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Novel Localization of Sensor Nodes in Wireless Sensor Networks using Co-Ordinate Signal Strength Database

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Abstract

The objective of the proposed system is to remove the dependency of radio irregularity problem in localization of static nodes in wireless sensor networks. Most of the existing range free localization algorithms are mainly suffered by the radio irregularity problem. The value of the degree of irregularity always affects the accuracy of the localization performance. The idea of this work is to calculate the location of sensor nodes using co-ordinate signal strength database. In wireless sensor networks, each flying anchor node will be equipped with a GPS receiver. The flying node calculates its position, which is transmitted as a beacon message to the sensor nodes. Upon reception of the beacon messages, each static node calculates its location using the 'Sensor Position based on Co-ordinate Signal Strength Database' (SP-CSSD) algorithm. The proposed idea increases the accuracy of the localization algorithm with minimal computational overhead and computational time.

"Keywords: wireless sensor networks; radio irregularity; co-ordinate signal strength database; SP-CSSD algorithm;"

1. Introduction

Wireless sensor networks (WSNs) can be helpful in many different areas such as ocean navigation, underwater monitoring, industrial automation and control, military surveillance, medical care, environmental monitoring, public service and home automation applications, etc. Design, analysis and construction of the WSNs have been a major research topic in the computer and communication fields [1]. In some significant applications of wireless sensor networks, for example pressure and temperature monitoring in boilers or fire detection in forest areas, data collected by the sensor nodes should include the information about the physical locations of the event i.e. the location of the sensor node. Otherwise, the gathered data will be useless. Some constraints like size of the sensor node, power,

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and computing capabilities, radio irregularity of both static sensor nodes and flying anchor nodes in WSNs, the accuracy of the localization algorithm is not in the satisfactory level[2], [3].

The localization mechanisms can be classified as range-based approaches and range-free approaches. The range-based approaches determine the node position based on distance or angular information acquired using the Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA), and Received Signal Strength Indicator (RSSI) techniques [4], [6], [8]. Although such range-based methods are reasonably accurate, each sensor node must be equipped with expensive hardware. Conversely, range-free approaches establish the sensor node location without the need for ranging measurements [2], [3], [5], [7]. However, these mechanisms typically require a large number of beacon nodes, a larger radio range, and specific deployments or the means to communicate among neighbouring sensor nodes to obtain a satisfactory accuracy.

This paper mainly focuses on how to ignore the impact of the radio irregularity problem in localization. The work mainly based on the co-ordinate signal strength database. The signal strength of all points in the transmission range boundary of each sensor node will be calculated based on the signal strength-distance relation. The calculated signal strength data will be stored in a database (memory) and will be shipped with the sensor nodes. Upon reception of the beacon message from the flying anchor, each node can refer its own co-ordinate signal strength database and calculates its own location using the SP-CSSD algorithm.

The rest of the paper is organized as follows. Section 2 describes the related work focused on the effect of radio irregularity. The concept of flying node, static node and transmission range boundary is discussed in section 3. In Section 4, the concept and development of the co-ordinate signal strength database is explained. Section 5 gives the working principle of the SP-CSSD algorithm. Section 6 compares the proposed algorithm with existing algorithm. Finally, Section 7 gives the concluding remarks.

2. Related work

Radio irregularity is a common and non-negligible phenomenon in wireless sensor networks. It results in irregularity in radio range and variations in packet loss in different directions, and is considered as an essential reason for asymmetric links as viewed by upper layers in the protocol stack. Several empirical studies say that the radio range varies significantly in different directions and the percentage of asymmetric links in a system varies depending on the average distance between nodes. The spherical radio patterns assumed by many localization algorithms such as [3] may not approximate real radio properties well enough and hence may lead to an inaccurate estimation of sensor node calculation.

Radio irregularity can also affect the performance and even correctness of networking. Actually, the impact of radio irregularity is not only confined to the MAC and routing layers, radio irregularity also influences other protocols, such as the localization, sensing converge and topology control protocols. Localization protocols such as DV-Hop and Centroid assume a spherical radio range. The performance of such protocols degrades when the radio range becomes irregular. The sensing coverage scheme assumes that sensing and communication ranges are spherical. In the presence of radio irregularity, they might not be able to guarantee full coverage and blind points would occur. So the dependence on radio irregularity leads to the degradation of the accuracy of any localization algorithm.

In [9], Zhen, Zhao, Cui, Geng, Lidong, and C heng proposed the method of using the *known co-ordinate database* method for localization of the nodes in the wireless sensor networks. But this method is only suitable for localizing the nodes, which are distributed in a grid structure i.e. the distance between any two neighbouring nodes is regular. Also this method has the overhead of passing location information between the nodes in the grid network. This causes each static node to consume the unnecessary power in the wireless sensor networks where the uninterrupted power supply is not possible.

3. Flying anchors, static nodes and transmission range boundary

The proposed method assumes the environment where the static nodes are deployed in the area to be sensed. The anchor nodes will fly through the sensing area and broadcast the beacon messages in a pre-defined time interval. The static nodes can receive the beacon messages within the transmission range boundary.

3.1 Flying Anchors

Each flying anchor is equipped with a GPS receiver or some other form of localization device such that it can identify its current location at all times. The flying nodes have sufficient energy to both fly and broadcast during the localization process. The anchors can either fly under their own power or be carried by some other vehicle such as a helicopter, a balloon, a low-flying Unmanned Aerial Vehicle (UAV), or an aerial robot.

3.2 Static nodes

The sensor nodes deployed in the sensing area will collect the data like temperature, pressure, etc., from the environment and transmit to the control station. These nodes are known as static nodes. These nodes should include their location details to the base station in order to complete the intended objective. As soon as any anchor node comes within the communication range of a static node, the static node will receive the beacon message transmitted by the anchor node. Each beacon message contains the current location information of the flying anchor. Static nodes will calculate their own physical location using beacon message broadcasted by the anchor nodes. All the static nodes have identical transmission range, computational ability.

3.3 Transmission range boundary

Both the static nodes and the flying anchors have their own transmission range boundary i.e. the region within that these nodes can be reached. Only within the transmission range of a static node, it can receive the beacon message broadcasted by an anchor node. Beyond the transmission range boundary, a static node cannot receive any beacon message broadcasted by the flying anchor. The existing localization algorithms assume the transmission range boundary as a perfect circle for their localization calculations. But the proposed method overcomes the dependency of the shape of the transmission range. The transmission boundary of each node can be represented by a circle of radius ‘r’. The sensor node will be at the centre of the transmission range.

4. Co-ordinate signal strength database development

The main aim of this paper is to reduce the impact of radio irregularity in localization algorithms. Each sensor node has its own communication range boundary. The sensor node’s centre is denoted as S(0,0,0). The maximum radius of the transmission range boundary of the sensor node is R. The point P_R lies on the circumference of the transmission range boundary of the sensor node at the maximum distance of d_R from the centre of the sensor node. The points in the transmission range boundary of a sensor node have various signal strengths depends on their distances from the centre of the sensor node. Using the signal strength- distance relation, we can calculate the distance of all points in the transmission range of the sensor node and store in a database. This database is referred as co-ordinate signal strength database. Each sensor node can be shipped with the co-ordinate signal strength database before deployed in the sensing area.

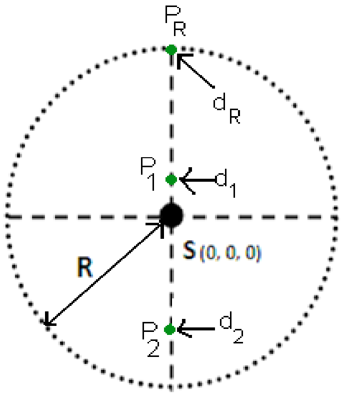

Fig. 1. Fundamental diagram for constructing a co-ordinate signal strength database

The distance of each point in the transmission range is calculated and stored in the simple database of the sensor node. For example, P_1 is a point in the transmission range boundary of the static sensor node at the distance d_1 from the centre of the sensor node and the point P_2 is located at the distance d_2. Similarly, we can calculate the distance of all points based on their signal strength and store in the memory in the sensor node. The same process can be repeated for all sensor nodes prior to the deployment of the sensor nodes. The following table shows a sample co-ordinate signal strength database.

Table 1: A general co-ordinate signal strength database

Co-Ordinate of points in transmission range	Signal Strength (dB)	Distance (m)
$S(X_0,Y_0,Z_0)$	SS_{MAX}	0
$P_1(X_0+d_1, Y_0+d_1, Z_0+d_1)$	SS1	d1
$P_2(X_0+d_2, Y_0+d_2, Z_0+d_2)$	SS2	d2
$P_R (X_0+d_R, Y_0+d_R, Z_0+d_R)$	SS_{MIN}	d_R

where SS_{MAX} is the maximum signal strength (at the center of the sensor node)
SS_{MIN} is the minimum signal strength (at the circumference of the transmission range)
SS_1 is the signal strength at the point P_1 & SS_2 is the signal strength at the point P_2

5. Working principle of SP-CSSD algorithm for localization

After deploying the sensor nodes in the area of interest to be sensed, the flying nodes will be launched for identifying the location of each sensor node. The flying nodes will deliver the beacon messages in a specified time period. When a flying node enters into the transmission range boundary of a static sensor node (i.e. the distance between flying node and static sensor node is less than or equal to R), the static node can receive the beacon message broadcasted by the flying anchor node. Upon reception of a beacon message from a flying node, a sensor node can calculate its own position using the SP-CSSD algorithm.

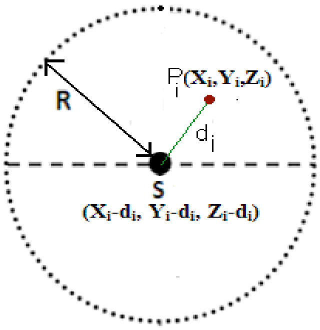

Fig. 2. Sensor location calculation

5.1 Steps involved in the SP-CSSD algorithm

- The flying node will receive its position information (X_i,Y_i,Z_i) through the GPS device attached with it. The flying node will broadcast the beacon message in a specified time period.
- Each beacon message contains the position information i.e. the current location of the flying anchor node, which is obtained through the GPS device.
- When the flying anchor node enters into the transmission range boundary of a sensor node, the static sensor node can receive the beacon message from the flying anchor and calculates the signal strength of the beacon message it received.
- The sensor node will refer its own co-ordinate signal strength database to map the received signal strength of the point of reception P_i and finds the distance (d_i) to that point.
- Once the distance of the point P_i in the transmission range boundary is found, the sensor node can calculates its own position as S $(X_i-d_i, Y_i-d_i, Z_i-d_i)$.

All the static nodes in the sensor network can calculate their locations as described above.

6. Results and discussions

Many of the existing localization algorithms are highly affected by the radio irregularity problem. Those algorithms assume the transmission range boundary of the static sensor nodes as a perfect circle. So the accuracy of the location information will be affected as the circumference of the transmission range is irregular in real time [3]. In the proposed method, the localization process is completely independent of the shape of the transmission range of the sensor node which leads to the success of the SP-CSSD algorithm. The existing algorithms execute complex calculations to find the location of the sensor nodes and thereby increasing the power consumption, which becomes the bottleneck in environments where uninterrupted power supply is not possible. Many existing systems require at least two beacon messages to proceed with their location calculation, but the proposed method can execute the localization algorithm with one beacon message. The proposed system and existing system [3] are tested with NS2 simulator and simulation results are compared. The comparison result is given in figure 3 and figure 4. The parameters like minimum number of beacons required for localization, average location error (in meters), and average localization time (in seconds) are considered for comparison.

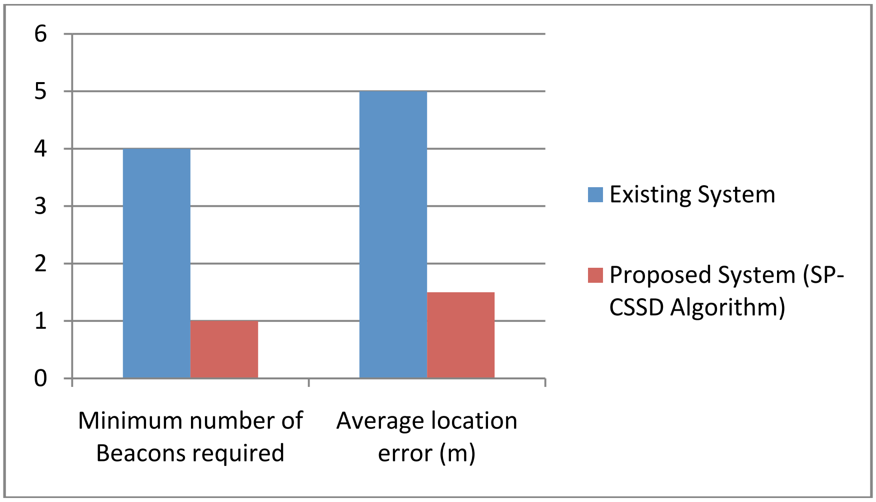

Fig. 3. Comparison of minimum number of beacons required and average location error between existing system and proposed system

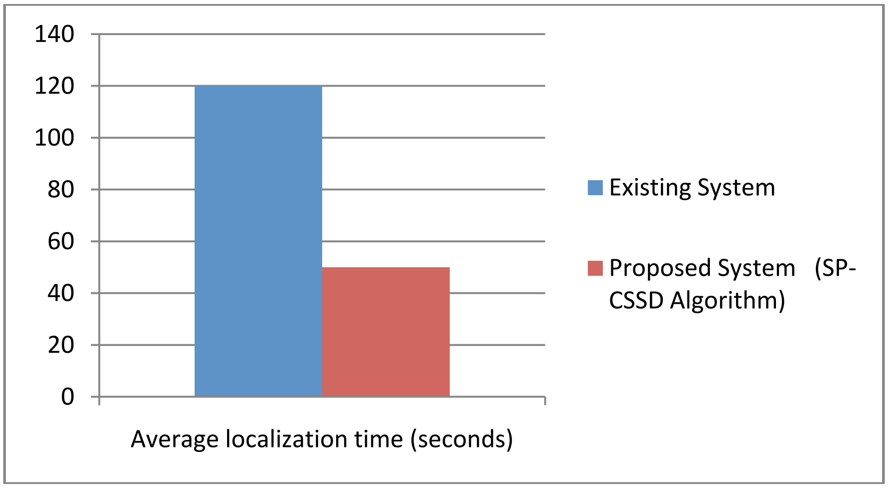

Fig. 4. Comparison of average localization time between existing system and proposed system

7. Conclusion

The proposed method utilizes the co-ordinate signal strength database system and overcomes the radio irregularity problem. Here distance to all the co-ordinates in the sensor's communication range boundary is calculated using the signal strength-distance relation before the deployment of the sensor nodes. The calculated distance of the points is stored in a co-ordinate signal strength database and shipped with the sensor nodes. The flying anchor broadcasts the beacon message to the sensor node, which calculates its position as explained in the SP-CSSD algorithm. The proposed algorithm has less computational overhead and independent of the radio irregularity problem, which could lead to the less power consumption and increased accuracy using a single beacon message.

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