IoT Objects Localization based on Time Difference of Arrival Measurements

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In the ecosystem of IoT applications, object localization and tracking play a predominant role. Although GPS is a possible solution to determine the position of "things", its cost and power consumption are not compatible with most IoT applications. CSEM developed a GPS-free localization TDoA-based localization solver for IoT devices using long-range ultra-low power RF technology.

Over the past few years, CSEM has developed several localization solvers based on the radio Receive Signal Strength Indicator (RSSI), using both deterministic and probabilistic techniques. Experience has shown that probabilistic techniques, such as Particle Filtering, provide more accurate and robust location estimation than deterministic techniques.

Using RSSI is a very attractive because it does not require additional hardware components and (almost) all radios can measure the signal strength power of received packets. However, the RSSI distribution is not always symmetric and identical at all locations, it is also dominated by reflections and other sources of noise and it is sensitive to the relative orientation of the transmitting and receiving antennas. Additionally, for the same transmission conditions (transmission power, position and others), the RSSI measured on radios from various suppliers can be substantially different.

By comparison, when clock synchronization and time resolution/granularity are not a problem, time-based approaches, such as Time-of-Arrival (ToA) and Time-Difference-of-Arrival (TDoA), offer alternatives to RSSI techniques. Although sensitive to Non-Line-of-Sight (NLoS) conditions, these approaches have been shown to outperform RSSI techniques. TDoA only requires clock synchronization between anchors. This consideration, coupled with the availability of suitable radio technology for precisely determining the arrival times of the radio signals, drove the selection of a TDoA approach for the localization solver.

The basic idea behind the TDoA approach is to measure the arrival time of a signal transmitted by a target node. The difference of arrival times is calculated for each pair of anchor nodes and converted to a distance difference (∆Distance). This ∆Distance together with the known positions of each pair of anchor nodes (behaving as foci), form a set of hyperbolas. Under ideal conditions, the intersection of the different hyperbolas yields the position of the target node.

The Particle Filtering algorithm implemented at CSEM is a particular case of Sequential Bayesian technique using a Monte-Carlo approach. The main objective is to determine the probability density function $p(x_t|z_0 \ldots z_t)$ which means "What is the probability of being at position *x* at time *t*, given all previous measurements *z*, for all possible positions *x*". This probability density function is known as the ***Belief*** and it is represented by a set of N samples (particles). Each particle contains the coordinates of a possible position of the target node, and a weight which defines how near or far the position of the particle is from the position of the target node, given the TDoA measurements at time ***t***. Particle Filtering is composed of 4 phases: Prediction, Updating, Resampling and Estimation.

At the beginning of the localization process, for the first execution of the *Prediction* phase, the particles are placed randomly in the deployment area. To accelerate the process of convergence, the particles are placed on points of higher probability (i.e. on points over the locus of the nearest branch on the hyperbolas built based on the first measured TDoA/∆Distances; see Figure 1). In subsequent iterations, the particles are randomly moved from their previous positions to new positions, following a predefined model. Then, in the second (*Updating)* phase, the degree of validity of the predicted positions of the particles are determined based on the new TDoA measurements received for the signals transmitted by the target node. The hyperbola formed by each particle and each pair of anchor nodes is compared with those formed by the measured ∆Distances and each pair of anchor nodes and, depending on the similarity (or dissimilarity) a weight is assigned. The process is repeated, with the *Resampling* and *Estimation* phase, until convergence is achieved.

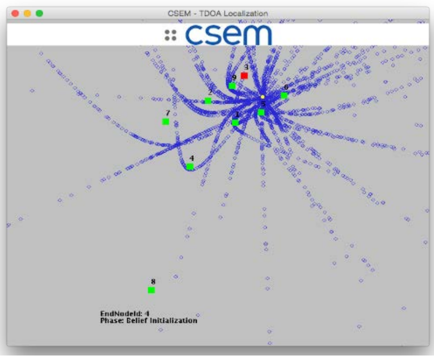

Figure 1: Particle initialization.

Figure 2 shows the Cumulative Distribution Function (CDF) obtained from a test in an urban environment using 9 anchor nodes spaced by 800 m to 12 km, and 4 static target nodes placed at different points. Each target node transmitted 60 beacons, one per second. 50 % of the beacons had a position estimation with an error less than 31.06 m and 70 % with an error less than 59.24 m. This reflects the propagation conditions and time stamp measurement variability. The results show that a good position estimation can be achieved using the Particle Filtering combined with TDoA measurements.

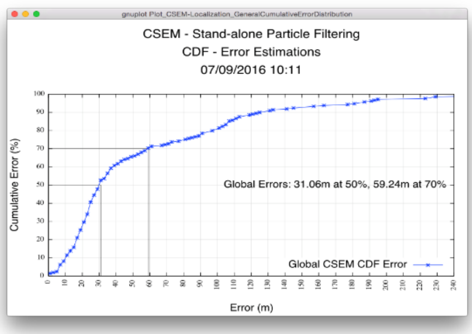

Figure 2: Cumulative error distribution.