Self-Organization in Autonomous Sensor/Actuator Networks

[SelfOrg]

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Overview

- **Self-Organization**
  Introduction; system management and control; principles and characteristics; natural self-organization; methods and techniques

- **Networking Aspects: Ad Hoc and Sensor Networks**
  Ad hoc and sensor networks; self-organization in sensor networks; evaluation criteria; medium access control; ad hoc routing; data-centric networking; clustering

- **Coordination and Control: Sensor and Actor Networks**
  Sensor and actor networks; communication and coordination; collaboration and task allocation

- **Self-Organization in Sensor and Actor Networks**
  Basic methods of self-organization – revisited; evaluation criteria

- **Bio-inspired Networking**
  Swarm intelligence; artificial immune system; cellular signaling pathways
Basic Methods of Self-Organization – Revisited

- Positive and negative feedback
- Interactions among individuals and with the environment
- Probabilistic techniques
## Positive and negative feedback

### Networking aspects

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>MAC</strong></td>
<td>positive and negative feedback for controlling the used transmission energy, e.g. in PCM; enforcement of synchronization between multiple nodes to a common schedule</td>
</tr>
<tr>
<td><strong>Ad hoc routing</strong></td>
<td>positive feedback for route discovery in most table-driven routing protocols; negative feedback for suppression further data messages over erroneous paths, both used e.g. in AODV and DYMO</td>
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<tr>
<td><strong>Data-centric networking</strong></td>
<td>positive feedback in form of interest messages controlling the behavior of sensor nodes, e.g. in directed diffusion; energy levels and timeouts as negative feedback to suppress unnecessary communication, e.g. in rumor routing</td>
</tr>
<tr>
<td><strong>Clustering</strong></td>
<td>feedback is provided for example in form of energy levels controlling system-inherent parameters such as the probability to become clusterhead in HEED</td>
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### Positive and negative feedback

<table>
<thead>
<tr>
<th>Coordination and control</th>
<th>Feedback loops are inherently used by all time synchronization techniques; positive and negative feedback enables adaptive coordination among nodes, e.g. for optimizing the utility by ASCENT or to ensure a latency bound by DEPR</th>
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<tr>
<td>Communication and coordination</td>
<td>positive feedback in the biddings in auction-based task allocation, e.g. in MURDOCH, and negative feedback through re-allocation; feedback based probability adaptation in the case of emergent cooperation</td>
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<tr>
<td>Collaboration and task allocation</td>
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## Interactions among individuals and with the environment

### Networking aspects

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<th>Description</th>
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<tr>
<td>MAC</td>
<td>Intensive protocol inherent interactions between neighboring nodes to detect or prevent collisions, e.g., MACA-based protocols; synchronization according to local message exchanges; indirect information exchange using signal strength measurements, e.g., in PCM.</td>
</tr>
<tr>
<td>Ad hoc routing</td>
<td>State and topology maintenance for address-based routing; interactions among neighboring and remote nodes to search shortest path information, e.g., in AODV and DYMO; duplicate address detection based on node interactions, e.g., in PDAD and DAA.</td>
</tr>
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<td>Data-centric networking</td>
<td>Optimized gossiping strategies exploiting the local topology information; agent-based approaches relying on stigmergic information exchange and on local interactions between neighboring nodes, e.g., in rumor routing; adaptation of source-sink relationships according to remote interactions in directed diffusion.</td>
</tr>
<tr>
<td>Clustering</td>
<td>Interaction provides the basis for clustering techniques; transmission power estimation and cluster affiliation using local interactions, e.g., in LEACH and HEED.</td>
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</table>
## Interactions among individuals and with the environment

### Coordination and control

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<tr>
<th>Communication and coordination</th>
<th>time synchronization based on exchanged data or specific time protocol messages (used by all the discussed algorithms); topology maintenance and clustering techniques based on local interactions, e.g. in Span, ASCENT, and DEPR</th>
</tr>
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<tr>
<td>Collaboration and task allocation</td>
<td>intentional coordination based on directed communication to a central decision taker, either for periodic state maintenance, e.g. in OAA, or for auction systems, e.g. in MURDOCH and mediation; local interactions among neighboring agents and stigmergic communication in emergent cooperation</td>
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## Probabilistic techniques

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<tr>
<td>MAC</td>
<td>reduced collision probability through randomized medium access; fairness and mutual exclusion are achieved by using random startup delays for the RTS/CTS handshake, e.g. in all MACA based protocols</td>
</tr>
<tr>
<td>Ad hoc routing</td>
<td>gossiping techniques to reduce the flooding overhead in reactive routing approaches, e.g. in optimized AODV; dynamic address allocation based on stateless random random address selections in combinations with DAD algorithms, e.g. in PDAD and DAA</td>
</tr>
<tr>
<td>Data-centric networking</td>
<td>probabilistic data forwarding in gossiping approaches; agent based techniques relying on random waypoint strategies, e.g. in rumor routing</td>
</tr>
<tr>
<td>Clustering</td>
<td>randomized clusterhead selection to maximize the network lifetime and to provide fair distribution of the energy load, e.g. in LEACH and HEED</td>
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## Coordination and control

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<tr>
<th>Communication and coordination</th>
<th>randomization through variation of network latencies; randomly distributed back-off delay, e.g. in Span; probabilistic state transitions, e.g. in DEPR</th>
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<tr>
<td>Collaboration and task allocation</td>
<td>probabilistic decision processes and task allocation according to estimations for winning the contest for a new task or the nest leaving probability</td>
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Evaluation Criteria

- Scalability
- Energy considerations
- Network lifetime
Scalability

- Protocol overhead
  - Number and size of state information that must be stored and maintained at each node in the network
  - Direct communication overhead – goodput vs. network load

- Capacity of wireless networks
  - Bounded capacity of wireless networks according to Gupta & Kumar

- Reduced determinism
  - Scalability vs. predictability
Energy considerations

- **Constraints on the battery source**
  - Battery size is direct proportional to its capacity

- **Selection of optimal transmission power**
  - Energy consumption increases with an increase in the transmission power (which is also a function of the distance between communicating nodes)
  - Optimal transmission power decreases the interference among nodes, which, in turn, increases the number of simultaneous transmissions

- **Channel utilization**
  - As seen before, a reduction of the transmission power increases frequency reuse → better channel utilization
  - Power control becomes especially important in CDMA-based systems
Computation vs. Communication Energy Cost

- Tradeoff?
  - Directly comparing computation/communication energy cost not possible
  - But: put them into perspective!
  - Energy ratio of “sending one bit” vs. “computing one instruction”:
    → something between 220 and 2900 in the literature
  - Transmitting (send & receive) one kilobyte ≈ computing three million instructions!

- Hence: try to compute instead of communicate whenever possible

- Key technique in WSN – in-network processing!
  - Exploit compression schemes, intelligent coding schemes, …
Network lifetime

- Considered as a comprehensive evaluation metric for sensor networks

- Individual parameters $\zeta(t)$
  - Active nodes, alive nodes, availability / service disruption tolerance
  - Area coverage, target coverage, $k$-coverage
  - Latency, loss, connectivity
  - Connected coverage

- Liveliness
  - $\zeta(t)$ : if all $\zeta(t)$ are provided

- Lifetime measures
  - Accumulated network lifetime $Z_a$ is the sum of all times the network is alive
  - Total network lifetime $Z_t$ is the time at which the liveliness criterion is lost for a time period longer than the service disruption tolerance
Summary (what do I need to know)

- **Self-organization techniques**
  - Basic methods (positive and negative feedback, interactions among individuals and with the environment, probabilistic techniques)
  - Applicability in sensor and actor networks

- **Evaluation criteria**
  - What are possible evaluation metrics?
References