



Mobile Ad hoc Networks COE 549 Localization

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Outline

- Overview
- Key Issues
- Localization Approaches
- Coarse-grained node localization using minimal information
- Fine-grained node localization using detailed information



Overview

- Each individual sensor observation can be characterized essentially as a tuple of the form $\langle S, T, M \rangle$, where S is the spatial location of the measurement, T the time of the measurement, and M the measurement itself. The location needed for the following reasons:
 1. To provide location stamps
 2. To locate and track point objects
 3. To monitor the spatial evolution of a diffuse phenomenon
 4. To determine the quality of coverage.
 5. To achieve load balancing
 6. To form clusters
 7. To facilitate routing
 8. To perform efficient spatial querying

However, localization is only important in random deployment



Key Issues

■ What to localize?

- The refers to identifying nodes have a priori known locations (called reference nodes) and which nodes do not (called unknown nodes)
- The number and fraction of reference nodes in a network of n nodes may vary all the way from 0 to $n-1$ and could be static or mobile. The same applies to the unknown nodes
- The unknown nodes can be cooperative or non-cooperative nodes
- In case of non-cooperative scheme, nodes cannot participate in the localization algorithm



Key Issues..

■ When to localize?

- location information is needed for all unknown nodes at the very beginning of network operation
- In static environments, network localization may thus be a one-shot process.
- In other cases, it may be necessary to provide localization on-the-fly, or refresh the localization process as objects and network nodes move around, or improve the localization by incorporating additional information over time
- The time scales involved may vary considerably from being of the order of minutes to days, even months



Key Issues..

■ How well to localize?

- The technique must provide the desired type and accuracy of localization, taking into account the available resources

■ How to localize?

- The signals used can vary from narrowband radio signal strength readings or packet-loss statistics, UWB RF signals, acoustic/ultrasound signals, infrared
- The signals may be emitted and measured by reference node, unknown nodes, or both
- The basic localization algorithm may be based on a number of techniques, such as proximity, calculation of centroids, constraints, ranging, angulation, pattern recognition, multi-dimensional scaling, and potential methods



Cone-Based Topology Control Protocol

- The authors claim that the protocol provides a minimal direction-based distributed rule to ensure that the whole network topology is connected, while keeping the power usage of each node as small as possible.

Protocol Description

- Each node keeps increasing its transmit power until it has at least one neighboring node in every α cone or it reaches its maximum transmission power limit
- It is assumed here that the communication range increases monotonically with transmit power
- CBTC showed that $\alpha \leq 2\pi/3$ suffices to ensure that the network is connected
- A tighter result has shown that α can further reduced to $\alpha \leq 5\pi/6$



Localization approaches

1. Coarse-grained localization using minimal information:

- Use a small set of discrete measurements, such as the information used to compute location
- Minimal information could include binary proximity, near–far information

2. Fine-grained localization using detailed information:

- Based on measurements, such as RF power, signal waveform, time stamps, etc. that are either real-valued or discrete with a large number of quantization levels
- These include techniques based on radio signal strengths, timing information, and angulation

While minimal information techniques are simpler to implement, and likely involve lower resource consumption and equipment costs, they provide lower accuracy than the detailed information techniques



Coarse-grained node localization using minimal information

Binary proximity

- A simple decision of whether two nodes are within reception range of each other
- A set of references nodes are placed in the environment in some non-overlapping manner
- Either the reference nodes periodically emit beacons, or the unknown node transmits a beacon when it needs to be localized
- If reference nodes emit beacons, these include their location IDs, then unknown node must determine which node it is closest to, and this provides a coarse-grained localization
- Alternatively, if the unknown node emits a beacon, the reference node that hears the beacon uses its own location to determine the location of the unknown node



Coarse-grained node localization using minimal information..

Binary proximity..

- Examples:
 - Active Badge Location System
 - Radio Frequency Identification (RFID)



Coarse-grained node localization using minimal information..

Centroid calculation

- When the density of reference nodes is sufficiently high that there are several reference nodes within the range of the unknown node
- In two dimensional scenario, let there be n reference nodes detected within the proximity of the unknown node, with the location of the i th such reference denoted by (x_i, y_i)
- Let the location of the unknown node (x_u, y_u)

$$x_u = \frac{1}{n} \sum_{i=1}^n x_i \quad y_u = \frac{1}{n} \sum_{i=1}^n y_i$$

- It is shown through simulations that, as the overlap ratio R/d is increased from 1 to 4, the average RMS error in localization is reduced from $0.5d$ to $0.25d$

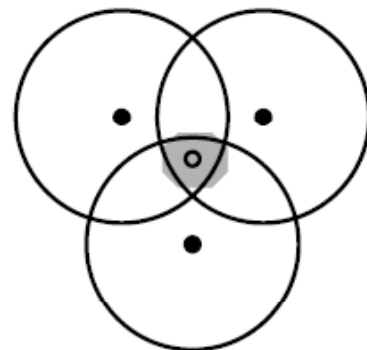


Coarse-grained node localization using minimal information..

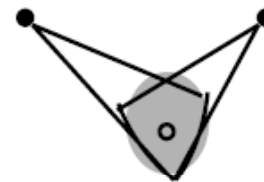
Geometric constraints

- The region of radio coverage may be upper-bounded by a circle of radius $R_{\max}$
- When both lower $R_{\min}$ and upper bounds $R_{\max}$ can be determined, based on the received signal strength, the shape for a single node's coverage is an annulus
- when an angular sector $(\theta_{\min}, \theta_{\max})$ and a maximum range $R_{\max}$ can be determined, the shape for a single node's coverage would be a cone with given angle and radius.
- A computational simplification that can be used to determine this bounded region is to use rectangular bounding boxes as location estimates. Thus the unknown node determines bounds $x_{\min}, y_{\min}, x_{\max}, y_{\max}$ on its position

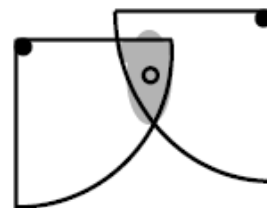
Coarse-grained node localization using minimal information..



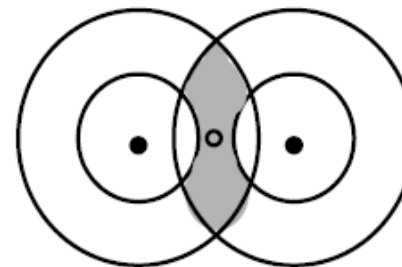
Disc



Sector



Quadrant



Annulus

- Reference node
- Unknown node
- Constrained location region

Localization using intersection of geometric constraints



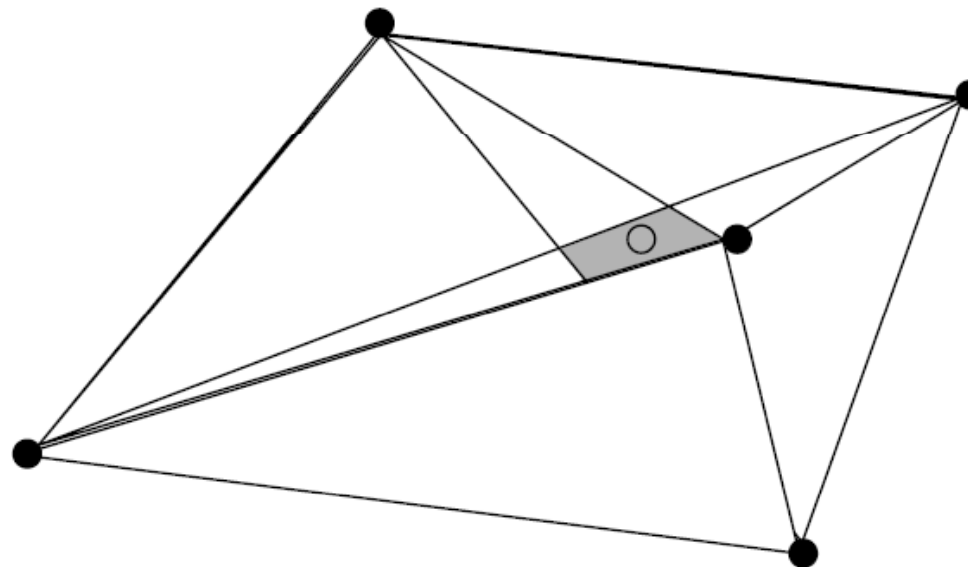
Coarse-grained node localization using minimal information..

Approximate point triangle (APIT)

- Similar to geometric constraints but the constraint region are defined as triangles between different sets of three reference nodes

Coarse-grained node localization using minimal information..

- Reference node
- Unknown node



The approximate point-in-triangle (APIT) technique



Coarse-grained node localization using minimal information..

Identifying codes

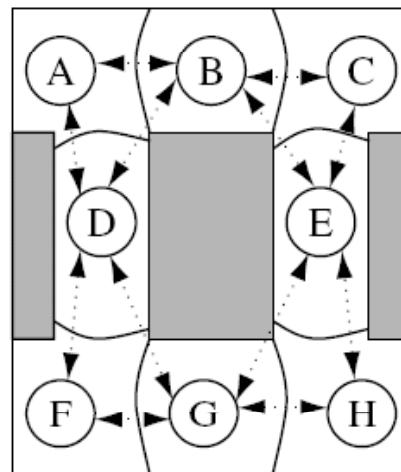
- The sensor deployment is planned in such a way as to ensure that each resolvable location is covered by a unique set of sensors

The algorithm runs on a deployment region graph $G = (V, E)$ in which vertices V represent the different regions, and the edges E represent radio connectivity between regions. Let $B(v)$ be the set of vertices that are adjacent to v , together with v itself. A set of vertices $C \in V$ is referred to as an *identifying code*, if, for all $u, v \in V$, $B(v) \cap C \neq B(u) \cap C$.

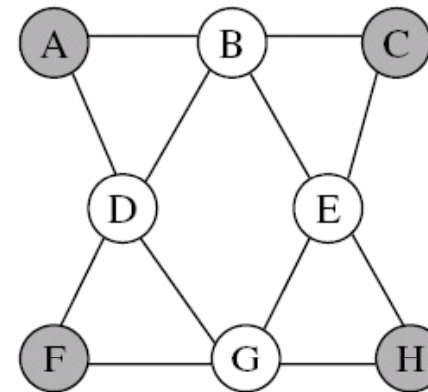
Illustration of the ID-CODE technique showing uniquely identifiable regions

Coarse-grained node localization using minimal information..

Identifying codes



Node locations



Connectivity graph

Transmitters A, F, C, H provide unique IDs for all node locations

V:	A	B	C	D	E	F	G	H
ID:	A	A,C	C	A,F	C,H	F	F,H	H

Illustration of the ID-CODE technique showing uniquely identifiable regions



Fine-grained node localization using detailed information..

Radio signal-based distance-estimation (RSS)

$$P_{r,\text{dB}}(d) = P_{r,\text{dB}}(d_0) - \eta 10 \log \left(\frac{d}{d_0} \right) + X_{\sigma,\text{dB}}$$

where $P_{r,\text{dB}}(d)$ is the received power at distance d and $P(d_0)$ is the received power at some reference distance d_0 , η the path-loss exponent, and $X_{\sigma,\text{dB}}$ a log-normal random variable with variance σ^2 that accounts for fading effects.

ranging using radio signal strengths (m-level accuracy)



Fine-grained node localization using detailed information..

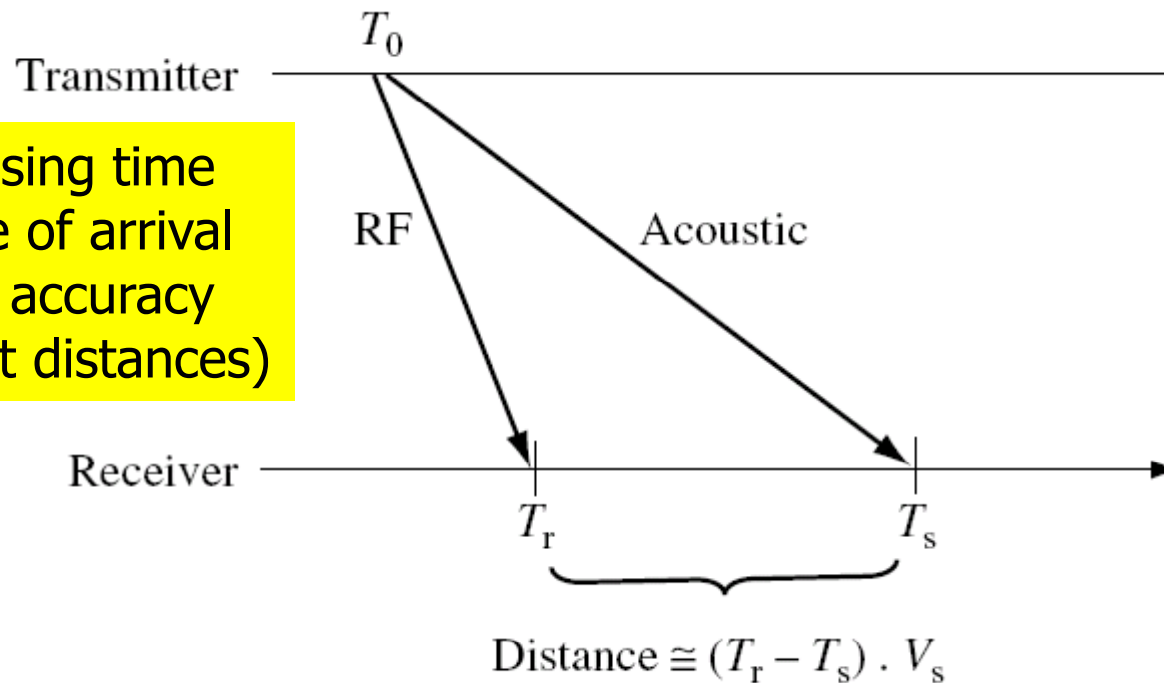
Distance-estimation using time differences (TDoA)

- The idea is to simultaneously transmit both the radio and acoustic signals (audible or ultrasound) and measure the times T_r and T_s of the arrival of these signals respectively at the receiver
- Since the speed of the radio signal is much larger than the speed of the acoustic signal, the distance is then simply estimated as $T_s - T_r * V_s$, where V_s is the speed of the acoustic signal
- One minor limitation of acoustic ranging is that it generally requires the nodes to be in fairly close proximity to each other

Fine-grained node localization using detailed information..

Distance-estimation using time differences

ranging using time
difference of arrival
(cm-level accuracy
over short distances)



Ranging based on time difference of arrival