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Different Approaches of Angle of Arrival Techniques In Wireless Sensor Networks

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Abstract- Despite of the fact that localization techniques in Wireless Sensor Networks are studied during last many years but there is no unanimity on the existence of simple, accurate, decentralized and energy efficient techniques on localization in WSN. For static WSNs, localization is not much a problem because once node positions have been determined they are unlikely to change. Whereas mobile sensors must frequently estimate their position, which takes tim and energy and consumes other resources needed by the sensing application.

1. Introduction

In Wireless Sensor Networks, localization of sensors is a key enabling technology because the sensor nodes need to know their locations in order to detect and record events so that their data is meaningful. Manual assignment of node coordinates is one possibility but is often impractical or impossible due to the number of nodes or the method of deployment. Equipping each sensor with a GPS receiver is another solution, however it is often cost prohibitive in terms of both hardware and power refinements. Moreover, since GPS requires line of sight between the receiver and the satellites, it may not work well in buildings or in the presence of obstructions such as dense vegetations, buildings or mountains blocking the direct view to the GPS satellites. There are several group of techniques that enables the sensors to detect their positions. Despite of huge research effort, there is still no well accepted technique on how to solve the localization issue in outdoor sensor networks.

2. Localization in wireless sensor networks

The process of finding the location of the nodes is called Localization. In this process we try to find the approximate location of the sensor node with high accuracy. The process of localization involves collecting the information about the longitude, latitude and altitude of the sensor node. Localization can be classified into two types: Local or Relative Localization in which location of a point is given in reference to a local point. In this technique local reference points are used to describe location of an object, and another is Global or Absolute Localization in which the location is given with respect to the world with the help of latitude, longitude and altitude. Location can be specified in two ways: *Geometric:* the location of an object can be specified using distance and angle. *Topological:* location is given by connections with the landmarks. Some localization methods examines the received signal strength of a message broadcast from a known location. Since free space signal strength model is governed by the inverse square law, accurate localization is possible.

2.1 Need of localization?

Wireless sensor networks are often deployed in unattended and hostile environments, leaving individual sensors dangerous to security compromise. Node self localization capability is a highly desirable characteristic of sensor network because sensor readings are meaningless without a coordinate tag. Most of the routing protocols use flooding technique for routing of packets. If we know the location of each and every sensor node, a selective forward routing technique can be used to route packets. Selective forwarding reduces the Network load and increases the network lifetime by saving power of the individual node. Sensor data must be registered to its physical location to permit deployment energy efficient routing schemes and source localization algorithms.

2.2 Troubles in localization in wireless sensor network

Most of the Wireless Sensor Network uses GPS receiver for Localization. But the sensor nodes is dense in nature and using GPS receiver is not economically good. GPS based receiver technique cannot be used for indoor localization. GPS receiver system require satellite communication, so it requires more battery power. Moreover GPS receivers are expensive. Since GPS requires line of sight with the receiver and the satellite, it may not work well in buildings or in the presence of obstructions blocking the direct view to the GPS satellites.

2.3 Alternatives to GPS in sensor network localization

In the search for Localization in the Wireless Sensor Networks there could be two types of techniques used for Sensor Localization namely: Cooperative and Non-cooperative. In the first approach few base stations are used for localization where every sensor node receives signals directly from base station in which distance between node and base station can be measured on the basis of signal strength and time of arrival (TOA), and in the second approach a small no of anchor nodes are used in network, where the anchor nodes have prior knowledge of location. The anchor nodes receives its location information either from GPS or from manual deployment of the sensor node. This sensor node helps the other nodes in the network to localize themselves using some algorithms. In this approach there is no need to get the signal direct from the base station to localize a sensor node.

2.4 Requirement of algorithms for localization

Sensor Network requires localization algorithm because it is not possible to provide the sensor nodes with location information at the time of deployment. In some sensor network the sensor nodes are mobile and when the sensor nodes move they need localization because of some applications.

2.4.1 *Different localization algorithms*

Using Time of arrival estimation(TOA):

Localization by Time of Arrival measures the time a signal takes to arrive at the sensors. This requires to know the time when the signal was transmitted and requires tight time synchronization between the sender and the receiver. The main drawback of this approach is that it is difficult to precisely record the arrival time of the radio signals, since they travel close to the speed of light. Time of arrival uses the time of arrival at certain base station rather than the measured time difference between departing from one and arriving at the other station.

Using Time difference of arrival(TDOA):

Time difference of arrival improves upon time of arrival by eliminating the need to know when the signal was transmitted. Many time synchronized nodes receive the signal and estimate the time difference of arrival or the difference in the signal phase at a specific time instant. As the signals travel at a constant speed, the source position can easily be determined if there are sufficient number of participating nodes.

Using Received signal strength(RSS):

Received signal strength is another localization algorithm that measures the signal strength of a message broadcast from a known location. Since the free-space signal strength is governed by inverse square law accurate localization is possible. RSS based ranging is attractive as a means of distance estimation because it is essentially free, wireless sensor nodes already have radios, and signal strength is often being measured for each radio packet somehow. RSS method uses the knowledge of the transmitter power, the path loss model and the power of the received signal to measure the distance of the receiver from the transmitter.

Using Angle of arrival(AoA):

Angle of arrival method uses array antenna to estimate the direction of arrival and at least two receivers called as sub array are required to locate sources. The angle of arrival method involves determining angular separation between two beacons or a single beacon and a fixed axis. By determining the angle of arrival at a number of sensor nodes, angulation can be used to estimate the position.

3.Angle of arrival estimation approaches

Angle-Of-Arrival Localization is a well-known technique and thoroughly described in the open literature, there are not many papers dealing with AoA schemes appropriate for wireless sensor networks and their specific objectives, requirements and applications.

3.1 Ad Hoc positioning system using AoA

Ad hoc network are mostly studied in the context of high mobility, high power nodes and moderate network sizes. The main features of ad hoc networks are large number of unattended nodes, lack of deploying supporting infrastructure and high cost of human supervised maintenance. Here we address the self positioning and orientation of the nodes in the field. This positioning and orientation algorithm is appropriate for indoor location aware applications, where the problem is not the unpredictable highly mobile topology rather the ad hoc deployment[3][17][18]. The orientation and positioning problems have been intensively studied in the context of mobile robot navigation[8]. The methods make extensive use of recognizable "landmarks". This method is proposed under the assumption that a small fraction of network has only the position capability. The proposed method is different from the other methods based on the capability of the nodes to sense the direction from which the signal is received which is known as the angle of arrival(AoA). AoA sensing requires either an antenna array or several ultrasound receivers but along with positioning it also provides the orientation capability.

The network is a collection of ad hoc deployed nodes where any node can only communicate directly only with its immediate neighboring nodes within radio range. In the ideal case, when radio coverage of a node is circular, these networks are modeled as a fixed radius random graphs. Each node in this network is assumed to have one main axis against which all angles are reported and the capacity to

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estimate approximately accurate direction from which a neighbor is sending data.

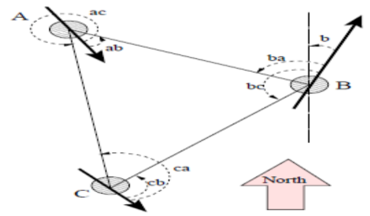

Fig. 1. Node with AoA Capability

We assume that after the deployment, the axis of the node has an arbitrary, unknown heading. Some of the nodes, called landmarks have additional knowledge about their position, from some external source, such as a GPS receiver, or manual input. The term bearing refers to an angle measurement with respect to another object [1][2]. Radial is a reverse bearing, or the angle under which an object is seen from another point. We use the term heading with the meaning of bearing to north, that is, the absolute orientation of the main axis of each node. In figure 1, for node B, bearing to A is $\widehat{ba}$ radial from A is $\widehat{ab}$ and heading is $\hat{b}$ [3]. in figure 1, Node A sees its neighbors at angles $\widehat{ac}$ and $\widehat{ab}$ and has the possibility of inferring one angle of the triangle, $\widehat{CAB} = \widehat{ac} - \widehat{ab}$ For consistency all angles are assumed to be measured in trigonometric direction. Node A can also infer its heading, if heading of one of the neighbors, say B, is known. If node B knows its heading or angle to the north to be $\hat{b}$, then A may infer its heading to be $2\pi - (\widehat{ba} + \pi - \widehat{ab}) + \hat{b}$.

If no compass is available in any node, but each node knows its position, heading can still be found because the orientations for the sides of the triangle can be found from positions of its vertices[4].

In Ad Hoc positioning system, the AoA schemes are described where sensor nodes are forwarding their bearings with respect to anchors, i.e. nodes which are assumed to know their own coordinates and orientations. Unfortunately, these methods require a strong cooperation between neighbor nodes, and they are prone to error accumulations.

3.2 Angle of arrival estimation using Cricket compass

By analogy to a traditional compass, knowledge of orientation through cricket compass attached to a mobile device enhances various applications including way-finding and navigation, directional service discovery. Context aware applications which adapt their behavior to environmental context such as physical location are an important class of applications in emerging pervasive computing environments[19]. The first motivating application is the *Wayfinder.* This application is designed to run in a handheld computer and help people navigate toward a destination in an unfamiliar setup. The second motivating application is called the *Viewfinder.* The user can point it any direction and specify a sweep angle and maximum distance. Using an active map integrated with a resource discovery system, the viewfinder then retrieves and displays a representation of the set of devices and services lying inside a sector of interest specified by the user and allows the user to interact with these devices through the representation on the map.

Figure 2 shows a beacon B and a compass with two ultrasonic receivers R_1 and R_2 which are located at a distance L apart from each other. The angle of rotation of the compass θ with respect to the beacon B is related to the differential distance d_1 and d_2, where d_1 and d_2 are the distances of the receivers R_1 and R_2 from B. Figure 2(b) shows the beacon B from figure 2(a) projected onto the horizontal plane along which the compass is aligned. In this figure, $x_1$and x_2 are the projections of distances d_1 and d_2 on to the horizontal plane. We assume the compass is held parallel to the horizontal plane.

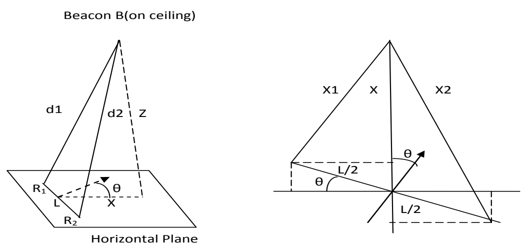

Fig. 2. (a) Determining the angle of Orientation θ along the Horizontal plane. (b) A rotated compass leading to difference in distance between the beacon and the receivers

From Figure 2(a):

$$x_1^2 = d_1^2 - z^2 \quad (1)$$

$$x_2^2 = d_2^2 - z^2 \quad (2)$$

$$x = \sqrt{\bar{d}^2 - z^2}$$

Where $\bar{d} \approx \frac{d_1 + d_2}{2}$ when d_1, d_2 □□ L

From Fig 2(b),

$$x_1^2 = (\frac{L}{2}\cos\theta)^2 + (x - \frac{L}{2}\sin\theta)^2$$

and

$$x_2^2 = (\frac{L}{2}\cos\theta)^2 + (x + \frac{L}{2}\sin\theta)^2$$

$$\Rightarrow x_2^2 - x_1^2 = 2Lx\sin\theta$$

Substituting for x_1^2 and x_2^2 from Equations (1) and (2) we get:

$$\sin\theta = \frac{d_2 + d_1}{2Lx}(d_2 - d_1) \quad (3)$$

This may be rewritten as:

$$\sin\theta = \frac{d_2 - d_1}{L\sqrt{1 - (\frac{z}{\bar{d}})^2}} \quad (4)$$

Equation (4) implies that it suffices to estimate two quantities in order to determine the orientation of the compass with respect to a beacon: (i) ($d_2 - d_1$), the difference in the distances of the two receivers from the beacon, and (ii) z/d, the ratio of the height of the beacon from the horizontal plane on which the compass is placed to the distance of the beacon from the center of the compass. The main goal of this method is to estimate each of these quantities with high precision so as to produce an accurate estimate of θ. The solution to this problem is to track the phase difference between the ultrasonic signals at the two different receivers and process the information.

The second quantity, z/d, is estimated by determining the (x,y,z) coordinates of the compass with respect to the plane formed by the beacons. This is done by placing multiple beacons in a room and estimating the time it takes for the ultrasonic signal to propagate between them and the compass. The differential distance can be measured as illustrated in figure 3. Let d_1 and d_2 be the distances to receivers R_1 and R_2 from the beacon B. Let $\delta d = d_1 - d_2$ and let w_1 and w_2 be the ultrasonic waveforms at the two receivers, ϕ, depends upon the difference in distances traversed from B to the receivers by the ultrasonic signal and the wavelength of λ of the signal is expressed as:

$$\phi = \frac{\delta d}{\lambda} * 2\pi \qquad \Rightarrow \qquad \delta d = \phi * \frac{\lambda}{2\pi}$$

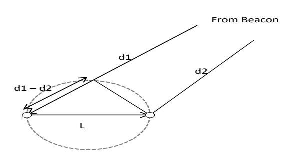

Fig.3. Receivers R_1 and R_2 measures the differential distance from a far away beacon

3.3 Orientation forwarding

The problem in an ad hoc network is that a node can only communicate with its immediate neighbor, which may not always be the landmarks. Ad hoc positioning system is a hybrid between DV routing and beacon based positioning. It is similar to DV routing because the information is forwarded in a hop by hop fashion independent of each landmark. This method aims at forwarding orientation to the nodes which are not in direct contact with the landmarks, but still can infer their orientation with respect to the landmark. This method includes two algorithms: DV-Bearing, which allows each node to get a bearing to a landmark and DV-Radial, which allows a node to get a bearing and a radial to a landmark as illustrated in Figure 4.

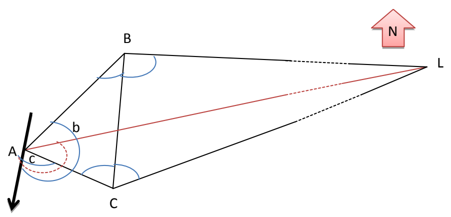

Fig. 4. Node A infers its beaing to L using B's and C's bearing to L

Assuming that node A knows bearings to immediate neighbors B andC i.e angles b□ and c□, which in turn knows their bearing to a far off landmark L. First node A should find its bearing to L. If B and C are neighbors of eachother then A has the possibilty to find all the angles in the triangles ΔABC and ΔBCL. This would allow A to find the angle $\angle LAC$, which yields the bearing of A with respect to L, as c□ + $\angle LAC$. Node A continues the process of forwarding its estimated bearing to L, to its neighbors which will help the farther nodes get their estimates for L. Forwarding orientations is done in a fashion similar to distance vecor routing algorithm. If the radial method is used, a similar argument holds with the difference that now A needs to know, besides bearings of B and C to L, the radials of B and C from L. Angle $\angle BLN$, the radial at B is known then the angle $\angle ALN$, radial at A can also be found since all angles in both the triangles is known.

3.5 Angle of arrival estimation using array of antenna

An antenna array[9] often called a 'phased array' is a set of 2 or more antennas. The signals from the antennas are combined or processed in order to achieve improved performance over that of a single antenna. The antenna array can be used to:

- increase the overall gain
- provide diversity reception
- cancel out interference from a particular set of directions
- "steer" the array so that it is most sensitive in a particular direction
- determine the direction of arrival of the incoming signals
- to maximize the SINR

The following figure shows an example of antenna array:

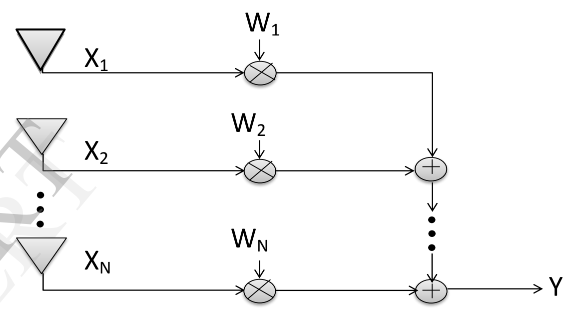

Fig.5. Geometry of an arbitrary *N* element antenna array. Weighting and summing of signals from the antennas to form the output in a Phased Array

The general form of an antenna array can be illustrated as in Figure 5. An origin and coordinate system are selected, and then the *N* elements are positioned, each at location given by:

$$d_n = [x_n \; y_n \; z_n]$$

The positions of the elements in the phased array are illustrated in the following Figure. Let $x_1, x_2, ..., x_N$ represent the output from antennas 1 thru *N*, respectively. The output from these antennas are most often multiplied by a set of *N* weights - $w_1, w_2, ..., w_N$ - and added together as shown in the above Figure The output of an antenna array can be written as:

$$y = \sum_{n=1}^{N} w_n \, x_n$$

To understand the benefits of antenna arrays, consider a set of 3-antennas located along the z-axis, receiving a signal (plane wave or the desired information) arriving from an angle relative to the z-axis of θ , as shown in Figure 6.

So from the antenna theory [16], as the gain of the antenna is a function of angle of arrival (θ),θ can be measured at a particular receiver if the gain is known. And thus can be helpful in estimating the location of the source.

The antennas in the phased array are spaced one-half wavelength apart (centered at z=0). The E-field of the plane wave (assumed to have a constant amplitude everywhere) can be written as:

$$E(x,y,z) = e^{-j\frac{2\pi}{\lambda}(k_x x + k_y y + k_z}$$
$$= e^{-j|k|(\sin\theta\cos\phi x + \sin\theta\sin\phi y + \cos\theta z)}$$
$$= e^{-jk.r}$$

$$E(x,y,z) = e^{-j\frac{2\pi}{\lambda}(k_x x + k_y y + k_z}$$
$$= e^{-j|k|(\sin\theta\cos\phi x + \sin\theta\sin\phi y + \cos\theta z)}$$
$$= e^{-jk.r}$$

In the above, **k** is the wave vector, which specifies the variation of the phase as a function of position. The (x,y) coordinates of each antenna is (0,0); only the z-coordinate changes for each antenna. Further, assuming that the antennas are isotropic sensors, the signal received from each antenna is proportional to the E-field at the antenna location. Hence, for antenna *i*, the received signal is: $X_i = e^{-j\frac{2\pi}{\lambda}\cos\theta z_i}$ The received signals are distinct by a complex phase factor, which depends on the antenna separations and *the angle of arrival(*θ*)* on the plane wave. If the signals are summed together, the result is:

$$Y = e^{-j\frac{2\pi}{\lambda}\cos\theta z_1} + e^{-j\frac{2\pi}{\lambda}\cos\theta z_2} + e^{-j\frac{2\pi}{\lambda}\cos\theta z_3}$$
$$\sum_{i=1}^{3} e^{-j\frac{2\pi}{\lambda}\cos\theta z_i}$$
$$\sum_{m=-1}^{1} e^{-jm\pi\cos\theta}$$

So from the antenna theory [16], as the gain of the antenna is a function of angle of arrival (θ),θ can be measured at a particular receiver if the gain is known. And thus can be helpful in estimating the location of the source. Though the angle of arrival measurement becomes highly accurate, overcoming different interferences to achieve accurate output, use of a group of antenna and complex calculations increases the cost of the technology with the increase in connectivity, time and space complexity as well. In spite of all the above drawbacks, it still doesn't guarantee of the exact angle of arrival calculation. The size and the portability issues restrict the system from the use in sensors.

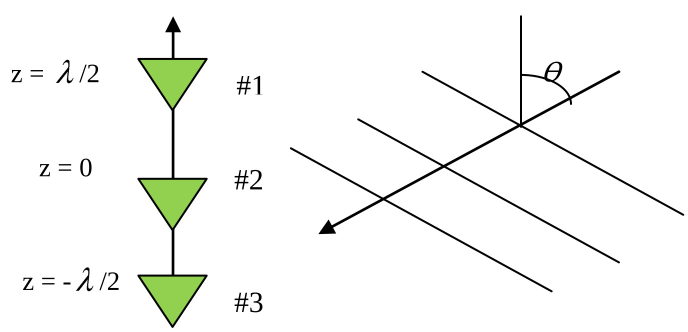

Fig. 6. 3-element Antenna Array receiving a plane wave

So as to overcome the drawbacks the other methodology are still in research domain.

4.COMPARISON AND CONCLUSION:

AoA measurement is an important technology of great practical interest in WSN. For long range transmissions and high accuracy Angle of Arrival measurement, the most preferred way is always found to be using Array of Antenna which is never acceptable for Wireless Sensor networks used for a specific low cost, low space and low weight application due to its high hardware complexity and cost.

But in a situation where the noise density is very less and the transmission range is very small like inside a closed room or in a closed boundary, if the sub-centimeter accuracy has to be achieved the devices like Cricket Compass plays a major role for Angle of Arrival and the Position Estimation. But in sensor networks, those which are meant for some specific purposes and placed in open areas and distributed in a long range of transmission the sub-centimeter accuracy is a very hard task to be achieved and the effect of the atmospheric noise is also very high which can affect the calculation of the angle of arrival and hence the position of a specific node.

So it is a very challenging research area to find a suitable technology to achieve a proper technique for this purpose.

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