Modeling Time-variant User Mobility in Wireless Mobile Networks
(Time-variant Community (TVC) Model)

Wei-jen Hsu, Dept. of CISE, U. of Florida
Thrasyvoulos Spyropoulos, INRIA, Sophia-Antipolis, France
Konstantinos Psounis, Dept. of EE, U. of Southern California
Ahmed Helmy, Dept. of CISE, U. of Florida

For TVC_model download: http://nile.cise.ufl.edu/TVC_model/

*This work is supported by NSF awards CNS-0520017 and career award 0134650.
Importance of Mobility Models

- Mobility models are of crucial importance for the evaluation of wireless mobile network protocols.

- A new class of mobility-assisted routing protocols is proposed to:
  - Increase the capacity of wireless networks [1]
  - Facilitate routing in challenging environments (DTN) [2][3][4]
  - No need for spatial paths: Nodes rely on mobility and encounters as the major enabling factor for communication.


Requirements and Our Approach

• Requirements for mobility models
  – Realism (detailed behavior from traces)
  – Mathematical tractability (simple, synthetic random models)
  – Parameterized, tunable behavior

• We abstract mobility characteristics from WLAN traces*, and propose a model amenable to math analysis.

*The most extensive available source for large-scale mobile user data to date.
Outline

• Introduction
• Observation from WLAN traces: key findings and lessons on mobility modeling
  • Time-variant community mobility model
  • Theory derivation – The hitting and the meeting time
• Simulation and Validation
• Future work and Conclusions
Mobility Characteristics from WLANs

- Skewed location visiting preferences
  - Nodes spend 95% of time at top 5 preferred locations.
  - Heavily visited “preferred spots”

- Periodical re-appearance
  - Nodes show up repeatedly at the same location after integer multiples of days.
  - Periodical “daily/weekly schedules”

Mobility Characteristics from WLANs

- Problems of simple random models (random walk, random direction)
  - No preferred locations in space domain (uniform nodal distribution across space)
  - No structure in time domain (homogeneous behavior across time)

- Benefit: Math analysis tractability

Can we improve realism and not sacrifice math tractability?
Other Mobility Models

• Mobility models with WLAN traces have been considered in several papers
  – They considered location preferences but not time-dependent behavior
  – Time-dependent behavior is suggested in [4] but not implemented
• Other realistic behaviors in mobility
  – Grouping of nodes [5]
  – Obstacles in movement [6]

Outline

• Introduction
• Observation from WLAN traces: key findings and lessons on mobility modeling
  • Time-variant community mobility model
  • Theory derivation – The hitting and the meeting time
• Simulation and Validation
• Future work and Conclusions
Community Model

- Skewed location visiting preferences
  - Create “communities” to be the preferred area of movement
  - Each node can have its own community
- Node moves with two different epoch types – Local or roaming
  - Each epoch is a random-direction, straight-line movement
  - Local epochs in the community
  - Roaming epochs around the whole simulation area
  - Torus boundaries

Time-variant Community Model

- Periodical re-appearance
  - Create structure in time – Periods
  - Node moves with different parameters in periods to capture time-dependent mobility
  - Repetitive structure

Simple version: Two time periods with a community in each time period.
Time-variant Community Model

- Major trends of mobility characteristics preserved with simple version model (extensions later)
- In addition, mathematical tractability is retained
Outline

• Introduction
• Observation from WLAN traces: key findings and lessons on mobility modeling
• Time-variant community mobility model
• Theory derivation – The hitting and the meeting time
• Simulation and Validation
• Future work and Conclusions
Theory Derivation

- Quantities of interest
  - Hitting Time – Time before a node moves into the communication range of a randomly selected target (e.g., discover a random event)
  - Meeting Time – Time before two nodes move into the communication range of each other (e.g., direct packet transmission)
  - Assume nodes start from stationary nodal distribution
Theory Derivation – Hitting Time

- We use an example of a single randomly-chosen community in two alternating time periods

Outline of steps
1. Condition on the target location – whether it is in the communities
2. Calculate the prob. of hitting for unit-time slice and the whole time periods
3. Calculate the expected hitting time using 2.
Theory Derivation – Hitting Time

• (Step1) By law of total probability:

\[
HT_{overall} = P_{in,\text{in}}HT_{in,\text{in}} + P_{in,\text{out}}HT_{in,\text{out}} + P_{out,\text{in}}HT_{out,\text{in}} + P_{out,\text{out}}HT_{out,\text{out}}.
\]

where \( P_{in,\text{in}} = (C_n^2/N^2)(C_c^2/N^2) \),
Theory Derivation – Hitting Time

• (Step2) Unit time hitting probability

\[ P_{h,n} = I(\text{target in comm. in NMP}) P_{\text{move,l,n}} 2K \bar{v}_l/n/C_n^2 \]
\[ + P_{\text{move,r,n}} 2K \bar{v}_r/N^2, \]

– Random direction movement cover the whole area equal likely

• Each time unit is an i.i.d. Bernoulli trial to discover the target, so hitting prob. for the whole time period

\[ P_{H,n} = 1 - (1 - P_{h,n})^{T_n} \]
Theory Derivation – Hitting Time

• (Step3)
  – Think of each time period as a flip of coin. It shows head (success in hitting) with a certain probability.

  \[ P = P_{H,n} + P_{H,c} - P_{H,n}P_{H,c} \]

  – One can calculate the expected number of cycles and remaining time units in the last cycle until the first hitting event.
Theory Derivation – Meeting Time

• Outline

1. Condition on the community locations – whether two nodes have overlapped communities
2. Calculate the prob. of meeting for unit-time slice and the whole time periods
3. Calculate the expected meeting time using step 2 – parallel to the derivation of hitting time.
Simulation

- A custom C++ simulator to get the hitting and the meeting times
  - Simple model with two time periods and one community in each time period
  - 50,000 iterations for the hitting time (one node hitting random target) and the meeting time (two nodes meeting each other)

<table>
<thead>
<tr>
<th>Model name</th>
<th>Description</th>
<th>$N$</th>
<th>$C_n$</th>
<th>$C_c$</th>
<th>$v_{max}, v_{min}$</th>
<th>$T_{max,n}$</th>
<th>$T_{max,c}$</th>
<th>$L_r$</th>
<th>$L_i$</th>
<th>$p_{m,n}$</th>
<th>$p_{r,n}$</th>
<th>$p_{m,c}$</th>
<th>$p_{r,c}$</th>
<th>$T_n$</th>
<th>$T_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>Match with the MIT trace</td>
<td>1000</td>
<td>100</td>
<td>100</td>
<td>15, 5</td>
<td>100</td>
<td>50</td>
<td>520</td>
<td>80</td>
<td>0.5</td>
<td>0.2</td>
<td>0.8</td>
<td>0.2</td>
<td>5760</td>
<td>2880</td>
</tr>
<tr>
<td>Model 2</td>
<td>Highly attractive communities</td>
<td>1000</td>
<td>200</td>
<td>50</td>
<td>15, 5</td>
<td>100</td>
<td>200</td>
<td>520</td>
<td>52</td>
<td>0.6</td>
<td>0.3</td>
<td>0.8</td>
<td>0.1</td>
<td>3000</td>
<td>2000</td>
</tr>
<tr>
<td>Model 3</td>
<td>Not attractive communities</td>
<td>1000</td>
<td>100</td>
<td>100</td>
<td>15, 5</td>
<td>50</td>
<td>200</td>
<td>800</td>
<td>80</td>
<td>0.5</td>
<td>0.5</td>
<td>0.6</td>
<td>0.3</td>
<td>2000</td>
<td>1000</td>
</tr>
<tr>
<td>Model 4</td>
<td>Large-size communities</td>
<td>1000</td>
<td>200</td>
<td>250</td>
<td>15, 5</td>
<td>50</td>
<td>100</td>
<td>800</td>
<td>200</td>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
<td>0.1</td>
<td>2000</td>
<td>1000</td>
</tr>
</tbody>
</table>
Simulation

- Good match between theoretical and simulation results
Extension of Model

- Richer granularity in both space and time domain

- Multi-tier communities
- Multiple time periods

![Graph showing extended model with more granularity in space and time domains. The graph compares different models: Model-simplified, Model-complex, and MIT-trace. The x-axis represents time gap in days, and the y-axis shows the probability of re-appearance. The graph also indicates the trend of online time fraction for Weekdays and Weekend.]
Future work

• Other quantities of interest (e.g., Inter-meeting time, contact time [1])
• Routing performance under the model [2][3]
• Reproduce the structure of nodal encounter [4] through careful parameter selection

Conclusions

• Time-variant community model captures important mobility features.
  – Based on intuition about how people move
  – Observed from multiple real WLAN traces

• Routing performance-related quantities (the hitting time and the meeting time) can be derived for the model.

• It provides a generic model which can be tuned for various mobile network scenarios.

• http://nile.cise.ufl.edu/TVC_model/
  – Fully customizable TVC-model
  – NS-2 compatible mobility traces or (time, location) mobility traces
Please visit
http://nile.cise.ufl.edu/TVC_model/
to download the mobility model

Thank you!!

Wei-jen Hsu, wjhsu@ufl.edu
Thrasyvoulos Spyropoulos, Thrasyvoulos.Spyropoulos@sophia.inria.fr
Konstantinos Psounis, kpsounis@usc.edu
Ahmed Helmy, helmy@ufl.edu
Backup Slides
Other quantities of interest

- Inter-meeting time
- Meeting duration

Both quantities follow power-law distributions
Theory Derivation – Meeting Time

• (Step 1) Community overlap probability
  – Nodes move locally more often
  – Nodes with overlapping community meet sooner
  – Community overlap prob.

\[ P_x = \frac{(C + 2K)^2}{N^2}. \]
Theory Derivation – Meeting Time

- (Step2) Unit time meeting probability
- Non-overlapping community
- Overlapping community

**Unique terms (both nodes in local epoch)**

\[
P_{m, no_ov} = \frac{2K \bar{v} \bar{v'}}{N^2} \times 2P_{move,r}(P_{pause,r} + P_{pause,l}) + \frac{2K \bar{v} \bar{v'}}{N^2} \times \frac{C^2}{N^2} \times \frac{2K \bar{v} \bar{v'}}{N^2} \times \frac{2K \bar{v} \bar{v'}}{N^2} \times ((P_{move,r} + P_{move,l})^2 - P_{move,l}^2),
\]

**Common terms for both cases (at least one node is in roaming state)**

\[
P_{m, ov} = \frac{2K \bar{v} \bar{v'}}{N^2} \times \frac{2K \bar{v} \bar{v'}}{N^2} \times \frac{C^2}{N^2} \times \frac{2K \bar{v} \bar{v'}}{N^2} \times \frac{2K \bar{v} \bar{v'}}{N^2} \times ((P_{move,r} + P_{move,l})^2 - P_{move,l}^2),
\]
Simulation

- Low error (<10% for 80% of the studied cases, <20% for the rest) for HT and MT under various parameter sets

Relative error = \( \frac{\text{Theory} - \text{Simulation}}{\text{Simulation}} \)

(a) Hitting time. (b) Meeting time.