Performance Analysis and Improvement of Information Dissemination Protocols in DTNs

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PhD Synopsis Seminar
Outline

1 Introduction and Background
   • Introduction
     • Delay Tolerant Networks (DTNs)
     • Challenges
     • Objectives of the Thesis
   • Background
     • Properties of agent-agent contacts
     • Mobility Models
     • Antenna Model
     • SIRS Epidemic Protocol for Information Dissemination
**Delay Tolerant Networks (DTNs)**

### What is DTN?
- Emerging from **wide use of mobile** hand-held devices
- Consists of mobile devices (agents) equipped with **short range transceiver antennas**

### Characteristics of DTNs
- **No end-to-end path** at any time
- Neighbors change with time
- **Links fail by nature**
- Communication follow **store-carry-forward paradigm**
- Achieves **eventual delivery**
- **Topology characterized by mobility patterns**

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**Emerging from wide use of mobile hand-held devices**

**Consists of mobile devices (agents) equipped with short range transceiver antennas**
Broadcasting and Routing in DTNs

- Two fundamental services to facilitate communication
  - Broadcasting
  - Routing
- These services are challenging in DTNs due to
  - Lack of end-to-end paths
  - Unpredictable delay in subsequent contacts

Factors that determine the performance of a protocol

- Properties of agent-agent contact
  - Pairwise contacts
  - Aggregated contacts
- Antenna model used for point-to-point communication
  - Omnidirectional antenna (OA)
  - Directional antenna (DA)
Objectives of the Thesis

1. Analyzing the performance of a broadcasting protocol when some agents use DA

2. Analyzing the performance of set of routing protocols when some agents use DA and design a technique to dynamically switch OA to DA and vice versa

3. Model the time correlation of contacts in a time-varying graph in order to design an efficient space-time routing protocol

4. Understanding the relationship among the properties of human movement that can potentially affect the performance of a protocol
Properties of agent-agent contacts

- **A contact** - some agents enter into each other's radio range, remain in range for some time, and then move away.

- **Pairwise contacts** - inter-contact time

  \[
  \begin{align*}
  t_1 &= T_2 - T_1 \\
  t_2 &= T_3 - T_2 \\
  t_3 &= T_4 - T_3 \\
  t_4 &= T_5 - T_4
  \end{align*}
  \]

  - **Pr(Time gap)**
    - \( Pr(t_1) \)
    - \( Pr(t_2) \)
    - \( Pr(t_3) \)

  - **Inter Contact Time (ICT)**
    - Distribution of ICT
      - may follow, e.g.,
        - exponential distribution
        - power law distribution

- **Aggregated contacts** - aggregate the contacts with all neighbors to compute inter-any contact time
Mobility Models

- Mobility models govern the properties of agent-agent contacts

- Broadly categorized into three types depending on the distribution of locations (may be visited by the agent) in a simulation area
  - Random based models, e.g., Random Walk (RW), Truncated Levy Walk (TLW)
  - Map based models, e.g., Map Based Movement (MBM), Shortest Path Map Based Movement (SPMBM)
  - Semi-map based movement, e.g., Self-similar Least Action Walk (SLAW)
Self-similar Least Action Walk (SLAW)

- Range of Hurst ($H$) - 0.55 to 0.85 as measured from traces
- Average inter-place distance is greater with a higher $H$
- Two sites, SF and NCSU, are created following SLAW model
Other Mobility Models

- **RW model** - any point in the map is a waypoints
- **TLW model** distance between consecutive waypoints is sampled from power law
- **MBM model**
  - Connects the waypoints - by lines similar to actual road network
  - Selecting next waypoint - randomly from adjacent waypoints
- **SPMBM model**
  - Connecting waypoints - by lines similar to actual road network
  - Selecting next waypoint - randomly from all other waypoints
  - Arriving to next waypoint - through shortest path
Antenna model

Omnidirectional antenna vs. directional antenna

Antenna parameters

- One parameter for OA - the range \( R_{OA} \)
- Three parameters for DA - the range \( R_{DA} \), the beamwidth \( \gamma \), the antenna rotation probability \( p_{rot} \)
- OA and DA use equal power to operate
SIRS Epidemics

- Agents can be in either susceptible (S), or infected (I), or recovered (R) state

- Recovered state - the agent is idle

- A time duration is associated with every state: susceptible time ($\tau_S$), infected time ($\tau_I$), and recovered time ($\tau_R$).

- SIRS model of epidemics suites better in DTN because of the $R$ state

- $\tau_I$ and $\tau_R$ should be tuned properly to achieve successful message delivery

SIRS epidemic protocol - used for both routing and broadcasting
Outline

2 Broadcasting using DA
   - The problem
   - Motivation
   - Experimental Setup
   - Analysis of the Results
   - Conclusion
The problem

Analyze the performance of SIRS broadcasting protocol in DTN when some of the agents use DA and the agents move following practical movement patterns

Performance metrics

- **Broadcast delay** - time to reach all the agent agents in the network
- **Broadcast diameter** - largest number of intermediate agents to reach an agent, for the first time, at the earliest

Mobility models considered

- SLAW, RW, TLW, MBM, SPMBM
Motivation of the study

- **Broadcast delay** - can be **reduced** by using DA, shown by an existing study

- The study conjectured - the **diameter of the network** gets **collapsed** due to the use of DA

- The study **considered simple random walk** mobility model (not a representative model of human movement)
Simulation Setup

- Agents are randomly placed on the waypoints
- A fraction of the agents, selected randomly, carry DA
- **Direction of focus** of DA - chosen from the range $[0,2\pi]$
- **Mobility model**
  - SLAW - SF site ($H = 0.75$) and NCSU site ($H = 0.66$)
  - Other mobility models - RW, TLW, MBM, SPMBM
Performance Evaluation Metrics

**Broadcast Delay** - time to reach all the agents from a source

- **Average broadcast delay** ($T_b$): average of the broadcast delays obtained over several runs by choosing different sources
- **Delay improvement factor** $I_T^b(x, y) = (T_b(x) - T_b(y))/T_b(x)$ - reported in the results

**Broadcast Diameter** - largest number of hops in earliest path

- **Average broadcast diameter** ($\Delta_b$): similar to $T_b$ - the diameter instead of the delay
- **Diameter improvement factor** $I_\Delta^b(x, y) = (\Delta_b(x) - \Delta_b(y))/\Delta_b(x)$ - reported in the results

$I_T^b(x, y)$ and $I_\Delta^b(x, y)$ are in short $I_T^b$ and $I_\Delta^b$ respectively
Impact of range of OA in an OA-only system

Figure 1: Variation of $T_b$ and $\Delta_b$ with $R_{OA}$ in both SF and NCSU sites with Hurst values 0.66 and 0.75, a (site, $x$) pair $\rightarrow$ a site (either SF or NCSU) with Hurst $H = x$.

- Increasing the range of OA reduces the delay
- But, it reduces the diameter initially, after that it increases
- 50m range balances both the delay and the diameter
Impact of $\chi$ and $p_{rot}$

**Figure 2:** Variation of $I_T^b$ and $I_{\Delta}^b$ with $\chi$ in SF site with $H = 0.75$ and NCSU site with $H = 0.66$ for different $p_{rot}$ values, a (site, $x$) pair $\rightarrow$ a site (either SF or NCSU) where the DA agents assume $p_{rot} = x$.

- A small number of DAs can reduce the delay, but may not reduce the diameter; $p_{rot}$ yields a similar result
- Increasing either $N_{DA}$ or $p_{rot}$ may not increase the reduction
Impact of mobility models

Figure 3: Variation of $I_T^b$ and $I_\Delta^b$ with mobility models having fixed $p_{rot} = 0.3$ with various $\chi$; $P_I = 5000$ and $P_R = 1000$.

- Highest amount of reduction - using random based models
- Lowest amount of reduction - using map based models
- RW model may reduce the diameter, but, it can get increased using other models

- $\chi$ - number of agents using DA
- $N = 100$
- RW - random walk
- TLW - truncated levy walk
- MBM - map based model
- SPMBM - shortest path MBM
- WDM - working day model

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Performance Analysis & Improvement of Protocols in DTNs
Summary & Conclusion

- Studied the performance of SIRS epidemic protocol for broadcasting when some agents use DA considering a larger number of parameters
- The broadcast delay can be reduced when only a small number of DAs are used
- Large number of DAs can not produce expected improvements
- Both the delay and the diameter may can be reduced at a higher agent density
- Performance improvements achieved using RW model may not be observed in practice
3 Routing using DA
- The problem
- Motivation
- Experimental Setup
- Analysis of the Results
- Conclusion
The problem

Analyze the performance of a set of routing protocols in DTN when some of the agents use DA

Performance metrics

- **Delivery delay** - time to reach the destination from a source
- **Number of hops** - number of intermediate agent to deliver the message

Mobility scenarios

Considering a large set of mobility models starting from RW to SLAW to map based models
Motivation of the study

Let A want to send a message to E
In OA-only system, it takes 3 times steps through B and D
In mixed system, it takes 2 time steps through B
However, a message from A to D may take more time
Simulation Setup

Simulation setup

- **Source and destination pair** - chosen randomly, and the distance ($D_{init}$) between the source and the destination is noted.

- A fraction of the agents, selected randomly, carry DA.

- **Direction of focus** of DA is chosen from the range $[0, 2\pi]$.

- **Mobility model**
  - SLAW - SF site ($H = 0.75$) and NCSU site ($H = 0.66$).
  - Other mobility models - RW, TLW, MBM, SPMBM.
Performance Evaluation Metrics

**Delivery Delay** - time to reach a destination

- **Average delivery delay** \( (T_r) \): average of the delivery delays obtained over several runs by choosing different source-destination pairs
  - **Delay improvement factor** \( I_T(x, y) = (T_r(x) - T_r(y))/T_r(x) \) - reported in the results

**Number of Hops** - number of intermediate agents to reach a destination at the earliest

- **Average number of hops** \( (\Delta_r) \): similar to \( T_r \), only the number of hops is considered instead of the delay
  - **Hop improvement factor** \( I_{\Delta}(x, y) = (\Delta_r(x) - \Delta_r(y))/\Delta_r(x) \) - reported in the results
Impact of range of OA in an OA-only system

**Figure 4:** Variations of $I_T$ and $I_{\Delta}$ with initial distance $D_{init}$ when $\chi = 0.2$ having $p_{rot} = 0.3$.

- $D_{init}$ - distance between source and destination
- $\chi$ - number of agents use DA
- $p_{rot}$ - DA rotation probability
- $H$ - Hurst parameter
- $N = 100$ - number of agents
- $R_{OA} = 50m$ - range of OA

- The delay $T_r$ - reduced when $D_{init}$ is beyond a threshold
- $\Delta_r$ may be increased for any $D_{init}$
Impact of $\chi$ and $p_{rot}$

Figure 5: Variations of $I_T$ and $I_\Delta$ with $\chi$, in NCSU site. The results are shown with $p_{rot} = \{0.0, 0.3, 1.0\}$ for $D_{init} = 350m$.

- A small number of DAs can reduce the delay
- But, the number of hops may be increased even when $\chi = 1.0$;
Impact of mobility models

Figure 6: Variations of $I_T$ and $I_\Delta$ with routing protocols in NCSU site, $H = 0.66$, $D_{init} = 350m$, $\chi = 0.2$, and various $p_{rot}$.

- The delay - reduced in any protocol considered,
- The reduction - less in single copy protocols
- In general, the number of hops may be increased

SIRS - SIRS epidemic
SNW - spray and wait
FC - first contact
PROPHET - prophet

- binary mode,
- 10 copies initially
- version - single copy
- aging - 30 timesteps
- probability of aging - 0.98
- initialization constant - 0.75
Summary & Conclusion

- Studied the performance of a set of routing protocols when some of the agents use DA, considering a large set of parameters.

- The delivery can be reduced when the distance between source and destination is more than a threshold.

- A small number of DAs is sufficient to reduce the delay significantly, though the number of hops may not be reduced.

- The amount of reduction in case of limited copy protocol that use no knowledge about the past contacts can be less than that in other protocols.

- The number of hops may slightly get increased irrespective of routing protocols.
4 Modeling time correlation of contacts
- The problem
- Motivation
- Experimental Setup
- Modeling time correlated contacts
- Compute best paths and build space-time routing table
- Conclusions
The problem

Leveraging time correlation of contacts among humans to design a space-time routing protocols in DTNs

Modeling time correlation of contacts

- Investigate the **time correlation of pair-wise contacts** among humans from real traces
- Model the correlation between times and contacts in **time varying graph**

Designing space-time routing framework

- Propose an **algorithm** to compute best time respecting paths
- Utilize the paths to build **space-time routing table**
- Propose a suitable recovery strategy to handle failure of any pre-scheduled contact
Humans come in contact at regular intervals with a high probability

Such regularity is seen due to the repetition of regular activities in daily life of humans

Existing protocols require the agents to
  - Move in predefined fixed trajectories, or
  - Move for a limited time
Analysis of real data sets

• Three data sets - univ. of milano, dieselNet, and univ. of Illinois movement
• 24 hours - equally divided into 6 slots, each of 4 hours
• Probabilities that contacts occur in different slots are reported

- Contacts - repeated only in 1/2 slots with a higher probability
Modeling time correlated contacts in time varying graph

Representing the repeated contacts in time varying graph (TVG)

Sets of contacts

- \( T_1, T_2, T_3, T_4, T_5, \ldots \)
- \( T_1^1, T_2^1, T_3^1, T_4^1, T_5^1, \ldots, T_k^1 \)
- \( T_1^2, T_2^2, T_3^2, T_4^2, T_5^2, \ldots, T_k^2 \)

Equal time gap

- \( g_1 = T_2^1 - T_1^1 = T_3^1 - T_2^1 = \ldots \)
- \( g_2 = T_2^2 - T_1^2 = T_3^2 - T_2^2 = \ldots \)

Contacts of (A, B) pair

- \( T_1^1, g_1 \)
- \( T_1^2, g_2 \)

Figure 7: A hypothetical TVG where A, B, .. H are the agents, and edges represents repeated patterns.
Compute best time respecting paths

- A path may best depending on
  - Earliest reaching time - foremost path, e.g.,
    - Considering the start time as 0, the foremost path from A to H is through B and G - takes 3 timesteps in Figure 7
  - Minimum commute time (reaching time - start time) - fastest path
  - Minimum number of hops - shortest path

Foremost paths are used to build a space-time routing table
Algorithm to compute foremost paths

Algorithm 1 $\text{SingleSourceFastestPath}(\tau_c, u_s, G)$

1. $n = 0$; put $u_s$ in set $S$
2. while $n \neq |V|$  
3. do $S' = \text{ExtractEdgeWithDelayZero}(S)$  
4. if $S'$ is empty  
5. then $\tau_c = \tau_c + 1$; $\text{UpdateDelay}(S, \tau_c)$; go to step 2;  
6. for each edge $(u_i, v_j) \in S'$  
7. do denote $v_j$ as reached; $n = n + 1$;  
8. for each $v_j$  
9. $S = S \cup (v_j, v_x)$ if $v_x$ not yet reached  
10. $\tau_c = \tau_c + 1$; $\text{UpdateDelay}(S, \tau_c)$

- Time complexity - same as Dijkstra’s algorithms
Next hop depends on the arrival time $T_c$ and the destination $D$ of a message

For example, at $A$, $T^A_R(T_c = 2, D = H) = B$ and $T^A_R(T_c = 7, D = H) = F$
Conclusions

- Investigated the time correlation of contacts among humans and utilized the temporal information to design an efficient space-time routing framework.

- Investigated some real data sets to find repeated patterns in contact among humans.

- Modeled repeat patterns of the contacts in a time varying graph.

- Proposed an algorithm to compute foremost paths.

- Build space-time routing table to be used in space-time routing protocol.
5 Relationships among the mobility properties
  - The problem
  - Motivation
  - Properties of human movement
  - Layer dependency relationships
  - Framework of mobility model
  - Results
  - Conclusions
The problem

Characterizing the impact of properties of human movement on each other and on information dissemination protocols in DTNs

Understanding the relationship among the properties of human movement

- Summarize from the existing methods of mobility analysis
- Understand the relationship among various properties
- Design a generic framework of a mobility model
- Exploit the importance of any particular property

Property - a parameter-distribution pair, e.g., “flight length is power law distributed”
Motivation

- The performance of information dissemination protocols - vary depending on the mobility models
- A large number of mobility models exists in the literature
- Difficult to choose what set of models for a better validation
- An alternative solution - figure out a set of important properties for a targeted application
Properties of human movement

<table>
<thead>
<tr>
<th>ID</th>
<th>Symbol</th>
<th>Parameter</th>
<th>Distribution</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$</td>
<td>-</td>
<td>Start and end time</td>
<td>Constant</td>
<td>$\Gamma_I$</td>
</tr>
<tr>
<td>$A_2$</td>
<td>$\alpha, \ VF$</td>
<td>Travel Plan</td>
<td>LATP</td>
<td>$\Gamma_I$</td>
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<tr>
<td>$A_3$</td>
<td>$M, H$</td>
<td>Map</td>
<td>-</td>
<td>$\Gamma_A$</td>
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<tr>
<td>$A_4$</td>
<td>$\iota$</td>
<td>Flight Length</td>
<td></td>
<td>$\Gamma_I$</td>
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<tr>
<td>$A_5$</td>
<td>$\omega$</td>
<td>Pause time</td>
<td>Power law</td>
<td>$\Gamma_I$</td>
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<tr>
<td>$A_6$</td>
<td>$\varphi$</td>
<td>Return time</td>
<td>Periodic</td>
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<tr>
<td>$A_7$</td>
<td>$\eta$</td>
<td>Radius of gyration</td>
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<td>$A_8$</td>
<td>$\tau$</td>
<td>Inter-contact time</td>
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<td>$\Gamma_A$</td>
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<tr>
<td>$A_9$</td>
<td>$\sigma$</td>
<td>Contact Duration</td>
<td>Power law</td>
<td>$\Gamma_A$</td>
</tr>
</tbody>
</table>

Flight Length

Map $M$

Waypoint

Place

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Categorizing the properties

Layer dependency relationships among the properties

- **Layer 1**
  - Start and End Time ($A_1$)
  - Travel Plan ($A_2$)
  - Map of WPs ($A_3$)

- **Layer 2**
  - Area of Gyration ($A_7$)
  - Pause Time ($A_5$)

- **Layer 3**
  - Flight Length ($A_4$)
  - Return Time ($A_6$)

- **Layer 4**
  - Contact Duration ($A_9$)
  - Inter-Contact Time ($A_8$)

- **Layer 5**
  - Broadcast Coverage
  - Rate of Message Spreading

Input Properties
Output Properties
Task Oriented Output Properties

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A generic framework of mobility model

Two main functions - \textit{findWPs()} and \textit{preparePlan()}

\textbf{findWPs}

For each agent $u_i$ - compute three sets of waypoints $R_i$, $T_i$ and $T'_i$

- Find a waypoint as home - proportional to its popularity
- Find an radius of gyration - sampled from a power law distribution
- $R_i$ - home and a waypoint located at a distance of length as diameter of gyration
- $T_i$ - all the waypoints inside area of gyration except in $R_i$
- $T'_i \subseteq T_i$ - selected randomly
A generic framework of mobility model

preparePlan:

For each agent $u_i$ - prepare a plan to travel through all the waypoints in $R_i \cup T'_i$ in each trip

- **Assign waiting times** at WPs - assuming the total travel time constant, waiting time at each waypoint is sampled from power law distribution

- **Select next WP** - to be visited from the present waypoint
An Illustrative example
Probability of having larger flights increases with higher $H$
Return time is not sensitive to $H$
Contacts of longer duration is more with higher $H$
Distribution of inter-contact time is not affected much by $H$
**Input to Task-Oriented Output Dependency**

**Figure 9:** Variation of the coverage (A1) and message spreading rate (A2) of epidemic broadcasting with Hurst value.

- Coverage slightly increases with $H$
- But, spreading rate is almost same
- Indicating, intra-place spreading is much faster than inter-place spreading
Table 2: Correlation between properties

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hurst - Flight Length</td>
<td>0.995</td>
</tr>
<tr>
<td>Visit Fraction - Flight Length</td>
<td>-0.906</td>
</tr>
<tr>
<td>Hurst - Coverage</td>
<td>0.933</td>
</tr>
<tr>
<td>Visit Fraction - Spreading Rate</td>
<td>0.933</td>
</tr>
<tr>
<td>Flight Length - Coverage</td>
<td>-0.571</td>
</tr>
<tr>
<td>Flight Length - Spreading Rate</td>
<td>-0.188</td>
</tr>
</tbody>
</table>

- **Positively correlated** both Hurst - Flight Length, and Hurst - Coverage.
- **Indicating** - flight length may drive coverage,
- **But**, flight Length - Coverage are negatively correlated.
conclusions

- Studied the correlation among the properties of human movement considering a particular task in DTN.
- Summarized exhaustive set of parameters of human mobility patterns.
- Proposed a framework to systematically explore the relationships among various parameter.
- Task oriented output parameters (coverage and spreading rate) are highly sensitive to some of the input properties.
- Output properties (flight length, inter-contact time) not much affected by those properties in general.
6 Conclusions of the Thesis
Conclusions of the Thesis

**Broadcasting in DTN using DA**

Broadcast delay can be improved by using DA, however, the cost of broadcasting may increase in general.

**Routing in DTN using DA**

Routing performance can be improved by using DA in general, however, the amount of improvement depends significantly on the protocol and the mobility models.
Conclusions of the Thesis

Modeling DTN as time-varying graph
- Time correlation of the contacts among humans is investigated in detail
- Modeled in a time-varying graph in order to build a space-time routing table

Characterizing the dependencies among the properties
- Summarized an exhaustive set of properties of human movement
- A layered dependency among the properties is proposed
- Several dependencies among the properties have been exploited
Introduction and Background

Broadcasting using DA
Routing using DA
Modeling time correlation of contacts
Relationships among the mobility properties
Conclusions of the Thesis

Publications

1. Rajib Ranjan Maiti, Arobinda Gupta, Niloy Ganguly, Delay Tolerant Networks as Spatio-Temporal Networks, as a poster paper in INFOCOM 2013, Turin, Italy.
5. Rajib Ranjan Maiti, Niloy Ganguly, Arobinda Gupta, Epidemic Broadcasting in DTNs using Directional Antenna, as a poster in COMSNETS 2012, Bangalore, India.

Papers under Review

Thank You!!!

Questions/Suggestions?