A New Reliable Transport Scheme in Delay Tolerant Networks Based on Acknowledgements and Random Linear Coding

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ITC 2011, September 6 - 8, San Francisco
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Outline

Delay Tolerant Networks (DTNs)

- Number of mobile nodes per unit area is low
  - Leads to intermittent connectivity
- Transfer of data depends on
  - Node mobility
  - Packet routing/replication methods

Applications of DTNs

- Military battlefield networks
- Sensor networks for wildlife tracking
- Inter-planetary networks
- Remote rural area (village) networks
- Social networks
- Vehicular Ad Hoc networks
- Underwater networks
- etc.

Challenges for reliable transport

- New engineering to meet user requirements
- User requirements
  - Reliability
  - Minimum transfer delays

Motivation

- TCP not suitable for intermittent networks
  - Misinterprets the large delays as congestion
- Need of a new transport protocol which offers reliability

Existing works

- Most works on routing, very few on reliable transport
- Bundle Protocol
- Deep space communication protocols
  - Licklider Transmission Protocol (LTP)
  - Deep-Space Transport Protocol (DS-TP)
  - TP-Planet
  - Space Communication Protocol Standards – TP
  - Saratoga
  - CCSDS File Delivery Protocol (CFDP)
  - Delay-Tolerant Transport Protocol (DTTP)
- Unreliable transport: RCP-Planet

Proposal

- New reliable data transport protocol in DTNs
  - Based on coding and acknowledgements (ACKs)
  - ACKs acknowledge missing **Degrees of Freedom** (DoF)
- Analysis and optimization of the proposal
  - In order to minimize the round trip delay

Our proposed reliable transport scheme

- 1 source, 1 destination, N relays
  - Inter meeting times are exponential with rate β
- The protocol is organized in cycles
- At the beginning of each cycle:
  - i= missing degree of freedom
  - M = number of information packets
  - The source generates M_i Random Linear Combinations (RLCs)
  - Gives one RLC to an empty relay upon meeting
- Relays replicate RLCs in an epidemic manner
  - $\tau_{i,s}$ = spreading time of each RLC
- Each RLC has an expiry time-out
  - β_e = exponential expiry rate of RLCs

Our proposed reliable transport scheme

- Destination sends an ACK upon receiving an RLC
  - ACKs spread epidemically
  - ACKs acknowledge missing degrees of freedom (DoF)
- Cycle duration:

$$\tau_i := t_{M_i} + \tau_{i,S} + \tau_{i,W},$$

- Between $\tau_{i,s}$ and $\tau_{i,w}$
  - $\tau_{i,w}$ = ACK wait time
  - Only ACKs spread
- At the end of the cycle:
  - the source determines the missing degree of freedom

Analysis and optimization

- Analysis of the scheme:
  - Using fluid-limit modeling
  - CDF of the packet and ACK transmission delays.
  - Mean completion time
- Joint optimization of the number of RLCs, M_i, to be sent in one cycle; spreading time of RLCs, $\tau_{i,s}$; ACK wait time,$\tau_{i,w}$
  - So as to minimize the mean completion time of a file

Fluid model (RLCs replication)

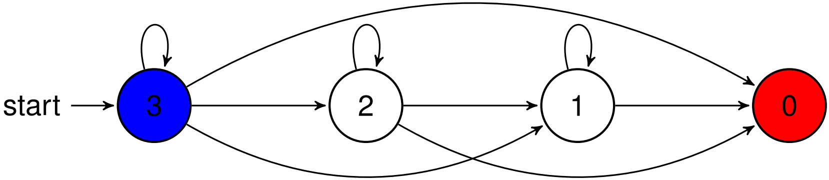
$$\frac{dx_k(t)}{dt} = \begin{cases} 0 \quad \text{for } 0 \leq t \leq \frac{k-1}{\lambda}, \\ \\ (\beta + \lambda x_k(t))(1 - x(t) - y(t)) - \beta x_k(t) \\ -\beta_e x_k(t) - \lambda x_k(t) y_0(t) \\ \text{for } \frac{k-1}{\lambda} < t \leq \frac{k}{\lambda}, \\ \\ \lambda x_k(t)(1 - x(t) - y(t)) - \beta x_k(t) \\ -\beta_e x_k(t) - \lambda x_k(t) y_0(t) \\ \text{for } \frac{k}{\lambda} < t \leq \frac{k}{\lambda} + \tau_{i,S}, \\ \\ -\beta x_k(t) - \beta_e x_k(t) - \lambda x_k(t) y_0(t) \\ \text{for } \frac{k}{\lambda} + \tau_{i,S} < t \leq \tau_i. \end{cases}$$

Fluid model (ACKs replication)

$$\frac{dy_l(t)}{dt} = \lambda y_l(t)(1 - x(t) - y(t)) + \beta Q_l^{(i)}(t)(1 - y_l(t)) + \lambda y_l(t) \sum_{m>l} y_m(t) - \lambda y_l(t) \sum_{m<l} y_m(t) + \mathbf{1}_{\{l=0\}} \lambda y_l(t) x(t), \text{ for } 0 < t \leq \tau_i,$$

$$Q_l^{(i)}(t) = \sum_{E \subset \{1,\ldots,M_i\} \,:\, |E| = i-l} \; \prod_{m \in E} P_{X_m}(t) \prod_{m' \in \{1,\ldots,M_i\} \setminus E} (1 - P_{X_{m'}}(t))$$

Sequence of cycles



$j = 0, 1, \ldots, i-1$
P_{ij} = Transition probability from state i to state j

$$P_{ij} = P_{Y_j}(\tau_i) \prod_{l=0}^{j-1} (1 - P_{Y_l}(\tau_i)), \text{ and } P_{ii} = 1 - \sum_{j=0}^{i-1} P_{ij}.$$

T_i = mean time to reach state 0 starting from state i

Sequence of cycles

Objective: *minimize* T_M

Optimization over parameters $\{M_i, \tau_{i,S}, \tau_{i,W}\}$, $i = 1, 2, \ldots, M$
M_i = Number of RLCs to be sent
$\tau_{i,S}$ = Spreading time of each RLC
$\tau_{i,W}$ = ACK wait time
$\forall i$, $i = 1, 2, \ldots, M$

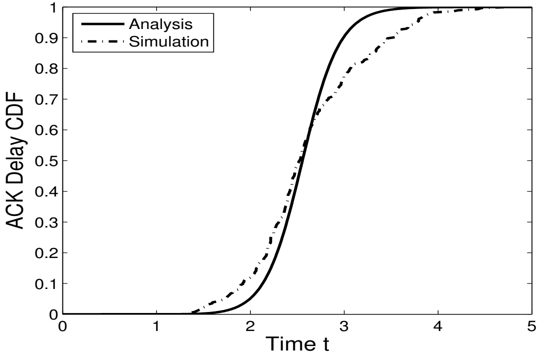
$$\min(T_i) = \frac{\tau_i + \sum_{j=1}^{i-1} P_{ij} \min(T_j)}{1 - P_{ii}}$$

Simulation setting

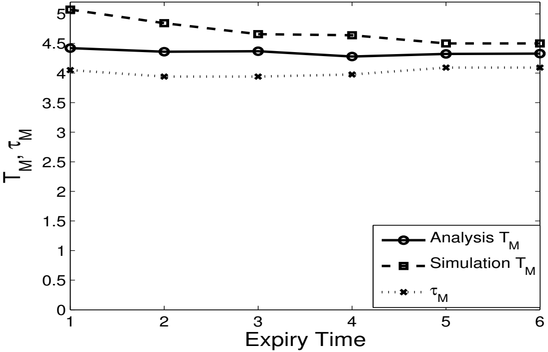
- Number of packets to be transferred $M = 5$
- Number of relay nodes $N = 100$
- Inter meeting rate $\beta = 0.05$
- Buffer expiry timeout is varied
  $i.e, \tau_e = 1/\beta_e = 1, 2, 3, 4, 5, 6$
- RLCs are generated with **binary** random coefficients
- Only useful RLCs are considered at destination
- Simulation results averaged over 1000 runs
- Developed a matlab based simulation

Simulation results[1]: Delay CDF of Final ACK

- Expiry time equal to 3



Simulation results[2]: Optimal values of file transfer time



Conclusions

- Proposal of a new reliable transport scheme for DTNs based on the use of ACKs and coding
- Modeling the evolution of the network under our scheme using a fluid limit approach
- Computation of optimal parameters for our reliable transport scheme

Perspectives

- Adding energy constraints
- Consideration of network partition