Mobile and Sensor Systems

Lecture 2: Infrastructure and Opportunistic Mobile Networks

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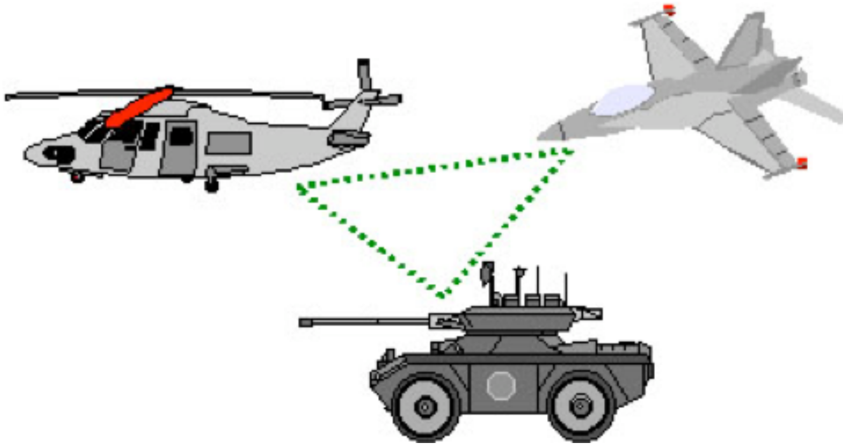
In this lecture

- In this lecture we will describe the difference in infrastructure and ad hoc networks and 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



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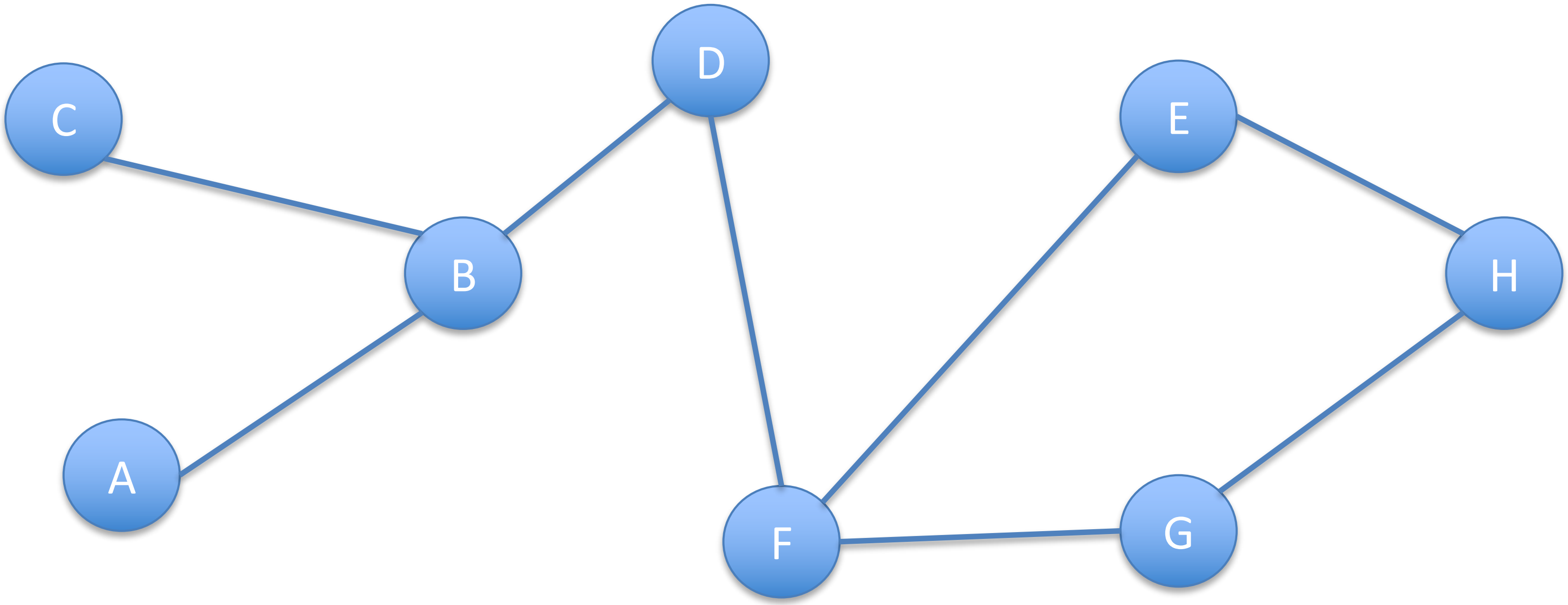
A schematic of an ad hoc network



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

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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.

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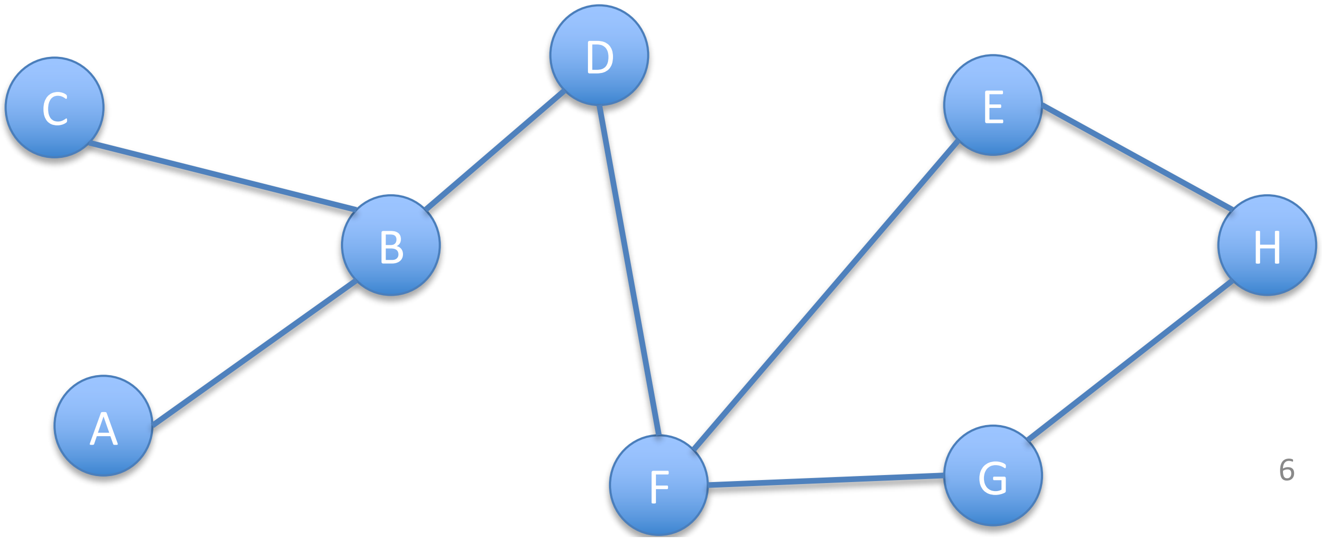
DSDV: Routing Table for Node D

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



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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.
- If equal (when would they be equal?), choose the smaller metric (hop count).

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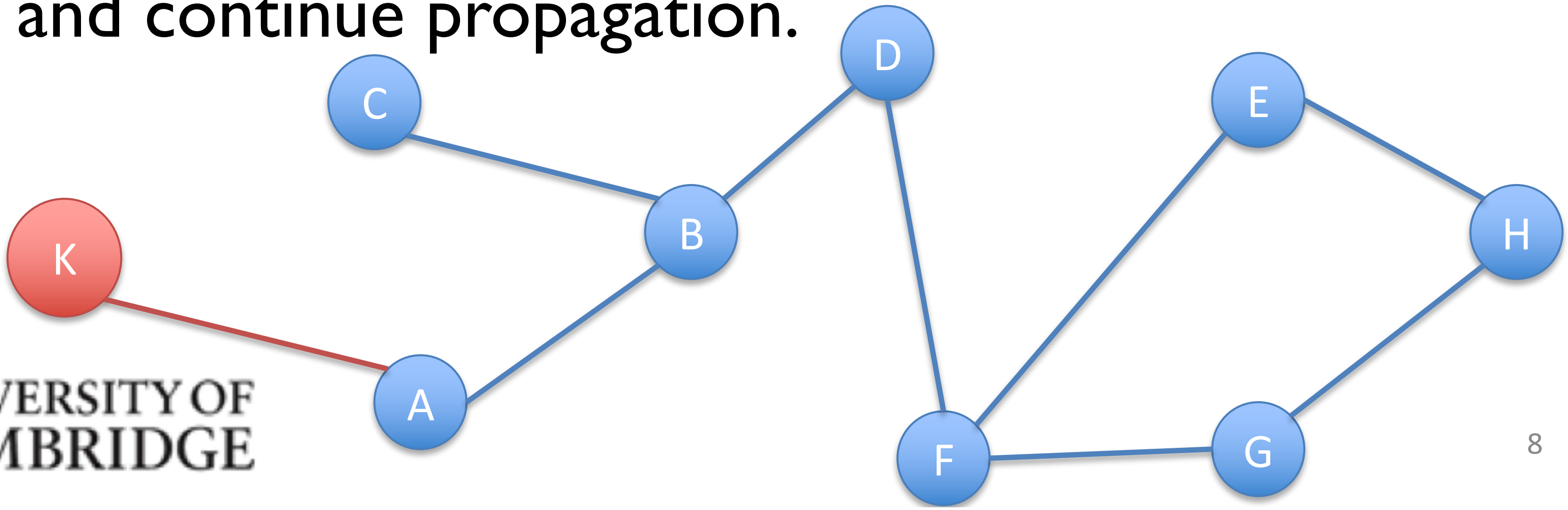
DSDV: When a new link appears (ie a node moved closer)

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



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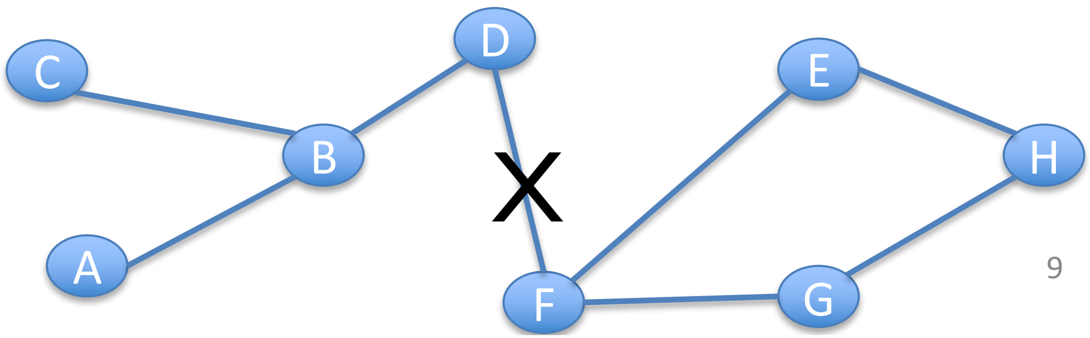
DSDV: When a link breaks (ie a node moves away)

- 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.
  - Increments the sequence number for F,E,G,H
  - Then:



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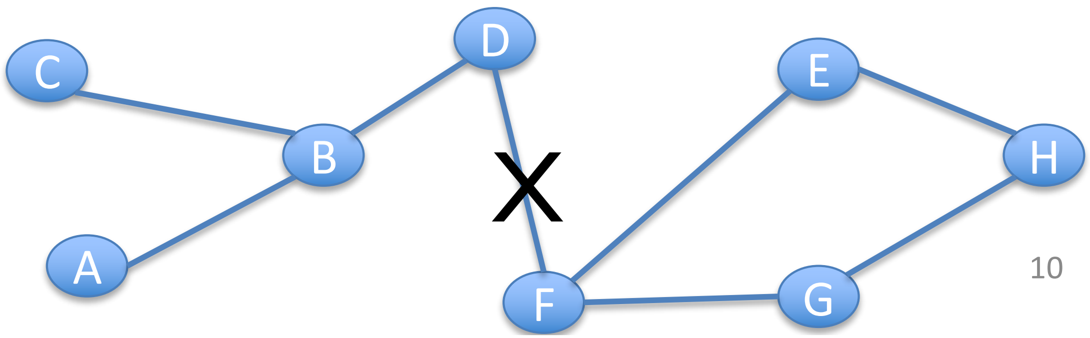
DSDV: When a link breaks (ie a node moves away)

– Then Node D sends updates with new route information:
  - <F, -,∞, 077>
  - <E, -,∞, 393>
  - <G,-,∞, 129>
  - <H,-,∞, 051>



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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?

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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?).

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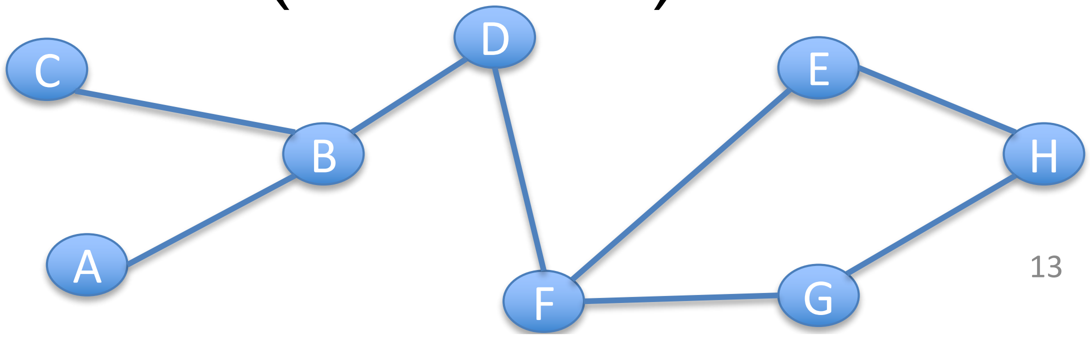
DSR example

- Node A needs to communicate with F. Sends request <A,F, [-],101>.
- Node B receives the request and forwards:
  - <A,F,[B],101>.
- Node D receives it and forwards:
  - <A,F,[B,D],101>.
- 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.

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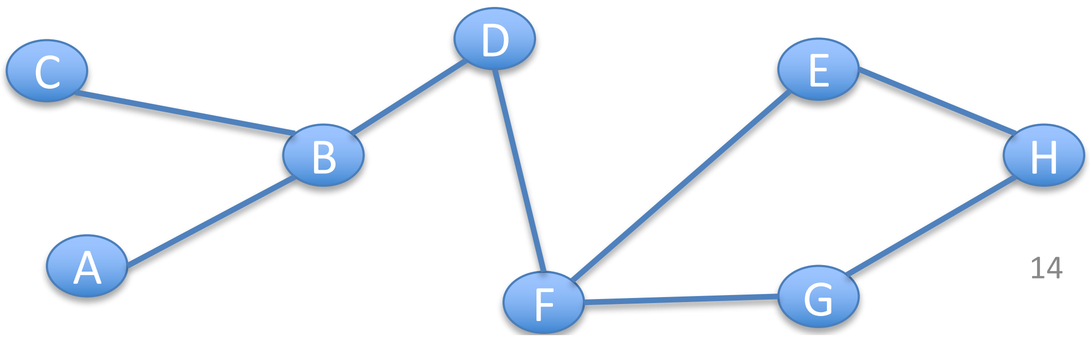

DSR Comments

- 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 low traffic 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.

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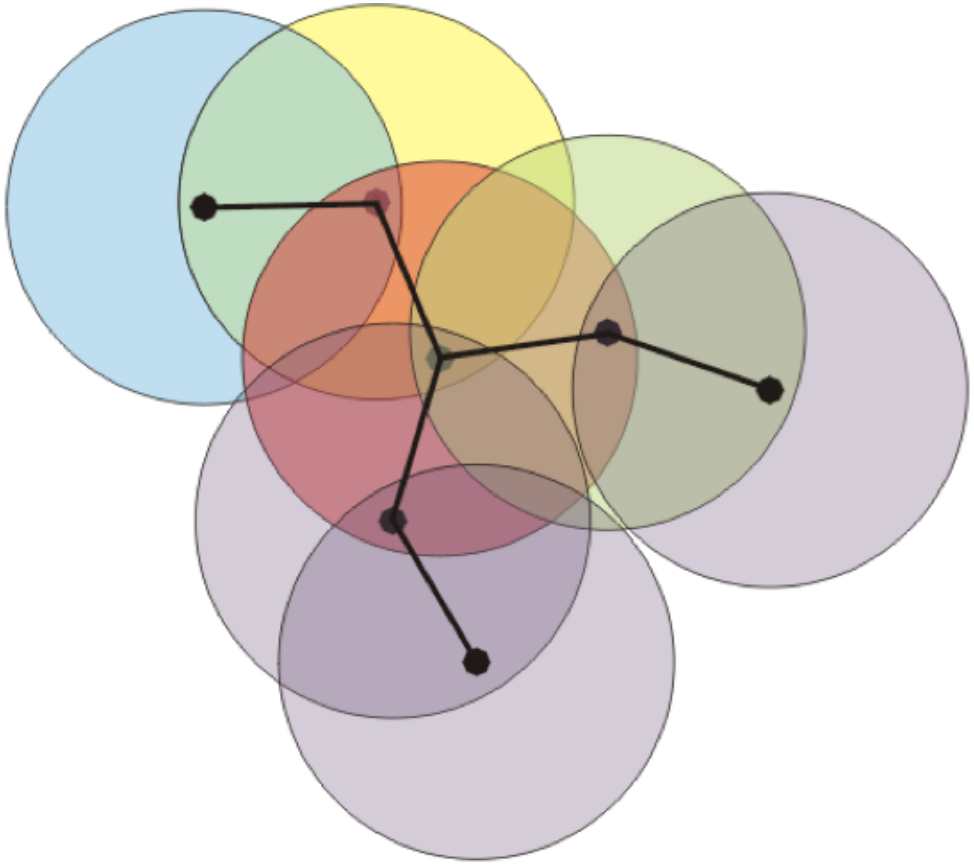
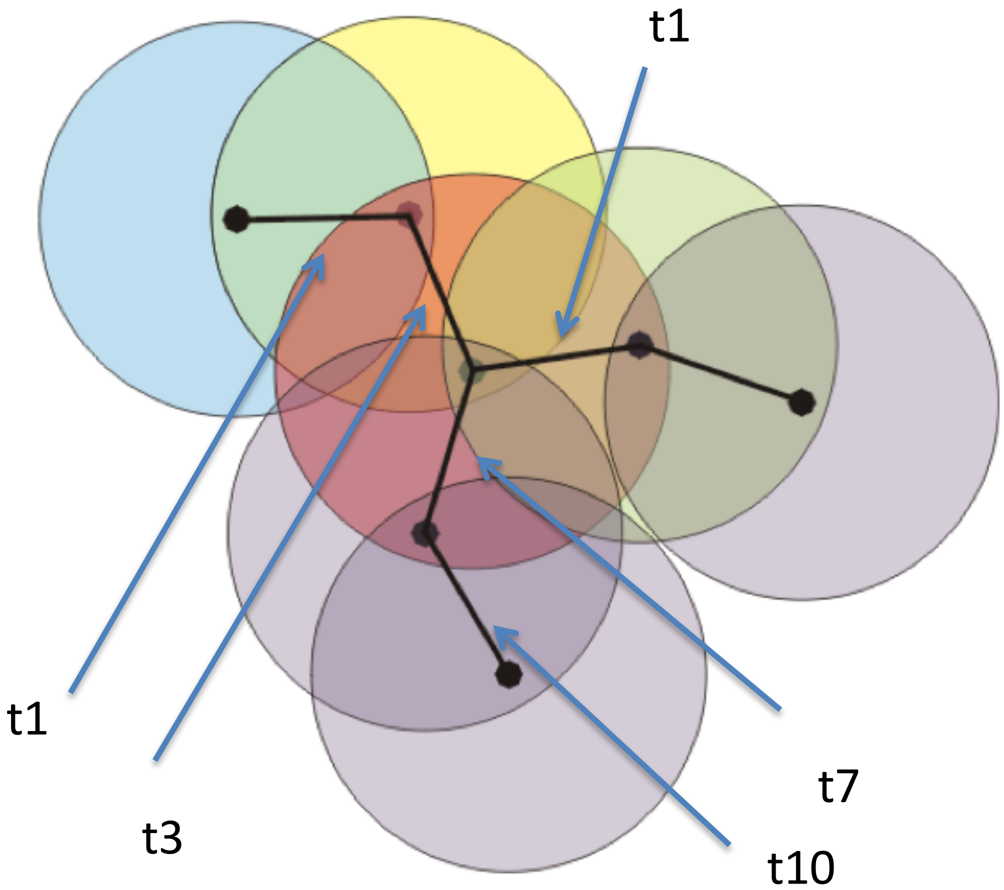
Connected vs Disconnected Ad-hoc Networks

Connected: there is a connected path among each couple



Disconnected: not all links are present at the same time



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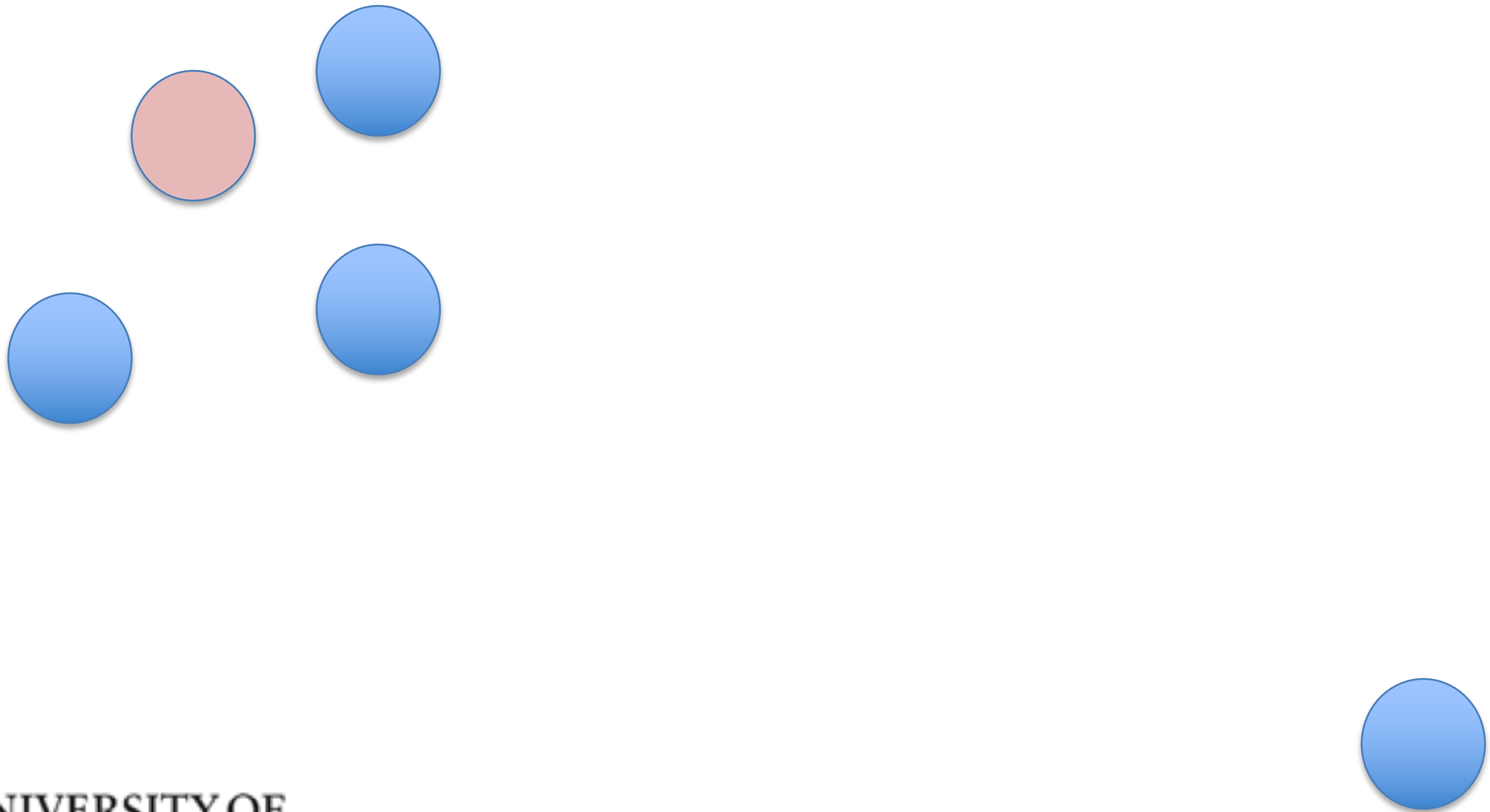
Delay Tolerant Networks and Protocols

- 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



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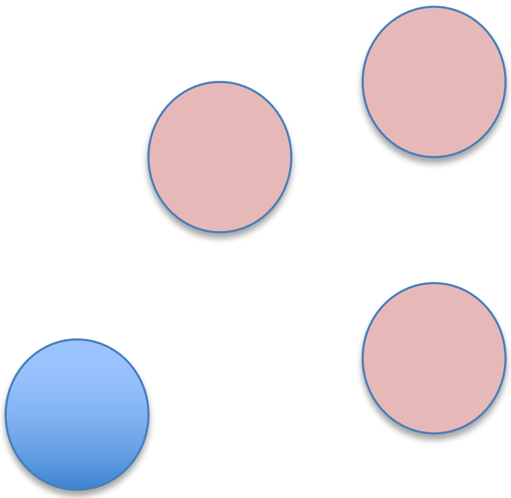
Epidemic Routing Example



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

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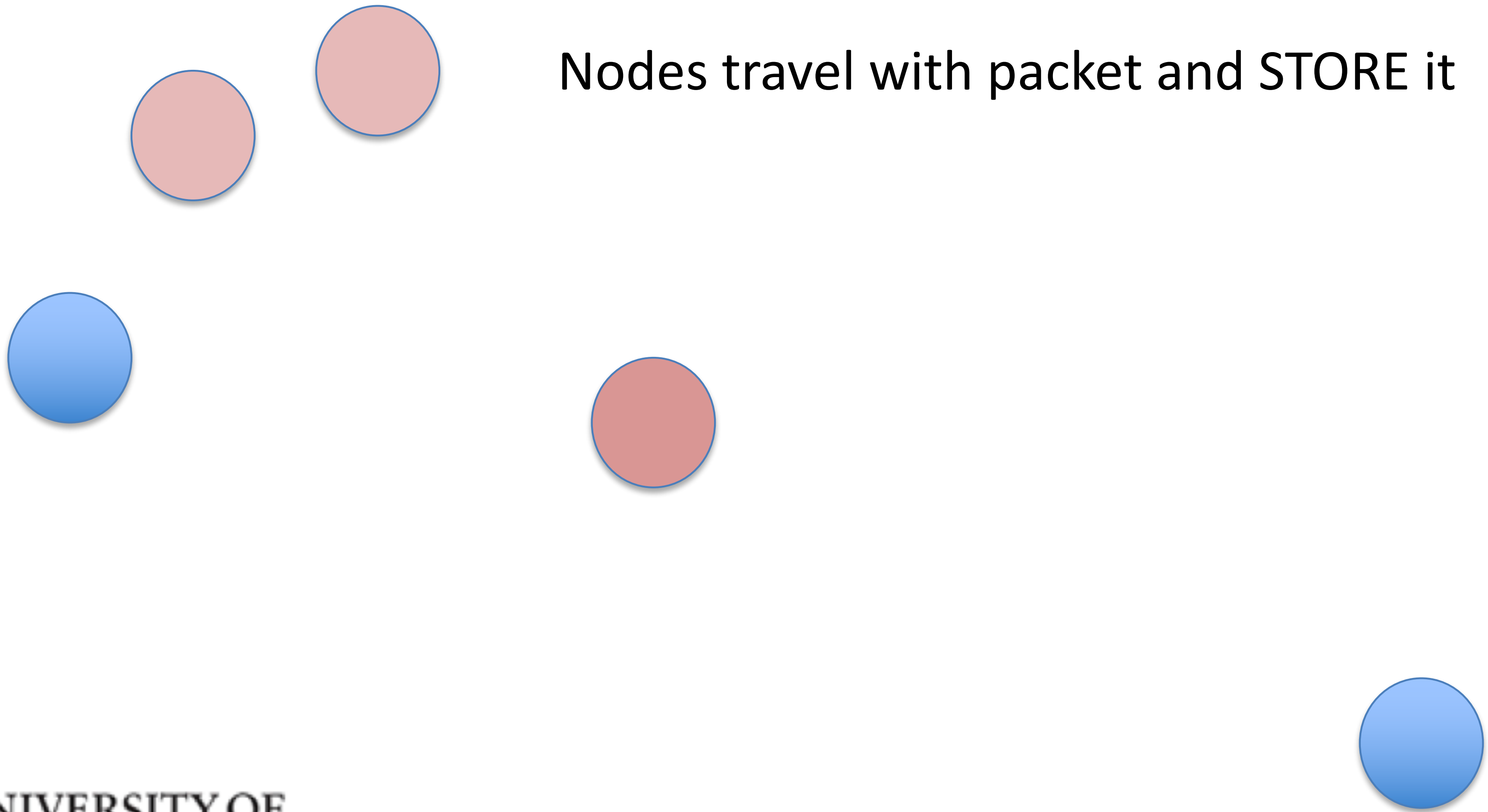
Epidemic Routing Example



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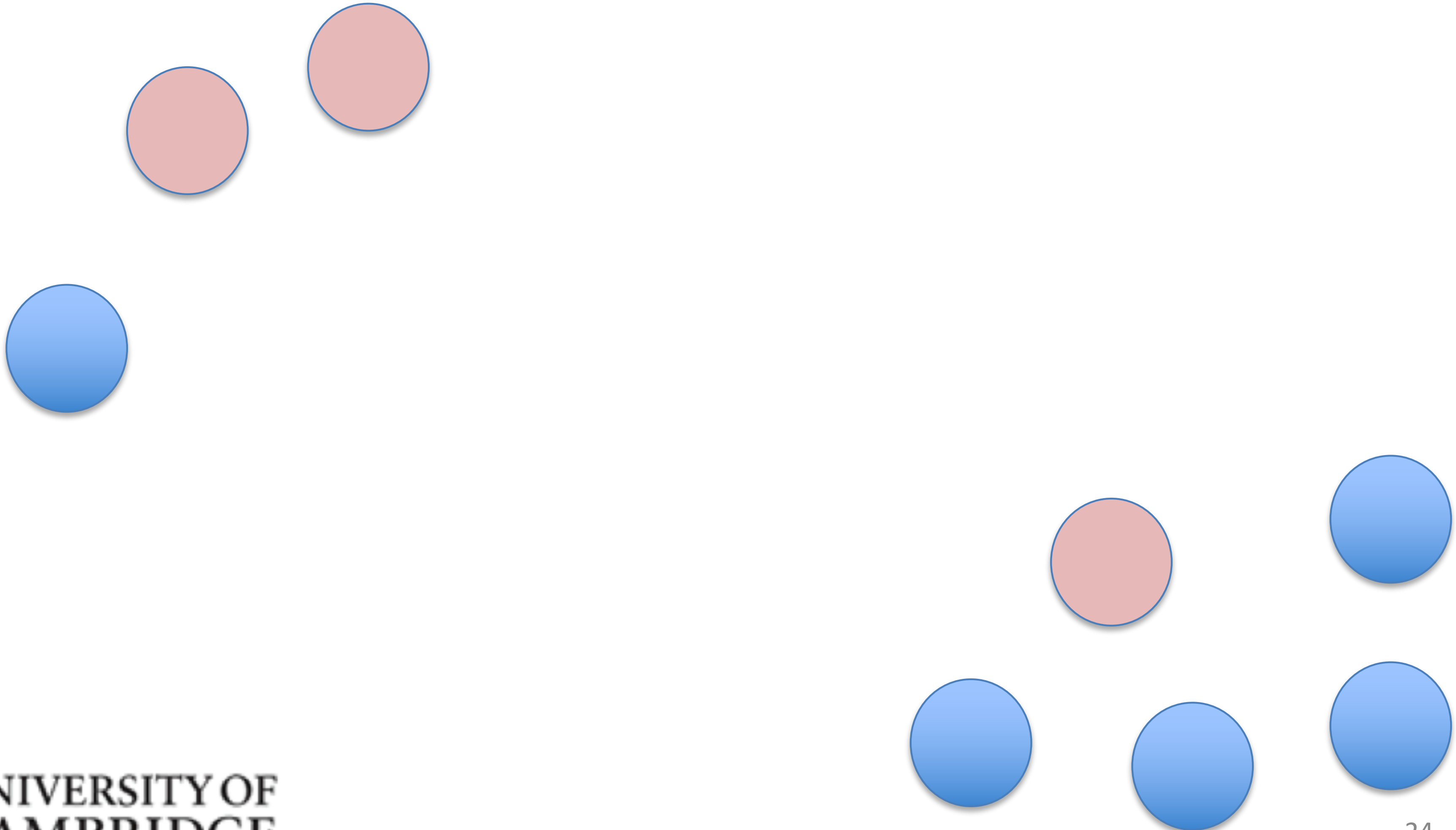
Epidemic Routing Example



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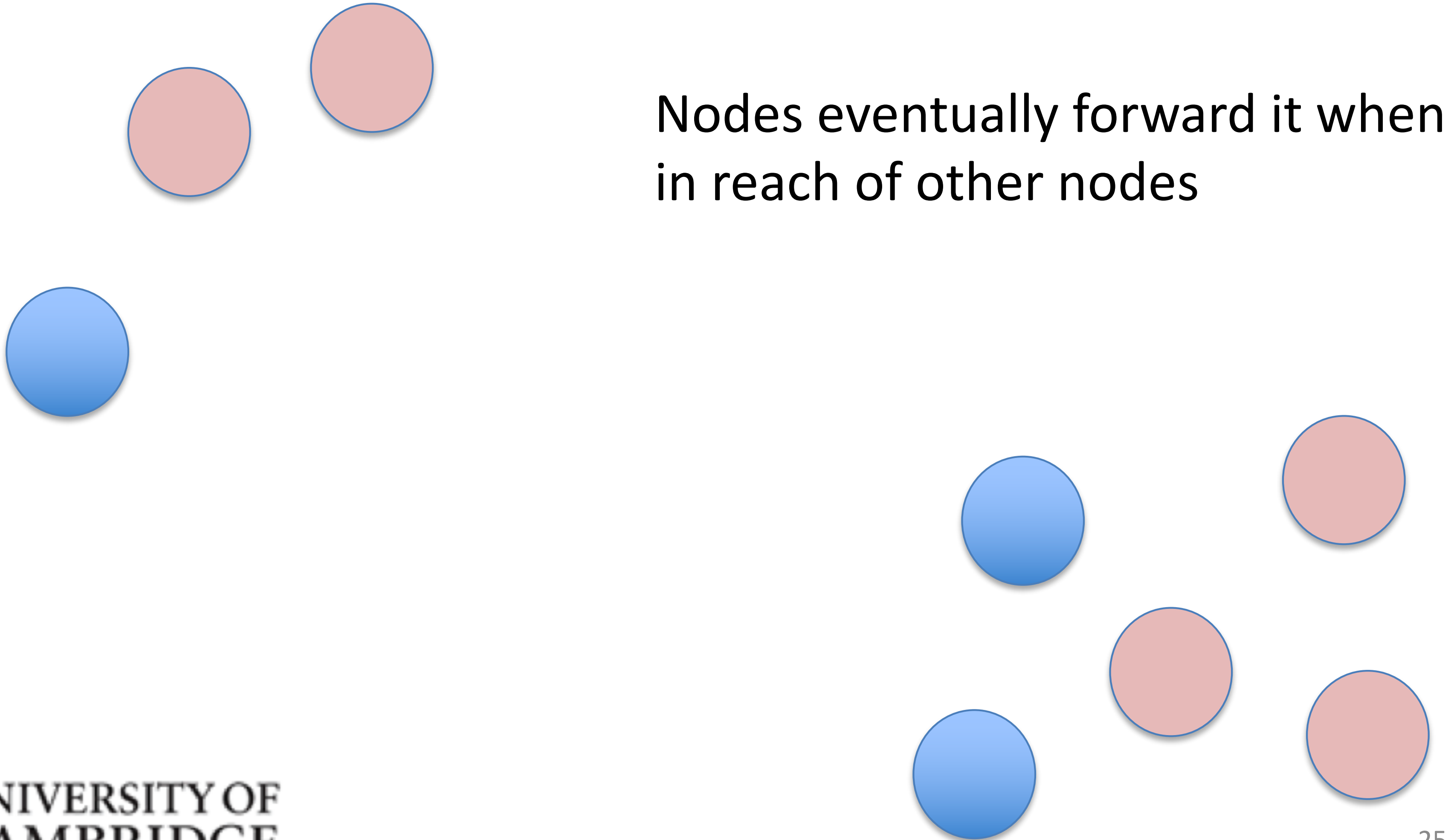
Epidemic Routing Example

Nodes eventually forward it when in reach of other nodes



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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)

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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…

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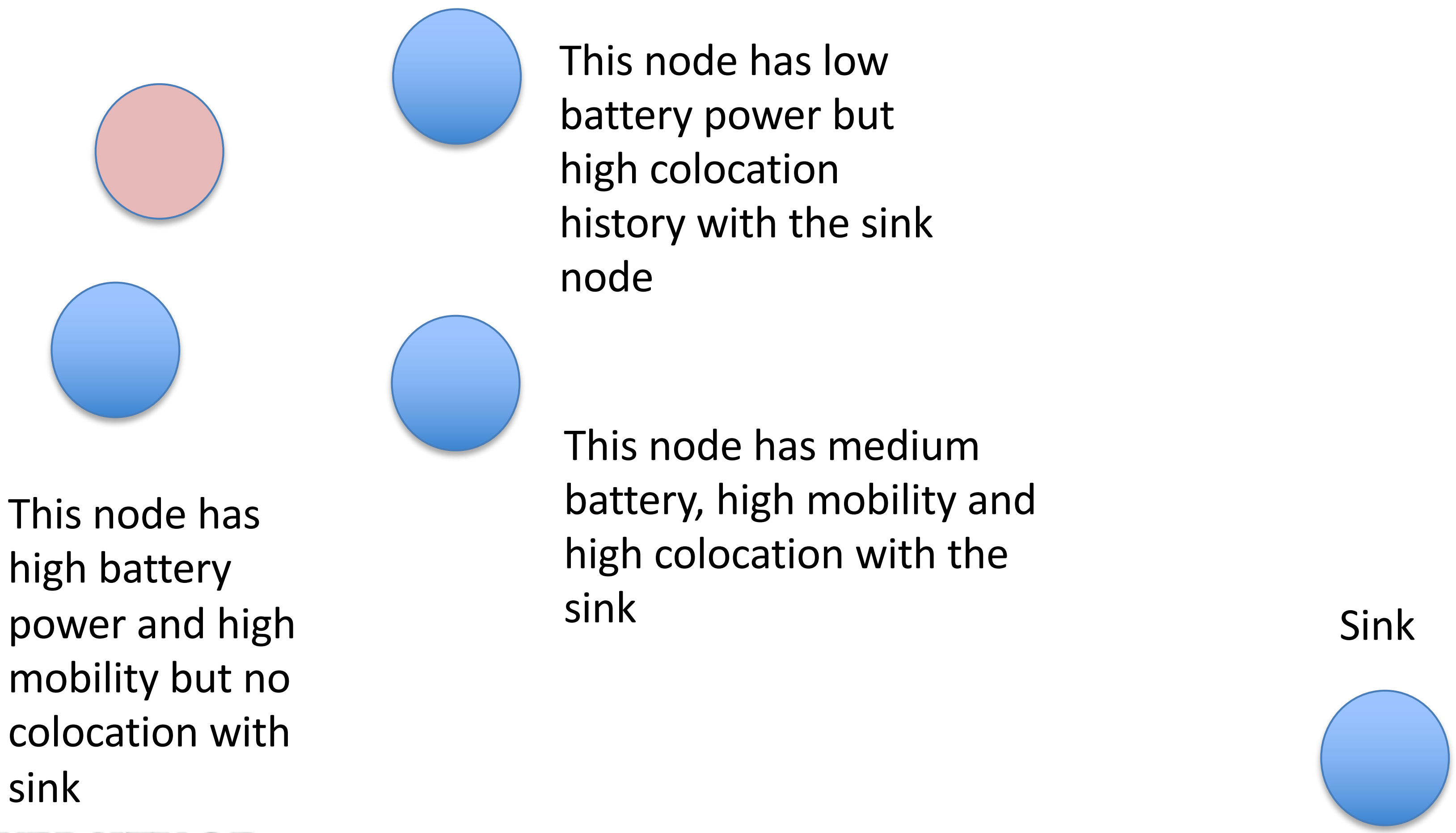
When mobility is predictable

- 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 colocation with destination node, battery.
  - A utility function which weights these aspects
  - Kalman Filter is used to predict future host colocation with destination based on previous history.
- The approach is based on local knowledge only.

Variant: SocialCast

- Uses the same idea of prediction for dissemination of information to nodes with the same interests [Assumption: *users with same interests are likely to be colocated periodically*]
- Publishers publish the information
- Carriers are chosen on the basis of the colocation with subscribers or high mobility

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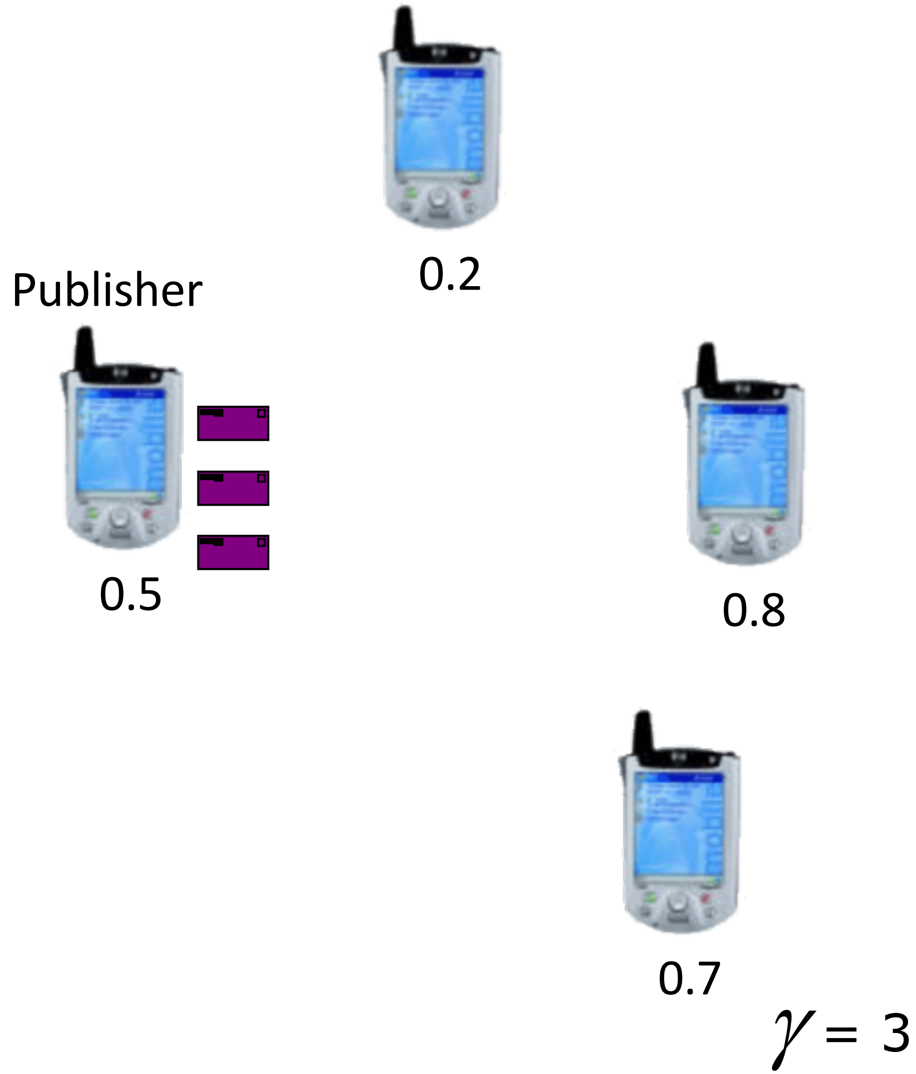
SocialCast Description

- γ replicas are created and disseminate only to "good" neighbors
  - Good means its utility is higher than mine



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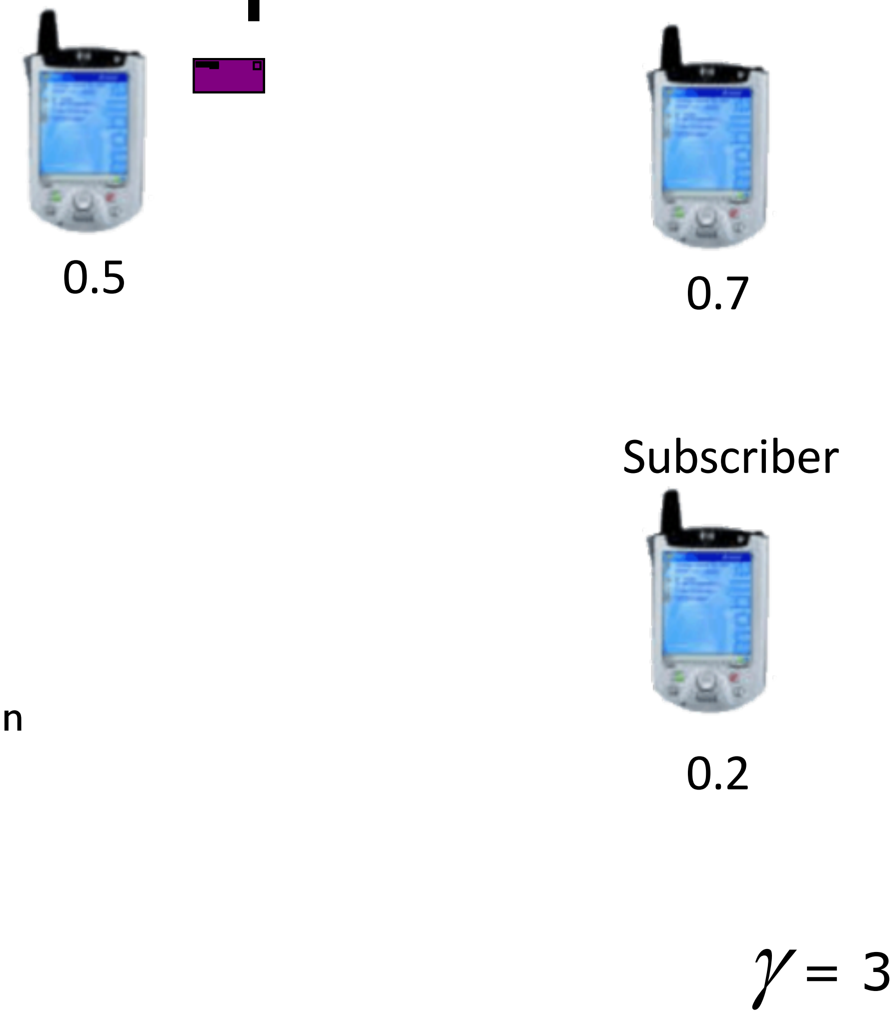
Protocol Description

- γ replicas are created and disseminate only to "good" neighbors
  - good: its utility is higher than mine
- Messages are kept until:
  - a better carrier is found
  - a subscriber is found
- Only carriers actively participate in message dissemination
  - replicas never increase
  - TTL is used to prevent infinite propagation
- A subscriber can act as carrier as well (if its utility is high enough)



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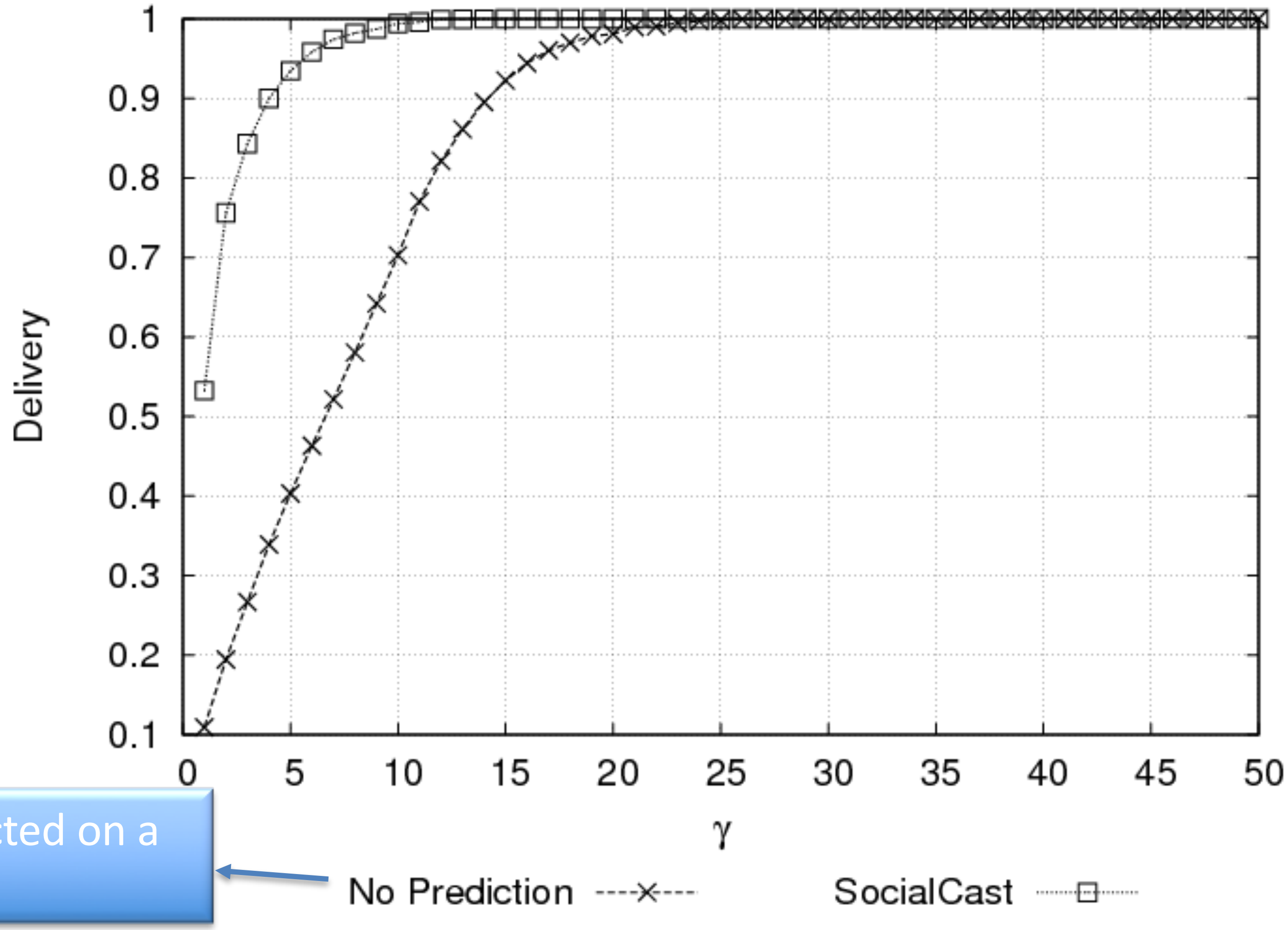
Delivery vs. Replicas



Next hop predicted on a random basis

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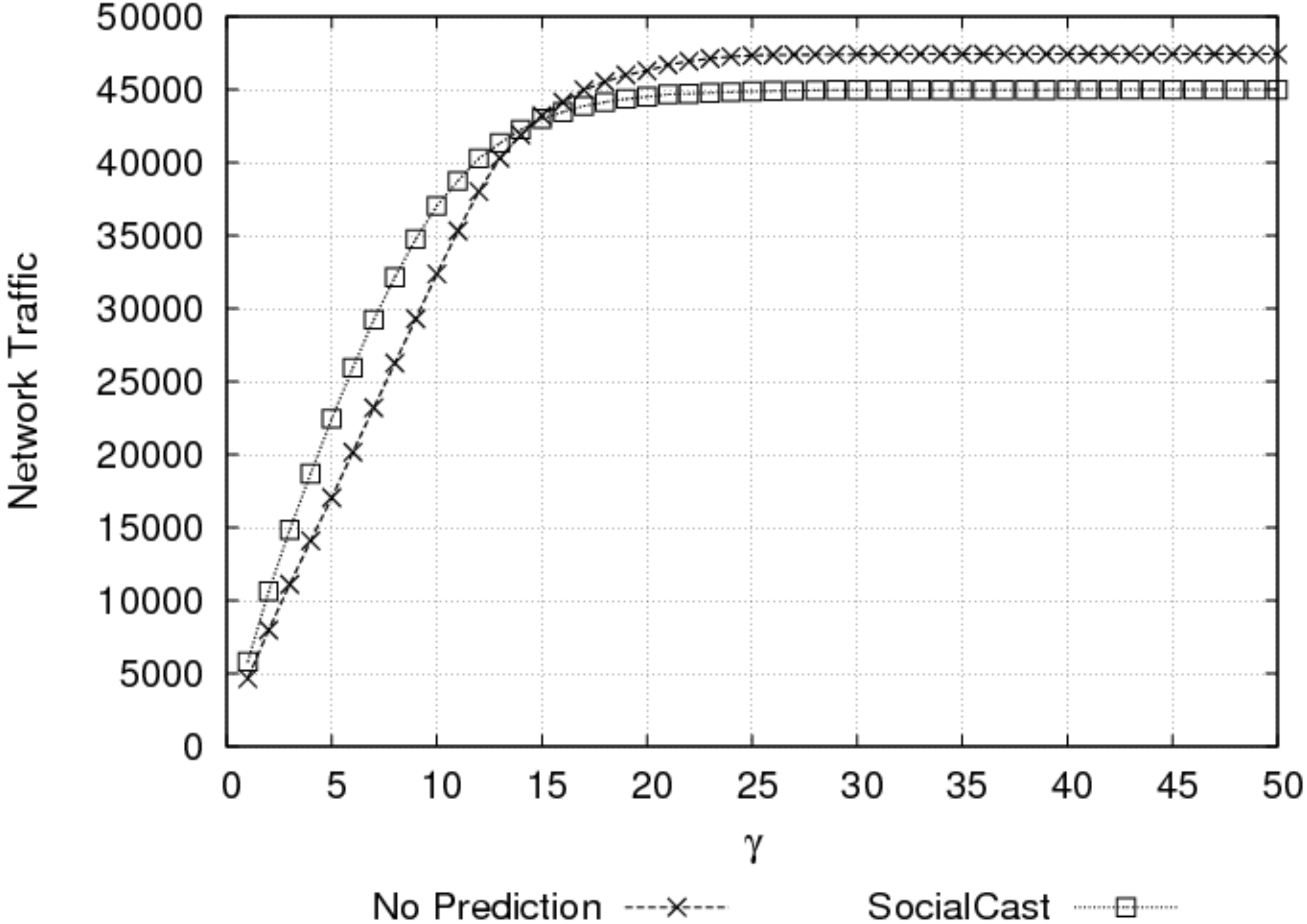
Overhead vs. Replicas



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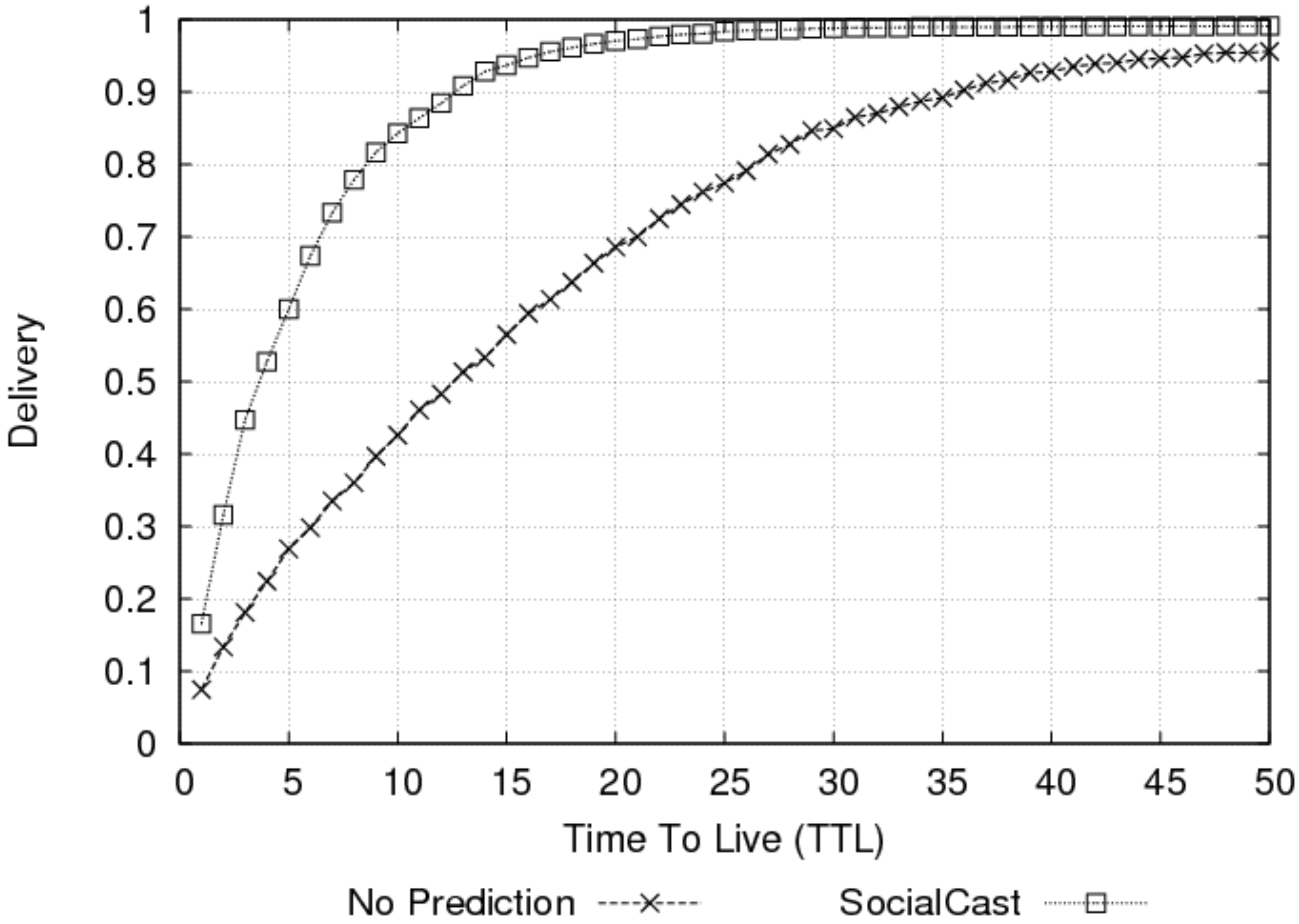
Delivery vs. TTL



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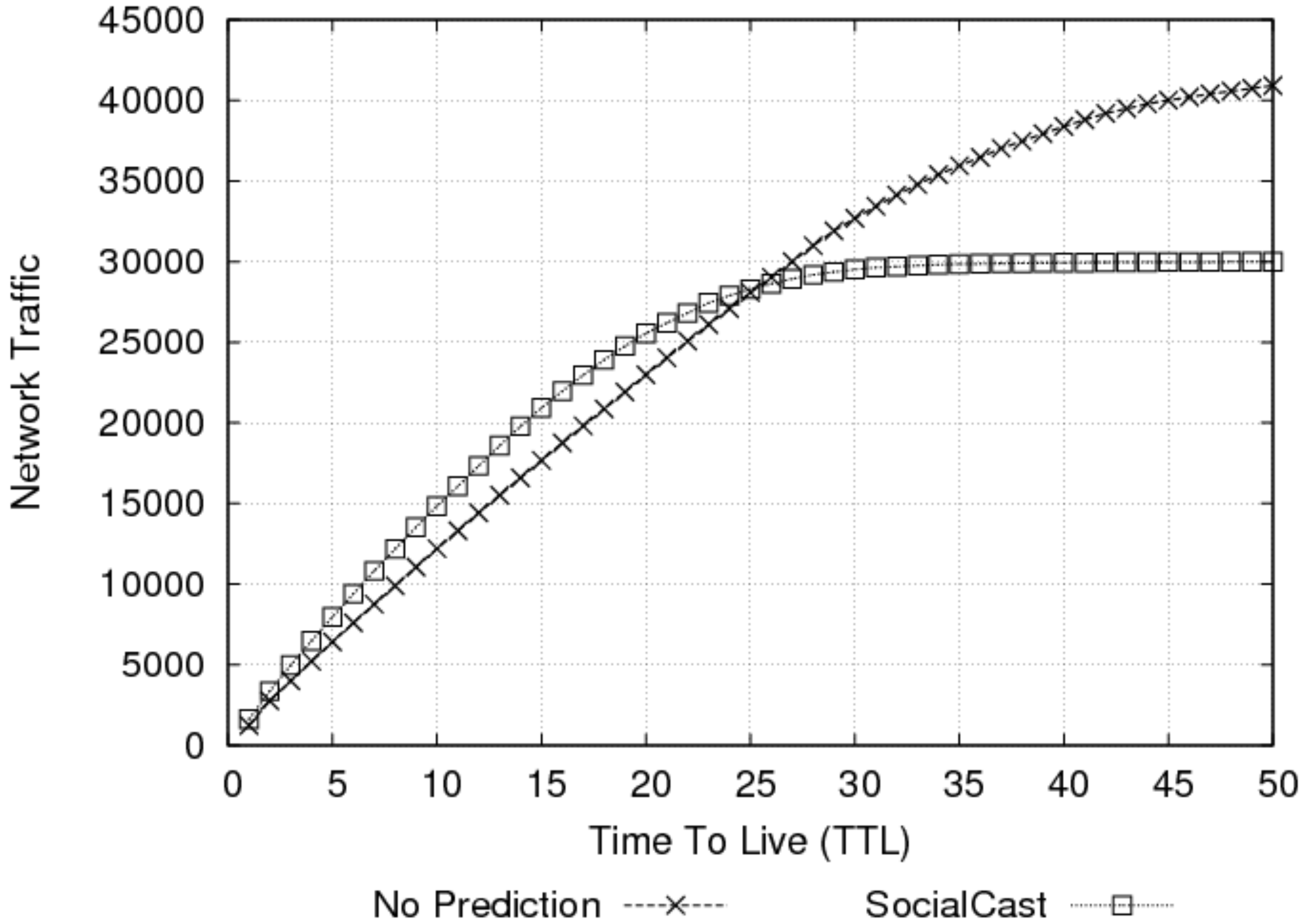
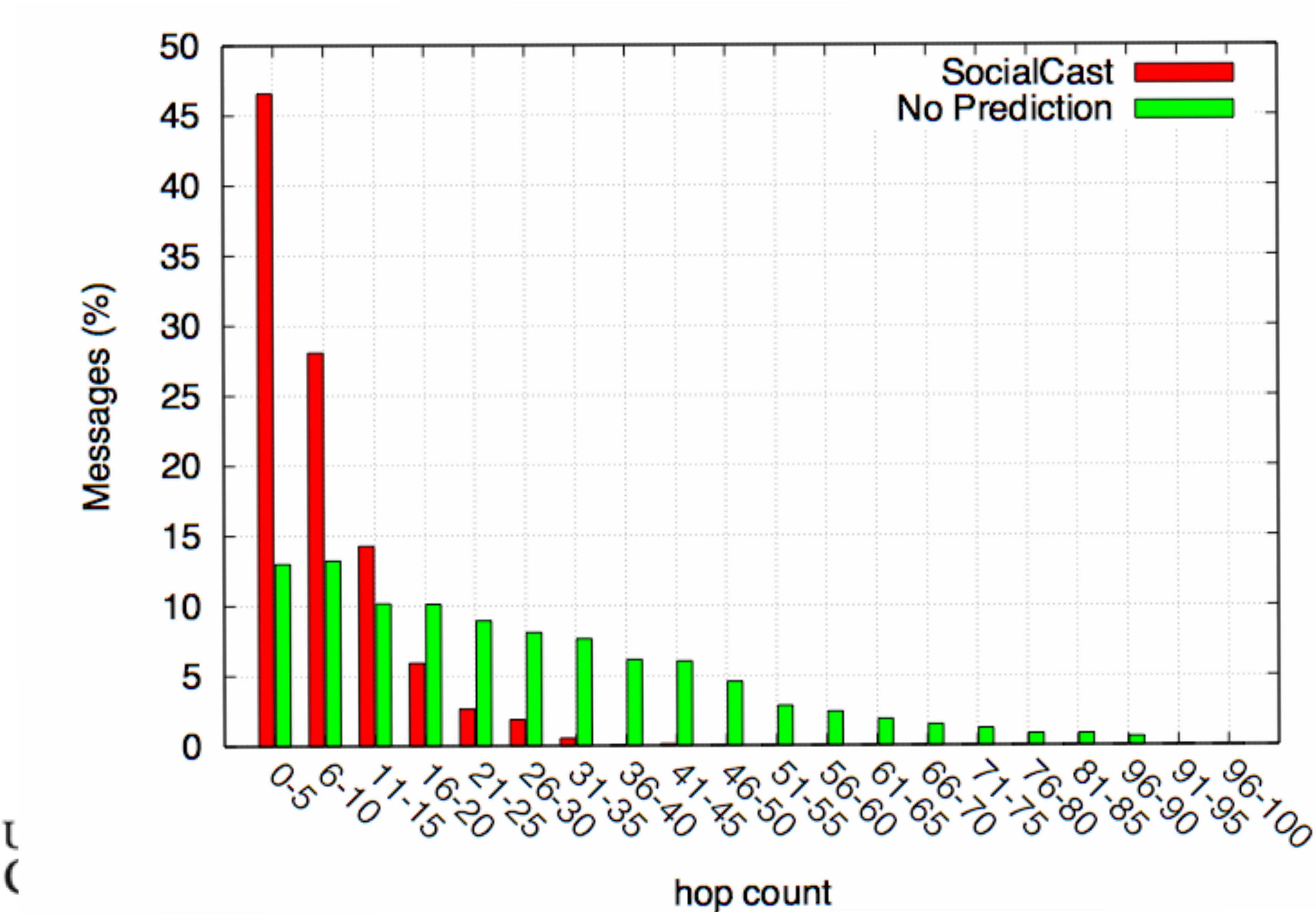
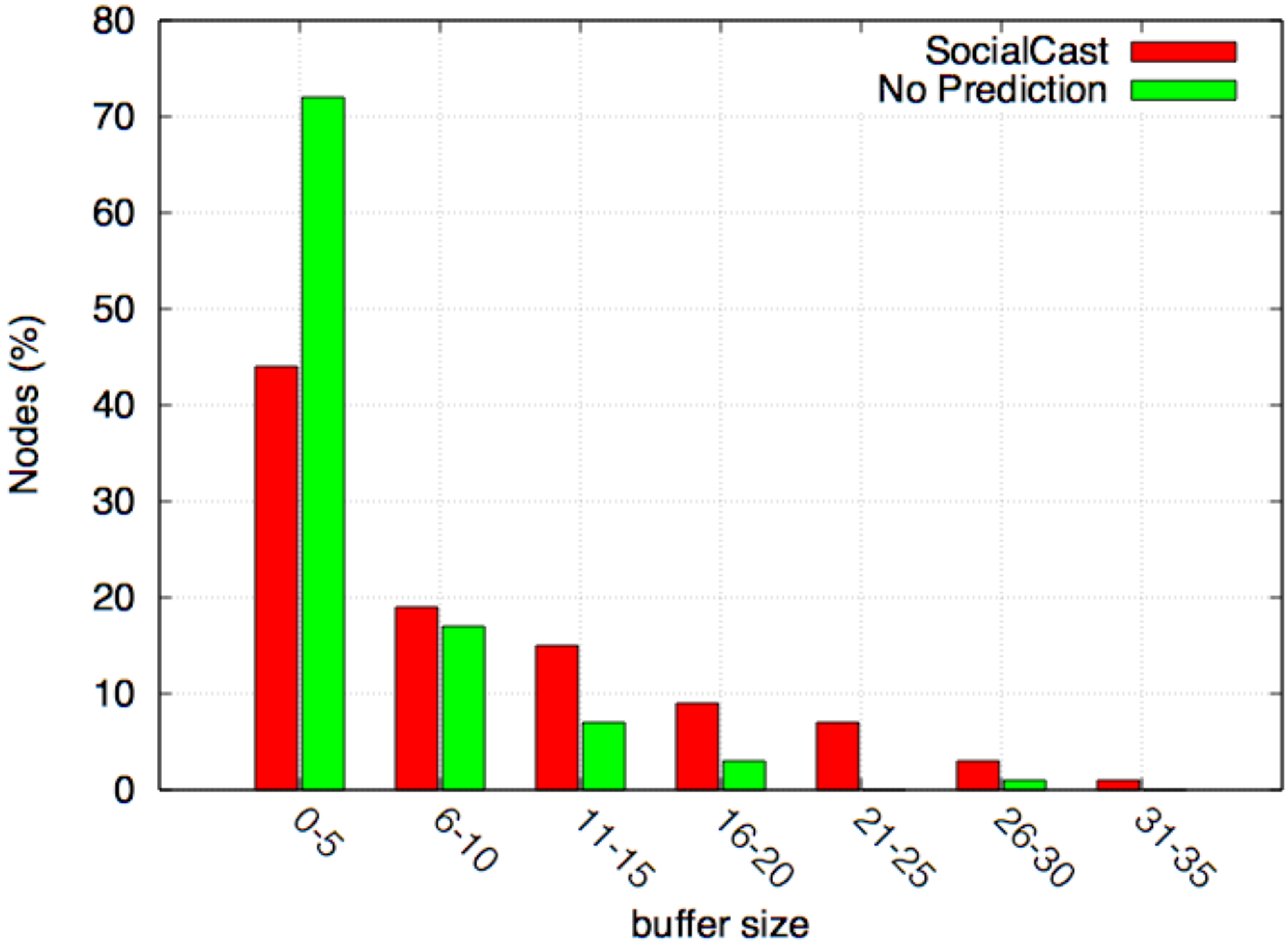
Overhead vs. TTL



Hop Count Distribution



Buffer Size Distribution



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

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Summary

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

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Reference

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- 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.
- P. Costa, C. Mascolo, M. Musolesi, GP. Picco. Socially-aware Routing for Publish-Subscribe in Delay-tolerant Mobile Ad Hoc Networks In IEEE Journal of Selected Areas of Communications. Vol. 26, No. 5, June 2008.

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