

Mobile and Sensor Systems

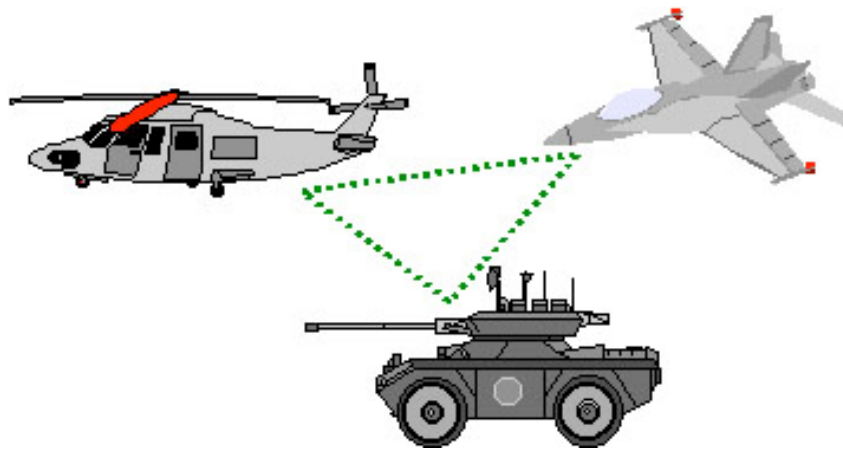
Lecture 2: Infrastructureless and
Opportunistic Mobile Networks

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In this lecture

- We will introduce ad hoc routing protocols.
- We will also introduce disconnected ad hoc networks and opportunistic routing protocols.

Examples of Multi-hop Ad hoc Networks



Rescue affair



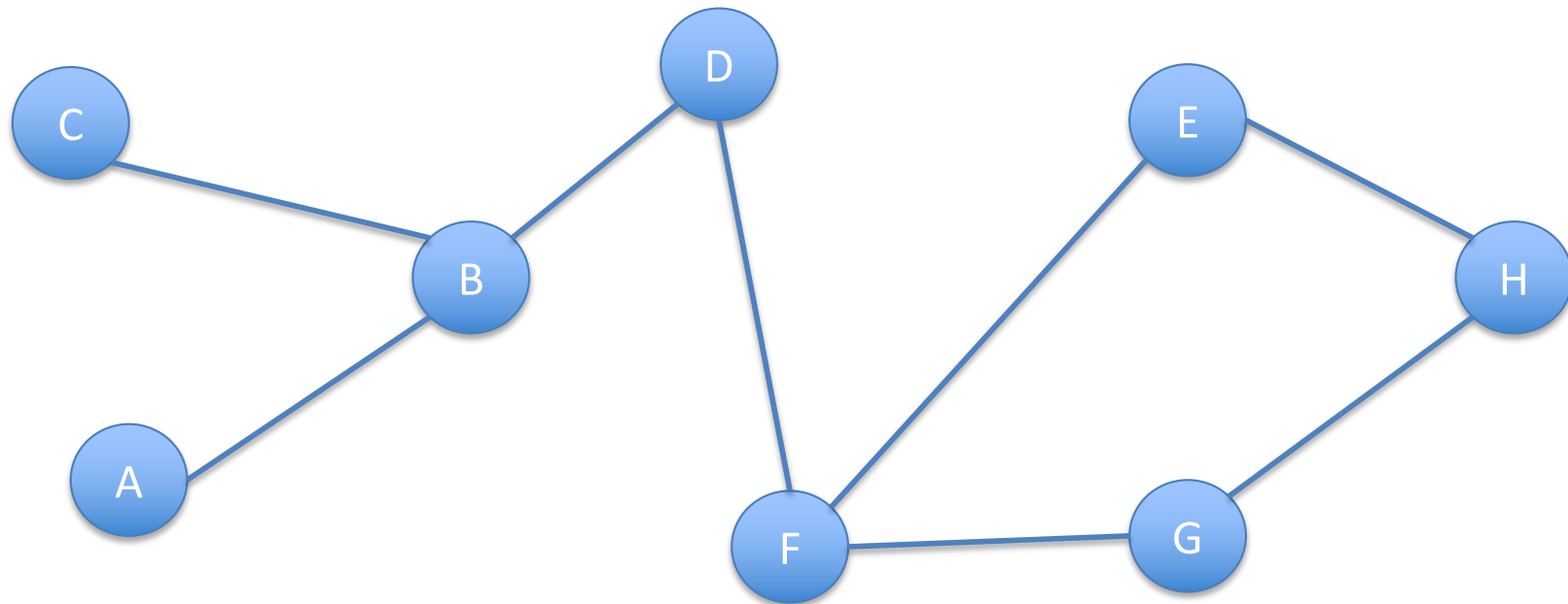
Collaborative work



Investigation of digging



A schematic of an ad hoc network



Note that this is a static snapshot:
the network will be reconfiguring
when nodes move.

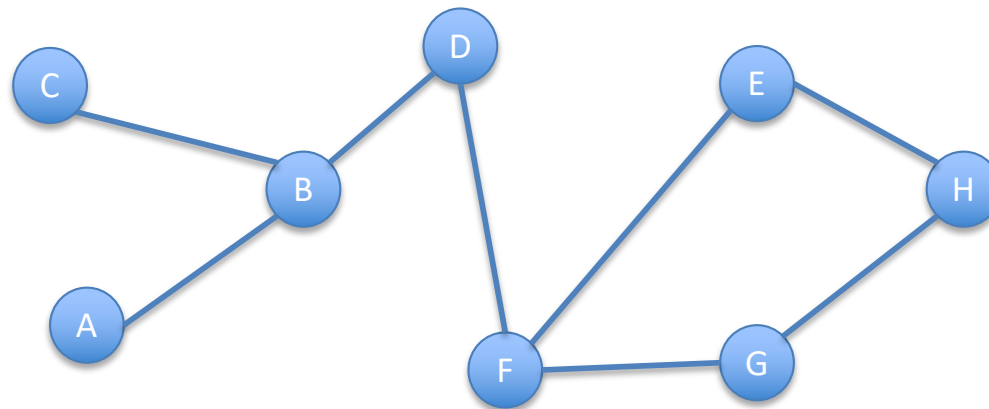
Examples of Ad-hoc Networking

- Destination Sequenced Distance Vector (**DSDV**) Routing.
- Proactive: routes are maintained also when not needed. Each node maintains a table with a route to every node.
- Each entry of the table has a sequence number assigned by the destination.

Dest. Next Hop, Hops Required, Dest. Seq. number.

Routing Table for Node D

Dest	Nexthop	Hops	SequenceN
A	B	2	406
B	B	1	128
C	B	2	564
D	D	0	710
E	F	2	392
F	F	1	076
G	F	2	128
H	F	3	050

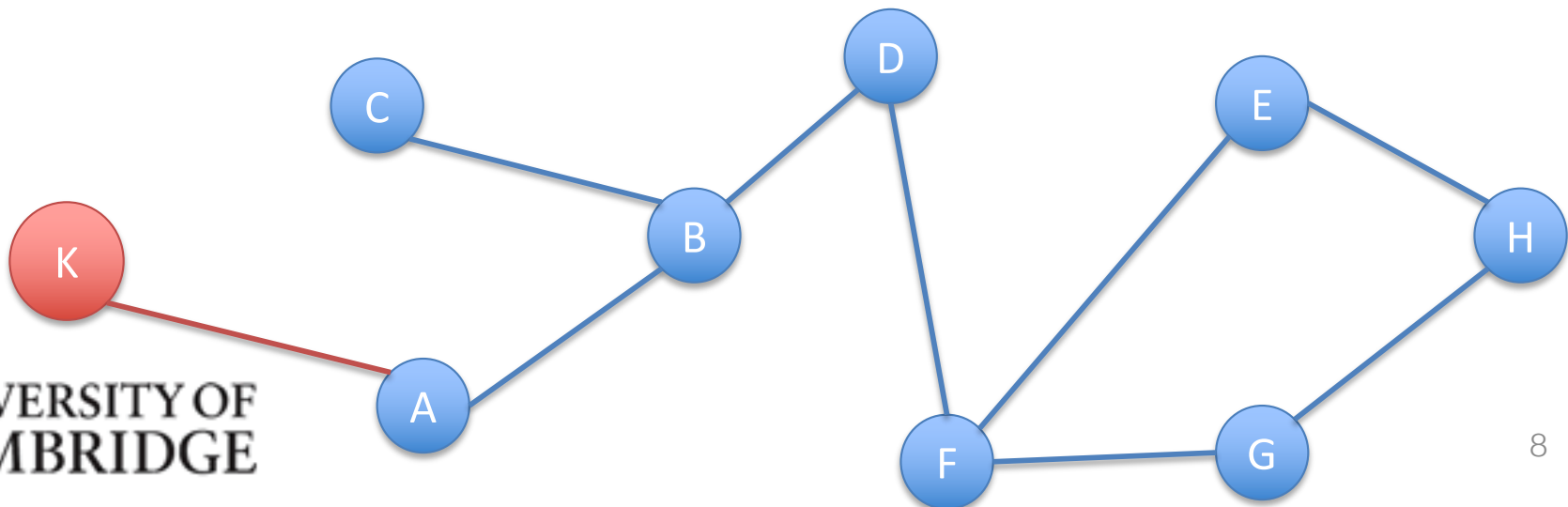


DSDV Routing Updates

- Each node periodically transmits updates.
- Includes its own sequences number, routing table updates.
- Nodes also send routing table updates for some incremental link changes.
- When two routes to a destination received from two different neighbors, choose the one with *greatest* destination sequence number.
- Sequence numbers help with loops

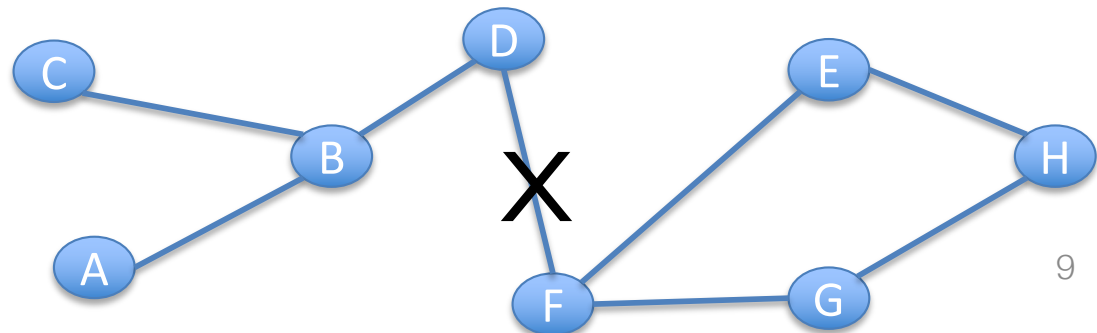
DSDV: When a new link appears (ie a node moved closer)

- When K joins it
 - Transmits routing table $\langle K, K, 0, 101 \rangle$
 - Node A receives it and inserts in routing table: $\langle K, K, 1, 101 \rangle$
 - Node A propagates the new route to neighbours.
 - Neighbours of A update table with $\langle K, A, 2, 101 \rangle$ and continue propagation.



DSDV: When a link breaks (ie a node moves away)

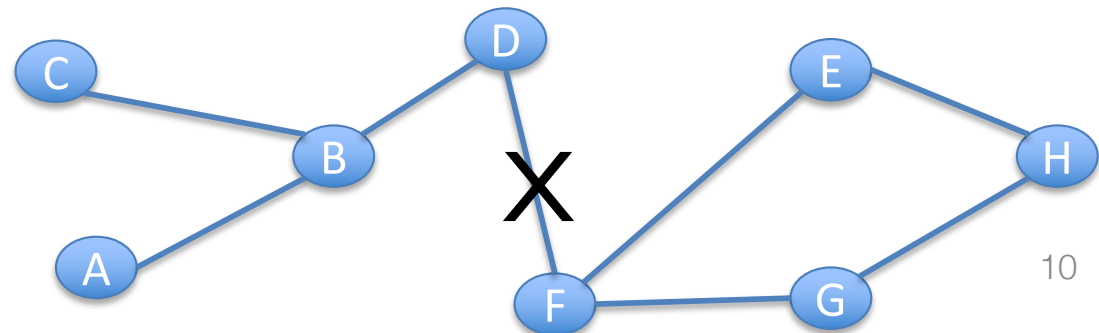
- The link between D and F breaks (the two nodes move apart or the wireless link has no connection for other reasons).
- Node D notices the break (eg lack of table update from F):
 - Updates hop count to F to infinity.
 - Then:



DSDV: When a link breaks (ie a node moves away)

– Then Node D sends updates with new route information:

- $\langle F, -, \infty, 076 \rangle$
- $\langle E, -, \infty, 392 \rangle$
- $\langle G, -, \infty, 128 \rangle$
- $\langle H, -, \infty, 050 \rangle$



DSDV: Limitations

- Circulating and maintaining table updates is expensive for the network.
 - Especially if this is battery powered.
- If the network changes a lot then these updates might be worthwhile but only if all nodes need to communicate to all others
 - Why would a node need to keep updates of routes to nodes it does not need to communicate with?

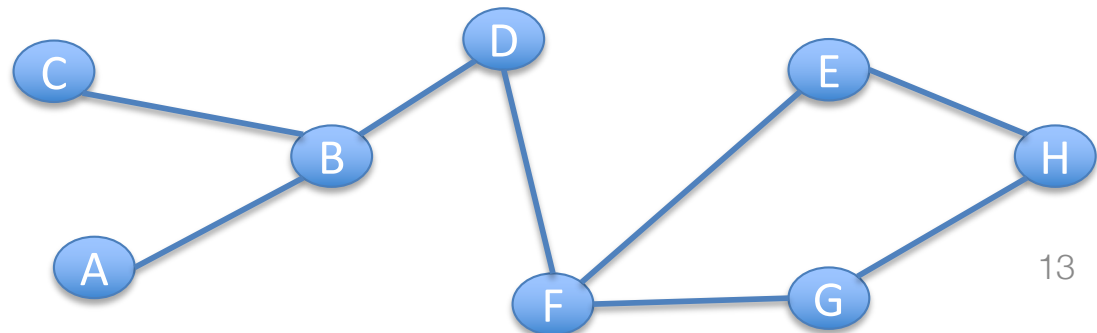
Another Ad-hoc routing example

Dynamic Source Routing (DSR)

- DSR is a reactive protocol: routes are searched only when communication with a node is needed.
- When a node needs to communicate it sends a route request packet.
- Nodes receive it and add themselves to the path and propagate the request to their neighbours.
- Eventually the destination node is found and the path is sent back to the source (how?).

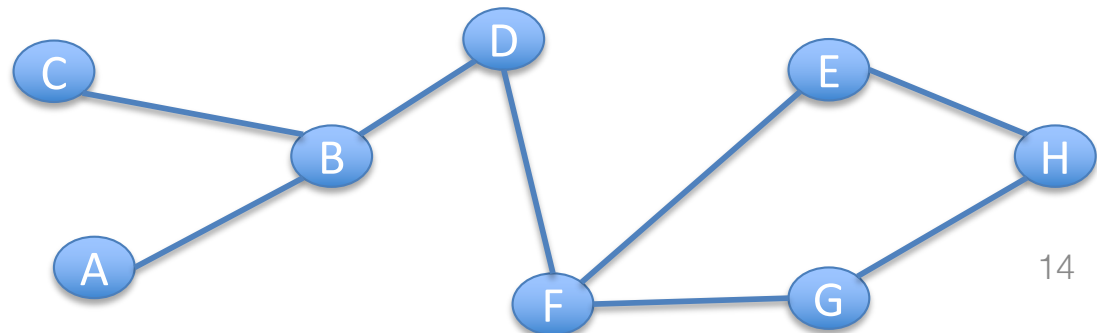
DSR example

- Node A needs to communicate with F. Sends request $\langle A, F, [-], 101 \rangle$.
- Node B receives the request and forwards:
 - $\langle A, F, [B], 101 \rangle$.
- Node D receives it and forwards:
 - $\langle A, F, [B, D], 101 \rangle$.
- Node F receives it and ? (continued).



DSR example (continued)

- Node F receives it and:
 - If links are symmetric sends the path back following the indicated inverse route.
 - Or, if it has cached a path to A uses it.
 - Otherwise it sends a route request for A.



DSR Comments

- Sequence numbers are used to avoid routing loops.
- Routes are cached for some time to avoid frequent route requests by intermediate nodes.
- Low mobility and stable origin-destinations are the best scenarios for this protocol.

Hybrid Solutions

Zone Routing Protocol (ZRP)

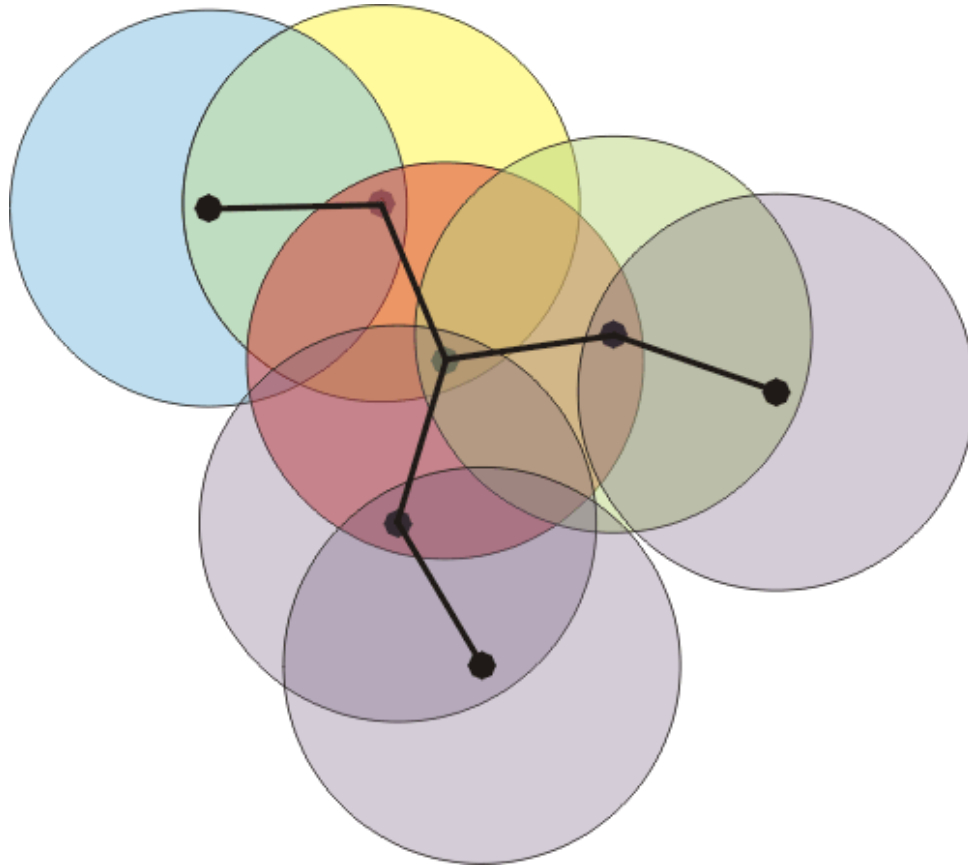
- Zone routing is a hybrid protocol which combines proactive with reactive approaches.
- A zone around node N is maintained where routes are collected proactively.
- Beyond the zone an inter zone protocol is responsible to determine the routes in a reactive way.

Disconnected Ad-hoc Networks

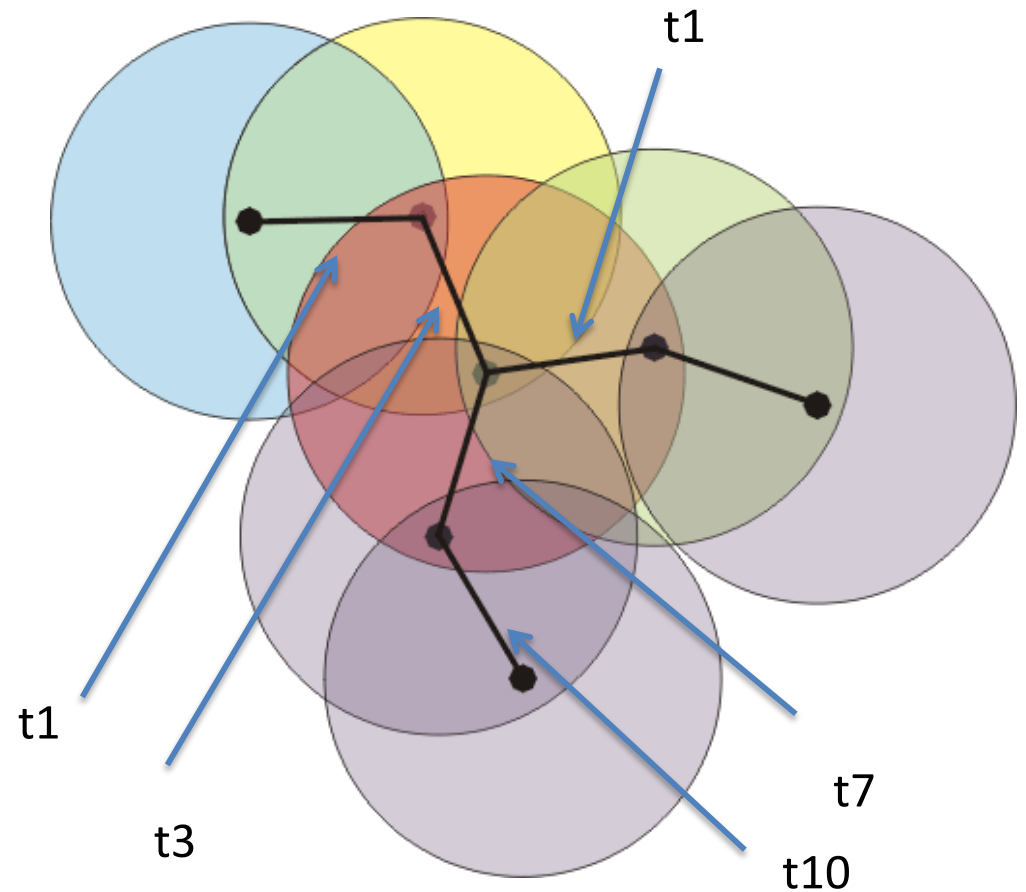
- The protocols we have seen until now only work when there is a “connected path” among the communicating nodes
- I.e. no storage on intermediate nodes is allowed.
- The protocols do not work when this is not the case.

Connected vs Disconnected Ad-hoc Networks

Connected: there is a connected path
among each couple



Disconnected: not all links are present
at the same time



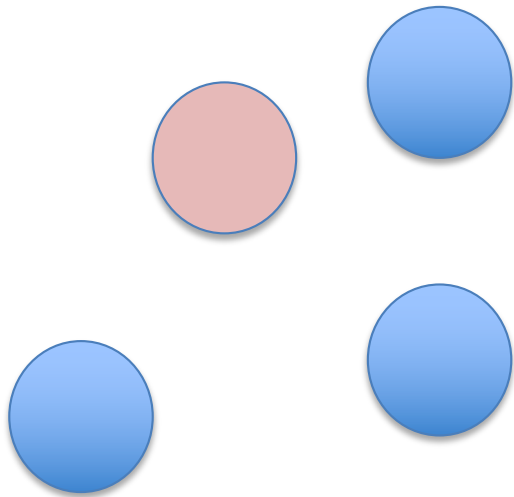
Delay Tolerant Networks and Protocols

- These protocols do not assume a temporally connected path among the nodes.
- Nodes can accept a packet and deliver it later, after some time storing it.

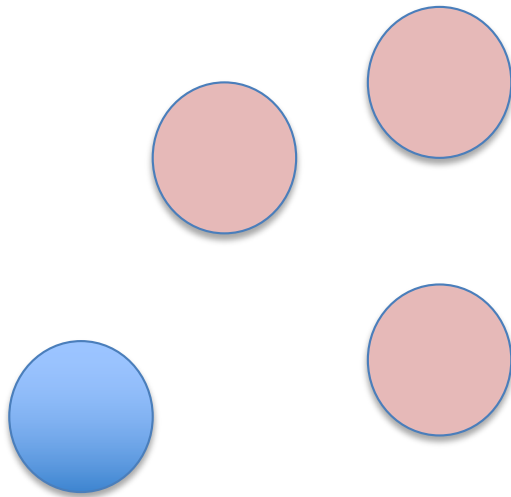
Example: Epidemic Routing

- A flooding protocol which allows nodes to store packets before forwarding.
- A node accepts a packet, moves while carrying the packet and then forwards at a different time to a different neighbourhood.

Epidemic Routing Example



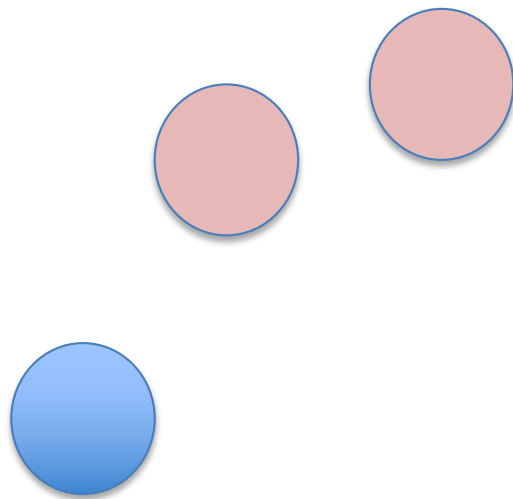
Epidemic Routing Example



Packet passed to a fraction of neighbouring nodes, which store it



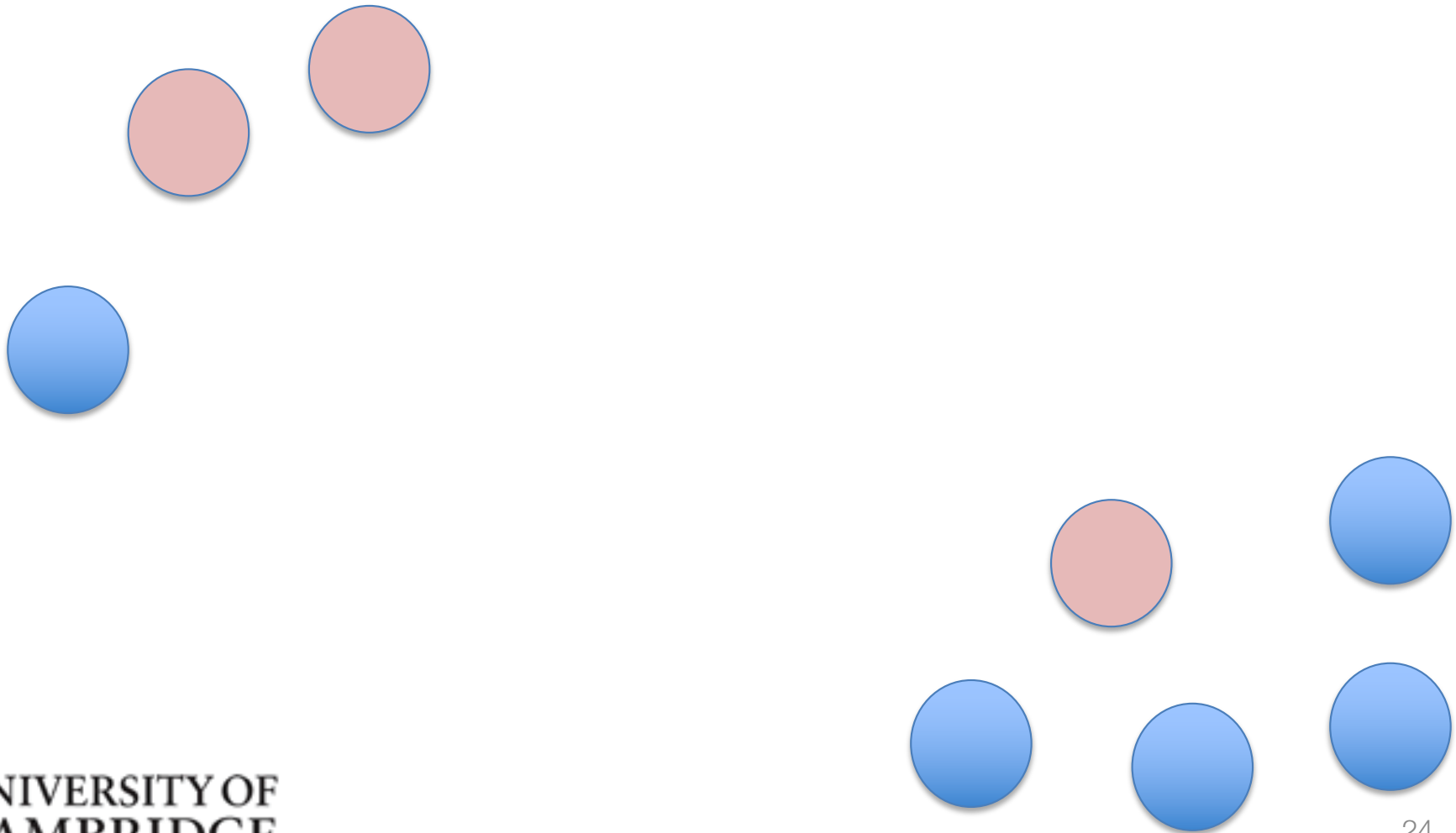
Epidemic Routing Example



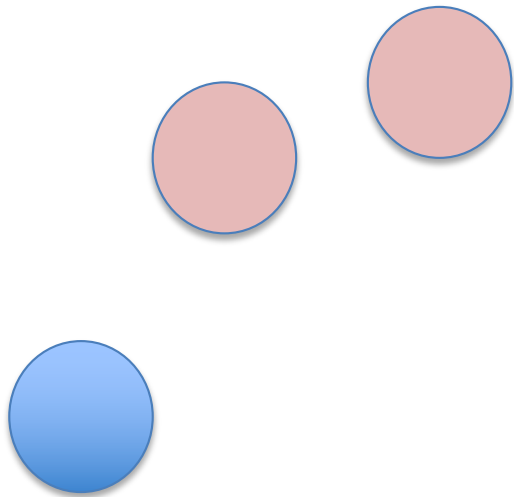
Nodes travel with packet and STORE it



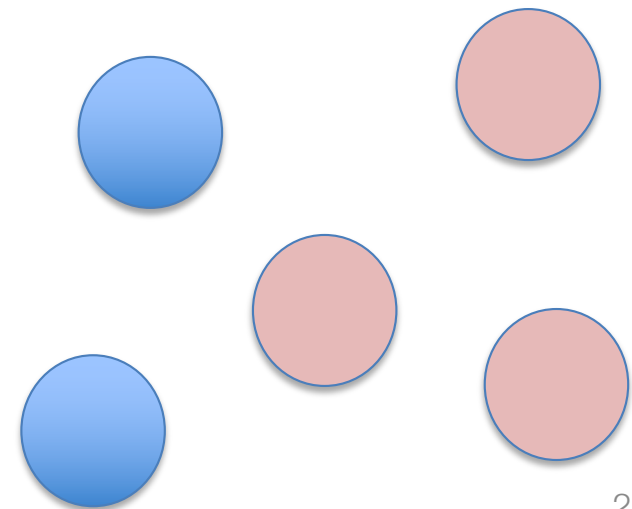
Epidemic Routing Example



Epidemic Routing Example



Nodes eventually forward it when
in reach of other nodes



Pros and Cons of Epidemic Routing

- If tuned right it reaches optimal delivery
- Needs large memory on nodes or buffers fill up and packets get ejected and lost
- Forwarding number (epidemic infectivity) needs to be tuned to avoid too many network transmissions (and collision which affect power)

Can we do better?

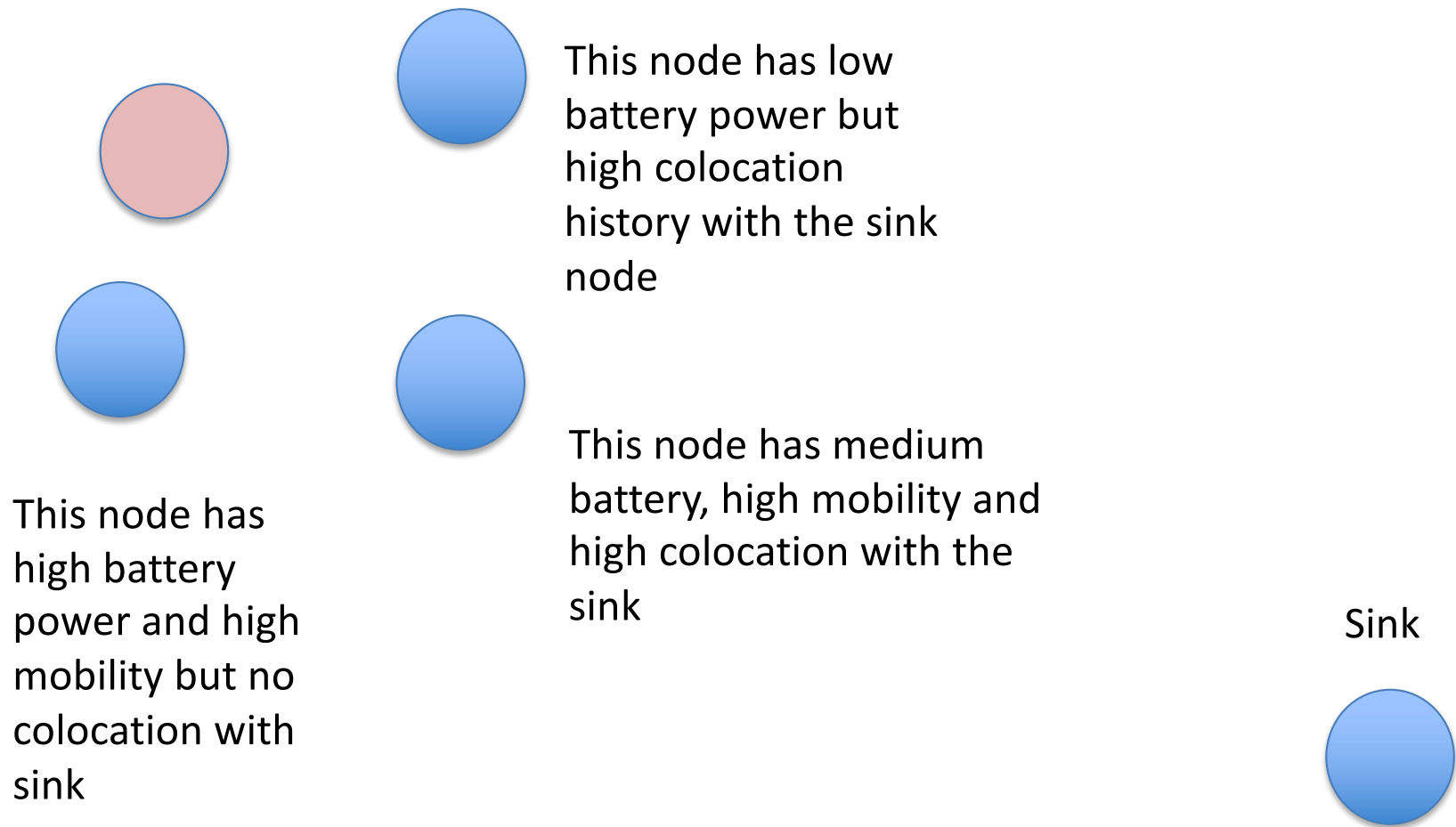
- Exploit the knowledge on the mobility of the nodes
- Is the mobility deterministic (ie. Always on the same path at same times like busses)? Maybe we can even control the mobility of some of the nodes!
- If not fixed, is it at least predictable?
- If not predictable, random...

When mobility is predictable

- Instead of blindly forwarding packets to all or some neighbours, 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.

Context Aware Routing Example

which node(s) to choose as carrier?



Context Aware Routing (CAR)

- A node chooses the best carrier to reach a specific node. How is the best carrier neighbour chosen?
 - Host mobility, host collocation with destination node, battery.
 - A utility function which weights these aspects
 - Kalman Filter is used to predict future host collocation with destination based on previous history.
- The approach is based on local knowledge only.

Applications...

- Remote areas
 - Developing regions
 - Military
 - Sensor systems
 - Hybrid models (store and forward can give good performance regardless of presence of infrastructure so why not use)
- But also...mesh networks where access points (APs) not connected to the wire select the best relay AP to forward packets

Summary

- We have talked about ad hoc and opportunistic routing protocols.
 - For connected and disconnected networks
- We have discussed applicability and applications

Reference

- Agrawal, D. & Zheng, Q. (2006). Introduction to wireless and mobile systems. Thomson.
- 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.