Energy Efficient Phone-to-Phone Communication Based on WiFi Hotspots in PSN

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Outline

• 1. Introduction
• 2. Model Description
• 3. Communication Strategy
• 4. Evaluation
• 5. Future Work
1. Introduction

1.1 Motivation

• Pocket Switched Networks (PSN)

  • Both human mobility and occasional connectivity to transfer messages among human-carried mobile devices

  • According to International Data Corporation (IDC), the number of smartphones will reach 982 million by 2015

• Limitation of WiFi ad hoc mode and WiFi Direct

• Phone-to-phone communications in the PSN without WiFi Aps

  • Hotspot mode
  • Client mode
1. Introduction

1.2 Problem

- The **phone-to-phone message dissemination process**

- How to **minimize wasted time and energy** due to phones being in **incompatible mode**?
1.2 Problem

- **Hotspot Switch Decision**

- **Multiple messages**: For each second, each node has the probability of $\alpha(t)$ to be in hotspot, and $1-\alpha(t)$ to be in client

- **Single message**: For each second, each node with a message has the probability of $\alpha(t)$ to be in hotspot mode, and each node without a message has the probability of $\beta(t)$
1. Introduction

1.2 Problem

A big picture

Y-Y:  1-1, 1-0, 0-1, 0-0
Y-N:  1-1, 1-0, 0-1, 0-0
N-N:  1-1, 1-0, 0-1, 0-0

maximize and minimize

Y: With Message, N: Without Message
1: Hotspot, 0: Client
1. Introduction

1.3 Contributions

- The proposed EPCWH is intended to **improve** message dissemination, while **minimizing** total energy consumption.
  - For multiple messages, the **uniform** policy is used for nodes with and without messages.
  - For a single message, **non-uniform** policies are used.
- Extensive simulations on the synthetic random-waypoint mobility
  - EPCWH achieves the best performance in terms of **message dissemination** and **energy consumption**.
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• 1. Introduction

• 2. Model Description

• 3. Communication Strategy

• 4. Evaluation

• 5. Future Work
2. Model Description

- Two phones within each other’s communication range can establish a connection iff one of them is in hotspot mode and the other in client mode.

- Intermeeting times tail off exponentially under many popular mobility patterns, including random walk, random waypoint, and random direction.

\[ f(x) = \lambda e^{-\lambda x} \quad (x \geq 0) \]

- Analysis on pairwise encounters, as opposed to optimizing communications within the clusters of more than two phones.
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3. Communication Strategy

3.1 Notations (multiple messages)

<table>
<thead>
<tr>
<th>Notation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>The total number of phones in PSN</td>
</tr>
<tr>
<td>$T$</td>
<td>Initial time-to-live (TTL) for messages</td>
</tr>
<tr>
<td>$\alpha(t)$</td>
<td>The frequency of switching to hotspot for each phone at time $t$</td>
</tr>
<tr>
<td>$P(t)$</td>
<td>Probability of establishing a connection at time $t$</td>
</tr>
<tr>
<td>$C$</td>
<td>Energy consumption rate of hotspot mode (without loss of generality, $C = 1J/s$)</td>
</tr>
<tr>
<td>$\Omega$</td>
<td>Maximum energy constraint to each phone</td>
</tr>
</tbody>
</table>
3. Communication Strategy

3.2 Phone-to-phone Communication of Multiple Messages

- When multiple messages coexist in PSN, we adopt a uniform switching strategy:
  - $\alpha(t)$ as the frequency of switching to the hotspot mode

- The probability of establishing a connection between two nodes within each other’s communication range:

$$P(t) = 2\alpha(t)(1 - \alpha(t))$$
3. Communication Strategy

3.2 Phone-to-phone Communication of Multiple Messages

- The problem changes to solve the following optimal equation

\[
\begin{align*}
\text{Maximize} & \quad \int_0^T 2\alpha(t)(1 - \alpha(t))\,dt \\
\text{s.t.} & \quad \int_0^T \alpha(t)\,dt \leq \Omega
\end{align*}
\]

- The maximum value of \( 2\alpha(t)(1 - \alpha(t)) \) is obtained iff \( \alpha(t) = 1/2 \). Hence, an optimal situation is shown as follows:

\[
\begin{cases}
\alpha(t) = 1/2, & \Omega \geq T/2 \\
\alpha(t) = \Omega/T, & \Omega < T/2
\end{cases}
\]
3. Communication Strategy

3.3 Additional Notations (single message)

<table>
<thead>
<tr>
<th>Notation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta(t)$</td>
<td>The frequency of switching to hotspot for the phone without the message at time $t$</td>
</tr>
<tr>
<td>$m(t)$</td>
<td>Number of the phones holding the message at time $t$</td>
</tr>
<tr>
<td>$n(t)$</td>
<td>Number of the phones without the message at time $t$, $(n(t) = N - m(t))$</td>
</tr>
<tr>
<td>$E(I)$</td>
<td>Mathematical expectation of intermeeting times</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Parameter in the exponential distribution of intermeeting times $(\lambda = 1/E(I))$</td>
</tr>
</tbody>
</table>
3. Communication Strategy

3.4 Phone-to-phone Communication of Single Message

- Two cases that lead to the increase of $m(t)$, the number of nodes with the message

  A phone holding the message in **hotspot (client) mode** encounters another phone without the message in **client (hotspot) mode**

- Therefore, the derivative of $m(t)$ is expressed as

$$\frac{dm(t)}{dt} = \lambda [m(t)\alpha(t)n(t)(1 - \beta(t)) + m(t)(1 - \alpha(t))n(t)\beta(t)]$$

$$= \lambda m(t)n(t) [\alpha(t) + \beta(t) - 2\alpha(t)\beta(t)]$$
3. Communication Strategy

3.4 Phone-to-phone Communication of Single Message

- Probability of establishing a connection $P(t)$, when a phone with message encounters another phone without message

$$P(t) = \alpha(t)(1 - \beta(t)) + \beta(t)(1 - \alpha(t))$$

$$= \alpha(t) + \beta(t) - 2\alpha(t)\beta(t)$$

- $m(T)$ could be calculated as follows:

$$m(T) = \frac{N}{(N - 1)e^{-N\lambda \int_0^T P(t)dt} + 1}$$

where $m(t)$ and $\int_0^T P(t)dt$ have a positive correlation
3. Communication Strategy

3.4 Phone-to-phone Communication of Single Message

- Connection probability distribution $P(t)$
3. Communication Strategy

3.4 Phone-to-phone Communication of Single Message

- The optimal solution: at each time $t$, $\alpha(t)$ and $\beta(t)$ satisfy $\alpha(t)=1$, $\beta(t)=0$ or $\alpha(t)=0$, $\beta(t)=1$, shown in the following example:

  - Y-Y: 1-1, 1-0, 0-1, 0-0
  - Y-N: 1-1, 1-0, 0-1, 0-0
  - N-N: 1-1, 1-0, 0-1, 0-0

- Because $m(t)$ increases along with $t$, in order to minimize the total energy consumption, a better solution is shown as follows:
3. Communication Strategy

3.4 Phone-to-phone Communication of Single Message

• When the energy is sufficient, the total energy consumption is achieved as follows:

\[ \Omega_{sum} = \int_{0}^{T} (m(t)\alpha(t) + n(t)\beta(t))dt \]

\[ = \int_{0}^{T'} m(t)dt + \int_{T'}^{T} n(t)dt \]

\[ = NT' + \frac{2\ln[(N - 1)e^{-N\lambda T'} + 1]}{\lambda} \]

• To minimize \( \Omega_{sum} \), the optimal switching time is \( T' \), which is the time satisfying \( m(T') = N/2 \).

\[ T' = \frac{\ln(N - 1)}{N\lambda} \]
3. Communication Strategy

3.4 Phone-to-phone Communication of Single Message

- Under different constraint conditions, the optimal switching time, \( T' = \frac{\ln(N - 1)}{N\lambda} \), can be achieved as follows:

<table>
<thead>
<tr>
<th>Constraint Condition</th>
<th>Optimal Switching Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Omega \geq \frac{T}{2} )</td>
<td>( T_1' = T_2' = T' )</td>
</tr>
<tr>
<td>Case 1: ( \Omega \geq T' ) and ( \Omega \geq T - T' )</td>
<td>( T_1' = T_2' = T' )</td>
</tr>
<tr>
<td>Case 2: ( \Omega &lt; T' ) and ( \Omega \geq T - T' )</td>
<td>( T_1' = T_2' = \Omega )</td>
</tr>
<tr>
<td>Case 3: ( \Omega \geq T' ) and ( \Omega &lt; T - T' )</td>
<td>( T_1' = T_2' = T - \Omega )</td>
</tr>
<tr>
<td>( \Omega &lt; \frac{T}{2} )</td>
<td>( T_1' = \Omega ) and ( T_2' = T - \Omega )</td>
</tr>
<tr>
<td>Case 4: ( \Omega &lt; T' ) and ( \Omega &lt; T - T' )</td>
<td>( T_1' = \Omega ) and ( T_2' = T - \Omega )</td>
</tr>
<tr>
<td>Case 5: ( \Omega &lt; T' ) and ( \Omega \geq T - T' )</td>
<td>( T_1' = T' ) and ( T_2' = T )</td>
</tr>
<tr>
<td>Case 6: ( \Omega \geq T' ) and ( \Omega &lt; T - T' )</td>
<td>( T_1' = T' ) and ( T_2' = T - \Omega )</td>
</tr>
</tbody>
</table>
3. Communication Strategy

3.4 Phone-to-phone Communication of Single Message
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4. Evaluation

4.1 Simulation Parameters (random-waypoint)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation time</td>
<td>10,000s</td>
</tr>
<tr>
<td>Simulation area</td>
<td>4,500m × 3,400m</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>100</td>
</tr>
<tr>
<td>Transmission range</td>
<td>30m</td>
</tr>
<tr>
<td>TTL</td>
<td>10,000s</td>
</tr>
<tr>
<td>Interval time of message generation</td>
<td>100s</td>
</tr>
<tr>
<td>Hotspot energy consumption rate</td>
<td>1J/s</td>
</tr>
<tr>
<td>$\alpha(t)$</td>
<td>0, 0.1, 0.2, ..., 0.9, 1</td>
</tr>
<tr>
<td>Energy constraint</td>
<td>1,000J, 2,000J, ..., 5,000J</td>
</tr>
</tbody>
</table>
4. Evaluation

4.2 Enough Energy (multiple messages)

- EPCWH ($\alpha(t) = 1/2$) achieves the best performance in terms of delivery ratio and average delay
4. Evaluation

4.3 Not Enough Energy (multiple message)

- EPCWH ($\alpha(t) = \Omega/T$) achieves the best performance in terms of delivery ratio ($\Omega=1000$, $\alpha(t) =0.1$ ... $\Omega=5000$, $\alpha(t) =0.5$)
4. Evaluation

4.4 Enough Energy (single message)

- EPCWH obtains the lowest energy consumption only when \( T' = 2600s \). Because \( N=100 \), and \( \lambda=1/56500 \), therefore, the simulation result precisely meets the theoretical result.
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5. Future Work

- Other replication-based routing schemes
  - Spray-and-wait, delegation forwarding, etc.

- Real network environment

Thank You