Mobile and Sensor Systems

Lecture 5: Ad Hoc and Delay Tolerant Routing

Dr. Cecilia Mascolo

UNIVERSITY OF CAMBRIDGE

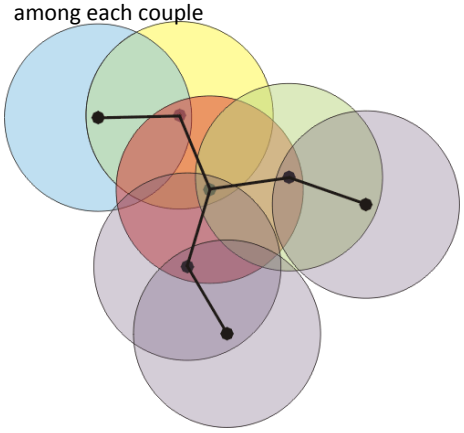
What' s in this lecture

- We will describe ad hoc routing protocols
- We will introduce delay tolerant networks which are disconnected ad hoc networks
- We will describe delay tolerant routing protocols
- We will illustrate examples of geographical routing

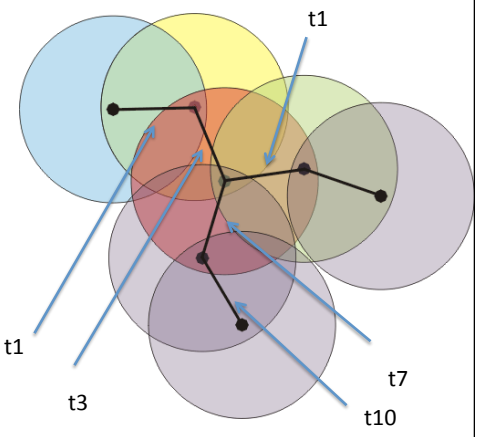
UNIVERSITY OF CAMBRIDGE

Connected vs Disconnected Ad Hoc Networks

Connected: there is a connected path among each couple



Disconnected: there is no connected path, just sometimes some temporal ones



UNIVERSITY OF CAMBRIDGE

Routing in Wired/Wireless Networks

- Link State
  - Each node sends its link information to all nodes in the network
  - Small vector to all large number of nodes
  - Dijkstra for shortest path
- Distance Vector
  - Each node sends its table to its neighbours
  - Large vector to small number of nodes
  - Bellman Ford for shortest path

UNIVERSITY OF CAMBRIDGE

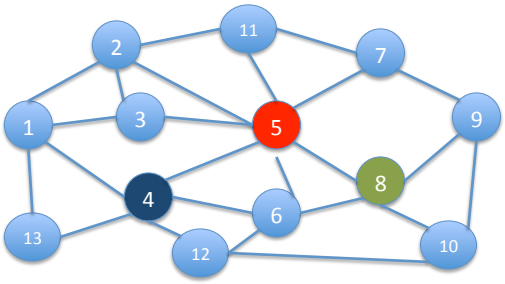
OLSR: Optimized Link State Routing Protocol

- Proactive
- Hello messages from a node to its neighbours with bidirectional links and list of known neighbours -> learning 2 hop neighbourhood
- Ask a subset of neighbours to forward a node's link state (subset=MPR, Multipoint Relay)
- If node X is in your MPR you are in X's MPR Selector
- Each MPR has a set of MPR Selectors
- Each node sends LS to all its neighbours
- MPR forwards LS of MPR's selectors
- Nodes use this info for routing tables but do not forward

UNIVERSITY OF CAMBRIDGE

OLSR Example

- Node 5 has selected 4 and 8 as MPR and sends LS to 2,3,4,6,7,8,11
- Nodes 2,3 6,7,11 use this info but do not forward
- Node 4 forwards to 1,6,12,13
- Node 8 forwards to 6,9,10



UNIVERSITY OF CAMBRIDGE

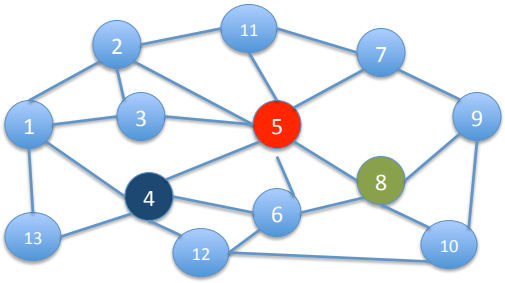
How are MPR Selected?

- MPR are arbitrarily selected
- A node can put all its neighbours into a MPR but
  - Not optimized -> lots of duplication
  - Optimal: min set such that all 2-hop neighbours get node's LS
  - Finding optimal MPR is NP complete
  - Heurisitics
    - N1(x)=1-hop neighbours
    - N2(x)=2-hop neighbours not covered
    - MPR(x)= empty
    - From N1(x)-MPR(x), select node A that has max connectivity to uncovered nodes (and update N2(x))
    - Add A to MPR(x)

UNIVERSITY OF CAMBRIDGE

Link State forwarding

- Each node maintains a routing table with
  - Node id, next hop, distance
- The table is never forwarded
- Updates on links are forwarded when there is a topology change



UNIVERSITY OF CAMBRIDGE

Drawbacks of OLSR (and partly of ad hoc protocols)

- Assumes a connected network
- Assumes bidirectional links
  - Extensions have been proposed to consider link quality and bidirectionality
- Being proactive means it consumes a lot of resources

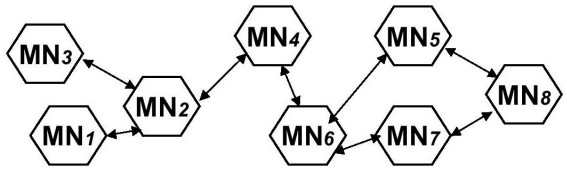
UNIVERSITY OF CAMBRIDGE

Destination Sequenced Distance Vector Routing

- Proactive
- Each node maintains a table with a route to every node
- Each entry of the table has a sequence number assigned by the destination
  - Sequence number, Destination, hops required, next hop

UNIVERSITY OF CAMBRIDGE

DSDV --- Routing Table at MN4



Dest	Nexthop	Metric	DestSequence	InstallTime
MN1	MN2	2	406	
MN2	MN2	1	128	
MN3	MN2	2	564	
MN4	MN4	0	710	
MN5	MN6	2	392	
MN6	MN6	1	076	
MN7	MN6	2	128	
MN8	MN6	3	050	

UNIVERSITY OF CAMBRIDGE

DSDV routing updates

- Each node periodically transmits updates
  - Includes its own sequences number, routing table updates
- Nodes also send routing table updates for important link changes
- When two routes to a destination received from two different neighbors
  - Choose the one with greatest destination sequence number
  - If equal, choose the smaller metric (hop count)

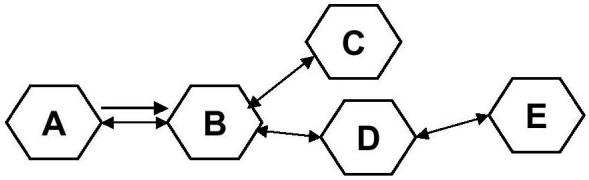
UNIVERSITY OF CAMBRIDGE

DSDV --- full dump

- Full Dumps
  - Carry all routing table information
  - Transmitted relatively infrequently
- Incremental updates
  - Carry only information changed since last full dump
  - Fits within one network protocol data unit
  - If can't, send full dump

UNIVERSITY OF CAMBRIDGE

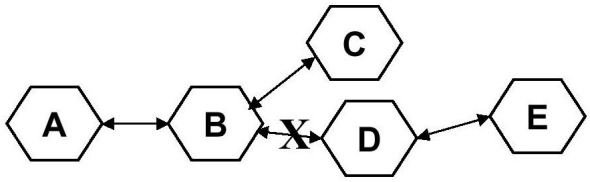
DSDV --- link additions



- When A joins network
  - Node A transmits routing table: <A, 101, 0>
  - Node B receives transmission, inserts <A, 101, A, 1>
  - Node B propagates new route to neighbors <A, 101, 1>
  - Neighbors update their routing tables: <A, 101, B, 2> and continue propagation of information

UNIVERSITY OF CAMBRIDGE

DSDV --- link breaks



- Link between B and D breaks
  - Node B notices break
    - Update hop count for D and E to be infinity
    - Increments sequence number for D and E
  - Node B sends updates with new route information
    - <D, 203, infinite>
    - <E, 156, infinite>

UNIVERSITY OF CAMBRIDGE

Dynamic Source Routing

- On Demand routing-> Reactive= construct a route only when needed
- Source route=list of routers along the path
- A node S wanting to send checks if it knows the route to the destination D
- If S does not know route to D and sends route request with its ID
- Each node adds itself to the request (compiling a “route record) and forwards to neighbours
- If a node knows the route it appends it and replies back with a route reply [in the worst case D replies back]

UNIVERSITY OF CAMBRIDGE

Dynamic Source Routing

- The node issuing the route reply places the route record in the reply as well as its known route to destination
- If this node has a path to the source this is followed, or the symmetric path can be followed (if bidirectional links are supported)
- Route Maintenance:
  - When a hop cannot be followed [due to link error] that hop is deleted from the cached route from that node

UNIVERSITY OF CAMBRIDGE

Issues with Reactive Routing

- If there is high node mobility, reactive routing is not performing well
  - Why?
- Routing overhead is proportional to path length

UNIVERSITY OF CAMBRIDGE

Zone Routing Protocols (ZRP)

- Zone routing is a hybrid protocol which combines proactive with reactive approaches
- A zone around node N is maintained where routes are collected proactively
- Beyond the zone an inter zone protocol is responsible to determine the routes in a reactive way

UNIVERSITY OF CAMBRIDGE

Delay Tolerant Routing

- When the network is not connected ad hoc routing protocols are unable to deliver the messages
- The strategy that works exploits **the fact that nodes can store the messages and forward them later**

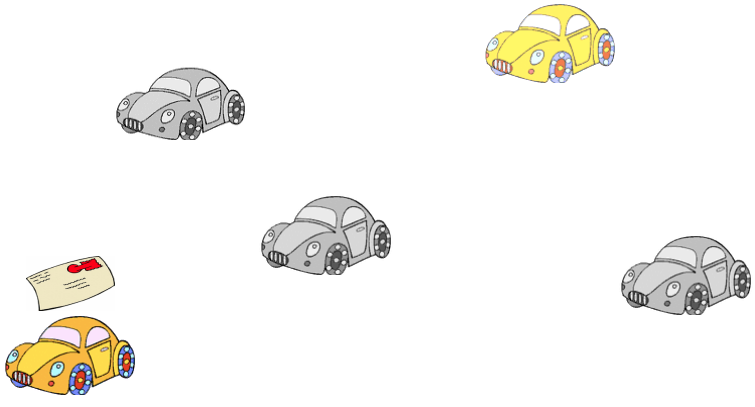
UNIVERSITY OF CAMBRIDGE

Epidemic Routing

- Vahdat and Becker
- Utilize physical motion of devices to transport data
- *Store-carry-forward* paradigm
  - Nodes buffer and carry data when disconnected
  - Nodes exchange data when met
  - data is replicated throughout the network
- Robust to disconnections
- Scalability and resource usage problems

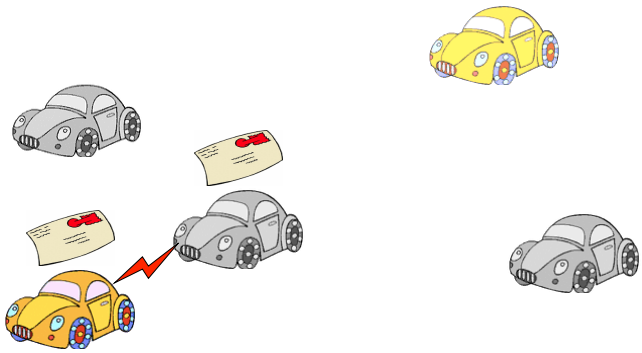
UNIVERSITY OF CAMBRIDGE

Epidemic Routing



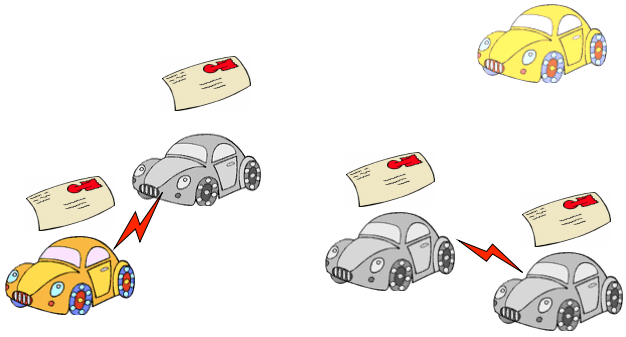
UNIVERSITY OF CAMBRIDGE

Epidemic Routing



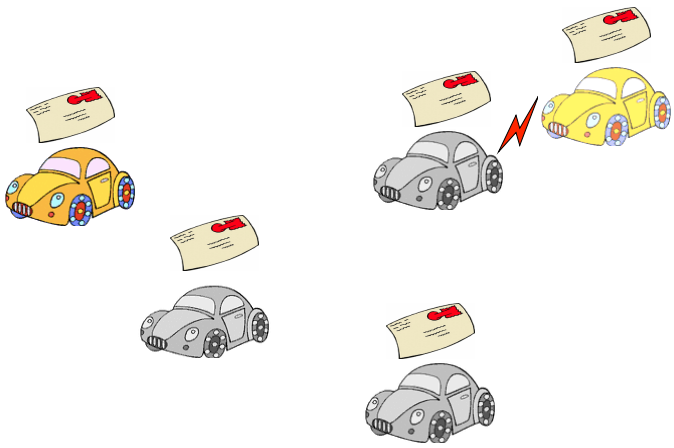
UNIVERSITY OF CAMBRIDGE

Epidemic Routing



UNIVERSITY OF CAMBRIDGE

Epidemic Routing



UNIVERSITY OF CAMBRIDGE

The Trouble with ER

- High delivery but also high overhead!
- Lots of duplications and collision

- Can we do better than this?
  - …with infinite buffers and bandwidth, not in terms of the delivery but only in terms of overhead!
  - With finite buffers and/or limited bandwidth, if we send less messages around we can do much better!

UNIVERSITY OF CAMBRIDGE

How can we improve from Epidemic Routing

- Exploit the knowledge on the mobility of the nodes
- Is the mobility deterministic (ie. Always on the same path at same times like busses)? Maybe we can even control the mobility of some of the nodes!
- If not fixed, is it at least predictable?
- If not predictable, random…

UNIVERSITY OF CAMBRIDGE

What when you do not know the mobility?

- Prediction of mobility techniques need to be applied unless you want to use “epidemic”
- Instead of blindly forwarding packets to all or some neighbors, intermediate nodes estimate the chance, for each outgoing link, of eventually reaching the destination.
- Based on this estimation, the intermediate nodes decide whether to store the packet and wait for a better chance, or decide to which nodes (and the time) to forward.

UNIVERSITY OF CAMBRIDGE

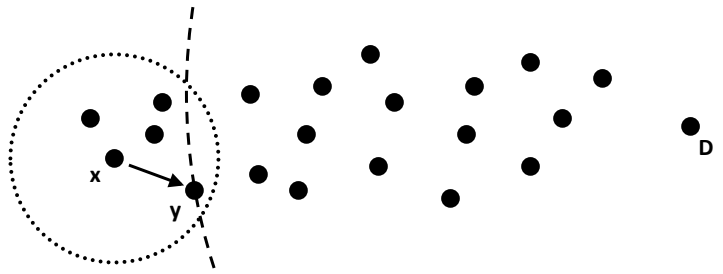
Context Aware Routing

- When a node wants to send a message to another known node in the network it forwards it to the best (carrier) neigbour
- How is the best carrier neighbour chosen?
  - Host mobility
  - Host colocation with destination node
  - Battery?
  - A utility function which weights these various aspects
  - Kalman Filter is used to predict future host colocation with destination based on previous history
- The approach is based on local knowledge only

UNIVERSITY OF CAMBRIDGE

Greedy Perimeter Stateless Routing (GPSR)

- The algorithm consists of two methods for forwarding packets:
- *greedy forwarding*, which is used wherever possible, and
- *perimeter forwarding*, which is used in the regions greedy forwarding cannot be.



UNIVERSITY OF CAMBRIDGE

Greedy Forwarding

- Under GPSR, packets are marked by their originator with their destinations' locations.
- As a result, a forwarding node can make a locally optimal, greedy choice in choosing a packet's next hop.
- Specifically, if a node knows its radio neighbors' positions, the locally optimal choice of next hop is the neighbor geographically closest to the packet's destination.
- Forwarding in this regime follows successively closer geographic hops, until the destination is reached.

UNIVERSITY OF CAMBRIDGE

Greedy Forwarding

- A simple beaconing algorithm provides all nodes with their neighbors' positions: periodically, each node transmits a beacon to the broadcast MAC address, containing only its own identifier (e.g., IP address) and position.
- Position is encoded as two four-byte floating point quantities, for x and y coordinate values.

UNIVERSITY OF CAMBRIDGE

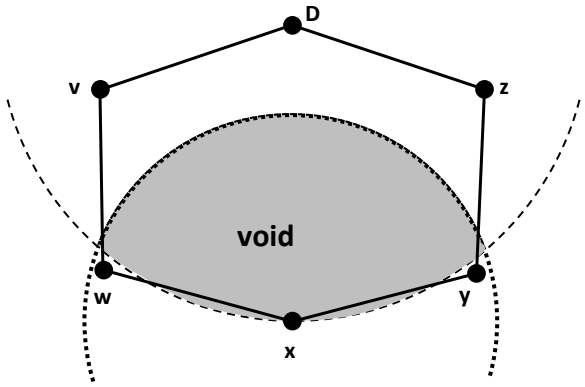
Greedy Forwarding

- Upon not receiving a beacon from a neighbor for longer than timeout interval T, a GPSR router assumes that the neighbor has failed or gone out-of-range, and deletes the neighbor from its table.
  - The 802.11 MAC layer also gives direct indications of link-level retransmission failures to neighbors; algorithm interprets these indications identically.

UNIVERSITY OF CAMBRIDGE

Greedy Forwarding Failure

Greedy forwarding not always possible! Consider:

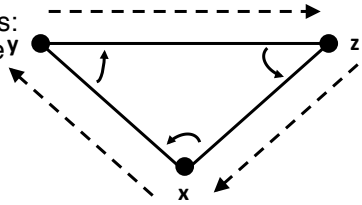


UNIVERSITY OF CAMBRIDGE

Void Traversal: The Right-hand Rule

Well-known graph traversal: right-hand rule
Requires only neighbors' positions

- Mapping perimeters by sending packets on tours of them, using the right-hand rule. The state accumulated in these packets is cached by nodes, which recover from local maxima in greedy forwarding by routing to a node on a cached perimeter closer to the destination
- This approach requires the no-crossing heuristic, to force the right-hand rule to find perimeters that enclose voids in regions where edges of the graph cross.
- Caveat: if the graph has cross cutting edges:
  - Remove those with a specific procedure



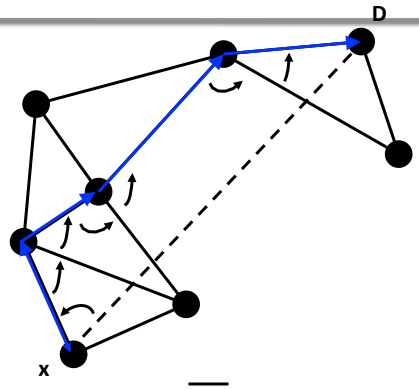
UNIVERSITY OF CAMBRIDGE

Full Greedy Perimeter Stateless Routing

- All packets begin in greedy mode
- Greedy mode uses full graph
- Upon greedy failure, node marks its location in packet, marks packet in perimeter mode
- Perimeter mode packets follow simple planar graph traversal:
  - Forward along successively closer faces by right-hand rule, until reaching destination
  - Packets return to greedy mode upon reaching node closer to destination than perimeter mode entry point

UNIVERSITY OF CAMBRIDGE

Perimeter Mode Forwarding Example



- Traverse face closer to *D* along $\overline{xD}$ by right-hand rule, until crossing $\overline{xD}$
- Repeat with next-closer face etc.

UNIVERSITY OF CAMBRIDGE

Summary

- We have described ad hoc routing protocols for connected networks
- When there is no connected path between nodes delay tolerant routing protocols should be applied
- When geographical position of the nodes is known and the network is connected geographical routing protocols can be used

UNIVERSITY OF CAMBRIDGE

References

- A. Vahdat and D. Becker, Epidemic routing for partially-connected ad hoc networks, 2000.
- M. Musolesi and C. Mascolo. CAR: Context-aware Adaptive Routing for Delay Tolerant Mobile Networks. In IEEE Transactions on Mobile Computing. Vol. 8(2). pp. 246-260. February 2009.
- Karp, B. and Kung, H.T., GPSR: Greedy Perimeter Stateless Routing for Wireless Networks, in Proceedings of the Sixth Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom 2000), Boston, MA, August, 2000, pp. 243-254

UNIVERSITY OF CAMBRIDGE