In this lecture

• We will introduce sensor network routing protocols, in particular:
  – Directed diffusion
  – MINT routing

• We will talk about sensor network management and reprogramming
Network Protocols

• Can we apply ad hoc networks protocols?
• Yes protocols like epidemic can be applied but overhead is an issue.
• Aims are usually different: not communication but data reporting to single or multiple source.
• Specific protocols have been devised.
• Specific nodes are interested in specific events:
  – Sink interested in all results;
  – Sink interested in a sensor reading change.
Protocols for Repeated interactions

• Subscribe once, events happen multiple times:
  – Exploring the network topology might actually pay off. But: unknown which node can provide data, multiple nodes might ask for data.
    ! How to map this onto a “routing” problem?

• Put enough information into the network: publications and subscriptions can be mapped onto each other. But try to avoid using unique identifiers: might not be available, might require too big a state size in intermediate nodes.
Directed Diffusion

• **Directed diffusion** as one option for implementation:
  – Try to rely only on *local interactions*.
  – Data-centric approach.

• Nodes send “interests” for data which are diffused in the network.

• Sensors produce data which is routed according to interests.

• Intermediate nodes can filter/aggregate data.

[Intanagonwiwat et al 2000]
Directed Diffusion

A sensor field

Sensor sources

Event

Directed Diffusion

Sensor sink
Interest Propagation

• Each sink sends expression of interests to neighbours.
• Each node will store interests and disseminate those further to their neighbours.
  – Cache of interest is checked not to repeat disseminations.
• Interests need refreshing from the sink (they time out).
• Interests have a “rate of events” which is defined as “gradient”.

S

N
Interest Example

Type = Wheeled vehicle // detect vehicle location
Interval = 20 ms // send events every 20ms
Duration = 10 s // Send for next 10 s
Field = [x1, y1, x2, y2] // from sensors in this area
Data delivery

• Sensor data sources emit events which are sent to neighbours according to interest (ie if there is a gradient).

• Each intermediate node sends back data at a rate which depends on the gradient.
  – ie if gradient is 1 event per second and 2 events per second are received send either the first or a combination of the two (aggregation).
Gradients Reinforcement

- Events are stored to avoid cycles (check if same event received before).
- Data can reach a node through different paths. *Gradient reinforcement needed.*
- When gradients are established the rate is defined provisionally (usually low). Sinks will ‘reinforce’ good paths which will be followed with higher rate.
- A path expires after a timeout so if not reinforced it will cease to exist. This allows adaptation to changes and failures.
Directed diffusion – Two-phase pull

- **Phase 1**: nodes distribute *interests* in certain kinds of named data:
  - Specified as attribute-value pairs
  - Interests are flooded in the network.
  - Apparently obvious solution: remember from where interests came, set up a “tree”.
  - Problem: Node X cannot distinguish, in absence of unique identifiers, between the two situations on the right – set up only one or three trees?
Direction diffusion
Gradients in two-phase pull

• Option 1: Node X forwarding received data to all “parents” in a “tree”: Not attractive, many needless packet repetitions over multiple routes.

• Option 2: node X only forwards to one parent. Not acceptable, data sinks might miss events.

• Option 3: Only provisionally send data to all parents, but ask data sinks to help in selecting which paths are redundant, which are needed.
  – Information from where an interest came is called gradient.
  – Forward all published data along all existing gradients
Direction diffusion
Gradients in two-phase pull

Event
A sensor field

Reinforced gradient
Sink
Directed diffusion – extensions

• Problem: Interests are flooded through the network.

• Geographic scoping & directed diffusion: Interest in data from specific areas should be sent to sources in specific geo locations only.

• Push diffusion – few senders, many receivers: Same interface/naming concept, but different routing protocol. Here: do not flood interests, but flood the (relatively few) data. Interested nodes will start reinforcing the gradients.
Issues

• Purely theoretical work.
• Apart from the flooding of the interests…No consideration of real world issues such as link stability or link load and load dependence.
• Mac Layer issues (assume nodes are awake…or does not discuss it).
• More recent approaches have considered link capabilities more explicitly as part of the routing decision making.
Data aggregation

- Less packets transmitted -> less energy used
- To still transmit data, packets need to combine their data into fewer packets! *aggregation* is needed
- Depending on network, aggregation can be useful or pointless
- Directed diffusion gradient might require some data aggregation
Metrics for data aggregation

- **Accuracy**: Difference between value(s) the sink obtains from aggregated packets and from the actual value (obtained in case no aggregation/no faults occur)
- **Completeness**: Percentage of all readings included in computing the final aggregate at the sink
- **Latency**
- **Message overhead**
Link quality based routing (MT Routing)

- Directed diffusion uses some sort of implicit ways to indicate which are the good links.
  - Through the gradient.
- Ad hoc routing protocols for mobile networks route messages based on shorter path in terms of number of hops.
- The essence of the next protocol we present: “number of hops might not be the best performance indication in wireless sensor network”.

[Woo et al 2003]
Routing based on Link Estimation

- Routing algorithms should take into account underlying network factors and under realistic loads.
- Link connectivity in reality is not spherical as often assumed.
RSSI – Stationary

Signal Strength (-dBm) - Top View - Source Node: 1
RSSI – Driving

Signal Strength (-dBm) - Top View - Source Node: 1
Link Estimation

A good estimator in this setting must:

– Be stable.
– Be simple to compute and have a low memory footprint.
– React quickly to large changes in quality.
– Neighbour broadcast can be used to passively estimate.
WMEWMA

• Snooping
  – Track the sequence numbers of the packets from each source to infer losses

• Window mean with EWMA
  – \( \text{EWMA}(t_x) = a \ (\text{MA}(t_x)) + (1-a)\text{EWMA}(t_{(x-1)}) \)
  – \( t_x \): last time interval; \( a \): weight
  – \( \text{MA}(t_x) \) is the number of packets received in the last period.
WMEWMA ($t = 30, \alpha = 0.6$)
Neighborhood Management

• Neighborhood table:
  – Record information about nodes from which it receives packets (also through snooping).

• If network is dense, how does a node determine which nodes it should keep in the table?

• Keep a sufficient number of good neighbours in the table.
Link Estimation based Routing

• Focus on “many to one” routing model:
  – Information flows one way.
• Estimates of inbound links are maintained, however outbound links need to be used!
  – Propagation back to neighbours.
• Each node selects a parent (using the link estimation table).
  – Changes when link deteriorates (periodically).
Distance vector routing: cost metrics

- Routing works as a standard distance vector routing.
- The DVR cost metric is usually the hop count.
- In lossy networks hop count might underestimate costs.
  - Retransmissions on bad links: shortest path with bad links might be worse than longer path with good links.
  - Solution: consider the cost of retransmission on the whole path.
Min Transmission Routing (Mint)
An Example

Routing Table on D:
<table>
<thead>
<tr>
<th>Id</th>
<th>Cost</th>
<th>NextHop</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.2</td>
<td>A</td>
</tr>
<tr>
<td>B</td>
<td>0.7</td>
<td>B</td>
</tr>
<tr>
<td>S</td>
<td>0.5</td>
<td>A</td>
</tr>
</tbody>
</table>
Summary

• We have described sensor network challenges and solutions
• We have given examples of sensor network routing protocols
References
