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Homing Spread: Community Home-based Multi-copy Routing in Mobile Social Networks

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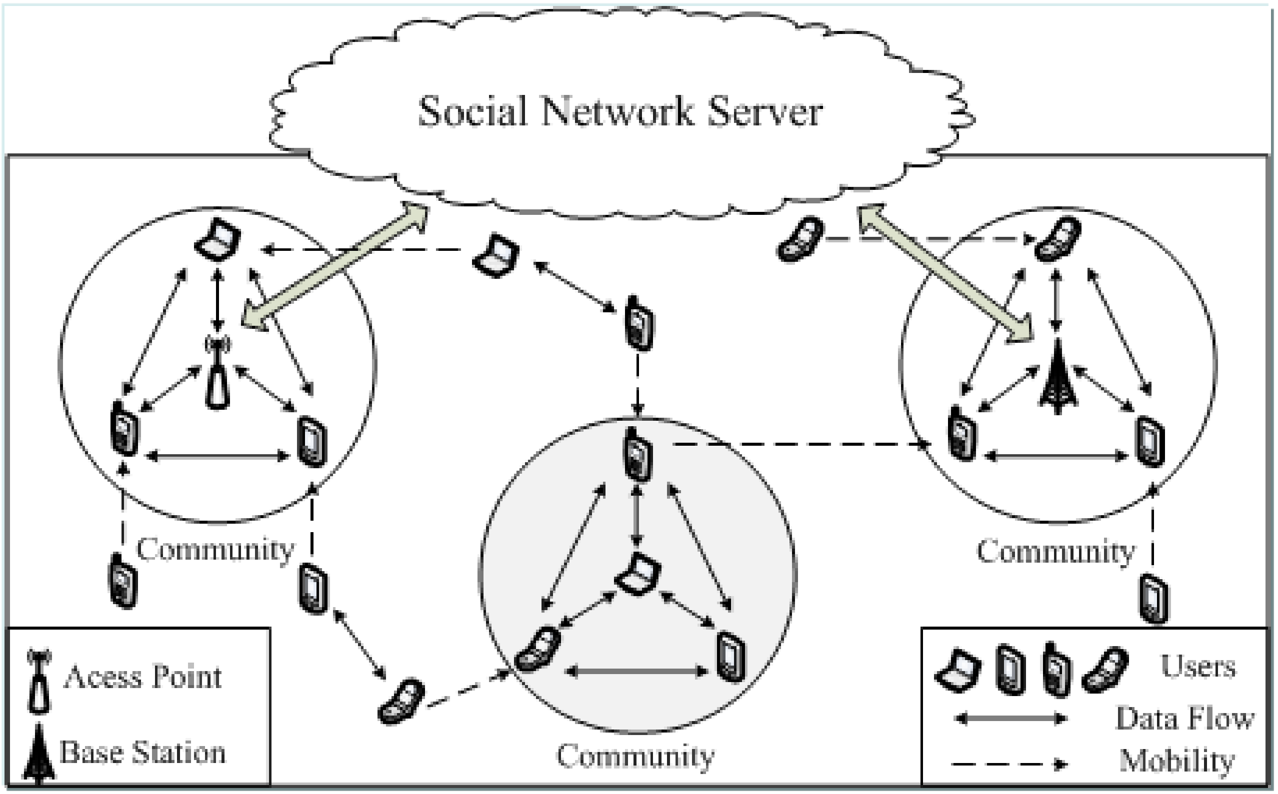
Motivation

- **Routing in Mobile Social Networks (MSNs)**
  - **MSN: a special Delay Tolerant Network (DTN)**



Motivation

- Existing Routing Algorithms
  - Knowledge-based routing
    - Probability-based routing algorithms: RAPID, Maxprop, R3, …
    - Social-aware routing algorithms: SimBet, Bubble rap, …

    …
  - Zero-knowledge routing
    - Epidemic, Spray&Wait

Motivation

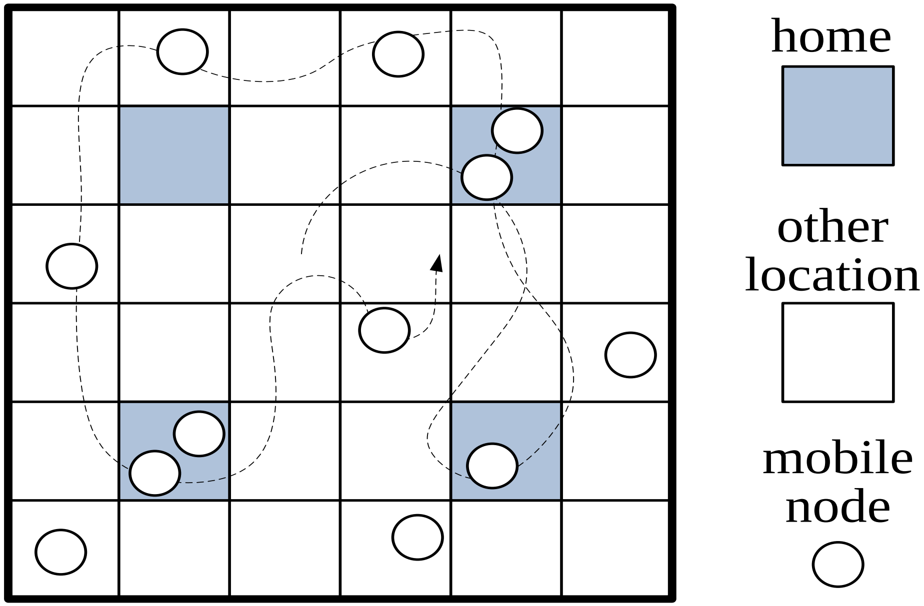
- **MSN**
  - **Social characteristics**

    Nodes visit some locations (community homes) frequently, while the other locations are visited less frequently.
  - **Real or virtual “throwbox”**

    Each community home is equipped with a real or virtual “throwbox” so that it can store and forward messages

Problem

- **Network Model**
  - **V={1,2,…,n}, H={n+1, n+2,…, n+h}**



- **Problem**
  - Given a fixed number of message copies *C*
  - Minimize the expected delivery delay

Solution

- **Homing Spread (HS)**

  Three phases:

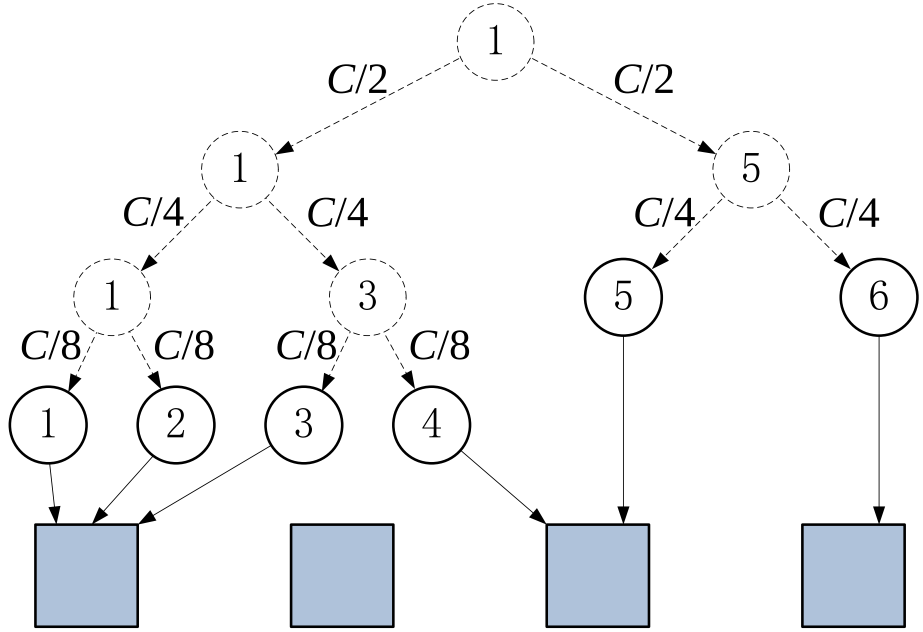
  – Homing phase
    - The source sends message copies to homes quickly

  – Spreading phase
    - Homes with multiple message copies spread them to other homes and mobile nodes

  – Fetching phase
    - The destination fetches the message when it meets any message holder

Solution

- **Homing Phase**
  - **Binary Homing Scheme:**
    - Each message holder sends all of its copies to the first (visited) home.
    - If the message holder meets another node before it visits a home, it binary splits the copies between them.



Solution

- **Homing Phase**
  - **Assume**:
    - Inter-meeting time between any two nodes follows the exponential distribution (λ)
    - Inter-meeting time between a node and a home follows the exponential distribution (Λ)
  - **Lemma 1**:
    - The binary homing scheme can spread the C message copies to the maximum number of nodes before they reach the homes.

Solution

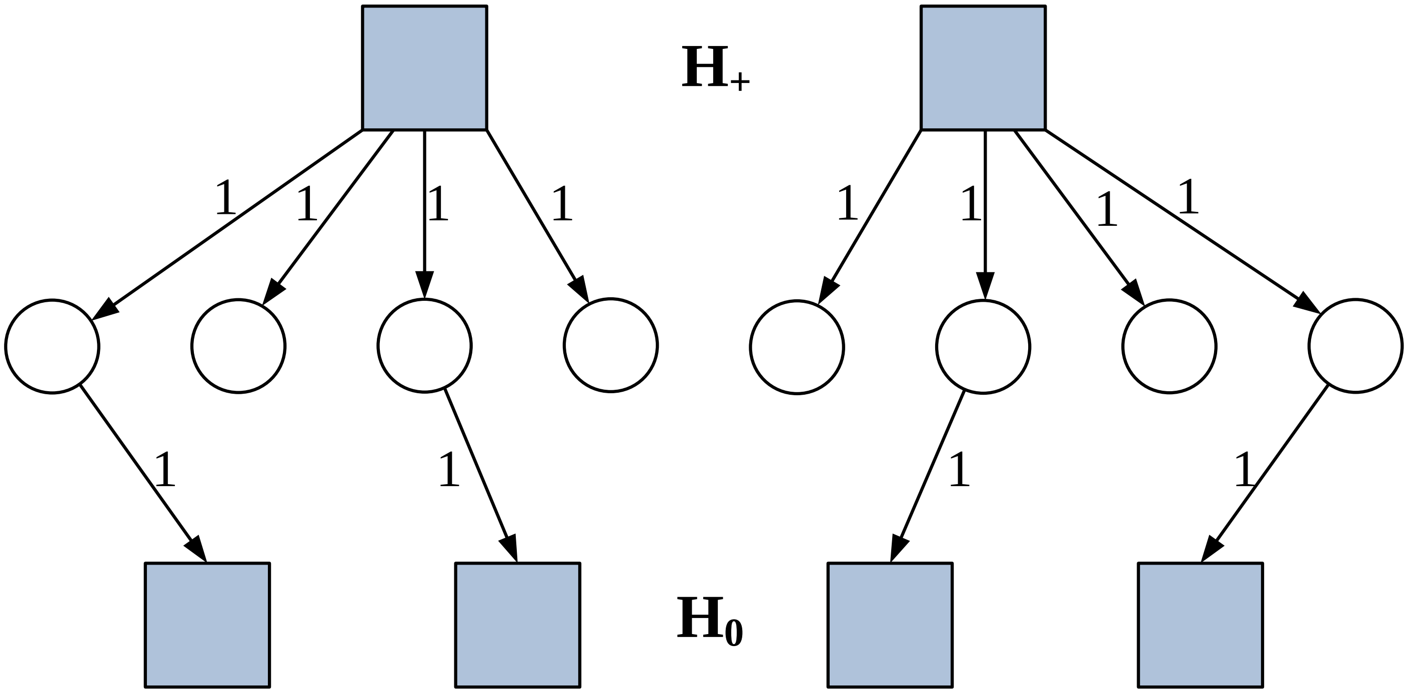
- **Homing Phase**
  - **Analysis**:
    - The expected delay of each message copy is always $1/h\Lambda$, no matter which splitting scheme is adopted
    - The maximum number of nodes received the message copies
    - The maximum number of homes received the message copies
  - **The binary homing scheme is the optimal homing scheme**

Solution

- **Spreading Phase**
  - **1-Spreading Scheme:**
    - Each home with more than one message copy spreads a copy to each visiting node until only one copy remains
    - If a node with one copy later visits another home, the node sends the copy to that home
  - **Result:**
    - Each home has at most one copy.
    - If $C > h$, there are $C - h$ nodes outside the homes that have a copy.

Solution

- **Spreading Phase**
  - **1-Spreading Scheme:**

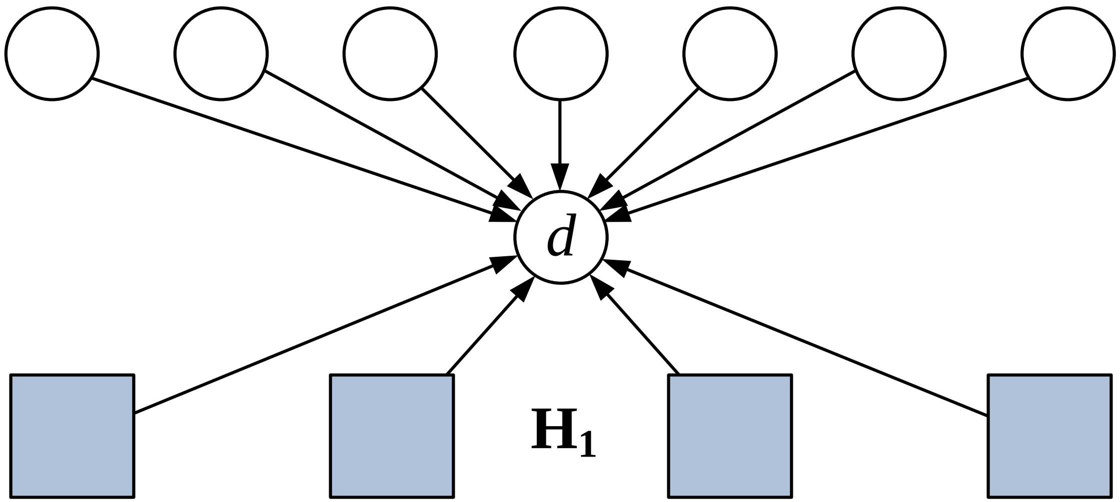


Solution

- **Spreading Phase**
  - **Lemma 2:**
    - The 1-spreading scheme can spread message copies from a home to the maximum number of nodes with the fastest speed.

Solution

- **Fetching Phase**
  - **Fetching Scheme:**
    - The destination fetches the message once it meets a message holder



Solution

- **The detailed HS algorithm**

Algorithm 1 The Homing Spread (HS) algorithm

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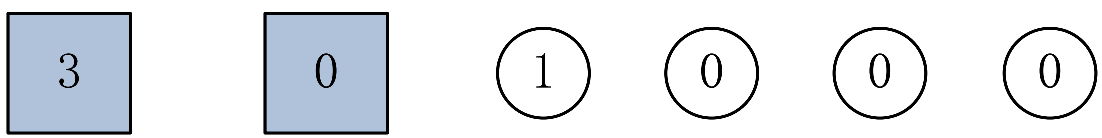
for each mobile node i **do**
  if node i encounters another node j **then**
    if node j is the destination **then**
      node i sends the message to j;
    if nodes i and j have r_i and r_j message copies **then**
      node i holds $\lceil r_i/2 \rceil + \lfloor r_j/2 \rfloor$ copies through exchange with node j;
  if node i visits a home h **then**
    node i sends all its copies to h;
    if $h \in H_+$ or i is the destination **then**
      h sends a copy to node i.

  – HS **is a distributed algorithm**
  – HS **is compatible with each phase**

Solution

- **Network State**
  - State s is a vector with h+n components, i.e., $s = \langle s_1, s_2, \ldots, s_h, s_{h+1}, \ldots, s_{h+n} \rangle$, in which s_i represents the number of message copies held by the i-th home (if $i \leq h$) or node $i-h$ (if $i > h$)

    For example: $s = \langle 3, 0, 1, 0, 0, 0 \rangle$



  - Start state: $s_t = \langle 0, 0, \ldots, 0, C, 0, \ldots, 0 \rangle$
  - Optimal state: $s_o = \langle 1, 1, \ldots, 1, 0, \ldots, 0 \rangle$

Solution

- **Optimality of HS**
  - HS follows the binary homing scheme and the 1-spreading scheme during message delivery
  - Lemma 1 and Lemma 2 show that the binary homing scheme and the 1-spreading scheme are the fastest ways to turn a network state into the optimal state s_o
  - Each state transition based on the binary homing scheme and the 1-spreading scheme can turn the current state into the best next state that has the minimum expected delivery delay

Solution

- **Compute the expected delivery delay**

  (continuous Markov chain)

  – State space s= $\langle s_1, s_2, \ldots, s_h, s_{h+1}, \ldots, s_{h+n} \rangle$

  $$\sum_{i=1}^{h+n} s_i = C \ \ (s_1 \geq s_2 \geq \cdots \geq s_h ; s_{h+1} \geq s_{h+2} \geq \cdots \geq s_{h+n})$$

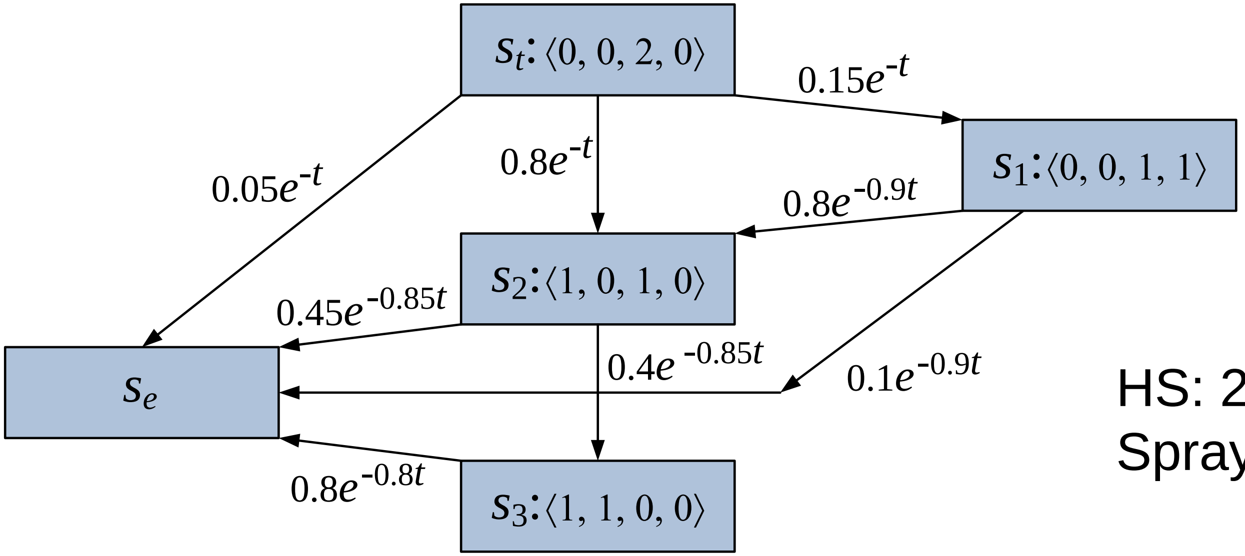
  – State transition graph

    - The binary homing scheme, the 1-spreading scheme
    - A directed acyclic graph
    - State transition function $\rho_{s,s'}(t)$

      the probability density function about the time t that it takes for the state transition from s to s′

Solution

- **Compute the expected delivery delay**
  - Theorem 4
    - Derive the cumulative probability density function for the state transition from the start state to the end state
    - Calculate the expected delivery delay



HS: 2.81
Spray&Wait: 12.25

h = 2, n = 5, C = 2, Λ=0.4, λ=0.05

Solution

- **Upper bound of the expected delivery delay**
  - **Corollary 6: The expected delivery delay of the HS algorithm, denoted by D, satisfies:**

$$D \le \begin{cases} \frac{1}{h\Lambda} + \frac{2}{\Lambda} + \frac{1}{C\Lambda}, & C \le h \\ \frac{1}{h\Lambda} + \frac{2}{\Lambda} + \frac{1}{h\Lambda + (C-h)\lambda}, & C > h \end{cases}$$

Simulation

- **Trace**
  - Synthetic trace based on Time-Variant Community Model (TVCM)
- **Settings**

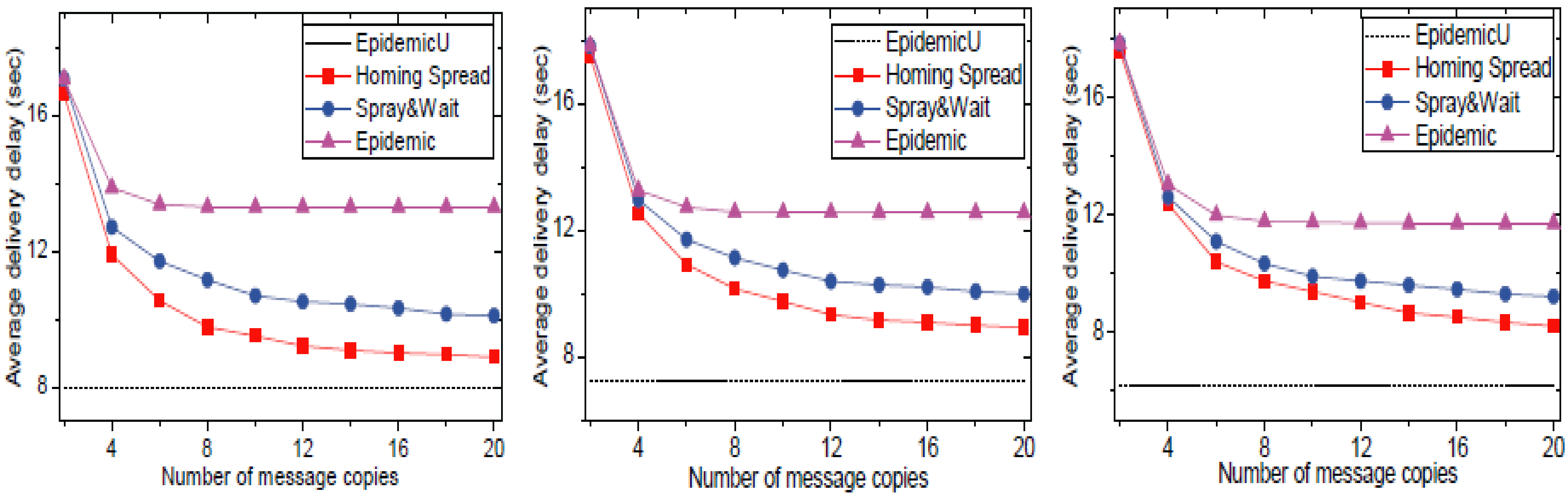
Parameter name	Default value	Range
Deployment area	20m × 20m	-
Number of nodes n	200	100-400
Number of homes h	5	0-15
Homing probability per sec Λ	0.04	0.04-0.16
Number of messages	10,000	-
Allowed message copies	10	2-20

Simulation

- Algorithms in comparison
  - Epidemic (C message copies)
  - EpidemicU (unlimited message copies)
  - Spray&Wait
- Metrics
  - Average delivery delay

Simulation

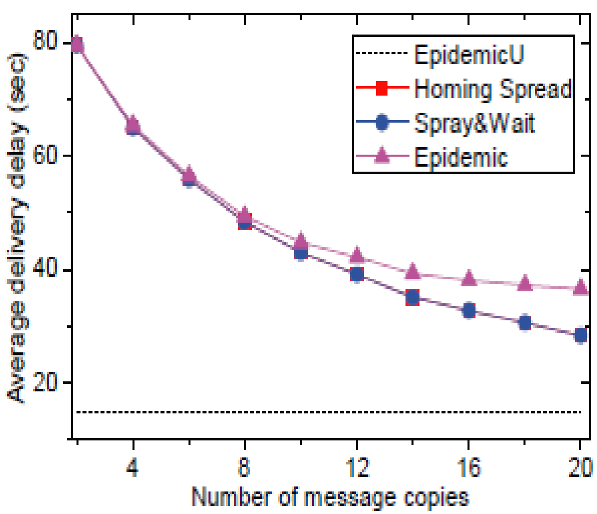
- Results
  - Average delay vs. number of nodes



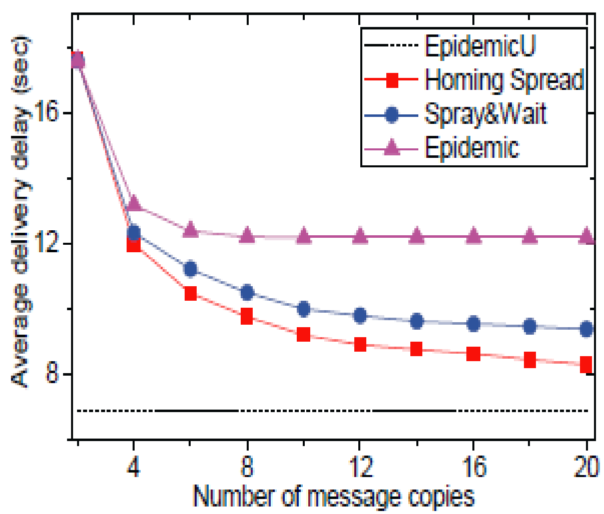
(a) Number of nodes: $n = 100$ (b) Number of nodes: $n = 200$ (c) Number of nodes: $n = 300$

Simulation

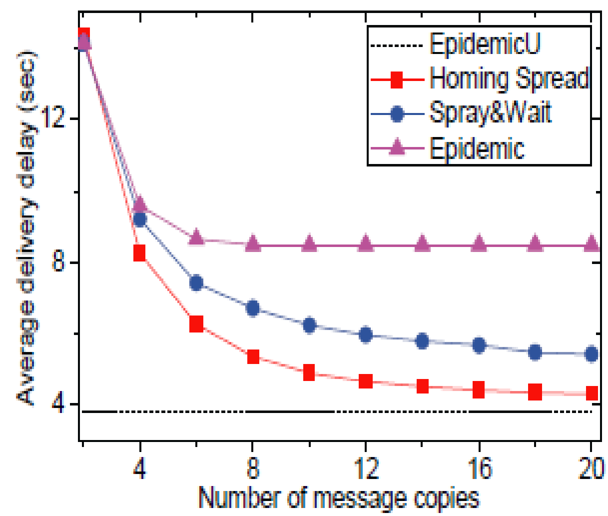
- Results
  - Average delay vs. number of homes



(a) Number of homes: $h = 0$



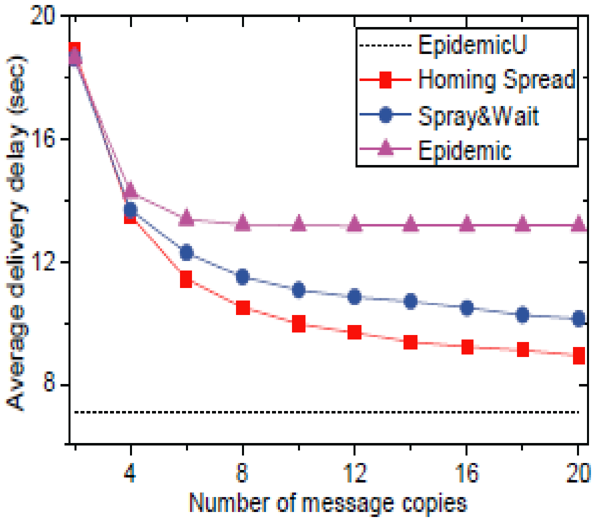
(b) Number of homes: $h = 5$



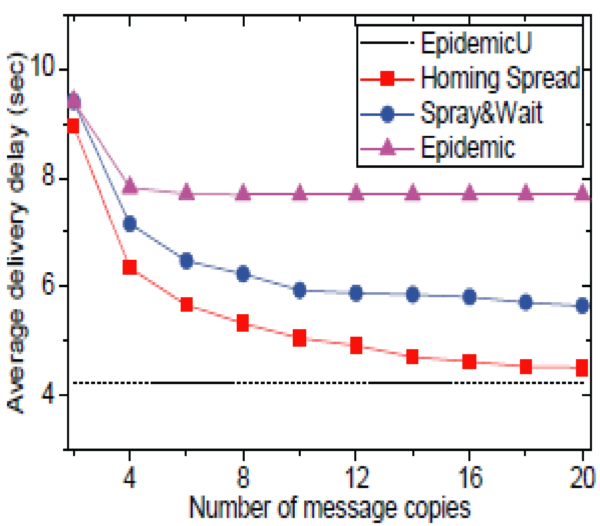
(d) Number of homes: $h = 15$

Simulation

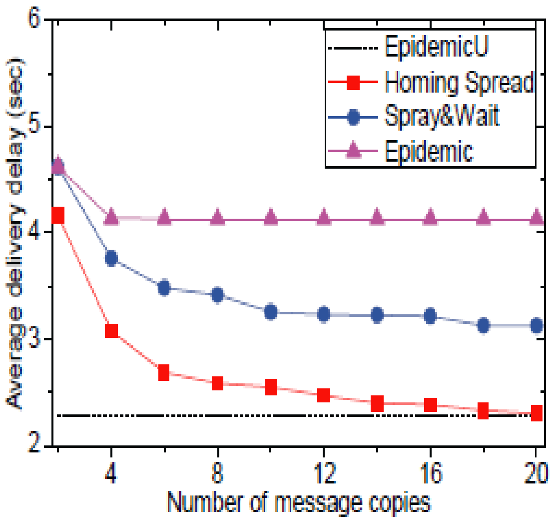
- Results
  - Average delay vs. homing probability



(a) Homing probability: $\Lambda = 0.04$



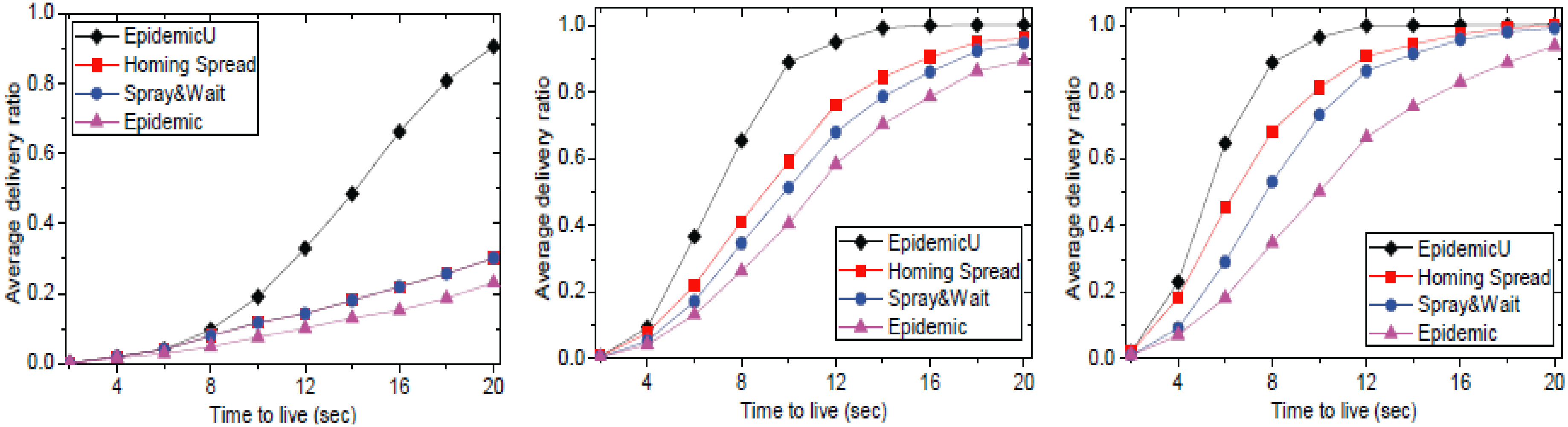
(b) Homing probability: $\Lambda = 0.08$



(d) Homing probability: $\Lambda = 0.16$

Simulation

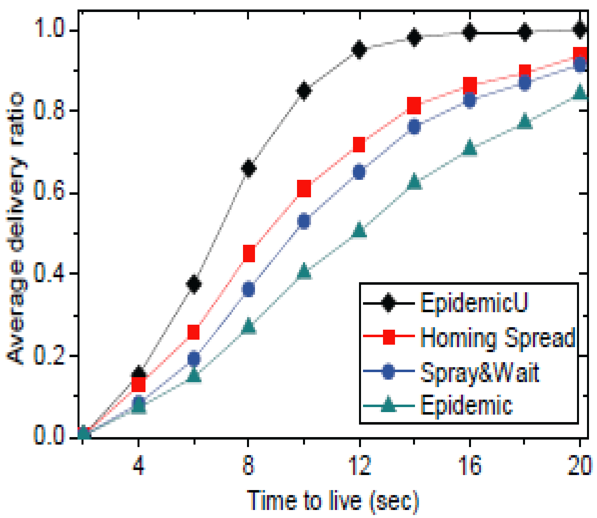
- Results
  - Average delivery ratio vs. number of homes



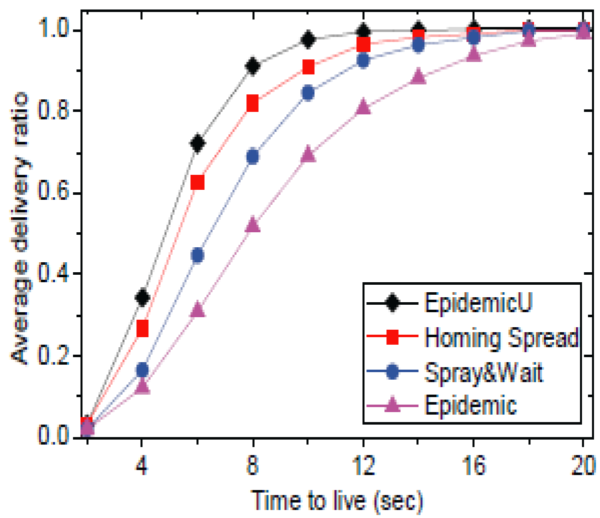
(a) Number of homes: $h = 0$ (b) Number of homes: $h = 5$ (c) Number of homes: $h = 10$

Simulation

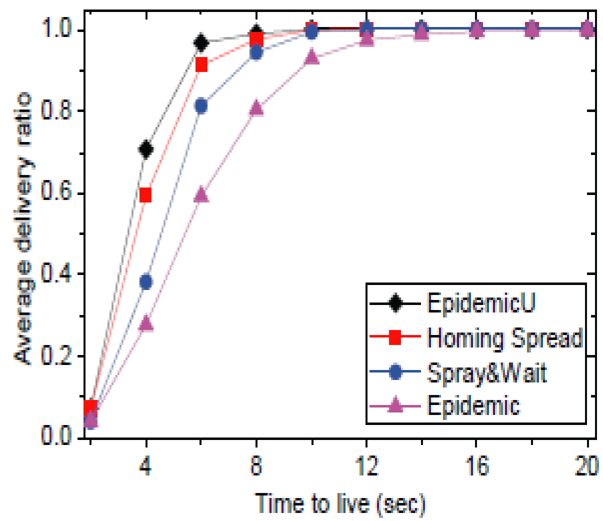
- Results
  - Average delivery ratio vs. homing probability



(a) Homing probability: $\Lambda = 0.04$



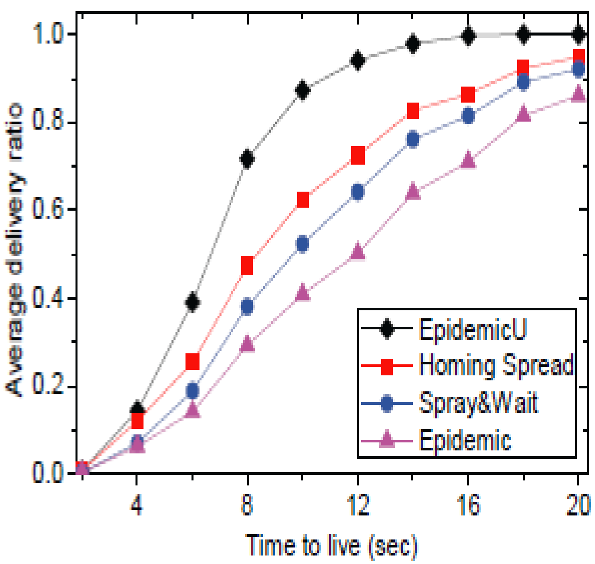
(b) Homing probability: $\Lambda = 0.08$



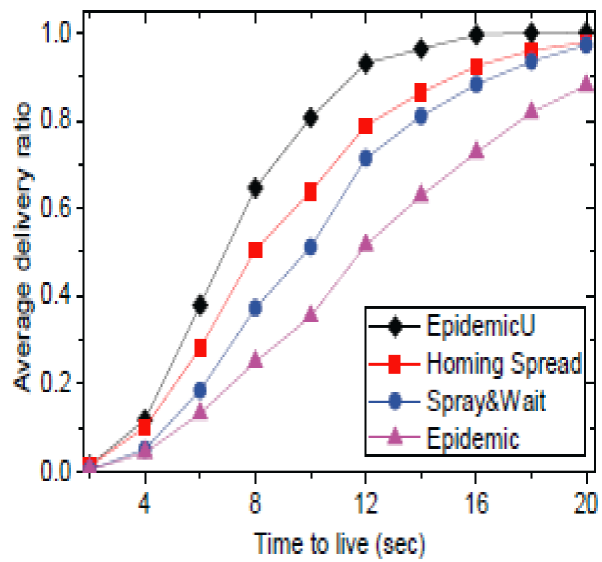
(c) Homing probability: $\Lambda = 0.12$

Simulation

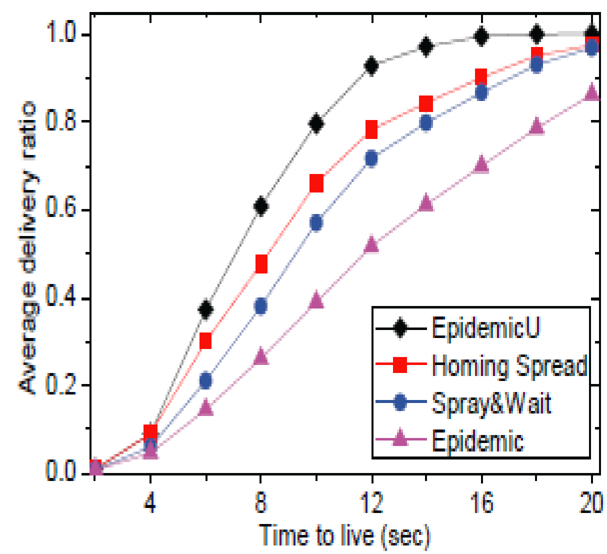
- Results
  - Average delivery ratio vs. number of copies



(b) Message copies: $C = 10$



(c) Message copies: $C = 15$



(d) Message copies: $C = 20$

Conclusion

- HS outperforms the compared algorithms in both the delivery delay and delivery ratio.
- When the number of homes or the homing probability increases, the average delivery delay of HS reduces significantly.
- When the number of homes is zero, HS is degraded to Spray&Wait.
- When the number of homes or the homing probability is sufficiently large, HS can achieve nearly the same performance as EpidemicU.

Thanks!

Q&A