Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Technology 7 (2013) 377 – 383

Procedia Technology

The 2013 Iberoamerican Conference on Electronics Engineering and Computer Science

A Survey of Hybrid Schemes for Location Estimation in Wireless Sensor Networks

Alejandro De Gante[a], Mario Siller[a]

[a]*CINVESTAV Unidad Guadalajara, Av. del Bosque 1145, Col. El Bajío, Zapopan, Jalisco 45019, México*

Abstract

Nowadays, the issues concerning wireless sensors nodes localization estimation is still a matter of research interest. This is driven by the complexity and the diversity of current and future wireless sensor networks applications. Several single schemes have been proposed and studied for location estimation, each with its own advantages and limitations. Furthermore, a number of hybrid schemes have been also proposed for the sake of generality and diversity of applications and the limitations of the single schemes. Some of the hybrid solutions combine measurements from more than a single technique to improve the estimation accuracy by employing data fusion. This paper presents a survey of single and fusion based hybrid location techniques.

Keywords: Localization; position; hybrid; AoA; TDoA; ToA; RSS

1. Introduction

Sensor position estimation techniques have been a matter of research for several years. Many areas make use of these estimation techniques to improve the performance of their applications such as smart homes, search and rescue, object tracking, to mention a few. In [1] and [2], position estimation is studied from two different approaches: relative position and global position. For the former, the position can be seen related to a point of reference, such as a room (e.g. center of the room). For the latter, position estimation is performed related to a global coordinator, such as a GPS (Global Position System).

In this paper, we study two different approaches in position estimation techniques: single estimation techniques and hybrid schemes. The considered single techniques include AoA (Angle of Arrival), TDoA (Time Difference of Arrival), ToA (Time of Arrival) and RSS (Received Signal Strength). The presented hybrid schemes are based on data fusion to improve the estimation accuracy. We stress that that hybrid schemes tend to outperform single schemes.

The rest of the paper is organized as follows. In Section II, several single position estimation techniques (AoA, TDoA, ToA and RSS) are discussed. In Section III, several hybrid schemes for position estimation (ToA/RSS, TDoA/RSS, TDoA/AoA and AoA/ToA) are presented. In Section IV, we show a comparison and discuss two of the studied approaches from sections II and III. In Section V concludes the paper.

* Corresponding author.
E-mail addresses: sdegante@gdl.cinvestav.mx (Alejandro De Gante), msiller@gdl.cinvestav.mx (Mario Siller),

doi:10.1016/j.protcy.2013.04.047

2. Single estimation techniques

This section presents the AoA, TDoA, ToA and RSS position estimation techniques.

The position estimation can be either relative or global. Beacon node is a simple sensor node that know its global or local position a priori or can calculate its position in any given instant of time (e.g. GPS). No-beacon node unknown its position initially. These nodes by using position estimation techniques calculate their approximate position in relation to one or more beacon nodes.

The number of employed beacon nodes in a wireless sensor network can affect its costs and energy consumption. Therefore, we need to use position estimation techniques to minimize the use of beacon nodes.

2.1. AoA - Angle of Arrival

Angle of Arrival technique in [1] and [2] can be studied from two approaches: The first uses the response amplitude, the second uses the response phase.

At the first, receiver sensitivity and the wave width are very important parameters. The problems arise when the transmitted signal strength varies. The receiver can't distinguish this variation in signal strength. An approach to solving this problem is the use of at least two stationary antennas with known antenna anisotropic patterns. By making overlap the values of each antenna in equal times and comparing the received signal strength, is possible detect the direction of transmission. A coarse fit is carried with signal strength measurements and after fine fit by comparing the responses amplitude.

At the second, measurements of the phase differences in the arrival of signal wave front are collected. It commonly used an antenna array. Assume an antenna array with N elements, each adjacent antenna is separated by a uniform distance d. The distance between a transmitter and the ith element of the antenna can be approximated by

$$R_i \approx R_0 - id \cdot \cos\theta \tag{1}$$

where R_0 is the distance between the transmitter and the 0 element of the antenna array, and θ is the bearing of the transmitter with respect to the antenna array. The Fig. 1 illustrates the above concepts. The signal phase difference of the transmitter between adjacent antennas is given by

$$2\pi \frac{d \cdot \cos\theta}{\lambda} \tag{2}$$

2.2. TDoA - Time Difference of Arrival

Time Difference of Arrival technique in [2] uses measurements of the transmitted signal in a number of receivers with known locations to estimate the transmitter location.

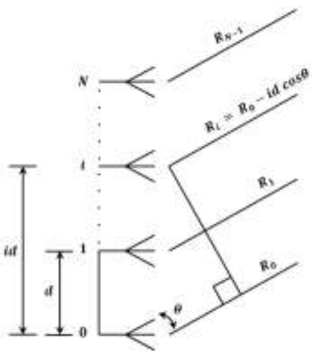


Fig. 1. Antenna array with N antenna elements

In the schemes in which implements this technique, each node is equipped with a microphone and speaker [1].

[1] First, the transmitter sends a message. This waits a fixed time interval t_{delay} and then, the speaker produces a beeps pattern. When the listener node captures radio signal notes the current time t_{radio}, and then turn on your microphone. When the microphone detects the beeps pattern, notes the current time t_{sound}.

Once the listener node has obtained t_{delay}, t_{radio} and t_{sound} then is able to calculate the distance between itself and the transmitter as follows

$$d = (S_{radio} - S_{sound}) \cdot (t_{sound} - t_{radio} - t_{delay}) \quad (3)$$

The Fig. 2 illustrates the above concepts.

2.3. ToA - Time of Arrival

Time of Arrival technique in [9] uses the travel time of radio signal between a transmitter and a remote receiver (according to the relationship between the light speed in vacuum and the signal carrier frequency).

This technique uses absolute time of arrival at a given base station. The distance can be calculated directly from the time of arrival of signals traveling with a known rate.

Information about the time of arrival of two base stations reduces the position to a circle; information from three base stations is required to resolve the precise position of a point.

The absolute difference in time of arrival of the signal on any two base stations is directly related to the absolute difference in the length d over which the signal travels [10].

When a signal is detected by two base stations (S_1 y S_2), the angle θ_{12} between the line connecting the base stations and the direction of the signal front can be calculated using the separation know D_{12} between the base stations and the distance d determined from the difference in arrival times of the signal at the base stations. This angle gives a cone of possible direction to the signal transmitter. With three base stations, two solution cones are generated, and the intersection of these cones give two possible directions. The Fig. 3 illustrates the above concepts.

2.4. RSS - Received Signal Strength

Received Signal Strength technique in [1] and [2] uses the radio sensors. In theory, the energy of a radio signal decreases with the square of the distance from the signal source.

In practice, the RSS range measurements contain noise in the order of several meters. This noise may be due to radio propagation tends to be patchy in real environments, physical obstacles, reflection and absorption of radio waves. This technique is attractive because the sensors do not require additional hardware and have a negligible impact on energy consumption, size and cost [2].

Let us the received power by $P_r(d)$, which is related to the distance d through the Friis equation as following

$$P_r(d) = \frac{P_t \cdot G_t \cdot G_r \cdot \lambda^2}{(4\pi^2 \cdot d^2)} \quad (4)$$

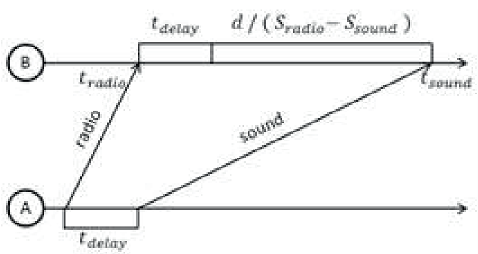
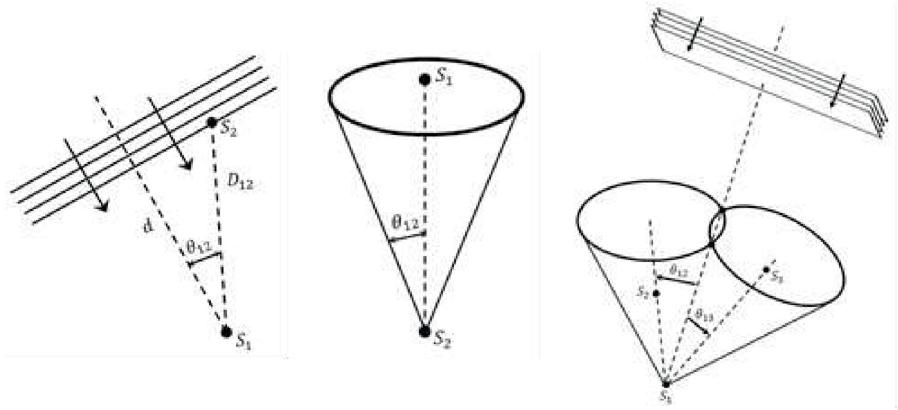


Fig. 2. Time Difference of Arrival illustrated



(a) (b)

Fig. 3. Time of Arrival illustrated; (a) 2-Base Stations; (b) 3-Base Stations

where P_t is the transmitted power, G_t is the transmitter antenna gain, G_r is the receiver antenna gain and λ is the wavelength of the transmitter signal in meters.

However, the above is a free space model, which is overly idealistic. A more careful physical analysis of radio propagation may allow improvements in the use of RSS data [1].

3. Hybrid Schemes

Nowadays, none single position estimation technique allows us to obtain better position estimation in all environments. This is due to the inherent limitations of single position estimation techniques [1] [2].

The measurements data fusion of position estimates by single position estimation techniques can improve accuracy in such measurements [2] [6].

Hybrid schemes of position estimation are schemes that take more of a single position estimation technique and through data fusion results in a more accurate measurement on position estimation. Among hybrid schemes are ToA/RSS, TDoA/RSS, TDoA/AoA and ToA/AoA.

3.1. ToA/RSS

ToA/RSS hybrid scheme in [8] considers a sensor device (mobile station), whose position is initially estimated, denoted as SN_0, and m reference devices (base stations) denoted with indices 1 ... m, which are within the range of SN_0. This assumed that each reference device i can simultaneously perform both observations t_i of ToA and r_i of RSS on the signal transmitted by SN_0.

The ability to perform ToA observations implies full synchronization of the network. Therefore, this scheme is intended only for application to wireless sensor networks synchronized.

After the results, the benefits of using RSS measurements in conjunction with TOA measurements are evident. It is in communications range below 30 meters, which is characteristic of wireless sensor networks. For long ranges, the hybrid scheme TOA / RSS has a performance equated to TOA.

3.2. TDoA/RSS

The hybrid scheme TDoA/RSS in [3] and [8] is proposed due to the difficulty of providing global synchronization in wireless sensor networks. In addition to the requirements related to the high accuracy of the central clock in sensor devices and low cost of network installation. The replacement of the measurements ToA with TDoA can mitigate the lack of synchronization.

In this scheme, with respect to the above scheme ToA/RSS, instead of the observations t_i de ToA, are used observations $T_i = t_i - t_1$, i = 2, ... , m of TDoA, to filter the clock unknown displacements between the clock of SN_0 and the clocks of the reference devices. TDoA sacrifices an observation and doubles the variance of the m – 1 remaining observations.

As in the hybrid scheme TOA / RSS have seen above, these benefits are short range communications. In the same way, for long range communications, the hybrid scheme TDoA/RSS has a performance equated to TDoA.

3.3. TDoA/AoA

TDoA/AoA hybrid scheme in [4] and [7] exploits the signaling and system resources for high accuracy in the position estimation in a low cost deployment.

Among the advantages found in this hybrid scheme includes qualities of both AoA and TDoA methods. In AoA, the position estimation process requires only a minimum of two base stations. When more than two base stations available to estimate the position, it is possible to achieve high accuracy of TDoA approach. In the case of the AoA dimensional design can solve the ambiguity problem TDoA approach. With TDoA approach, the mobile stations need not be synchronized with the base stations, leaving a single mobile station receiver.

In [4] describes the case of two base stations with accurate measurements. If TDoA and AoA measurements are accurate, it only takes the starting point of a base station and any other base station to estimate the location of a mobile station in this hybrid scheme.

We consider a case where BS_1 is the starting point, BS_2 is another base station, β is the AoA measurement in BS_1 in relation to the reference direction. For simplicity of analysis, a new coordinate system is defined. Using the AoA and TDoA measurements and the known coordinates (0, 0) from BS_1 and (x_2, y_2) from BS_2 is possible to obtain the location (x, y) from mobile station by solving the following equation

$$x = \frac{x_2^2 + y_2^2 - c^2 \cdot t_2^2}{2(x_2 + c \cdot t_2)} \tag{5}$$

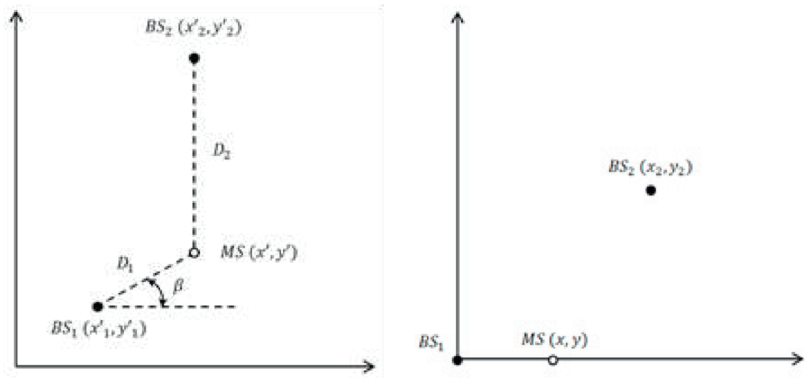
where t_2 is the TDoA between the pilot signals of BS_2 and BS_1, and c is the light speed. The Fig. 4 illustrates the above concepts.

3.4. ToA/AoA

ToA/AoA hybrid scheme in [5] is proposed for location in multipath environments, focusing more on where the line of sight path is not available for each base station involved in the position estimation of the mobile station.

The AoA and TDoA calculation is done jointly. When the signal experiences multipath propagation, AoA can't distinguish between line of sight paths of reflected or diffracted paths.

In this scheme, when detected several angles, the direction of line of sight more likely is the one with the shortest ToA. In addition, using the difference in ToA measurements, it is possible to improve the accuracy of the estimate of AoA and vice versa.



(a) (b)

Fig. 4. Time of Arrival illustrated; (a) 2-Base Stations; (b) 3-Base Stations

It is proposed radiolocation scheme of a single base station. It is assumed that around a mobile station has at least one base station with direct path of line of sight to it. It was proposed a method to distinguish between base stations with line of sight path and non-line of sight path through measurements of the standard deviation of the ToA. Thus, selecting the most likely base station line of sight, which have the lowest standard deviation of ToA. Once selected, this base station is used to estimate the position of the mobile station.

Thus, the steps for radiolocation scheme of a single base station are: 1) Selection of the base station with line of sight. 2) Identify the AoA and ToA multiple signal propagation paths of the mobile station. 3) Choose the smallest ToA and the corresponding AoA. 4) TOA provides a sphere centered at the base station, which is the mobile station. AoA provides a line originating from the base station on which the mobile station is located. The intersection of the sphere and the line forms an estimate of the position of the mobile station.

4. Comparison and discussion

After studying the various position estimation techniques, both single estimation techniques as hybrid schemes, is possible to list the advantages and disadvantages.

In [1], [2], [9] and [10] we begin with single estimation schemes, which have the advantage of performing position estimation from a single approach. Regularly in a two dimensional space is necessary to have three base stations to estimate the position of a mobile station. AoA allows this work by using only two base stations. Among the disadvantages we can find special hardware requirements of a receiving station, which regularly consists of a set of aligned antennas that allow such calculation. TDoA has the advantage of not requiring very complex hardware, commonly a microphone and speaker. The need for multiple measurements to calculate the transmitter becomes a major disadvantage. ToA breaks with the disadvantage of TDoA it does not need so much information to estimate the location of a mobile station and to obtain a more accurate estimation. This is achieved by synchronizing base stations and mobile stations, such synchronization must be highly accurate, which becomes a disadvantage. Finally, we have the technique of RSS. In this technique the sensors do not require additional hardware, since all the sensors must be able to obtain this measurement, have little impact in terms of energy consumption and cost. The disadvantage is that measurements are highly susceptible to physical obstacles, signal reflection or absorption, besides the fact that the signal tends to be patchy. Usually RSS is together with signal propagation models that improve the accuracy of the measurements.

In [3], [4], [5], [6], [7] and [8] we analyze hybrid schemes which facing disadvantages of single estimation techniques by merging information from different single estimation schemes. This is achieved by obtaining the benefits of more than a single estimation scheme. A major disadvantage of hybrid schemes is the impact on the computational cost, since the measurement is now done from more than one approach and possibly special hardware is now more robust and expensive. Both ToA/RSS and TDoA/RSS have similar advantages in terms of the location of devices in the vicinity of reference devices. ToA achieve estimation measurements most accurate that TDoA, but only applies to wireless sensor networks with full synchronization. Both maintain an improved estimate regarding its single estimation techniques in short communication ranges. TDoA/AoA achieves high accuracy in position estimation with low cost implementations. Combines benefits as the minimum requirement of two base stations to estimate the position of a mobile station, which is in the AoA technique and the improvement in accuracy when there are a lot of base stations, found TDoA technique. Also, avoids ambiguity in TDoA measurements by AoA measurements and avoids the need for full synchronization between base stations and mobile station. ToA/AoA explores the solution to the line of sight between a mobile station and base stations that provide service position estimation. It handles the issue of multipath propagation of signals by the ToA measurements since AoA can't distinguish between line of sight and that are reflected signals. Maintain high accuracy measurements using ToA and the fact that of full synchronization network. Among the most notable disadvantage is the need for high precision clock synchronization, both base stations and mobile stations. In addition, special hardware and the necessary measurements to estimate the position carries a high impact on computing and energy consumption.

5. Conclusions

Sensor position estimation techniques have been a matter of research for several years. Many areas make use of these estimation techniques to improve the performance of their applications such as smart homes, search and rescue, object tracking, to mention a few. In [2], position estimation is studied from two different approaches: relative position and global position. For the former, the position can be seen related to a point of reference, such as a room (e.g. center of the room). For the latter, position estimation is performed related to a global coordinator, such as a GPS (Global Position System).

In this paper, we study two different approaches in position estimation techniques: single estimation techniques and hybrid schemes. The considered single techniques include AoA (Angle of Arrival), TDoA (Time Difference of Arrival), ToA (Time of Arrival) and RSS (Received Signal Strength). The presented hybrid schemes are based on data fusion to improve the estimation accuracy. We stress that that hybrid schemes tend to outperform single schemes.

The rest of the paper is organized as follows. In Section II, several single position estimation techniques (AoA, TDoA, ToA and RSS) are discussed. In Section III, several hybrid schemes for position estimation (ToA/RSS, TDoA/RSS, TDoA/AoA and AoA/ToA) are presented. In Section IV, we show a comparison and discuss two of the studied approaches from sections II and III. In Section V concludes the paper.

References

[1] Bachrach J, Taylor C. Localization in Sensor Networks. Massachesetts Institute of Technology.
[2] Mao G, Fidan B, Anderson B. Wireless Sensor Network Localization Techniques. Elsevier B. V. 2006
[3] McGuire M, Plataniotis KN, Venetsanopoulos AN. Data fusion of power and time measurements for mobile terminal location. IEEE Transactions on Mobile Computing; vol. 4, no. 2, pp. 142–153, 2005, 1536-1233.
[4] Li C, Zhuang W. Hybrid TDOA/AOA mobile user location for wideband CDMA cellular systems. IEEE Transactions on Wireless Communications; vol. 1, no. 3, pp. 439–447, 2002.
[5] Gu Z, Gunawan E. Radiolocation in CDMA cellular system based on joint angle and delay estimation. Wireless Personal Communications; vol. 23, no. 3, pp. 297 – 309, 2002.
[6] Kleine-Ostmann T, Bell AE. A data fusion architecture for enhanced position estimation in wireless networks. IEEE Communications Letters; vol. 5, no. 8, pp. 343–345, 2001.
[7] Thomas N, Cruickshank D, Laurenson D. Performance of TDOA-AOA hybrid mobile location system. In Procedings International Conference on 3G Mobile Communication Technologies; 2001, pp. 216–220.
[8] Catovic A, Sahinoglu Z. The Cramer-Rao bounds of hybrid TOA/RSS and TDOA/RSS location estimation schemes. IEEE Communications Letters; vol. 8, no. 10, pp. 626–628, 2004.
[9] ISO/IEC 24730-5. Information technology – Real-time locating systems (RTLS) – Part 5: Chirp spread spectrum (CSS) at 2,4 GHz air interface.
[10] Cosmic Gamma-Ray Bursts – a continuing mystery. Summer 1982/LOS ALAMOS SCIENCE.