Multi-copy Routing with Trajectory Prediction in Social Delay-Tolerant Networks

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Outline

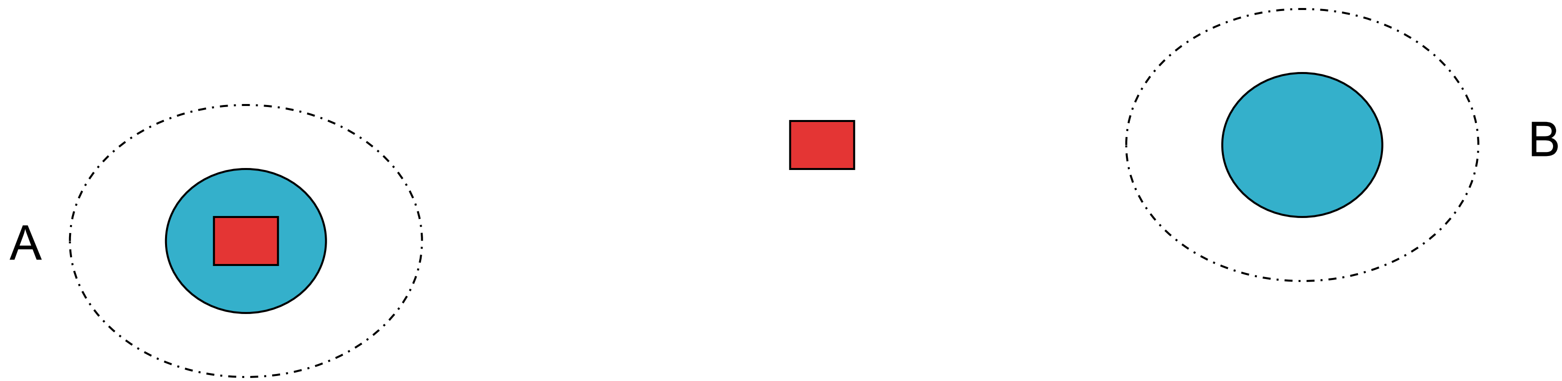
- Background
- Motivation
- Prediction-based Multi-copy Routing
- Simulation
- Conclusion

Background

- Traditional Wireless Networks
  - Base station support
  - End-to-end Round Trip Time is not terribly large
  - Some path exists between endpoints
  - Always finds single "best" existing route
  - Low loss rates (under 2% or so)
- Disruption-Tolerant Networks (DTNs)
  - Limited base station support
  - Dynamic network topology
  - Unstable link connectivity, disruption
  - High delay and packet loss
  - Example: Underwater Sensor Networks, Animal Tracking Networks, Military Ad-hoc Networks
  - **Routing in DTNs becomes a big challenge!**

Background

- To improve routing performance in DTNs
  - Only "proper" nodes can get a copy: 1) *Destination* node, 2) *Messengers* - nodes who will encounter the destination in the near future.
  - Store-Carry-and-Forward delivery



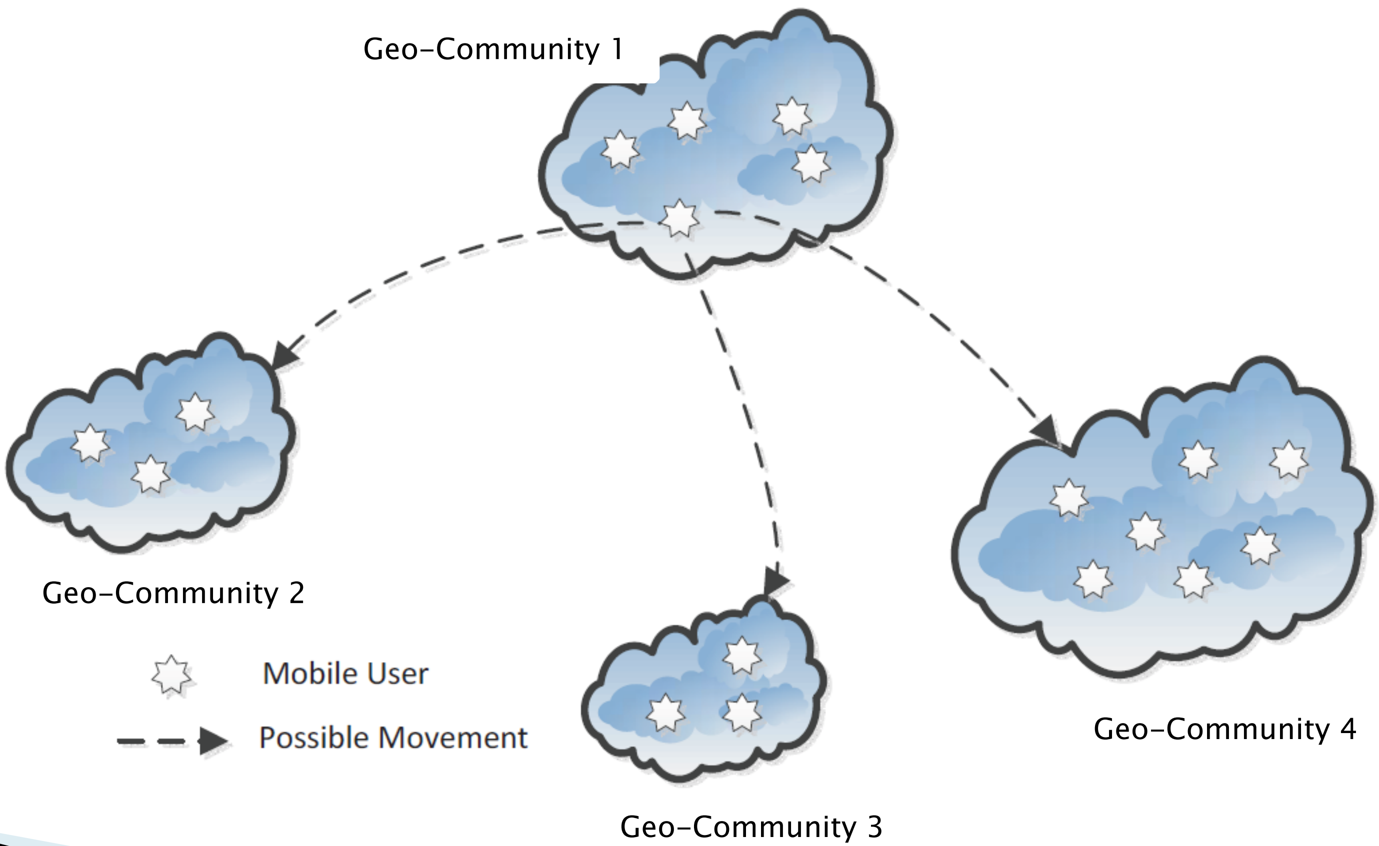
  - How to define those messengers??

Background

- Prediction-based Routing
  - Inter-node contacts and mobility behaviors are predicted first.
  - Messengers (next hops) are determined based on such predictions to maximize QoS (e.g. delay or delivery ratio).
  - Two types:
    - single-copy routing: minimum traffic overhead but relatively large delay.
    - multi-copy routing: more copies to improve delay and delivery ratio.

Background

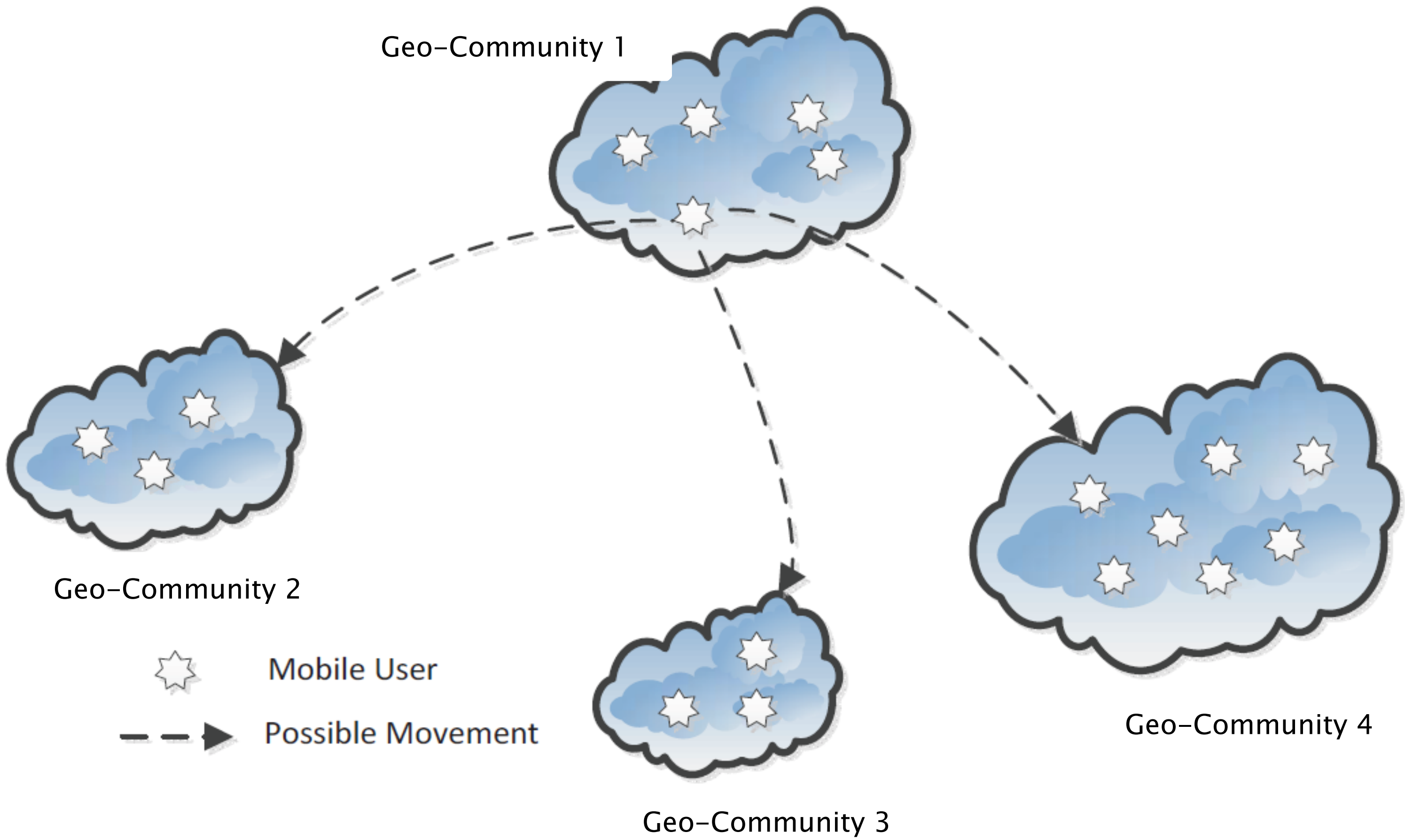
- Meanwhile, most DTNs have a social network nature



Motivation

- Goal: employing the social network nature to improve routing performance in social DNTs.
    - Social network nature is helpful to further improve mobility prediction accuracy by evaluating future contacts and their occurring time.
    - Then, pick a group to proper messengers to deliver packets to the destination.
    - Employ the multi-copy strategy to further reduce the delivery delay and enlarge delivery ratio.
- McRTP: a Multi-copy Routing protocol with Trajectory Prediction for social DTNs.

System Model & Assumptions

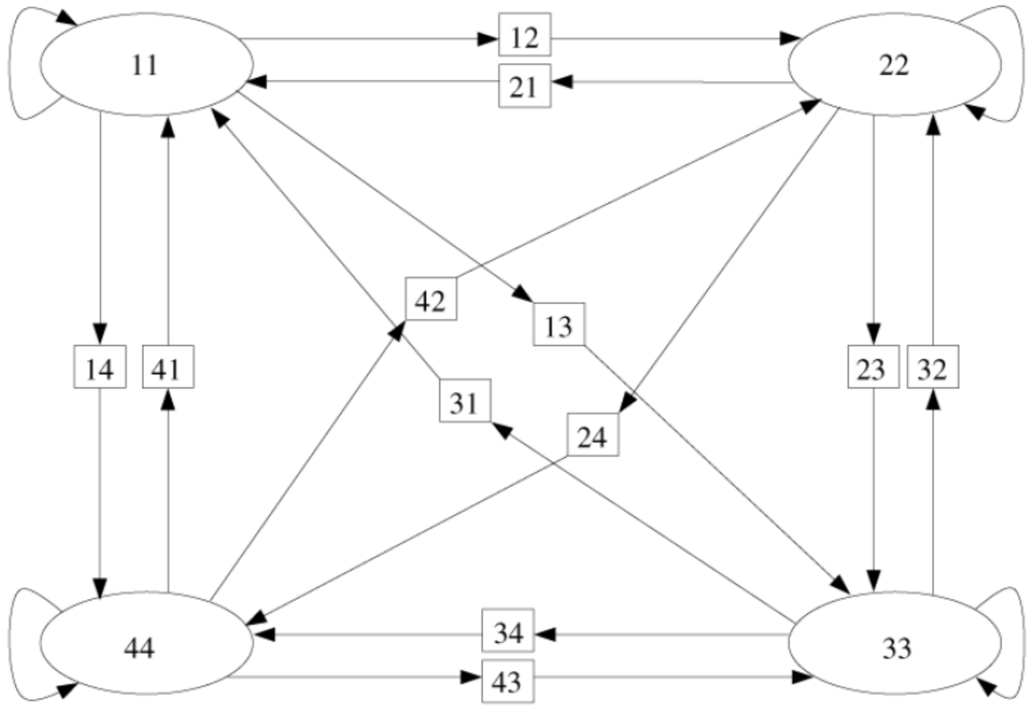


Protocol Overview

- Basic idea
  - A node can forward one or more copies of the same message to different nodes, during successive contacts.
  - The number of copies for a message is initialized at the source.
  - A node only distribute message copies to the nodes who are most likely to see the destination.
- Three core components
  - Candidate paths selection
  - Copy count assignment
  - Message forwarding policy

Contact Prediction (1)

- Time-Homogeneous Semi-Markov process



- *Define* $S_{ij}(k)$, as the probability that a node will move from state i to j within k time units
- Define $p_{ij} = P(X_{n+1} = j | X_n = i)$ as the state transition probability from Markov state i to j $(1 \leq i, j \leq l2)$

Contact Prediction (2)

- Time-Homogeneous Semi-Markov process
  - The homogeneous Semi-Markov kernel Q of this process is

$$\begin{aligned} Q_{ij}(k) &= P(X_{n+1} = j, T_{n+1} - T_n \leq k | X_0, ..., X_n; \\ & \quad T_0, ..., T_n) \\ &= p_{ij} S_{ij}(k). \end{aligned}$$

  - Further, we have the node trajectory prediction

$$\begin{aligned} \phi_{ij}(k) &= P(Z_k = j | Z_0 = i) \\ &= (1 - S_i(k))\delta_{ij} + \sum_{r=1}^{l^2} \sum_{\tau=0}^{k} \dot{Q}_{ir}(\tau) \phi_{rj}(k - \tau) \end{aligned}$$

  - Contact profile $C_{ab}(k)$ that gives the contact probability of two nodes a, b at time $k \geq max\{t_a, t_b\}$

$$C_{ab}(k) = \sum_{x=1}^{l} \phi^a_{i_a(L_x L_x)}(k - t_a) \phi^b_{i_b(L_x L_x)}(k - t_b)$$

Path Selection (1)

- Path evaluations
  - Define the delay distribution *d*() as the probability of a message that at time *T* is at node *a*, to be delivered at node *b* at time *T* +*t*,

$$d(T,t,ab) = \begin{cases} 1 \\ (a \text{ and } b \text{ are in contact at time } T) \\ C_{ab}(T+t)\prod_{k=0}^{t-1}(1 - C_{ab}(T+k)) \\ (a \text{ and } b \text{ not in contact at time } T \text{ and } t > 0) \\ 0 \\ (\text{if } a \text{ and } b \text{ not in contact at time } T \text{ and } t = 0) \end{cases}$$

  - The delay distribution *d(T, t,R1R2)* is then extended for a path made of the concatenation of two adjacent sub-paths *R1 and R2*

$$d(T,t,R_1R_2) = \sum_{k=0}^{t} d(T,k,R_1)d(T+k,t-k,R_2)$$

Path Selection (2)

- Path evaluations
  - Further, the probability that a message transmitted at time *T* on a path *R* arrives with maximum delay *t*

$$D(T, t, R) = \sum_{k=0}^{t} d(T, k, R)$$

D is called the *maximum delay distribution* for messages on path R before time t, and it is used by McRTP as a prediction metric to select the most promising paths.

  - Based on TTL, algorithm computes the *maximum delay distribution D* at the source for all possible paths of lengths 2, ..., λ (λ is limited to 3 to diminish overhead)
  - Then sort the paths according to their *D* value in a decreasing order, and form the candidate paths set *Q*.

Path Selection (3)

- Generating candidate paths set Q algorithm

Algorithm 1 Candidate Paths Selection

Require: V, set of nodes; s, source node; T, current time; m_{path}, set of nodes already visited by message m.

Ensure: set Q with candidate paths on which to forward the message

set $\mathcal{R} = \emptyset$ {set with paths from s to destination d}
{for adding paths of length 2}
for all $i \in V \setminus m_{path} \setminus \{s, d\}$ **do**
  if $D(T, ttl(m), si) > 0$ **then**
    $R = [s, i, d]$
    $D_R = D(T, ttl(m), R)$
    if $D_R > 0$ **then**
      $\mathcal{R} = \mathcal{R} \cup \{R\}$
{for adding paths of length 3}
if $m_c > 2$ **then**
  for all $i \in V \setminus m_{path} \setminus \{s, d\}$ **do**
    if $D(T, ttl(m), si) > 0$ **then**
      for all $j \in V \setminus m_{path} \setminus \{s, d, i\}$ **do**
        $R = [s, i, j, d]$ {path from s to d of length 3}
        $D_R = D(T, ttl(m), R)$
        if $D_R > 0$ **then**
          $\mathcal{R} = \mathcal{R} \cup \{R\}$
sort paths R from $\mathcal{R}$ based on decreasing value D_R
create β vector with n elements
set $Q = \emptyset$ {set with selected paths from s to d}
$k = 1$ {index in sorted set $\mathcal{R}$}
while $k \le |\mathcal{R}|$ **do**
  R_k = the k^{th} path from $\mathcal{R}$ sorted in decreasing order of D_R
  if CountCopies$(m_c, Q \cup \{R_k\}, \beta) \le m_c - 1$ **then**
    $Q = Q \cup \{R_k\}$
  $k = k + 1$

Copy Account Assignment

- function *CountCopies* (c, Q, β)
  - computes the total number of message copies needed to send a message from a node s to destination d on all paths in the candidate paths set Q from the previous phase.
  - Parameter β is a vector of n elements, whose element is the total number of message copies needed for all paths in Q that begin with a index node.
  - Parameter c is the current count. If the computed count reaches c, the function returns c.
  - Example: For example, if $Q = \{sad, sbd, sacd\}$, then *CountCopies*(10, Q, β) computes $\beta_{sabcd} = [4, 2, 1, 1, 0]$ and the function returns 4, which is the value of β_s.

Message Forwarding

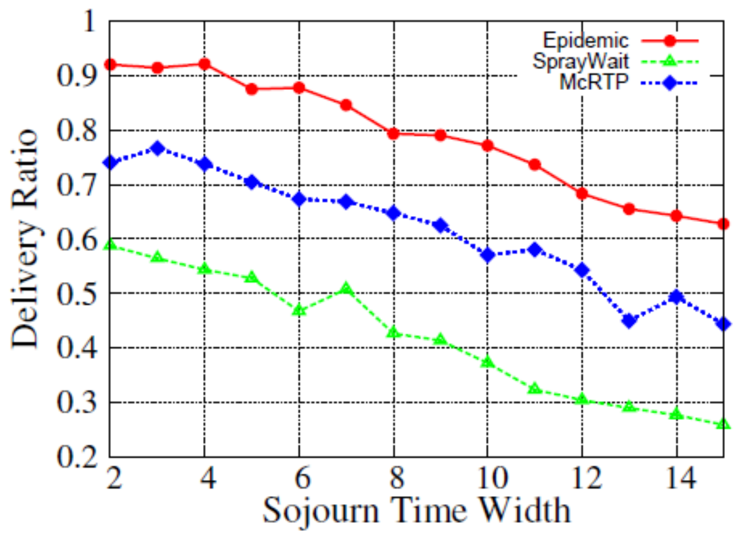
- Each message maintains a message copy property, which is called *copy account*.
- Once the β values are computed at source, source node *s* sends β_j copies to node *j* when they are in contact, as evaluated in the copy account assignment phase, if $\beta_j > 0$.
- If $\beta_j = 0$, then node *s* does not forward the message to node *j*.

Simulation

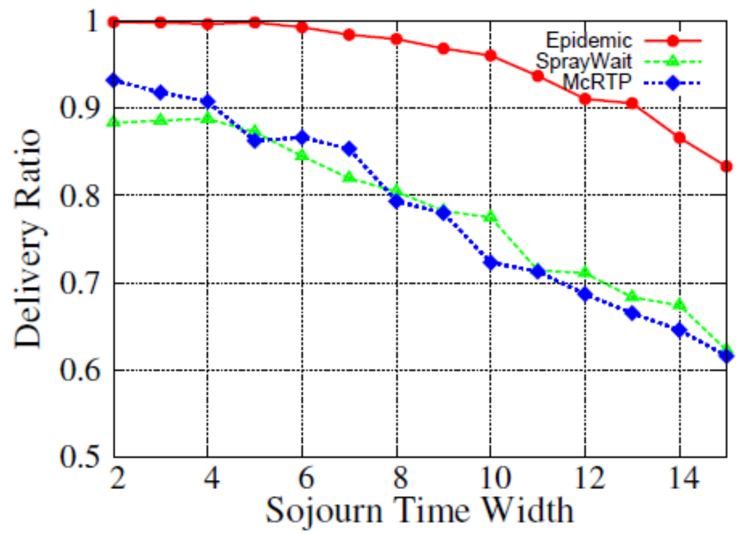
- Algorithm in comparison
  - Epidemic routing
  - Spray-and-wait
  - On a custom packet-based simulator
- Settings
  - 10 *geo-communities* with *n* nodes uniformly distributed
  - Travelling time between two *geo-communities* is uniformly distributed in [2, 3].
  - The sojourn time is uniformly selected in [w,w+2], where w from 2 to 15 time units.
  - Mobility preference *P* is 10%
  - TTL is 35 time units
- Metrics
  - Delivery ratio
  - Delivery latency

Simulation

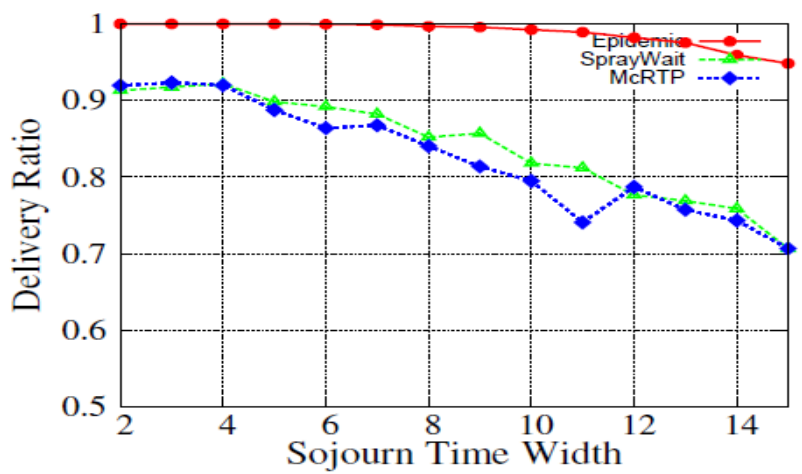
- Results – Delivery ratio comparison



(a) Network with 10 nodes



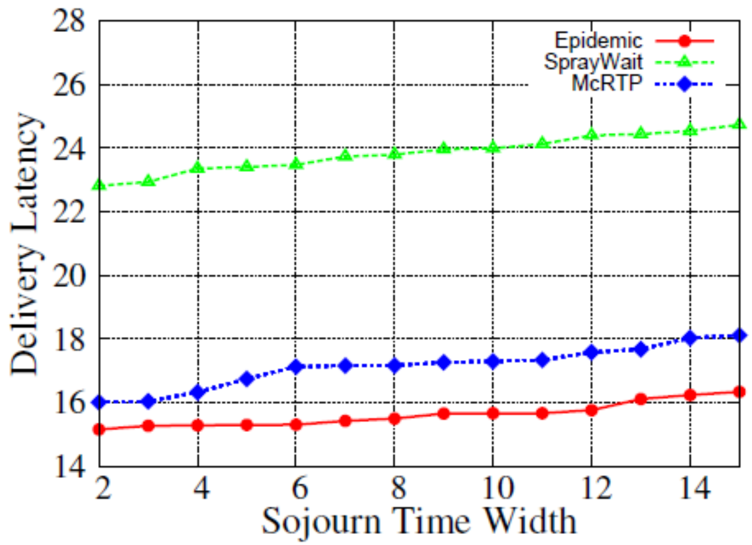
(b) Network with 20 nodes



(c) Network with 30 nodes

Simulation

- Results – Delivery ratio comparison



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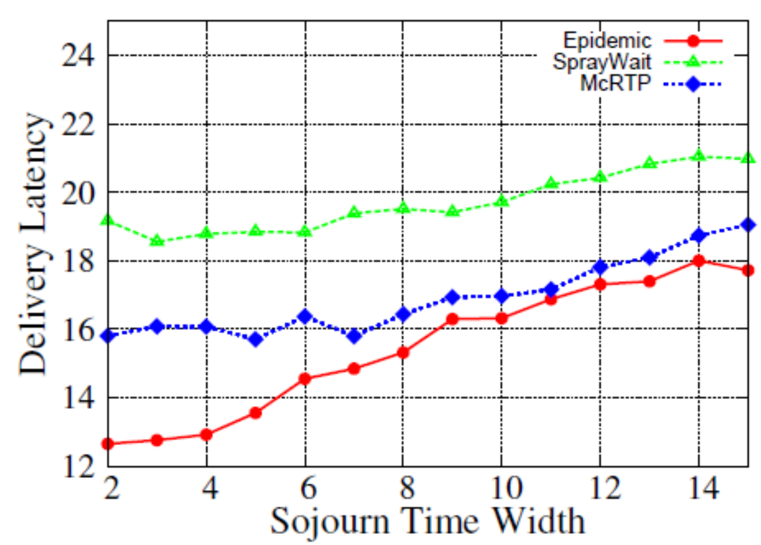
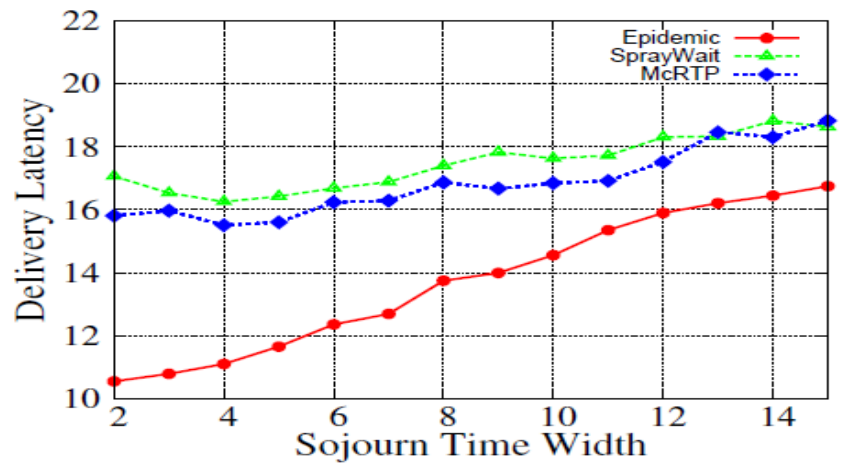


(b) Network with 20 nodes



(c) Network with 30 nodes

Conclusion

- McRTP predicts where and when the contact occurs using the social network nature.
- McRTP offers solutions for multi-copy prediction-based routing in social DTNs.
- McRTP outperforms traditional SprayWait, especially in sparse networks.


Thanks
QUESTIONS?