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 predicable 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

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Performance Metrics

Parameter:

- *Target reach (α):* 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

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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.

→ The ODE model tends to over-estimate the size of the infection over time.

Model Selection: AAWP Model!

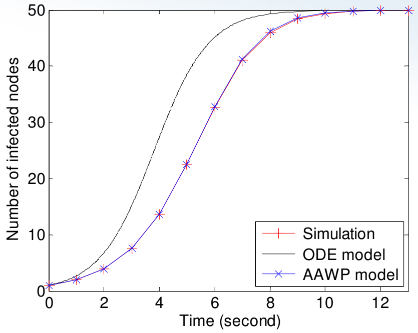
- Discrete-time AAWP model:

$$I(t+1) = I(t) + [N - I(t)]\left[1 - \left(1 - \frac{1}{N-1}\right)^{I(t)}\right]$$

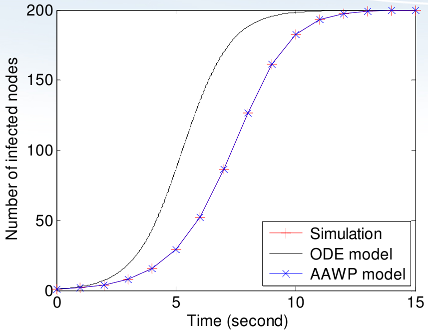
- A node cannot send a message to any neighbor before the message is received completely.
- An uninfected node can only receive message from at most one neighbor.

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

Model Comparison



$N = 50$



$N = 200$

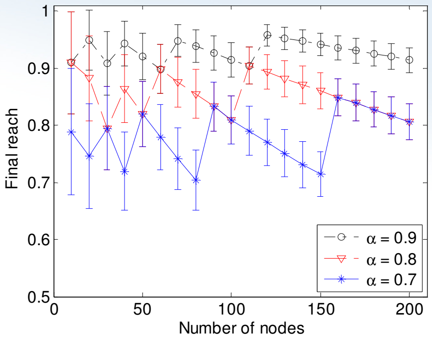
Time-Based Self-Stopping Strategy?

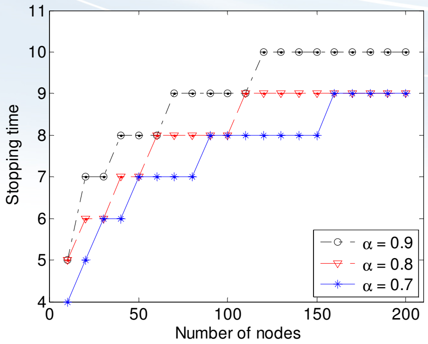
- First, predict message life time t_f from the AAWP model: $I(t_f - 1) < \alpha N \le I(t_f)$

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
```

Simulation Results





- 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
$I(t)+R(t)+S(t)=N$

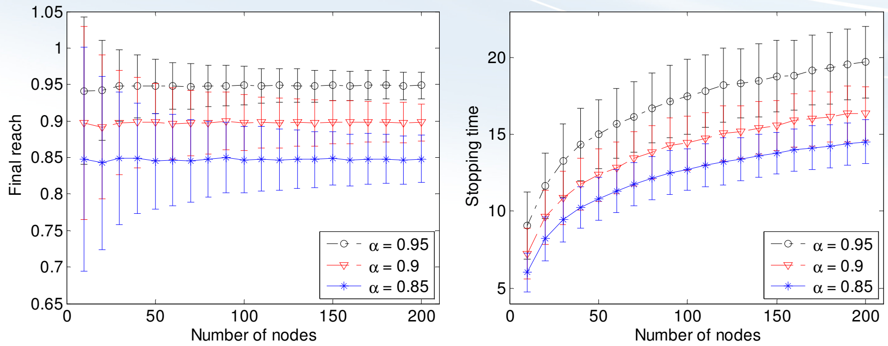
Algorithm

- 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%)

→ 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 α. 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:*

$$\alpha N = I(t_f-1) + [N - I(t_f-1)]\left[1-\left(1-\frac{1}{N-1}\right)^{qI(t_f-1)}\right]$$

$$q = \frac{\ln\left(N - I(t_f-1)\right) - \ln(N-\alpha N)}{I(t_f-1)[\ln(N-1)-\ln(N-2)]}$$

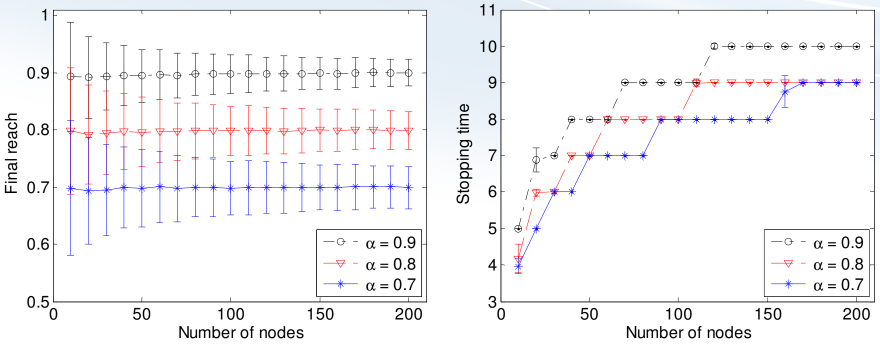
Algorithm

- 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 $t$ ($t \ge t_0$ 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 $r \le q$ 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!