

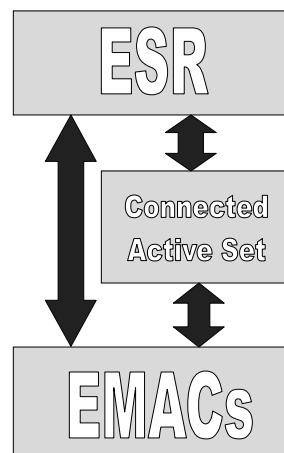
Prolonging Network Lifetime by Cross-layer Optimization

Energy efficient sensor networks

Tim Nieberg, Jian Wu, Lodewijk van Hoesel

Overview

- Cross-layer Approach
 - EMACs
 - TDMA-based, self-organizing MAC-scheme
 - Connected Active Set
 - Identify nodes that are needed for connectivity ("ACTIVE" nodes)
 - Other nodes can follow sleeping pattern ("PASSIVE" nodes)
 - ESR (Eyes Source Routing)
 - On-demand, dynamic routing protocol
 - Limited flooding to reduce routing overhead during dynamic changes in topology



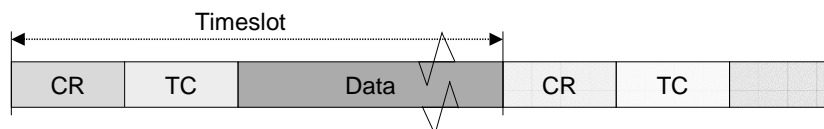
EMACs: *Introduction*

- Self-organizing, TDMA-based MAC protocol
 - Nodes can autonomously chose time slot
 - No base stations needed
 - Collision-free communication
- Supports efficient transmission of short multicast messages
 - Used in *clustering, routing etc.*
- Scalable, adaptive for network topology
- Allows sleep patterns
- Acknowledgements of messages is decided on higher protocol layers

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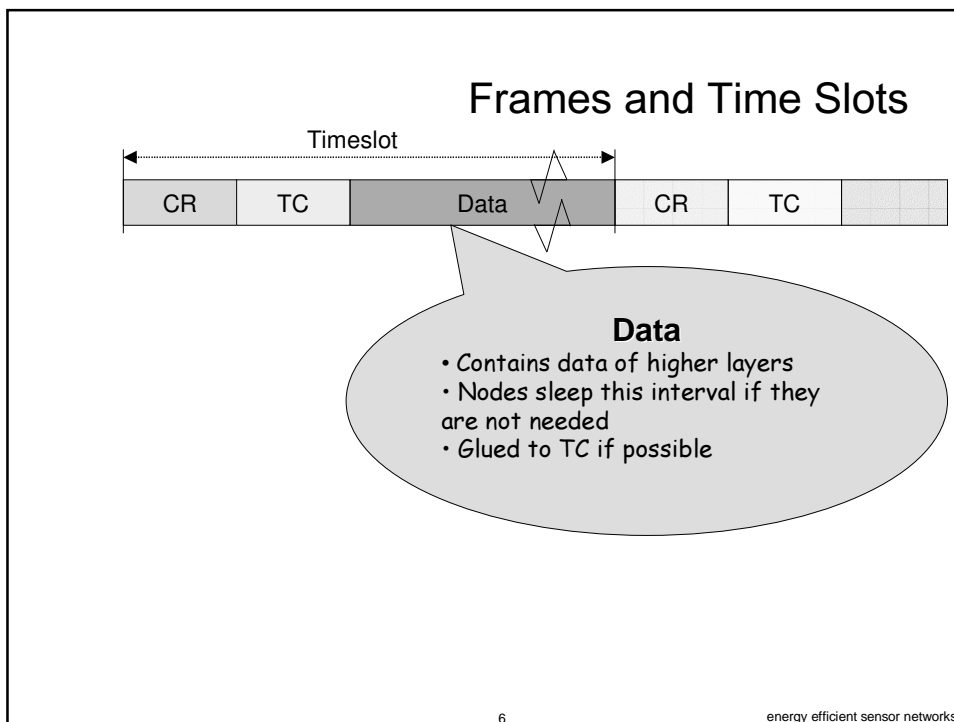
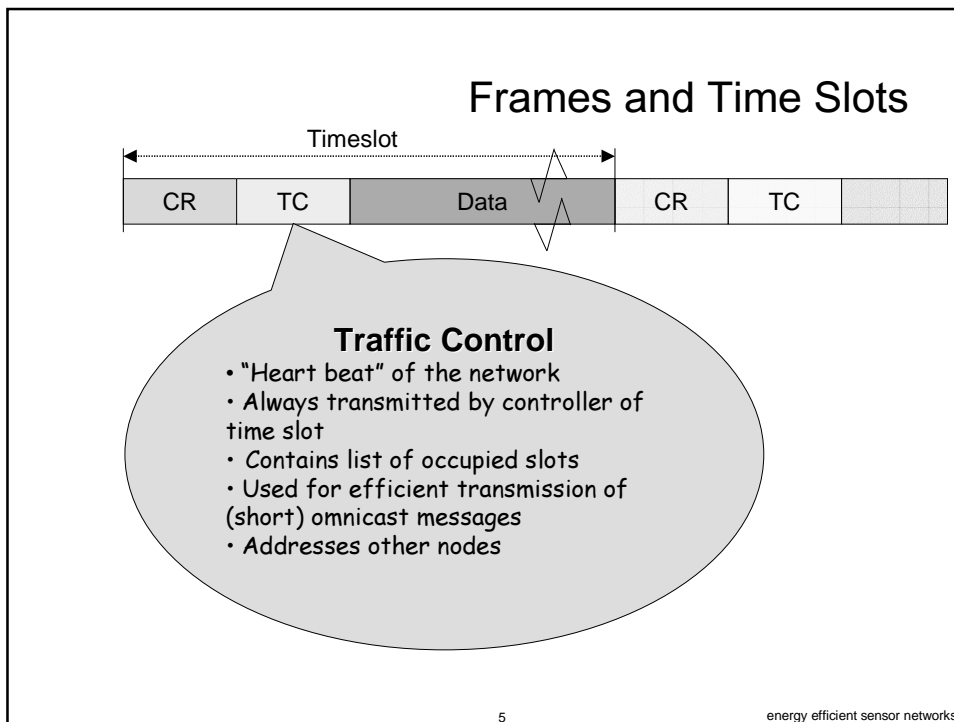
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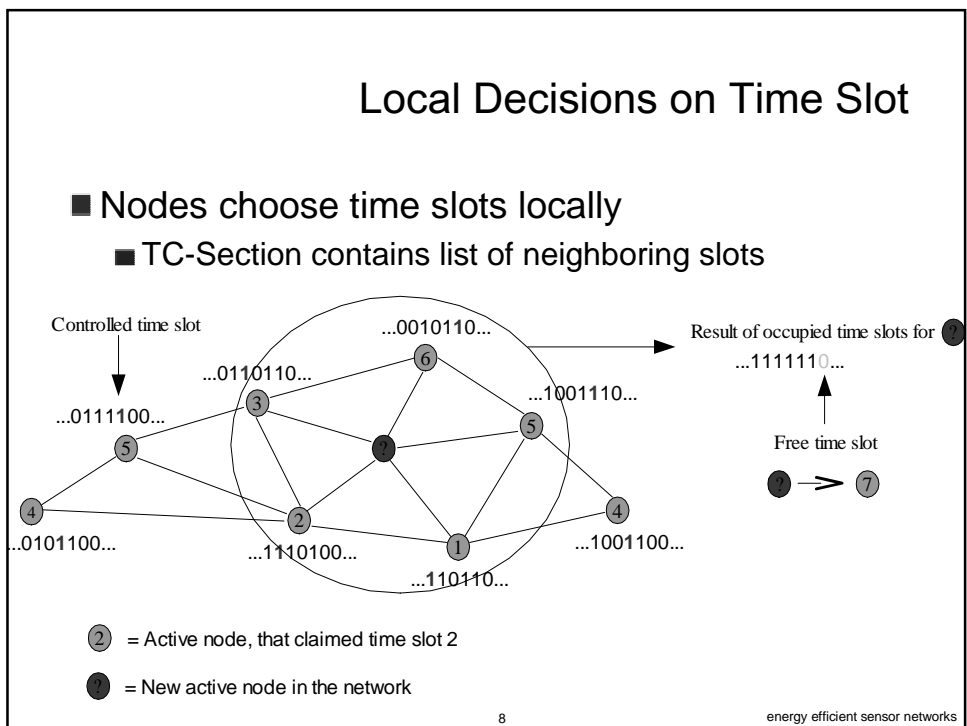
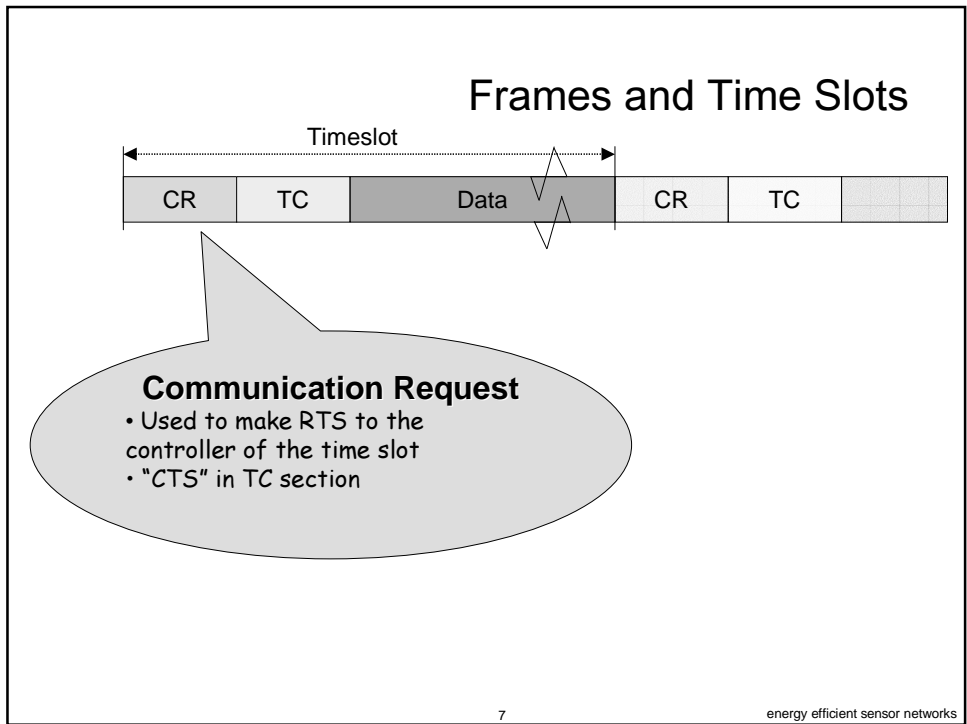
Frames and Time Slots



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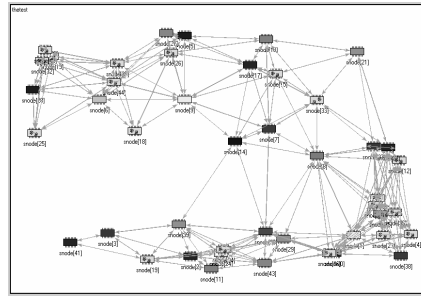
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Simulation

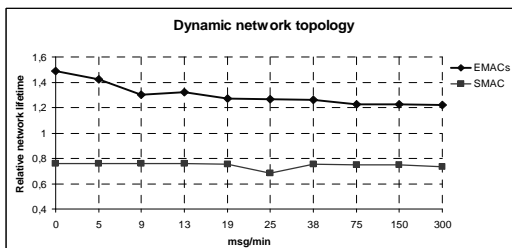
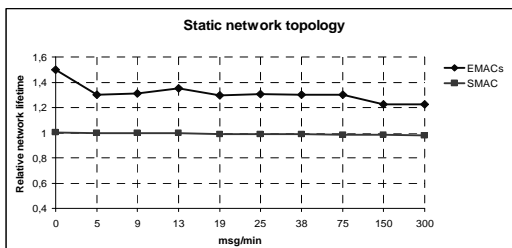
- 50 nodes in 800x500 m area
 - One sink, 5 sensing nodes
 - Other nodes are "intermediate relays"
- Random Waypoint model
 - 2-10 m/s
- Transmission range: 150m
- Metric: Network Lifetime
 - Physical model of RFM
 - Time until 30% of relay nodes run out of energy
- Comparison to S-MAC



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EMACs: Comparison with SMAC



- DSR routing
- EMACs gives a 20-50% increase of network lifetime
- EMACs performs comparable for static and dynamic topology
- SMAC suffers from:
 - Increased number of routing messages
 - Increased listen interval *In mobile scenario*

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EMACs: Energy modes

- EMACs supports three energy modes:
 - Active:
 - Node controls a time slot
 - Node can communicate collision-free
 - Passive:
 - Node does NOT control a time slot
 - Node uses CR of other (active) nodes
 - No collision-free communication
 - Dormant:
 - Node shuts down for agreed interval
 - Not considered in simulations...
- Passive mode saves energy...
... but how to decide?

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Connected Active Set

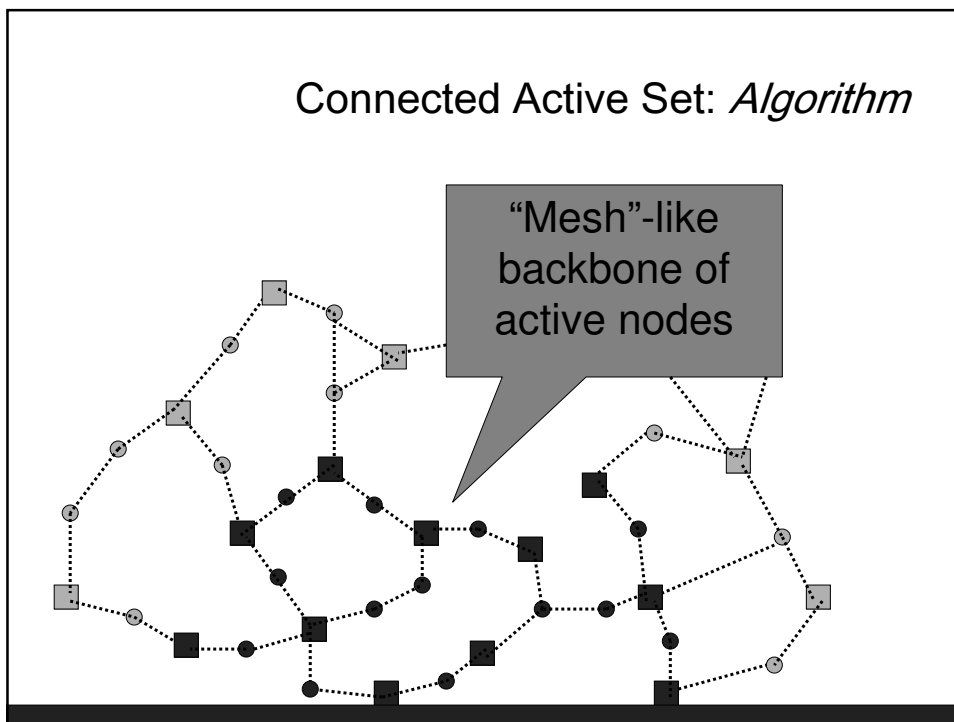
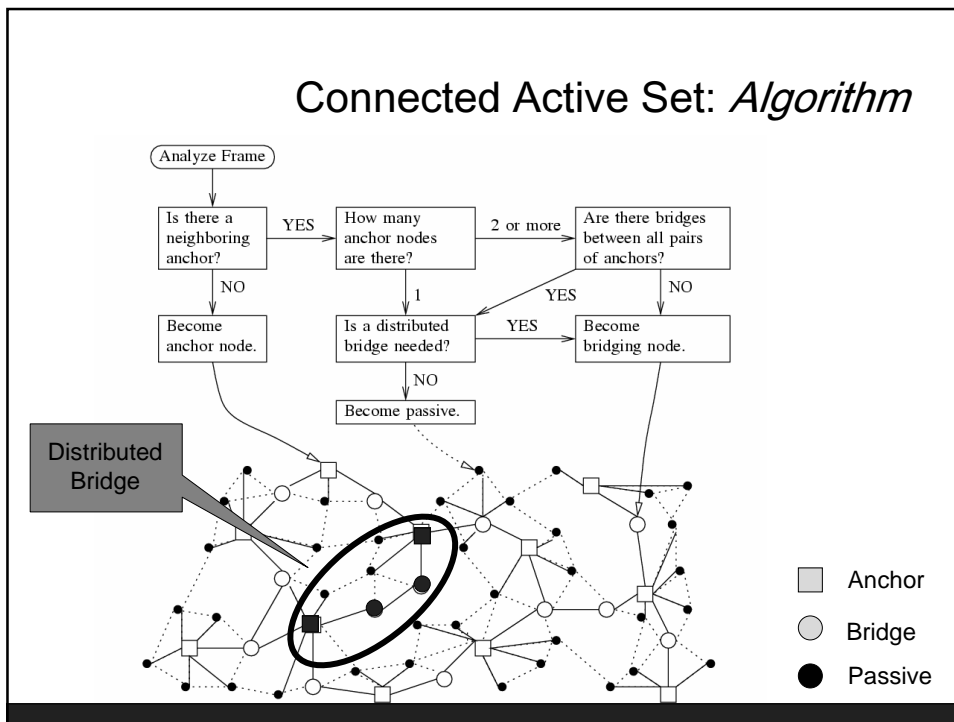
- Local decision algorithm to create connected subset of nodes which will remain active
 - Passive nodes **can** follow sleeping pattern
 - Each node is neighbor to non-passive node

Idea:

- 1. Identify *Anchor* Nodes
 - Nodes form Independent, Dominating Set (IDS)
- 2. Introduce *Bridges* for connectivity
 - May have to use *distributed* bridge consisting of 2 intermediate nodes

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Execution of Algorithm

- (Re-) Decision on status is invoked
 - at wake-up
 - when topology changes
 - Active nodes only
- Node will listen to one more frame before becoming *passive*
 - Detect current changes of neighbors

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Efficient Execution

- No extra transmissions needed (!)
 - TC-Section of EMACs contains all necessary information
 - Extra Field: AID (active id) to encode all information

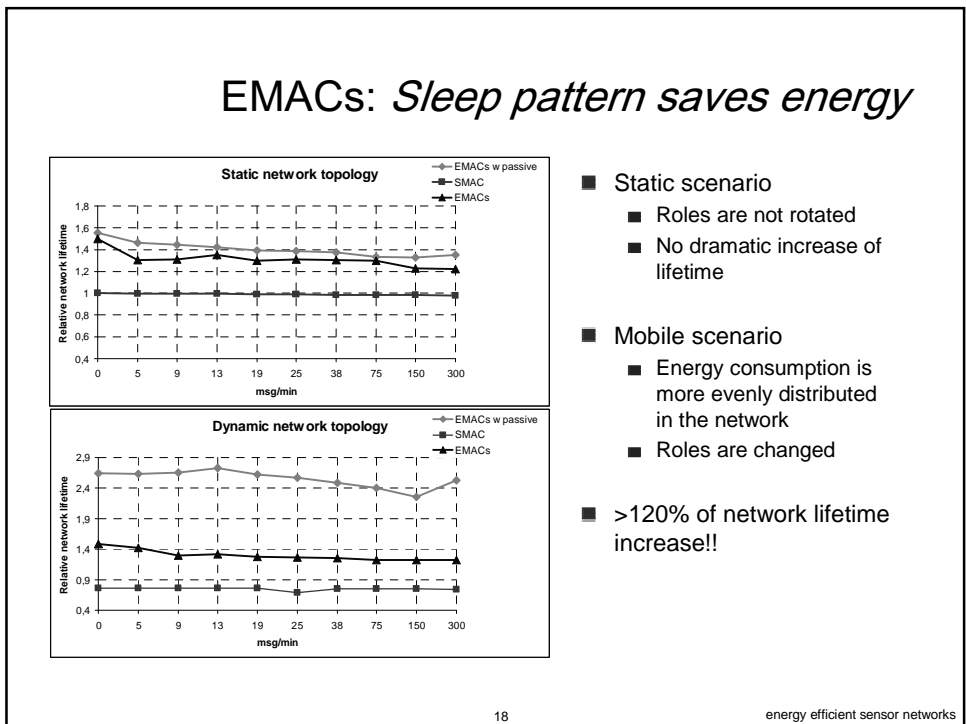
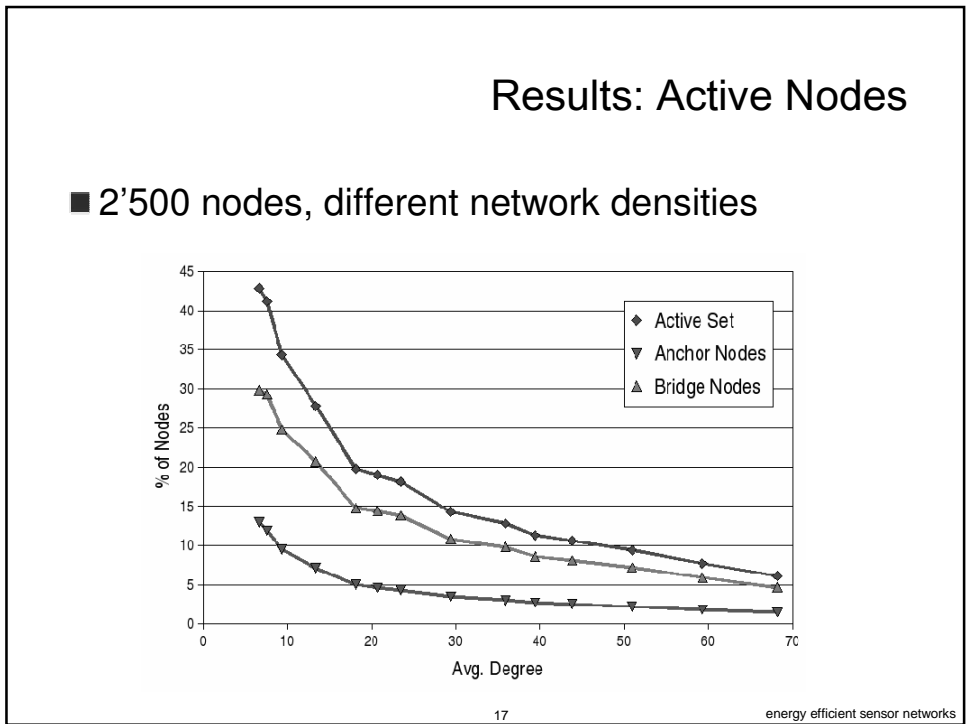
<i>Description</i>	<i>Encoding</i>
Anchor	AID = ID
Bridge	AID = (Anchor1 XOR Anchor2) ¹
Undecided Active	AID = 0
Nonmember	AID = ID (lowest Anchor)

¹⁾ 1st bit of ID is always 0 -- if 1st bit of AID = 1 then node is bridge

- All control-messages can be inferred (=> not needed)

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EYES Source Routing Protocol (ESR)

- On Demand driven routing algorithm
- three phases
 - *Setup*: routes created only needed by a source node
 - *Maintenance*: existing routes maintained by route maintenance procedures
 - *Reestablishment*: reconstruct route when maintenance fails
- fast route recovery relying on MAC
- route optimization during maintenance
- locally restricted flooding with high efficiency
- only two neighbor's ID stored in the node
- all routing messages with short fixed size
- characteristics: low overhead, can handle mobility and failures

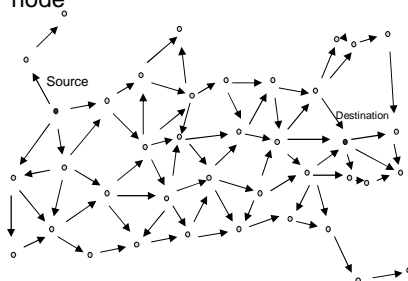
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Route Setup

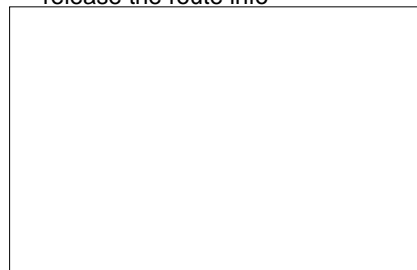
Request

- initial flooding with very short request
- greatly reduced energy consumption
- fitted into the TC section of EMAC
- nodes only forward the first received request
- store the best neighbor to the source node



Reply

- destination only replies first request
- only the best route is confirmed
- nodes on the best route record the best neighbor to the destination node
- nodes Not on the best route release the route info

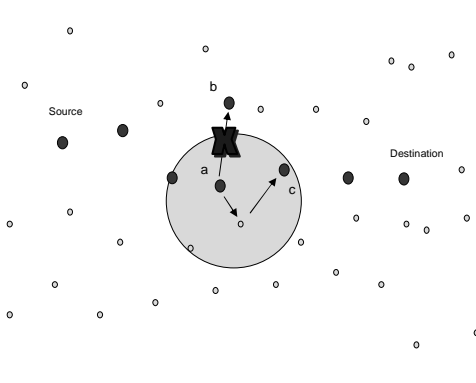


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Route Maintenance

- two kind of scenario mainly occur
 - Route Re-Catch
 - Route Cut

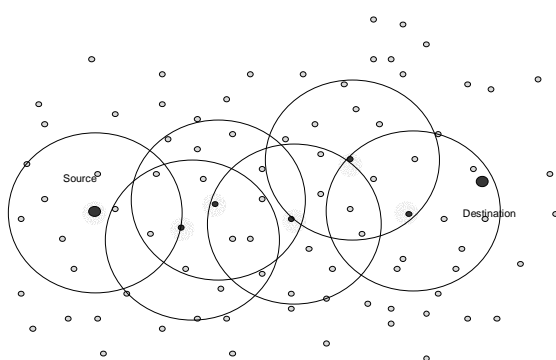


- route re-catch when next node moves away
- noticed form MAC neighbor list
- send Re-Catch with short TTL (1 or 2)
- locally restricted Flooding, only to the second order neighbor
- efficiently re-catch the floated away node
- intermediate node initiated *Route Setup*

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Route Reestablishment

- When route re-catch fails
- Resend Route Request with limited Hops To Live (HTL)
- Nodes, which were on-route, rebroadcast HTL as repeater
- Re-catch propagation restricted in the limited area



- Flooding directed to the direction of the destination
- The overall effect is a destination aware and directional request flood
- efficient compared with network wide flooding
- more advantageous if the network diameter grows.

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