Locating the Information: Technologies and Challenges

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Introduction

In today's world the demand for information is growing rapidly due 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 have led 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 sensed [1].

There are many application areas of wireless sensor nodes. To mention a few: target detection, logistics, security tracking, asset management, search and rescue operations, control of home appliances, animal habitat and water quality monitoring, patient monitoring, and precision agriculture. In most of these applications, location-awareness is an essential feature, because the information is often meaningless without the location knowledge.

Ultra-wide bandwidth (UWB) technology has recently been specified in IEEE 802.15.4a communication standard for wireless personal area networking [2]. It has proven to be a promising technology for localization systems because of its high-ranging resolution and through-wall penetration capabilities. UWB theoretically offers a ranging accuracy of a few centimeters when combined with time-based ranging methods [3]. Furthermore low-cost, low-complexity and low-power design features make UWB technology quite suitable for wireless sensor networks (WSNs). In WSN localization, the range information from multiple sensors is combined in order to estimate the position. In this respect, there is a distinct difference with radar systems, which typically rely on a stand-alone transmitter and/or receiver.

In the following sections, we explain how localization is performed in UWB systems. And then we introduce the current limitations of the system, and describe possible improvements that are currently investigated in the Telecommunication Engineering group.

UWB localization

The aim of localization is to estimate the position of a particular node, called the target node, relative to the positions of so-called beacons or anchor nodes, which are known in a priori. It usually consists of two steps: ranging and positioning.

In the ranging step, the distances between the target node and beacons are estimated by exploiting certain propagation characteristics of the signal. The common range estimation methods are received signal strength (RSS), time-of-arrival (TOA), two-way TOA and time-difference-of-arrival (TDOA). The RSS technique exploits the relation between the received signal power and the distance, and is commonly used in mobile and Wi-Fi localization (i.e fingerprinting) systems. This method is easy to implement since most of the wireless devices provide an estimate of the received signal strength level. On the other hand, it is heavily affected by variations due to scattering and multipath properties of the environment, resulting in erroneous range estimates. Time-based ranging methods such as TOA result in very fine range estimates in UWB localization systems. In TOA-based ranging, the range is estimated from the propagation time, i.e the time difference between the signal transmission and reception. Under the assumption that the signal travels with the speed of light, we can calculate the range. UWB signals are composed of ultra-short pulses in the order of a few nanoseconds which yields bandwidths in the order of several hundreds of MHz or even several GHz. Because of the huge time-resolution, it is possible to estimate the propagation time in nanoseconds, resulting in a ranging accuracy of just a few centimeters. TOA estimation requires very fine clock synchronization between the target node and the beacons, which is impractical for sensor nodes. Therefore, in practice TDOA and two-way TOA are commonly used ranging methods. In the TDOA method, the difference in distance between the target node and two different beacons is estimated by measuring the difference in arrival time for two beacons. In that case, only the clocks of the beacons need to be synchronized. In two-way TOA ranging, the round-trip time between the transmitter node and the receiver node is measured, and the range is estimated by incorporating the processing delay at the receiver node.

In the second step, the position of the target node is determined by combining the obtained range estimates. Let us assume that we obtained the distances between the target node and beacons by means of TOA-based ranging. We may then apply the tri-lateration method to combine the range estimates, as shown in the Figure 1(a), in order to obtain the position of the target node (shown in red). The radii of the circles around the beacons (shown in blue) indicate the estimated distances between the target node and the corresponding beacons. If these estimates were perfect, these three circles would intersect in a single point. In practice, however, the measurements are affected by noise as illustrated in Figure 1(b), causing an uncertainty region in the position estimates. In order to localize the target node in two-dimensional or three-dimensional spaces, we need three or four beacon nodes, respectively.

(a) (b)

Figure 1: The positioning with (a) perfect and (b) noisy range measurements [4].

Although time-based UWB localization systems theoretically offers centimeter-level accuracy, there are still some open issues as discussed in [5], such as non-line-of-sight (NLOS) or multipath propagation, which decrease the accuracy of the system in practical implementations.

NLOS propagation

NLOS propagation occurs if there is a blockage between the transmitter and the receiver, as illustrated in the Figure 2. Conversely, line-of-sight (LOS) is defined as the condition where there is no obstruction between both entities. The direct-path signal arrives at the receiver first, followed by the multi-path components, which are typically reflected by the walls (Tx-Rx1 in Figure 2). Notice that, the propagation time of the direct-path signal is directly determined by the real distance between the transmitter and the receiver, whereas the multipath components travel longer distances. Also, the power of the direct-path component is generally larger than the power of each multipath component in LOS conditions. Therefore, identifying the direct-path component in the received signal is possible simply by looking at the strongest peak. However, in the condition of Tx-Rx2 an additional propagation delay occurs due to the fact that the signal propagation velocity through the materials is less than the speed of light. This also results in larger distance estimates between these nodes. Furthermore, since the direct-path component is attenuated, its power may be less than the power of the multi-path components, requiring more sophisticated direct-path identification techniques such as introduced in [6]. In Rx3, the direct-path component does not even exist since the signal is severely attenuated by two walls, resulting in a significant distance estimation error.

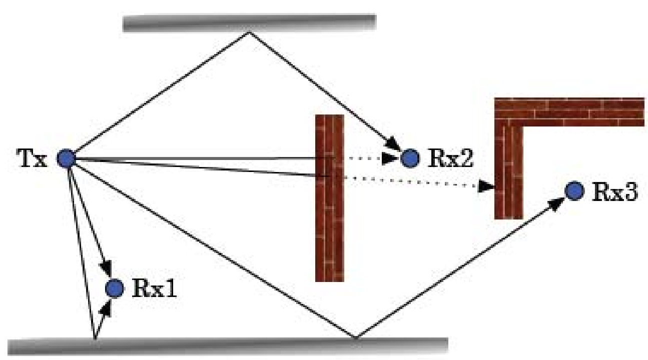

Figure 2: Possible LOS (Tx-Rx1) and NLOS (Tx-Rx2, Tx-Rx3) conditions [5]

The ranging bias, introduced by NLOS propagation may cause large positioning errors. One possible way to deal with this issue is identification of NLOS links and discarding the corresponding range estimates from the positioning algorithm, provided that we have sufficient anchor nodes. Recent studies have revealed that certain features of the received signal could be used for channel condition identification. This is illustrated in Figure 3, showing examples of received signal shapes under LOS and NLOS conditions, respectively. Under LOS conditions the received signal will typically contain a clear peak, which can be identified using advanced signal processing techniques. If there are not enough beacon nodes (i.e less than three after discarding), then we need more sophisticated localization techniques. One possible solution is to assign different weights to the different range estimates, according to their reliabilities. For instance, once the node is identified as an NLOS node, one may assign lower weight to this range estimate in order to decrease the effect of the NLOS-induced positive ranging bias on the final position estimate.

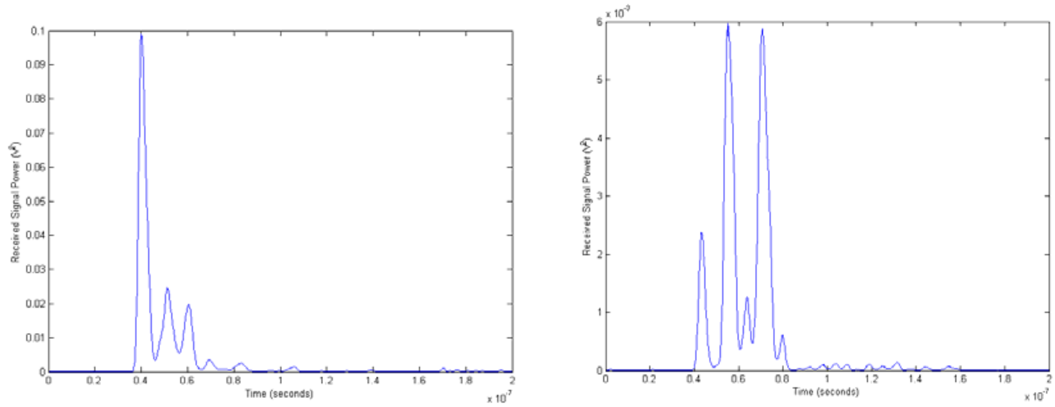

Figure 3: Example of received signal waveforms in (a) LOS and (b) NLOS conditions

In our research group, we are currently working on the prediction of ranging errors, exploiting the relation between the ranging error and the features that can be extracted from the received signal. Once the ranging error has been estimated, NLOS-related errors could be mitigated simply by subtracting the error estimates from the distance estimates. In a recent master assignment in our group [4], this has been investigated and demonstrated by measurements.

Conclusion

TOA-based ranging using UWB technology is very promising for high-resolution localization in WSNs, but it still has several challenging open issues. Therefore it is one of the active research topics in Short Range Radio within the Telecommunication Engineering group.

In case you are interested in this topic, for instance for doing an assignment, please send an e-mail to Yakup Kilic, or contact Mark Bentum or Arjan Meijerink for more information about our research activities in Short Range Radio. More general information about the group and its research activities in Microwave Photonics and Electromagnetic Compatibility can be found on the web site [7].

References

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