Self-Organization in Autonomous Sensor/Actuator Networks

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Overview

- **Self-Organization**
  Basic methodologies of self-organization; comparison of central and hierarchical control, distributed systems, and autonomous behavior; examples of self-organization

- **Mobile Sensor/Actuator Networks**
  Ad hoc routing; reliable communication and congestion control; sensor assistance for mobile robots; applications

- **Coordination of Autonomous Systems**
  Coordination and synchronization; communication aspects; clustering

- **Bio-inspired Mechanisms**
  Swarm intelligence; artificial immune system; intra/inter cellular information exchange
Localization in Sensor Networks

- Axes of application requirements
  - Granularity and scale of measurements
  - Accuracy and precision
  - Relation to established coordinate system
  - Dynamics
  - Cost
  - Form factor
  - Communication requirements
  - Environment
  - Target cooperation, system passivity
Taxonomy of Localization Systems

- **Active localization**
  - Non-cooperative
    - Usually based on reflected signals, e.g. radar systems
  - Cooperative target
    - Exchange of signals with known characteristics
  - Cooperative environment
    - Elements of the infrastructure emit signals, e.g. GPS

- **Passive localization**
  (difference to active systems due to techniques unrelated to normal behavior)
  - Blind source localization
    - Requires coherent signals, localize the most prominent source
  - Passive target localization
    - Similar to blind source, assumes some knowledge about the source, e.g. habitat monitoring
  - Passive self-localization
    - Existing beacon signals from known infrastructure are used to passively deduce the location
Localization Techniques

- Distance Measurement
- Distance Approximation
- Triangulation
- Coverage / Neighborhood
Localization Techniques

- Distance measure (triangulation)
  - Measurement of the distance to dedicated nodes
  - Easy to achieve, no HW/SW modifications required
  - Usually low quality due to radio transmission properties
Localization Techniques

- **Coverage (neighborhood discovery)**
  - Detection of neighboring nodes, approximation of current position
  - Easy to achieve, no HW/SW modifications required
Ranging Technologies

- RF RSS
  - Received Signal Strength (RSS)
  - Roughly a measure of the amplitude of a detected radio signal
  - Highly dependent on the environment
    - Open space: $1/R^2$
    - Near the ground: $1/R^4$
  - Difficulties in automatically choosing a valid model
    - Measurements required to obtain the characteristics
Ranging Techniques

- RF ToF
  - Time of Flight (ToF)
  - Can be more accurate
  - Two main challenges
    - Synchronization must use signals also traveling at the speed of light
    - Requires high frequency RF signals and fast, accurate clocks
      → timing and synchronization
  - Examples
    - GPS satellites carry atomic clocks for timing, these clocks are conditionally adjusted to account for relativistic effects as they orbit the earth. Also, the trajectory of the satellites is carefully measured
    - More down-to-earth implementations are based on infrastructure elements connected by carefully measured cables
Radio Connectivity based Approaches

- Measure of radio connectivity
- Basically measure of packet loss
- Based on periodic beacon messages
- Reference to the increasing probability of collisions or lost messages due to low signal quality with increasing distance
Case Study

- Mica2 Motes – Signal Quality

- Signal Strength
  - In general: using TOS_Msg.strength field
  - Not set in standard TinyOS messages!
  - Requires reprogramming of the Mica2 software, e.g. using the surge message fields
    - $V_{\text{rssi}} = V_{\text{batt}} \times \text{ADC0} / 1024$ (ADC0=TOS_Msg.strength)
    - $\text{RSSI(dBm)} = -50.0 \times V_{\text{rssi}} - 45.5$ (for frequency of 915MHz)

- Transmission quality: getQuality()
  - Based on a neighbor table maintained to track link history and relationship to nodes within radio range
  - Link estimation technique is an exponentially weighted moving average
  - On packet arrival the number of missing packets is calculated based on the seq. no. difference
  - The number of lost packets is accumulated using a timeout count
  - Loss ratio is used as a quality measure
Measurement Results

[Graph showing measurement results for distances 1m to 5m, with data points plotted at various measurements.]
Localization – Current Research

- Autonomic Reconfiguration
  - Adaptation of the signal strength at the sender
  - Goal: detection of “lost” neighbors
  - Combination of coverage and distance measure

- Adaptation of radio frequency and position