. It uses the received signal strength (RSS) measurements, based on the relation between power level and distance. However this relation is affected by multipath fading, resulting in accuracy in the order of several meters. In this context, the fingerprinting technique was also proposed. In fingerprinting, the power vs. distance relationship is exploited and a database showing the power level for each location is created. When the receiver gets the power level from several transmitters, looking at the database it can determine its position. However this method is heavily affected by the (dynamic) structure of the environment.

The demand for locating the nodes with high accuracy in indoor and outdoor situations has led researchers towards ultra-wide band (UWB) based localization systems. Together with time-based ranging techniques, UWB offers positioning information with centimetre-level accuracy [3]. What makes UWB different from other systems? Basically UWB is defined as occupying an absolute bandwidth of more than 500 MHz or a relative bandwidth larger than 20%. This huge bandwidth compared to narrowband systems (like GSM, Wi-fi, GPS) provides a high time resolution, making it suitable for localization systems when combined with time-based ranging.

Basically, localization consists of two steps, as shown in Figure 3. In the first step, the range is determined between beacon nodes, whose position is known in a priori, and the target node. In the second step, the position of the target node is estimated through a position estimation method such as tri-lateration, as introduced before. Note that, in order to localize the target node in two-dimensional or three-dimensional spaces, we need three or four beacon nodes, respectively. The range is estimated through received signal strength (RSS), time-of-arrival (TOA), time-difference-of-arrival (TDOA) and angle-of-arrival (AOA) measurement techniques [4]. As also discussed in Wi-Fi case, RSS exploits the distance v.s. the power relationship to determine the range. Although this technique does not give accurate results due to the channel effects, its complexity is very low compared other techniques. The accuracy of TOA measurements increases with respect to the transmission bandwidth. However due to the clock synchronization problem between the nodes, two alternative methods are introduced in the literature. In two-way TOA ranging, the round-trip time between the transmitter node and the receiver node is calculated and the range is estimated with considering the processing delay at the receiver node. Another alternative to the TOA is the TDOA method which requires the synchronization between beacon nodes. The AOA arrival method provides the direction of an incoming signal. The angle information is obtained by measuring the differences in arrival times of an incoming signal at different antenna elements. Then the tri-angulation method is used to estimate the position. However this technique requires an antenna array at the receiver nodes, resulting in an increase of the overall system complexity.

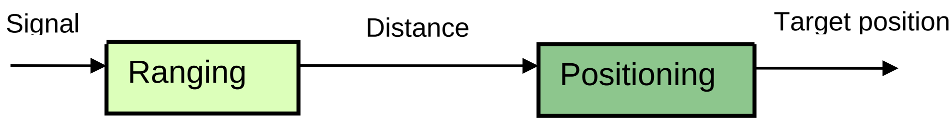

Figure 3 Basic Localization structure

Although time-based UWB localization systems theoretically offers centimeter-level accuracy, there are still some open issues as discussed in [5], like non-line-of-sight (NLOS) or multipath propagation, which decrease the accuracy of the system in real implementations. Basically, NLOS conditions introduce an additional positive bias to the TOA estimation, since signals cannot propagate at the speed of light through obstacles. In this regard, identification of NLOS paths is utterly important to mitigate this effect on both ranging and positioning steps. In our group, we are currently working on NLOS identification and mitigation methods. We are working in collaboration with HOLST Center for indoor UWB measurements.

The demand for accurate location information is increasing as location-based applications are increasing. Today, the number of location-based applications in our mobile phones has reached about 5000 [6]. Fine localization systems can improve the performance of current communication systems. Together with UWB, it is feasible to achieve centimetre-level accuracy for WSNs.

Please visit our website at http://www.ewi.utwente.nl/te/ for information about our other research groups: *Electromagnetic Compatibility (EMC)* and *RF Photonics*. And please send an e-mail to Yakup Kilic or Mark Bentum for more information about our research activities in *Short-Range Radio*.

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