Optimal Data Partitioning and Forwarding in Opportunistic Mobile Networks

Ning Wang and Jie Wu

Dept. Computer and Information Sciences
Temple University
Agenda

• Introduction
  - Current network trends
  - New opportunities in wireless communication

• Routing Design
  - Related Works
  - Cooperative forwarding

• Experiments

• Conclusion and future works
• From Internet to Internet of Things
  - Powerful computation, sensing, and communication abilities
    - Smartphones, vehicles, wearable devices, etc.
  - Wide availability of (various) devices
    - 8 billions of mobile-ready devices, 10 times of PCs [Cisco White Paper]

Internet of things, pervasive computing, Ubiquitous computing, edge computing, etc.
Opportunistic Communication

• **Store-Carry-Forward (Mobility)**
  - Mobile nodes physically carry data as relays
  - Forwarding data upon contacts
    - Forwarding path: path S-B-D and path A-C-E
  - Delay-tolerant (location-based) applications:
    - Emails, news, advertisements dissemination
    - Social networks updates
Opportunistic networks

• Applications
  - Opportunistic mobile social networks
    - Data offloading, disaster communication
  - Vehicular networks
    - Autonomous Driving, intelligence transportation system
• **Epidemic**
  - Every node can forward data to every one
  - 2-hop extension: only the data source can copy to others

• **Delegation forwarding**
  - The relay forwards the message to an encounter with a higher quality than those in all previous nodes seen so far.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>delay</th>
<th>Cost (n)</th>
<th>Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epidemic</td>
<td>Minimum</td>
<td>N</td>
<td>No</td>
</tr>
<tr>
<td>2-hop extension</td>
<td>Moderate</td>
<td>N/2</td>
<td>No</td>
</tr>
<tr>
<td>Delegation</td>
<td>Compared to Epidemic</td>
<td>√N</td>
<td>Yes</td>
</tr>
</tbody>
</table>
• Can the data always be fully transferred in a contact (a common assumption)?
  ➢ Not always! We verified through two human traces.

INFOCOM trace

SIGCOMM trace

• Observation:
  ➢ Longer contacts are just a few while short contacts are many.
  ➢ The contact duration distribution fits the exponential distribution.
Cooperative Data Forwarding

• **A better contact model:**
  - Delivery probability is not a constant value, $P$.
  - We model the delivery probability of a node as

\[
P(s) = p \beta(s),
\]

where $\beta(s)$ is a non-increasing decay function with data size, $s$.

• **Cooperative forwarding:**
  - Partition original data into small data chunks!
  - *Cooperative forwarding:* maximally improve the probability of data delivery by sending data segments through **multiple** paths
    - *Forwarding path:* a sequence of contact opportunities
Cooperative Data Forwarding

• Distinguish with replication-based routing

  ➢ All previous algorithms (e.g., Epidemic, 2-hop, Delegation forwarding routing).

Original data with size $S$

Replication-based routing
• Success: Data in any path is delivered;
• Data size: original data size.

Cooperative-based routing
• Success: Data in every path is delivered.
• Data size: small data chunk
Cooperative Data Forwarding

• A motivation example

  ➢ The expected delivery probability of different strategies:

  ✤ Single path routing
    \[ P = 0.22 \]
  
  ✤ With one replication
    \[ P = 1 - (1 - 0.22)(1 - 0.22) = 0.39 \]
  
  ✤ Split to 2 data chunks
    \[ P = 0.67 \times 0.67 = 0.45 \]
  
  ✤ Split to 3 data chunks
    \[ P = 0.74 \times 0.74 \times 0.74 = 0.41 \]

<table>
<thead>
<tr>
<th>Data size</th>
<th>S</th>
<th>S/2</th>
<th>S/3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability</td>
<td>0.22</td>
<td>0.67</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Fig. 2. An illustration of trade-off in the data partitioning.
• Cooperative Data Forwarding

🔥 How to determine the optimal partition

💡 Good: higher delivery probability for each small data chunk
💡 Bad: need to receive data from multiple forwarding paths

Theory: To maximize data delivery probability if nodes' mobility follows the random-waypoint model and $\beta(s)$ is a decreasing function, the optimal data-partitioning strategy within deadline $T$ in the epidemic routing is:

$$s = -p \frac{d\beta(s)}{ds} T$$

🔥 Algorithm

- Calculate the optimal chunk size
  $$s = -p \frac{d\beta(s)}{ds} T$$
  
- if there exists some chunks that the encountered node does not have
  - Replicate data chunk in a round-robin fashion.
Cooperative Data Forwarding

- Cooperative Data Forwarding

<table>
<thead>
<tr>
<th></th>
<th>Epidemic</th>
<th>Single-copy probability-based</th>
</tr>
</thead>
<tbody>
<tr>
<td>With partition</td>
<td>EP</td>
<td>SP</td>
</tr>
<tr>
<td>Without partition</td>
<td>EN</td>
<td>SN</td>
</tr>
</tbody>
</table>

INFOCOM trace

SIGCOMM trace
• Extension

- Disadvantage: if one of the data chunk is missed, the data forwarding fails.

- Solution: network coding technique!

![INFOCOM trace](https://example.com/info_com_trace.png)

![SIGCOMM trace](https://example.com/sigcomm_trace.png)
Opportunistic networks

- There are many opportunistic contacts in IoT environment
- Opportunistic communication (Store-Carry-Forward)

Routing methods

- The contact duration might be insufficient for data transmission
  - Cooperative Data Forwarding
  - Verified through two human traces

Future works

- Try more data traces, e.g., vehicular traces.
- Try to use network knowledge to optimize routing performance.
Thank you!

ning.wang@temple.edu