Routing in Delay Tolerant Networks

Primary Reference: S. Jain, K. Fall and R. Patra, "Routing in a Delay Tolerant Network," SIGCOMM'04, Aug. 30-Sep. 3, 2004, Portland, Oregon, USA

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For EECS 800: Survivable, Resilient and Disruption Tolerant Networking

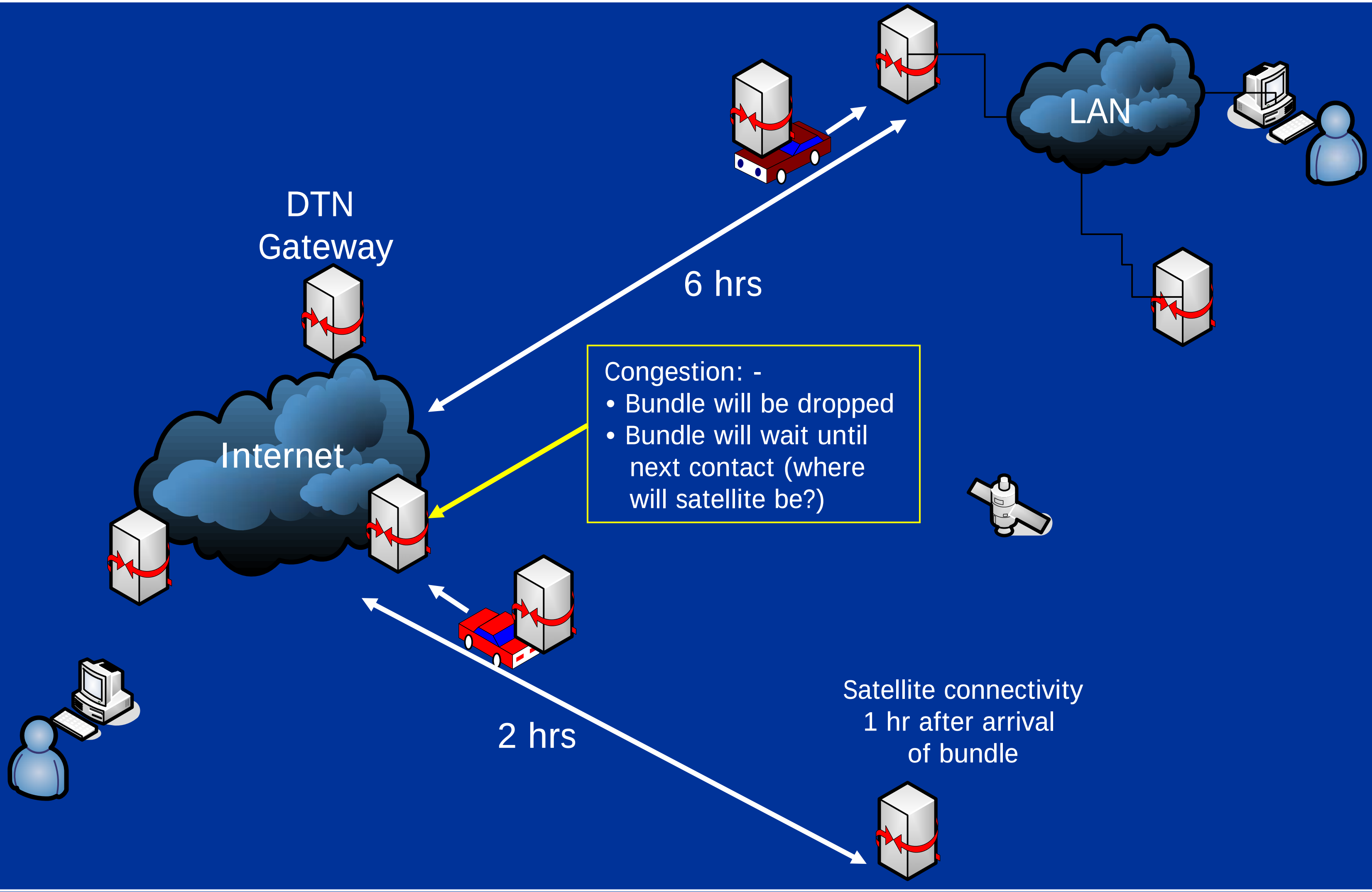
University of Kansas,

November 1, 2005

Outline

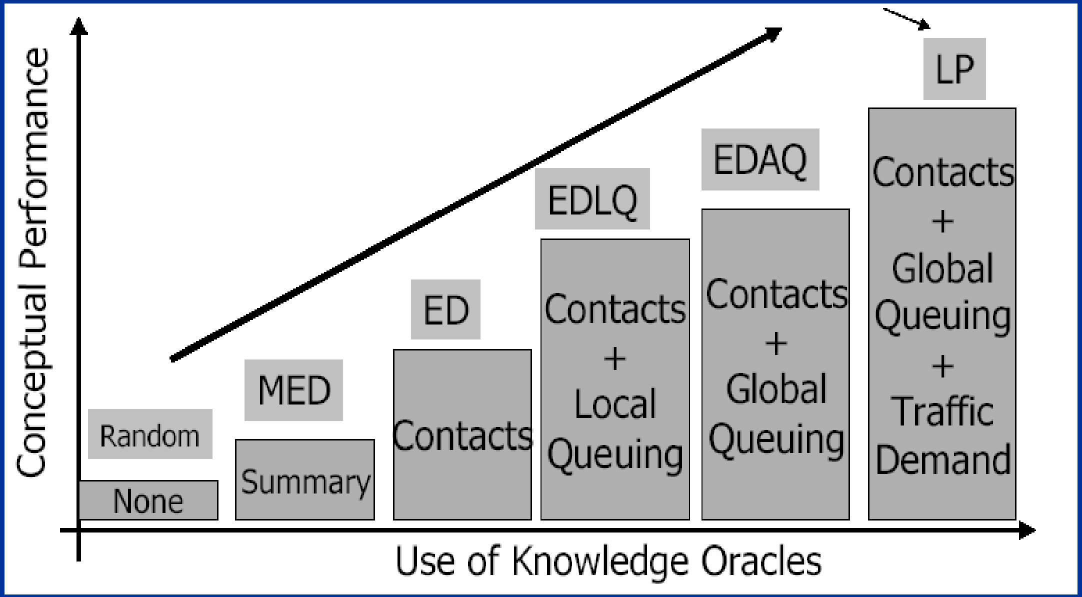
- Motivation: DTN routing problem example
- Routing with zero knowledge (FC)
- Routing with partial knowledge (MED,ED,EDLQ,EDAQ)
- Routing with complete knowledge (LP)
- Simulation Results
- Conclusion

DTN routing problem (example)



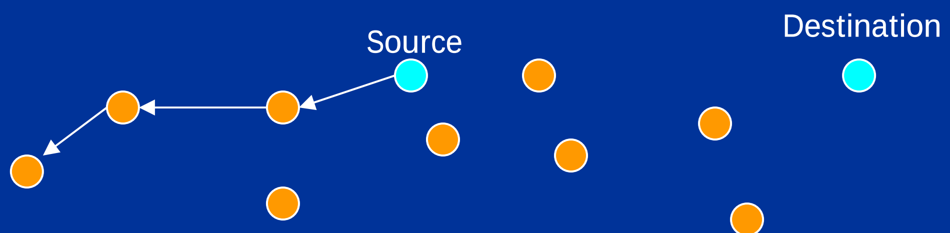
Knowledge oracles

- Abstract knowledge oracles are able to answer questions
- Contacts Summary Oracle: Aggregate statistics (e.g., avg. waiting... ...time until next contact for an edge)
- Contacts Oracle: Knowledge of all contacts for all edges at all times
- Queuing Oracle: Instantaneous queue lengths of all nodes
- Traffic Demand Oracle: Present and future traffic demand



Routing with zero knowledge
First contact (FC)

- No knowledge oracles are used
- Forward along a randomly chosen edge (from available contacts)
- If no contacts available wait for first contact
- Problems
  - Message may not make progress towards the destination



  - Loops (especially when frequent contacts present among a set of nodes)
  - No provision to route around congestion
- Improvements
  - Incorporate sense of trajectory to route towards destination
  - Use path vector type approach to avoid loops

Routing with partial knowledge
MED, ED, EDLQ, EDAQ

- One or more of oracles: contacts summary, contact and queuing
- Path that minimizes delay increases delivery probability
- Dijkstra's algorithm finds minimum-cost path
- Costs assigned to edges to reflect estimated delay of message in...

  ...taking that edge
- Dijkstra's algorithm then finds the minimum-delay paths
- Algorithms differ in the way costs are assigned
- Costs may be
  - Time invariant (MED)
  - Time varying (ED, EDLQ, EDAQ)
- Limitation of this method
  - Only single path may be derived

Routing with partial knowledge

Modified Dijkstra's algorithm

$$Input : G = (V, E), s, T, w(e,t)$$

$$Output : L$$

$$Q \leftarrow \{V\}$$

$$L[s] \leftarrow 0, L[v] \leftarrow \infty \forall v \in V\_s.t.\_v \neq s$$

$$while\_Q \neq \{\ \}\_do$$

$$\_\_\_Let\_u \in Q\_be\_the\_node\_st\_L[u] = \min_{x \in Q} L[x]$$

$$\_\_\_Q = Q - \{u\}$$

$$\_\_\_for\_each\_edge\_e \in E, st\_e = (u,v)\_do$$

$$\_\_\_\_\_\_if\_L[v] > (L[u] + w(e, L[u] + T))\_then$$

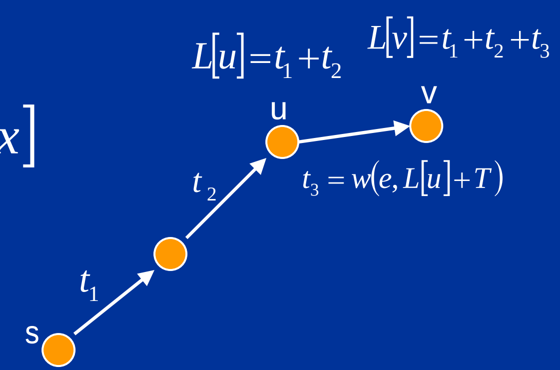
$$\_\_\_\_\_\_\_\_\_L[v] \leftarrow L[u] + w(e, L[u] + T)$$

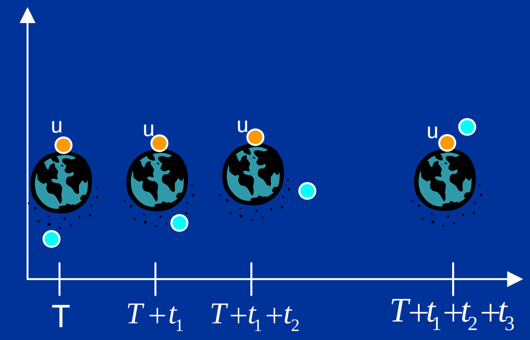
$$\_\_\_\_\_\_end\_if$$

$$\_\_end\_for$$

$$end\_while$$

Different





Routing with partial knowledge
Minimum Expected Delay (MED)

- Uses the contacts summary oracle
- Edge costs are time-invariant (average time until next contact)
- Cost of an edge is avg. waiting time + prop. + transmission delay
- Route of a message independent of time
- Problems
  - No mechanism to route around congestion
  - When direct contact becomes available, message still waits for…
    ...pre-computed next-hop
- Improvements
  - Modify pre-computed route in transit when a contact becomes available

Routing with partial knowledge

Time-varying costs

- ED, EDLQ and EDAQ assign time-varying costs
- Let $w(e,t) = w'(e,t,m,s)$
- m is the message size, s is the node assigning the cost

$$w'(e,t,m,s) = t'(e,t,m,s) - t + d(e,t')$$

$$t'(e,t,m,s) = \min\left\{ t'' \,\middle|\, \int_{x=t}^{t''} c(e,x)\,dx \geq (m + Q(e,t,s)) \right\}$$

Routing with partial knowledge
Earliest Delivery (ED)

- Contacts oracle is used
- Queuing information is not used $Q(e,t,s)=0$
- Routes are loop free (Dijkstra's algorithm)
- Routes determined at source and fixed (source routing)
- Messages may be dropped due to congestion
- Will work good when
  - Queues in path are empty
  - Contact capacity is high (queues emptied in negligible time)
- Will not work good when
  - Messages in queue, contact may end before message is sent
  - Disastrous because contact in next hop may be missed
  - Continuing on route computed earlier may not be optimal

Routing with partial knowledge

Earliest Delivery with Local Queuing (EDLQ)

- Contacts oracle is used
- Local queue occupancy is taken into account

$$Q(e,t,s) = \begin{cases} data\_queued\_for\_e\_at\_time\_t\_if\_e = (s,*) \\ 0\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ otherwise \end{cases}$$

- Q accounts only for queuing at outgoing edges of current node
- Helps route around congestion at first hop
- Unlike ED, re-compute route at every hop
- Problem
  - May result in routing loops
- Improvement
  - Use path vectors to avoid loops
- Problem
  - Like ED messages might get dropped because of buffer overrun

Routing with partial knowledge

Earliest Delivery with All Queues (EDAQ)

- Contacts and Queuing oracles used
- Instantaneous queue sizes across entire topology at any point of...

  ...time are used

  $$Q(e,t,s) = data\_queued\_for\_e\_at\_time\_t\_at\_node\_s$$
- Like ED, messages are source routed
- Problem
  - Congestion losses may occur because EDAQ is oblivious to buffer sizes

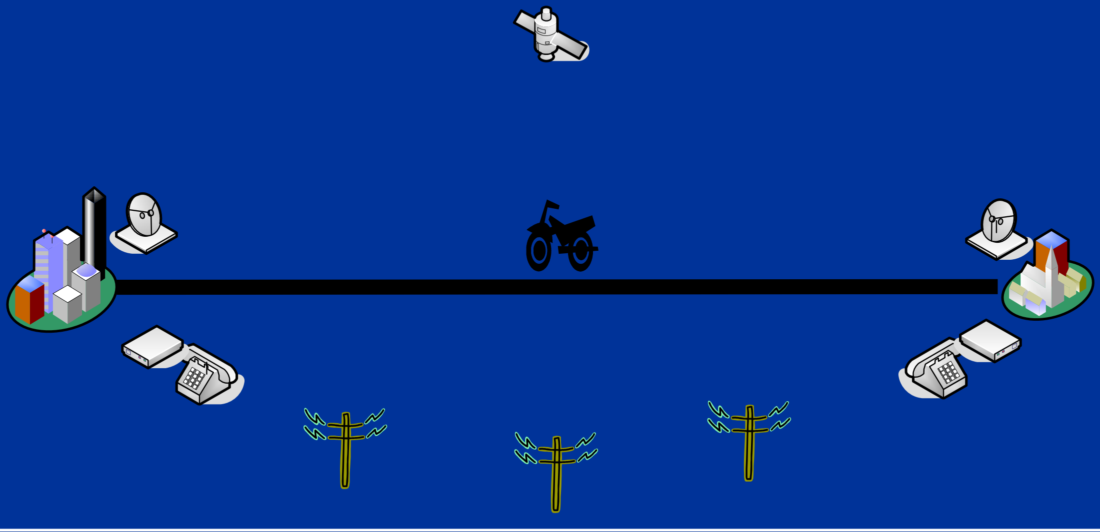
Routing with complete knowledge
LP formulation

- LP formulation is discussed in paper
- Objective function is to minimize the average delay
- Contacts, Queuing and Traffic oracles are used
- Buffer sizes are assumed to be known
- Even for a very simple topology computation time is about 8 minutes..
  ... on a 8 processor P3 machine
- Not feasible to compute routes in real-time for realistic topologies

Simulation Setup

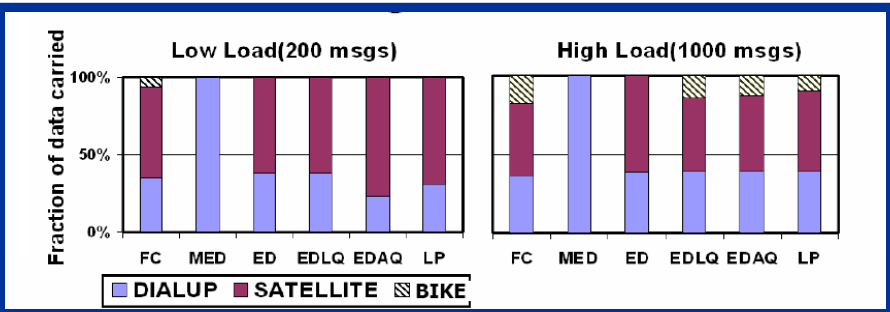
Scenario 1: Routing to a remote village

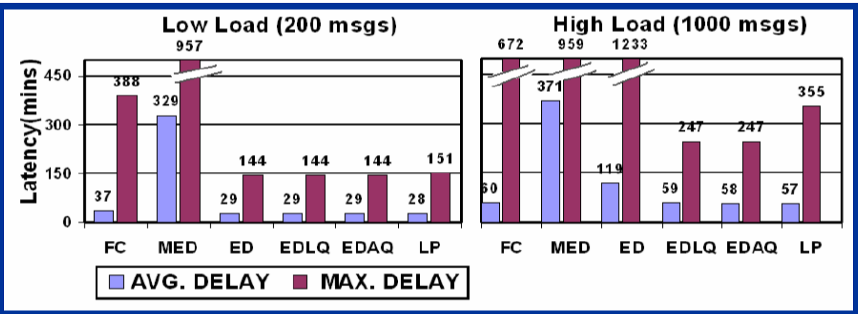
- Dialup: 4Kbps (available 11AM to 6PM)
- LEO satellite (position determined by tracking software)
- Motorbike (2 hrs – one way, bandwidth to/from motorbike 1Mbps,...
  ...can store up-to 128 MBytes in USB stick)
- Messages: village to city 1KB, reverse dir. 10KB, low load = 200 messages per day, high load = 1000 messages, messages generated for one day, simulation time = 2 days



Simulation Results

Scenario 1: Routing to a remote village





- MED routes all data over dialup (best average delay, time-invariant)
- ED: most data satellite, rest dialup (motorbike not used: satellite crossings less than 2 hrs)
- FC performs ok for simple topology (all paths lead to the city)
- Congestion aware schemes use motorbike at high loads
- ED and MED remain same at low and high loads (not congestion aware)
- Both ED and MED suffer because of not being congestion aware
- EDLQ and EDAQ average delay performance is close to LP

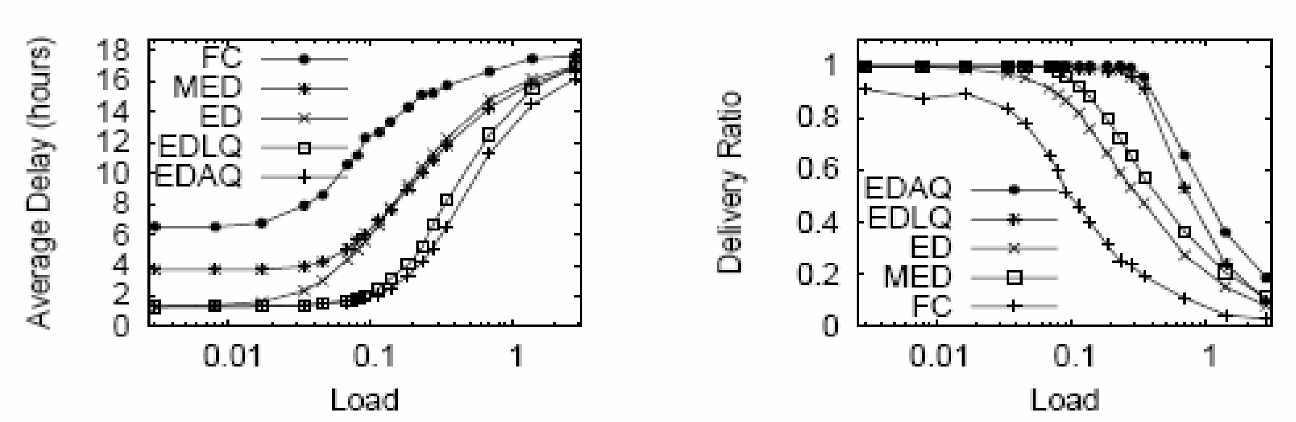
Simulation Setup

Scenario 2: a network of city buses

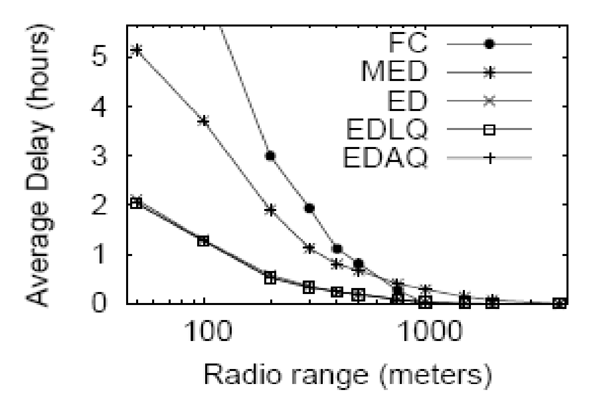
- Map of San Francisco used for bus movements of 20 buses
- Bus stop when bus makes a turn to a new street
- Stop time 0 to 5 mins uniform distributed
- Bus speed 10-20 m/sec uniform distributed
- Buses communicate when in radio range: default = 100m
- Messages generated for 12 hrs
- 20 random source destination pairs chosen in each hour
- Each source bus sends 200 messages to its destination in 1 hr
- Messages injected simultaneously at a randomly chosen time in the 1 hr interval
- This represents bursty traffic
- Load=Traffic demand/Contact volume
- Even with a load less than 1 network may be congested (message has to traverse… …multiple hops, contacts may be present but no traffic to utilize them)
- Load is changed by changing the contact volume (change contact bandwidth or … … change contact duration – radio range)
- Default storage capacity=100MB, default link bandwidth =100Kbps

Simulation Results

Scenario 2: a network of city buses



- Change load: bandwidth based
- Low loads: delay does not change problem is contacts not bandwidth
- Higher loads: there is congestion
- EDAQ, EDLQ perform better
- Very high load: most not delivered
- Average delay decreases with increase in radio range
- High radio range, buses in contact higher percent of time
- Difference in algorithms more pronounced when...
  ...connectivity is intermittent



Conclusion

- ED,EDLQ,EDAQ outperform FC,MED: both delay and delivery ratio
- ED performs worse than EDLQ,EDAQ: congestion mitigation
- Performance difference more pronounced when contacts intermittent
- EDLQ and EDAQ performance comparable
- LP cannot compute routes in real-time
- Paper assumes that knowledge oracles are present
- Realizing knowledge oracles in real-world is a big problem (with...
  ...frequent disconnects and high delays)
- Algorithms may be useful in special case scenarios where contacts...
  ...can be predicted