Localization of Network Nodes for Extra-Terrestrial Deployment

D. M. Havey, G. Kaymaz, K. E. Schubert

April 20, 2006

Objectives The topic of sensor networks has received a thorough treatment in academic literature and has even begun to make appearances in the popular press. It has even been suggested that sensor network technology be deployed in spacecraft missions. Once a sensor node has been safely delivered to an extra-terrestrial surface the first thing it must know is its location relative to the rest of the network. Therefore our work will primarily concentrate on localization algorithms. This work can be applied to similarly developed technologies such as sensor webs described in Delin et al. [5, 3, 4]. In this work we will show that the APIT[7] algorithm is mathematically unsound due to a problem with dead spots not characterized in the original work. In addition we will test two of the more popular algorithms including centroid[2] and trilateration [6, 8] using metrics of energy consumed, accuracy of localization and ease of implementation to evaluate each algorithm. We will develop software implementations of these two algorithms and deploy them on test hardware for our experiments.

APIT Analysis The APIT algorithm is derived from the Point In Triangle Test (PIT), which relies on two propositions. Proposition I: If a node D is inside a triangle ABC, then when D is shifted in any direction, the new position must be nearer to or further from at least one anchor A, B or C. Proposition II: If D is outside triangle ABC then when D is shifted, there must exist a direction in which the position of D is further from or closer to all three anchors A, B and C. The PIT test works because it considers all possible directions of shift. The APIT algorithm as we shall see does not.

The APIT algorithm works by forming triangles of anchor nodes. A node to be localized then determines which triangles it is inside of and the algorithm localizes the node to the center of gravity of the intersection of these triangles. The APIT algorithm states that if no neighbor of a node is further from or closer to all three anchors simultaneously then the node is inside the triangle. Otherwise it is outside the triangle. However since APIT relies on the positioning of neighboring nodes it is susceptible to error. If a node is outside of the triangle we will develop cone shaped error zones radiating in either direction from the node as shown in Fig 1. If the neighboring nodes are within these error cones then the algorithm will incorrectly determine that the node is within the triangle. The closer to the anchor triangle the larger the danger regions and thus the likelihood of encountering the problem. This is the basis of the OutToIn problem noted in [7]. To avoid the problem more neighbor nodes are needed, which increases the InToOut error. APIT thus overestimates the interior of the triangle, or underestimates it.

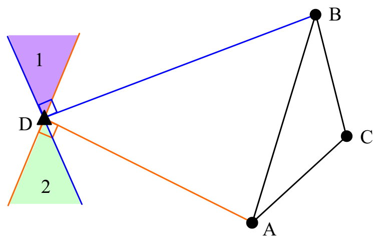

Figure 1: APIT problem: if neighbor is within cone region 1 then it will look closer to B but further from A, similarly a neighbor in region 2 will be closer to A and further from B.

Test Methodology We will test the trilateration and centroid algorithms in various configurations both inside the lab and in an outdoor environment. We will test for the following three metrics accuracy of localization, energy consumed, and ease of implementation. We will measure accuracy against external measurements and surveying techniques. Accuracy is obviously desirable as errors in localization will distort the map formed by the sensor network and could have undesirable effects on the application implemented. We will measure energy consumed by counting the number of transmissions required to localize each node of the network. Energy efficiency is of course desirable because the sensor nodes are small and run primarily from battery power so the longer we can conserve the battery the longer we can keep the node functioning to take measurements. Finally we will measure ease of implementation by the lines of code required to implement each algorithm. Fewer lines of code are desirable because the sensor nodes have limited memory capacity and less memory taken up by localization algorithms and other housekeeping techniques means more memory available for scientific experiments.

We plan to deploy Micaz motes from CrossBow as our test bed system. Micaz motes are commonly used for sensor network research in universities and provide a stable platform from which to deploy our experiments. The motes run TinyOS an open source OS for wireless sensor networks and are programmed in nesC a C like hardware control language making them ideal for our purposes.

We will implement both algorithms on the motes for our experiments. The Micaz motes provide a Received Signal Strength Indicator RSSI that can be translated into an estimate of the distance using an empirical model as described in the Radar system [1]. This distance estimate will be used in both algorithms.

The first algorithm we will test is trilateration. Trilateration is a range-based algorithm by which we mean that it depends exclusively on RSSI distance estimates. Taking the distance from three known nodes and using this information to calculate the location of a fourth node accomplishes trilateration.

Secondly, we will evaluate the centroid algorithm. The centroid algorithm differs from trilateration in that it is a range-free algorithm. Range free algorithms do not depend entirely on RSSI distance measurements for localization. When localizing with the centroid algorithm a node will receive signals from all anchor nodes that are in range. The node is then localized to the center of gravity of the intersection of the circles formed by the propagation model of each anchor node. This is accomplished by simply averaging the x and y coordinates. Because centroid assumes a simplistic circular propagation model it has errors, which are characterized by the Euclidian distance formula.

We will test each algorithm in configurations including three, five and seven anchor nodes with varying numbers of nodes to be localized to determine that accuracy increases as additional anchor nodes are added. We will place the nodes in various configurations to look for any unanticipated problems with the algorithms while performing our tests. All test results will be provided at the conference.

Benefits Benefits that can be realized by deploying sensor network technology in spacecraft missions include an omnipresent sensing environment for rover operations, a fast reacting sensing apparatus for tracking dynamic events (such as weather patterns) and the ability to cover a larger field than a single monolithic instrument.

References

[1] P. Bahl and V. N. Padmanabhan. Radar: An In-Building RF-Based User-Location and Tracking System. *Proc. IEEE INFOCOM 2000*, 2:775–84, March 2000.

[2] Nirupama Bulusu, John Heidemann, and Deborah Estrin. Gps-less low cost outdoor localization for very small devices. *IEEE Personal Communications Magazine*, 7(5):28–34, October 2000.

[3] K.A. Delin, S.P. Jackson, D.W. Johnson, S.C. Burleigh, R.R. Woodrow, M. McAuley, J.T. Britton, J.M. Dohm, T.P.A. Ferr, Felipe Ip, D.F. Rucker, and V.R. Baker. Sensor Web for Spatio-Temporal Monitoring of a Hydrological Environment. League City, TX, March 2004. Presented at the 35th Lunar and Planetary Science Conference.

[4] Kevin A. Delin, Shannon P. Jackson, Scott C. Burleigh, David W. Johnson, Richard R. Woodrow, and Joel T. Britton. The JPL Sensor Webs Project: Fielded Technology. Pasadena, CA, July 2003. Space Mission Challenges for Information Technology.

[5] Kevin A. Delin, Shannon P. Jackson, David W. Johnson, Scott C. Burleigh, Richard R. Woodrow, J. Michael McAuley, James M. Dohm, Felipe Ip, Ty P.A. Ferr, Dale F. Rucker, and Victor R. Baker. Environmental Studies with the Sensor Web: Principles and Practice. *Sensor*, 5:103–117, 2005.

[6] T. Eren, D.K. Goldenberg, W. Whiteley, Y. R. Yang, A. S. Morse, B. D. O. Anderson, and P. N. Belhumeur. Rigidity, Computation, and Randomization in Network Localization.

[7] T. He, C. Huang, B. Blum, J. Stankovic, and T. Abdelzaher. Range-free localization schemes in large scale sensor networks.

[8] Dragos Niculescu and Badri Nath. DV-based Positioning in Ad hoc Networks. *Telecommunication Systems*, 7(22):267–280, 2003.