Self-Stopping Epidemic Routing in Cooperative Wireless Mobile Sensor Networks

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Outline

• Motivations and problem definition
• System model
• Proposed strategy
• Summary

Epidemic Routing in Mobile Networks

• Application scenario: Wireless mobile sensor networks for critical event detection and reporting
• Random mobility and liability to damage make it difficult to find and maintain a stable end-to-end routing path.
• Epidemic routing: each node transmits information to a random neighbor in its communication range.

Challenge: limit the unnecessary spreading of messages, in order to save energy consumption and buffer usage.

Existing Work and Our Goal

• Existing work:
  – Reduce the relaying overhead
  – Explicit stopping mechanisms based on local decisions
• Our focus: a self-stopping strategy in epidemic routing that
  – Ensures a message to reach a certain percentage of nodes, and
  – Stops forwarding when this percentage of nodes have received a copy of the message
Overview of Our Work

• A mathematical model for epidemic routing
  – To accurately characterize information dissemination in wireless sensor networks with rapid and random mobility

• A time-based probabilistic self-stopping strategy
  – Fast: spreading converges fast with a predictable stopping time
  – Accurate: final reach consistently follows the predicted target reach (can be small)
  – Energy efficient: spreading stops when the goal is met

System Model

• $N$ moving sensor nodes: transmits sensed information; store, carry, and forward to the closest neighbor; the forwarding will continue until certain stopping criteria have been met.

• Assumptions:
  – Moving speed is fast compared to the inter-transmission time: Neighbors in successive transmission windows are independent
  – A message is limited in size and can be successfully transmitted during a single node contact.
  – Synchronous time model: Transmission time is divided into discrete time slots

Performance Metrics

Parameter:
• Target reach ($\alpha$): a pre-set fraction of the network nodes to receive a copy of the message

Metrics:
• Final reach: the actual fraction of node that have received the message when the spreading stops
• Stopping time: the total time to complete the whole spreading process

Model Selection: ODE Model?

• Continuous-time ODE model:
  $I(t)$: number of “infected” nodes
  \[ I'(t) = \beta I(t)(N - I(t)) \]
  where pairwise meeting rate $\beta = \frac{1}{N-1}$

• Limitations:
  – The time that a node takes to forward and receive the message is not considered.
  – A node can be double-counted as multiple relay nodes can choose it as the next forwarder.

$\rightarrow$ The ODE model tends to over-estimate the size of the infection over time.
Model Selection: AAWP Model!

- Discrete-time AAWP model:
  \[ I(t + 1) = I(t) + [N - I(t)] \left[ 1 - \left( 1 - \frac{1}{N-1} \right) I(t) \right] \]

- A node cannot send a message to any neighbor before the message is received completely.
- An uninfected node can only receive a message from at most one neighbor.

→ The AAWP model is more accurate than the ODE model.

Model Comparison

![Graphs comparing AAWP and ODE models for different values of N and α](image)

Simulation Results

- **First, predict message life time** \( t_f \) **from the AAWP model:** \( I(t_f - 1) < \alpha N \leq I(t_f) \)

**Algorithm 1** Time-based self-stopping strategy

- **Input:** \( t_0, t_f, \) and current time \( t \) (\( t \geq t_0 \) and \( t \) is discrete)
  - if \( t < t_0 + t_f \) then
    - Forward the message to a randomly selected neighbor
  - else
    - Stop forwarding
  - end if

- Although the spreading halts in a timely and predictable manner, the final reach is usually beyond the target reach and with a large standard deviation.

→ NOT accurate, NOT energy-efficient
Probability-Based Self-Stopping Strategy?

- If a relay node finds a selected neighbor already “infected”, it will stop spreading the message with a stopping probability \( p \) and enter “recovery” mode.
- **Extended AAWP model:**
  \[
  I(t+1) = I(t) + S(t) \left[ 1 - \left( 1 - \frac{1}{N-1} \right)^{I(t)} \right] - pI(t)f(t),
  \]
  \[
  R(t+1) = R(t) + pI(t)f(t),
  \]
  \[
  f(t) = 1 - \frac{S(t)}{N-1},
  \]

  - \( I(t) \): # of infected nodes
  - \( R(t) \): # of recovered nodes
  - \( S(t) \): # of vulnerable nodes
  - \( I(t) + R(t) + S(t) = N \)

Algorithm

- First, calculate stopping probability \( p \) from the extended AAWP model

**Algorithm 2 Probability-based self-stopping strategy**

**Input:** Stopping probability \( p \)
Randomly select a neighbor \( n \)
if \( n \) has not received the message then
  Forward the message to it
else
  Generate a random number \( r \) in \([0, 1)\)
  if \( r \leq p \) then
    Stop forwarding and become recovered
  end if
end if

Simulation Results

- Although the final reach converges to the specified target reach, the stopping time is much longer and with a higher variation.
- It is impossible to control the spreading to a smaller scale (e.g., under 80%)

\[ \blacktriangleright \text{NOT fast, NOT energy-efficient} \]

Time-Based Probabilistic Self-Stopping Strategy

- Another look at the time-based self-stopping strategy: The spreading does not stop at target reach \( \alpha \). Some nodes may need to stop forwarding before \( t_f \).
- A relay node will continue forwarding the message with a final forwarding probability \( q \) after \( t_f - 1 \).
- **Modified AAWP model:**
  \[
  \alpha N = I(t_f - 1) + \left[ N - I(t_f - 1) \right] \left[ 1 - \left( 1 - \frac{1}{N-1} \right)^{q(t_f-1)} \right]
  \]
  \[
  q = \frac{\ln \left( N - I(t_f - 1) \right) - \ln(N - \alpha N)}{I(t_f - 1) \ln(N - 1) - \ln(N - 2)}
  \]
Algorithm

- First, estimate message life time $t_f$ and final forwarding probability $q$ from the modified AAWP model.

Algorithm 3 Time-based probabilistic self-stopping strategy

Input: $t_0$, $t_f$, $q$, and current time $t$ ($t \geq t_0$ and $t$ is discrete)

if $t < t_0 + t_f - 1$ then
  Forward the message to a randomly selected neighbor
else if $t = t_0 + t_f - 1$ then
  Generate a random number $r$ in $[0, 1)$
  if $r \leq q$ then
    Forward the message to a randomly selected neighbor
  else
    Stop forwarding
  end if
else
  Stop forwarding
end if

Simulation Results

- The final reach closely follows the preset target reach (can be below 80%), with very small variance.
- The spreading converges fast with a predictable stopping time.

→ Fast, accurate, and energy-efficient!

Summary

- **Epidemic routing** is studied for information dissemination in cooperative wireless mobile sensor networks with rapid and random node movement.

- A **time-based probabilistic self-stopping strategy** is proposed based on the modified AAWP model, which is more accurate than the continuous-time ODE model.

- This self-stopping strategy is shown to be **fast, accurate, and energy efficient**.

Thanks for Your Attention!