Mobility-Centric Geocasting For Mobile Partitioned Networks

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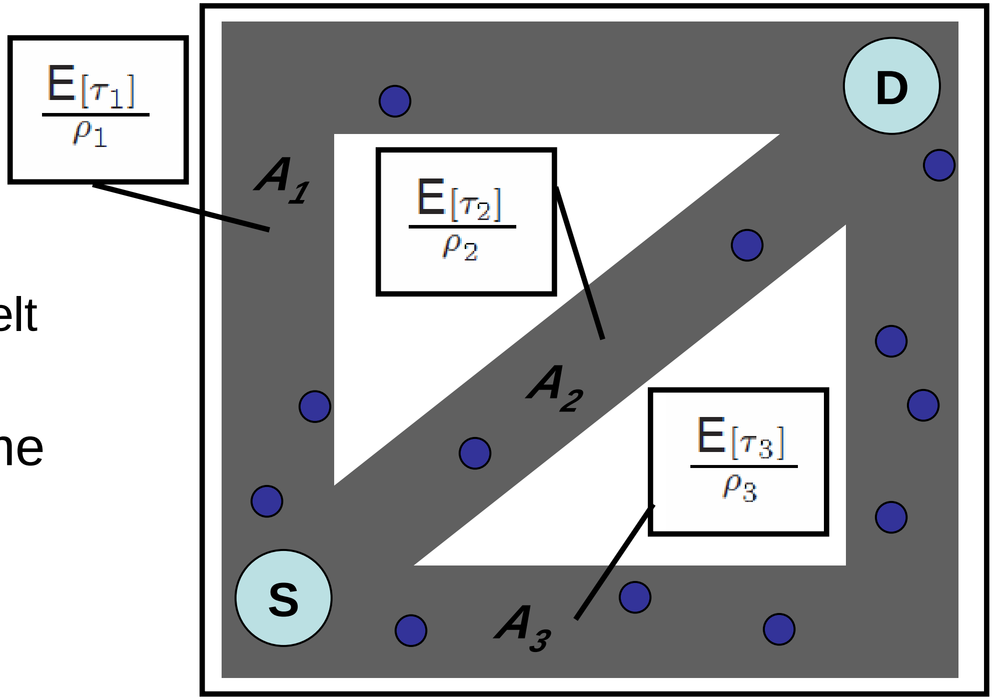
Context

- Geographic routing (*geounicast, geomulticast, geocast*) is gaining more reputation in mobile networks
  - resilient to frequent topology changes: it does not require global knowledge about network topology at every node
  - positioning is no longer a nightmare (soon GPS in every mobile device)
- Mobile Partitioned Networks (MPNs)
  - Sparse, clustered or highly mobile networks
  - Limited end-to-end connectivity: opportunistic message exchange
- Exploiting mobility for communication: *mobility-assisted forwarding*
  - Message ferrying
  - Predictable individual mobility
  - Time-stable collective mobility

Georouting in MPNs

- <u>Objective:</u> minimizing the expected message delay
- <u>Observation:</u>
  - message delay = *f(*density, inter-contact time*)* [Groenevelt et al.,Perform.Eval.'05]
  - density and inter-contact time may be specific to a certain subregion
- <u>Approach:</u> rely on mobility characteristics specific to subregion, which contains S and D

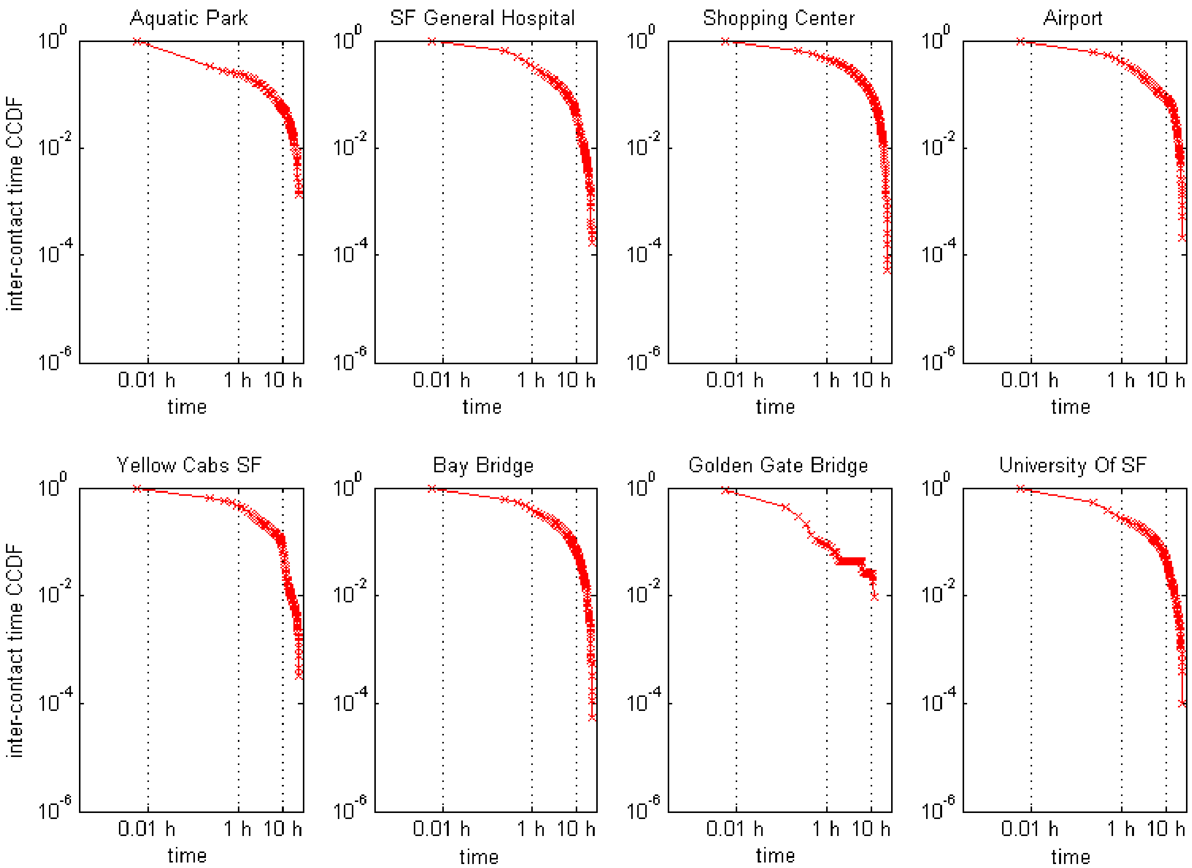


Design guidelines:

- Is the *forwarding subregion* topologically connected?
- What the *node density* within forwarding subregion is?
- What the *mobility characteristics* there are?

Spatial Heterogeneity of Mobility

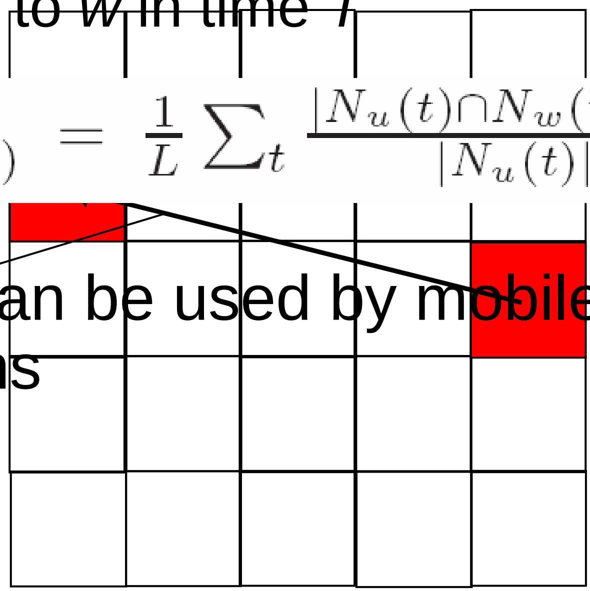
- Real-life mobility trace: >500 taxi cabs in Bay Area over 30 days
- Empirical CCDF of inter-contact time at eight different locations



Mobility Map: definition

- Global shared map, which stores mobility patterns of nodes from one region to another
- Markovian model of aggregate mobility behavior:
  - directed graph *M*(*V,E*); *V*(*M*): locations, *E*(*M*): *mobility links*
  - $\pi^T_{(u,w)}$: *transition probability* - probability that a random node moves from *u* to *w* in time *T*

$$\pi^T_{(u,w)} = \frac{1}{L} \sum_t \frac{|N_u(t) \cap N_w(t+T)|}{|N_u(t)|}$$



- If time-stable, can be used by mobile nodes to take better routing decisions

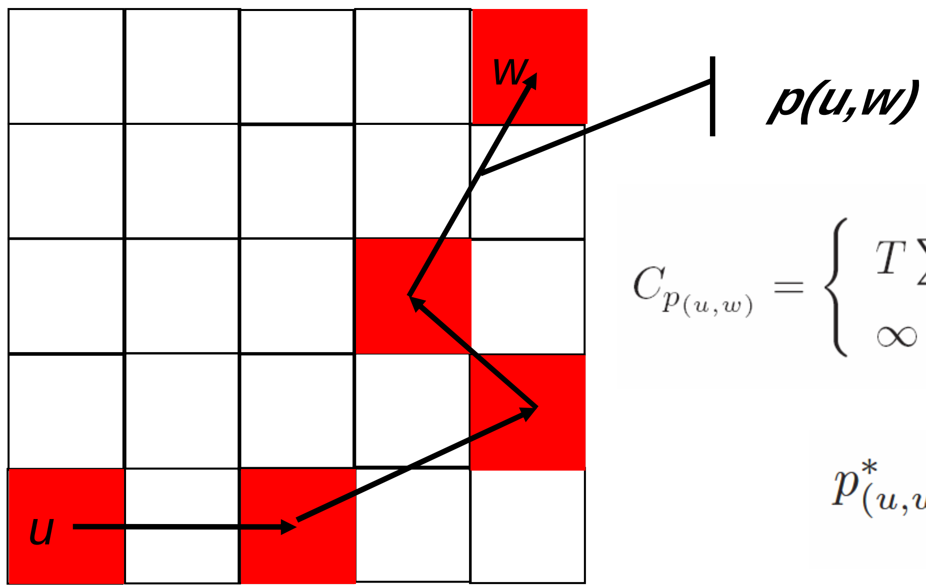
Mobility Map: features & evidence

- Required characteristics:
  - *Time-stability*: aggregate mobility pattern is stable in time
  - *Explorability*: for any two locations *u* and *w* from *V*(*M*) there exists sample path (corresponding Markov chain is irreducible)

- Evidence from the real-life mobility trace:
  - For each day *d* (=[1…30]) and time lag T=100s we find empirical mobility map: $M^d(T)$
  - *Time-stability*: 10% of all visited locations over 30 days can be considered as time-stable
  - *Explorability*: on average 50% of all visited locations at one day *d* belong to the largest irreducible set of $M^d(T)$

Mobility Map: application

- Nodes from which locations should be responsible for forwarding message **m** to destination region **D**?



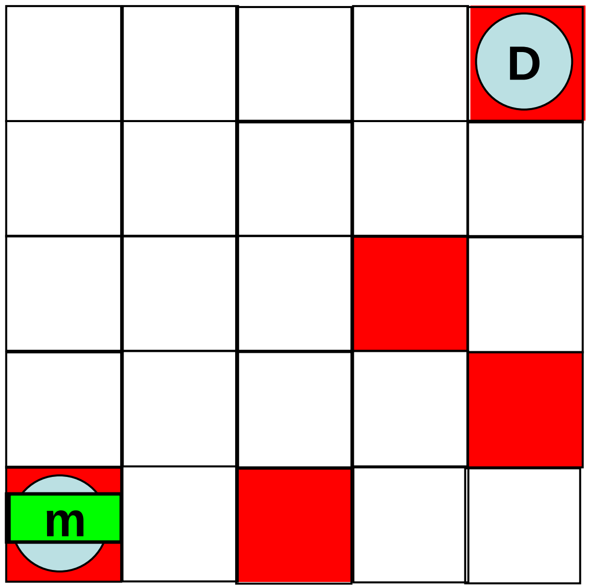
$$C_{p_{(u,w)}} = \begin{cases} T \sum_{(v_k,v_l) \in p_{(u,w)}} \frac{(1-\pi^T_{(v_k,v_l)})}{\overline{N}_{v_l}} & \text{if } p_{(u,w)} \neq \emptyset \\ \infty & \text{if } p_{(u,w)} = \emptyset \end{cases}$$

$$p^*_{(u,w)} = \operatorname*{argmin}_{p_{(u,w)} \in \mathcal{P}_{(u,w)}} C_{p_{(u,w)}}$$

- *minimum delay path:* ***p*(u,w)*** = topologically connected forwarding subregion with optimal collective mobility pattern

GeoMobCast: *geocast* for MPNs

- Best effort, multi-copy, probabilistic geocast for MPNs designed to minimize expected message delay

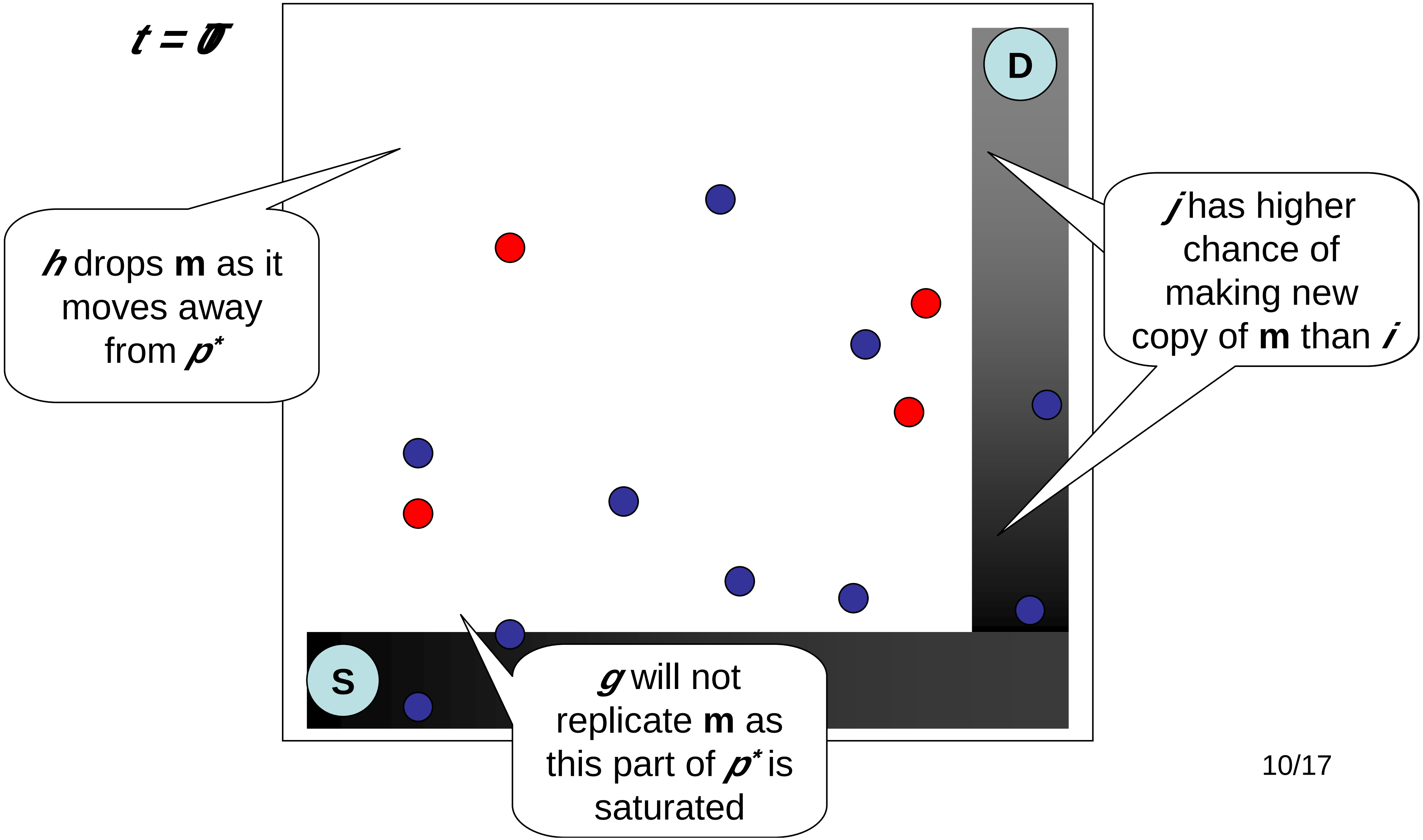


- Greedy approach may *got stuck* (obstacles, no long-term mobility information)
- Instead, **m** can be *pushed* towards intermediate locations where *stable* mobility pattern is observed – there **m** can *hitchhike* mobile nodes moving towards locations from the forwarding subregion determined by ***p****

GeoMobCast: protocol details

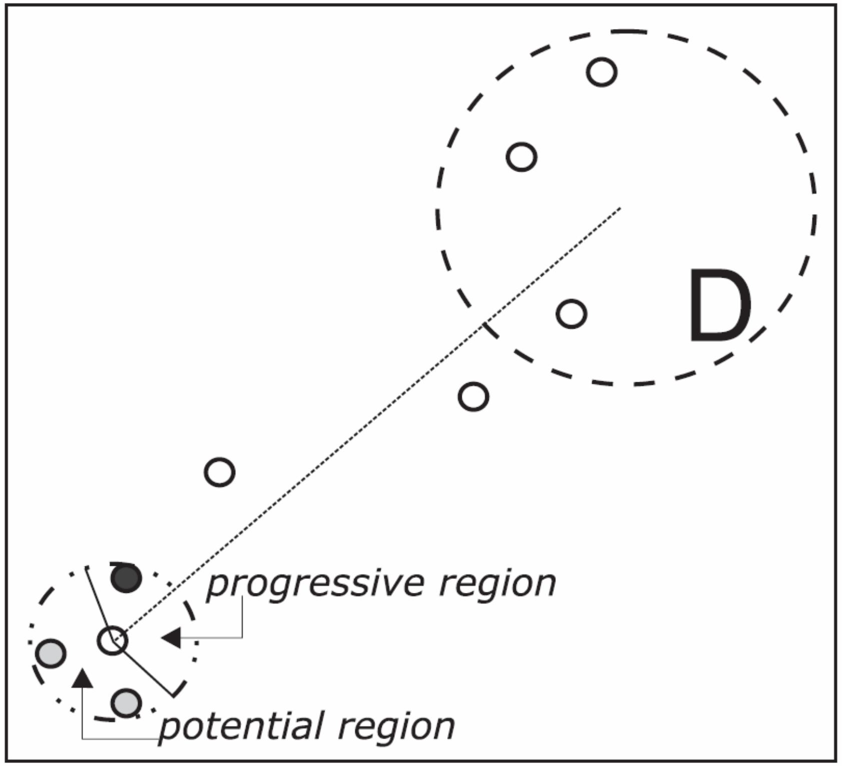
- Message format
  - ***p**** encoded in the header (similarly to IP source routing)
- Forwarding rules
  - **m** is propagated along ***p****
  - **m** is more likely propagated towards destination
  - **m** is more likely propagated by a distant node
- Removing obsolete copies
  - suppressing by counting
  - messages that do not make progress are dropped

GeoMobCast: example



Reference Scheme

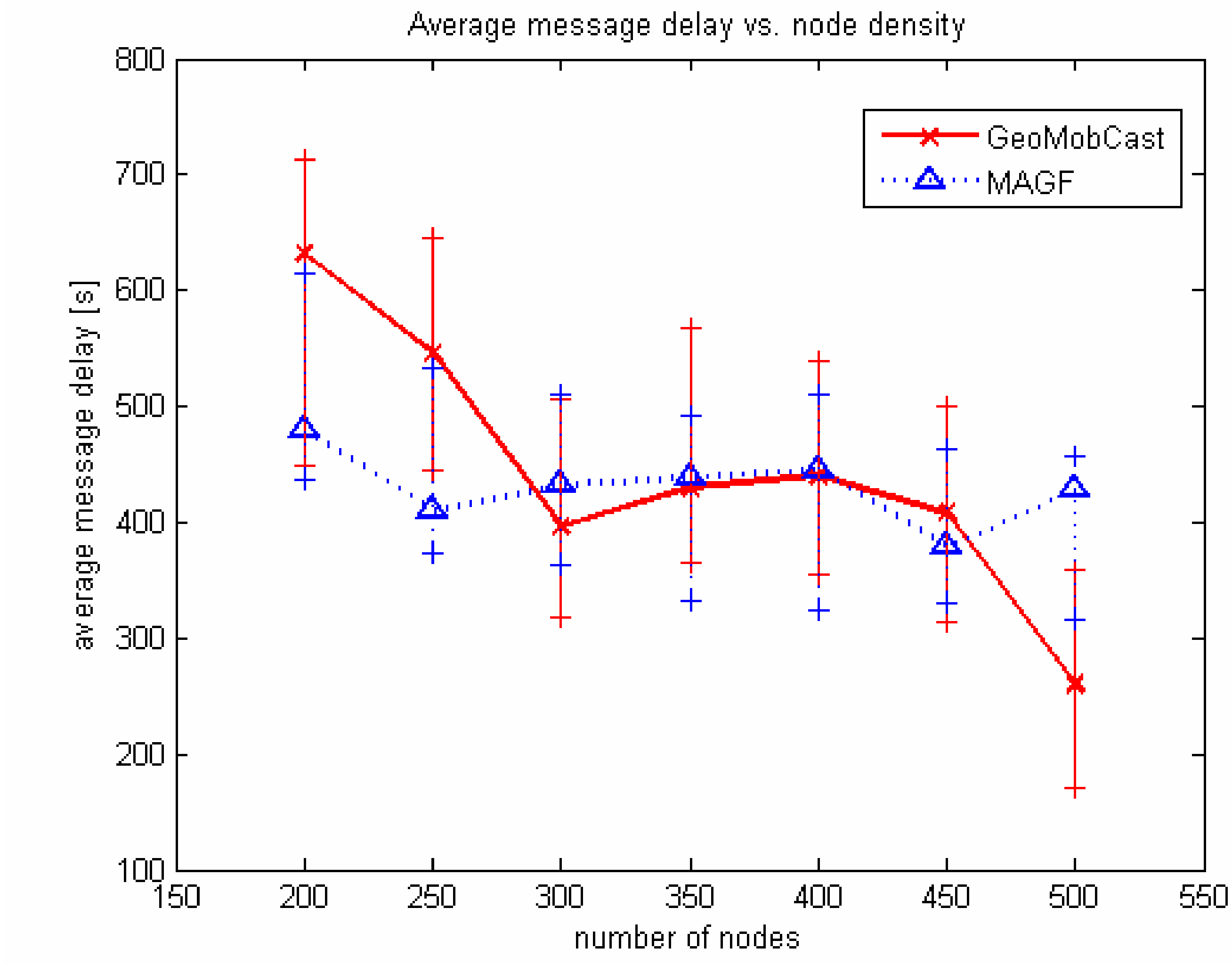
- Mobility-based Adaptive Greedy Forwarding (MAGF) [Li, Shatz MODUS'07]
  - By default **m** is forwarded to node from progressive region
  - Otherwise **m** is passed to a node with the highest *mobility potential* from the potential region



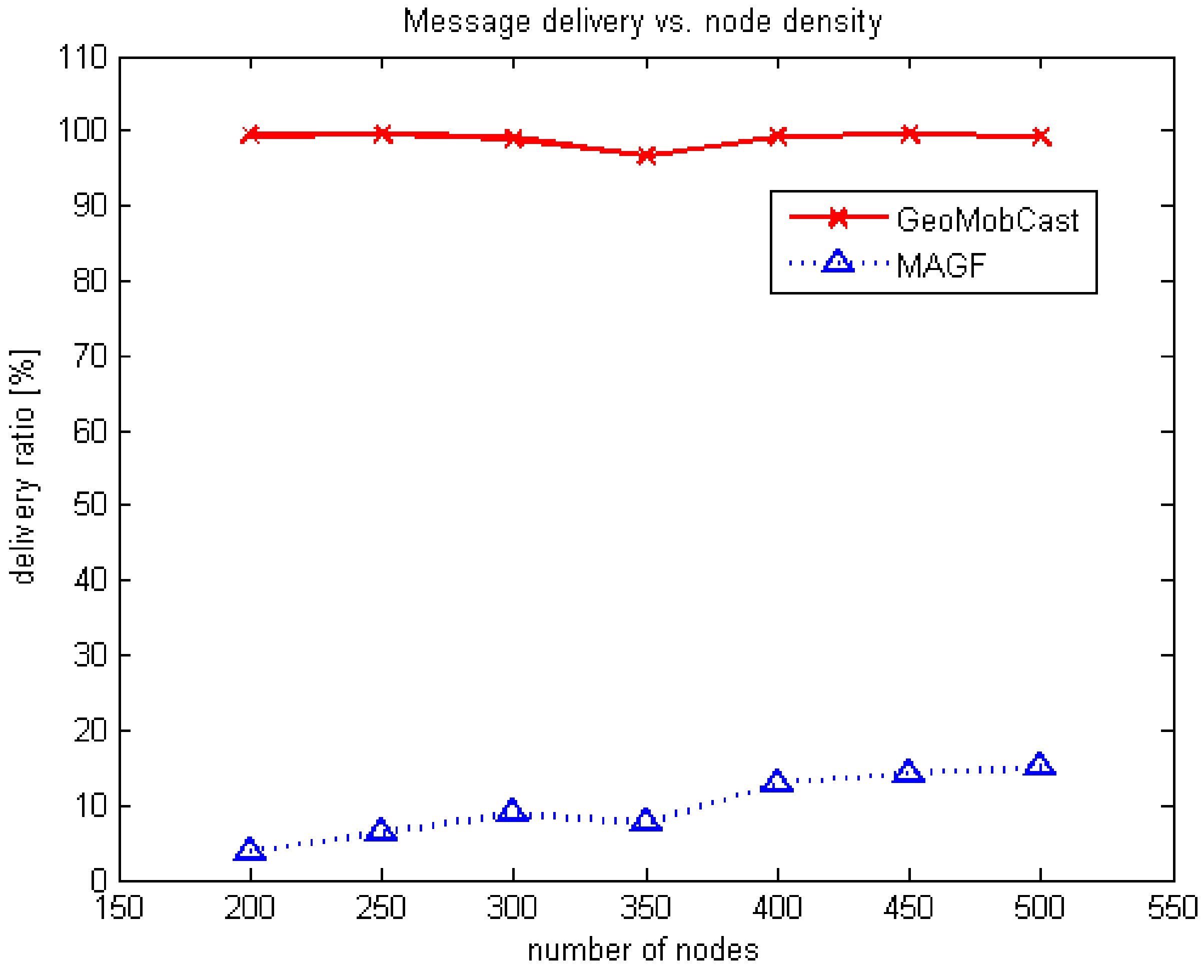
Simulation Details

- JiST/SWANS – Java-based simulator with realistic PHY & MAC
- 200-500 nodes
- Squared surface: 5000 x 5000 [m]
- Restricted Random Waypoint Mobility Model [Blazevic et al. IEEE TMC'05]
- Performance metrics:
  - ***message delay and delivery***
  - ***extinction time*****:** interval between the delivery time and time when the last copy of the message was made
  - ***message overhead*****:** average number of message copies made

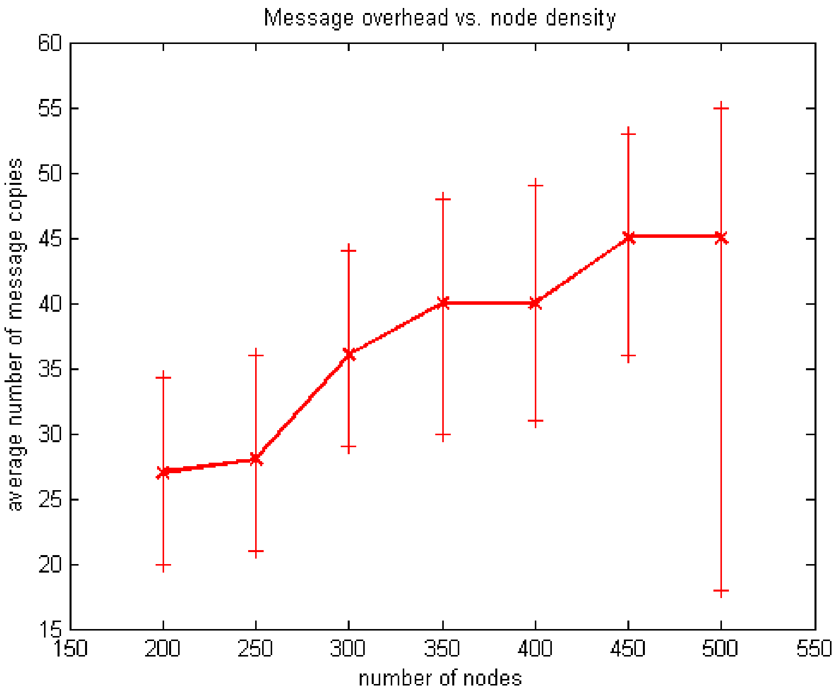
Simulation Results: *message delay*

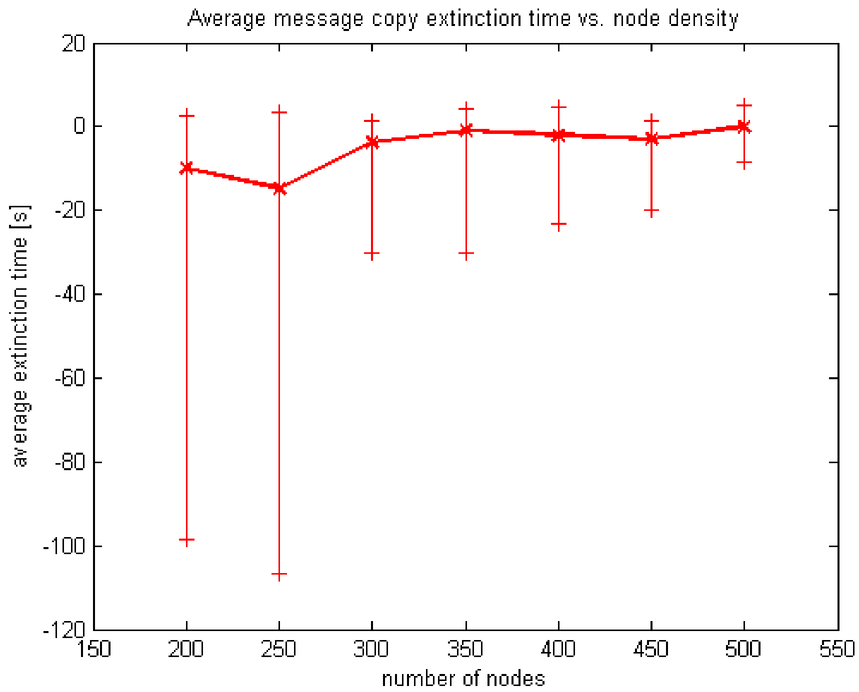


Simulation Results: *message delivery*



Simulation Results: *message extinction & overhead*





Future Work

- Analysis of further mobility traces in the context of Mobility Maps
- Improving the performance of GeoMobCast
  - reducing overhead
  - single-copy GeoMobCast
- Collaborative Discovery of Mobility Maps
  - spatially-decaying aggregation of mobility links [Cohen,Kaplan SIGMOD'04]
- Using Mobility Maps for mobility-centric worm mitigation techniques [Yan et al. ACM ASIACCS'07]

Conclusions

- Effective georouting in MPNs requires knowledge about the forwarding subregion:
  - topological characteristics (path-connected subregion)
  - mobility pattern
  - node density

- Time-stable collective mobility pattern is inhomogeneous and it is prevalent in real-life mobility scenarios

- It can be learned collaboratively by nodes and can be used to improve packet delivery performance, e.g. GeoMobCast - geocast service for MPNs

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