Performance Analysis and Improvement of Information Dissemination Protocols in DTNs

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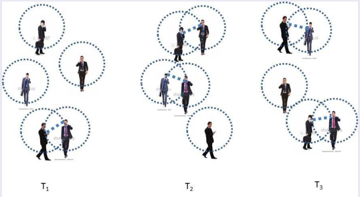
PhD Synopsis Seminar

Outline

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 fails by nature
- Communication follow *store-carry-forward* paradigm
- Achieves eventual delivery
- Topology characterized by mobility patterns

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)

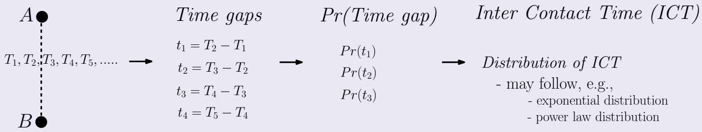
Objectives of the Thesis

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

Agent-agent contacts

- A contact - some agents enter into each others radio range, remain in range for some time, and then move away
- Pairwise contacts - inter-contact time

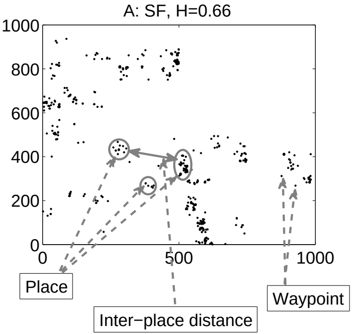


- Aggregated contacts - aggregate the contacts with all neighbors to compute inter-any contact time

Mobility Models

- Mobility models governs 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)



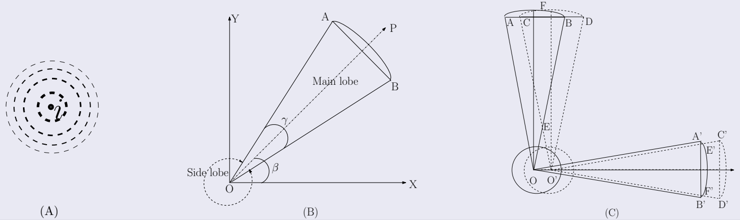
- Range of Hurst (H) - 0.55 to 0.85 as measured from traces
- Average inter-place distance is greater with a higher H
- Two sites, SF and NCSU, are created following SLAW model

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 (γ), 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 (τ_S), infected time (τ_I), and recovered time (τ_R).
- SIRS model of epidemics suites better in DTN because of the R state
- τ_I and τ_R should be tuned properly to achieve successful message delivery

SIRS epidemic protocol - used for both routing and broadcasting

Outline

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 of 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

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 (Δ_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_Δ^b respectively

Impact of range of OA in an OA-only system

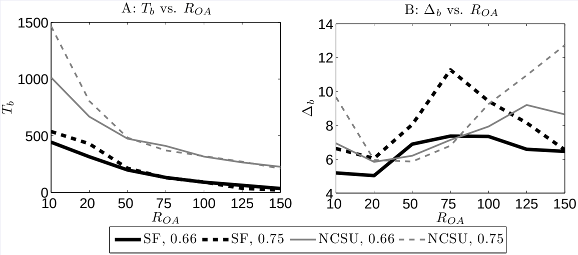
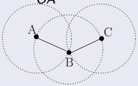


Figure 1: Variation of T_b and Δ_b with R_{oa} in both SF and NCSU sites with Hurst values 0.66 and 0.75, a $(site, x)$ pair $\rightarrow$ a $site$ (either SF or NCSU) with Hurst $H = x$.

- R_{OA} - OA range
- $N = 100$ - number of agents
- SF site - 1000m $\times$ 1000m
- NCSU site - 2400m $\times$ 2400m
- With $R_{OA} = 10m$



- 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 χ and p_{rot}

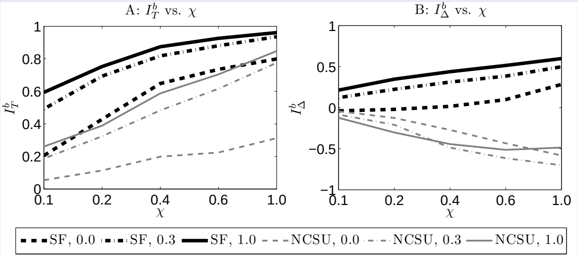


Figure 2: Variation of I_T^b and I_Δ^b with χ in SF site with $H = 0.75$ and NCSU site with $H = 0.66$ for different p_{rot} values, a $(site, x)$ pair $\rightarrow$ a *site* (either SF or NCSU) where the DA agents assume $p_{rot} = x$.

- χ - fraction of agents using DA
- p_{rot} - DA rotation probability
- $R_{OA} = 50m$
- $N = 100$
- N_{DA} - number of agents use DA

- 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

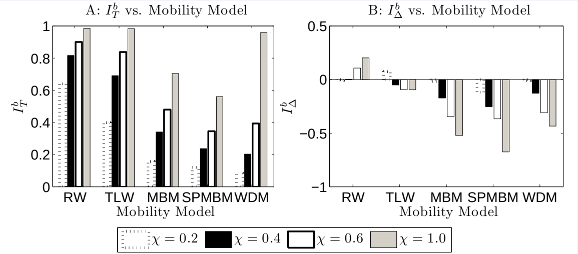


Figure 3: Variation of I_T^b and I_Δ^b with mobility models having fixed $p_{rot} = 0.3$ with various χ; $P_I = 5000$ and $P_R = 1000$.

- χ - 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

- 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

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

Outline

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

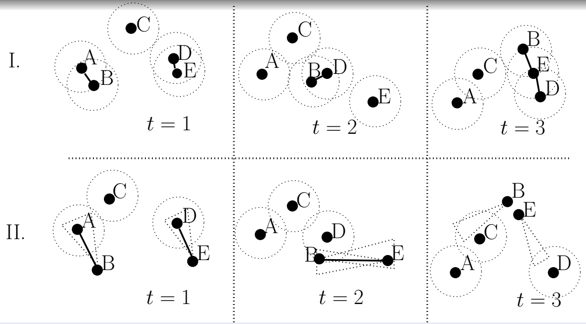
Performance metrics

- 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 $I_T^r(x, y) = (T_r(x) - T_r(y))/T_r(x)$ - reported in the results

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

- Average number of hops (Δ_r): similar to T_r, only the number of hops is considered instead of the delay
  - Hop improvement factor $I_\Delta^r(x, y) = (\Delta_r(x) - \Delta_r(y))/\Delta_r(x)$ - reported in the results

Impact of range of OA in an OA-only system

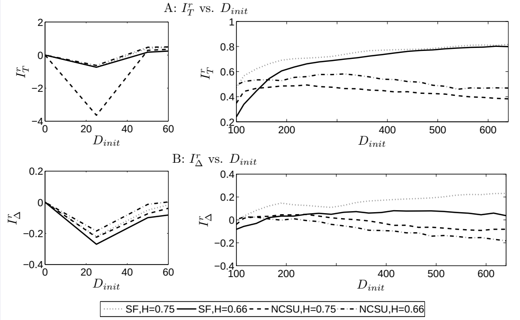


Figure 4: Variations of I_T^r and I_Δ^r with initial distance D_{init} when $\chi = 0.2$ having $p_{rot} = 0.3$.

- D_{init} - distance between source and destination
- χ - 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
- Δ_r may be increased for any D_{init}

Impact of χ and p_{rot}

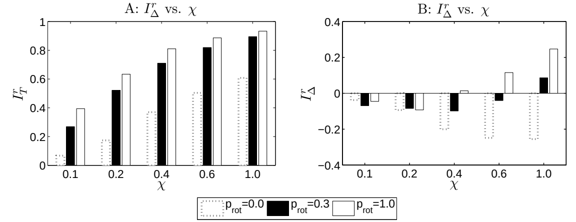


Figure 5: Variations of I_T^r and I_Δ^r with χ, in NCSU site. The results are shown with $p_{rot} = \{0.0, 0.3, 1.0\}$ for $D_{init} = 350m$.

- χ - fraction of agents using DA
- p_{rot} - DA rotation probability
- D_{init} - distance between source and destination
- $N = 100$
- $R_{OA} = 50m$

- 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

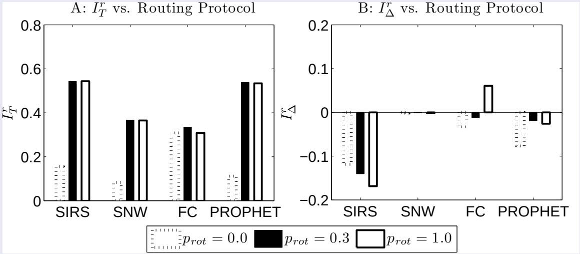


Figure 6: Variations of I_T^r and I_Δ^r with routing protocols in NCSU site, $H = 0.66$, $D_{init} = 350m$, $\chi = 0.2$, and various p_{rot}.

- SIRS - SIRS epidemic
- SNW - spray and wait
  - binary mode, 10 copies initially
- FC - first contact
- PROPHET - prophet
  - version - single copy
  - aging - 30 timesteps
  - probability of aging - 0.98
  - initialization constant - 0.75

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

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

Outline

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

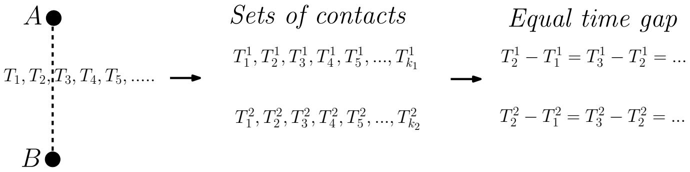
Modeling time correlation of contacts

- 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

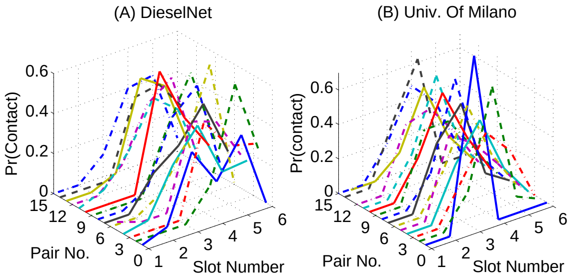
- Humans come in contact at regular intervals with a high probability



- 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)

A — B: $T_1, T_2, T_3, T_4, T_5, \ldots$ →

Sets of contacts

$T_1^1, T_2^1, T_3^1, T_4^1, T_5^1, \ldots, T_{k_1}^1$

$T_1^2, T_2^2, T_3^2, T_4^2, T_5^2, \ldots, T_{k_2}^2$

→ *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)

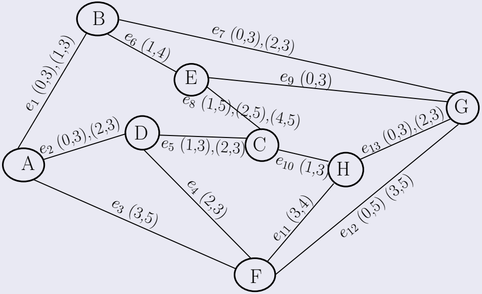


Figure 7: A hypothetical TVG where A, B, .. H are the agents, and edges represents repeated patterns.

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 *SingleSourceFastestPath*$(\tau_c, u_s, \mathbb{G})$

1. $n = 0$; put u_s in set S
2. **while** $n \neq |V|$
3. **do** $S' = ExtractEdgeWithDelayZero(S)$
4. **if** S' is empty
5. **then** $\tau_c = \tau_c + 1$; $UpdateDelay(S, \tau_c)$; 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. $\tau_c = \tau_c + 1$; $UpdateDelay(S, \tau_c)$

- Time complexity - same as Dijkstra's algorithms

Space-time routing table

Table 1: Routing table for node A, T_R^A.

Message arrival time (T_c)

Destination	0	1	2	3	4	5	6	7	8	9	10	...
A →	A	A	A	A	A	A	A	A	A	A	A	...
B →	B	B	B	B	B	B	B	B	B	B	B	...
C →	D	D	D	B	D	D	D	D	D	D	D	...
D →	D	D	D	D	D	D	D	D	D	D	D	...
E →	B	B	B	B	B	B	B	D	D	B	B	...
F →	F	F	F	B	F	F	F	F	D	F	F	...
G →	B	B	B	B	B	B	B	F	B	B	B	...
H →	B	B	B	B	D	B	B	F	B	B	F	...

- Next hop depends on the arrival time T_c and the destination $\mathbb{D}$ of a message
- For example, at A, $T_R^A(T_c = 2, \mathbb{D} = H) = B$ and $T_R^A(T_c = 7, \mathbb{D} = H) = F$

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

Outline

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

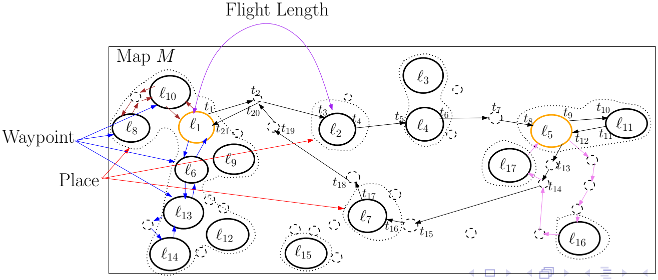
Property - a parameter-distribution pair, e.g., "flight length is power law distributed"

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

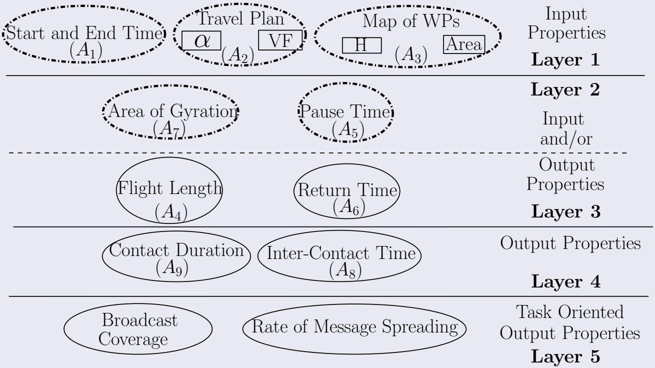
Properties of human movement

ID	Symbol	Parameter	Distribution	Category
A_1	-	Start and end time	Constant	Γ_I
A_2	α, VF	Travel Plan	LATP	Γ_I
A_3	M, H	Map	-	Γ_A
A_4	ι	Flight Length	Power law	Γ_I
A_5	ω	Pause time	Power law	Γ_I
A_6	φ	Return time	Periodic	Γ_I
A_7	η	Radius of gyration	Power law	Γ_I
A_8	τ	Inter-contact time	Power law	Γ_A
A_9	σ	Contact Duration	Power law	Γ_A



Categorizing the properties

Layer dependency relationships among the properties



A generic framework of mobility model

Two main functions - *findWPs()* and *preparePlan()*

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

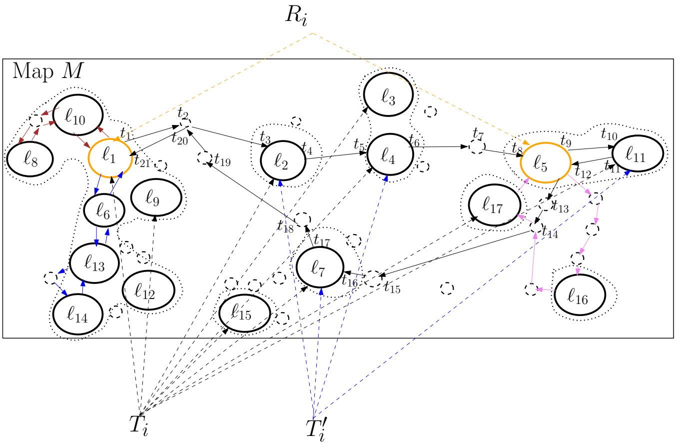
A generic framework of mobility model

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



Input to Output Dependency

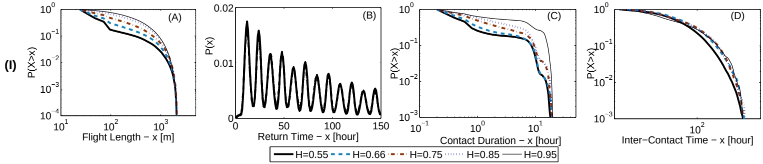


Figure 8: Variations of (A) CCDF of ι, (B) $P(\varphi)$, (C) CCDF of σ (D) CCDF of τ with various Hurst H values.

- 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

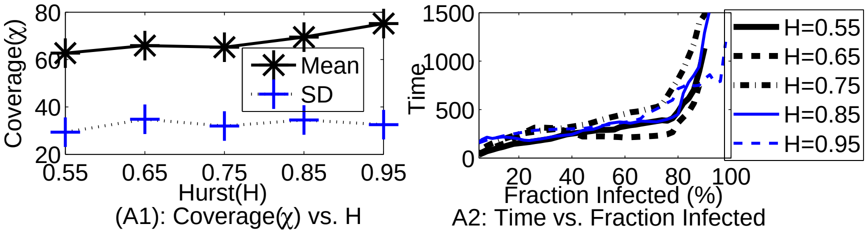


Figure 9: Variation of the coverage ($A1$) and message spreading rate ($A2$) of epidemic broadcasting with Hurst value.

- Coverage slightly increases with H
- But, spreading rate is almost same
- Indicating, intra-place spreading is much faster than inter-place spreading

Output to Task-Oriented Output Dependency

Table 2: Correlation between properties

Parameters	Correlation
Hurst - Flight Length	0.995
Visit Fraction - Flight Length	-0.906
Hurst - Coverage	0.933
Visit Fraction - Spreading Rate	0.933
Flight Length - Coverage	-0.571
Flight Length - Spreading Rate	-0.188

- 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

Outline

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 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 propertied of human movement
- A layered dependency among the properties is proposed
- Several dependencies among the properties have been exploited

Publications

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.
2. Rajib Ranjan Maiti, Niloy Ganguly, Arobinda Gupta, DTN as Spatio-Tempral Network, in PhD Forum *ICDCN* 2013, Mumbai, India.
3. Rajib Ranjan Maiti, Niloy Ganguly, Arobinda Gupta, Using Directional Antennas for Epidemic Routing in DTNs in Some Practical Scenarios, as a poster paper in *ICDCN* 2013 , Mumbai, India.
4. Rajib Ranjan Maiti, Niloy Ganguly, Arobinda Gupta, Analyzing the Performance of Epidemic Broadcasting in DTNs using Directional Antenna, in *COMSNETS* 2013, Bangalore, India.
5. Rajib Ranjan Maiti, Niloy Ganguly, Arobinda Gupta, Epidemic Broadcasting in DTNs using Directional Antenna, as a poster in *COMSNETS* 2012, Bangalore, India.
6. Rajib Ranjan Maiti, Saurabh Gandhi, Niloy Ganguly, Towards Modeling Realistic Human Mobility, in PhD Forum *COMSNETS* 2012, Bangalore India.

Papers under Review

1. Rajib Ranjan Maiti, Arun Mallya, Animesh Mukherjee, Niloy Ganguly, Characterizing the Impact of Human Movement Patterns on Opportunistic Forwarding Protocols. Journal of *Advances in Complex Systems*.

Thank You!!!

Questions/Suggestions?