Wireless Sensor Networks
24th Lecture
06.02.2007

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Overview

- Unicast routing in MANETs
- Energy efficiency & unicast routing
- Geographical routing
Energy-efficient unicast: Goals

- Particularly interesting performance metric: Energy efficiency

Goals
- Minimize energy/bit
  - Example: A-B-E-H
- Maximize network lifetime
  - Time until first node failure, loss of coverage, partitioning

Seems trivial – use proper link/path metrics (not hop count) and standard routing

Example: Send data from node A to node H
Basic options for path metrics

- **Maximum total available battery capacity**
  - Path metric: Sum of battery levels
  - Example: A-C-F-H

- **Minimum battery cost routing**
  - Path metric: Sum of reciprocal battery levels
  - Example: A-D-H

- **Conditional max-min battery capacity routing**
  - Only take battery level into account when below a given level

- **Minimize variance in power levels**
- **Minimum total transmission power**
A non-trivial path metric

- Previous path metrics do not perform particularly well

- One non-trivial link weight: 
  \[ w_{ij} = e_{ij} (\lambda^{\alpha_i} - 1) \]
  - \( w_{ij} \) weight for link node i to node j
  - \( e_{ij} \) required energy, \( \lambda \) some constant, \( \alpha_i \) fraction of battery of node i already used up

- Path metric: Sum of link weights
  - Use path with smallest metric

- Properties: Many messages can be send, high network lifetime
  - With admission control, even a competitive ratio logarithmic in network size can be shown
Multipath unicast routing

- Instead of only a single path, it can be useful to compute multiple paths between a given source/destination pair
  - Multiple paths can be *disjoint* or *braided*
  - Used simultaneously, alternatively, randomly, …
Overview

- Unicast routing in MANETs
- Energy efficiency & unicast routing
- Geographical routing
  - Position-based routing
  - Geocasting
Geographic routing

- Routing tables contain information to which next hop a packet should be forwarded
  - Explicitly constructed
- Alternative: Implicitly infer this information from physical placement of nodes
  - Position of current node, current neighbors, destination known – send to a neighbor in the right direction as next hop
  - Geographic routing
- Options
  - Send to any node in a given area – geocasting
  - Use position information to aid in routing – position-based routing
    - Might need a location service to map node ID to node position
Basics of position-based routing

➢ “Most forward within range r” strategy
  - Send to that neighbor that realizes the most forward progress towards destination
  - NOT: farthest away from sender!

➢ Nearest node with (any) forward progress
  - Idea: Minimize transmission power

➢ Directional routing
  - Choose next hop that is angularly closest to destination
  - Choose next hop that is closest to the connecting line to destination
  - Problem: Might result in loops!
Problem: Dead ends

- Simple strategies might send a packet into a dead end.
Right hand rule to leave dead ends – GPSR

- Basic idea to get out of a dead end: Put right hand to the wall, follow the wall
  - Does not work if on some inner wall – will walk in circles
  - Need some additional rules to detect such circles

- Geometric Perimeter State Routing (GPSR)
  - Earlier versions: Compass Routing II, face-2 routing
  - Use greedy, “most forward” routing as long as possible
  - If no progress possible: Switch to “face” routing
    - Face: largest possible region of the plane that is not cut by any edge of the graph; can be exterior or interior
    - Send packet around the face using right-hand rule
    - Use position where face was entered and destination position to determine when face can be left again, switch back to greedy routing
  - Requires: planar graph! (topology control can ensure that)
GPSR – Example

➤ Route packet from node A to node Z

Leave face routing

Enter face routing

Wireless Sensor Networks

06.02.2007 Lecture No. 24 - 12
Another Approach

➢ is presented in my Inaugural Lecture on

Online Routing in Ad-Hoc-Netzwerken
Christian Schindelhauer
Donnerstag, 15. Februar 2007, 16 h ct
Hörsaal 00-026, Geb. 101
Georges-Köhler-Allee
Geographic routing without positions – GEM

- Apparent contradiction: geographic, but no position?
- Construct virtual coordinates
  - that preserve enough neighborhood information to be useful in geographic routing but do not require actual position determination

- Use polar coordinates from a center point
- Assign “virtual angle range” to neighbors of a node, bigger radius
- Angles are recursively redistributed to children nodes
Geographic Random Forwarding (GeRaF)

➢ How to combine position knowledge with nodes turning on/off?
  – Goal: Transmit message over multiple hops to destination node; deal with topology constantly changing because of on/off node

➢ Idea: Receiver-initiated forwarding
  – Forwarding node S simply broadcasts a packet, without specifying next hop node
  – Some node T will pick it up (ideally, closest to the source) and forward it

➢ Problem: How to deal with multiple forwarders?
  – Position-informed randomization: The closer to the destination a forwarding node is, the shorter does it hesitate to forward packet
  – Use several rings to make problem easier, group nodes according to distance (collisions can still occur)
GeRaF – Example

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06.02.2007 Lecture No. 24 - 16
Overview

- Unicast routing in MANETs
- Energy efficiency & unicast routing
- Multi-/broadcast routing
- Geographical routing
  - Position-based routing
  - Geocasting
Location-based Multicast (LBM)

- Geocasting by geographically restricted flooding
- Define a “forwarding” zone – nodes in this zone will forward the packet to make it reach the destination zone
  - Forwarding zone specified in packet or recomputed along the way
  - Static zone – smallest rectangle containing original source and destination zone
  - Adaptive zone – smallest rectangle containing forwarding node and destination zone
    - Possible dead ends again
  - Adaptive distances – packet is forwarded by node u if node u is closer to destination zone’s center than predecessor node v (packet has made progress)
- Packet is always forwarded by nodes within the destination zone itself
Determining next hops based on Voronoi diagrams

- Goal: Use that neighbor to forward packet that is closest to destination among all the neighbors
- Use Voronoi diagram computed for the set of neighbors of the node currently holding the packet
Trajectory-based forwarding (TBF)

➢ Think in terms of an “agent”: Should travel around the network, e.g., collecting measurements
  – Random forwarding may take a long time

➢ Idea: Provide the agent with a certain trajectory along which to travel
  – Described, e.g., by a simple curve
  – Forward to node closest to this trajectory
Mobile nodes, mobile sinks

- Mobile nodes cause some additional problems
  - E.g., multicast tree to distribute readings has to be adapted

Sink moves downward
Sink moves upward
Conclusion

- Routing exploit various sources of information to find destination of a packet
  - Explicitly constructed routing tables
  - Implicit topology/neighborhood information via positions

- **Routing can make some difference for network lifetime**
  - However, in some scenarios (streaming data to a single sink), there is only so much that can be done
  - Energy efficiency does not equal lifetime, holds for routing as well

- **Non-standard routing tasks (multicasting, geocasting) require adapted protocols**
Data-centric and content-based networking

- Apart from routing protocols that use a direct identifier of nodes (either unique id or position of a node), networking can talk place based directly on content.

- Content can be collected from network, processed in the network, and stored in the network.

- This chapter looks at such content-based networking and data aggregation mechanisms.
Data-centric and content-based networking

- Interaction patterns and programming model
- Data-centric routing
- Data aggregation
- Data storage
Desirable interaction paradigm properties

- Standard networking interaction paradigms:
  Client/server, peer-to-peer
  - Explicit or implicit partners, explicit cause for communication

- Desirable properties for WSN (and other applications)
  - Decoupling in space – neither sender nor receiver need to know their partner
  - Decoupling in time – “answer” not necessarily directly triggered by “question”, asynchronous communication
Interaction paradigm: Publish/subscribe

- **Achieved by publish/subscribe paradigm**
  - Idea: Entities can publish data under certain names
  - Entities can subscribe to updates of such named data
- **Conceptually: Implemented by a software bus**
  - Software bus stores subscriptions, published data; names used as filters; subscribers notified when values of named data changes

- **Variations**
  - **Topic-based** P/S – inflexible
  - **Content-based** P/S – use general predicates over named data
Publish/subscribe implementation options

- Central server – mostly not applicable
- Topic-based P/S: group communication protocols
- Content-based networking does not directly map to multicast groups

   - Needs content-based routing/forwarding for efficient networking

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Wireless Sensor Networks
06.02.2007 Lecture No. 24 - 27
Data-centric and content-based networking

- Interaction patterns and programming model
- *Data-centric routing*
- Data aggregation
- Data storage
One-shot interactions with big data sets

➢ Scenario
  - Large amount of data are to be communicated – e.g., video picture
  - Can be succinctly summarized/described

➢ Idea: Only exchange characterization with neighbor, ask whether it is interested in data
  - Only transmit data when explicitly requested
  - Nodes should know about interests of further away nodes

→ Sensor Protocol for Information via Negotiation (SPIN)
SPIN example

(1) ADV
(2) REQ
(3) DATA
(4) ADV
(5) REQ
(6) DATA
Repeated interactions

- More interesting: 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?

- Idea: Put enough information into the network so that 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 as one option for implementation
  - Try to rely only on local interactions for implementation
Data-centric and content-based networking

- Interaction patterns and programming model
- Data-centric routing
- *Data aggregation*
- Data storage
Data aggregation

➢ Any packet not transmitted does not need energy
➢ 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
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**
Partial state records

- Partial state records to represent intermediate results
  - E.g., to compute average, sum and number of previously aggregated values is required – expressed as <sum,count>
  - Update rule: \(< s, c > \leftarrow < s_1 + s_2, c_1 + c_2 >\)
  - Final result is simply s/c
Thank you
and thanks to Holger Karl for the slides