Impact of Mobility Constraints on Epidemic Broadcast Mechanisms in Delay-Tolerant Networks

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Outline

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Epidemic Broadcast

A store-and-carry message forwarding for one-to-all communication

- A message is repeatedly forwarded *among encounter nodes*
- All nodes perform the same *probabilistic message forwarding*
  - Every node has very limited knowledge on the network (e.g., existence of neighbor nodes)
  - Decentralized autonomous mechanism (i.e., no centralized controller)

Major Factors Affecting Epidemic Broadcast Performance

Forwarding algorithm

- E.g., forwarding probability, the number of copies, message history, knowledge exchange among nodes

Node mobility

- E.g., node density, node velocity, destination, path selection, interference with other nodes

Impact of forwarding algorithm and node mobility on epidemic broadcast has been actively studied in the literature, but...

Motivation

Impact of mobility constrains on epidemic broadcast has not been well understood

- Several *open-space mobility models* have been used in epidemic broadcast studies
  - e.g., Random Walk, Random Waypoint, Aggregation Points, Swarm Mobility
- However, the mobility of node is usually restricted by *several geographical constrains* (e.g., roads, obstacles, no-entrance zones)

Objectives

Quantitatively investigate the effect of mobility constrains on epidemic broadcast mechanisms

- What type of mobility constrains does affect their performances/properties?
- How much are performances/properties affected with mobility constrains?
  - Reachability
  - Dissemination speed
  - Efficiency

Related Works

MANET researches generally uses unconstrained mobility models

- Random Walk
- Random WayPoint
- Aggregation Point
- Swarm Mobility

Some VANET researches uses constrained mobility models

- Manhattan mobility model
- Obstacle mobility model
- Roadmap-based mobility model

However, no comparative study on the impact of mobility constraints

Two Types of Mobility Constrains

Path constrains

- A node has to move along one of predetermined paths (e.g., roads in VANETs)

Area constrains

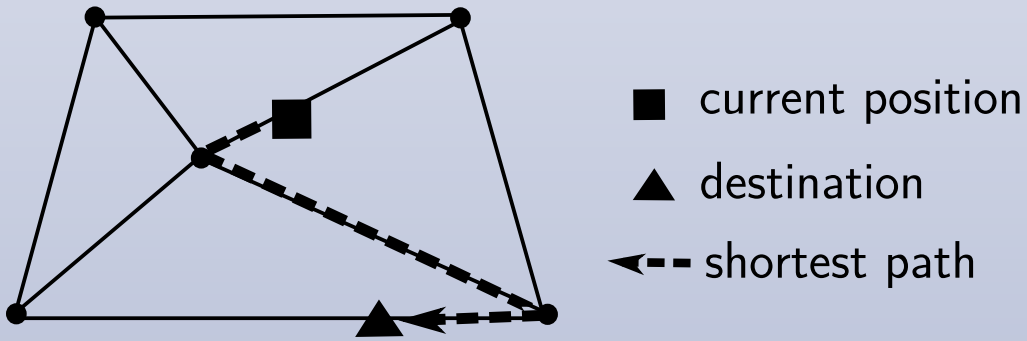
- A node cannot cross a part of the filed (e.g., no-entrance zones and obstacles)

We focus on path constrains since they are commonly observed in MANETs and they can easily approximate area constrains

Mobility Model with Path Constraints

We extend the Random Waypoint mobility model, one of the most popular mobility models, to incorporate path constraints

- For a given *set of paths (i.e., graph)*, every nodes moves according to RWP except:
  - The initial position and destination of a node are placed on randomly-chosen paths
  - Every node moves toward its destination following the shortest-path to its destination



Experiment Setup

- A fixed number of nodes randomly move according to the CRWP mobility model on 1,000 [m] $\times$ 1,000 [m] simulation field
- The velocity of nodes are uniformly distributed in [1, 2] [m/s]
- The radio communication range of a node is 10 [m]
- At the initial state, only a single node (i.e., originating node) has a message and starts its message broadcast.

Epidemic Broadcast Mechanisms (1/2)

A simple epidemic broadcast

- P-BCAST (PUSH-based BroadCast)
  - A node forwards the message *whenever* it encounters other node
  - Achieves *the optimal effectiveness* (maximum reachability, maximum dissemination speed) with *the worst efficiency* under infinite bandwidth

Epidemic Broadcast Mechanisms (2/2)

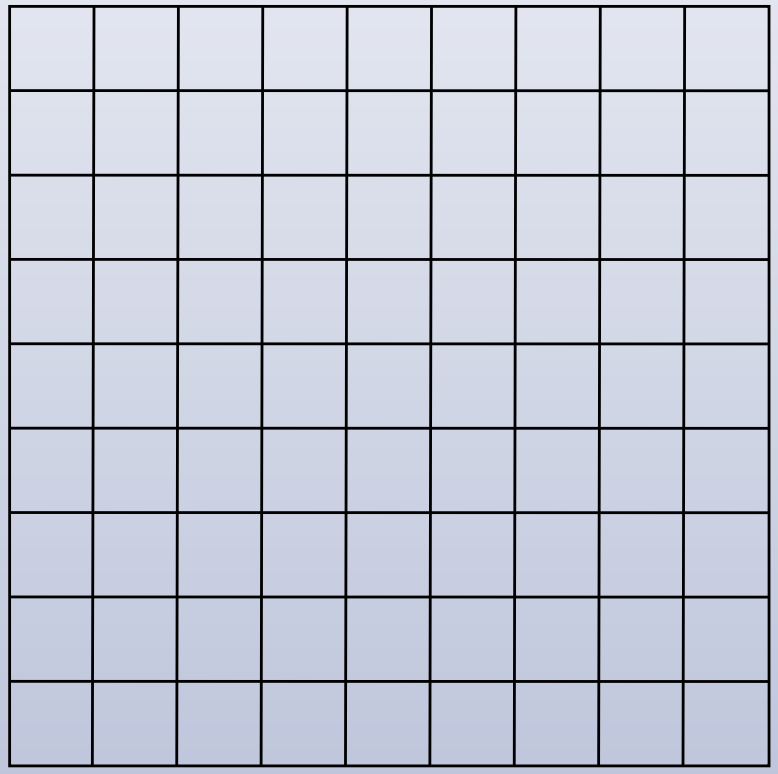
Two extensions (self-adaptation and history) to P-BCAST

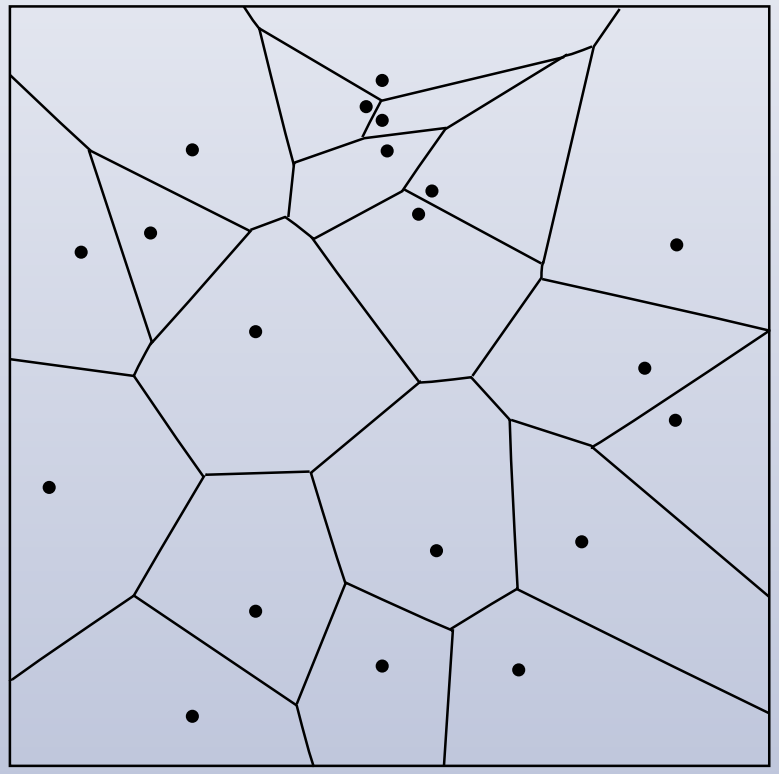
- SA-BCAST (Self-Adaptive BroadCast)
  - *Forwarding probability is adjusted* based on the number of duplicate messages
  - A node forwards only when a fraction of neighbor nodes are changed
- HP-BCAST (History-based P-BCAST)
  - *Using message history*, a node refrains messages forwarding when the encounter node is in the history (i.e., the message was sent to or received from the encounter node)

Path Constraints

In simulation, we use three types of path constraints

- No constraint
- Grid
- Voronoi



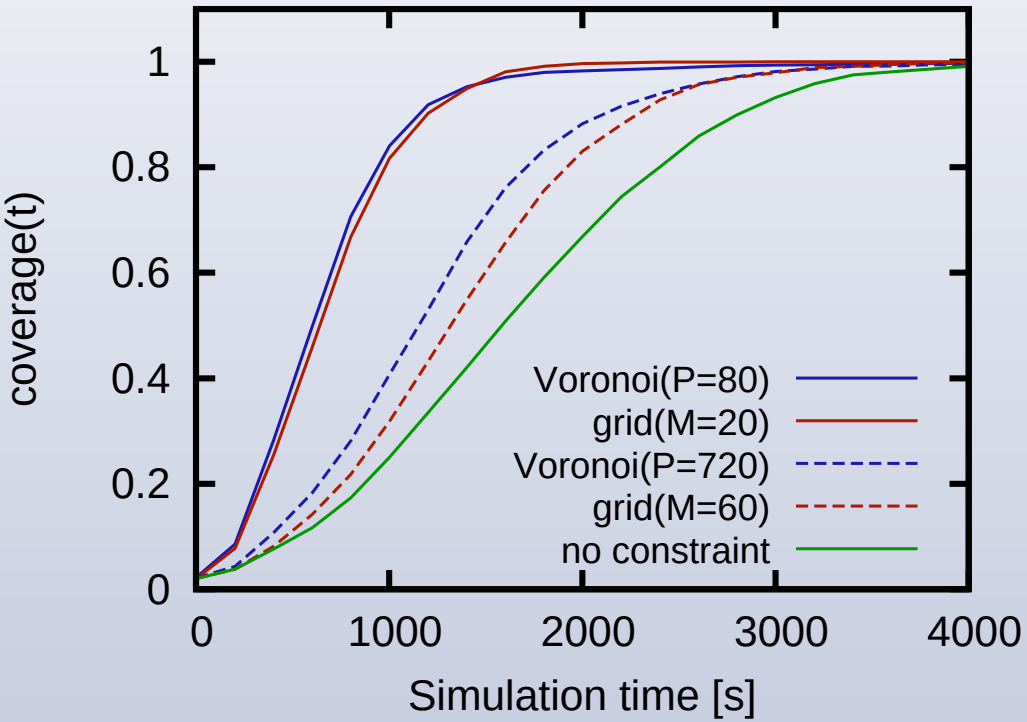


Performance Metrics

- Reachability
  We define coverage(t) as the ratio of infected nodes in the simulation area at time t.
- Dissemination speed
  The speed of message dissemination is measured by p%-delivery_time, which is defined as the time elapsed until p % of all nodes successfully receives the message.
- Efficiency
  We define messages_per_delivery(t) as the average number of messages transmitted for making a node to be infected by time t.

Simulation Result: Reachability

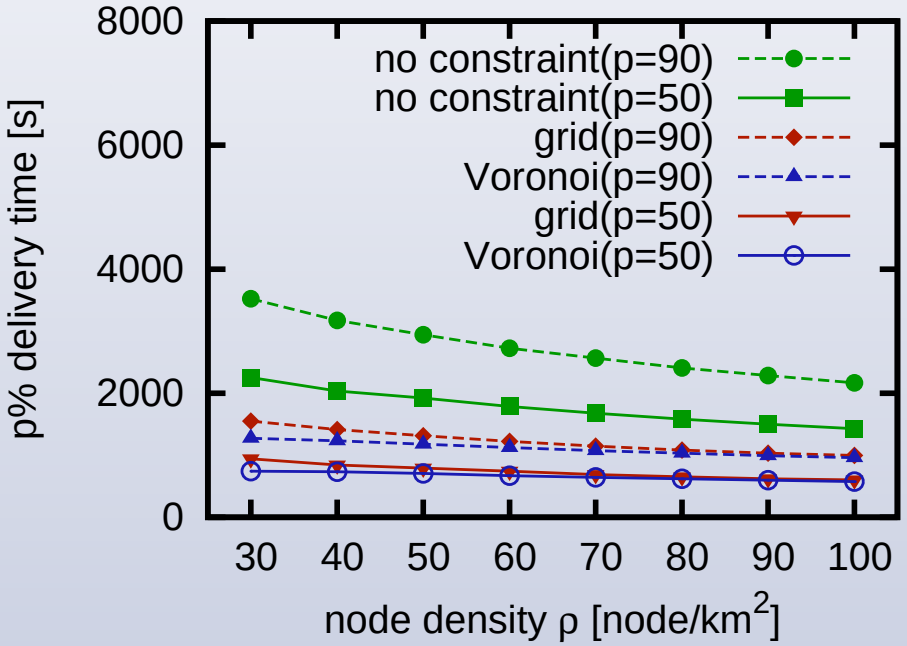
Evolution of coverage(t) with different mobility constraints in P-BCAST ($\rho = 50$ [node/km^2])



Existence of mobility constraints significantly improves reachability of epidemic broadcast mechanisms

Simulation Result: Dissemination speed

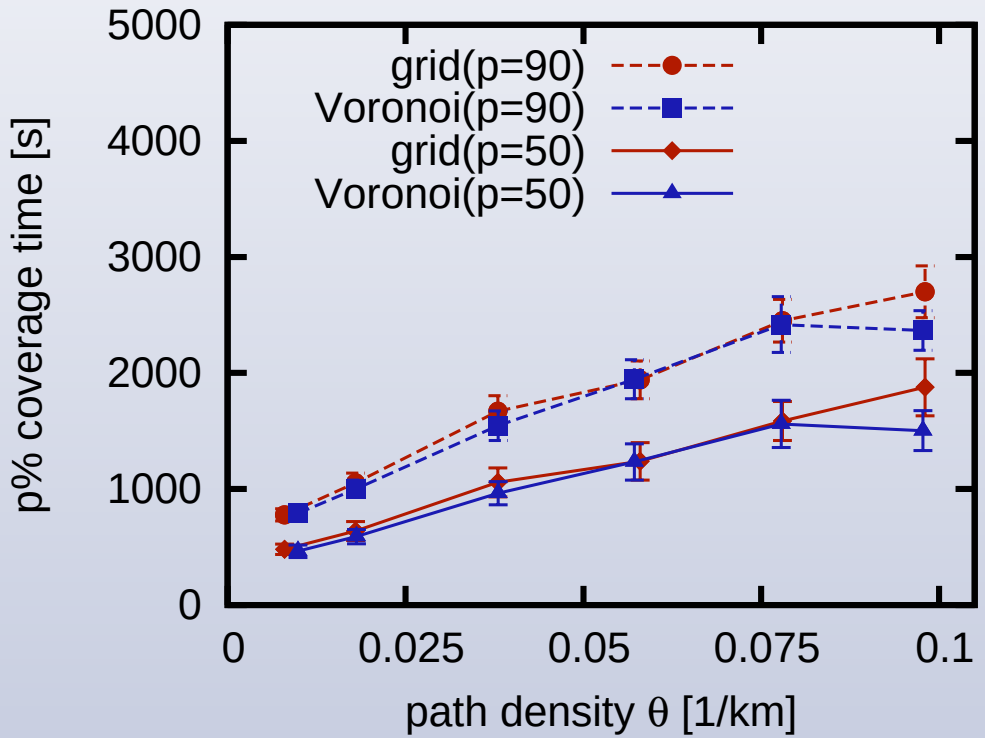
50%- and 90%-delivery_time with different mobility constraints for varied node densities ρ



The speedup factor (i.e., the ratio of p%-delivery_time with and without mobility constraint) is approximately 0.4 regardless of the node density and the value of p

Simulation Result: Path Density

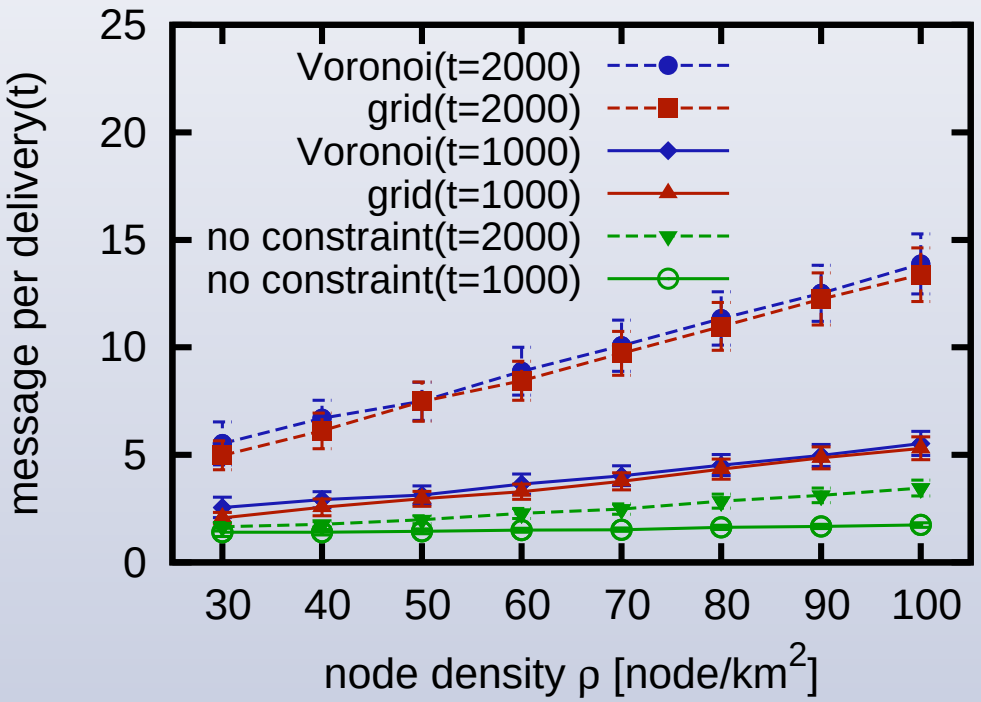
50%- and 90%-delivery_time are plotted as a function of the path density (= total path length / field size)



The impact of mobility constraints is well characterized by the path density

Simulation Result: Efficiency

messages_per_delivery(t) at $t = 1,000$ and 2,000 with different mobility constraints



Existence of mobility constraints worsen the efficiency of epidemic broadcast mechanisms

Conclusion (1/2)

We have investigated the effect of mobility constraints on epidemic broadcast mechanisms in DTNs

- Epidemic broadcast mechanisms
  - P-BCAST, SA-BCAST, and HP-BCAST
- Mobility model
  - CRWP (Constrained Random WayPoint) mobility model

Conclusion (2/2)

Our findings include...

- Existence of mobility constraints significantly improves the performance of epidemic broadcast mechanisms
  - Performance evaluation only with unconstrained mobility models might lead to wrong conclusion
- The impact of mobility constraints is well characterized by the path density, which is defined as the ratio of total path lengths to the size of the field

Future Works

- Design an epidemic broadcast mechanism, which improves the inefficiency under constrained mobility models
- Mathematical analysis of epidemic broadcast mechanisms with mobility constraints