Mobility-Centric Geocasting For Mobile Partitioned Networks

Michał PióRKOWSKI
School of Computer and Communication Sciences
EPFL, Switzerland

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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

- **Objective**: minimizing the expected message delay
- **Observation**: 
  - message delay = \( f(\text{density}, \text{inter-contact time}) \) [Groenevelt et al., Perform. Eval.’05]
  - density and inter-contact time may be specific to a certain subregion
- **Approach**: 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 $T$

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

• 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 $D$?

- **Minimum delay path**: $p^*(u, w) = \text{topologically connected forwarding subregion with optimal collective mobility pattern}$

\[
C_{p(u, w)} = \begin{cases} 
T \sum_{(v_k, v_l) \in p(u, w)} \frac{(1 - \pi_{v_k, v_l})}{N_{v_l}} & \text{if } p(u, w) \neq \emptyset \\
\infty & \text{if } p(u, w) = \emptyset 
\end{cases}
\]

\[
p^*(u, w) = \arg\min_{p(u, w) \in \mathcal{P}(u, w)} C_{p(u, w)}
\]
GeoMobCast: *geocast* for MPNs

- Best effort, multi-copy, probabilistic geocast for MPNs designed to minimize expected message delay
- Greedy approach may not work (obstacles, no long-term mobility information)
  - Instead, message can be pushed to 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

\( t = 0 \)

- \( h \) drops \( m \) as it moves away from \( p^* \)
- \( j \) has higher chance of making new copy of \( m \) than \( i \)
- \( g \) will not replicate \( m \) as this part of \( p^* \) is saturated
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*

![Graph showing average message delay vs. node density](image)
Simulation Results: message delivery

Message delivery vs. node density

- GeoMobCast
- MAGF

delivery ratio [%]

number of nodes
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

http://people.epfl.ch/michal.piorkowski