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GPS-less location algorithm for wireless sensor networks

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Abstract

The node location problem in wireless networks has been a research interest in the last years. In environments where GPS is not an option (e.g., for consumption reasons or because there is no direct link with the satellite constellation), the estimation of a node position using only RF signals is not a trivial task. Although some other systems have been proposed (ultrasonic signals, IR, etc.), these require additional hardware that is only useful for location purposes. According to this point, some algorithms have been proposed for providing sensible position estimations in the presence of distance errors. These methods normally require heavy computational processes to overcome the presence of these errors or easily degrade when the distance measurements have a certain magnitude. This paper describes an algorithm to compute the location of a node in the presence of severe distance estimation errors and analyzes its performance and computational cost. To make the implementation of this algorithm feasible in wireless sensor networks, different optimization techniques are proposed, in order to speed-up the location estimation of a node, without losing its estimating power.

Keywords: Wireless sensor networks; Location algorithm; Noise immunity

1. Introduction

In the last decades, the number of mobile devices and applications (from PDA embedded cellular phones to wireless sensor networks) has boomed. The main reason for this is the availability of cheap wireless electronic devices which, when used with low cost microcontrollers, enables the appearance of low power communication nodes. In many wireless applications, apart from connectivity, some other characteristics, such as node location measurement, are desirable to provide a complete service:

- In wireless sensor networks, the system must not only provide the measurement of a certain magnitude, but its location as well. Let us suppose that this kind of network is used to measure the temperature in a building. The fact that sensor A measures a temperature of T degrees, is unmeaning if we do not know where this node is.
- In many medical facilities, the rapid location of doctors is needed to give a better service to patients. Wireless devices (PDAs or cellular phones) may be used to decide who should attend each emergency in this scenario [1].
- In large offices, where wireless LAN enabled laptops are heavily used to enable workers to move around, it is also useful to locate each laptop, to accelerate the search process of an employee [2,3].
- At airports or ports, there are huge stocks, where thousands of containers are kept. If these containers were provided with a wireless device, the port authority could track their position and the space management in these facilities could be eased [4].
- In Ad-Hoc networks, the geographical topology may be used to route datagrams more efficiently and to save battery power in every node [5–8].

For outdoor applications, existing GPS [9] provides very low errors in location estimation. However, it is not

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suitable for indoor applications or areas with dense foliage: as this system uses satellites as beacons, the signals that allow the target location come from space and obstacles, such as buildings, branches or leaves, attenuate them, preventing the location system from working. On the other hand, in wireless sensor networks, where power consumption is a major concern, the use of GPS nodes, which usually require large amounts of energy to work, is not recommended. Therefore, in these environments, some other kind of strategy is to be used. In this article, a new algorithm for node position estimation is presented. In Section 2, some of the methods used for node location are discussed. Section 3 describes the proposed algorithm, showing procedure for estimating the target's location. Several improvement strategies for this algorithm are proposed in Section 4 and a quantitative and qualitative performance analysis of this algorithm is shown in Section 5, comparing it with other methods. Conclusions are presented in Section 6.

2. Related work

Strategies for target location using wireless sensor networks fall into the following categories:

- Angle of Arrival (AoA) detection systems: this approach needs that each beacon has a directive antenna, which can be (mechanically or electronically) rotated around its axis. When one of the beacons detects a peak in the received power, it is assumed that the target is in the direction pointed by the antenna [10–13]. This location approach does provide a reasonably high accuracy but it is not suitable for wireless sensor networks, because it requires moving parts or complex antenna configurations, which make the nodes expensive.
- Time of Arrival (ToA) detection systems: these systems measure the amount of time a wave needs to get from a beacon to the target. Thus, the distances between the target and a set of known beacons can be used to estimate the actual position of the target [2,14]. For example, GPS uses the traveling time of an RF signal from a satellite to the receiver to establish its actual position. However, this kind of scheme only allows the use of RF signals when the distances are high (thus, the lapse of time of the traveling signal is noticeable). Indoors, or in places where the presence of obstacles reduces the operative range of the beacons, flight times are quite short, and very fast hardware is required to measure lapses of times that may be as short as 1 ns. In these cases, UWB hardware has been proved to be a powerful tool to measure ranges [15,16]. Nevertheless, these UWB circuits are usually more expensive that traditional narrow band RF transmitters and the hardware required to measure very short lapses of time needs very high frequency clocks, increasing the power consumption of the circuit. To avoid the drawbacks of RF range measurements, most approaches use ultrasonic waves, which are much slower. However, this makes them more sensitive to ambient noise and two different "communication" systems must be supported: the ultrasonic ranger and the RF interface used for synchronization and data sharing functions.
- Power of Arrival (PoA) detection systems: these systems use the power of the incoming radio signal to estimate the distance between the target and the beacon. The presence of obstacles will affect negatively to the measured power, so the distance estimation will not be accurate [1,17,18].
- Frequency of Arrival (FoA) detection systems: they are based on the Doppler effect: as the target moves, the signals it transmits suffer from a frequency deviation (called "Doppler shift"), which depends on the relative velocity of the emitter to the receiver. Thus, using several receivers, the exact position of the target and its velocity can be calculated [19,20].

The location procedures in wireless sensor networks are usually supported by a relatively large group of inexpensive nodes, which actively track the position of mobile nodes. However, the same infrastructure (a set of wireless sensors deployed throughout the region of interest) may be used to passively estimate the position of a target [21], whose trajectory must be tracked. This time, it is the own target's responsibility to emit some kind of signal (for simplicity, we shall suppose that the target sends a radio signal, which can be caught by the wireless sensors), whilst the nodes of the wireless network will simply measure this signal and try to cooperate to find the actual position of the target.

The ability of accurately finding the position of a certain node enables some more complex location algorithms, where the new calculated positions are taken as premises so that the location of other nodes in a network can be estimated [22]. Thus, we only need to know the position of some nodes (or establish automatically a reference system) to find the position of the nodes around the reference system, which will iteratively lead us to know the position of all the nodes in the network. Reusing this kind of information involves accumulating position estimation errors, which are propagated through the whole network. An erroneous estimation of the distance between two nodes will corrupt the position estimation for a certain node, which will invalidate the estimations that depend on this result. This is the reason why robust algorithms (such as the algorithm described in this article) are required, which provide higher accuracies in the presence of errors.

3. The proposed algorithm

3.1. Overview

The algorithm proposed in this paper is a distance-based location system, which exploits the recurrent data inherent in wireless sensor networks, in order to reduce the position estimation errors. This algorithm is based on a metaphor with the mechanical world: the nodes are considered to