Delay and Disruption Tolerant Networks

CMPE257: Wireless and Mobile Networks

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April 16th, 2015
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Traditional Internet

Fig 1. TCP/IP Basic Stack Functionalities
Traditional Internet TCP/IP

1. Client/server communication model
2. Point-to-Point communication
Traditional Internet

• End-to-End Paradigm
  – Is one of the central design principles of the Internet
Issues of Communications During disaster and Emergency

Lack of adequate communication

Terrorist Attack

Tsunami

Earthquake

Hurricane
Issues of Communications in Extreme Environments

Undersea Acoustic Networking - Seaweb Network

Deep Space Communication
Interplanetary Internet (IPN)

• “to permit interoperation of the Internet resident on the Earth with other remotely located Internets resident in another planets or spacecraft in transit”

• Characteristics:
  – High propagation delay
  – Intermittent connectivity
  – Low and highly asymmetric bandwidth
  – High bit-error rate
Delay and Disruption Tolerant Networks

- DTN is a set of protocols that act together to enable a standardized method of performing store-carry-and-forward communication.
- Characteristics of DTN
  - Intermittent connectivity
    - No end-to-end path between source and destination
  - Long variable delay
    - Long propagation delay between nodes
DTN Architecture

Internet Protocols
- Transport (TCP)
  - Network (IP)
  - Link
  - Physical

DTN Protocols
- Transport
  - Network
  - Link
  - Physical

Lower-layer protocols, common across all Internet nodes

common across a DTN

Lower-layer protocols, optionally specific to each DTN node

IPNSIG, http://www.ipnsig.org
DTN Architecture

- Types of contact
  - Scheduled
  - Opportunistic
  - Probabilistic

- DTN forwarding techniques
  - Pure epidemic forwarding
    - Spray and wait, Prophet, etc

- “Reliability” concept
  - Custody transfer

IPNSIG, http://www.ipnsig.org
DTN Simulator and Framework

• The ONE Simulator

• ION – Interplanetary Overlay Network
  – [https://ion.ocp.ohiou.edu](https://ion.ocp.ohiou.edu)

• N4C DTN project
  – ns-3 physical layer, not free
  – [http://www.n4c.eu](http://www.n4c.eu)

• DTN Code for [ns-2 and ns-3](http://www.netlab.tkk.fi/tutkimus/dtn/ns/)

Note: DTN2 - Bundle Protocol Reference Implementation.
Application Scenario – Wildlife Monitoring

• **ZebraNet**

Do zebras in the African bush have a pattern of migration or do they just move around in a random fashion across the year?

• A Princeton University project
• Custom tracking collar with GPS (node) is put on the neck of the zebra.
• Nodes record zebra’s location and stores in memory.
• Nodes carry the data until meet another node.
• Exchanges data with another zebra when in communication range.
• Mobile base station (MBS) collects data from collars when researchers are in the field.
• MBS is not fixed, rather it moves and is only intermittently available.
• Physical presence of the researchers is no longer required at the deployment site in order to collect and publish zebra mobility pattern data.
• Network connectivity is intermittent and opportunistic.
DTN Application

Application Scenario – Communication in Rural Villages

- **DakNet**
  
  **Goal:** Bring Internet connectivity to rural areas

- It is aimed at providing cost-effective connectivity to rural villages in India, where deploying a standard Internet access is not cheap.
- Kiosks are built up in villages and are equipped with digital storage and short-range wireless communications.
- Mobile Access Points (MAPs) mounted on buses, motorcycles, etc., exchange data with the kiosks wirelessly.
- MAPs may also download requested info (news, music, etc.) and bring it to villages.
- Kiosks connectivity
  - Dial-up - slow (28 kbps)
  - Short range communication
DTN Performance

Factors that impact Performance

- Mobility Pattern
- Routing Mechanism
- Size of Area
- Number of Nodes
- Node Speed
- Type of Communication
- Transmission Range
- Message Size
- Buffer Size
- Time-to-Live
- Battery Life
Background
Network Congestion

Congestion control is needed to decide how well a network *effectively and fairly allocates resources*
Congestion control

– Efforts made by network nodes and end-points to prevent or respond to overload condition.

*Congestion control* paces senders preventing them from overloading the network (e.g., due to network resource unavailability).
Internet Congestion Control

• Performed by TCP
  – Each source being sensitive to resource depletion in network to determine the supported rate.

• End-to-end paradigm
  • End-to-end TCP ACK.
DTN Congestion Control

Example: Interplanetary Network (IPN)

Intermittent Connectivity
Long and variable delay
Asymmetric data rates
High error rates

TCP’s end-to-end congestion control mechanisms don’t work in DTNs.
Terrestrial DTN Congestion Control

• Several control schemes have been designed to terrestrial scenario subject to:
  – Small delays
  – Routing protocols based on opportunistic contacts
  – Terrestrial environmental conditions

• Can we use these schemes for IPN?
DTN Congestion Control: Terrestrial x Interplanetary

• Questions?
  1. Which are the good design principles for DTN congestion control mechanisms?
  2. Are the terrestrial DTN congestion control mechanisms sufficient for IPN scenarios?
  3. Is there an “universal” congestion control mechanism that will be applicable to all DTN scenarios?
A Quantitative Analysis of DTN Congestion Control
Methodology

• Four DTN congestion control mechanisms have been selected.

• The selected mechanisms are a representative subset of the DTN congestion control design space.

• More details:
DTN Congestion Control Mechanisms

- Retiring replicants congestion control (RRCC)

1. Nathanael Thompson, Samuel C. Nelson, Mehedi Bakht, Tarek Abdelzaher, Robin Kravets, Retiring Replicants: Congestion Control for Intermittently-Connected Networks, INFOCOM’2010
DTN Congestion Control Mechanisms

• Average forwarding number based on epidemic routing (AFNER)

2. Li Yun, Cheng Xinjian, Liu Qilie, You Xiaohu; A Novel Congestion Control Strategy in Delay Tolerant Networks; Proceedings of Second International Conference on Future Networks, 2010, IEEE.
DTN Congestion Control Mechanisms

- Storage routing (SR)

DTN Congestion Control Mechanisms

- Credit-based congestion control

Experimental Setup

• Simulation environment
  – The ONE simulator
  – Two IPN scenarios
    • With and without congestion control.
  – 6000 runs with 5 different seeds, total of 30000 runs
  – Performance metrics:
    • Average delivery ratio and average latency
Experimental Setup

• Simulation parameters

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario.endTime</td>
<td>simulation time</td>
<td>43200 seconds</td>
</tr>
<tr>
<td>btInterface.transmitSpeed</td>
<td>bandwidth</td>
<td>[0.5, 1.0, 1.5, 2.0, 2.5] Mbps</td>
</tr>
<tr>
<td>btInterface.transmitRange</td>
<td>transmitting range</td>
<td>150 m</td>
</tr>
<tr>
<td>Group.router</td>
<td>routing protocol</td>
<td>EpidemicRouter, ProphetRouter, SprayAndWaitRouter (10 msg copies)</td>
</tr>
<tr>
<td>Group.movementModel</td>
<td>mobility model</td>
<td>StationaryMovement</td>
</tr>
<tr>
<td>Group.bufferSize</td>
<td>node buffer size</td>
<td>[1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000] KB</td>
</tr>
<tr>
<td>Group.msgTTL</td>
<td>message time to live</td>
<td>43200 seconds</td>
</tr>
<tr>
<td>Group.nrofHosts</td>
<td>number of nodes in network</td>
<td>5</td>
</tr>
<tr>
<td>MovementModel.worldSize</td>
<td>area where simulation takes place</td>
<td>6km x 6km</td>
</tr>
<tr>
<td>Events1.size</td>
<td>message size</td>
<td>[50, 100] KB</td>
</tr>
<tr>
<td>Events1.interval</td>
<td>i.e. one new message every 1 to 100 seconds</td>
<td>[1-100, 1-200, 1-300, 1-400, 1-500] seconds</td>
</tr>
</tbody>
</table>

These routing protocols were designed for terrestrial networking.
Experimental Scenario

- Propagation delay
  - the Earth base station and Mars Satellites: 240s
  - the Mars satellites and the rovers: 1s
Results

- Message delivery ratio for IPN scenario as a function of the message generation period.

![Graph showing average delivery ratio for different message generation periods.](image)

Routing protocol: epidemic
Buffer size: 8000kbytes
Transmit speed: 2.5Mbps
Period between contacts: 1000s
Results

• Average delivery ratio (different periods between contacts)
AFNER

Average delivery ratio AFNER for epidemic routing for different periods of contact.

<table>
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<tr>
<th>Periods of contact (s)</th>
<th>Delivery Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>1</td>
</tr>
<tr>
<td>2000</td>
<td>2</td>
</tr>
<tr>
<td>3000</td>
<td>3</td>
</tr>
<tr>
<td>4000</td>
<td>4</td>
</tr>
<tr>
<td>5000</td>
<td>5</td>
</tr>
</tbody>
</table>

Periods of contact (s)

CCC

Average delivery ratio CCC per routing protocol for different periods of contact.

<table>
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</tr>
<tr>
<td>5000</td>
<td>5</td>
</tr>
</tbody>
</table>

Periods of contact (s)

RRCC

Average delivery ratio RR per routing protocol for different periods of contact.

Periods of contact (s)

SR

Average delivery ratio SR per routing protocol for different periods of contact.

Periods of contact (s)
Results

• Average delivery ratio (different contact durations)
Summarizing

• This paper evaluated the performance of four DTN congestion control mechanisms in an interplanetary networking scenario.
  – AFNER, CCC, RRCC and SR
    • Designed for terrestrial scenario, not for interplanetary networks

• Proposed congestion control mechanisms do not significantly improve the baseline IPN scenario performance.
  – Low delivery ratio
Summarizing

• Our studies also indicate that good design principles for congestion control in IPN scenario include:
  • Combination of reactive and proactive control
  • Using local information instead of relying on global knowledge
  • Routing-protocol-independent control
Modeling DTN Congestion Problem
Modeling DTN Congestion Problem

- Goals of the Proposed Model
  - Cross-validate our simulation evaluation

- Model Output
  - The probability of existing a path to delivery the message.
  - The delivery delay
What is the probability that the center of the stone is wetted?
Modeling DTN Congestion Problem

Percolation Theory

If there are only a few white sites, clusters are too small to connect opposite sides of the square lattice.

If the number of white sites is sufficiently large, it is possible to connect the top and the bottom of the lattice, for example with the highlighted path.
Modeling DTN Congestion Problem

• Percolation theory
  – Site Percolation: Each node of the network is randomly set as blocked or unblocked. We are interested in finding a path...
Modeling DTN Congestion Problem

• Percolation theory
  – Bond Percolation: Each edge of the network is randomly set as closed or open. We are interested in finding a path connected by component of open edges.
Modeling DTN Congestion Problem

- Percolation Theory
  – Theory to determine connectivity in systems.

Transition:
- connected $\rightarrow$ disconnected
- congested $\rightarrow$ noncongested

Our approach…
What is the probability of a message to be delivered from a fixed origin to a given destination by finding the probability of existence of a path that contains only unblocked sites and open bonds?

Modeling DTN Congestion Problem

• Site-bond percolation
  – Every node decides to broadcast based on some probability.
  – Nodes forward messages when existing an opportunistic contact.

Site-bond percolation – Every node decides to broadcast based on some probability. – Nodes forward messages when existing an opportunistic contact.
Modeling DTN Congestion Problem

• Our proposed model
  – Collection of nodes in a domain $S$ where $S \subset \mathbb{Z}^d$
    • Each node can generate and send messages
    • Each node cover a region of **fixed coverage radius**
    • Each node can detect the identity any node within its coverage area.
  – bonds $\rightarrow$ **contact opportunity**
  – sites $\rightarrow$ **DTN node buffer**

\[
e = ((x, t), (x_i, t + 1)) \rightarrow \eta(e)
\]
Modeling DTN Congestion Problem

• All nodes have **the same buffer size**, capable of storing $Q$ messages.
• $m(i,x,t)$ represents a message.
• The set of all messages within $x$ node buffer in $M(x, t)$

![Figure Network time segments](image)
Modeling DTN Congestion Problem

\[ F(x, t) \] The number of forwarded messages

\[ N(x) \] Total number of neighbors of node \( x \).

\[ B(x, t) \] The number of generated messages.

\[ O(x, 0) \] Buffer occupation

\[ \mu(x, t) \] The total number of Received messages.

\[ S(x, t) \] The number of outgoing Messages.

Figure Message forwarding \( t \rightarrow t+1 \)
What is the buffer occupation at next time step \((t+1)\) ?
Modeling DTN Congestion Problem

• What is the buffer occupation at next time step \((t + 1)\) ?
  – The number of outgoing messages

\[
S(x, t) = D(x, t) + \beta \sum_{i=1}^{O(x, t)} f(i, x, t)
\]

Discarded messages
1. TTL has expired
2. Drop policy
3. Duplicated message

\[
f(i, x, t) = \begin{cases} 
1 & \text{if } m(i, x, t) \text{ has already been forwarded} \\
0 & \text{if } m(i, x, t) \text{ has not been forwarded yet}
\end{cases}
\]

\(\beta \in \{0, 1\}\).

1 --- the original message is on buffer
0 --- the original message isn’t on buffer
Modeling DTN Congestion Problem

- What is the buffer occupation at next time step \((t + 1)\)?
  - The number of received messages

\[
\mu(x, t) = \sum_{i=1}^{N(x)} \sum_{j=1}^{O(x_i, t)} \eta((x_i, t), (x, t + 1)) [R(x_i, x, t) - l(i, j, x, t)]
\]

- Contact
- Duplicated messages
- The number of messages received from neighbor i
- Forwarding algorithm

\[
l(i, j, x, t) = \begin{cases} 
1 & \text{if } f(j, x_i, t) = 1 \text{ and } m(j, x_i, t) \in M(x, t) \\
0 & \text{otherwise}
\end{cases}
\]
Modeling DTN Congestion Problem

- Is the buffer blocked (Congested)?

\[ O(x, t + 1) \]
\[ \{O(x, t) + B(x, t) + \mu(x, t) - S(x, t)\} > Q \]
\[ \omega(x, t) = \begin{cases} 
0 & \text{if } x \text{ is blocked in time } t \\
1 & \text{if } x \text{ is not blocked in time } t 
\end{cases} \]

We want to find a path that contains only unblocked/uncongested sites/buffers and open bonds/opportunistic contacts.
Modeling DTN Congestion Problem

• The path is:

\[ \Gamma = [(x_0, t_0), (x_1, t_1), (x_2, t_2), (x_3, t_3), \ldots, (x_n, t_n)] \]

A path is open if

• \( \omega(x^i, t^i) = 1 \ \forall \ i = 0, \ldots, n \)

• \( \eta((x^i, t^i), (x^{i+1}, t^{i+1})) = 1 \ \forall \ i = 0, \ldots, n - 1 \)
Modeling DTN Congestion Control: MatLab Experiments

Proposal Modeling in $\mathbb{Z}^{d+1}$ | $d = 1$
Modeling DTN Congestion Control: Evaluation Metrics

• Average buffer occupancy
• Average buffer blocked time
• Average message delivery probability
• Average delivery delay
Modeling DTN Congestion Control: Drop Policies

- Drop incoming
  - Incoming message is dropped
- Drop head
  - The first message in the buffer is dropped
- Drop last
  - The newly received message is first removed
- Drop oldest
  - The message with the shortest TTL is dropped
Modeling DTN Congestion Problem

• Results
Modeling DTN Congestion Control

• Summary
  – First DTN congestion control model using percolation theory.
    • Probability of existence of a path.
    • Delivery latency.
  – Considers forwarding by replication.
  – The proposed model was implemented in MatLab
    • And in ONE simulator to cross-validate model.
Reinforcement Learning Based Congestion-Aware Mechanism
Machine Learning?

“A computer program is said to learn from experience $E$ with respect to some task $T$ and some performance measure $P$, if its performance on $T$, as measured by $P$, improves with experience $E$.” -- Tom Mitchell, Carnegie Mellon University
Reinforcement Learning (RL)?

They give you a lot of treats while they're training you, so play dumb for as long as you can.
RL: Basic Idea

- Set of states and a set of actions
  - Based on Markov Decision Process
- Select an action
- If action leads to reward, reinforce that action
- If action leads to punishment, avoid that action
RL: Challenges

- Reward/punishment typically delayed
- How do you choose your actions?
  - Exploration vs exploitation
Why RL in DTN?

• Characteristics of a novel DTN Congestion control scheme:
  – Provide an autonomous control
    • An agent learns by itself
  – Work independent of the routing protocol
    • The agent tries to know the environment
  – Allow different ranges of applications
    • Terrestrial DTN
    • Interplanetary networks
  – Trigger between different control strategies
    • The agent try to optimize the reward
Our Approach

DTN NODE STATES

EWMA - POSITIVE

CONGESTED

PROSPECTIVE - CONGESTED

BUFFER FREE - 0%

BUFFER OCP <= NC-RATE

EWMA - NEGATIVE

NON-CONGESTED

BUFFER OCP <= NC-RATE

BUFFER FREE - 0%

EWMA - NEGATIVE

DECREASE-CONGESTED

BUFFER OCP <= NC-RATE

BUFFER FREE - 0%

EWMA - POSITIVE

CONGESTED
Our Approach

DTN NODE ACTIONS

- Increase message generation period
- Broadcast CNB – Congestion Notification Beacon
- Discard expired message
- Discard old message
- Discard random message
- Discard message that will expire before next contact arises
- Decrease message generation period
- Broadcast DCNB – Decrease CNB
- Migrate messages
Our Approach

ACTION SELECTION – Two Strategies

• First strategy:
  – Variable learning rate and
  – “Win or Learn Fast”

\[
P^t_{a_i} = (P^{t-1}_{a_i} + \gamma_{\text{max}}), \quad \text{where}\ (P^{t-1}_{a_i} + \gamma_{\text{max}}) < 1
\]  

\[P^t_{a_j} = \frac{1 - P^t_{a_i}}{|I - 1|}, \forall j \in I, j \neq i
\]  

\[
P^t_{a_i} = P^{t-1}_{a_i} - \gamma_{\text{min}}, \quad \text{where}\ P^{t-1}_{a_i} - \gamma_{\text{min}} > 0
\]

\[P^t_{a_j} = P^{t-1}_{a_j} + \frac{\gamma_{\text{min}}}{I - 1}
\]
Our Approach

ACTION SELECTION – Two Strategies

• Second strategy: Q-learning
  – Update Qvalue of each action

\[
\hat{Q}_n(s, a) \leftarrow (1 - \alpha_n)\hat{Q}_{n-1}(s, a) + \alpha_n[r + \max_{a'}\hat{Q}_{n-1}(s', a')]
\]

\[
\alpha_n = \frac{1}{1 + \text{visits}_n(s, a)}
\]

  – Boltzmann strategy/ distribution

\[
\Pr(a|x) = \frac{e^{\frac{Q(s, a)}{T}}}{\sum_i e^{\frac{Q(s, a_i)}{T}}}
\]
Our Approach: Experiments

• We have been using ONE Simulator
• Our algorithm (Q-learning) is an extension of Markov Decision Process (MDP)
  – Our case is a non-deterministic MDP
• Q-learning algorithm
  Start with all entries in Qvalue table set to 0
  Repeat
  1. look at the current state s and choose an action a
  2. do the action a and obtain some reward R(s,a)
  3. observe the new state S(s,a)
  4. perform update
  \[
  \hat{Q}_n(s, a) \leftarrow (1 - \alpha_n) \hat{Q}_{n-1}(s, a) + \alpha_n [r + \max_{a'} \hat{Q}_{n-1}(s', a')] 
  \]
Delay and Disruption Tolerant Networks

CMPE257: Wireless and Mobile Networks

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April 16th, 2015
The distance between Earth and Mars varies from 100,000,000 km to 400,000,000 km. In August 2012 it was about 248,000,000 km.

Radius of Earth: 6738 km
Radius of Mars: 3397 km
Orbit of Mars (around Sun): 678 days
Orbit of Odyssey: 1hr 58min
Orbit of MRO: 1hr 52min
Naming Schemes in Electromagnetic Spectrum

The electromagnetic spectrum covers the range of frequencies of electromagnetic signals. Portions of the spectrum have been given names. Unfortunately, there are different naming schemes and sometimes the exact frequencies for a particular name are not clearly defined. A common naming system for regions of the spectrum includes: radio, microwave, infrared, visible light, ultraviolet, X-rays, and gamma rays. Some more precise schemes have been defined by ITU and IEEE. ITU defines radio bands with names based on the frequency, such as Very Low Frequency (VLF), High Frequency (HF), Ultra High Frequency (UHF) and Tremendously High Frequency (THF). As an alternative, IEEE uses the common HF, VHF, and UHF, but mainly letters for other portions of the spectrum, e.g., S-band, X-band, K_u-band, K_a-band. A summary of some of the more common names is below.
an introduction to Disruption Tolerant Networking
DTN: To enable communication during a disaster.
DTN: some fast facts

• Time taken by light
  – Earth : Jupiter – 32.7 min
  – Earth : Saturn – 76.7 min
  – Earth : Pluto – 5.5 hours
  – Earth : Voyager1 – 13 hours