Wireless Sensor Networks

24th Lecture

06.02.2007

CoNe Freiburg

University of Freiburg
Computer Networks and Telematics
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Overview

- **Unicast routing in MANETs**
- *Energy efficiency & unicast routing*
- **Geographical routing**

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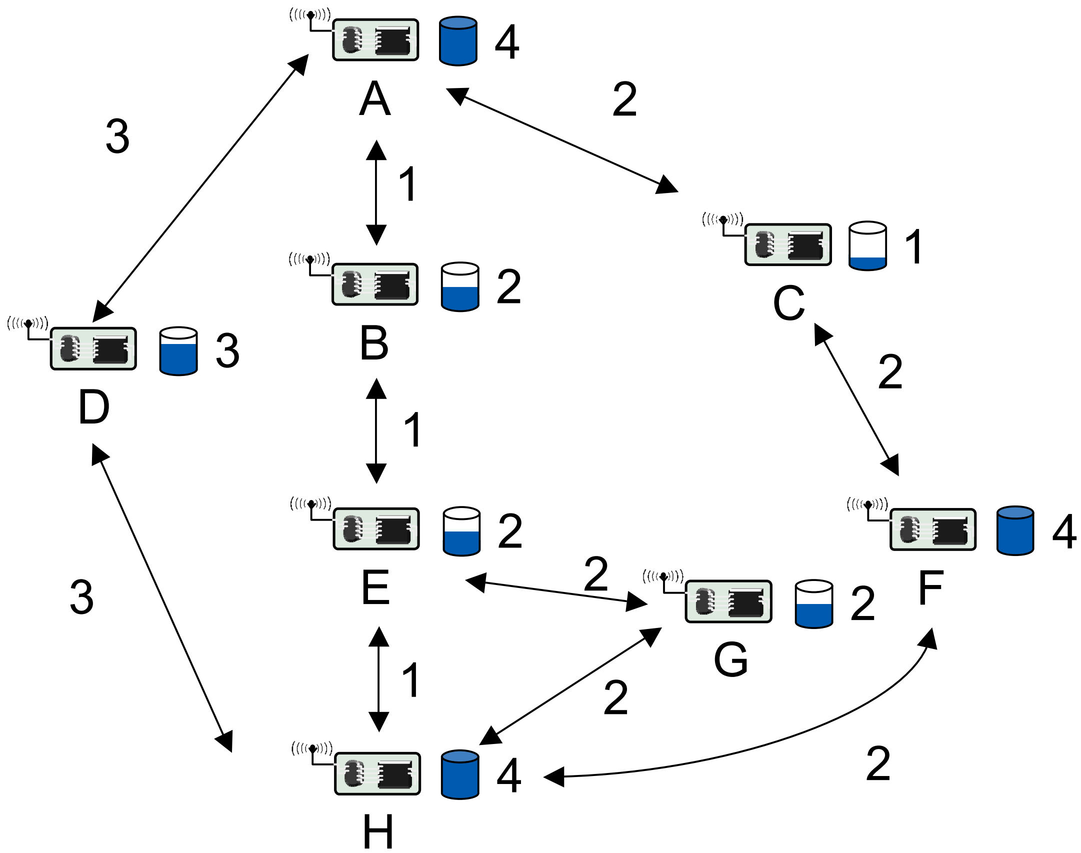
Energy-efficient unicast: Goals

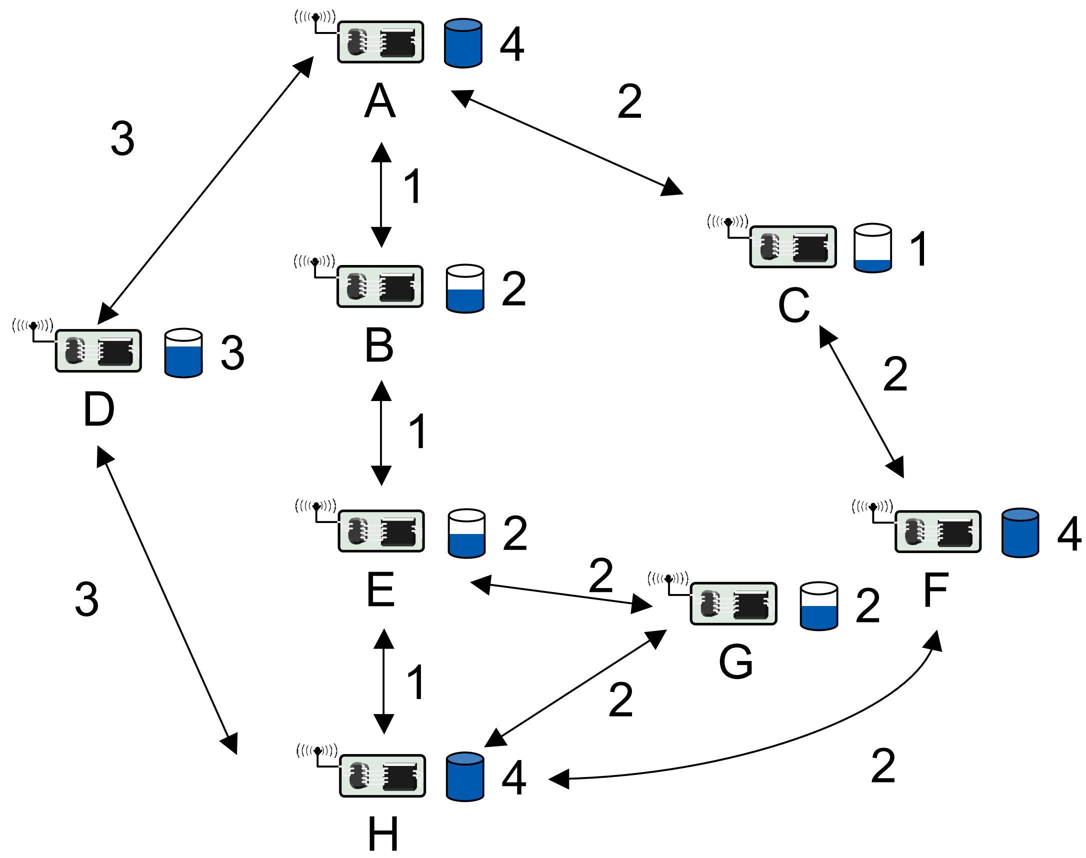
- **Particularly interesting performance metric: Energy efficiency**
- **Goals**
  - Minimize energy/bit
    - Example: A-B-E-H
  - Maximize network lifetime
    - Time until first node failure, loss of coverage, partitioning
- **Seems trivial – use proper link/path metrics (not hop count) and standard 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

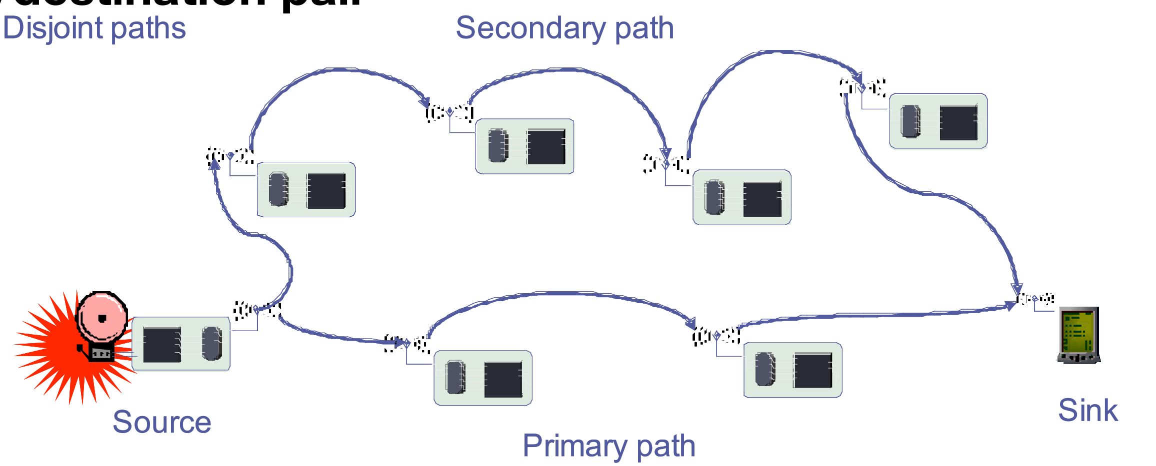
- **Previous path metrics do not perform particularly well**

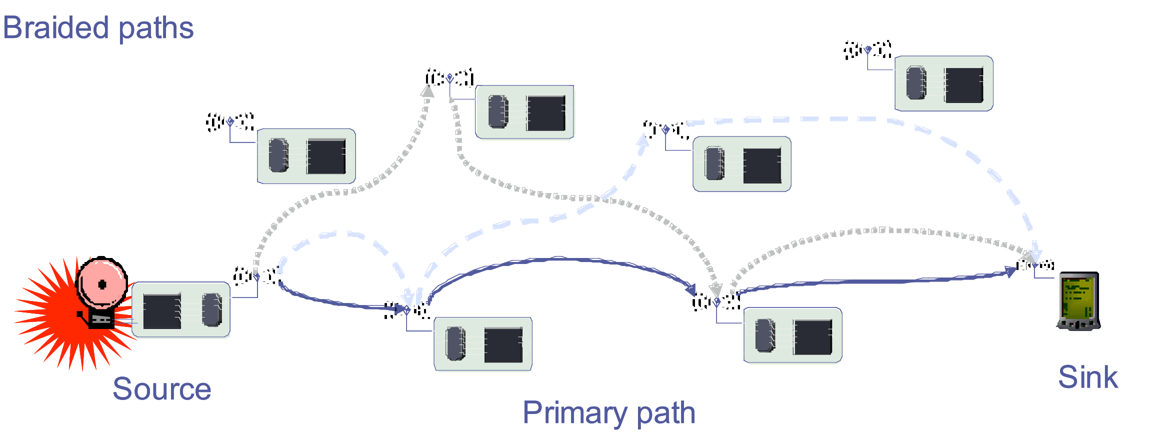
- **One non-trivial link weight:** $$w_{ij} = e_{ij}(\lambda^{\alpha_i} - 1)$$
  - w_{ij} weight for link node i to node j
  - e_{ij} required energy, λ some constant, α_i fraction of battery of node i already used up
- **Path metric: Sum of link weights**
  - Use path with smallest metric

- **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

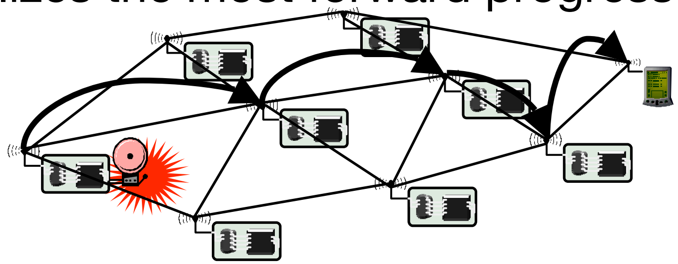
- **Unicast routing in MANETs**
- **Energy efficiency & unicast routing**
- *Geographical routing*
  - ***Position-based routing***
  - Geocasting

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

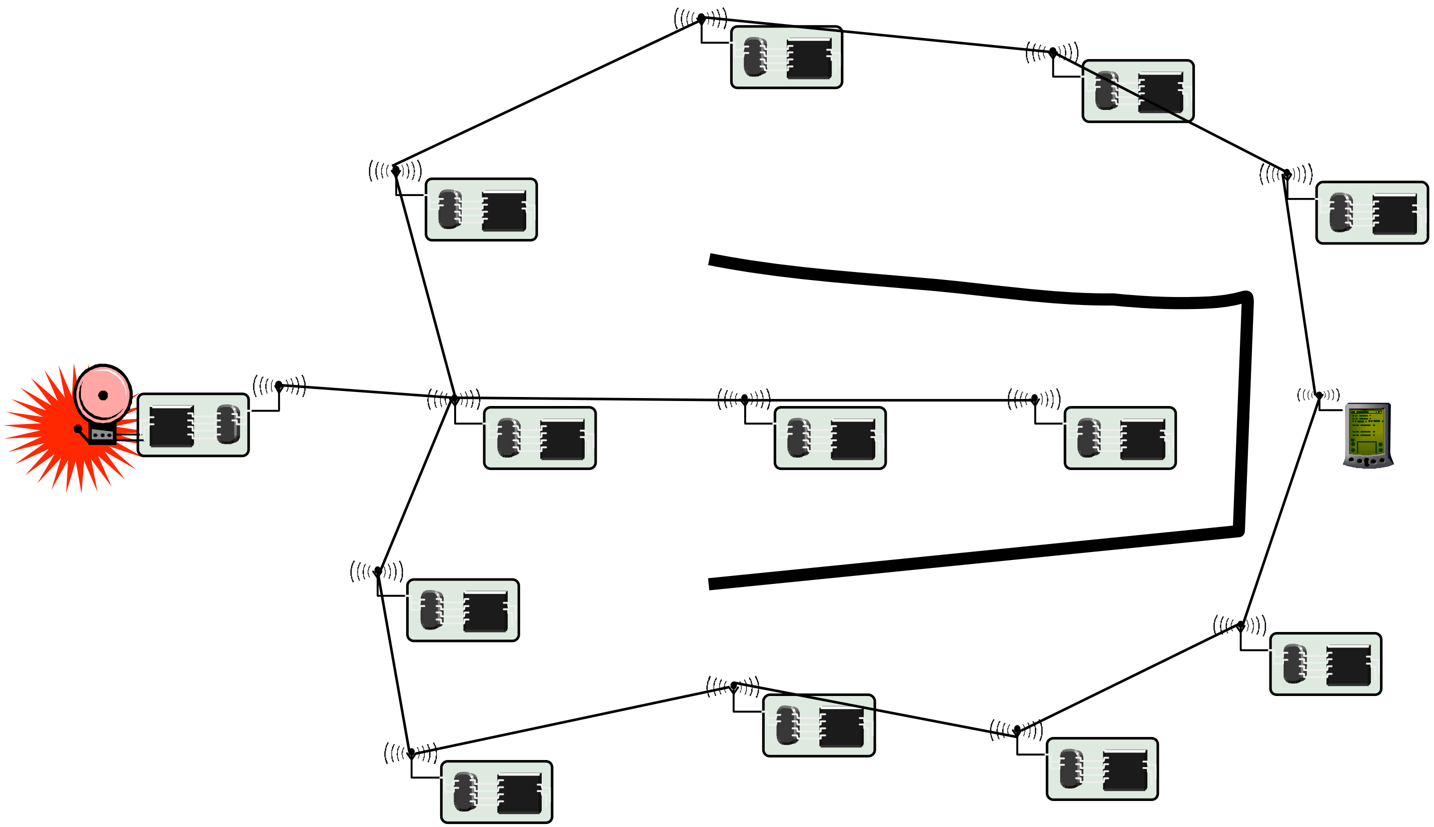
- **"Most forward within range r" strategy**
  - Send to that neighbor that realizes the most forward progress towards destination
  - NOT: farthest away from sender!



- **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

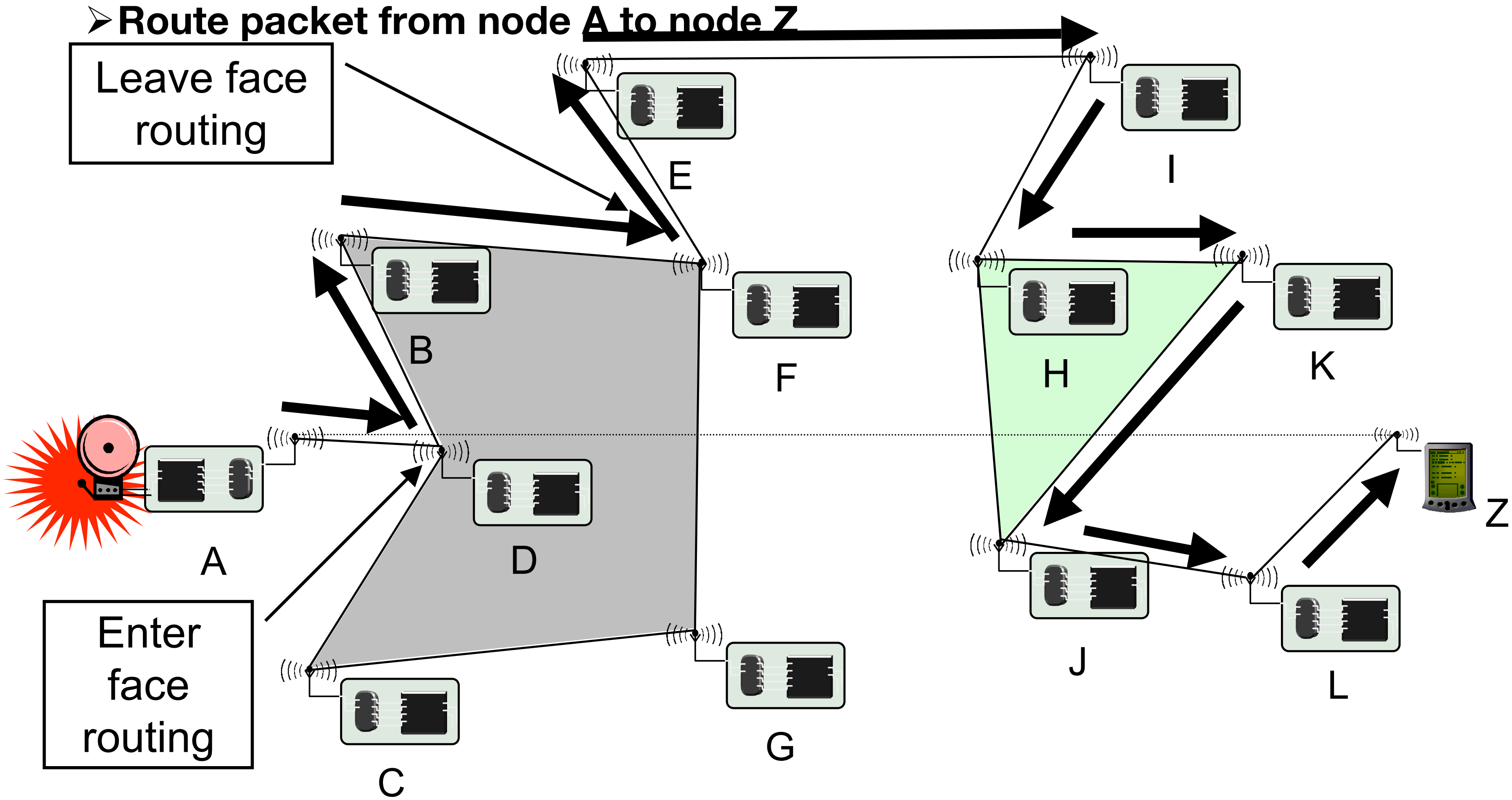


Right hand rule to leave dead ends – GPSR

- **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



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

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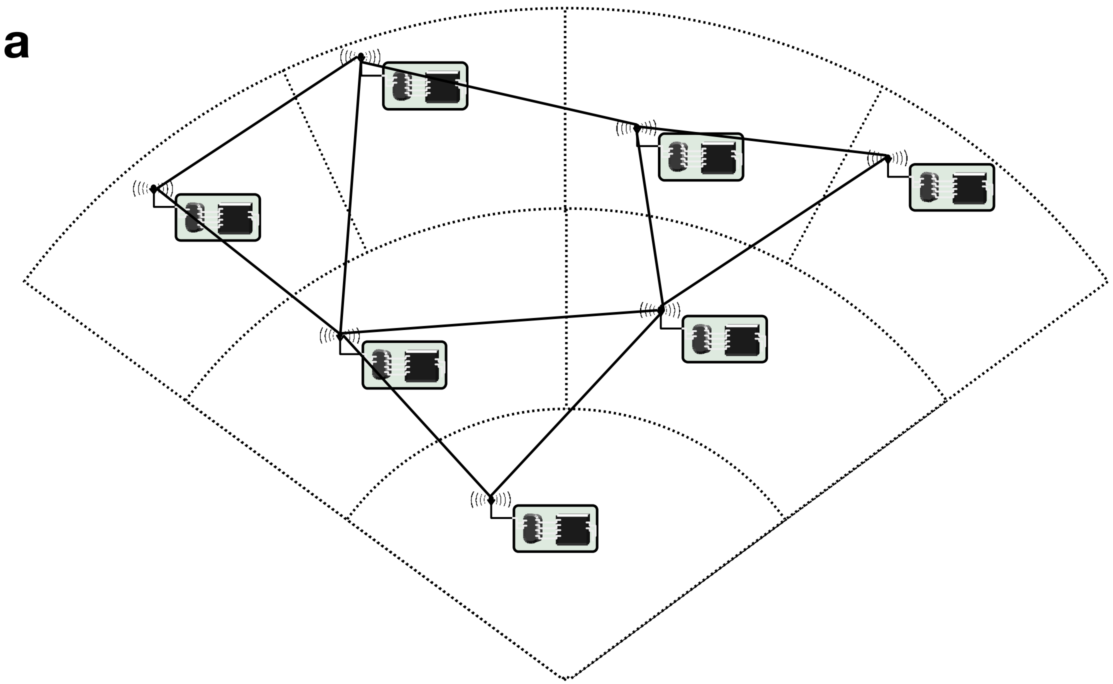
- **Apparent contradiction: geographic, but no position?**
- **Construct *virtual coordinates***
  - that preserve enough neighborhood information to be useful in geographic routing but do not require actual position determination

- **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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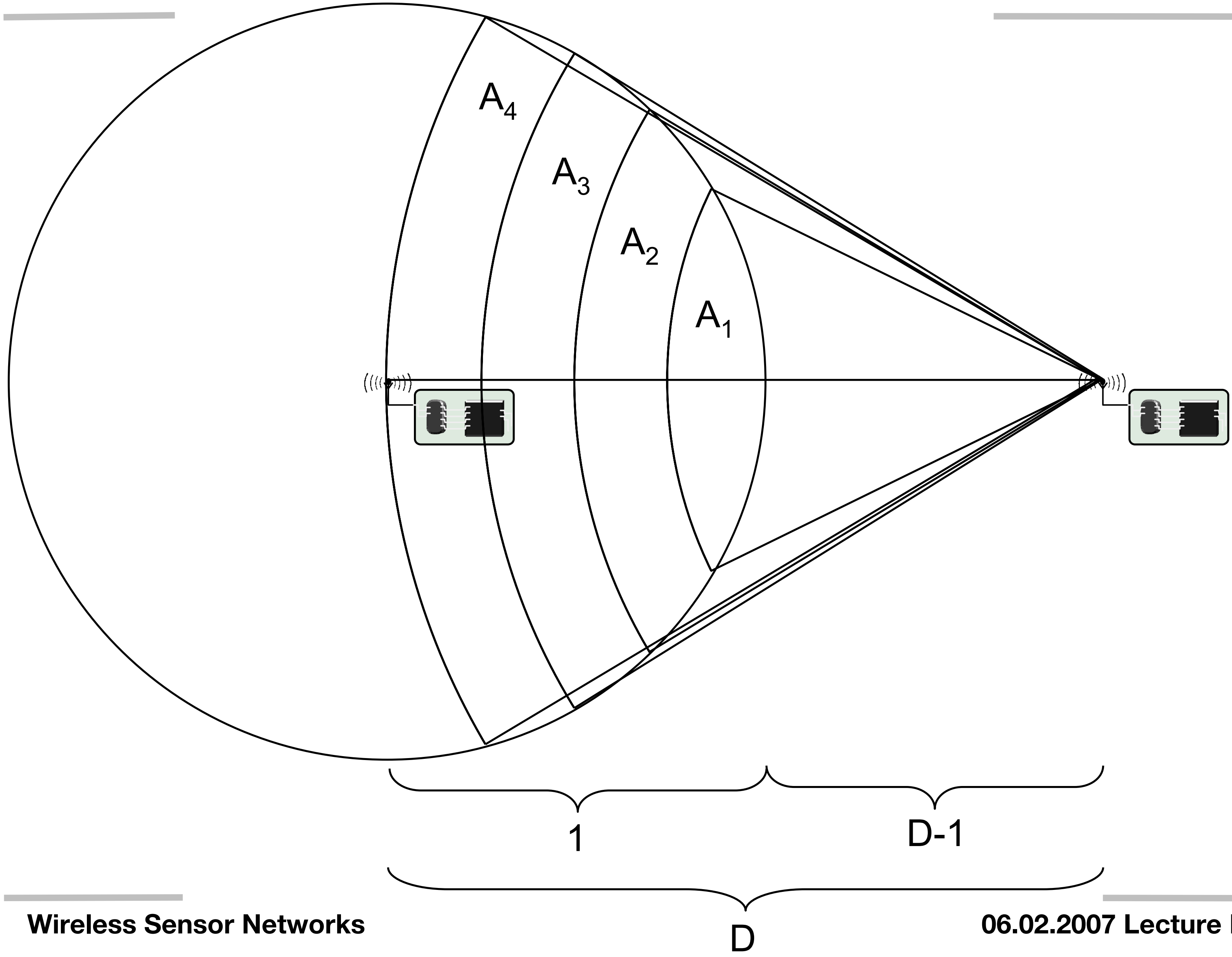


Overview

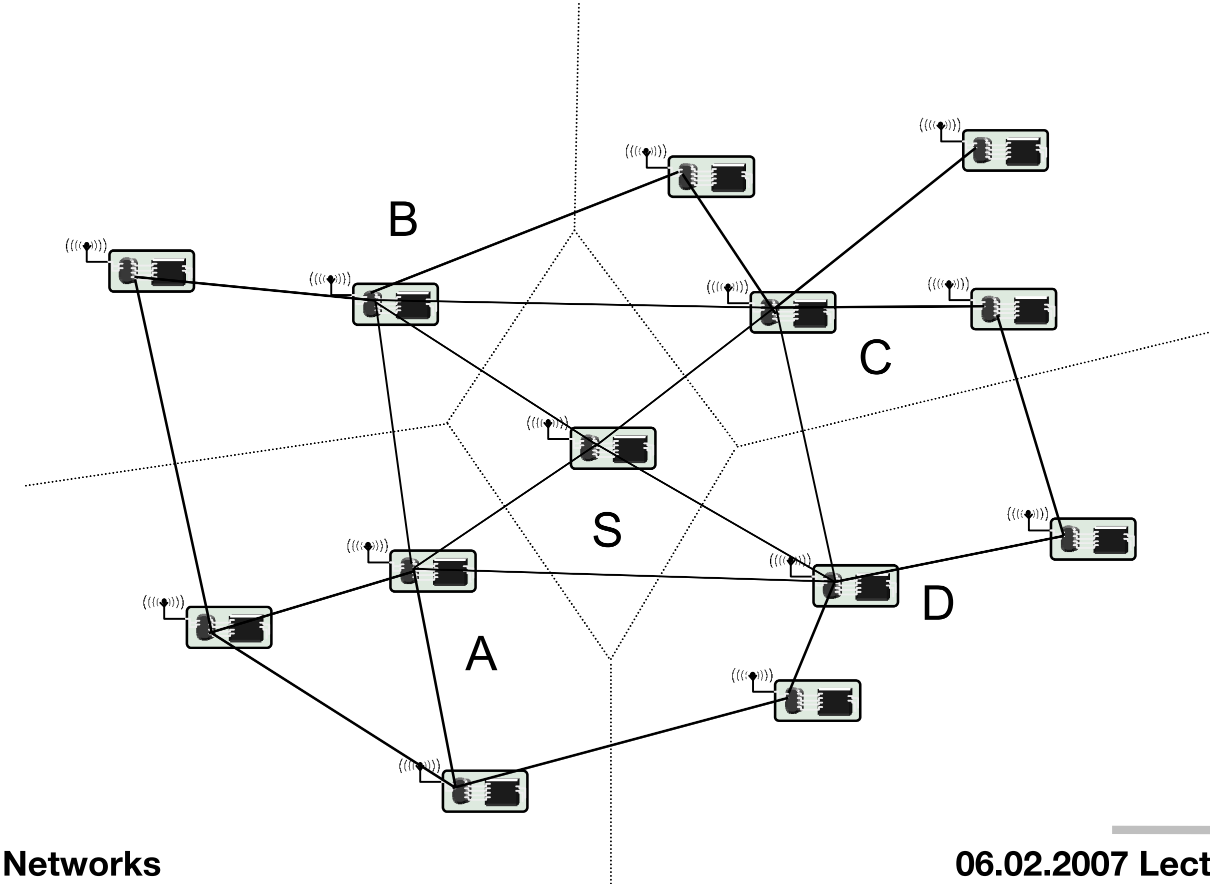
- **Unicast routing in MANETs**
- **Energy efficiency & unicast routing**
- **Multi-/broadcast routing**
- *Geographical routing*
  - Position-based routing
  - ***Geocasting***

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**

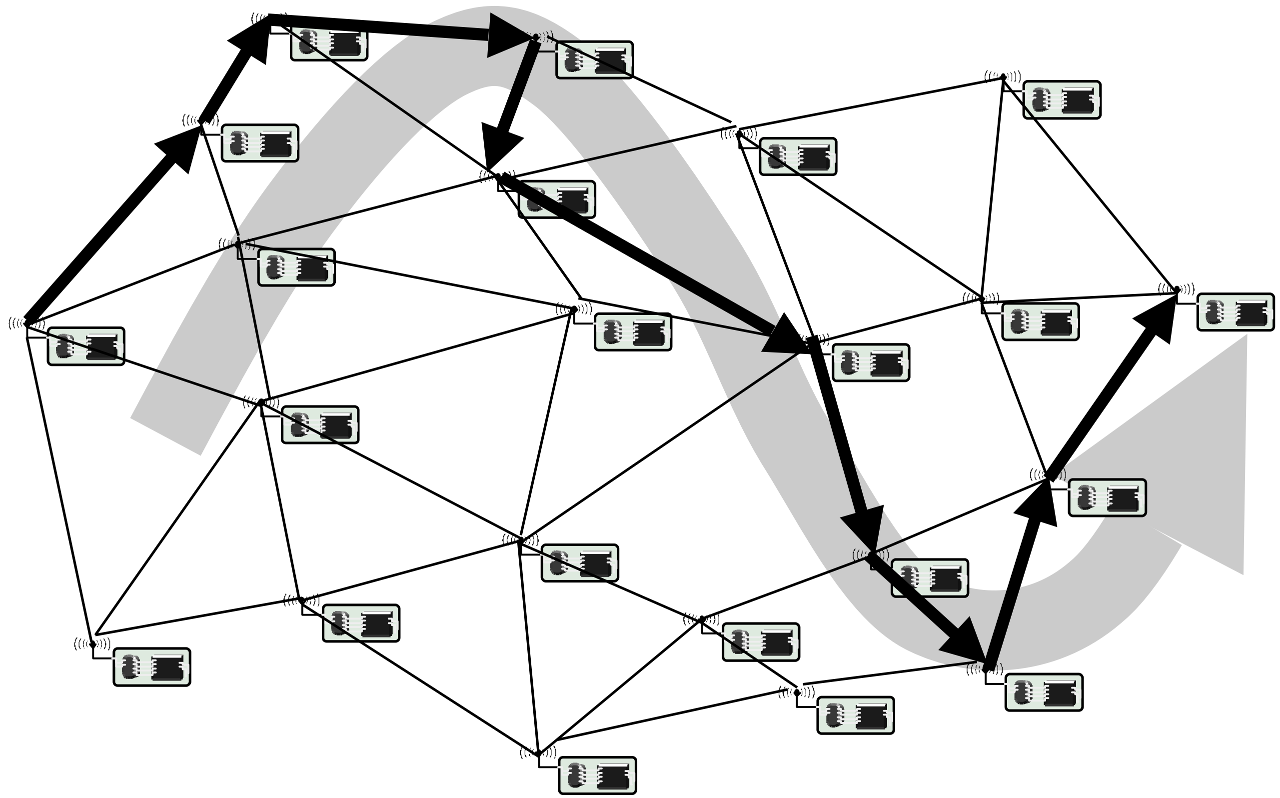
Determining next hops based on Voronoi diagrams

- **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**



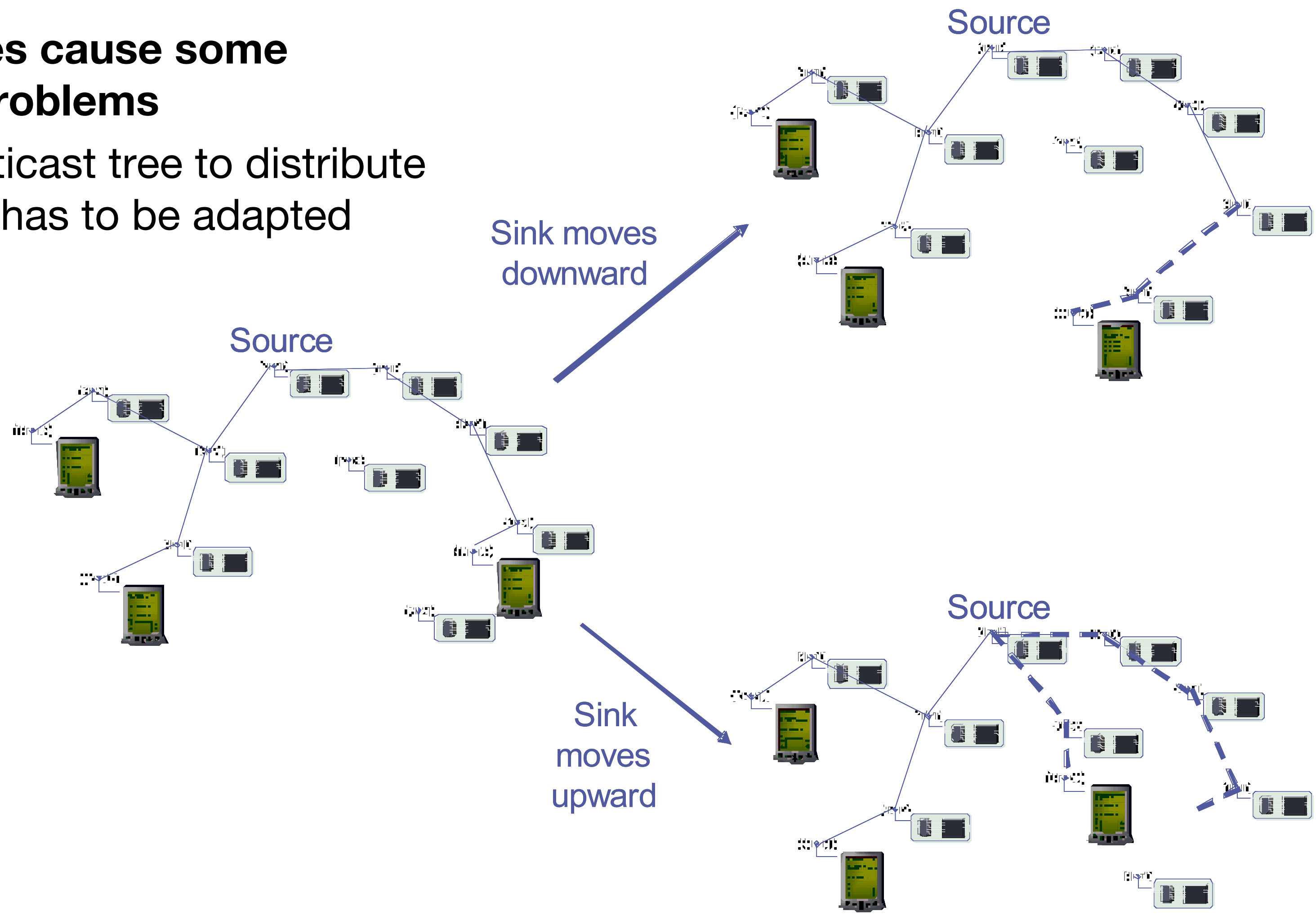
Trajectory-based forwarding (TBF)

- **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



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

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

Desirable interaction paradigm properties

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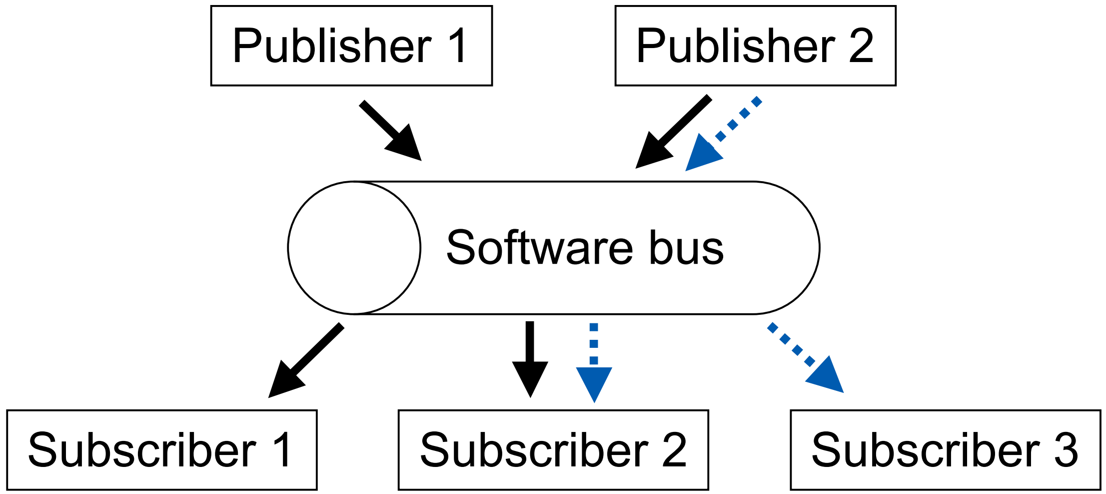
- **Standard networking interaction paradigms: Client/server, peer-to-peer**
  - Explicit or implicit partners, explicit cause for communication

- **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

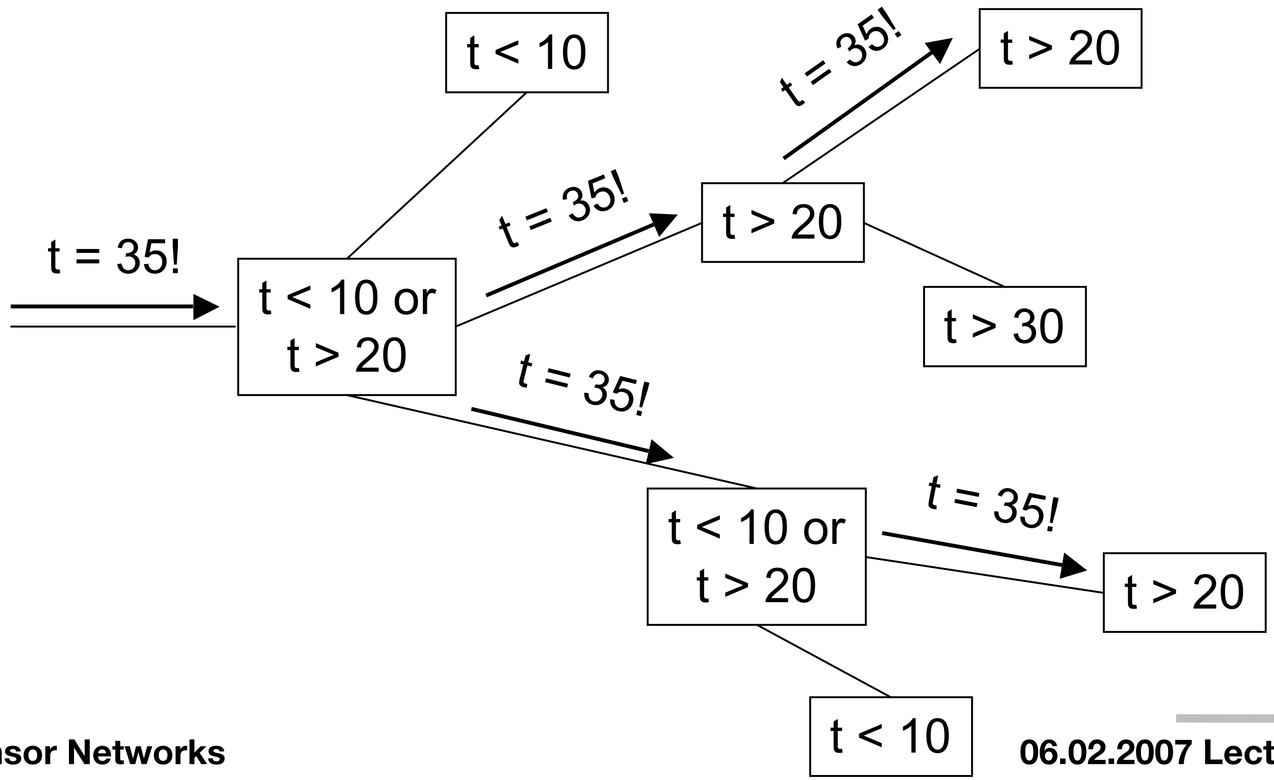
Interaction paradigm: Publish/subscribe

- **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



Data-centric and content-based networking

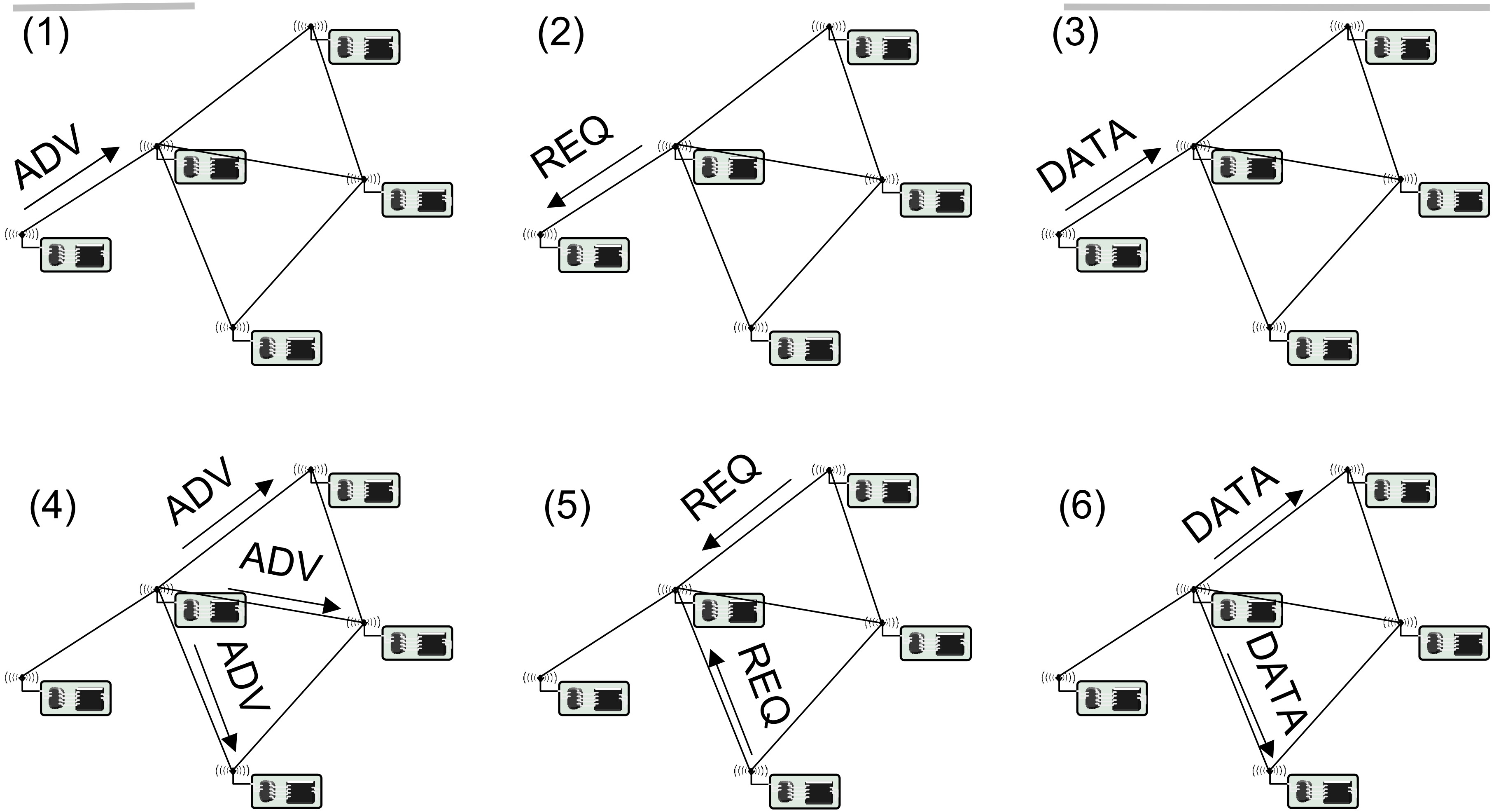
- **Interaction patterns and programming model**
- *Data-centric routing*
- **Data aggregation**
- **Data storage**

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



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

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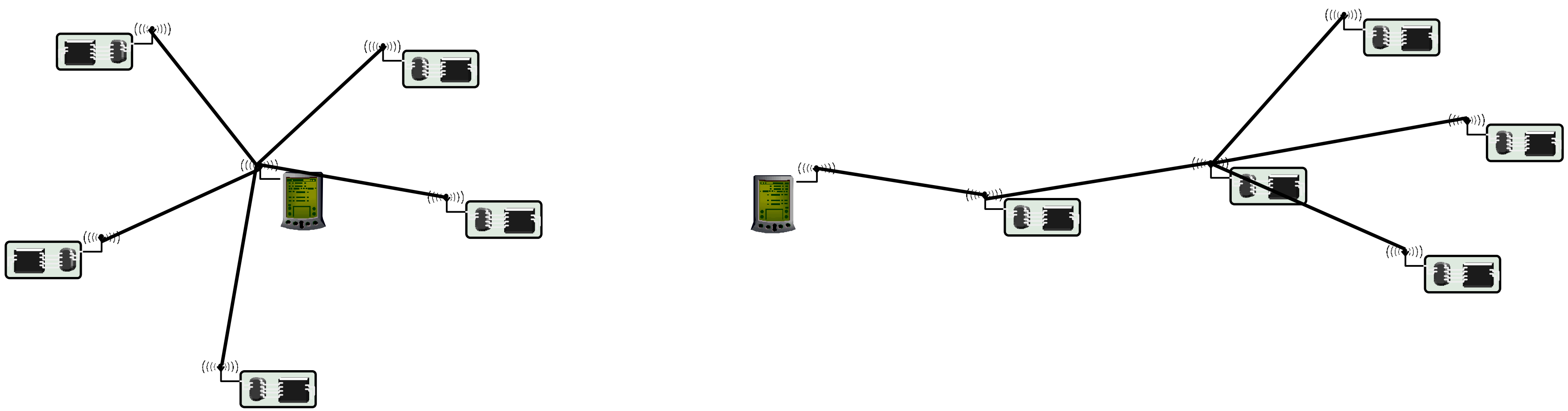
- **Interaction patterns and programming model**
- **Data-centric routing**
- *Data aggregation*
- **Data storage**

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: $<s,c>=<s_1+s_2,c_1+c_2>$
  - Final result is simply s/c

Thank you

and thanks to Holger Karl for the slides

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