WIRELESS SENSOR NETWORK LOCALIZATION IN 3D USING STEERABLE ANCHORS' ANTENNAS

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ABSTRACT

Wireless sensor network localization plays an important role in mobile computing. Moreover, Sensor nodes are often deployed non-uniformly in anisotropic WSNs with holes in various applications such as monitoring area terrain. The existence of holes will invariably affect the Euclidean distances between nodes and result in low accuracy of node localization. The proposed algorithm is suitable for four different topologies, including the semi-C-shape topology, the O-shape topology, the multiple O-shape topology and the concave-shape topology and is exceedingly accurate and efficient comparing with state-of-the-art methods in anisotropic WSNs with holes. Our results show that the error in horizontal plane is less than 0.25 m while in the Z-axis is less than 0.5 m.

KEYWORDS

Antenna, wireless network, Mobile Network, RSSI, Localization

1. INTRODUCTION

Wireless sensor networks (WSNs) are the one of the key means of advancing in application of surveillance and monitoring. Sensor network usually consisting of tiny nodes, beacons/ anchors and gateways. For many application localizations plan an important role in finding the position of the unknow nodes. Using connectivity information between sensor nodes without ranging (i.e., distance or angle) information. However, these approaches lead to larger localization errors.

It is costly to equip each sensor node with a GPS unit, especially for large scale WSNs. A feasible method to localize unknown nodes is to use several anchor nodes, which are equipped with GPS units among unknown nodes and broadcast their current locations (anchor points) to help nearby unknown nodes with localization [1-3]. Since the anchor node is not as energy constrained as an unknown node and the localization accuracy also can be improved by GPS. Moreover, the size and resources of an anchor is much larger than the sensor node and thus it is much easier to install a GPS unit on it and perform complex operations [4,5]. Therefore, this viable solution could be used. The anisotropic WSNs with holes invariably exist in practice. For example, in military applications, due to geographical obstacles, the nodes cannot be deployed uniformly over the field. Even though the initial network is isotropic, the unbalanced power consumption between nodes will likely result in holes in the network. Finally yet importantly, signal interference may give rise to communication failures, which create holes in the network.

2. RELATED WORK

Many techniques have been proposed to determine the locations of the nodes in WSNs. A general overview of state-of-the-art localization methods is available in [6-9]. In this section, existing works under both the range-based and range free context are reviewed.

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In range-based methods the distances between nodes can be estimated directly. The node locations can be achieved using the trilateration method or the maximum likelihood algorithm [7-11]. However, this method requires an efficient node synchronization algorithm that is hard to implement in small cheep nodes.

The TDOA method does not need to know the transmission time of a signal [12-16] and different signals are transmitted at the same time. Due to different signal propagation speed in the air, the two signals arrive at the receiving node at different time. The distances between nodes can be obtained by signal time difference of arrival. The TDOA method applies the trilateration method or the maximum likelihood algorithm to obtain accurate coordinates of the nodes. The AOA method is a localization method based on angle techniques [17,18]. It allows a node to estimate relative directions between neighbours by setting an antenna array for each node and using the triangulation method to obtain precise coordinates of the nodes.

In range-free methods the trilateration method is used to obtain the node locations. The amorphous algorithm is similar to the DV-Hop algorithm and has three steps. In the first step, the unknown node estimates the minimum hop count between itself and each anchor. In the second step, the communication radius of a node is replaced by the hop distance to obtain the distances between a node and each anchor. In the third step, actual coordinates of the nodes are calculated using the trilateration method or the maximum likelihood algorithm [19]. In the approximate point-in-triangulation test (APIT) algorithm [20], the node selects three anchors to form a triangular region and a circular test is used to determine whether a node is located inside the triangle area. The triangles which met the conditions that are collected and their intersections are found. The next step is to calculate the centre of gravity of the intersections so as to obtain the node locations.

3. ALGORITHM DESIGN

3.1. Motivation

The existing localization methods suffers high localization error, energy consumption and computation resources. The range-based methods show more accuracy compared to range free methods. In contrast, the range-based methods have the following problem:

1) *Received signal strength indicator (RSSI):* the RSSI suffers from multi path problem, which creates error in distance measurement by constructive interference (i.e. shorter distance measured) or distractive interference (i.e. longer distance measured). Moreover, RSSI suffers from attenuating obstacles, which gives wrong distance estimation and may leads to miss angle calculation if no other method is used for angle measurement [21].
2) *Time of arrival (TOA):* the TOA suffers from miss synchronization among WSN nodes. In contrast, to improve the synchronization each node must be equipped with advanced clock generator that is resource consumption and leads to higher cost.
3) *Time difference of arrival (TDOA):* the TDOA shows promising idea but lack implementation because it needs two different types of signals. Each signal mush has its own receiver, which increase the node size, cost and energy consumption. If TDOA can be used with the same signal, it will be much better and cheaper [22-24].
4) *Angle of arrival (AOA):* the AOA is the best way to measure the angles between nodes. However, attaching an antenna array with each node will increase the node size, cost and energy consumption. Moreover, to transmit a packet per each neighbouring node gives high energy consumption and delay.

In order to improve the localization performance by minimizing the localization error and decrease the nodes energy consumption, cost and size, this paper targets shifting the complexity of the localization system to anchors. This make the sensor nodes cheaper, more energy saving and has low required resources. In other words, we aim to benefit from the anchors advanced capabilities and power to achieve higher accuracy (i.e. less than 0.2 m) and cheaper nodes.

3.2. System Model

We consider *M* distributed WSN nodes geographically collocated with *N* anchor nodes in an 3D indoor location. Anchors are powerful nodes with no battery constrain and high resources. Each anchor is equipped with GPS receiver and steerable antennas.

In contrast, each sensor node is a cheap small node that is equipped with single half-duplex transceiver with one antenna. We assume high density of nodes as the case in typical wireless sensor network applications. However, a multi hop communication is allowed. All nodes are considered to be static. Each node is battery powered, resource constrained. Deployed sensor nodes are homogenous in terms of hardware and initial battery power. Over time, the sensor nodes may be left out with non-uniform level of energy.

The indoor location consists of multi obstacles that lower the received signal level and leads to multipath. Moreover, the 3D distribution of nodes may contain one or more of four different topologies, including the semi-C-shape topology, the O-shape topology, the multiple O-shape topology and the concave-shape topology i.e. network holes.

3.3. The Proposed Protocol

In this paper, we propose a localization method based on range and angle measurement in three phases. The first phase is measuring the neighbouring range using RSSI from each anchor at minimum transmit power. The second phase is measuring the neighbouring angle using a TDOA between two signals from each anchor one of them is omni-directional, the other is sweeping signal start at the north direction, and sweeps horizontally counter clockwise in a constant speed [25, 26]. This process is repeated in the vertical direction in case of 3D localization of the nodes. Finally, we consider all neighbouring nodes know their location with high accuracy and use any other method that depends only on RSSI to locate the non-neighbouring nodes with moderate accuracy.

3.3.1. RSSI at Minimum Transmit Power (MRSSI)

Each anchor starts to distribute the range location by transmitting a packet with its maximum power containing its ID and location, which enables all one hop nodes (i.e. neighbouring nodes) to receive the signal. The packet is then followed by a long stream of bits with decreasing power to minimum, which enables neighbouring nodes to identify the transmit power level before losing the signal. This method is a modification to the RSSI, which enable sensor nodes to measure distance without multipath components of the signal as shown in figure 1.

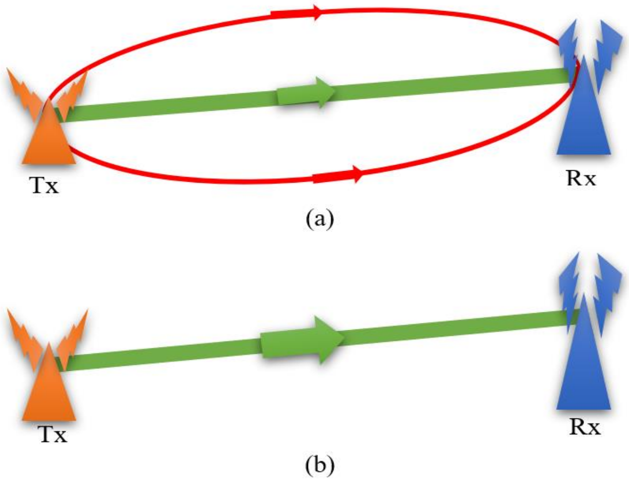

Figure 1. (a) multipath effect at RSSI and (b) no multipath at minimum RSSI

3.3.2. Angle Measurement using TDoA

After measuring the distance accurately, each anchor transmit two signals with variable time difference depends on the angle of between the anchor and the node. The first signal is an omni-directional packet with its maximum power containing its ID and location in order to be received by all neighbours and marks the time start. The second signal is a long stream of bits in a single beam swiped using the anchor steerable antennas horizontally counter clockwise from the north direction as shown in figure 2.

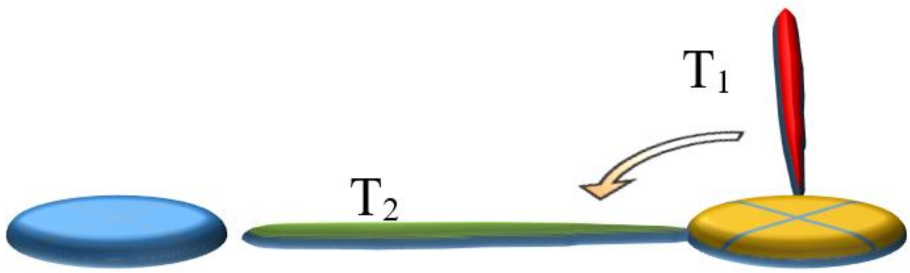

Figure 2. anchor steer the antenna beam. Each node (blue) receive only when the beam is directed towards its location.

TDOA is used to compute the azimuth from the time differences (T_2 –T_1), where T_1 is the omni-directional (i.e. broadcasting) marker signal and T_2 is the narrow beam reception as in figure 2. For 3D localization, this process is repeated in the vertical direction to compute the elevation angle.

3.3.3. Non-Neighbouring Nodes

In this paper, we refer to all nodes that do not have at least three neighbouring anchors as non-neighbouring nodes. The non-neighbouring nodes cannot reach a high accuracy final location using the anchor nodes only. Then they may use the location information from another accurate node. The range is measured using RSSI at minimum transmit power for more accuracy. However, the position calculation is done using proximity based map (PDM)[27,28].

4. PERFORMANCE EVALUATION

4.1. Experimental Setup

We evaluate the performance of the proposed method using custom-made Matlab 2016b simulator. We consider a system of 10 anchors and 100 nodes uniformly distributed in a hall of 100×100×3 m. Table I summarizes the simulation parameters.

TABLE I. Simulation Parameters

Definition	Value
Hall dimensions	100×100×3 m
min. RSSI error	1 m
single hop range	50 m
Number of anchors	10
Number of sensors	100
Number of sectors in angle calculations	256

4.2. Localization Error for Neighbouring Nodes

In order to calculate the localization error, we first build the WSN distribution as shown in Figure 3. For range measurement, each node receives the mRSSI from its neighbouring anchors then preforms the range calculations. For angle measurement, each node measure the time difference from receiving the anchor's omni-directional packet and receiving the anchor's directional packet, which contains the angle ID. In addition, measuring the time difference between these two packets enables the node to preforms the angle calculations. The position of each node is the position of the anchor in the 3D (i.e. X,Y and Z) in addition to the range component in each direction. The node treats the mean of the calculated positions from all neighboring anchors as the final position. On the other hand, the estimated error is the standard deviation of these calculated positions.

Figure *shows the estimated positions of all nodes compared to the original positions. Moreover, the standard deviations in both the X- and Y-axis are shown in Figure 4. Figure 7 shows the zoomed version of Figure 4, which contains two nodes with their original positions, the estimated positions and the estimated error in XY plane. Finally,*

Figure and Figure 6 shows the localization error in X-,Y- and Z-axis for all the 100 nodes. The error in horizontal plane is less than 0.25 m while in the Z-axis is less than 0.5 m.

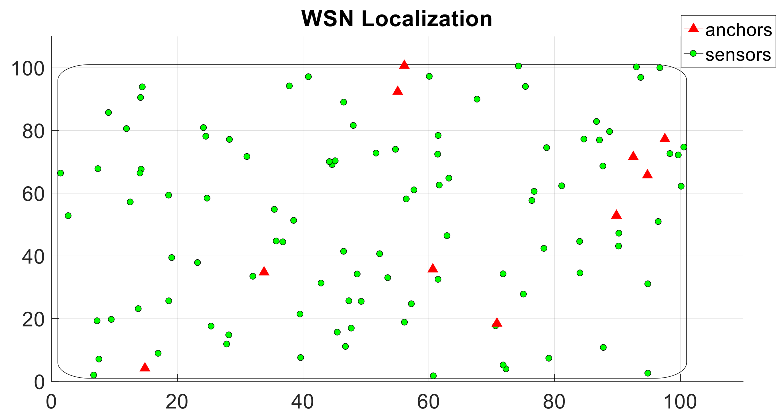

Figure 3. WSN anchors (red) collocated with nodes (green) in a uniform distribution.

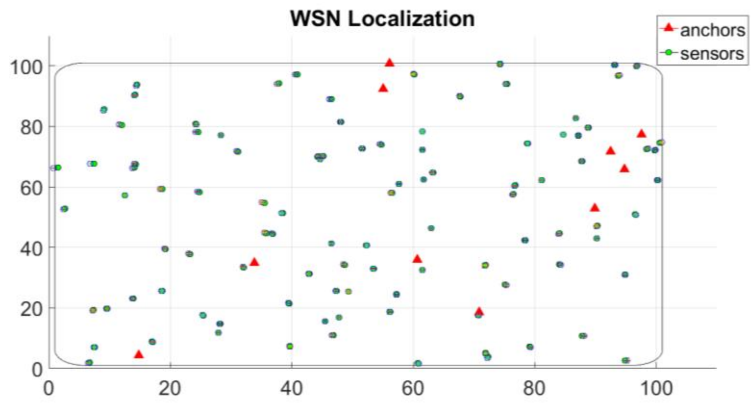

Figure 4. the localization error of nodes (green) in a uniform distribution.

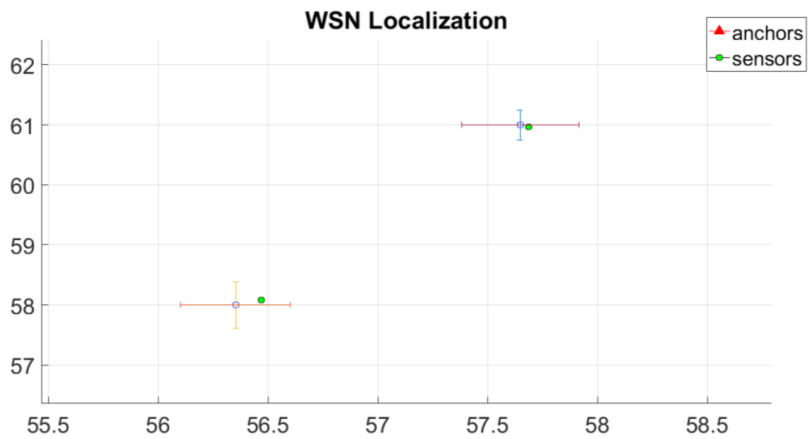

Figure 5. zoomed version of the localization error of nodes (green) with small localization error and high standard deviation.

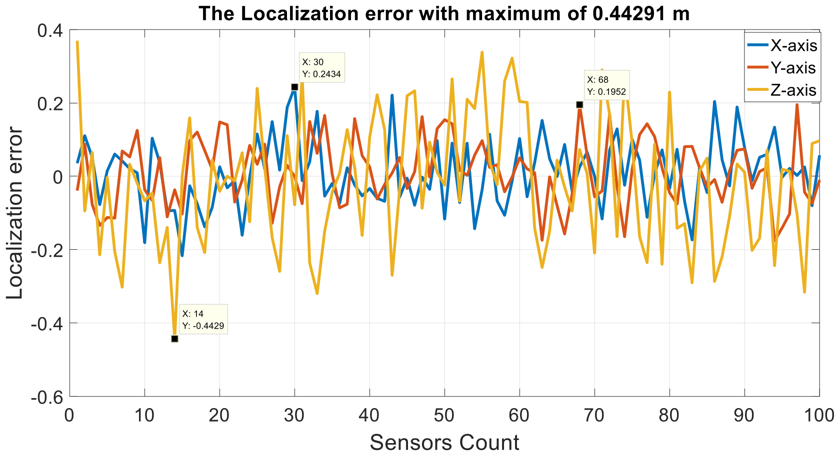

Figure 6. the localization error in each axis showing high z-axis error compared to x- and y-axis.

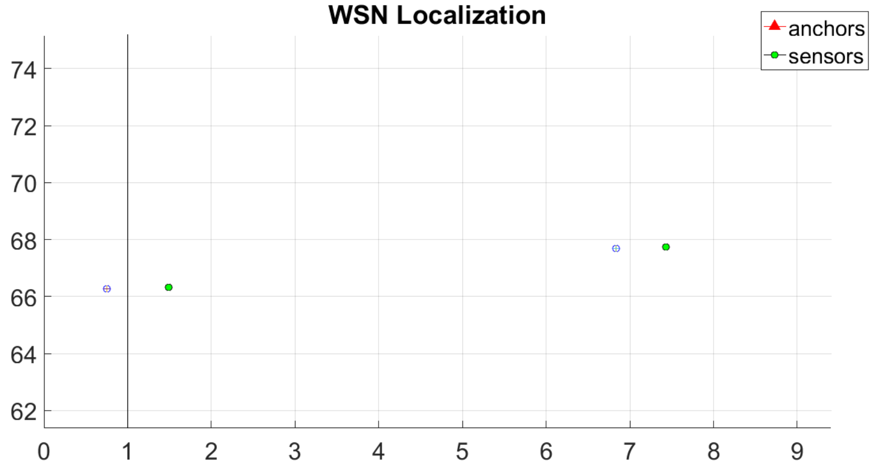

Figure 7. zoomed version of the localization error of non-neighbouring nodes (green) and their estimated positions (blue).

However, some sensor nodes are randomly located far from all anchors. Such nodes are non neighbouring nodes and performs a modified PDM with minimum RSSI (mRSSI) instead of RSSI for increased accuracy.

Figure shows the positions of two of these nodes with their estimated positions. The localization error is less than 1 m.

5. Conclusions

In this paper, we have presented two new concepts for sensors localization in 3D. On one hand, we have presented the range calculation method mRSSI, which calculates the RSSI at the minimum transmit power to avoid the multi-path error in calculations. On the other hand, we have presented the angle calculation method in azimuth and elevation using TDOA. Our results show that the localization error is less than 0.25 in horizontal plane and 0.5 in Z direction. In addition, our proposed localization algorithm simplify the sensor node required capabilities to be a small simple node with single transceiver and single antenna.

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