DATA ROUTING IN A BUS-BASED DTN

Maestro retreat, Avignon 22 Sept. 2009

Giovanni Neglia

Joint work with Paolo Giaccone, David Hay, Leonardo Rocha

and Saed Tarapiah (new entry)
HOW TO SELFISHLY EXPLOIT MAESTRO RETREAT TO GET FEEDBACKS ON ONGOING WORKS

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Joint work with Paolo Giaccone, David Hay, Leonardo Rocha

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(almost) Zero knowledge about future meetings
- Random waypoint model, random direction model, ...
- Copies (not only forwarding) necessary to guarantee fast delivery time

Complete knowledge about future meetings
- Deterministic single-copy routing
- It is possible to apply standard algorithms for static graphs
TRANSFORMING A TIME – DEPENDENT DTN GRAPH

A → B → C

\[ b_A, b_B, b_C \]

\[ t_1, d_1, t_2, d_2 \]

\[ t_i: \text{meeting time instant} \]
\[ d_i: \text{max amount of data transferable} \]
\[ b_i: \text{buffer size at node } x \]
TRANSFORMING A TIME-DEPENDENT DTN GRAPH

- \( t_i \): meeting time instant
- \( d_i \): max amount of data transferable
- \( b_i \): buffer size at node \( x \)

Path from A to C?
Maximum data transferable?
TRANSFORMING A TIME-DEPENDENT DTN GRAPH

\[ t_i: \text{meeting time instant} \]
\[ d_i: \text{max amount of data transferable} \]
\[ b_i: \text{buffer size at node x} \]

Path from A to C?
YES
Maximum data transferable?
max\{b_A, d_1, b_B, d_2\}
SOMETHING IN THE MIDDLE?

Complete knowledge

Zero knowledge
WHERE WE PLACE OURSELVES

Complete knowledge

Zero knowledge

Quasi-deterministic mobility

- There is some information available a priori (e.g. a schedule)
- But also some (small) noise affecting expected meeting time
A CASE STUDY: A BUS-BASED DTN

- Turin bus transportation system
  - about 60 schedule-based bus lines
  - about 50 frequency-based bus lines (up to 12 buses per hour)
  - About 3000 bus stops

- Route a message from a source to a destination
  - using only bus-stop meetings (for which we have a schedule) and stop2stop transfers
  - target: maximize delivery probability
    - by a given deadline $T$
    - with not too many copies

- What different from people routing?
  - Messages cannot walk...
  - but can be duplicated
THE DTN GRAPH

Bn.m  m-th vehicle of line n

t_i  scheduled meeting time
A feasible vehicle path if $t_4 \leq t_5$ and $t_6 \leq T$

$B_{n.m}$ m-th vehicle of line n
$t_i$ scheduled meeting time
An actual vehicle path if $t_4 + n_4 \leq t_5 + n_5$ and $t_6 + n_6 \leq T$

$B_{n.m}$ m-th vehicle of line n
$t_i$ scheduled meeting time
The corresponding line path:
• take the 1st bus of line 10 arriving at stop $S_0$
• get off at stop $S_2$
• take the 1st bus of line 55 arriving at stop $S_2$
• get off at stop $S_4$
What noise looks like
- distribution
- Temporal and spatial noise correlation
  - $n_1$ correlated with $n_2$ (e.g. necessarily $t_1+n_1 \leq t_2+n_2$
  - $n_1$ correlated with $n_7$ (e.g. if there is traffic nearby stop $S_0$)

Max delivery prob. not equivalent to max a link-additive cost
- No standard routing algorithms
Look for known results in transportation networks
- Models
- Measurements
- Traffic simulators

Look directly in real traces
Look for known results in transportation networks
- Models
- Measurements
- Traffic simulators

The expert answer: “Have you googled it?”

Look directly in real traces
Provided by Turin transportation system (GTT)
Average delay = -1 minute

Ask to GTT engineers:
“There is probably a problem somewhere. Thanks to help us debugging the system”
1. Find the vehicle path that maximizes the waiting time at each stop while respecting the deadline T
   - similar to what we do when planning flight trips

2. Estimate its delivery probability
   - assuming noise independence at different bus stops
   - \( P=(s_0,e_0,s_1,e_1,\ldots,s_{n-1},e_{n-1},s_n) \)
   \[
   \text{Prob}\{P \text{ is successful}\} = \text{Prob}\{t_{0,1} \leq t_{0,2} \leq t_{1,1} \leq t_{1,2} \leq \ldots t_{n-1,1} \leq t_{n-1,2} \leq T\} = \\
   = \text{Prob}\{t_{0,1} \leq t_{0,2} \} \text{Prob}\{ t_{0,2} \leq t_{1,1} \mid t_{0,1} \leq t_{0,2} \} \\
   \text{Prob}\{t_{1,1} \leq t_{1,2} \mid t_{0,1} \leq t_{0,2} \leq t_{1,1} \} \ldots \\
   \text{Prob}\{ t_{n-1,2} \leq T \mid t_{0,1} \leq t_{0,2} \leq t_{1,1} \leq t_{1,2} \leq \ldots t_{n-1,1} \leq t_{n-1,2} \} \leq \\
   \text{Prob}\{t_{0,1} \leq t_{0,2} \} \text{Prob}\{ t_{0,2} \leq t_{1,1} \} \text{Prob}\{t_{1,1} \leq t_{1,2} \} \ldots \text{Prob}\{t_{n-1,2} \leq T\} \\
   
3. Evaluate if it can be useful to do a copy and where
QUALITY OF PROBABILITY DELIVERY ESTIMATION

Exponential Noise, scale = 3.0, vehicle routing_nocheck

- toy
- toy theo
- min conf
- max conf

Exponential Noise, scale = 3.0, vehicle routing_nocheck

- path 5
- theo 5
- min conf
- max conf
SOME SIMULATION RESULTS ON TURIN NETWORK

Best line path

2\textsuperscript{nd} best line path

Is it worthy to do multiple copies?
A MARKOVIAN MODEL FOR LINE PATH DIFFERENCES

- Packet move along a path described by the state evolution of a Markov process
  - Delivery time is time to absorption

- Determine region of parameters (minimum travel times, connection times, bus frequencies and deadline) such that the second path can be worthy to be exploited

- Check in which region Turin bus network is operating