Energy Sensitive Routing in Ad hoc Networks

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Ad hoc Networks – Wireless without Infrastructure

- Wireless networks work without any central administration.
- Comparing to mobile cellular telephone systems, ad hoc networks have smaller cover range.
- Ad hoc is generally packet-switch system.
- IEEE 802.11 standards

Ad hoc Physical Layer

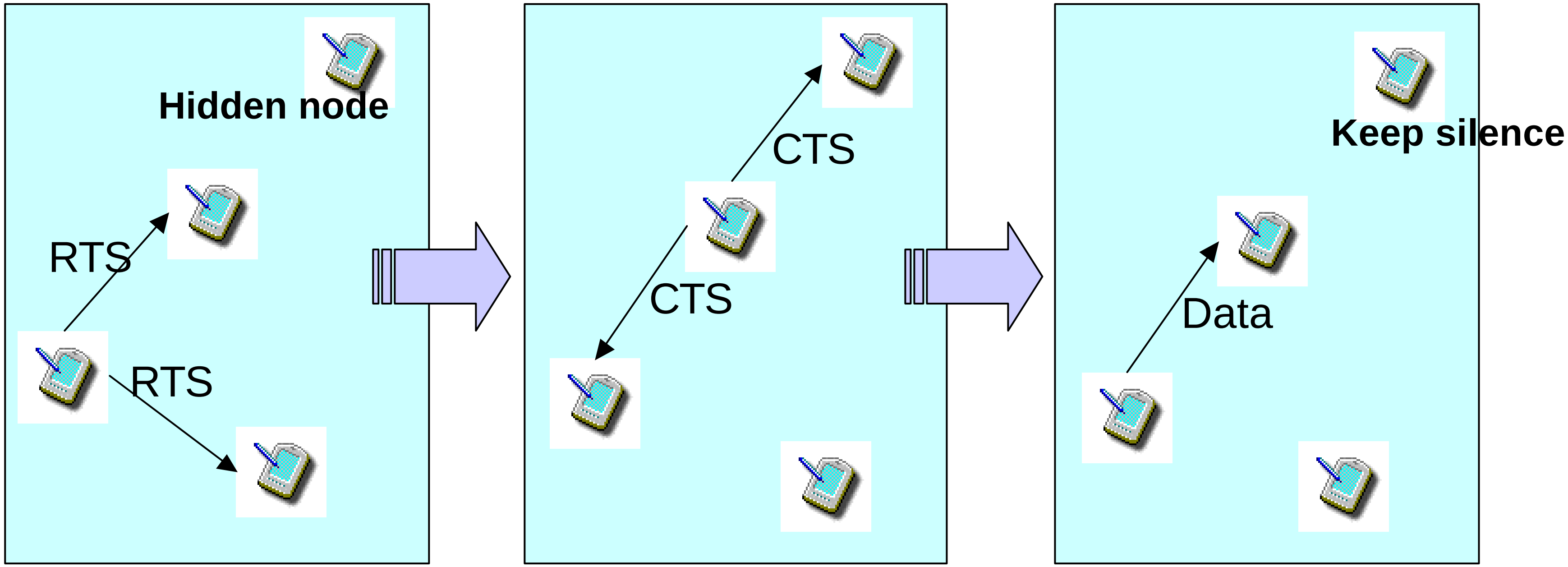
- Basics:
  - 2.4G Hz FHSS (Frequency Hopping)
  - 2.4G Hz DSSS (Direct Sequence)
  - Infrared
- 1Mbps or 2Mbps raw data rate
- 11Mbps or higher data rate (IEEE 802.11a, IEEE 802.11b)

Ad hoc MAC layer

- Ad hoc MAC layer uses a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol.
- First the radio interface (carrier) is sensed.
- Source node sends (broadcasts) a Request-to-Send (RTS) packet with the destination node address
- The specified node replies a Clear-to-Send (CTS) packet

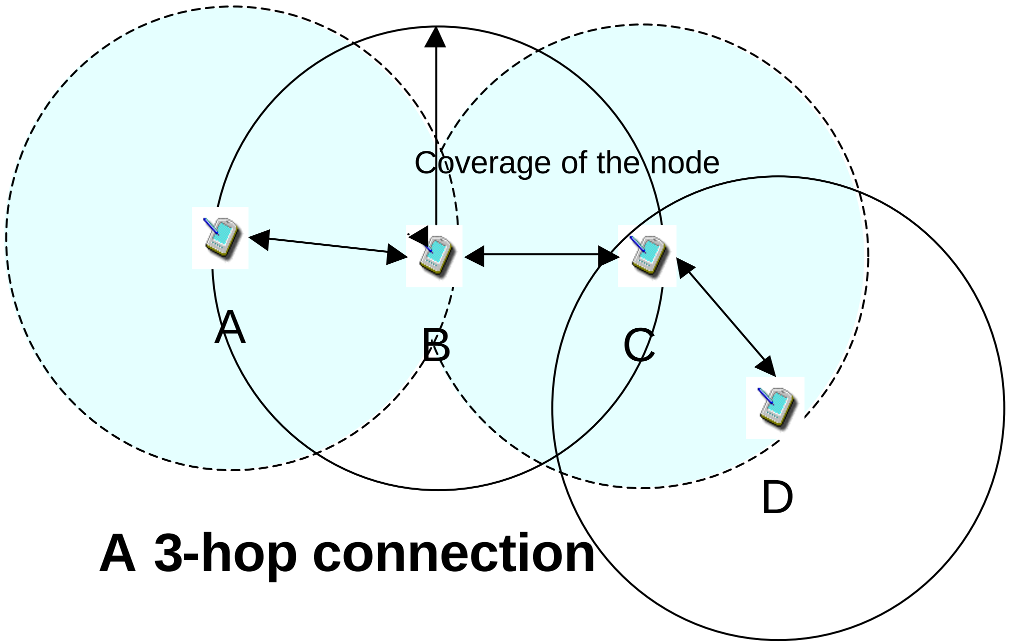
Ad hoc MAC layer

RTS-CTS can eliminate Hidden Node and Expose Node problems



Multihop Ad hoc Networks

- The devices in Ad hoc network generally have limited power supply
- Ineffective to use high transmission power to cover all nodes in the network
- Data packets are relayed by intermediate nodes – multihop ad hoc network



A 3-hop connection

Energy consumption by Multihop

- For a given threshold receiver power *Pr*, the minimum transmit power *Pt* is

$$\mathrm{Pt}(d) = \mathrm{Pr}\frac{d^n}{K}$$

- *n* is the path loss exponent, typically is 4. *K* is a constant.
- With an intermediate node between the source and destination, the transmit power (energy) is the sum of two hops:

$$\mathrm{Pt}'(d) = \mathrm{Pt}(d_1) + \mathrm{Pt}(d_2) \quad \text{where } d = d_1 + d_2$$

- One can derive that the transmitting energy consumed by two-hop scenario is 1/8 of the single hop if the intermediate node has the same distance to the source and destination

Ad hoc Network Routing

- Routing protocols are necessary in order to find a path between source and destination nodes in multihop ad hoc networks.
- Routing is challenged by the dynamic topology of the network.
- Basically there are two classes of routing algorithms: proactive and reactive.

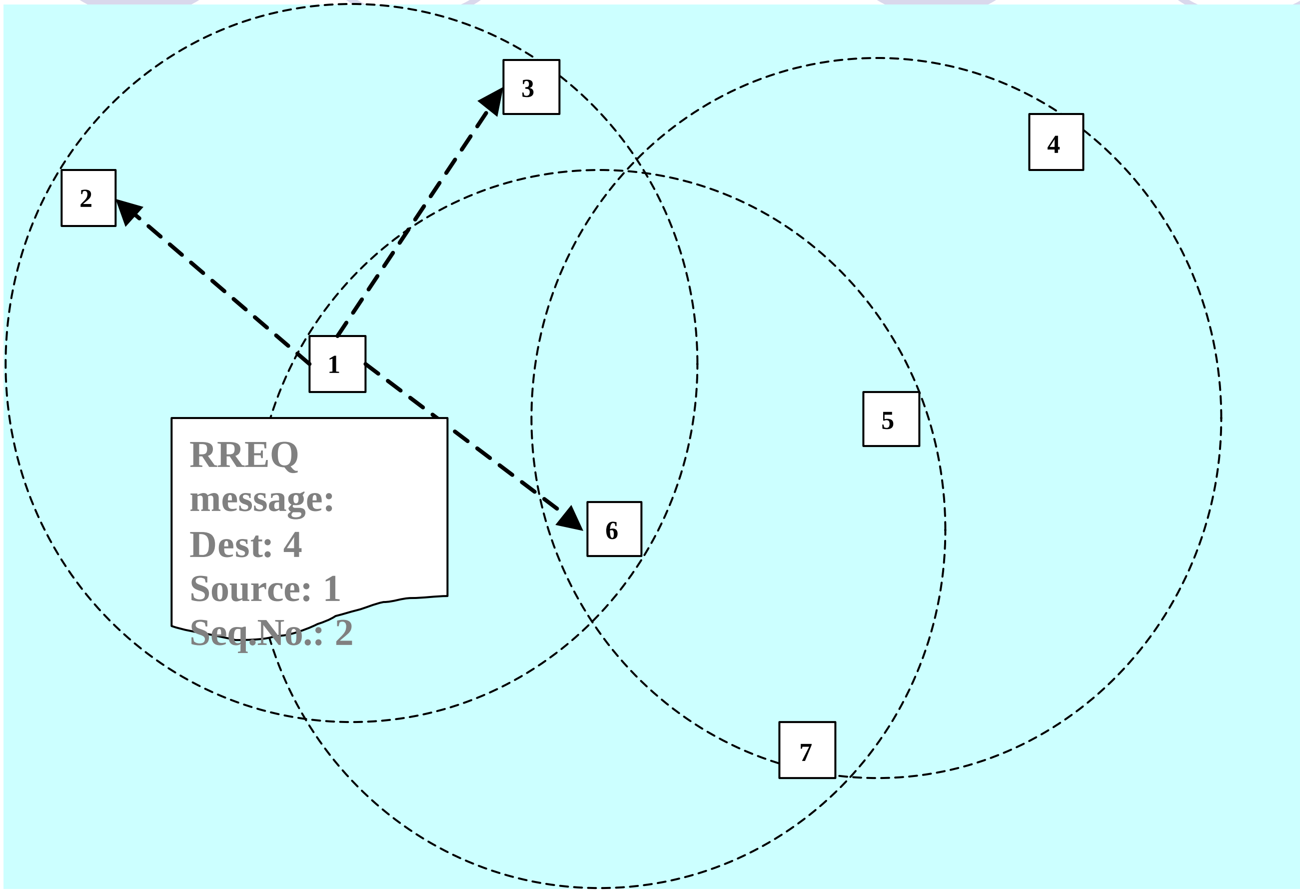
Ad hoc Network Routing

- In proactive routing, all the nodes maintain and periodically refresh routes to any other node in the network, even no traffic is carried on a maintained route.
- In reactive routing, a route is established on demand.
- Research shows that reactive routing schemes generate less overhead packets, thus consume less power than proactive ones.

Reactive Routing Example: Ad hoc On-demand Distance Vector (AODV)

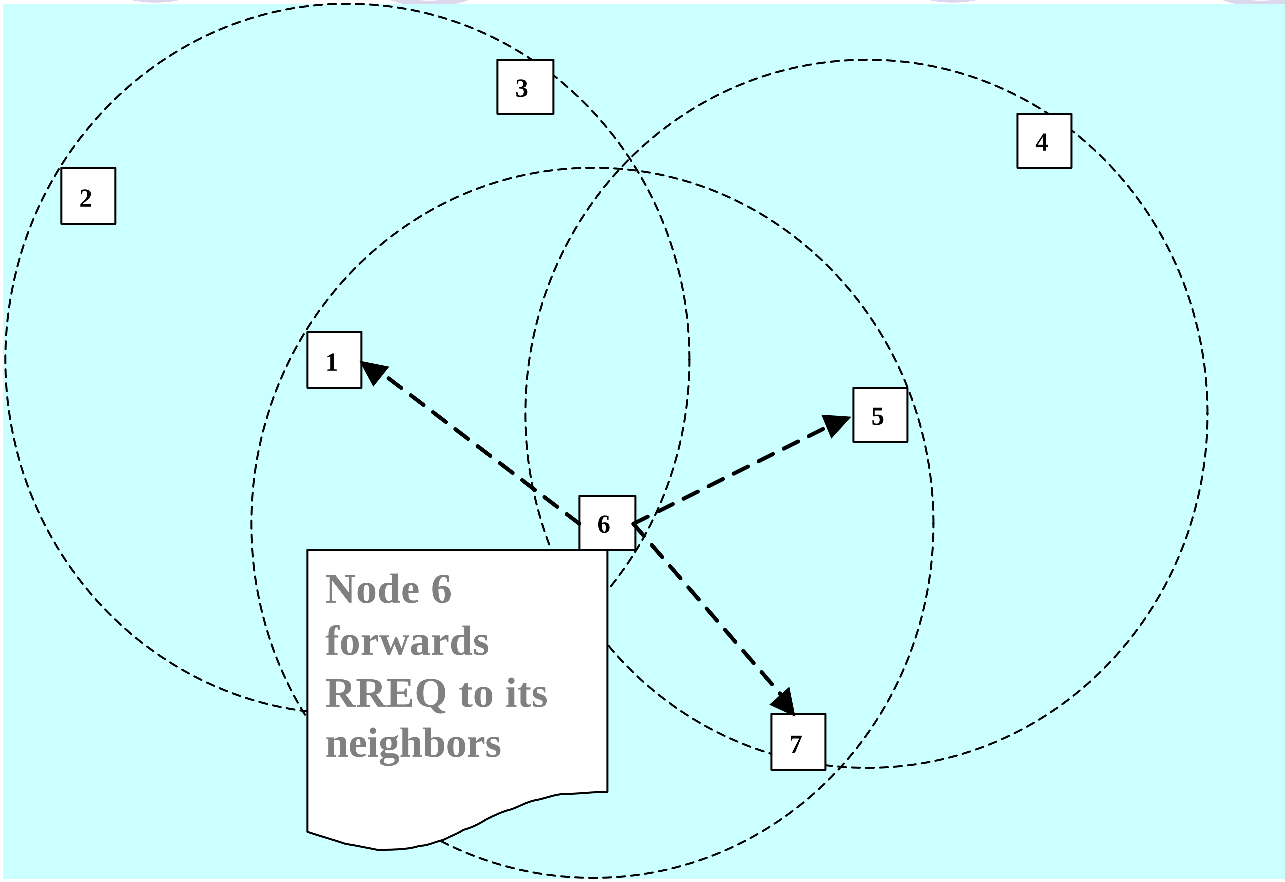
- AODV is a reactive routing algorithm
- In AODV, there are 4 types of overhead packets (Routing Signalling):
  - HELLO to notify neighbours
  - RREQ (Routing Request) to initiate a routing procedure
  - RREP (Routing Reply) to confirm a route
  - RERR to indicate a route failure

AODV – Path Finding (1)



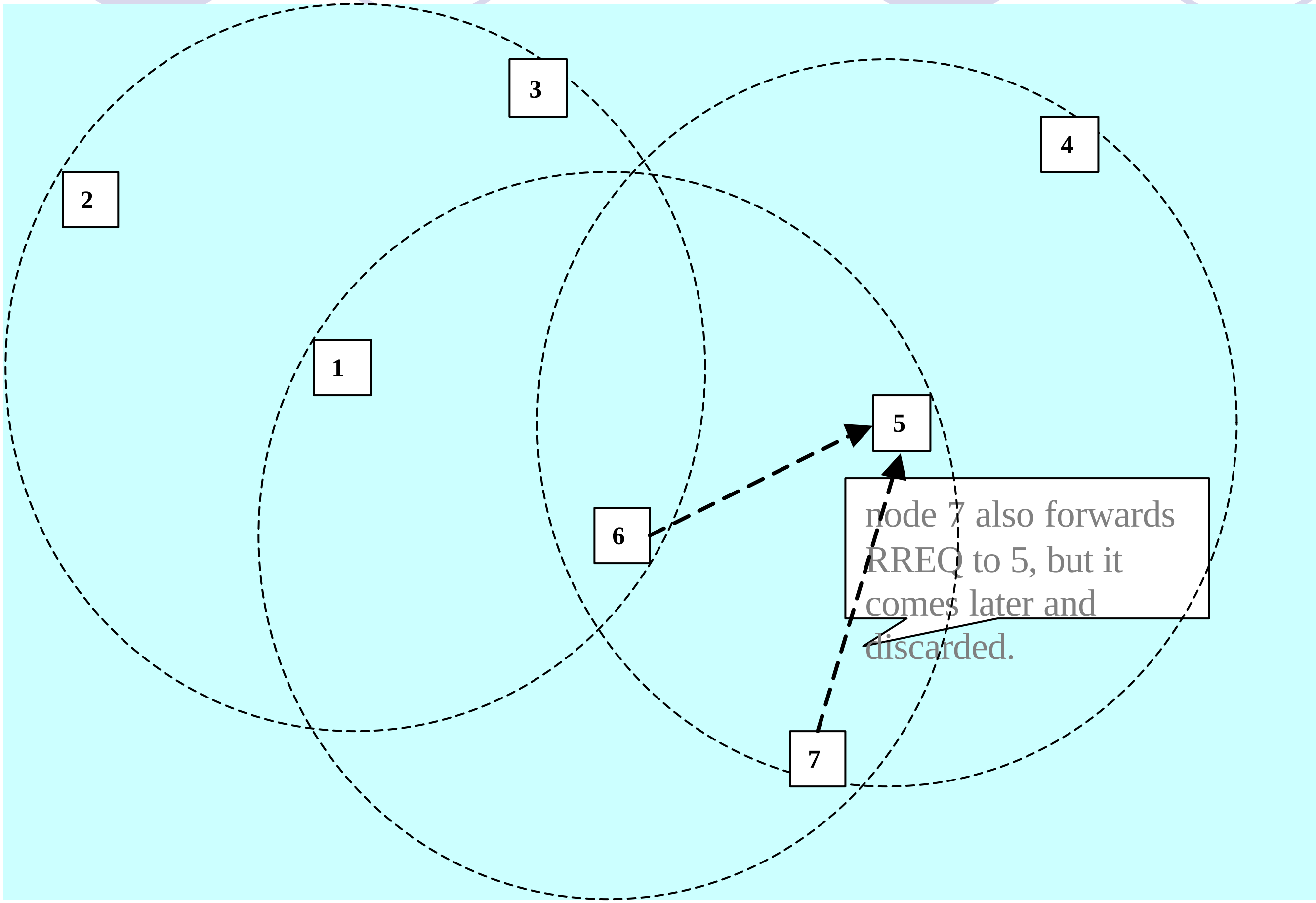
The source node broadcasts RREQ message to its neighbours.

AODV – Path Finding (2)



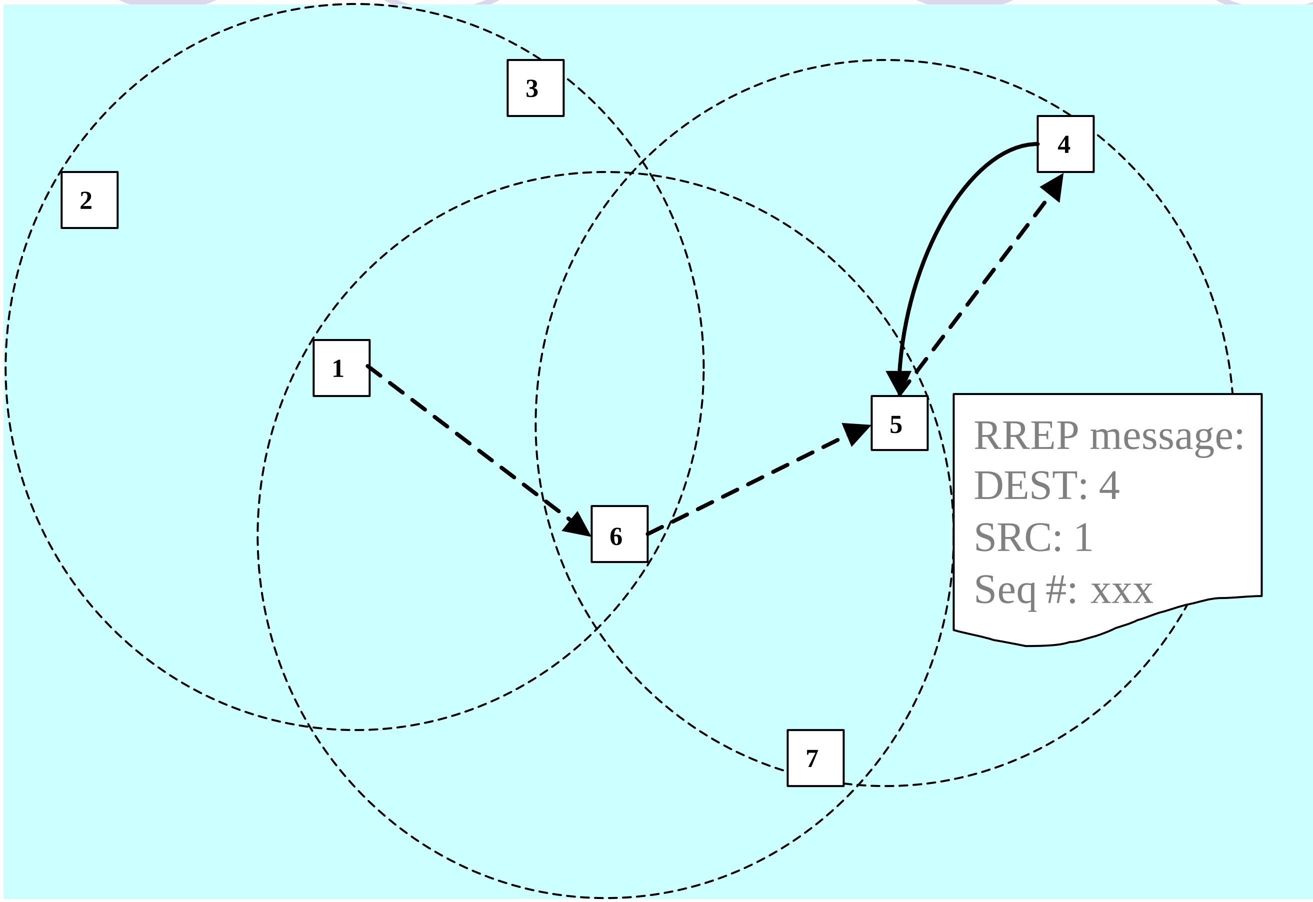
On receiving RREQ, an intermediate node will broadcast it again.

AODV – Path Finding (3)



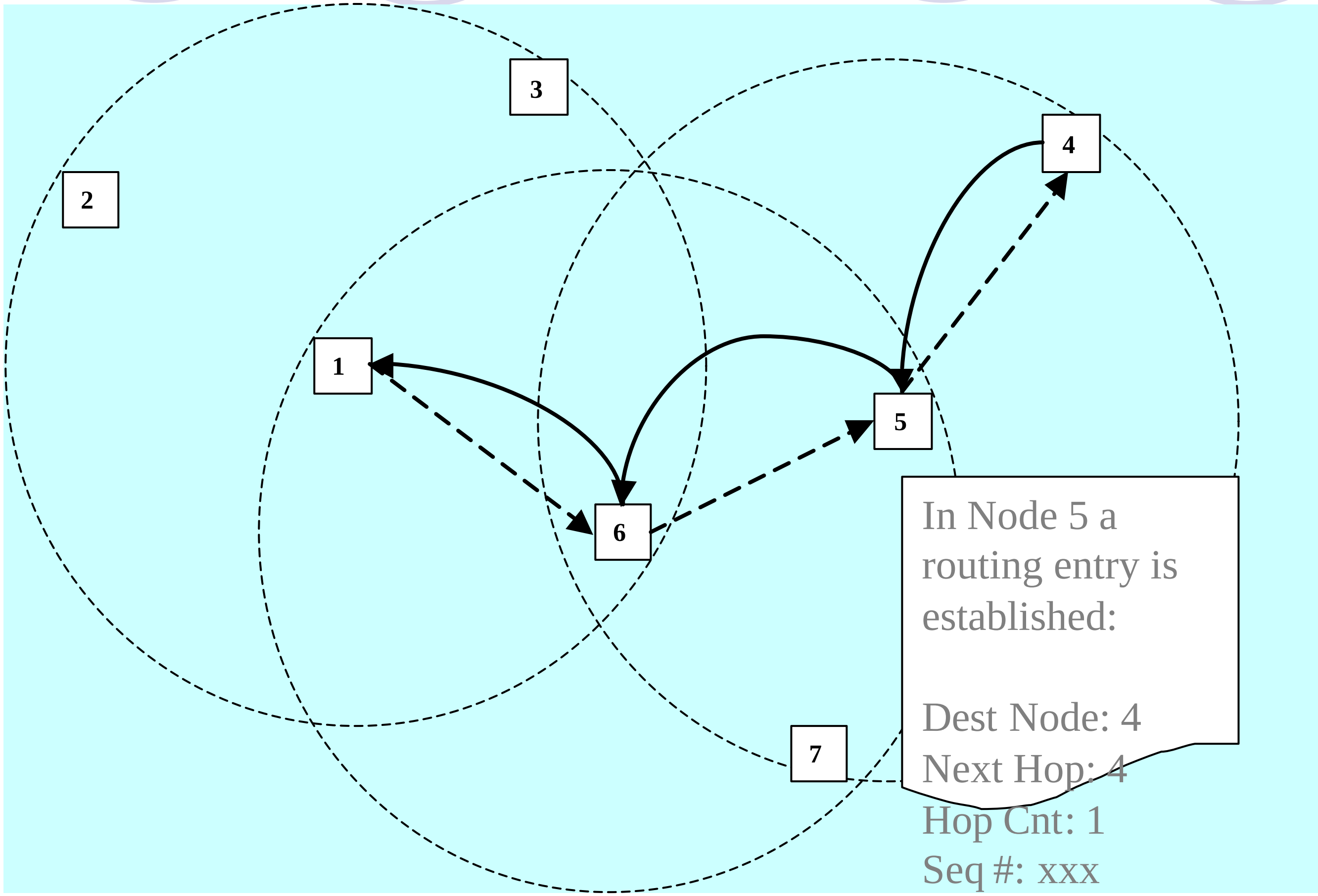
Duplicated RREQ is discarded.

AODV – Path Finding (4)



The destination node* replies RREP message when it receives a RREQ.

AODV – Path Finding (5)



The RREP will be propagated through inverse path to confirm a route.

Energy-Conserving Routing Schemes

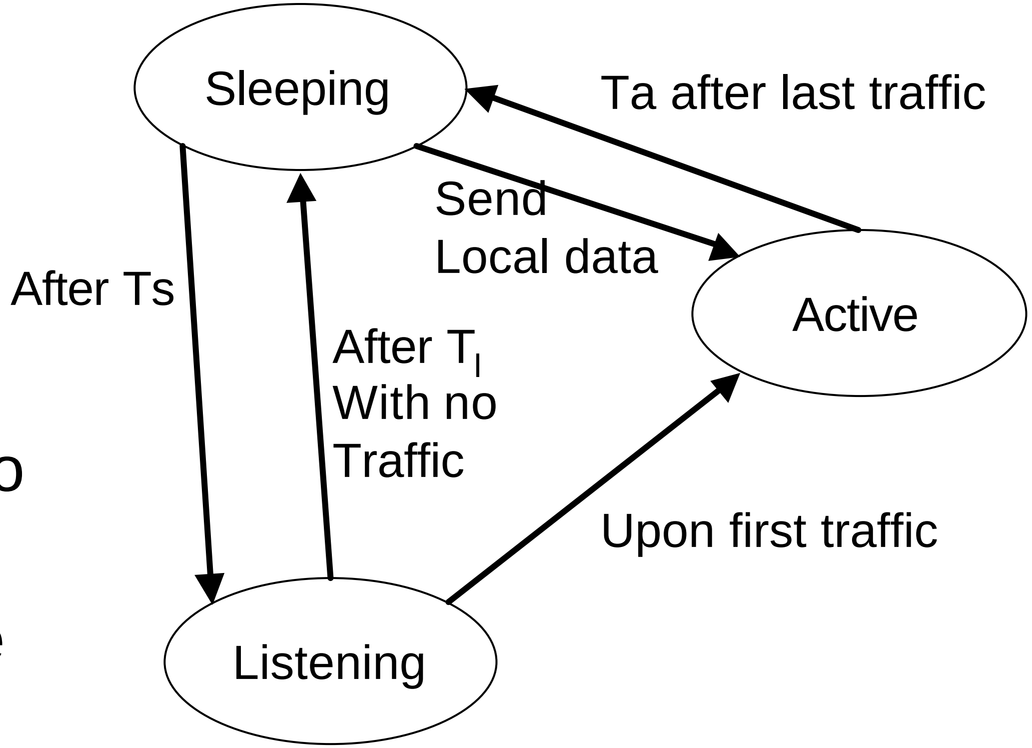
- Network Device Power Control
  - Adaptive Energy-Conserving Routing (AECR)
  - Coordinated Energy-Conserving Routing (CECR))
- Battery-Lifetime Determination
  - Time Delay On-Demand Routing (TDOR)
- Battery-Lifetime & Traffic-Load Determination
  - EAODV for Optimal Path Discovery* (EAODV)

Energy-Conserving Routing (1)

- *Adaptive Energy-Conserving Routing for Multihop Ad hoc Networks*, by Ya Xu, John Heidemann, and Deborah Estrin, http://citeseer.nj.nec.com/310126.html
- The research shows that in receiving/listening mode, the power consumption is still considerable.
- Two algorithms are presented here:
  - Basic Energy-conserving Algorithm (BECA)
  - Adaptive Fidelity Energy-Conserving Algorithm (AFECA)
- Basically these two algorithms will determine the chance that a node may participate in a route.

Energy-Conserving Routing (1)

- In BECA, nodes are in one of three states:
  - Sleeping
  - Listening
  - Active
- When in the sleeping state, radio is turned off to save energy.
- A timer is used to change state when time-out.



Energy-Conserving Routing (1)

- In AFECA, a node can improve energy conservation by estimating node populating and increasing sleep time when other nodes are available.
- The sleeping timer is simply set as Tsa, which is

$$T_{SA} = random(1, N) \times T_S$$

- Here N is the number of neighbours, Ts is the unit sleeping time in BECA.

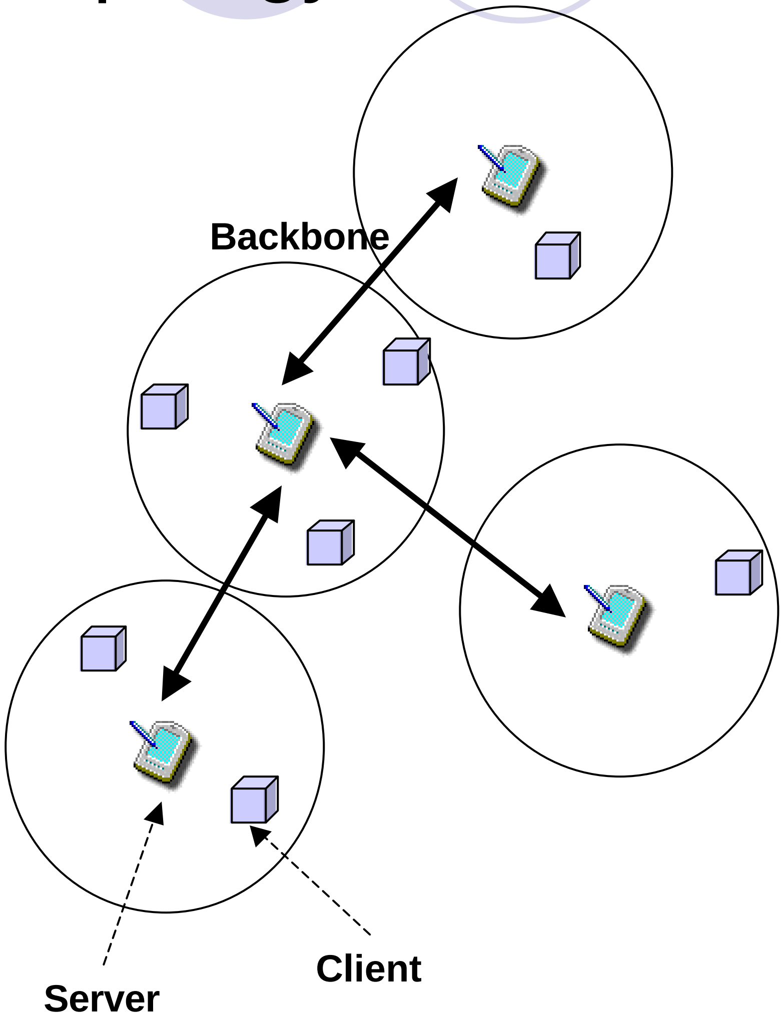
Energy-Conserving Routing (2)

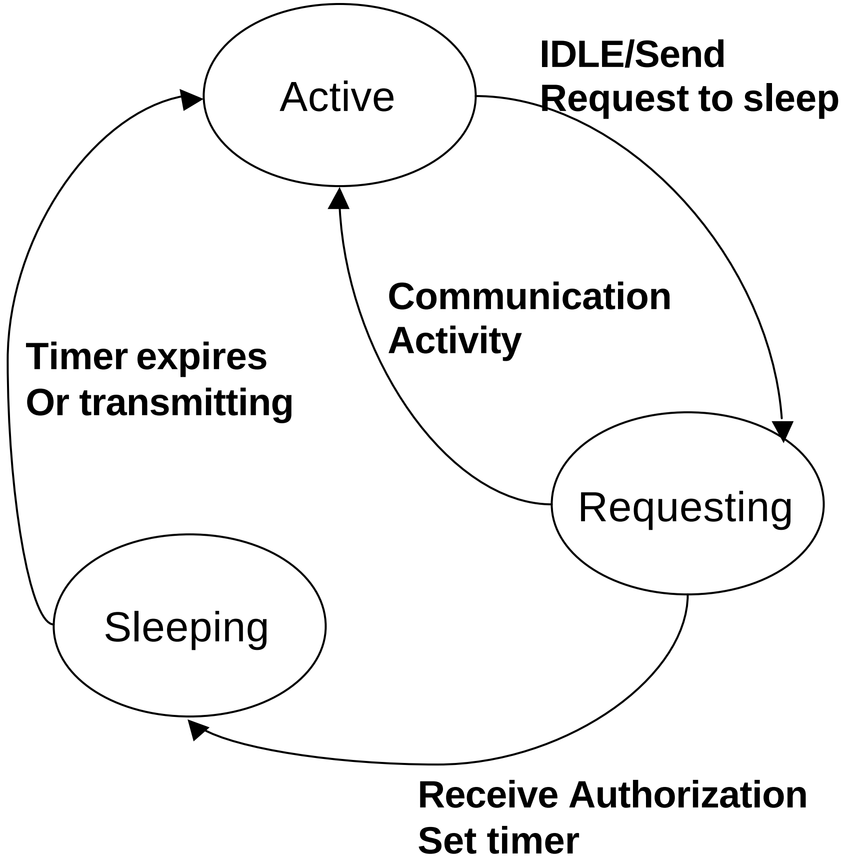
- *Coordinated Energy Conservation for Ad hoc Networks*, by Chavalit Srisathapornphat, Chien-Chung Shen, Communications, 2002. ICC 2002. IEEE International Conference on , Volume: 5 , 2002
- An algorithm called <u>Coordinated Energy Conservation</u> (CEC) for ad hoc was introduced
- A set of <u>backbone nodes</u> are selected to coordinate energy conservation.

Energy-Conserving Routing (2)

- A backbone node works as a server, which serves a group of clients.
- A server and its clients use Coordinated Energy Conservation Algorithm to collaborate.
- A client sends its states (include intension to transmit, battery remaining, etc) to its server.
- The server replies either a grant to transmit or a duration that the client can turn off the radio interface (sleep).

Energy-Conserving Routing (2): Network topology and Client Algorithm





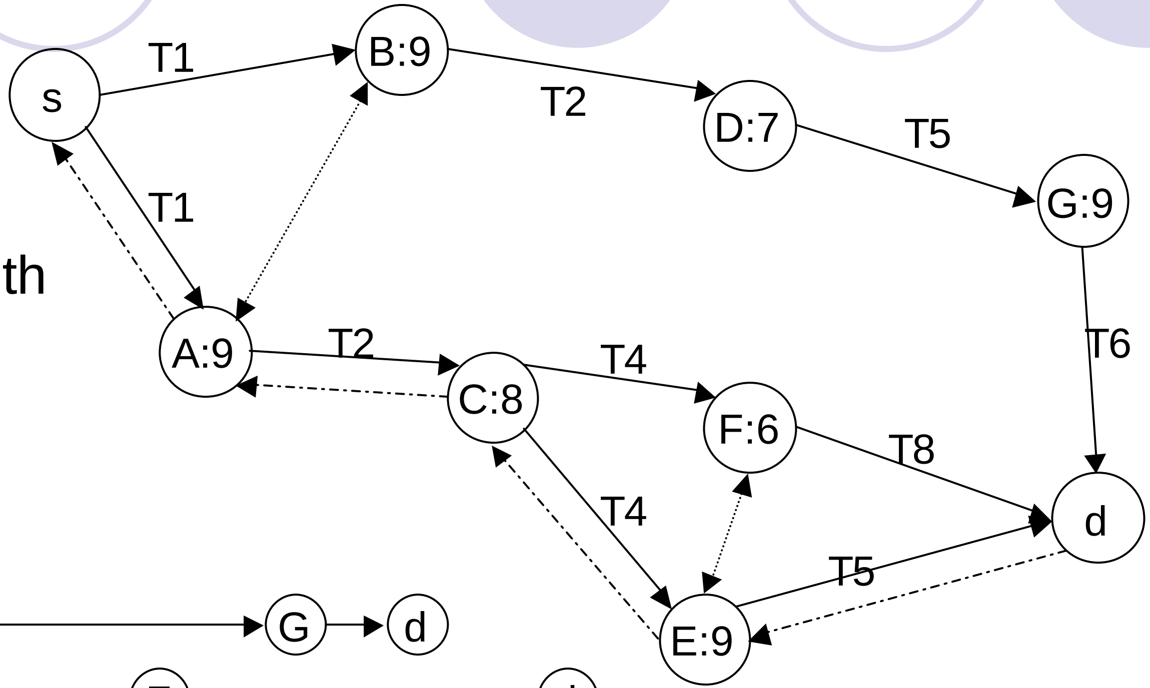
Energy-Conserving Routing (3)

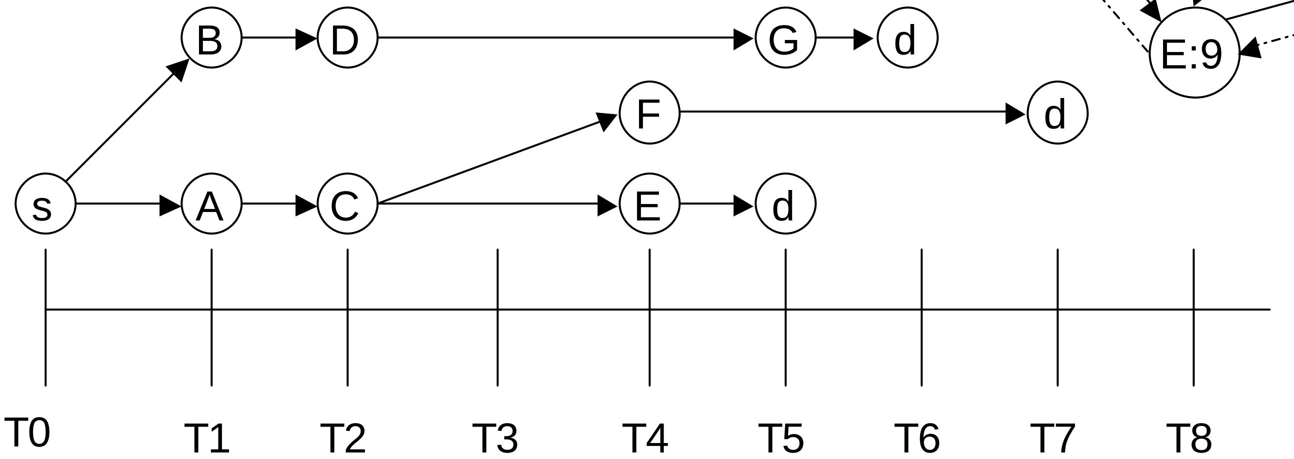
- *Implementation of an Energy-Efficient Routing Protocol: Time Delay On-Demand Routing Algorithm (TDOR)*, Tran Minh Trung and Seong-Lyun Kim, Proc. IEEE Conference on Mobile and Wireless Communications Networks, Stockholm, Sweden, 2002
- In TDOR, a node holds the RREQ packet for some times, inversely proportional to its own residual battery capacity.

$$T_i(C_i^{\,t}) = \frac{1}{C_i^{\,t}}$$

Energy-Conserving Routing (3)

A Path is Found with Maximum Battery Residual

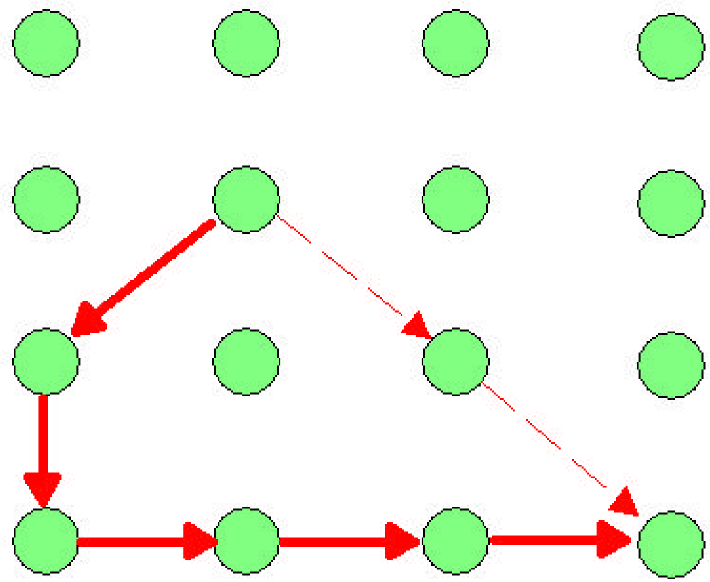




Optimal Path Routing AODV

-Based on Ad hoc research group result at Vaasa University

- In the original AODV, the destination node sends RREP message immediately after receiving the first RREQ message.
- This mechanism cannot guarantee that the optimal path is found.



Optimal Path Routing AODV

- Meanwhile, the intermediate nodes involved in the established route may be already heavily loaded (traffic consideration) or running out of battery power (energy aware).
- A new approach is considered, in which some Additional (Extended) information is added to the RREQ and RREP packets. It gives the network possibilities to find an optimal route.
- The purpose to let the nodes in ad hoc network equally participate the network activity. Thus energy dissipation is equally decreased and the total network lifetime increases.

The Extended Message in RREQ

- In the extended message of RREQ, we need **route select field (RSF)**, which is a metric of the node's battery residual and the traffic load the node has taken recently

Type (8) | reserved bits (5) | others (11) | hop count (8)
RREQ ID
Destination IP address
Destination Sequence Number
Originator IP address
Originator Sequence Number
Route-select Field

← 32-bit word →

Route Select Field (RSF)

- Noted as

$$t_R = \frac{B}{L}$$

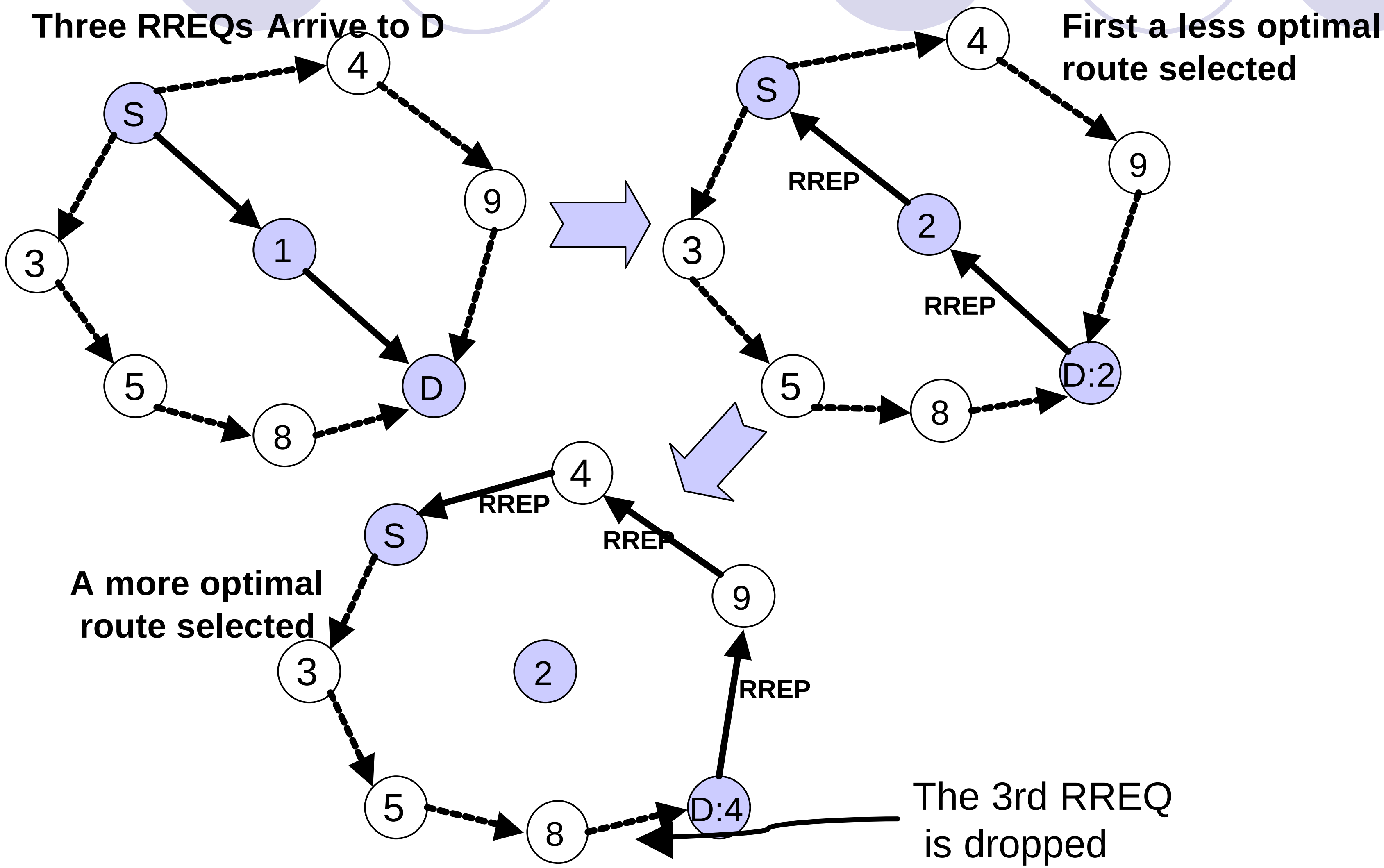
- Battery Lifetime *B*
  - Can be retrieved from OS (Linux)
- Traffic Load *L* is a historical value.
  - Can be given by the ratio of the number of bits transmitted by the node in a fixed past time.

$$L = \frac{N_b}{T_0}$$

The Route Establishment

- The source node initiates a RREQ will maximum RSF.
- Every node that has received a RREQ will check the RSF and calculate its own battery/load metric. If it is lower than the one in RSF, it will replace it by its own.
- The destination node will reply the first arrived RREQ to ensure the minimum latency of route establishment. Meanwhile, it will keep the value of RSF in its cache.
- If another RREQ arrives at the destination, the node will compare the RSF with its cached value. If the new RSF is greater than the cached one, send a RREP and replace the cache by the new value.
- The source node will change its route table if another RREP comes from the same destination.

The Route Establishment



Advantages & Disadvantages

- Trade-offs:
  - Longer Packet Length of RREQ and RREP
  - More than one copy of RREP may be sent out
  - Node load is increased to calculate RSF and more memory required.
- Gains:
  - Energy Conservation
  - Optimal Path possibility increase
  - Data packets propagation improved through the better path
  - Compatible with original AODV nodes

Conclusion

- Routing plays an important role in energy conservation (to select suitable nodes to relay packets).
- Energy conservation routing increases the node complexity and decreases the throughput of the network; meanwhile, it prolongs the network lifetime thus increases overall performance.
- Questions described here are still open

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