Wireless sensor localization techniques

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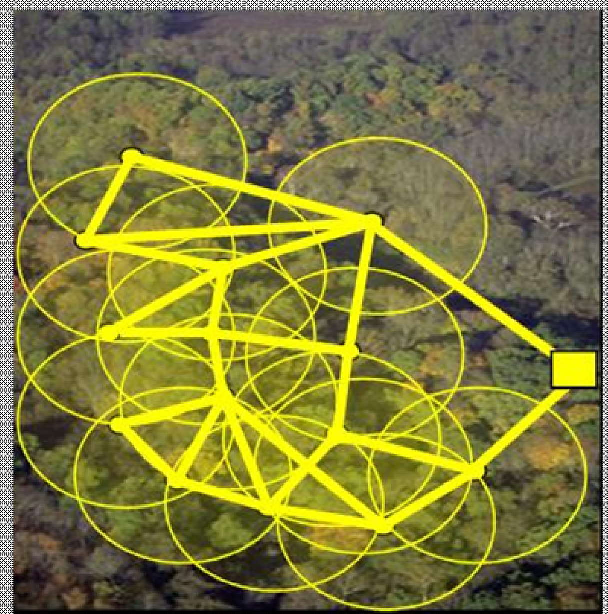
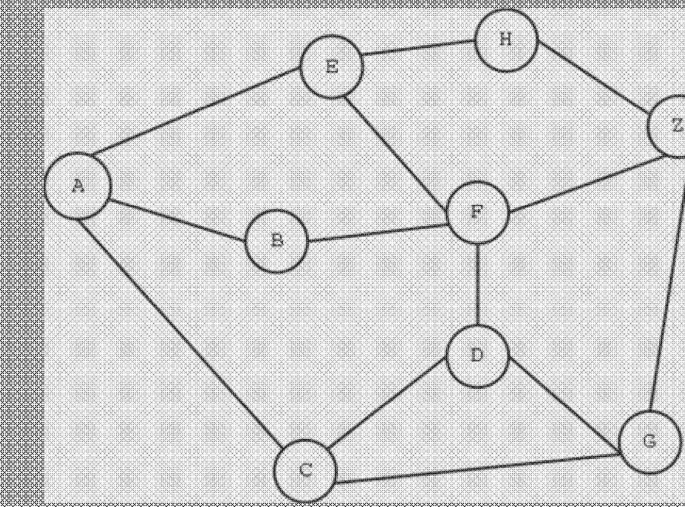
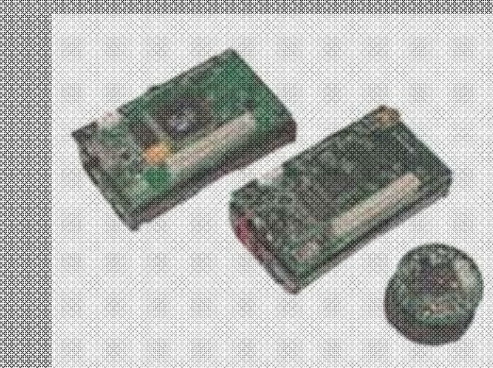






Abstract

Intelligent wireless sensing devices are becoming ubiquitous and are being applied in many applications ranging from environmental monitoring to animal tracking and numerous other applications. The devices themselves are usually small and inexpensive. They typically have limited computing resources and limited wireless range. These devices are often assembled into vast networks that communicate between the devices, or nodes, and perhaps a central location. Often in order for these systems to function, the nodes need to know their location within the network and/or a central location needs to know their location within the network. The work we've been conducting involves investigating algorithms that perform localization of wireless sensor nodes using only connectivity information, also referred to as range free localization. These algorithms allow the sensor nodes to reduce hardware complexity and power requirements. We've been evaluating the effectiveness of several these connectivity based algorithms with respect to location accuracy.

Range or Angle Based Approaches

Range Based Approaches

- Uses signal travel time to measure distance between nodes
- Requires time synchronization between nodes
- By measuring the distance between three or more nodes and using the known position of three or more nodes, lateration can be used to calculate the position of a fourth node.
- Requires hardware to make ToF measurements

Angle Based Approaches

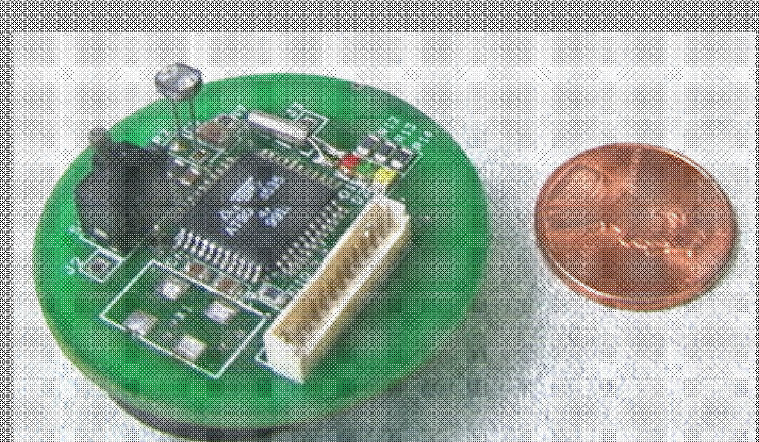
- Uses directional antennas to measure the angle of arrival of a signal
- By measuring three or more angles and using the known position of three or more nodes, angulation is used to calculate the position of a fourth node.
- Requires hardware to make Angle of Arrival (AoA) measurements

Global Positioning System

- The Global Positioning System is mature, inexpensive and ubiquitous
- Perhaps the most accurate mechanism for locating a device.
- GPS uses satellites orbiting the earth and precise measurement of timing signals sent from the satellites to determine position.
- It uses a time difference of arrival technique (TDOA) to compute the position.
- Requires additional hardware and must have clear access to the sky to receive the GPS signals.

Signal Strength Based Approaches

- Received Signal Strength Indicator, RSSI, has been proposed as alternative to TOF for making distance measurements.
- Power of a signal decreases at 1/d^2.
- RSSI is not an accurate indicator of distance. Environmental factors, such as the presences of a wall and other obstructions affect the received signal strength. Transmissions from other devices also interfere with RSSI.
- RSSI is incorporated into all wireless transceivers and is readily available with no additional hardware.



Range Free Approaches

Multidimensional Scaling

- Utilizes connectivity information to derive the location of nodes in a network.
- Multidimensional Scaling (MDS) is a data analysis technique often used in data visualization to uncover the similarities or dissimilarities within a data set and is taken from work done in psychometrics and psychophysics. In our case the data set comprises the connectivity between neighbors in the network.
- The technique is summarized in the follow pseudo code:

```
Compute MDS-MAP
Begin
    Using an all pairs shortest path
    algorithm, estimate the distance
    between each of the possible nodes

    Using these distance, use MDS to the
    estimated distances to a coordinate
    system

    Using any known nodes, normalize the
    positions

End Compute MDS-MAP
```

Force Directed

- Utilizes connectivity information to derive the location of nodes in a network.
- Views the nodes of a network as physical elements, such as weights and springs. The nodes are modeled as having forces applied to them. The original work was from a VLSI technique called Force Directed Placement.
- The algorithms can be some of the most flexible algorithms for simple undirected graphs.
- The Fruchtermann-Reingold algorithm defines an attractive force function and repulsive force function. The attractive force function is used for adjacent nodes and the repulsive force function is used for non-adjacent nodes. Vertices in the graph are moved repeatedly until a low energy state is achieved.
- The technique is summarized in the follow pseudo code:

```
Force Directed
Begin
    For All Nodes v in Graph loop
          Compute Attractive Force
        Compute Repulsive Force
        Compute
   Until low energy state achieved
End Force Directed
```

Monte Carlo

- Utilizes connectivity information to derive the location of nodes in a network.
- A Monte Carlo approach is a class of algorithms that depend on generating random sampling of data to compute a result.
- The approach is a particle filtering approach. This research focused on mobile networks.

```
Monte Carlo
Begin
   Choose N samples from the initial
distribution of the system
   Perform Sampling
        Choose N samples from the
distribution
        Compute the weight of each sample
        Normalize the weights
   Perform Re-sampling
End Monte Carlo
```

Combinatorial Delaunay Complex

- Utilizes connectivity information to derive the location of nodes in a network.
- One of the problems faced by many of the approaches is the ability to handle large networks with complex structure and holes.
- Another problem is global flip
- Combinatorial Delaunay Complex utilizes graph rigidity theory and higher order topological extraction to determine the positions of the devices.
- The steps involved in this algorithm are:

```
Identify Landmarks
Begin
   Compute Boundaries
   Determine Medial Axis
   Identify Landmarks
End Identify Landmarks
Compute Voronoi Diagram
Begin
   Flood for Voronoi Cells
   Build Voronoi Cells
   Identify Voronoi Cells for Landmarks
End Compute Voronoi Diagram

 Compute Delaunay Complex
Begin
   Identify Witnesses
   Collect Delaunay Edges
   Construct Simplices
End Compute Delaunay Complex

Begin Main
Identify Landmarks
    Compute Voronoi Diagram
    Compute Delaunay Complex
    Tri-laterate Remaining Nodes
End Main
```

Conclusion

A Microsoft C# language application was developed to investigate each of these algorithms. The application allows the investigator to create a random graph of any size with any number of nodes. It uses a Hammersley sequence to generate a quasi-random distribution of nodes. The application also allows the investigator to specify the radio range of a node. This is used to determine the connectivity graph of the network. A graph can be saved and restored for use in later tests. This research project is using this tool to investigate the effectiveness of the four connectivity based approaches. Each of these approaches has strengths and weakness. Utilizing what we will have learned, we will attempt to design an algorithm that utilizes the identified strengths of these approaches, creating a hybrid.

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