Evaluating Mobility Pattern Space Routing for DTNs

Jérémie Leguay
Thales Communications/U. P&M Curie

coop-authors: Timur Friedman (U. P&M Curie), Vania Conan (Thales Communications)

Barcelona, 27 April 2006
Main Contribution
- Euclidean virtual space for DTN (Delay Tolerant Networks) routing
  - Space built on mobility patterns
- Evaluation using “real” mobility traces

Outline
- Problem statement
- Routing proposition
- Dartmouth data
- Simulation results
Problem statement

Problem of routing

- **Routing is a challenge in DTNs** (Delay Tolerant Networks) [Lindgren, Burgess, Wang, Widmer, ...]. Regular ad hoc routing protocols fail because topology suffers from connectivity disruptions:
  - Partitions
  - Long-delay links

Example:

- B wants to send a bundle to E, but B and E are not at the same location.
- B has 3 possibilities:
  - keep the bundle.
  - give it to A.
  - give it to D.
Our contribution: MobySpace [WDTN]
- Routing decisions are taken using nodes’ mobility patterns.
- Give bundles to nodes that we believe are more likely to deliver them.
- Use of a virtual Euclidean space to make routing decisions.

MobySpace usage
- A node’s mobility pattern defines its position in the virtual Euclidean space.
- To route a bundle, a node passes the bundle to the neighbor whose position is closest to the destination’s.
A MobySpace is defined by:
- The number of dimensions
- The meaning of the dimensions (a probability, a frequency, etc…)
- A distance function

Examples of MobySpace:
- **Frequency of visit based**: Each dimension in the MobySpace represents a physical location. Each coordinate corresponds to the probability of finding the node at that location.
- **Contact based**: Each dimension in the MobySpace represents the frequency of contacts between two given nodes.
Dissemination of mobility patterns
- The mobility pattern of the destination needs to be known.
- Mobility patterns may be difficult to share between nodes.

Nature of mobility patterns
- Mobility pattern of nodes may change too rapidly.
- The mobility pattern might not capture some essential information.
  - E.g. time of day

Single copy scheme
- May suffer in a lossy environment.
The frequency of visit based MobySpace

Each dimension in the MobySpace represents a physical location. Each coordinate corresponds to the probability of finding the node at that location. (≠ geographical routing)

Motivation

Nodes’ frequencies of visits to locations have been observed to follow a power-law distribution in a certain number of cases. [Dartmouth, UCSD].

INFOCOM – April 2006
Dartmouth Wi-Fi access network [Kotz]
- One of the largest data collection efforts
- Between 2001 to 2004
  - 13,000 MAC addresses
  - 550 APs (academic buildings, library, sport infrastructures, administrative buildings, student residences, etc...)

Mobility data used
- Users’ sessions (pre-processed by Song et al.)
- January 26th 2004 and March 11th 2004 (Spring semester prior to spring break)
- Hypotheses to obtain DTN-like data
  - APs considered to be locations
  - Connection to a same AP = contact
Simulation parameters

- **General settings:**
  - 45 days of Dartmouth traces replayed
  - 300 mobile nodes sampled from 5545 (computational reasons)
  - 536 locations (No sampling)

- **Traffic generation:**
  - 100 random mobile nodes are *active* (*i.e.*, generate traffic)
  - Each active node sends 5 bundles to different destinations
  - Active nodes are present the first week
  - Nodes have knowledge of their mobility patterns

- **5 global runs**
  - Student $t$ distribution to compute 90% confidence intervals
Routing comparisons

- **Epidemic routing**
  - Bundles are flooded in the network. It is the optimum in terms of delays and delivery but leads to high buffer and radio utilization.

- **Opportunistic routing**
  - A source waits to meet the destination in order to transfer its bundle. It involves only one transmission per bundle.

- **Random routing**
  - Like MobySpace but random node preferences as opposed to preferences defined by mobility patterns.

- **Hot potato routing**
  - At any time, a node may transfer the bundle to a neighbor chosen at random. Loops are avoided.
Simulation results

Summary:

<table>
<thead>
<tr>
<th></th>
<th>Delivery ratio (%)</th>
<th>Delay (days)</th>
<th>Route length (hops)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epidemic</td>
<td>82.0</td>
<td>12.5</td>
<td>7.1</td>
</tr>
<tr>
<td>Opportunistic</td>
<td>4.9</td>
<td>15.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Random</td>
<td>7.2</td>
<td>16.6</td>
<td>3.12</td>
</tr>
<tr>
<td>Potato</td>
<td>10.7</td>
<td>19.1</td>
<td>72.7</td>
</tr>
<tr>
<td>MobySpace</td>
<td>14.9</td>
<td>18.9</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Lessons:

- MobySpace outperforms the other single copy protocols in delivery ratio.
- Potato engenders many more transmissions.
- MobySpace is next to Epidemic in delivery ratio, while only using selected contact opportunities.
With “most active” users:
- Users that are present all 45 days (835 users)
- Summary:

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Delivery ratio (%)</th>
<th>Delay (days)</th>
<th>Route length (hops)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epidemic</td>
<td>96.7</td>
<td>3.1</td>
<td>7.9</td>
</tr>
<tr>
<td>Opportunistic</td>
<td>10.7</td>
<td>17.6</td>
<td>1.0</td>
</tr>
<tr>
<td>Random</td>
<td>14.0</td>
<td>17.9</td>
<td>3.5</td>
</tr>
<tr>
<td>Potato</td>
<td>38.9</td>
<td>19.1</td>
<td>317.0</td>
</tr>
<tr>
<td>MobySpace</td>
<td>50.4</td>
<td>19.5</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Lessons:
- Results are globally improved
- MobySpace far outperforms other single copy protocols
Conclusion

- Proposition of MobySpace, a routing scheme for DTN that uses a virtual space constructed upon nodes’ mobility patterns.
- Evaluation with real mobility traces
- MobySpace outperforms the other single copy schemes we evaluated in delivery ratio while keeping a low number of transmissions

Ongoing and future work

- Introduction of controlled flooding mechanisms
  - we expect a gain in delay and delivery ratio
- Definition of other kinds of MobySpace
- Study using other data sets