Wireless Sensor Networks (WSN) or Low-Rate WPANs (LR-WPANs)

Dietmar Köther and Patrice Siatchoua
What are Wireless Sensor Networks (WSN)?

- A collection of sensor motes that perform autonomous sensing to form the basis of a massively integrated sensor network which sends some useful information to a base station.
WSN Applications & Motivation

• Industrial control and Monitoring
• Home automation and consumer electronics
• Security and military sensing
• Asset tracking and supply chain management
• Intelligent agriculture and environmental sensing
• Health monitoring
WSN Performance Requirements

- Low power consumption
- Low cost
- Worldwide availability
- Network type
- Security
- Low required data throughput
- Higher message latency
- Mobility
WSN Performance Requirements

- Low computing power required
- Low memory consumption
- Short range communication only
- Only information on neighbourhood required
- Automatic configuration
WSN Related Works

- Wireless Integrated Network Sensors (WINS)
- PicoRadio
- µAMPS
- MANET
- Terminodes
- Underwater acoustic & deep space networks
WSN Protocol Stack

ICS/Network Team@IMST

Wireless Solution Team@IMST & UWBGroup@IMST
WSN Network Layer

- At the network layer, the main aim is to find ways for energy-efficient route setup and reliable relaying of data from the sensors nodes to sink to maximize the lifetime of the network.

- Routing is a very challenging task in WSNs due to several characteristics that distinguish them from other communication networks and wireless ad-hoc networks.

- Performance of routing protocol closely related to architectural model.
WSN System Architecture and Design Issues

- **Network dynamics**
  - Stationary / moving nodes

- **Node deployment**
  - Deterministic / Self-organizing deployment

- **Energy Consideration**
  - Direct communication / Multi hop routing

- **Data delivery models**
  - Continuous / Event-driven / Query-driven / Hybrid
WSN System Architecture and Design Issues

- **Node capabilities**
  - Relaying / Sensing / Aggregation nodes
  - Homogeneous / Heterogeneous nodes

- **Data aggregation opportunities**
  - Suppression / Min / Max / Average
  - Performed fully / partially in a sensor node / specialized nodes
WSN Routing: Protocols Classification

- **Address centric protocol (normally not WSN):**
  - Routing in accordance to addresses (e.g. TCP/IP)

- **Data centric protocols:**
  - Query based and depend on the naming of desired data.

- **Hierarchical protocols:**
  - Aim at clustering the nodes so that cluster heads can do some aggregation and reduction of data in order to save energy.
WSN Routing: Protocols Classification

- Direct communication
- Flat routing
- Clustering routing protocols

Source: I. Stavrakakis, Wireless Sensor Networks (WSNs)
**Flooding**: Broadcasts data to all neighbours regardless if they receive it before or not until the destination is reached. Data ignored if already received.

(+) No Topology maintenance

(-) Implosion, Overlap, resource blindness

**Gossiping**: Sends data to randomly selected neighbour.

(+ ) Solves implosion problem

(-) Overlap and long propagation delay
Sensor Protocols for Information via Negotiation (SPIN): Sends data to sensor nodes only if they are interested; has three types of messages: ADV (meta-data), REQ(meta-data), and DATA.

- **SPIN 1**: Does not consider energy consumption
- **SPIN 2**: If energy is low, reduced its participation
  - (+) More energy-efficient than Flooding/Gossiping while distributing data with at least the same rate;
  - (+) Strong against topological changes.
  - (-) Cannot guarantee the delivery of data
WSN Routing: Data-Centric Protocols

- **SPIN (cont‘d)**

![Diagram of SPIN protocol steps](image)
WSN Routing: Data-Centric Protocols

- **Directed Diffusion**: sets up gradients for data to flow from source to sink during interest dissemination; has several elements: *interest messages, data messages, gradients, and reinforcements*

<table>
<thead>
<tr>
<th>Diffusion Element</th>
<th>Design choices</th>
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<tbody>
<tr>
<td>Interest propagation</td>
<td>• Flooding</td>
</tr>
<tr>
<td></td>
<td>• Constrained or directional flooding based on location</td>
</tr>
<tr>
<td></td>
<td>• Directional propagation based on previously cached data</td>
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<tr>
<td>Data propagation</td>
<td>• Reinforcement to single path delivery</td>
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<tr>
<td></td>
<td>• Multipath delivery with selective quality along different paths</td>
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<tr>
<td></td>
<td>• Multipath delivery with probabilistic forwarding</td>
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<tr>
<td>Data caching and aggregation</td>
<td>• For robust data delivery in the face of node failure</td>
</tr>
<tr>
<td></td>
<td>• For coordinated sensing and data reduction for directing interests</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>• Rules for deciding when to reinforce</td>
</tr>
<tr>
<td></td>
<td>• Rules for how many neighbours to reinforce</td>
</tr>
<tr>
<td></td>
<td>• Negative reinforcement mechanisms and rules</td>
</tr>
</tbody>
</table>
WSN Routing: Data-Centric Protocols

- Directed Diffusion (cont’d)

Interest propagation

Initial gradients set up

Data delivery along reinforced path

Gradient establishment

Reinforcement

Multiple sources

Multiple sinks

Repair
Energy-aware Routing: uses a “optimal” path occasionally to reduce the network “costs”. This path is chosen by means of a function which depends on the energy consumption of each path.

This protocols has three phases:

- Setup phase
- Data communication phase
- Route maintenance phase
WSN Routing: Data-Centric Protocols

- **Energy-aware Routing** (cont’d)

  (+) Network lifetime increases
  (+) Energy efficient
  (-) Problem to recover from path failure
  (-) Location information needed
• **Rumor Routing:**
  intended for contexts in which geographic routing criteria are not applicable. Routes the queries to the nodes that have observed a particular event rather than flooding the entire network to retrieve information about the occurring events.

  (+) **Tuneable** best effort delivery
  (+) **Tuneable** for a range of query/event ratios
  (+) Performs well for small number of events
  (-) Cannot guarantee the delivery of data
  (-) Optimal parameters heavily depends on topology
  (-) Cost of maintaining event table for large number of events
**Rumor Routing (cont’d)**

- When a node detects an event it adds such event to its local event table and generates an agent.
- Agents travel the network to propagate information about local events.
- The nodes that know the route for a query can respond by referring its event table.
Further Protocols

- Gradient-Based Routing (GBR)
- Constrained Anisotropic Diffusion Routing (CADR)
- COUGAR
- ACtive QUery forwarding In sensoR nEtworks (ACQUIRE)
WSN Routing: Hierarchical protocols

- **Low Energy Adaptive Clustering Hierarchy (LEACH):** utilizes randomized rotation of local clusterheads to evenly distribute the energy load among the sensors in the network; it incorporates data fusion in the routing protocol.

- Two phases of operation
  - The setup phase
  - The steady phase
WSN Routing: Hierarchical protocols

- **LEACH (cont’d):**

  - $C$: set of clusterheads at time $t_0$
  - $C'$: set of clusterheads at time $t_0 + \delta_0$

Source: I. Stavrakakis, Wireless Sensor Networks (WSNs)
LEACH (cont’d):

(+) Factor of 7 reduction in energy dissipation compared to direct communication and factor of 4 to 8 reduction compared to MTE routing

(+) No global knowledge of network needed

(+) Nodes die randomly and dynamic clustering increases the system lifetime

(-) Dynamic clustering may bring extra overhead

(-) Not applicable to networks deployed in large regions
WSN Routing: Hierarchical protocols

- Power Efficient GAthering in Sensor Information Systems (PEGASIS):
  forms chains from sensor nodes so that each node communicates only with a closer neighbour and takes turns transmitting to the base station

![Diagram showing a chain of sensor nodes communicating to a base station](image)
PEGASIS (cont’d):

(+) Shown to outperform LEACH by about 100 to 300% for different network size and topologies

(-) Introduces excessive delay for distant node on the chain

(-) The single leader can become a bottleneck

(-) Need global knowledge of the network
Threshold sensitive Energy Efficient sensor Network (TEEN): designed to be responsive to sudden changes in the senses attributes such as temperature; based on hierarchical grouping of sensor nodes

Defined two operational threshold values:

- **Hard threshold (HT)**: a minimum possible value of an attribute to trigger a sensor node to switch on its transmitter and transmit to the cluster head
- **Soft threshold (ST)**: once a node sense a value that is beyond the HT it transmits data only if the value of that attribute changes by an amount equal to or greater than the ST.
WSN Routing: Hierarchical protocols

- **TEEN** (cont’d)

- Cluster architecture same as LEACH

  (+) Suited for time critical sensing applications

  (+) Energy efficient due to control transmission

  (-) If thresholds are not reached then nodes will never communicate
## WSN Routing: Hierarchical vs. Flat

<table>
<thead>
<tr>
<th>Hierarchical</th>
<th>Flat</th>
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<tbody>
<tr>
<td>Reservation-based scheduling</td>
<td>Contention-based scheduling</td>
</tr>
<tr>
<td>Collision avoided</td>
<td>Collision overhead present</td>
</tr>
<tr>
<td>Reduced duty cycle due to periodic sleeping</td>
<td>Variable duty cycle by controlling sleeping of nodes</td>
</tr>
<tr>
<td>Data aggregation by cluster head</td>
<td>Node on multi-hop path aggregates data from neighbours</td>
</tr>
<tr>
<td>Simple but not optimal routing</td>
<td>Routing is complex but optimal</td>
</tr>
<tr>
<td>Requires global and local synchronization</td>
<td>Links formed on the fly without synchronization</td>
</tr>
<tr>
<td>Overhead of cluster formation throughout the network</td>
<td>Routed formed only in regions that have data for transmission</td>
</tr>
<tr>
<td>Energy dissipation is uniform</td>
<td>Energy dissipation depends on traffic patterns</td>
</tr>
<tr>
<td>Lower latency as multi-hop network formed by cluster-heads is always available</td>
<td>Latency in waking up intermediate nodes and setting up the multi-hop path</td>
</tr>
<tr>
<td>Fair channel allocation</td>
<td>Fairness not guaranteed</td>
</tr>
</tbody>
</table>
WSN Routing: Open Issues

- Improved or new routing protocol to address:
  - Higher topology changes
  - Higher scalability

- Interworking scheme for communication between WSNs and external network, e.g. Internet.

Source: I. Stavrakakis, Wireless Sensor Networks (WSNs)