

Accurate Localization Technique using Virtual Coordinate System in Wireless Sensor Networks

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Abstract—The problem of localization, i.e., to physically locate the nodes in Wireless Sensor Network (WSN) is a challenging one. In spite of this, it plays an extremely crucial role in many next generation pervasive and sensor network functionalities. Considerations while practically implementing a network, such as the small size, cost and power constraints of nodes rule out the dependence on GPS (Global Positioning System) on all nodes in these networks. Although many network localization systems have recently been proposed and evaluated [1, 2, 3, 4 and 5], but most of them suffer from requirement of extra hardware with either all or some of the nodes. Moreover, many hardware independent schemes suffer from inaccuracy of the location information generated.

In this paper we propose design and implementation of an Accurate Localization Technique (ALT) using Virtual Coordinate System (VCS) in WSNs. ALT provides a pin point location information to the Sensor Nodes (SNs) without any expense of cost or power. Thus, the protocol is energy efficient and is implemented with a negligible load over the SNs. It also introduces the concept of location aware IDs for SNs. This will be highly advantageous for applications with large number of SN deployments where maintaining a unique ID for each node is difficult.

Index Term—WSN, Location Aware, ALT, VCS

I. INTRODUCTION

'Localization' is a term that can be defined as the determination of the exact physical location of each Sensor Node (SN) in a geographic map or to find its relative location from a topology map in a given network structure. Localization is considered to be one of the fundamental problems in a Wireless Sensor Network (WSN). One example to be quoted here is a WSN application in which we would like to know the exact location of the occurrence of the desired event. This requirement may arise in case of battlefield surveillance, habitat monitoring, forest fire applications or other disaster management applications. There are numerous applications that require not only location awareness of WSN nodes rather, more specifically, the relative locations of WSN nodes [11, 9]. Let us consider geographic routing in WSNs. There are many different geographic routing algorithms, such as GPSR (Greedy Perimeter Stateless Routing) [7], GEDIR [10], GFG [6],

and GOAFR [8], which are specifically designed to satisfy different applications of WSNs. All of them use sensor nodes' relative locations, at least, as their addresses, and then select a neighbor with the shortest projected distance. After that, these protocols forward packets in a greedy or other manner toward to the destination. In order to implement these protocols, we need to know the locations of nodes in their WSN. Other examples include applications in security wireless sensor networks, which intend to protect WSNs against different attacks to disturb the network, such as wormhole attack. Localization can help to develop detection and defense mechanisms against such attacks by measuring irregular relative positions of nodes in such applications to detect those attacks that from are inside of the WSNs.

High efficiency, robustness, and scalability are some of the major advantages imparted by location-based routing protocols in addition to their suitability to be deployed in wireless multi-hop networks [12]. Besides, location-based routing protocols can save significant energy by eliminating the need for route discovery [13, 14 and 16] and improve caching behavior for applications where requests may be location dependent [15].

Sometimes pin point location information is required, rather than a general idea about the event occurrence. That is, different applications need different granularity of location information. Geographic routing may only need the relative positions of nodes based on the shape of the network, while other applications such as healthcare applications and certain others mentioned previously, may require WSNs to report physical locations of particular nodes as accurately as possible.

In this paper we propose ALT, an Accurate Localization Technique using Virtual Coordinate System (VCS) in WSNs. The establishment of VCS is mainly the responsibility of a BS. Most important feature of the protocol is the fine grained location information it provides to the nodes in a highly energy and cost efficient manner.

Rest of the paper is organized as follows. Section II summarizes related work. In Section III the useful system model is introduced. In Section IV we present the implementation of ALT using VCS in detail. In Section V we will discuss the effectiveness of proposed protocol.

Finally, we conclude our paper and draw directions for future work in Section VI.

II. RELATED WORK

Two simple methods for achieving localization in a WSN are manual configuration and the Global Positioning System (GPS) [17]. However, none of the methods scales well and both suffer from inherent physical limitations. For example, the SNs equipped with GPS receivers are costly both in terms of hardware and power requirements. Furthermore, the requirement of line-of-sight between the receiver and the GPS satellites in GPS enabled applications makes it unsuitable for deployments that are indoors, underground, or in the presence of obstructions such as dense vegetation, buildings, or mountains blocking the direct view to these satellites [18]. GPS solves the problem of localization in an outdoor environment. However, for large sensor networks, practical considerations such as size, form factor, cost and power constraints of the nodes preclude the use of GPS on all nodes [4].

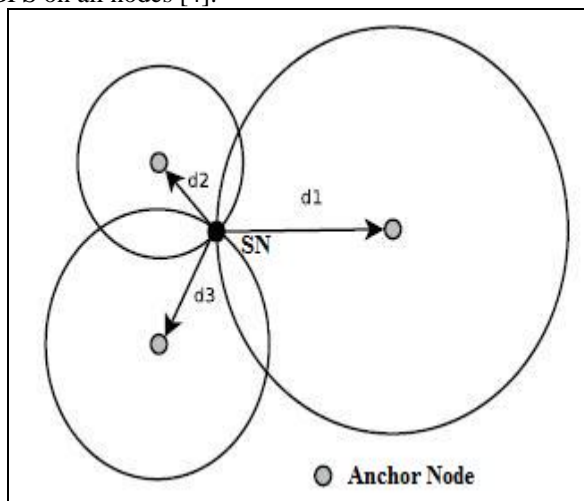


Figure 1 Triangulation

Localization algorithms, with no GPS device requirements, can be classified as follows:

- **Triangulation:** This approach uses trigonometry for determination of location of a sensor node, i.e., lateration or angulation. In this method, some of the nodes called 'Anchor nodes' are equipped with a positioning device such as a GPS and thus, are assumed to know their own locations. These nodes periodically broadcast their location information to all of their one-hop neighbors. Lateration [21] is the calculation of position information by SNs based on the distance estimated from the anchors. Three distance measurements are required to be localized in a 2D plane. In Figure 1, for example, a node calculates its own location by using the estimated distances from the three nearby beacons. The distance estimation can be based on, either of, the relative signal strength (RSSI) or time difference of arrivals (TDOA). Equivalently,

the angulation approach uses the angle of arrival (AOA) information from the three anchors to find the relative location of a sensor node.

- **Range-free localization:** This approach is used to obtain a coarse-grained location estimate by simply figuring out what beacons are nearby [19, 20]. Instead of estimating either the distance or angle of arrival from anchors, this approach relies on the mere presence of anchors.

In addition, several schemes [20, 21] have been proposed for multi-hop localization, in which the number of anchors is insufficient to directly localize all the nodes in the WSN.

The above mentioned techniques suffer from one or both of following problems:

- **Special hardware Dependence:** Techniques that depend on measuring ranging information from signal strength [2], time of arrival [17], time difference of arrival [25] or angle of arrival [24] require hardware that is typically not available on sensor nodes. Adding the required hardware increases the cost and size of the nodes.
- **Particular network topology Requirements:** Most techniques require seed nodes (termed Anchor nodes or beacons earlier) to be numerous and evenly distributed in order to cover the whole network. But prior deployment of seeds is not possible in many sensor network applications (for example, sensor nodes dropped from plane over a hostile territory). Hop count based techniques [22, 23] avoid the need for a large number of seeds, but instead require dense and uniform node distribution.

These limitations call for a method of localization which requires no special hardware installation, is accurate and energy efficient. In this paper we propose an Accurate Localization Technique (ALT) that comes to our rescue from these problems. It virtually creates a coordinate system over the network, such that each SN gets its accurate position on the field. It induces no extra hardware requirements (such as GPS etc.) and relieves the network from any kind of extra effort. This makes the protocol highly size, cost and power efficient.

III. SYSTEM MODEL

In ALT, we have assumed that all sensors are distributed in a uniformly randomized manner in a square field of side 'a', and the network has the following properties:

1. There exists a unique BS, located far away from the network.
2. All sensors cannot move after being deployed.
3. Network is homogeneous i.e. all sensor nodes are equivalent, both in terms of computation and communication capacity.
4. The network is location unaware i.e. physical location of nodes is unknown in advance.

The BS mobility is desirable in many energy efficient approaches [27, 28] but in case it's not possible because of any reason, the protocol provides a simple cost effective alternative to this. The second assumption

about lack of mobility of SNs is typical for WSNs employing some clustering or grouping methodology for network organization. Nodes that travel frequently in the network may degrade the group quality, because they alter the organization of nodes in their group and may require a lot of topology maintenance efforts. Assumptions like node homogeneity and prior location unawareness are rather advantageous as far as hardware cost and resource requirements are concerned.

ALT provides a pin-point granularity of location awareness to the network. In fact, it creates a virtual coordinate system (VCS) in the network, with each node allocated its respective coordinate in the given deployment. The proposed system suffers from no scalability issues. It can work equally efficiently with hundreds or thousands of nodes.

The protocol proposed in this paper provides a simple, power, cost and size effective method for estimation of location of each SN in a given network deployment. It encourages no GPS requirement with either all nodes or with certain special seed nodes. Moreover, the protocol imparts extremely negligible load over an individual node for this purpose and exploits the resources at BS for entire VCS setup maneuver. This is in contrast to certain other methods which require a lot of initial local communication for providing location awareness to the system.

One of the additional advantages of proposed system is the unique sensor ID independence, i.e. ALT doesn't require each node to have a unique ID. This is highly advantageous in applications with huge deployments where maintenance of a separate ID for each node is a big issue. The VCS provides a coordinate to each node and that itself can be treated as its ID. This gives rise to the concept of location aware IDs and can prove to be very useful in many applications, especially the geographic routing protocols. The packets for data transmission may appear as follows:

(X, Y) (ID)	DATA
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ALT enabled Packet

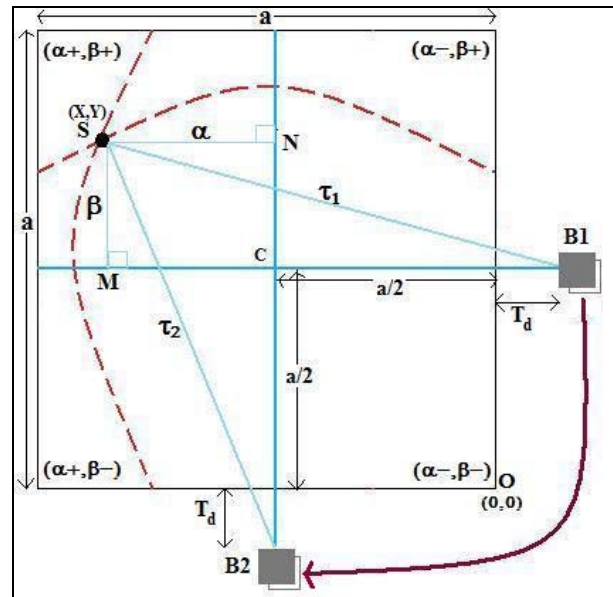


Figure 2 Setting Up of Virtual Coordinate System

IV. ALT IMPLEMENTATION

We use a simplified model shown in [26] for the radio hardware energy consumption. The energy radio expends for receiving an l -bit message is:

$$E_{RX}(l) = lE_{elec} \quad \dots (1)$$

The electronics energy, E_{elec} , depends on factors such as the digital coding, modulation, etc.

After the nodes are deployed in the field, the BS will locate itself at a distance, T_d , from one edge of the field. The selection of this distance does not affect the formation of virtual coordinate system, since, a different value of T_d leads to a similar coordinate value for each node.

The BS then broadcasts a signal with strength, B_s , sufficient to reach all SNs in the field. The receiving nodes calculate their distance from the BS based on the received signal strength using the free energy dissipation model [29]:

$$P_r(d) = P_{tx} \times \frac{\epsilon}{\tau_1^2} \quad \dots (2)$$

Where, the power of received signal is P_r , τ_1 is distance and ϵ the attenuation coefficient.

Form (2) τ_1 can be calculated as:

$$\tau_1 = \frac{r}{\sqrt{p_r}} \quad \dots (3)$$

Where, r is constant.

A similar process is repeated by BS upon moving to an adjacent edge of the field, i.e. broadcasts a signal with strength, B_s from a distance, T_d from the field. This distance for second transmission need not be same as the previous step; rather any convenient choice can be made. But, in this paper we have taken both the values same just

in order to simplify the calculation. The receiving SNs again calculate the distance, τ_2 from BS using the same relation as stated above.

Now, if the BS mobility is a big issue, because of any reason, then an effective alternative is to use a SN or any other device with strong transmission capacity, instead of BS, for second transmission on adjacent edge. This will solve the same purpose because the sole purpose of this step is to provide the SNs a second value, τ_2 for coordinate calculation.

After this phase, each node is equipped with two values τ_1 and τ_2 (Figure 2). These values are used to calculate the exact location of a SN in the given deployment. In the rest of the section we will provide a mathematical treatment for the establishment of VCS.

$$\text{Let, } \left(\frac{\alpha}{2} + T_d\right) = d$$

$$\text{In } \Delta B_1MS: \quad \beta^2 = \tau_1^2 - (d + \alpha)^2 \quad \dots (4)$$

$$\text{Similarly, in } \Delta B_2NS: \quad \alpha^2 = \tau_2^2 - (d + \beta)^2 \quad \dots (5)$$

$$(4) - (5), \quad \tau_1^2 + 2d\beta = \tau_2^2 + 2d\alpha \quad \dots (6)$$

$$\Rightarrow \beta = (\tau_2^2 - \tau_1^2 + 2d\alpha) / 2d$$

$$(4) + (5), \quad \Rightarrow 2(\alpha^2 + \beta^2) = \tau_1^2 + \tau_2^2 - 2d^2 - 2d(\alpha + \beta) \quad \dots (7)$$

$$\text{Substituting (6) in (7) and simplifying,} \quad 2\alpha^2 + \left(2d + \frac{\tau_2^2 - \tau_1^2}{d}\right)\alpha - \left(\tau_1^2 - d^2 - \frac{(\tau_2^2 - \tau_1^2)^2}{4d^2}\right) = 0 \quad \dots (8)$$

$$\Rightarrow 2\alpha^2 + G_1\alpha - G_2 = 0 \quad \dots (9)$$

Where, $G_1 = \left(2d + \frac{\tau_2^2 - \tau_1^2}{d}\right)$, $G_2 = \left(\tau_1^2 - d^2 - \frac{(\tau_2^2 - \tau_1^2)^2}{4d^2}\right)$

are known and thus are treated as constants. One of the two roots of the quadratic equations will be the value of α , the other one will be obviously ignorable. This estimate can also be derived based on the value of τ_1 . Now from (6) the value of β can also be calculated. To calculate the absolute virtual coordinates (X, Y) with respect to origin O,

$$X = \frac{\alpha}{2} + \alpha \quad \dots (10)$$

$$Y = \frac{\alpha}{2} + \beta \quad \dots (11)$$

The sign (+ve/-ve) before α and β in (4), (5), (10) and (11) are as shown near the vertices of the Figure 2. The complete derivation is shown for $\alpha+$ and $\beta+$. Similar equations can be obtained for other cases too. Thus, the protocol provides a way to exactly localize a SN in a network field.

V. PERFORMANCE EVALUATION

ALT is a novice mechanism of virtual coordinate establishment in WSNs. The following are the simulation parameters considered for the implementation of ALT:

- The distance between the BS and the network is taken as 100m.
- the electronic power is 50 nJ/bit
- free space attenuation coefficient is 12 pJ/bit/m²
- multipath attenuation coefficient is 0.0012 pJ/bit/m⁴
- nodes' initial energy is 6.0 J

The major advantage provided by the proposed protocol is the accuracy of the localization information produced. Certain other approaches use an anchor node which can only help in getting a rough idea of the SN location. The coordinates generated by VCS can also be used as an ID of the node. This is specifically useful in a case where the nodes are too many in number and a unique ID maintenance is a big issue.

Figure 3 shows the variation of energy consumption in VCS setup process with the increase in number of nodes. This is clearly visible that there is a linear relationship, thus, the increasing density doesn't affect the protocol in any manner, such as increase in complexity or a non linear increase in energy consumption.

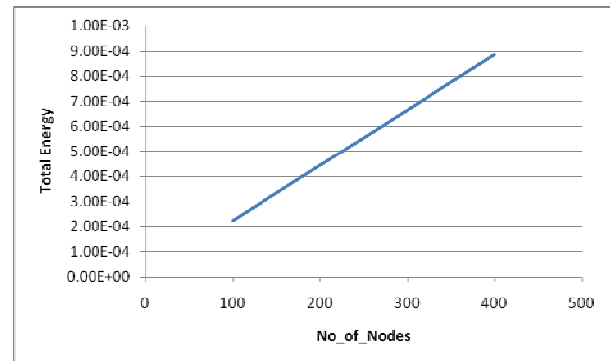


Figure 3 Energy Consumption Vs Nodes

VI. CONCLUSION AND FUTURE WORK

Locating a SN in a WSN is required in most of the present day functionalities. Moreover, the granularity of the location information needed differs from application to application. In this paper we presented ALT, an Accurate Localization Technique, for WSNs. It uses a Virtual Coordinate System for this purpose. It saves all the costs of hardware and power, as demanded by many other current schemes. The protocol also provides two options for VCS establishment. One with a One-Time BS mobility requirement and because of any reason, if this is not possible then a device with high transmission capacity may be used. This is also a One Time requirement, so is easily affordable.

The load of protocol implementation is placed mainly on the sink and prevents the heavy involvement of SNs in this process. We also provided a mathematical treatment for complete implementation process. Finally,

we saw that the protocol remains indifferent even by an increase in density of network nodes.

Future directions in this line can be the development of a fault tolerant and secure method for geographic routing in WSNs. Moreover, the proposed scheme is only for static nodes. A positioning system needs to be developed for dynamic nodes also.

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