Intelligent Routing for Delay Tolerant Networks (DTN)

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18 Nov 2008

DTN - Overview

Most systems assume full connectivity, in a mobile ad-hoc network, this may not always be possible, and in some cases may never be fully connected.

Examples

- Mobile sensor nodes with limited communication range
- In the event of an emergency when telecomms infrastructure has been destroyed
- Military deployment, where there is no existing infrastructure
- Interplanetary communications where sattelites are obscured regularly (by planets)

DTN - Why?

Using mobile devices to report sensor data, without the need for expensive infrastructure.

- Bandwidth constraints
- Infrastructure cost
- Decentralised control

Literature

Li & Rus

[1] Qun Li and Daniela Rus, *"Sending messages to mobile users in disconnected ad-hoc wireless networks"*, MobiCom '00: Proceedings of the 6th annual international conference on Mobile computing and networking, ACM, 2000
(GS: 155, ACM: 35, Citeseer: 74)

Epidemic Routing

[2] Amin Vahdat and David Becker, *"Epidemic routing for partially-connected ad hoc networks"*, Duke University, 2000 (Technical Report)
(GS: 420, Citeseer: 59)

CAR

[3] Mirco Musolesi, Cecilia Mascolo, "*CAR: Context-Aware Adaptive Routing for Delay Tolerant Mobile Networks*," IEEE Transactions on Mobile Computing, 16 Jul 2008. IEEE computer Society Digital Library. IEEE Computer Society
(Based on well cited previous work - this paper has more detail)

Delay Tolerant Networks

Routing Algorithms

- Proactive - probe routes periodically
- Reactive - triggered when host sends a message

ICN - Intermittantly Connected Networks

Ad-Hoc (wireless) Networks

Delay Tolerant Networks

Li & Rus (2000)

Epidemic Routing (2000)

CAR: Context-aware Adaptive Routing (2008)

Li & Rus - Overview

First paper that analyses the problem of asynchrounous communication in intermittantly connected mobile ad-hoc networks [3].

Approach:

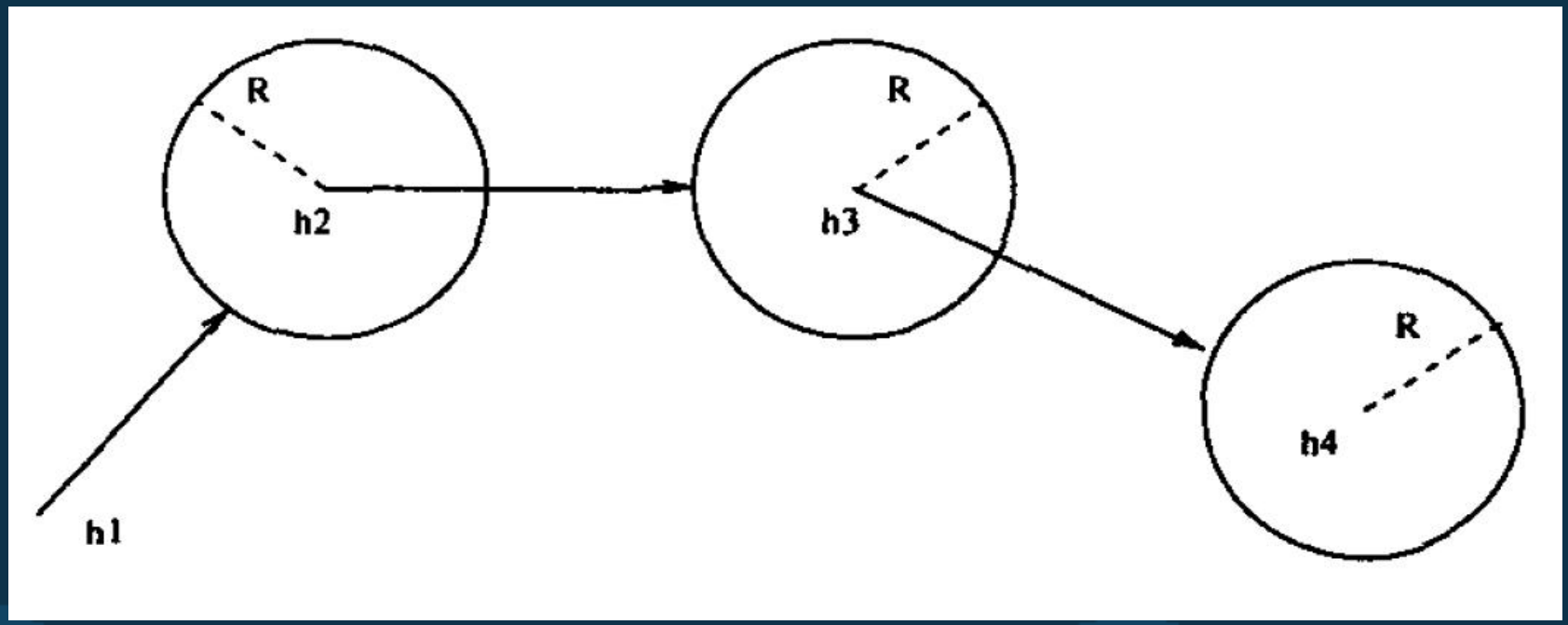
- Nodes are mobile, change trajectory to deliver a message
- Active Message - lightweight agent
  - capable of jumping between nodes
  - possibility of staying on one node if link is lost.
- One copy of the message

Goal:

- Minimize movement necessary to relay the message

Li & Rus - Why?

For networks where nodes are mobile and have control over their own movements.



Li & Rus - Detail

Full Knowledge of network

- Moving trajectories of ***all*** nodes are known and hosts ***actively move*** to relay the message.

Partial Knowledge of network

- Each node has a scope of movement, and it updates its location with well known nodes.

Li & Rus - Detail

Underlying Behaviour - Message Relay

- Calculate the optimal path between host and the destination
- If there are intermediate hosts
  - move into transmission range
  - transmit message

Extended Behaviour - when host movement uncertain

- Each node has a defined scope of movement (error)
- Moving nodes must update their position to their nearest neighbour if leaving scope

Example *- battlefield movements, some nodes will update their location via walkie-talkie when normal transmission is not possible.*

Li & Rus - Testing / Evaluation

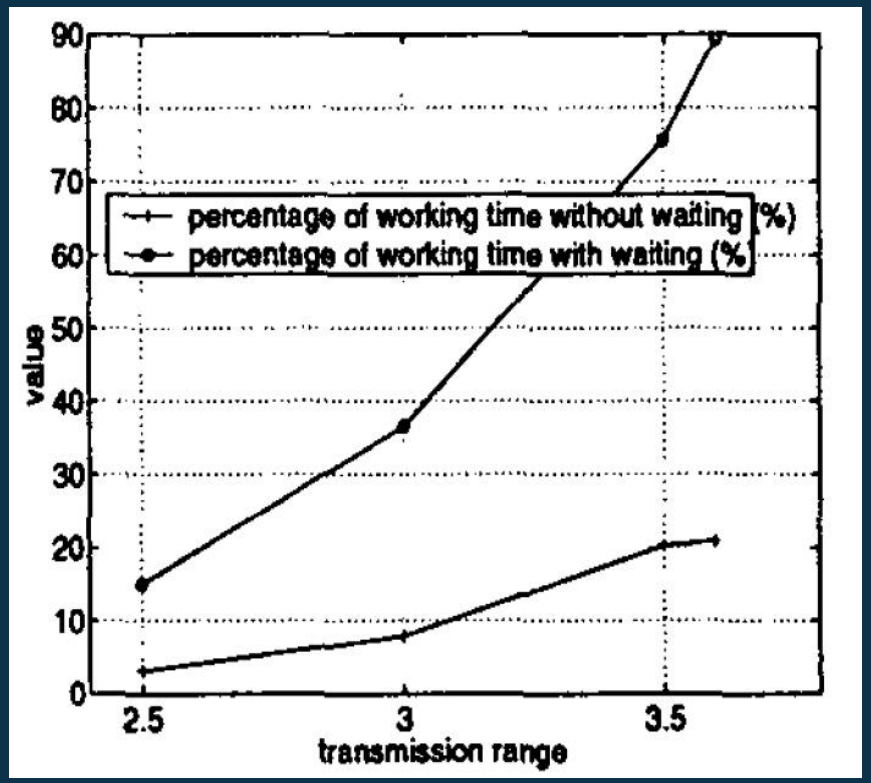
Instant Transmission vs Delayed Transmission

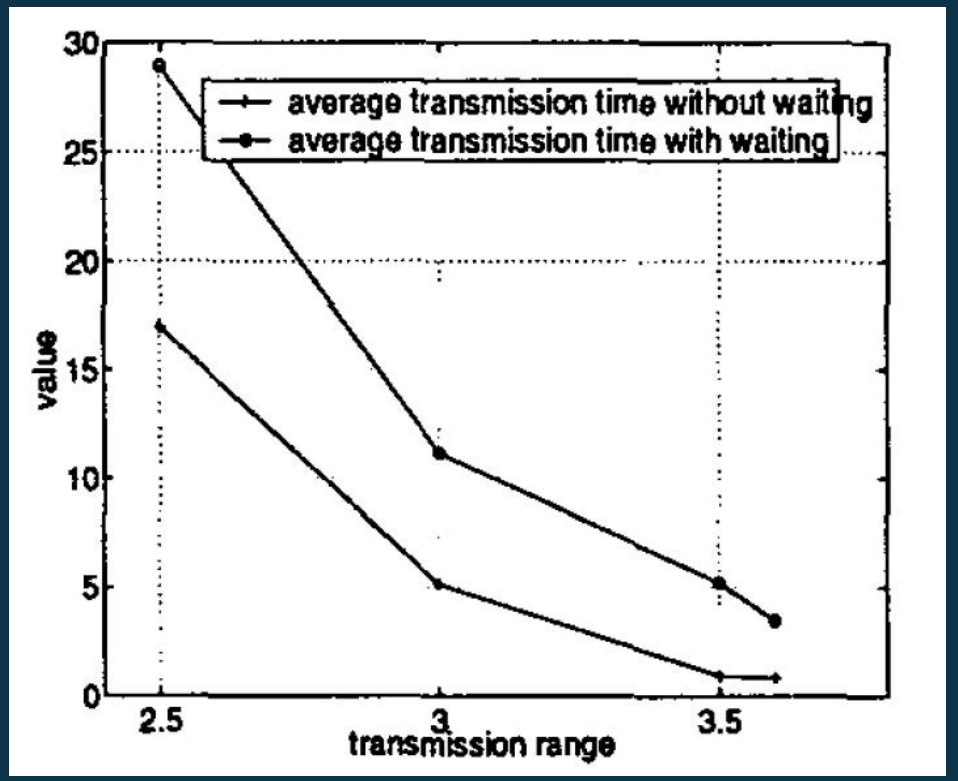
Metrics

- *time spent on own work*
- *balance of workloads*
- *speed of transmission*

Brownian Motion for modelling host movement.

Li & Rus - Results





Useful

- When most of the network is connected
- Where the distance between hosts is slightly larger than transmission range

Epidemic Routing - Overview

Most interesting paper describing routing in delay tolerant networks [3].

Approach:

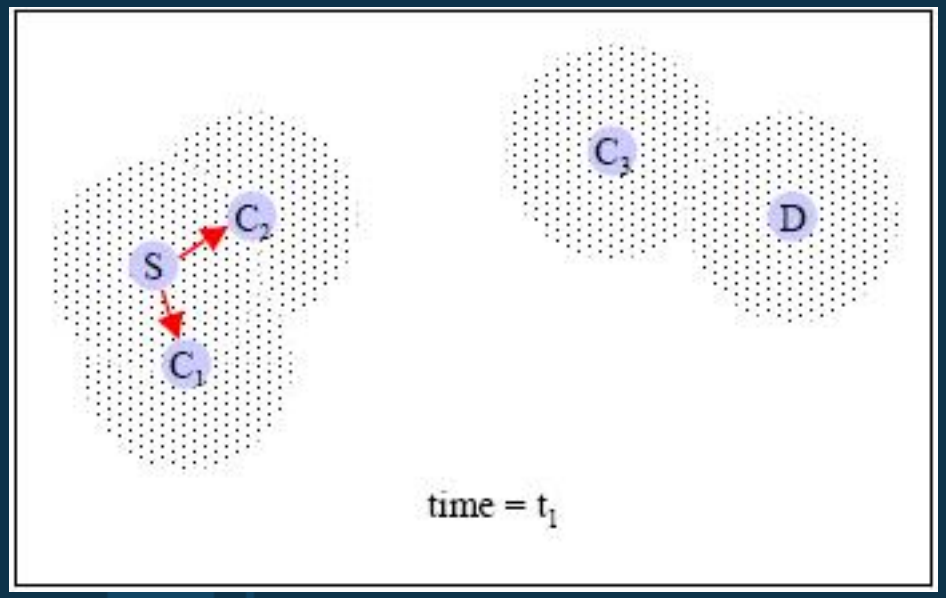
- Multiple message copies
- Random pair-wise exchanges of messages between hosts (carriers)
- Limits on buffer size
- Limits on hop count

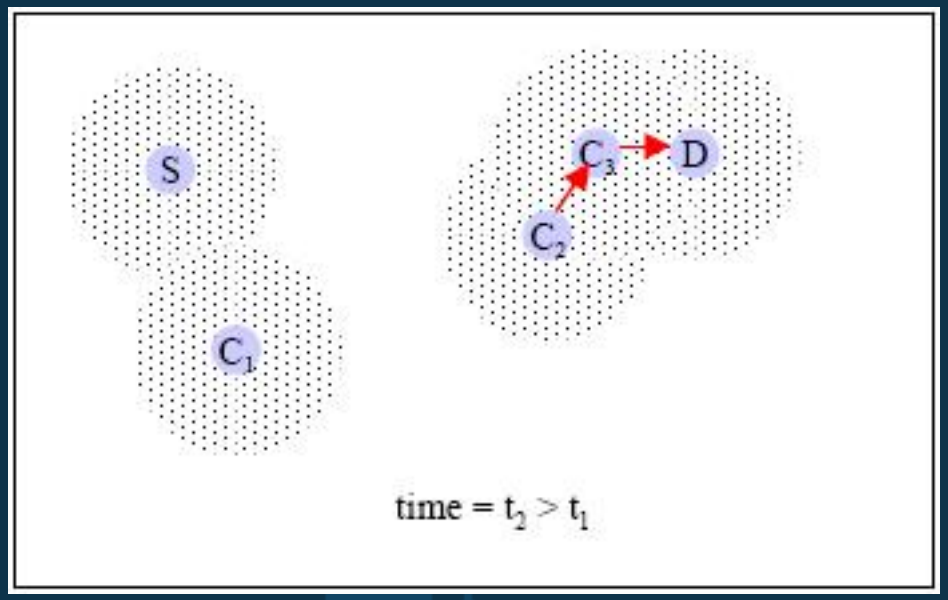
Goal:

- Maximise message delivery rate
- Minimize message latency
- Minimize total resources used in message delivery

Epidemic - Why?

There may never be a connected path from source to destination.





Epidemic - Detail

1. A sends B a list of message IDs it holds
2. B sends A a list of message IDs it does not know about that it wants to recieve
3. A sends B the requested messages

B *may choose* not to receive certain messages - e.g. messages for a certain host, or above a certain size.

Example: mobile sensor networks or military deployment, distributed geographically and out of range.

Epidemic - Detail

Hop count reduced at each message transmission.
Hop count of 1 means transmit only to destination host.

Buffer size means that messages are dropped when buffer overflows.

Epidemic - Testing / Evaluation

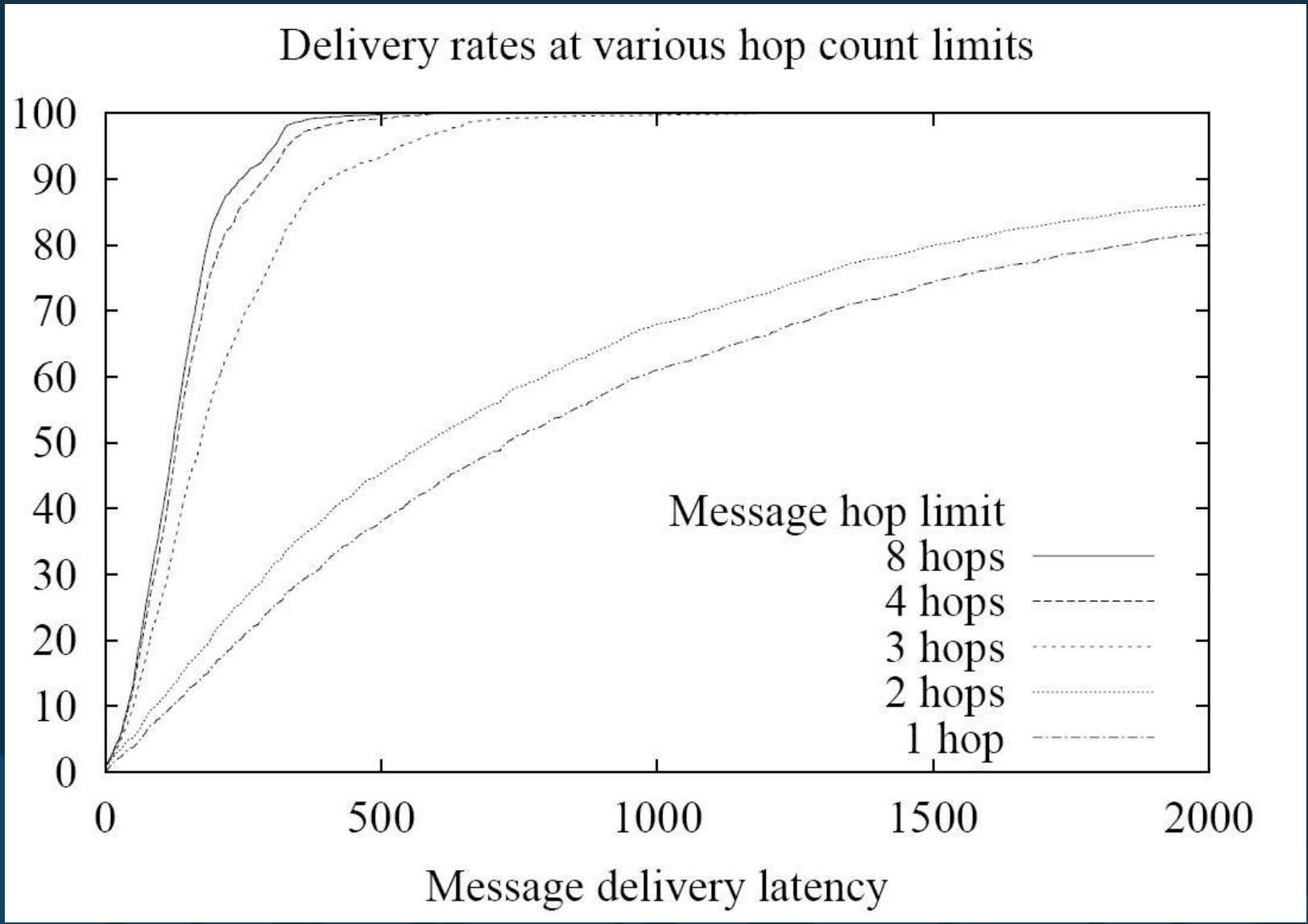
NS-2 Simulator with Monarch extension to model wireless ad-hoc network.

50 nodes, 1500m x 300m area, random start and end point.
1980 messages sent 1s apart, buffer size of 2000 (infinite).

Metrics:

- Delivery Rate
- Latency
- Resources used

Epidemic - Results



Epidemic - Results

Characteristics as a function of transmission range.

Range (m)	Delivery Rate (%)	Baseline Rate (%)	Latency (s)	Hops	Coverage (%)
250	100	98.2	0.2	2.4	10.91
100	100	34.3	12.8	6.3	1.75
50	100	0.9	153	3.7	0.44
25	100	0	618 (3758)	3.3	0.11
10	89.9	0	44829 (198107)	3.4	0.02

Total Duration 200,000s (55hrs)

Baseline rate = % messages delivered using conventional fully connected algorithm (DSR - Broch et.al 1998)

Epidemic - Results

Delivers 100% of messages with reasonable resource consumption, where traditional end to end mechanisms failed to deliver any messages because no end-to-end results are available.

CAR - Overview

First approach to exploit forecasting techniques for carrier selection founded on analytical prediction models [3].

Approach:

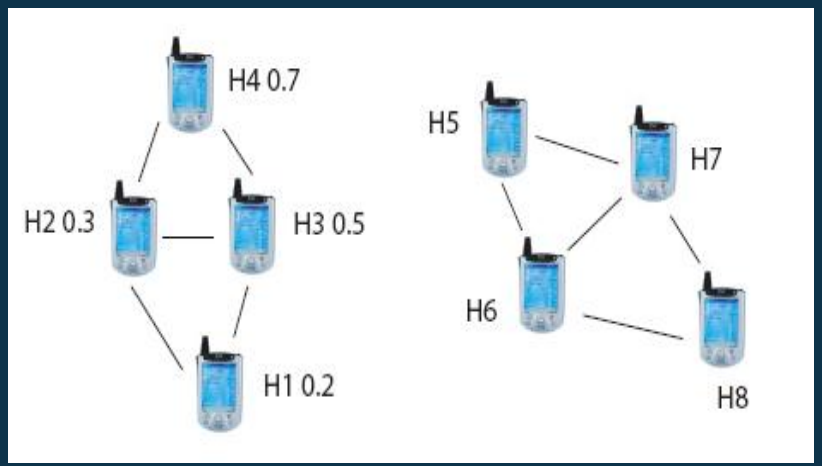
- Individual message
- Host only knows about logical connectivity
- Hosts co-operate to deliver messages
- Delivers messages sychronously when there are no partitions in the network
- Delivers messages asynchronously when there are partitions
- Store and probablistic forwarding approach

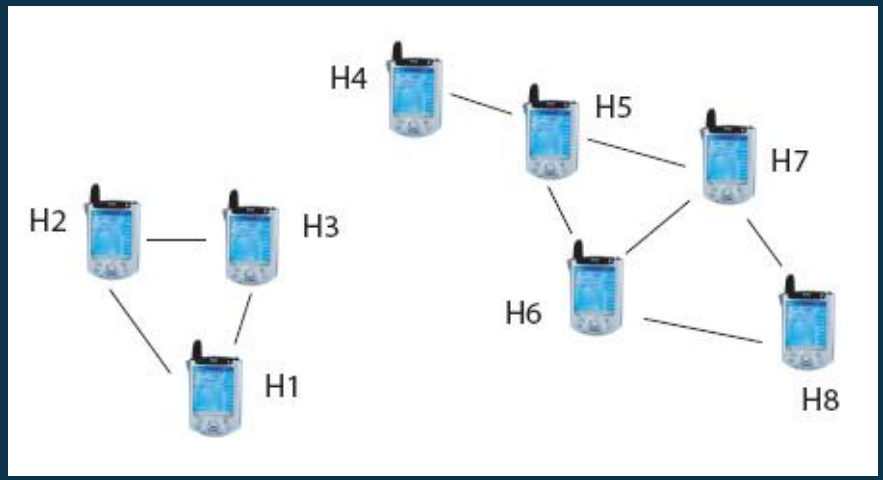
Goal:

- Support communication in intermittantly connected networks

CAR - Why?

For networks with limited resources, where low overheads are important.





CAR - Detail

Pro-active routing algorithm (DSDV) when connected.

- if host is reachable, then message is sent synchronously
- else the message is sent to the host with highest probability of delivery

Uses weighted utility of context to decide delivery probability

- Change Degree of Connectivity
- Colocation with destination host

Kalman filter* used to predict state at next time interval.

*(*descibed seperately)*

CAR - Testing / Evaluation

OMNet++ network simulator

Various alternative algorithms

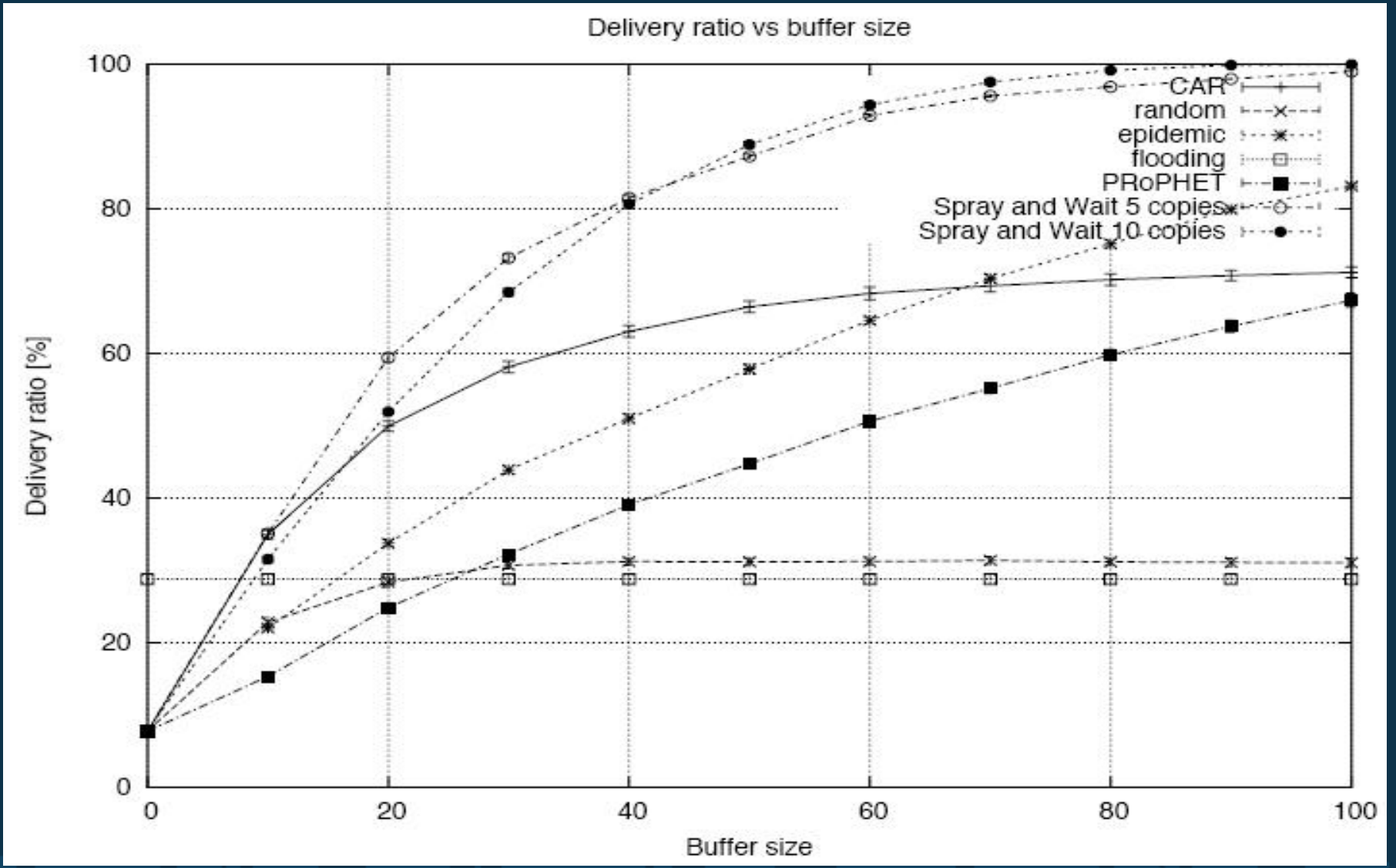
50 hosts, 1km x 1km space

Modelled human social networks using caveman community model (Watts 1999), also evaluated using the CRAWDAD dataset (Haggle Project - 2005).

Metrics

- Delivery Delay
- Delivery Ratio
- Number messages delivered
- Predictability level

CAR - Results


Delivery ratio vs buffer size
Delivery ratio [%]
Buffer size
0
20
40
60
80
100
CAR
random
epidemic
flooding
PRoPHET
Spray and Wait 5 copies
Spray and Wait 10 copies

CAR - Results

Guarantees good performance with limited overhead in terms of messages sent.

Out-performs other methods in situations with sparse connectivity and very small buffers.

Comparison

Li & Rus	Efficient for autonomous mobile agents/nodes
Epidemic	Good to guarantee* delivery
CAR	Good for small devices / low overhead

My research* to route based on profiling.

* probably

Questions?

Questions?

Why is routing so much fun?

How would we send our packets without it?

Where can I get a DTN fix?

Read survey paper by Zhensheng Zhang

Whats the future of DTN?

Metropolitan evironmental sensing with mobile phones!