User Mobility for Opportunistic Ad Hoc Networking

WMCSA 2004

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Overview

- Motivation
- Experiment
- Results
- Conclusions
- Related Work

Motivation

- Can a network be built on pairwise interaction?
- Can routing algorithms be improved?
  - Exploit predictability in user mobility
  - Explore replication and latency trade-off
- Evaluate research using real mobility

Applications

- ZebraNET, SWIM
- Infrastructure-less research or military networks
- Supplement to infrastructure networks
  - Improve power or cost
  - Extend coverage and availability

Methodology

- Collect traces of pairwise contact
  - Give devices to human test subjects
  - Devices search for other test subjects
  - Collect data at end of study

- Trace-based simulation to determine network characteristics

Requirements

- Provide incentive to carry device
  - Use currently available mobile devices
  - Instrumentation software shouldn't disrupt user
- Go for whole work-day on single charge
- Catch serendipitous contact
  - even when user is not aware
- Chose Palm devices, using Bluetooth
  - 802.11 has 10x power requirement over Bluetooth

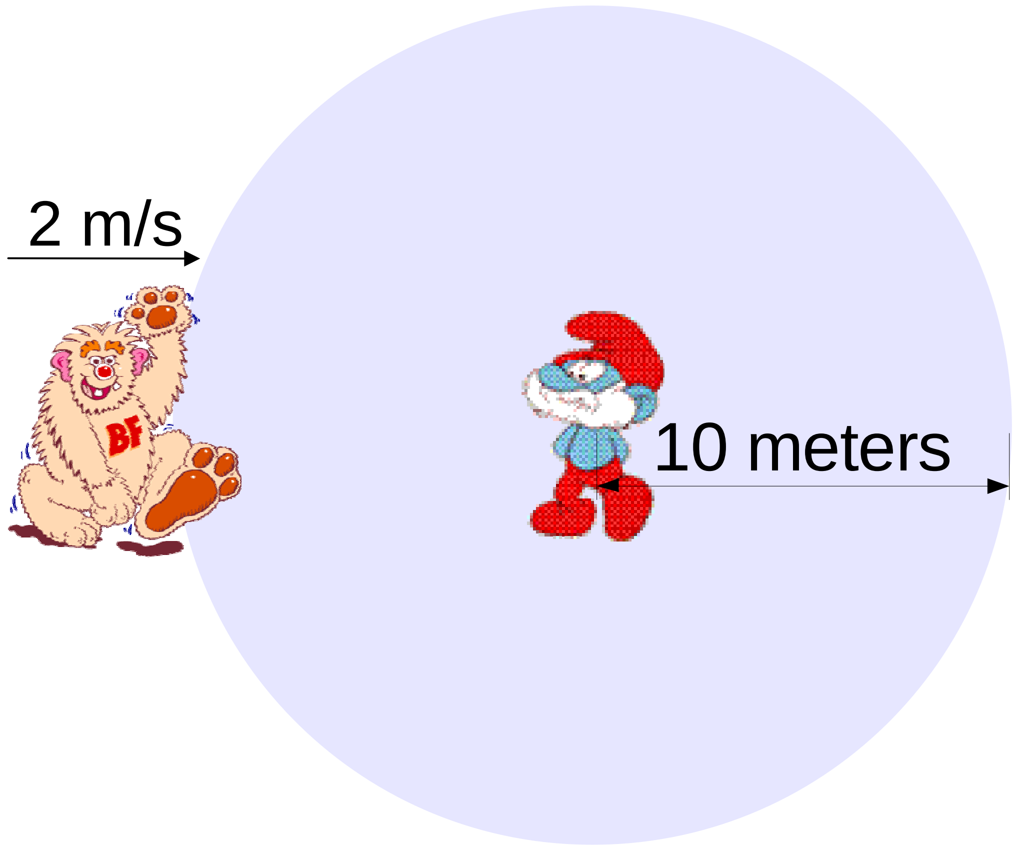
Experimental Setup

- 20 Mobile Devices
  - Palm Tungsten T
  - Given to subjects to carry around

- 3 Stationary Devices
  - Palm m125
  - Placed near high-traffic locations
  - Simulate infrastructure

Search Frequency

- “Pings” have to be spaced for power management
- Want to catch serendipitous contact
  - Need to search at least once every 10 seconds



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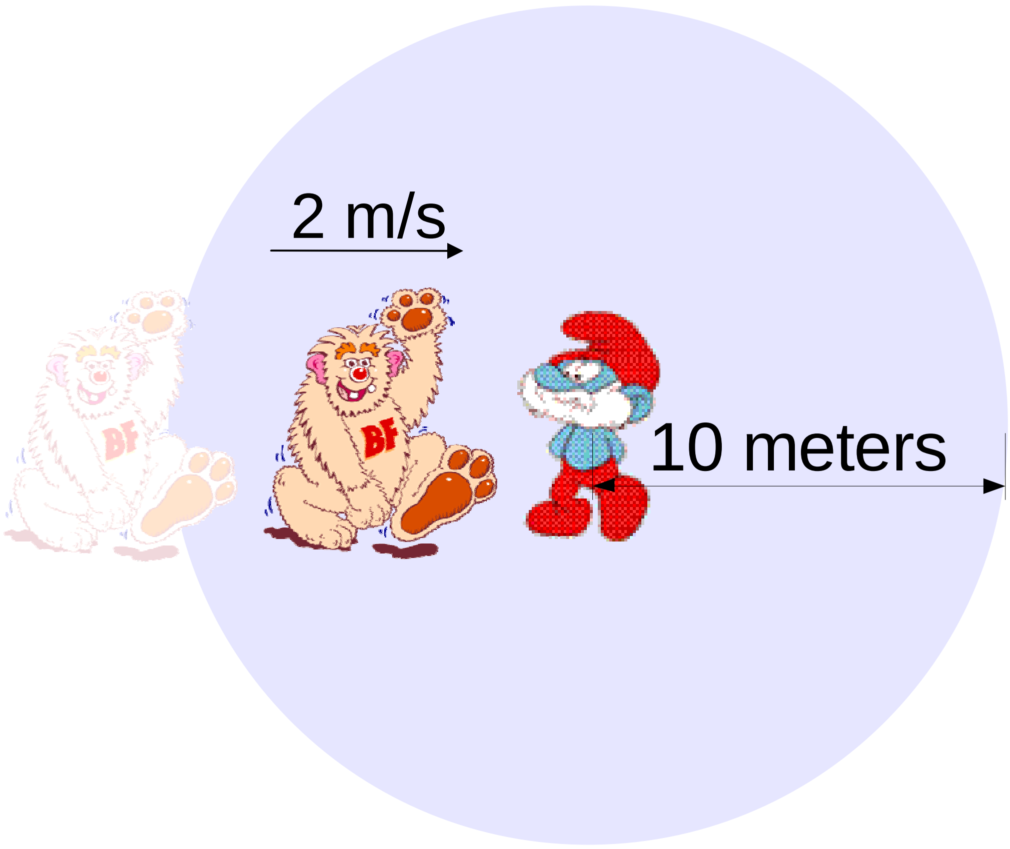

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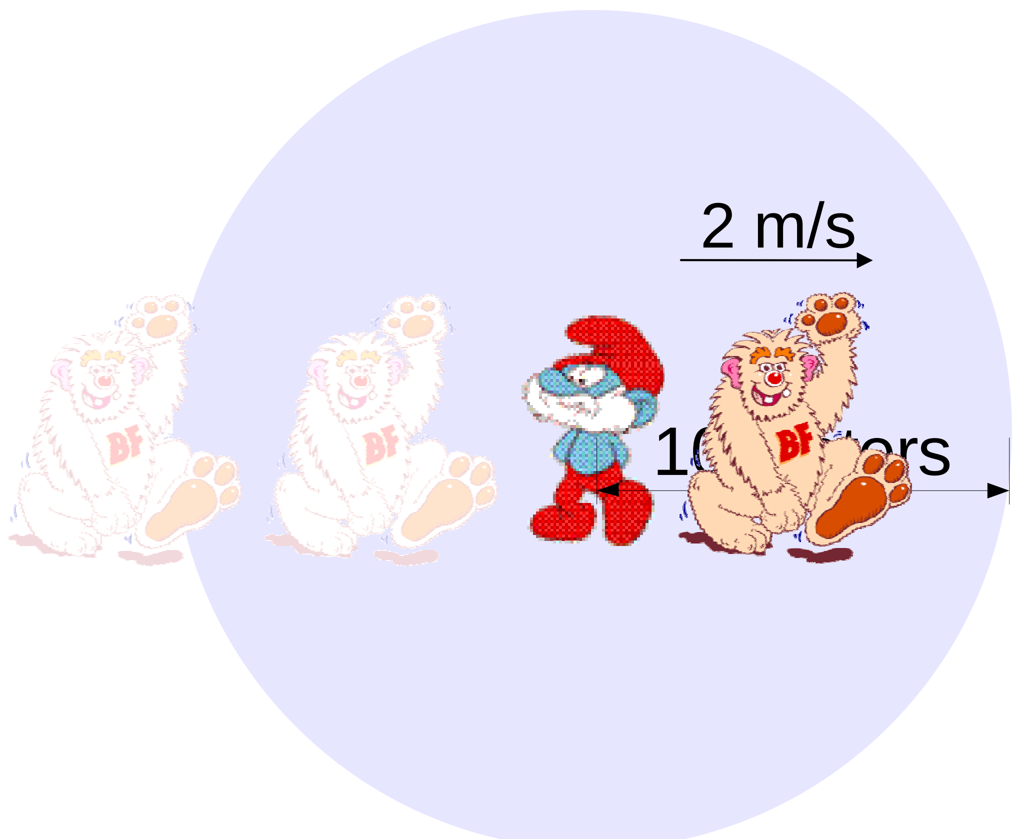

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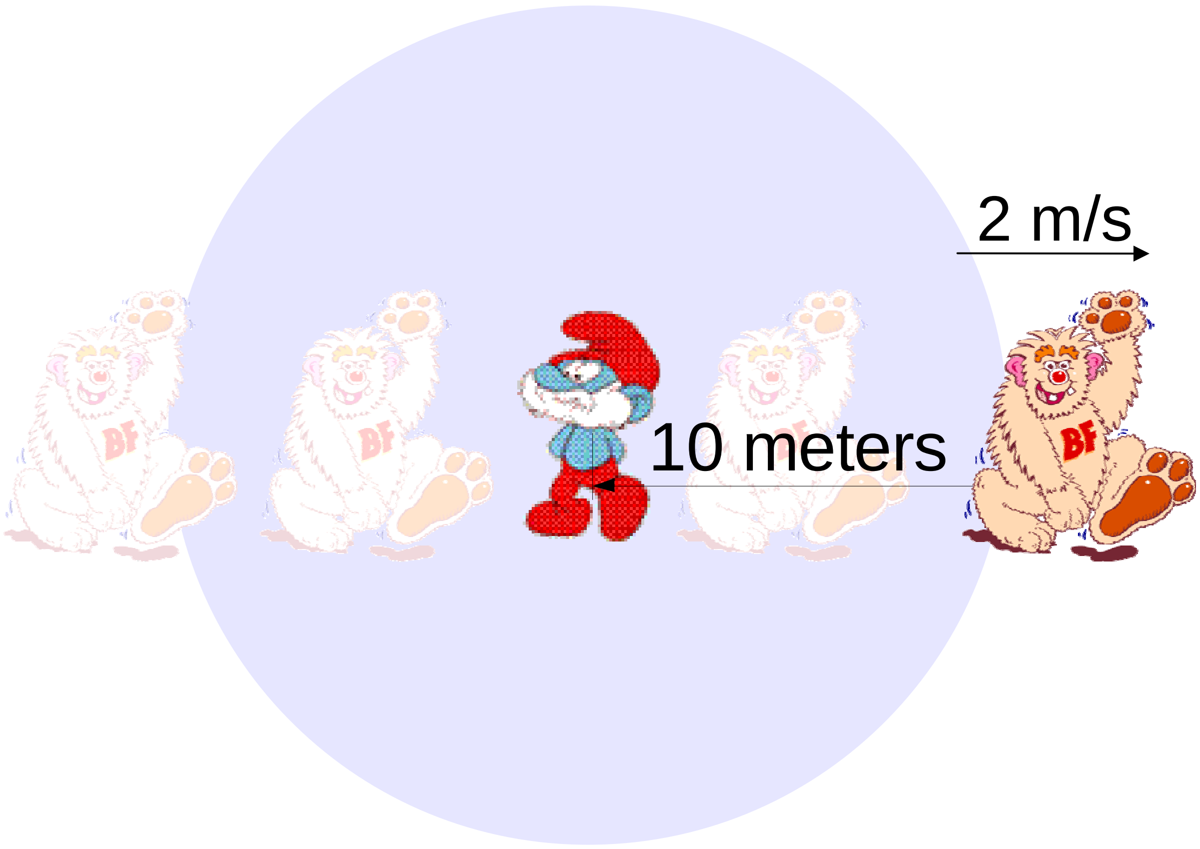

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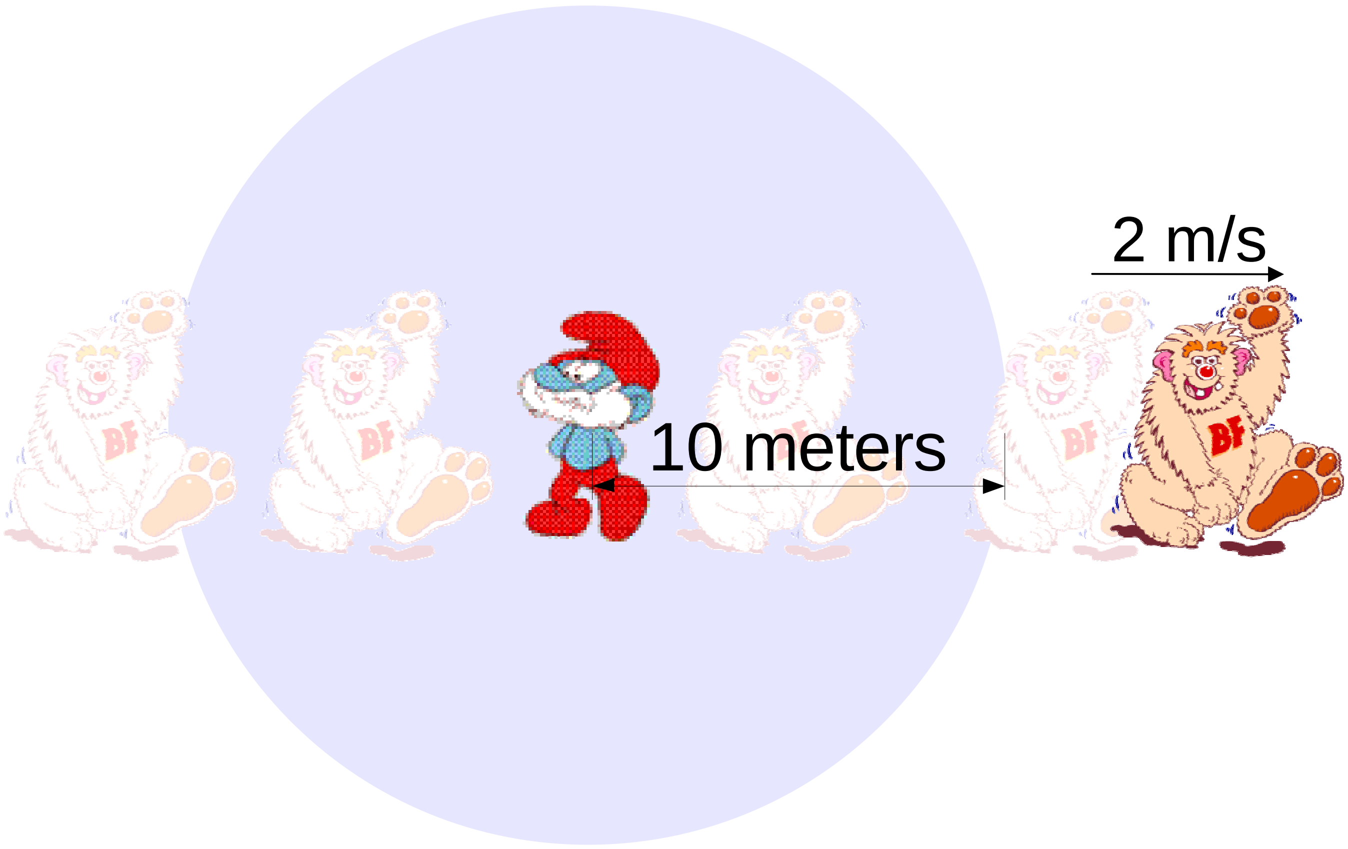
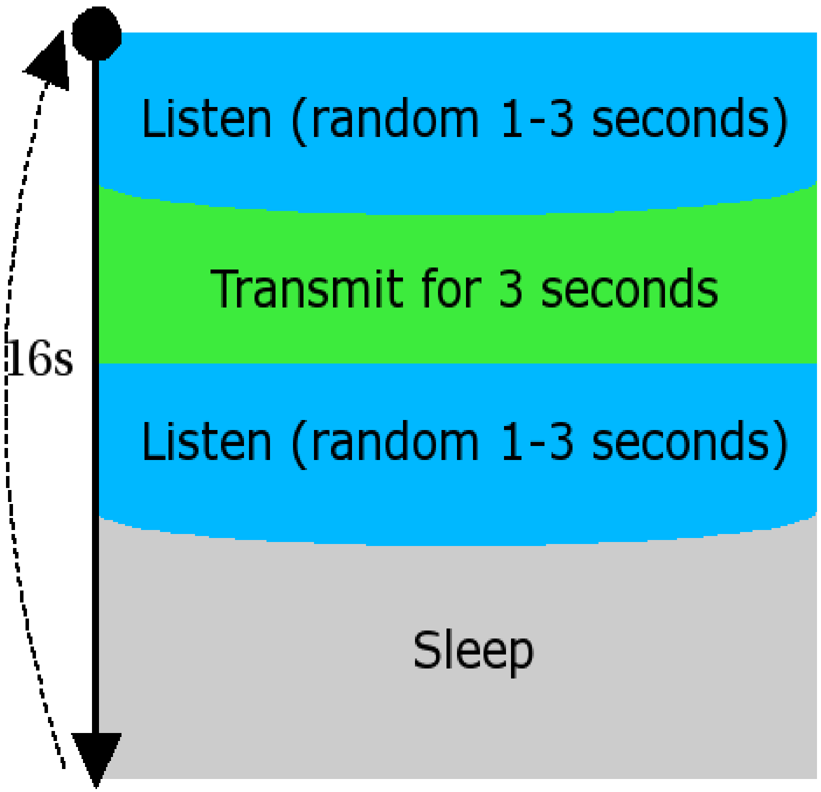


Search Protocol

- Synchronized clocks
- Bluetooth is half duplex
- Gives 8-10 hours battery life
- May miss data
- Our results are conservative



User Studies

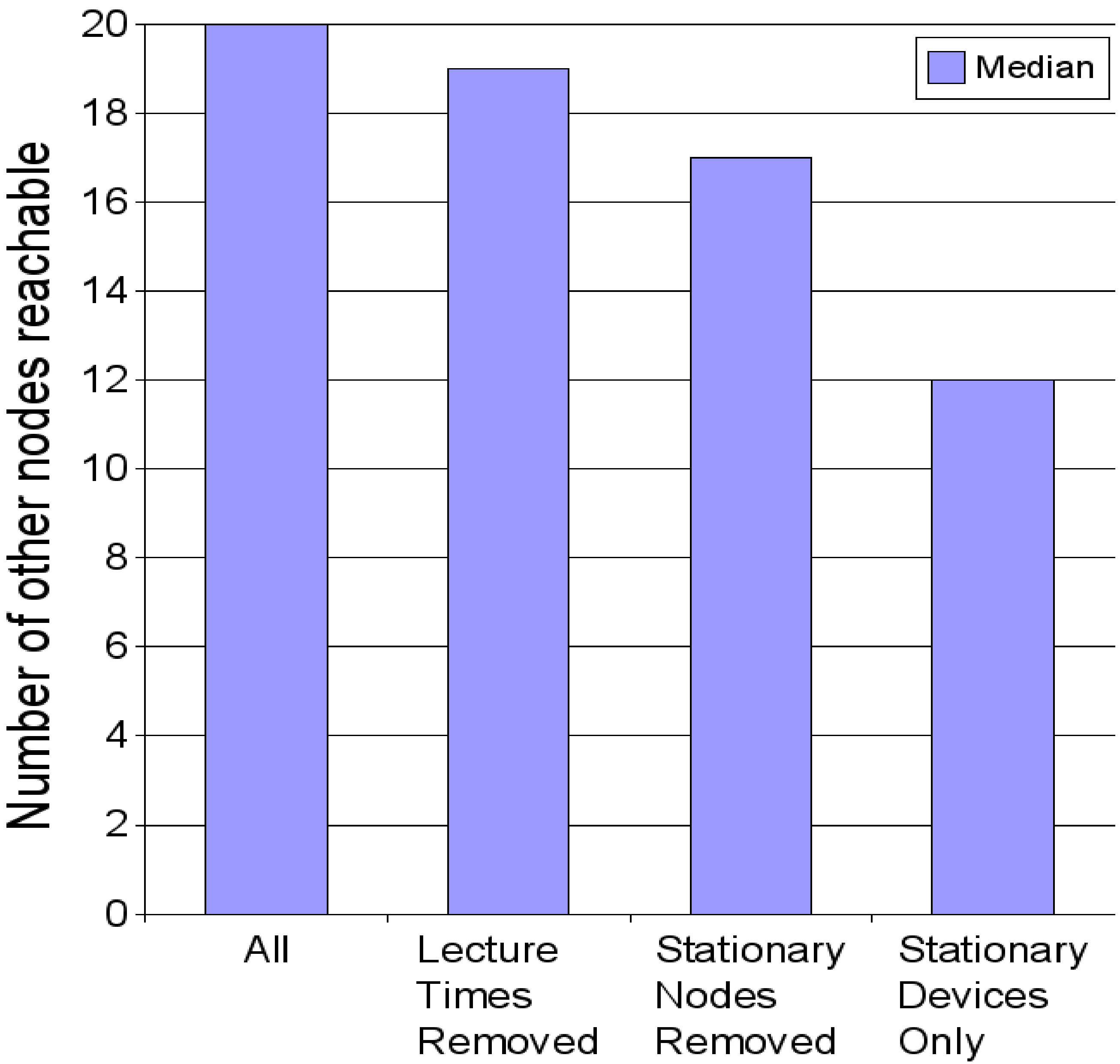
- 18 Graduate students
  - 2.5 weeks, Autumn 2003
  - 9 in CS, 9 in ECE
- 20 Undergraduate students
  - 8 weeks, Spring 2004
  - 10 in CS, 10 in ECE

Results

- Reachability
- End-to-end latency
- Latency versus replication trade-off
- User experiences

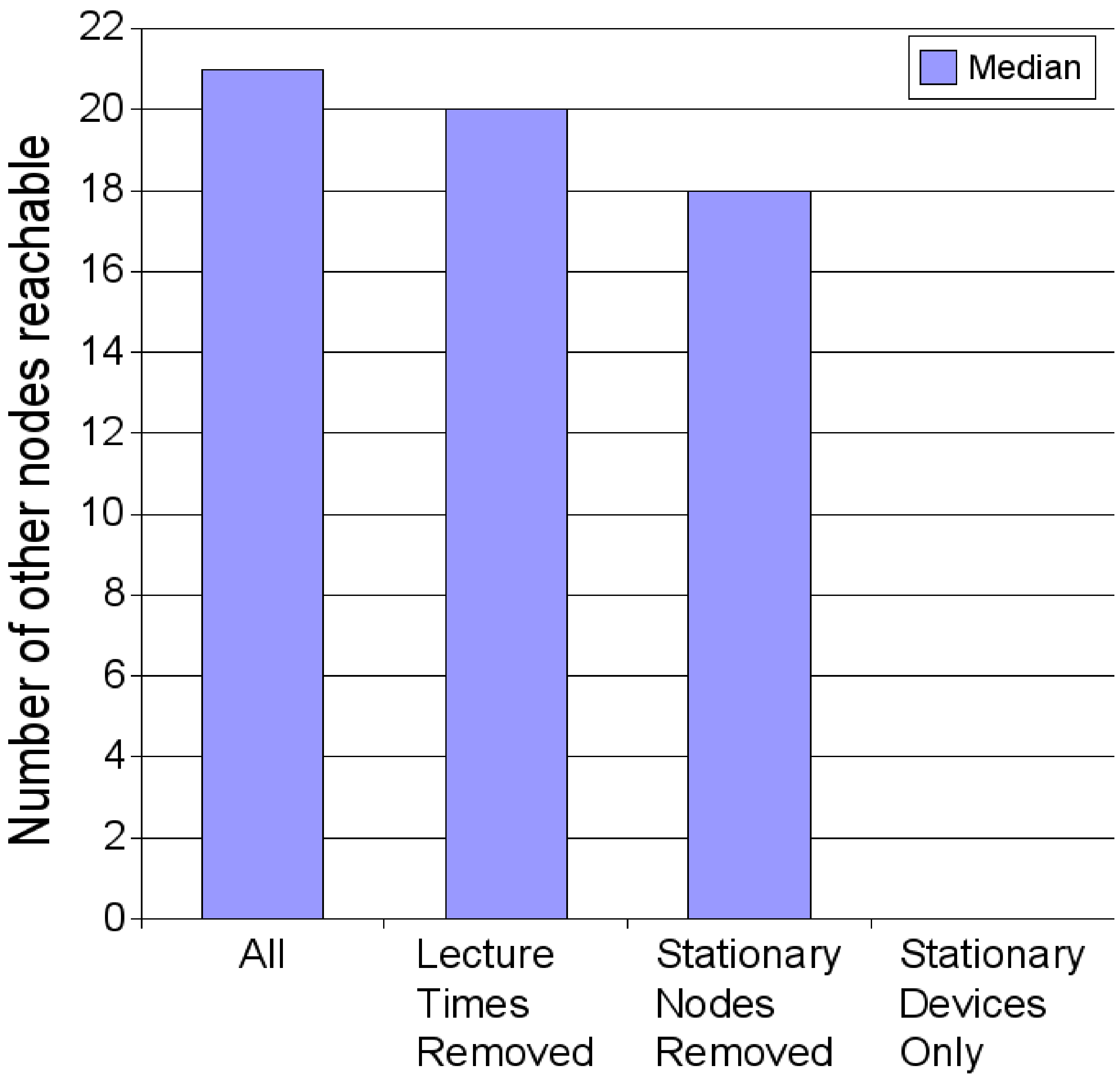
Reachability (study #1)

- User Study #1
- 21 nodes total
  - 18 Mobile
  - 3 Stationary



Reachability (study #2)

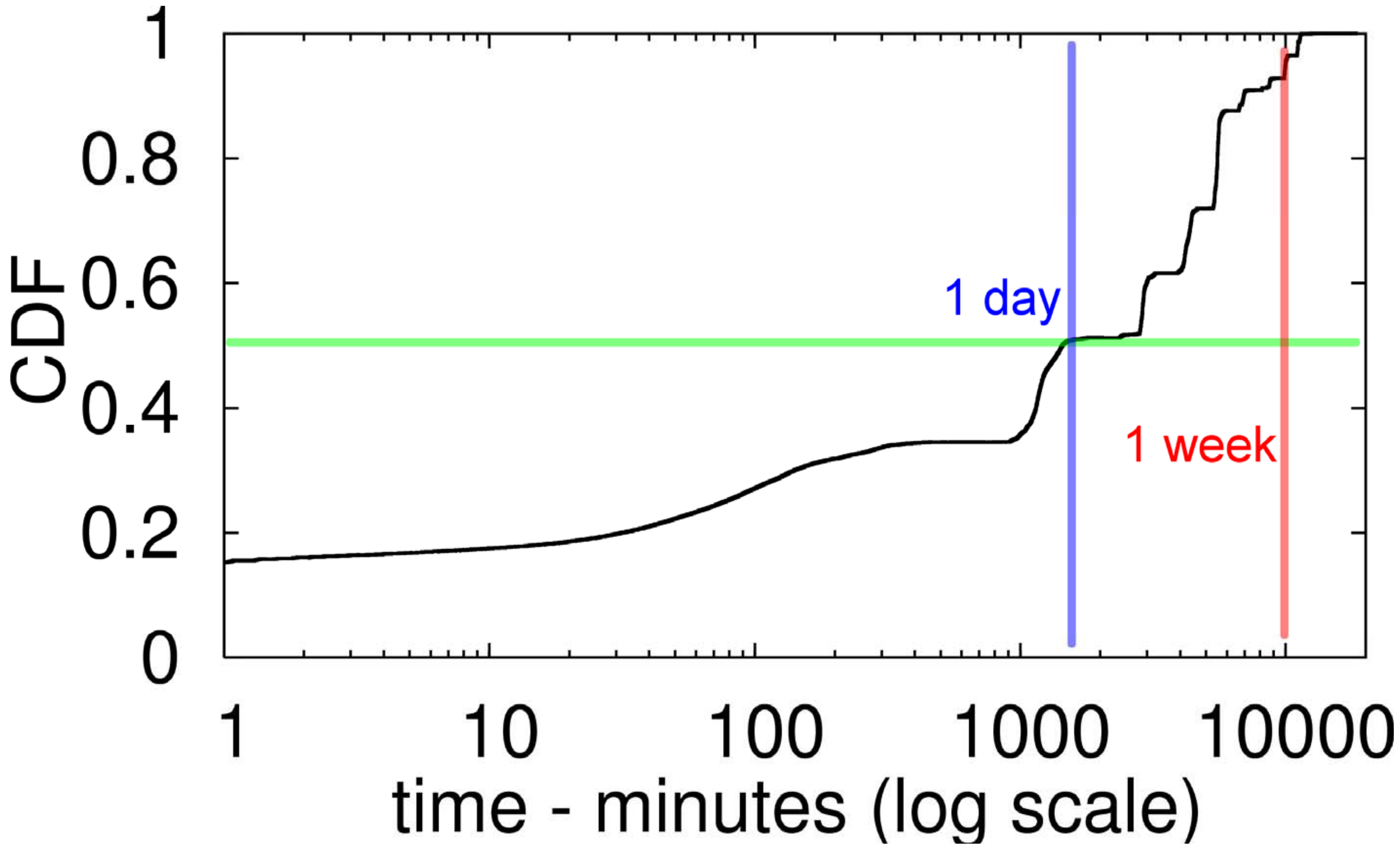
- User Study #2
- 23 nodes total
  - 20 Mobile
  - 3 Stationary



Trace-Based Simulation

- Packet creation
  - When node meets new node
- Packet propagation
  - Epidemic
  - Unlimited bandwidth
  - Unlimited memory

End-to-End Latency (All Packets)

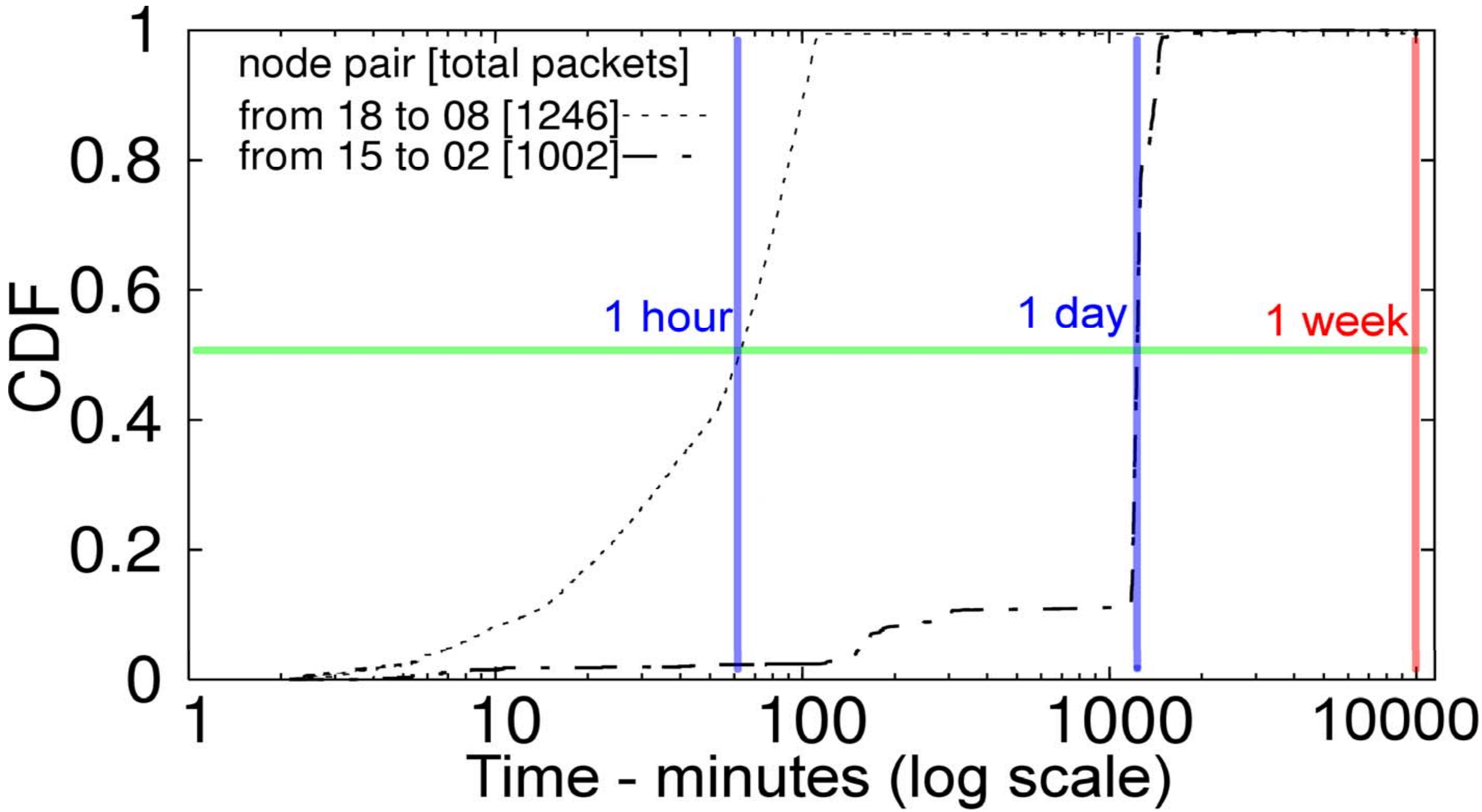


User Study #1

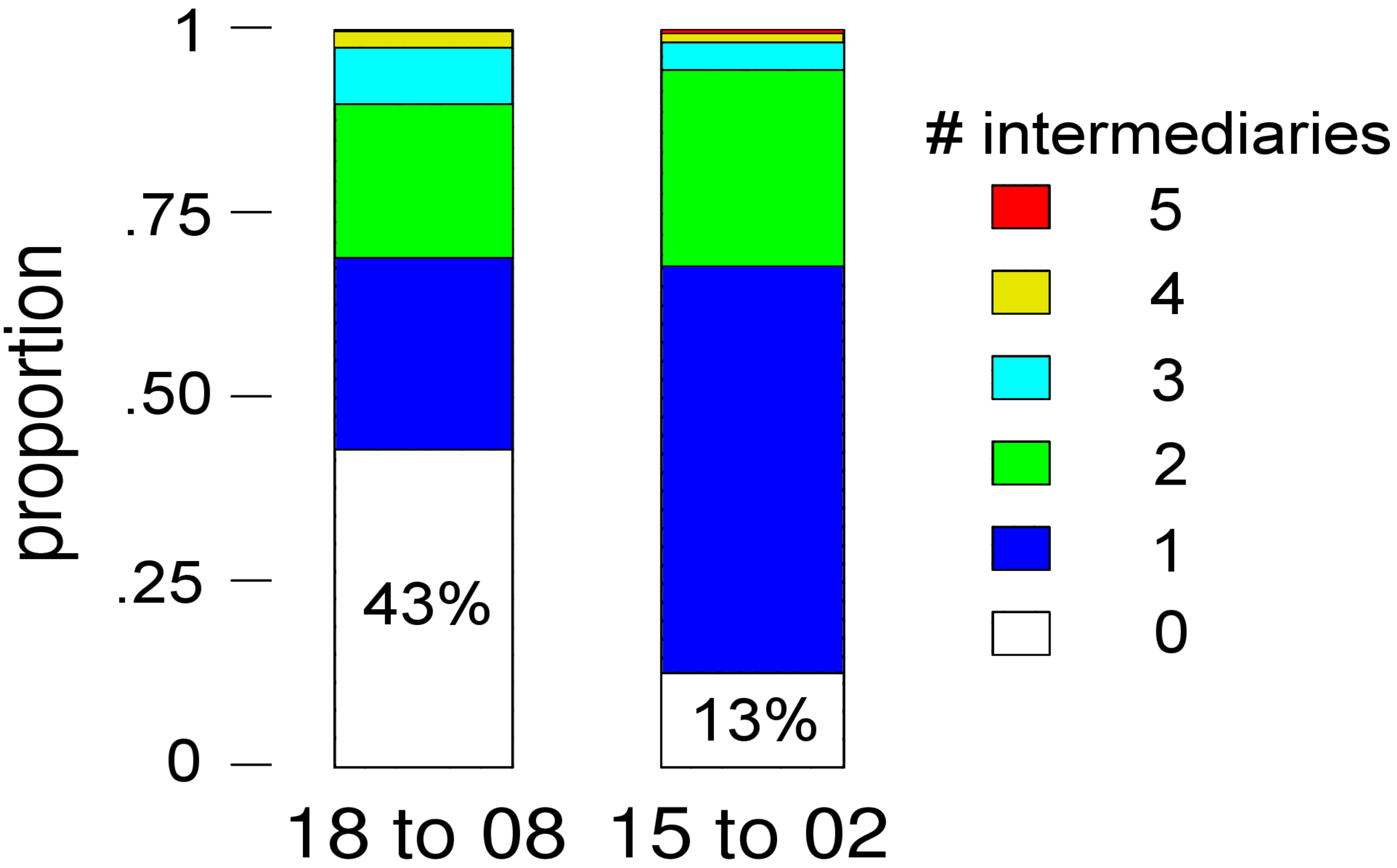
A Closer Look

- Most nodes communicated infrequently
- Look at select node pairs that communicate frequently
  - Called “social nodes”
  - 18 to 08 , 15 to 02
- We expect our best-case to be representative of average case in a larger network

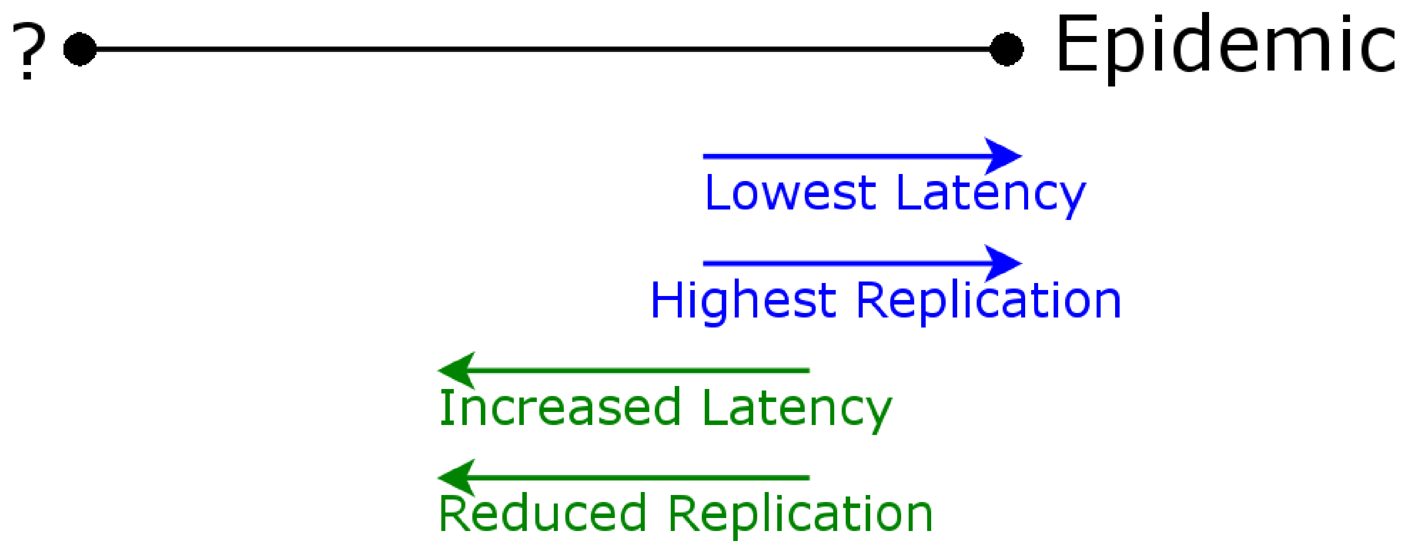
End-to-End Latency for Social Nodes



Distribution of Intermediaries



Latency versus Replication Trade-off



- Minimal replication
  - Who should be the next hop neighbour?
  - Prefer certain neighbours
- Efficient source routing using biased handoff

Biased Handoff Neighbors

18 to 08	
Handoff Node	% First Copy Arrival
12	38.4
10	33.6
11	10.9
06	10.7
13	6.2
19	0.2

15 to 02	
Handoff Node	% First Copy Arrival
14	62.9
11	14.3
07	10.8
06	6.0
23	3.9
16	0.6
05	0.6
17	0.5
03	0.3
20	0.1
09	0.1

User Experiences

- Graduate students
  - Used devices sparingly
  - Treated them very carefully
  - Power conservation protocol worked well
- Undergraduate students
  - Frequently used device
  - Many filled the memory with games
  - Power conservation protocol was not sufficient

Related Work

- Jetcheva et al 2003 , Ad Hoc City Buses
- Zhao et al 2004 , Message Ferries
- Kotz et al 2002 , Analysis of Wireless Networks
- Herrmann 2003 , Modeling Sociological Aspects
- Wang et al 2004 , Postmanet
- Jain et al 2004 , Delay Tolerant Networks

Conclusion

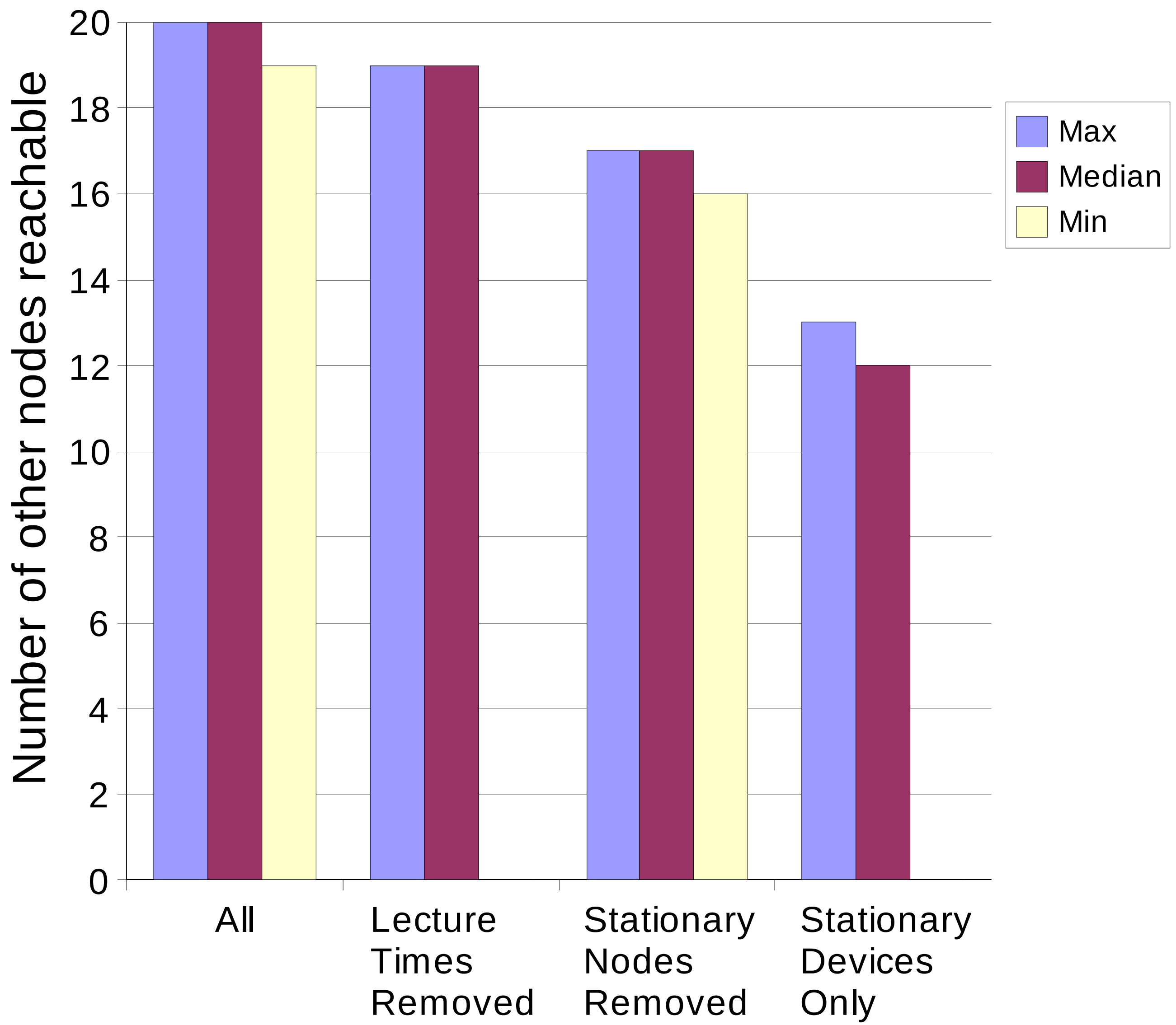
- Lessons
  - Current wireless devices need better application-level control/hints for power management
  - Context aware computing will be a challenge
- Pairwise contact enables building network for latency insensitive packets
- Biased handoff can be used to improve routing

Future Work

- Want "denser" data
- Practical algorithm to determine biased handoff
- Using data to evaluate mobility models

Questions?

Reachability (user study #1)



Reachability (user study #2)