ROPE:
Robust Position Estimation in wireless sensor networks

Wireless Sensor Networks (IN4181)

Venkatraman Iyer

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Localization

Estimating the position of a sensor in the wireless network.

Applications

- **Routing,** based on physical location of nodes.
- **Querying** nodes over a geographical area.
- **Coverage** study of a network.

Different Approaches to Localization

Distance Estimation Techniques

- Received signal strength indicator (RSSI)
- Time (Difference) of arrival. (ToA, TdoA)
- Angle of arrival. (AoA)

Combining Techniques

- Tri-lateration/Multilateration
- Triangulation
- Maximum Likelihood Estimate (ML)

What is Localization lacking?

SECURITY !!!

An attacker can

- Disrupt distance estimates .
- Replay beacons to a different region (Mafia Frauds.)

Objectives of a Secure Localization System

- Achieve robust estimates.
- Ability to verify a location.

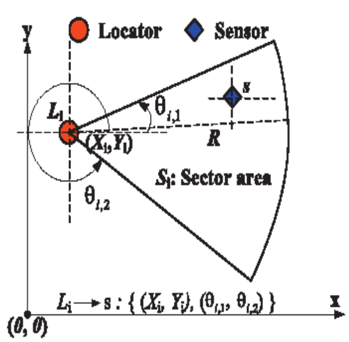
The ROPE Positioning System

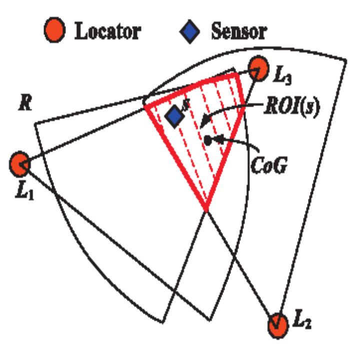
- A de-centralized, range-free, robust positioning system.
- Can verify location of sensors.

Key features

- ***Distance Bounding:*** **bounds an attacker's ability to spoof a sensor.**
- ***Verifiable Multilateration (VM): Multilateration with validity checks.***
- ***Secure Range Independent Localization***
    - ***Verifiers/Locators with predetermined locations.***
    - ***Directional Antennas for longer range.***
    - ***Use of pair-wise keys between sensors and locators.***

Range-free Localization principle





Threats handled

- **Wormhole**
  - Record information at one point, replay at another.
  - Can not be detected by message authentication codes.
- **SYBIL**
  Impersonation of nodes.
- **Jamming**
  Enlarges distance estimates.

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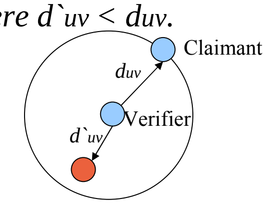
Distance Bounding Principle(1)

Concept

- A claimant node at a distance *duv from a verifier cannot claim to be at a distance d`uv from it, where d`uv < duv.*



- *Exchange of RF signals between the claimant and the verifier.*

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Distance Bounding Principle(2)

Distance bounding protocol

- The claimant ***u*** commits to a random nonce Nu.
  i.e. Generate commitment (c,d) = commit(Nu),
  send c to verifier.

- The verifier sends a challenge Nv, and starts a timer.

- The claimant responds by sending Nv Θ Nu (Θ = EX-OR).

- The verifier on receiving the challenge response, calculates *dvu*.

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Distance Bounding Principle(3)

Distance bounding protocol(contd.)

- ***The claimant sends the decommit value d thorough an encrypted pairwise key Kvu.***

Assumptions/Requirements

- ***Binding and Hiding commitment scheme.***

- **Nanosecond precision for time measurement and computations.**

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Verifiable Multilateration (VM)

Principle

- At least three reference points.
- Central Authority estimates sensor position and runs the verification checks.
- Prevents spoofing of honest nodes, and nodes from lying about their positions.

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Range Independent Localization(1)

Features

- **De-centralized Passive localization.**
- ***Two tier network architecture. Locators i.e. reference points and sensors,***
- ***Sensor collects beacons from all locators within range, determines regions of intersection (ROI).***

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Position Estimation in ROPE (1)

Network Model

- **Sensors.**
  - **Randomly deployed with density ρs.**
  - **Sensor-sensor Communication range of *r***
- **Locators.**
  - **randomly deployed with density ρL << ρs.**
  - **M directional antennas, each of beamwidth 2π/M.**
  - **Locator-sensor Communication range of *R*.**
  - ***Sensor-locator communication range*** $r_{SL} = rG^{\frac{1}{\gamma}}$
- **Key based security.**
  - Each sensor shares pair-wise key with every locator.

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Position Estimation in ROPE (1)

Secure Localization

- **Sensor broadcasts Id with a random Nonce.**
- **Locators in the sensor's range perform distance bounding**
- **Sensor performs VM, when it has distance bounds with at least three locators. Notify neighbouring locators on completion.**
- **Compute Distance Bounding Intersection Region (DBIR) if multilateration is not feasible.**

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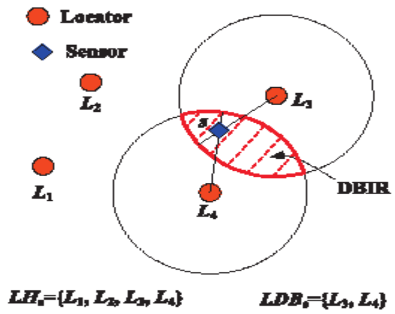
Position Estimation in ROPE (2)

Secure Localization(contd.)

Distance Bounding Intersection Region (DBIR)



- **Meanwhile, Locators wait for a notification.**

Position Estimation in ROPE (3)

Secure Localization(contd.)

- **Locators that do not hear the notification re-broadcast the sensor Id, the original Nonce , with their Id.**
- **Re-transmission covers all locators within sensor's range.**
- **A locator on hearing the broadcast transmits the**

$$\left\langle M_j^k, MAC_{K_{L_j}^s}(M_j^k) \right\rangle,$$

$$M_j^k : Id_{L_j} \parallel (X_j, Y_j) \parallel (\theta_{j,1}^k, \theta_{j,2}^k) \parallel N_s,$$

M_j^k **:message transmitted by**

(X_j, Y_j) **:position of locator j**

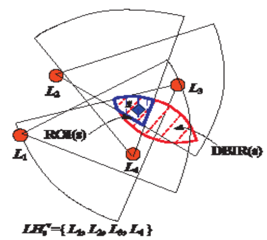
$(\theta_{j,1}^k, \theta_{j,2}^k)$ **:slopes of the sector boundary.**

$MAC_{K_{L_j}^s}(M_j^k)$ **: Message Authentication code.**

Position Estimation in ROPE (4)

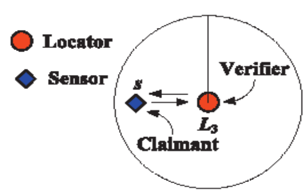
Secure Localization(contd.)

- **Collect beacons within the range *after* a time-out, and build a set of locators.**
- **Region of Intersection (ROI) determined**
- **Centre of gravity yields position estimate**



Position Verification in ROPE

- **Locators also operate as data collectors.**



- **Achieved through distance bounding.**

Attacks and the ROPE system(1)

Types of attacks

- **Wormhole**
  Record information at one point, replay at another.
- **SYBIL**
  Impersonation of nodes.

Metric for analyzing robustness

Maximum Spoofing Impact (MSI)*: *The maximum distance between the actual sensor position and the faulty position.

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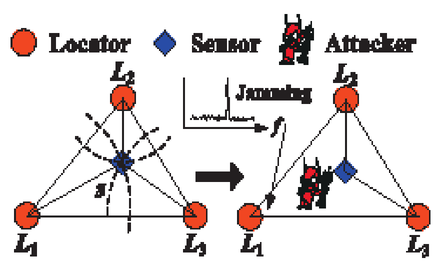
Prevention of attacks in ROPE (1)

- Attacker can either jam the transmissions or replay beacons after a delay.

- If VM can be performed, distance bounding thwarts the attack.



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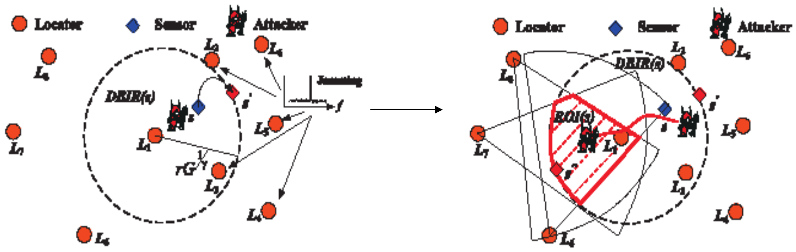
Prevention of attacks in ROPE (2)

Wormhole attack



Cost of an attack makes it prohibitive.

Prevention of attacks in ROPE (3)

SYBIL attack

- **Infeasible to find (M',K') such tha** $MAC_{K'}(M')=MAC_{K^s_{L_i}}(M_i^k)$
- **A sensor can perform distance bounding with *Kmin* *locators to mitigate impact of a single locator compromise.***
- ***Trade-off between security, and locator density.***

Performance Evaluation(1)

Experiment Setup

- Sensors deployed in an area 100m X 100m with density $\rho_s = 0.5$.
- Varying density ρ_L of locators.

Metric for analyzing robustness

Maximum Spoofing Impact (MSI)*: *The maximum distance between the actual sensor position and the faulty position.

$$MSI = \max_{p \in DBIR} \|s - p\|.$$

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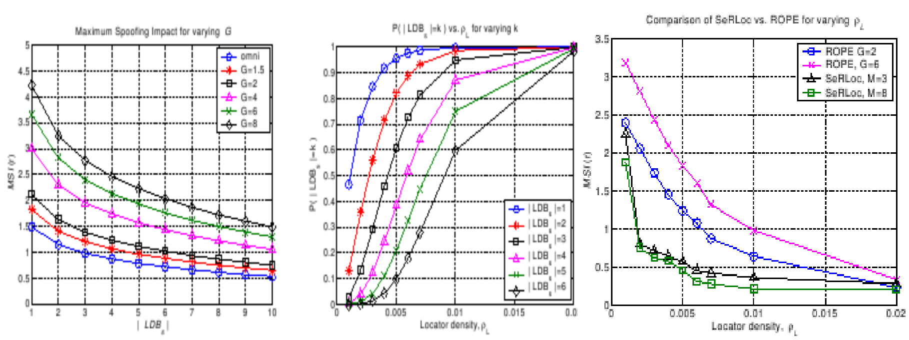
Performance Evaluation(2)



(a) (b) (c)

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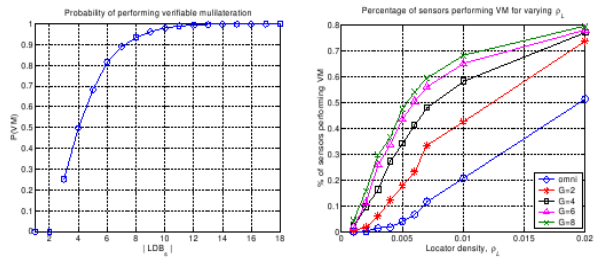
Performance Evaluation(3)



(a) (b)

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Conclusions

- ROPE performs a robust and verifiable localization using distance bounding and VM.
- Resists wormhole attacks, impersonation and jamming.
- Limits MSI even for low locator densities.

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