Position and Orientation in Ad Hoc Networks

Dragos Niculescu, Badri Nath {dnicules, badri} @cs.rutgers.edu

Rutgers University
summary

- problem and motivation
- example
- basic idea
- AoA capable nodes
- algorithm outline
  - bearing propagation (DV)
  - error control
- simulation results
- conclusions
problem statement

ad hoc deployed nodes should be able to know their

- location
  - global coordinates
  - low overhead for mobility
  - accuracy comparable with the node communication range
  - independent operation for disconnected regions
  - without additional infrastructure

- orientation
  - heading
motivation

☐ a sensor reports a phenomenon and its:
  - position
    • place it on a map
    • routing with small or no routing tables
  - orientation
    • remote navigation
    • fine grained control – camera orientation
  - intensity

☐ possible solutions
  - GPS + digital compass in each node
    • compasses do not work well indoors
    • GPS needs line of sight
example
example
example
example
example
example
example
example
example
example
example
example
example
example
example
example
example
example
terminology and assumptions

- **landmark** - a node which knows its own position
- **range** - distance to an objective
- **bearing** - angle between one’s facing direction and some objective
- **heading, orientation** - absolute bearing, or angle to north

- **assumptions**
  - nodes are deployed randomly → connected graph
  - a fixed fraction of nodes are landmarks
  - nodes have a limited radio range
basic idea

- Given (imprecise) bearings to at least three landmarks, $\hat{ABD}$, $\hat{BDC}$, $\hat{CDA}$
- the positions of the landmarks $(x_i, y_i), i = A, B, C$

- a node may infer its own position $(x, y)$
- and its orientation/heading, once $(x, y)$ and $(x_A, y_A)$ are known
angle of arrival capability - example
angle of arrival capable nodes

- **Cricket** compass - MIT (Hari Balakrishnan, Mobicom 2001)
  - uses 5 ultrasound receivers
    - 0.8cm each
    - a few centimeters across
  - TDoA (time difference of arrival)
  - ±10% accuracy for angles < 40 degrees

- **Medusa** node - UCLA (Mani Srivastava, Mobicom 2001)

- antenna arrays
“Cricket” compass - basic principle

Beacon $B$ (on ceiling)

Horizontal plane
“Cricket” compass - disambiguation

- based on measuring ranges
  - front - back ambiguity

- range differentials are measured using phase difference
  - wavelength $\sim L \rightarrow$ range ambiguity
“Medusa” node
algorithm outline

- a few nodes (landmarks) know their position
- all nodes have the AoA capability → find bearings to immediate neighbors
- regular nodes infer bearings to at least three landmarks
  - non-collinear
  - non-cocircular (with the node itself)
- like in DV, bearings to landmarks are propagated hop by hop
- each landmark is treated independently at each node
bearing propagation (DV)

- green angles are known → find bearing to $L$ (red angle)
position computation

- each node obtains a table \( \{X_i, Y_i, dir_i\} \) - coordinates and bearings to landmarks
- several ways to solve:
  - solve a nonlinear system to intersect the \( n \) circles
  - \( \binom{n}{2} \) pairs of landmarks, find distances to centres → GPS problem
  - \( \binom{n}{3} \) triplets of landmarks, find \( \binom{n}{3} \) estimates → centroid
  - there are \( O(n) \) algorithms providing the same accuracy
- absolute position + bearing to known point = heading(absolute orientation)
error control

- lightweight methods → CPU, memory, communication
- the propagation scheme compounds errors
  - limit the travel distance of packets (TTL)
- small angle error → large distance error
  - avoid angles below a threshold
- large errors are clustered
  - prune position estimations that are far off the centroid
- these three methods together reduce the errors by half
error control - propagation

GPS=0.05 err=0.4 eps=0.05 nodes=200
error control - small angles
error control - remove outliers

Centroid of all points

Centroid of half

True location

hopsize=2000
simulation

- random topology 100 nodes
  - isotropic \(^1\)
  - AoA errors
    • white Gaussian noise
    • with a 95% probability, the measured angle is within \(\pm 2 \text{ stddev of mean}\)

- performance metrics
  - coverage - how many nodes get a position/heading
  - absolute position error - in number of hops
  - bearing error - with respect to landmarks
  - heading error - absolute orientation

\(^1\)the network has the same properties (density, radio range) in all directions
coverage
bearing error

![Graph showing bearing error vs measurement stddev](image)
heading error

- Heading error = double of the bearing error
- More landmarks don’t bring more precision

- gps = 5%
- gps = 50%
location error

The diagram shows the positioning error in terms of the number of hops as a function of measurement standard deviation. The x-axis represents the measurement standard deviation, ranging from $\pi/16$ to $\pi/4$, with markers at $\pi/8$ and $\pi/4$. The y-axis represents the positioning error, with markers at 0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, and 1.6. Several curves represent different GPS accuracy levels: 5%, 10%, 20%, 35%, and 50%. The curves indicate an increase in positioning error with increasing measurement standard deviation, especially noticeable at lower GPS accuracy levels.
simulation summary

- error reduction - simple methods
- error - coverage tradeoff
- heading error is about double the heading error
- nodes inside the convex hull of acquired landmarks get better estimates
- # of landmarks is more critical for position than for orientation
future work

○ multimodal estimation
  – can AoA and signal strength be used together?

○ node mobility
  – a moving landmark
    • is a new landmark
    • one flying landmark could be enough for the entire static network
  – mobile nodes are supported by static nodes
conclusions

❖ APOS (Ad Hoc Positioning and Orientation System)
  - provides position and orientation for randomly deployed nodes
  - needs AoA capability in all nodes, but no signal strength
  - distributed, no infrastructure
  - uses a DV based scheme to propagate landmark bearings
  - positioning accuracy → one hop away from the true location
  - orientation accuracy → double the measuring accuracy