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Prospective View of Localization in Wireless Sensor Networks: A Survey

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Abstract: The range of services offered by Sensor Networks is much larger than the difficulties faced in its deployment. In this paper we investigate some of the proposed techniques to localize sensor nodes in wireless sensor networks. Technologies based on location awareness of the sensor have become a part of our lives. We use them without realizing that it's a location based service. Relating sensed data with the geographic location of the sensor nodes make it much more relevant for the user and also provides an image of the environment to distant user. Location of the sensor nodes also helps in some basic functions like routing, coverage, detection, clustering, etc. of the distributed wireless networks.

Keywords: Wireless Sensor Network, Localization, Quality of Service, Radio Signal Strength

1. Introduction

Advances in wireless communications, MEMS technology, digital electronics has helped us to develop low cost and power sensor nodes that are small in size and communicate short distances. These tiny sensor nodes can sense, process and communicate data and has made us think on collaborative effort of a large number of nodes.

Development of large scale wireless sensor network [1] is a difficult task but because of the number of application dependent of such networks is huge we are ready to take up this task. Sensor networks provide us the capacity to place the sensor close to the actual phenomenon under observation that helps us to develop better understanding of the problem and give us sufficient time to react in case of emergencies. This has led to recent growth in wireless sensor networks applications. In this paper we discuss the importance and need of localization in sensor networks based on certain applications. We also analyze some of the localization mechanism based on physical measurement technique to develop better understanding of localization mechanism.

2. Localization

Sensor network introduce a very interesting feature of coupling sensor nodes to the physical world and the spatial relationship of node to the real world objects is of utmost importance in the operation of such networks. Localization in itself means collection of mechanisms or techniques that measures the spatial relation of the nodes to the real world. It is a mechanism to relate nodes position according to geographic of the real world.

The development of wireless and mobile devices has increased the demand for context-aware applications, where location is considered to be the most significant contexts. For example, pervasive medical care to record and manage patient movements; modern logistics for goods transportation, inventory; environmental monitoring networks; and mobile peer-to-peer computing. We can say that services based on location are part of our daily lives and application based on location based services from short range Bluetooth to long range telecommunication have become a necessity in today's world. A detailed survey on location-based applications can be found in [2-3].

Effect and capacity of data from a network increases when the data is correlated to the spatial information as compared to raw data. For example, if we have temperature record of an surrounding the best we can do is to calculate average of the surrounding however at certain points in the surrounding it can differ to a great extent from the actual temperature. However when the same data is correlated with the spatial information a temperature map is formed which can be analyzed more effectively.

Location information also is also important for some network services like routing, clustering, coverage, topology control, boundary detection, etc. some of them are discussed over here:

Routing: Routing is a process of selecting paths in a network, along which network traffic travels. Geographic routing schemes require location information, making the routing process stateless, scalable, and low-overhead in terms of route discovery.

Coverage: It tells us how well the network covers the surrounding; thus, it can be considered as quality of service (QoS) of sensing function. The geometric approaches [4] are able to obtain accurate and reliable results, in which locations are essential.

Clustering: To facilitate network management, researchers often propose to group sensor nodes into clusters and organize nodes hierarchically [5]. Location information can also be used to rebuild clusters locally when new nodes join the network or some nodes suffer from hardware failure [5].

The field of networked sensor systems encompasses a very broad array of applications, with a broad range of requirements. To introduce this variety, we first present the points in the application space that characterize the requirements space of localization systems.

PASSIVE HABITAT MONITORING: When an acoustic source is detected by a node, it communicates with nearby nodes to try to estimate the location of itself by comparing the times of arrival of the signals. From this application we can derive a number of requirements:

Outdoor Operation: The system must be able to operate outdoors, in various weather conditions.

Power Efficiency: Power may be limited, whether by battery lifetime or by the feasibility of providing sufficient solar collectors.

Non-cooperative Target, Passive Infrastructure: The animal does not emit signals designed to be detected by the system (i.e. non-cooperative), and the system does not emit signals to aid in localization.

Accuracy: The system must be accurate enough to be able to produce a reliable count, and to accurately focus a camera on suspected locations.

Availability of Infrastructure: In some cases GPS may be available to localize the sensors themselves. In these cases, if surveying the sensors is inconvenient, the sensors will need to self-localize.

SMART ENVIRONMENTS: Smart environments are deeply instrumented systems with very demanding localization requirements. The operation requirements can also be assessed along similar axes some of which are:

Granularity and Scale of Measurements: Local coordinate systems for a sensor network might scale from centimeters to hundreds of meters, whereas GPS coordinates have a global scale and a granularity on the order of meters.

Accuracy and Precision: The closeness of the answer to ground truth (accuracy), and consistency of the answers (precision).

Cost: Node hardware cost, in terms of both power consumption and monetary cost; Latency of localization mechanism; Cost of installing infrastructure, in terms of power, money, and labor.

Communications Requirements: What kind of coordination is required among nodes? What assumptions does the system make about being able to send or receive messages at any time? What kind of time synchronization is needed?

Over here we analyze some of the important localization mechanisms based on physical measurement techniques. The design of such mechanisms depends on a wide range of factors like resource availability, accuracy requirements etc. and application for which they are used, thus we cannot grade which is a better algorithm.

3. Methods for Localization

Localization is the correlation of the nodes with the spatial information so its localization is not possible without physical information. The measuring techniques can be classified as location, distance, area, angle, hop count, and neighborhood based on the type of hardware available.

GPS is a classical example of location based techniques. In GPS the physical measurements directly obtaining without any computation, hence it is a very powerful technique. However equipping sensor nodes with GPS makes them costlier which increases the overall cost of network and GPS requires more energy for communication. Therefore GPS technique does not fulfill the basic requirements of sensor networks and will not be discussed any further.

4. Based on Coverage Area

Coverage area of a signal is mostly defined by some geometric shape; locations can be estimated by determining which geometric areas that anode is in. The basic idea of area estimation is that sensor networks are generally dense networks then there are overlapping of coverage areas of the reference nodes. We calculate this overlapping area and choose the centroid as the location estimate. As the number of overlaps increase the accuracy also increases.

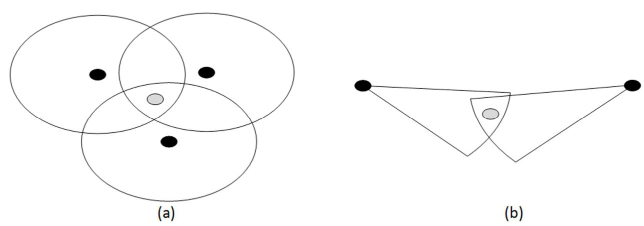

***Figure 1.** Area measurements.*

If a node hear from two or more reference nodes that means the concern node lies in the maximum range R of the reference nodes. The node computes the intersection of these coverage areas and estimates its location by calculating the centroid. For nodes the coverage areas are normally circular in shape as in Figure 1 (a) however if the nodes are equipped with directional antennas sectoral regions can also be considered which improves the estimation as the overlapping area reduces Figure 1 (b). A detailed discussion on these can be found in [6].

5. Neighborhood Measurement

Easiest positioning technique is to take a decision whether two nodes are in non-overlapping (or nearly non-overlapping) reception range of each other. Unknown nodes localized by this using course-grained localization i.e. the nodes estimate their position. But, when the density of the nodes is much larger, k-proximity approach is used to localize the node. Let us suppose there are k reference nodes within the unknown nodes. The k-proximity approach is based on centroid technique and it provides more accurate results. This is a k-nearest-neighbor approximation and all reference nodes have equal weights.

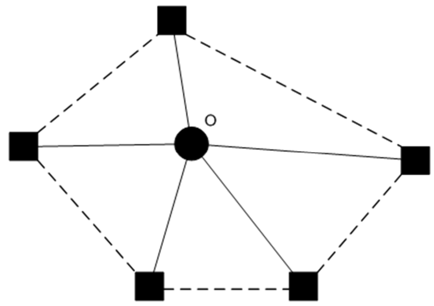

Figure 2. *K-neighbor proximity.*

6. Based on Distance or Angle

The distances from an unknown node to several references constrain the presence of this node, which is the basic idea of the so called multilateration. We will explain this in 2D scenario where three reference nodes are used to calculate the position of a node. This is also called trilateration, a special case of multilateration.

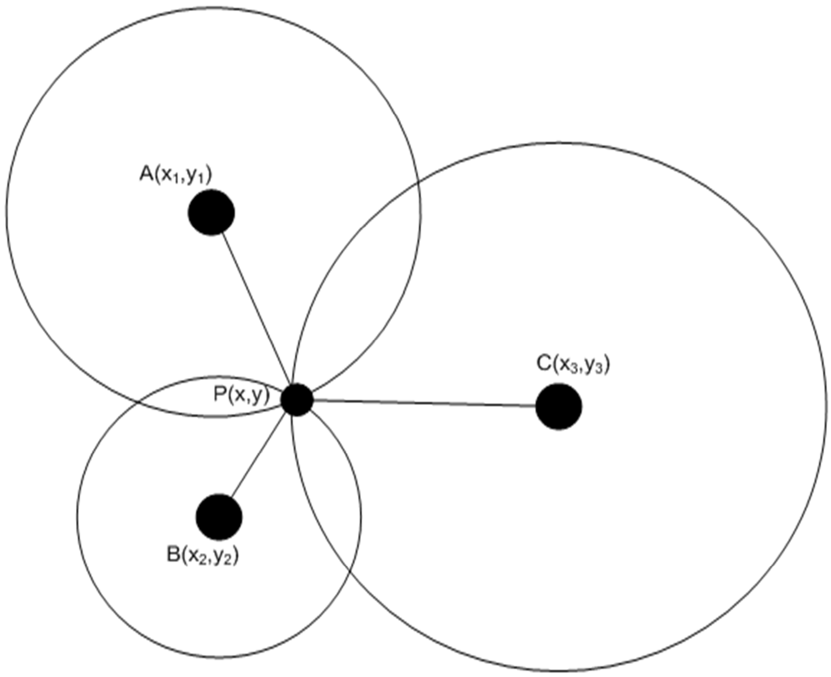

Figure 3. *Trilateration.*

A node P (x, y) calculates its distance from any of the three reference nodes which are A (x_1, y_1), B (x_2, y_2) and C (x_3, y_3). The intersection of these three distances gives the location of the node. Trilateration does not give valid result under two conditions

1. When at least two known points have the same position.
2. When all three points A, B and C lies in one line

We can find position of a node:

- By knowing direction from two points (x_1, y_1) and (x_2, y_2) where x_1, y_1, x_2 and y_2 are known (AoA algorithm).
- By knowing distances from three points (x_1, y_1), (x_2, y_2) and (x_3, y_3) where x_1, y_1, x_2, y_2, x_3 and y_3 are known (TDoA, RSS algorithms).

Distance Based Ranging: For distance based ranging some of the proposed techniques to measure the distance between the nodes are as:

Radio Signal Strength (RSS): RSS is based on the fact that signal strength reduces during propagation which helps up to physical distance. In theory, radio signal strengths diminish with distance according to a power law.

$$P_r = \frac{P_t}{d_r^m}$$

$$d_r = \sqrt[m]{\frac{P_t}{P_r}}$$

Where P_r is the received power, P_t is the transmitted power, d_r is the distance between the nodes and m is a constant that depends on environment.

Time Difference of Arrival (TDoA): It uses a combination of ultrasound/acoustic and radio signals to estimate distances [7-9]. Each node is equipped with an ultrasound transceiver along with RF transceiver. The concept it that the reference nodes first sends a RF signal and then waits for certain time before sending the ultrasound signal. The receiving nodes calculates the distance using

$$d = \frac{v_{RF} v_{ultra}}{v_{RF} - v_{ultra}} \left(t_{ultra} - t_{RF} - t_{delay}\right)$$

Where v_{RF} and v_{ultra} are velocity of radio and acoustic signal. The concept is shown in figure.

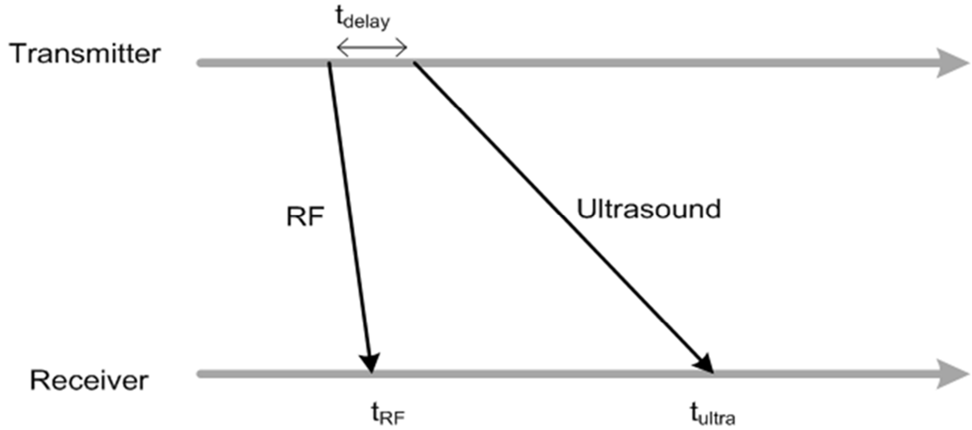

Figure 4. *The Time difference of arrival measurement.*

TDoA methods are impressively accurate under line of sight conditions.

Angle Based Ranging: The Angle of Arrival (AoA) mostly uses an array of antennas to determine the direction of the transmitter. When a number of different antennas placed in different direction receive a signal from the same transmitter then the AoA data can be retrieved by analyzing the phase or time difference between the signals.

These methods obtain accuracy within a few degrees [10]. However the AoA hardware is costly and bulk as each node is equipped with an array of antennas. Therefore this technique is not preferred as compared to TDoA. A more detailed description of AoA based triangulation techniques is provided in [11].

7. Hop Count

Hop count measurement technique is used to find the inter-node distances. Let us suppose an unweighted graph, where the vertices are wireless nodes and edges represent direct radio links between nodes. The hop count C_{ij} between two nodes n_i and n_j is defined by length of the shortest path between n_i and n_j.

A better estimate for the distance covered by one radio hop is given by

$$d_{hop} = R\left(1 + e^{-n_{local}} - \int_{-1}^{1} e^{-(n_{local}/\pi)\cos^{-1} t - t\sqrt{1-t^2}}\, dt\right)$$

Where n_{local} is expected number of neighbors per node and R is Range of the node.

Experimentally, this equation gives better result when the No. of nodes lies between 5 and 15. Nagpal et al. [12] demonstrate that by averaging distances with neighbors better hop-count distance estimates can be computed.

Another method to estimate per-hop distance is to employ a number of reference nodes. The pair-wise distances can be computed because the locations of the reference nodes are known. Hop count based localization approaches are more cost-effective than the ranging based approaches. But, most of these hop based approaches fail in anisotropic network topologies, where holes exist among wireless networks which is a common feature because of random deployment of the network or because the nodes tend to die out.

8. Conclusion

Location-awareness is a key feature of future generation networks, enabling a large number of pervasive applications. In this article, we have provided an overview of existing localization approaches and discussed several research challenges, including location aided network services, geographical information measuring, and design principles of algorithms. We offer this survey to help researchers to understand the state-of-the-art and to address directions of future research in the new and largely open areas of location-aware technologies.

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