Study of a Bus-based Disruption Tolerant Network: Mobility Modeling and Impact on Routing

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Summary

- Studied mobility traces taken from Umass DieselNet - a DTN consisting of Wi-Fi nodes attached to buses.
  - What is a DTN?
- Characterized the contact process between buses and its impact on DTN routing performance.
  - What is the right granularity?
- Constructed route-level generative models.
  - What is a generative model?
- Conducted trace-driven simulations of epidemic routing.
Terms and Pointers

- DTN (Disruption-Tolerant Network): network architecture and protocol designs that route data despite intermittent connectivity among nodes.
- The granularity that captures the aspects of mobility that are most important in determining DTN performance.
- Generative model: the model that can be used to generate synthetic traces to drive a trace-driven simulation.
Testbed

- 40 buses equipped with two 802.11b interfaces and a GPS device.
- Access a central repository via fixed access points in a café or bus garage.
- Bus-to-bus transfer records.
- Bus-to-AP check-in records.
- Ten routes. Three most popular:
  - SHUTTLE.
  - SN_SA.
  - NA_BR.
- Each route has multiple shifts 15 minutes apart.
DTN Routing Performance

- Basic epidemic routing is chosen for the best-case delivery delay performance.
- Store-carry-forward propagation.
- Destination initiates a recovery process upon infected.
  - Adopt VACCINE to propagate ACK in the same manner as data packet.
- Performance Metrics.
  - Delivery delay.
  - Total number of copies.
  - Number of hops of the min-delay-path.
Aggregation Statistics

- Inter-contact time: the duration of time between two subsequent contacts.
- Assumptions.
- Inter-contact observations:
  - Fully observed.
  - Start-censored.
  - End-censored.
  - No-meeting.
- Ignoring censored observations leads to an under-estimation of the inter-contact time distribution.
Aggregation Model

- Kaplan-Meier estimator for empirical distribution.
  - Advantage: take censored observation into account.
- Definitions:
  \[
  S(t) := Pr(X > t)
  \]
  \[
  \hat{S}(t) = \prod_{T_i < t} \frac{n_i - d_i}{n_i}
  \]
- Large difference in CCDF (Figure 3 (c)) and simulation results (Figure 4 and 5).
Route-level Modeling

- Problems in modeling at bus-pair level.
- Expect different shifts within the same route to exhibit similar contact processes.
- Route-level characteristics (Figure 7):
  - Same number of start-censored and end-censored inter-contact times.
  - Many no-meeting observations.
  - Fully observed exhibits periodic behavior and a trend of decreasing probability for longer inter-contact times.
  - A large number of small inter-contact times.
Deterministic Meeting Behavior

- Assumptions:
  - Following bus schedules.
  - Running at constant speed.
- Inter-meeting time: the duration of time between when two buses are in transmission range.
- Route classification:
  - Linear.
    - Meeting every half round trip time.
  - Butterfly-shaped.
    - Meeting every T or 2T time period where T is the left or right loop round trip time.
Mean-restricted Mixture Normal Model

- Inter-meeting time is a random variable with the normal distribution.

- For the case:
  - There is a single inter-meeting time between a bus pair running on the route-pair.
  - OR when the inter-meeting times are multiples of a single based value.

- Inter-contact time can be modeled as:

\[
\hat{f}_{SM}(x) = \sum_{i=1}^{G} w_i f_i(x | i\mu, \sigma^2)
\]
Mean-weight-restricted Mixture Normal Model

- Shortcomings of the last model.
  - Weights and the number components have no clear physical interpretations.
  - Unclear how to take into account censored observations when estimating parameters.
- Figure 9 (b) reveals a geometric trend in the weights of the last model.
  - Weight can be taken as:
    \[ w_i = p^{i-1}(1 - p) \]
  - \( p \) is the probability that two nodes in transmission range failed to establish a contact.
Mean-weight-restricted Mixture Normal Model (Continued)

- Assume the time we start to observe a shift-pair is a random incident into an inter-contact time interval.
- Start-censored observations is the residual lifetime with PDF: 
  \[ f_Y(x) = \frac{1 - F_X(x)}{E_X} \]
- No-meeting observations correspond to residual lifetime longer than \( t_e - t_s \):
  \[ 1 - F_Y(t_e - t_s) \]
- An end-censored observation of value \( y \) corresponds to a longer than \( y \) ICT:
  \[ 1 - F_X(y) \]
New Models

• One-Base-Mean Model.
  • For bus pairs with a single inter-meeting time.

\[ f_{GEO_{MP1BM}}(x) = \sum_{i=1}^{C} \sum_{l=1}^{\infty} w_i p_i^{l-1}(1-p_i) f_N(x|l\mu, \sigma^2) \]

• Two-Base-Mean Model.
  • For the shuttle route where bus pairs meet every T or 2T.

\[ f_{GEO_{2BM}}(x) = \sum_{i=1}^{2} \sum_{l=1}^{\infty} w_i p_i^{l-1}(1-p_i) f_N(x|li\mu, \sigma^2) \]
Thank You
Expectation Maximization (EM)

- For finding Maximum Likelihood Estimation (MLE) of parameters in probabilistic models.
- Expectation – introduce hidden variables representing the number of physical meetings with the observed inter-contact time.

\[
p(l|x_i, \Theta_t) = \frac{p(l, x_i|\Theta_t)}{p(x_i|\Theta_t)} = \frac{p_t^{l-1}(1 - p_t)f_N(x_i, l\mu_t, \sigma_t^2)}{\sum_{j=1}^{\infty}p_t^{j-1}(1 - p_t)f_N(x_i, j\mu_t, \sigma_t^2)}
\]

- Maximization.

\[
Q(\Theta, \Theta_t) := E[\log(P(X, Y|\Theta)|X, \Theta_t)]
\]

\[
\Theta_{t+1} = \arg\max_{\Theta} Q(\Theta, \Theta_t)
\]