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

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

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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 challenged environments (DTN) [2][3][4]
  - No need for spatial paths. Nodes rely on mobility and encounters as the major enabling factor for communication

Mobility Models → Connectivity Graphs → Protocol Performances

F. Bai, N. Sadagopan, A. Helmy, "*IMPORTANT*: A framework to systematically analyze the Impact of Mobility on Performance of RouTing protocols for Adhoc NeTworks", *IEEE INFOCOM* 2003.

[1] M. Grossglauser and D. Tse, "Mobility increases the capacity of ad hoc wireless networks," IEEE/ACM Transactions on Networking, 10(4), 2002.
[2] T. Spyropoulos, K. Psounis, and C. Raghavendra, "Efficient Routing in Intermittently Connected Mobile Networks: The Multi-copy Case," to appear in ACM/IEEE ToN, 2007.
[3] T. Spyropoulos, K. Psounis, and C. Raghavendra, "Efficient Routing in Intermittently Connected Mobile Networks: The Single-copy Case," to appear in ACM/IEEE ToN, 2007.
[4] S. Jain, K. Fall, and R. Patra, "Routing in a delay tolerant network," ACM SIGCOMM04.

Requirements and Our Approach

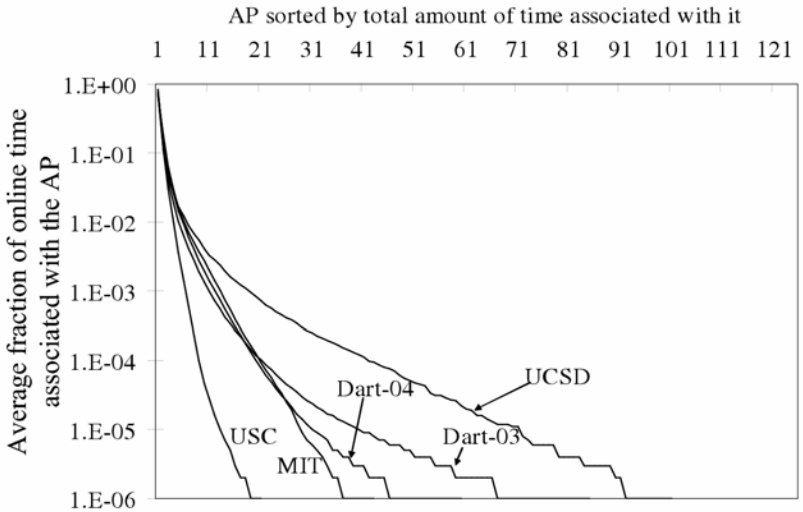
- Requirements for mobility models
  - Realism (detailed behavior from traces)
  - Mathematical tractability (simple, synthetic random models)
  - Parameterized, tunable behavior
- We abstract mobility characteristics from WLAN traces*, and propose a model amenable to math analysis.

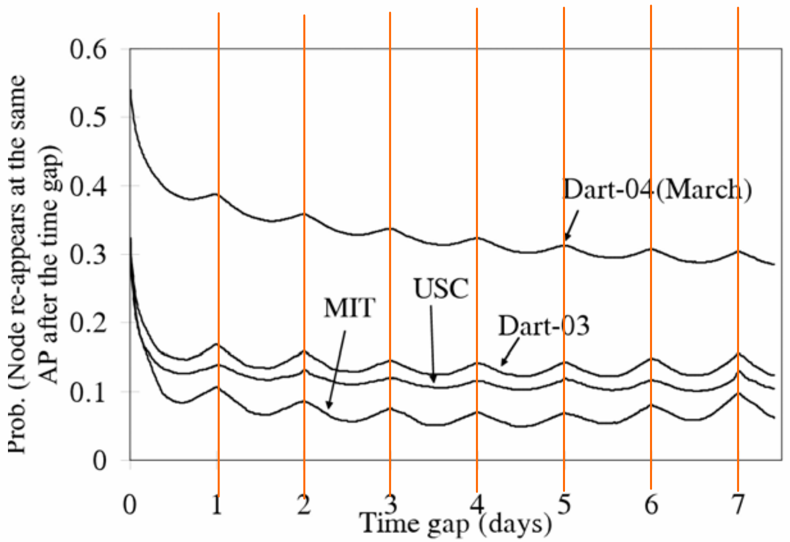
*The most extensive available source for large-scale mobile user data to date.

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



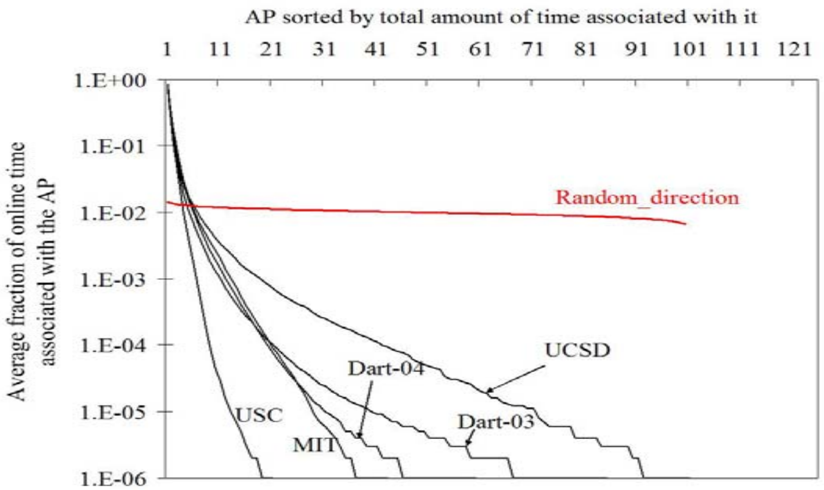


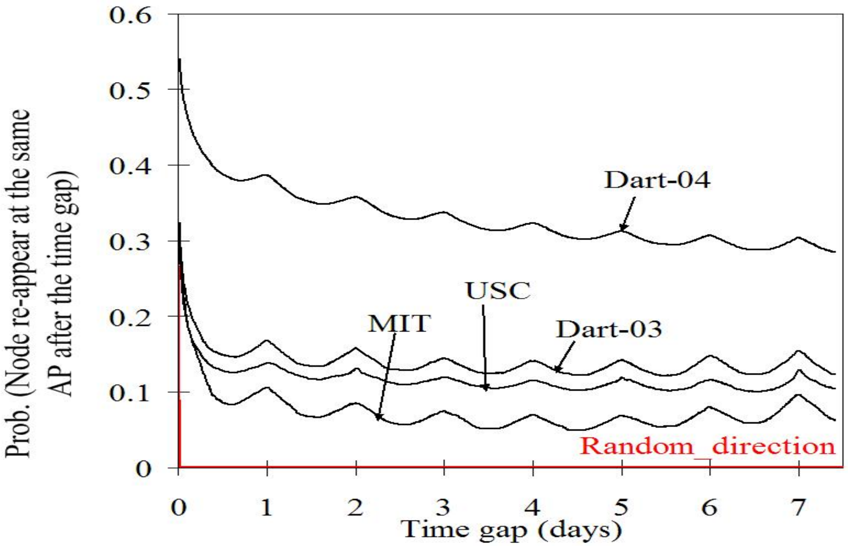
- Skewed location visiting preferences
  - Nodes spend 95% of time at top 5 preferred locations.
  - Heavily visited “preferred spots”
- Periodical re-appearance
  - Nodes show up repeatedly at the same location after integer multiples of days.
  - Periodical “daily/weekly schedules”

W. Hsu and A. Helmy, "On Important Aspects of Modeling User Associations in Wireless LAN Traces," IEEE WinMee 2006.

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)





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]

[1] C. Tuduce and T. Gross, "A Mobility Model Based on WLAN Traces and its Validation," IEEE INFOCOM 05.
[2] R. Jain, D. Lelescu, M. Balakrishnan, "Model T: An Empirical Model for User Registration Patterns in a Campus Wireless LAN," ACM MOBICOM 05.
[3] D. Lelescu, U. C. Kozat, R. Jain, and M. Balakrishnan, "Model T++: An Empirical Joint Space-Time Registration Model," ACM MOBIHOC 06.
[4] M. Kim, D. Kotz, and S. Kim, "Extracting a mobility model from real user traces," IEEE INFOCOM 06
[5] X. Hong, M. Gerla, G Pei, and C. Chiang, "A Group Mobility Model for Ad Hoc Wireless Networks," ACM International Workshop on Modeling Analysis and Simulation of Wireless and Mobile Systems, 1999.
[6] A. Jardosh, E. Belding-Royer, K. Almeroth, and S. Suri, "Towards Realistic Mobility Models for Mobile Ad Hoc Networks," ACM MOBICOM 03.

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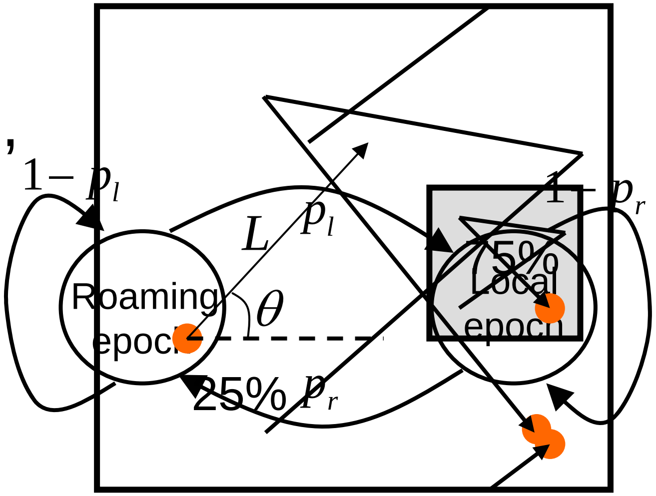
Community Model

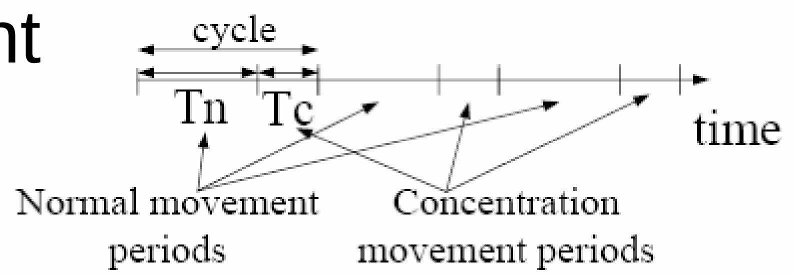
- Skewed location visiting preferences
  - Create "communities" to be the preferred area of movement
  - Each node can have its own community
- Node moves with two different epoch types – Local or roaming
  - Each epoch is a random-direction, straight-line movement
  - Local epochs in the community
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



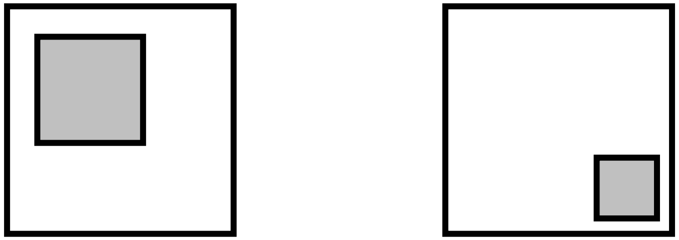
T. Spyropoulos, K. Psounis, and C. Raghavendra, "Performance Analysis of Mobility-Assisted Routing," ACM MOBIHOC, 2006.

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



Normal Movement Period (NMP)

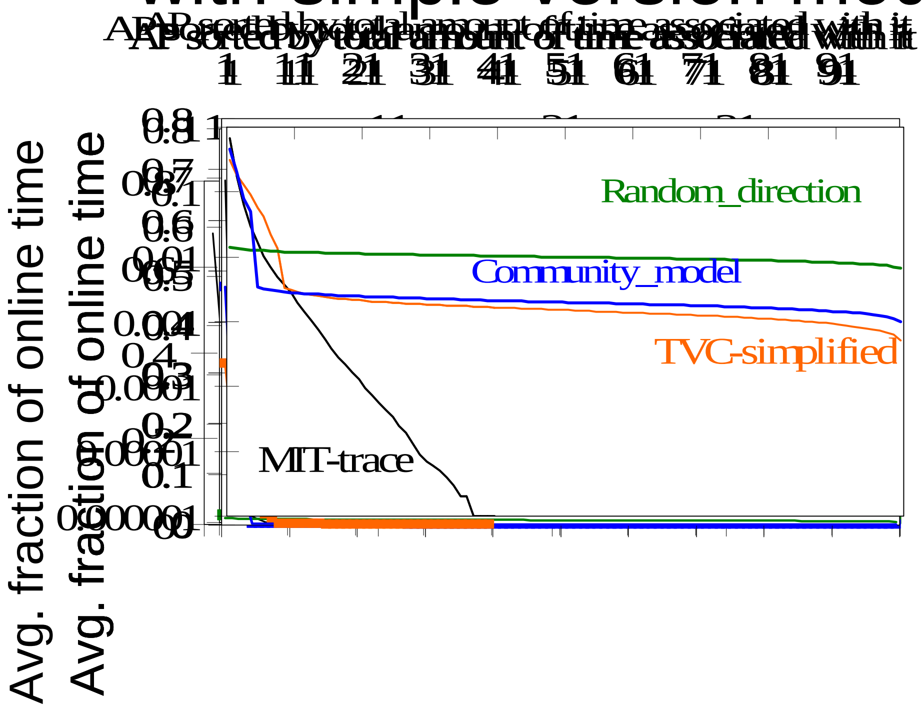


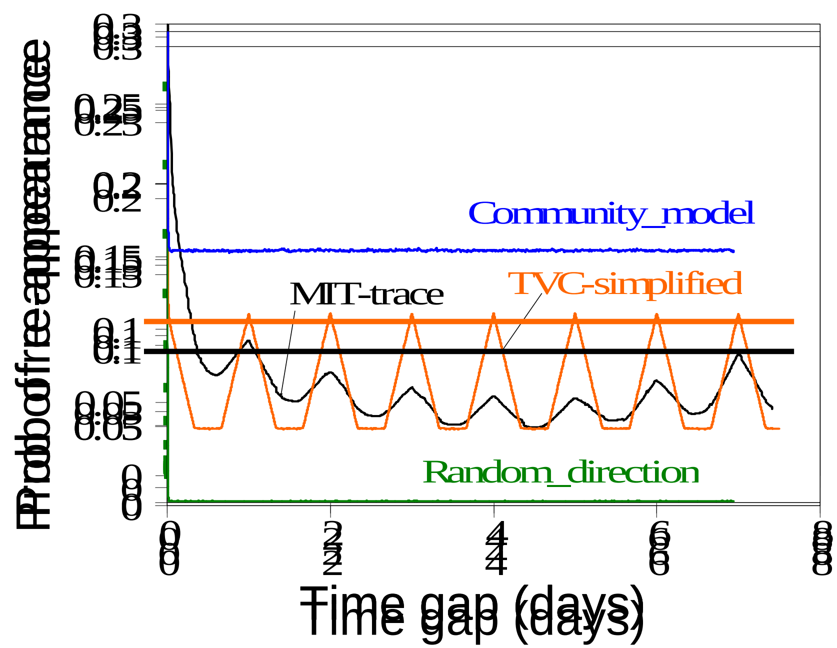
Concentration Movement Period (CMP)

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

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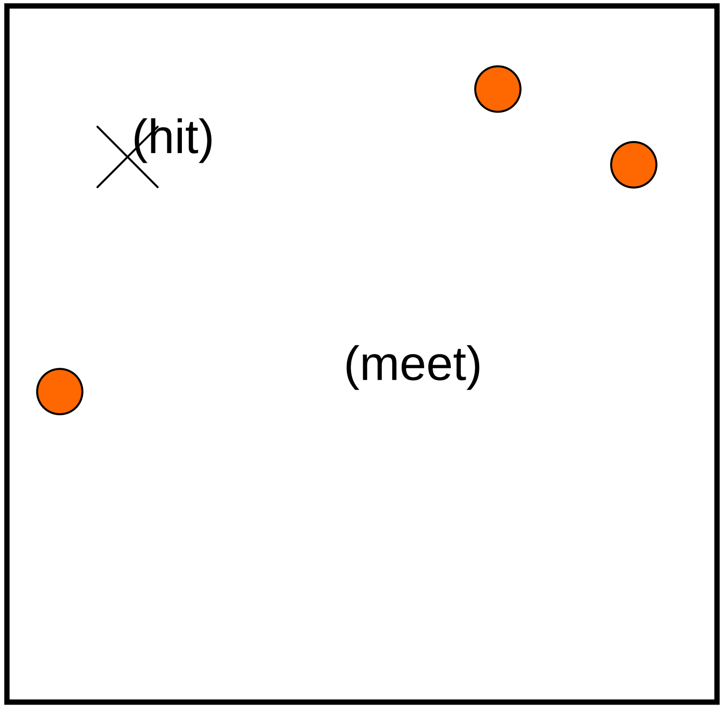
Theory Derivation

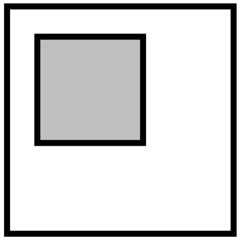
- Quantities of interest
  - Hitting Time – Time before a node moves into the communication range of a randomly selected target (e.g., discover a random event)
  - Meeting Time – Time before two nodes move into the communication range of each other (e.g., direct packet transmission)
  - Assume nodes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

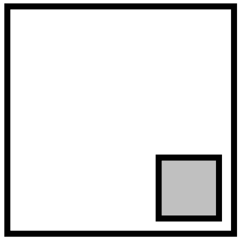


Theory Derivation – Hitting Time

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

Normal Movement Period (NMP)





Concentration Movement Period (CMP)

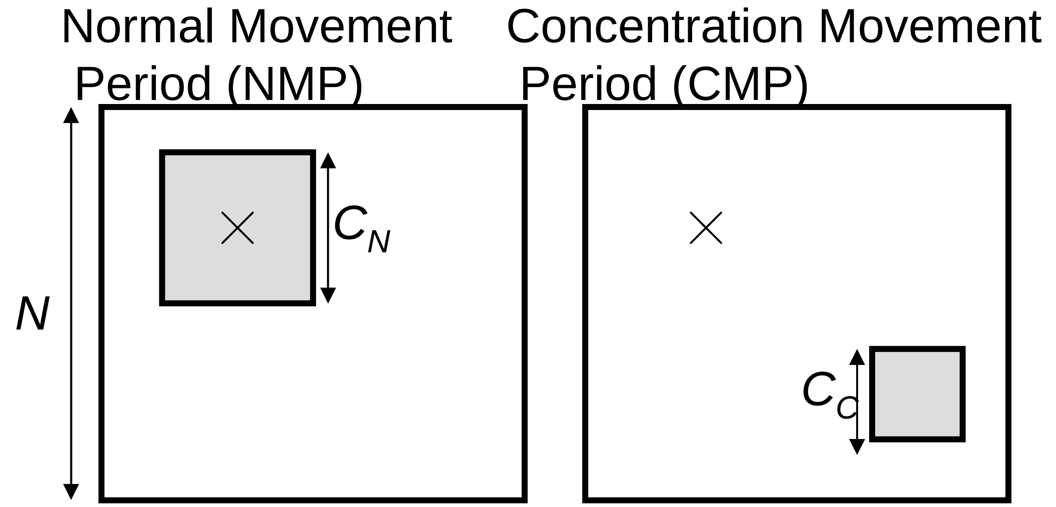
- Outline of steps
  1. Condition on the target location – whether it is in the communities
  2. Calculate the prob. of hitting for unit-time slice and the whole time periods
  3. Calculate the expected hitting time using 2.

Theory Derivation – Hitting Time

- (Step1) By law of total probability:

$$HT_{overall} = P_{in,in}HT_{in,in} + P_{in,out}HT_{in,out} \\ + P_{out,in}HT_{out,in} + P_{out,out}HT_{out,out},$$

$$where\ P_{in,in} = (C_n^2/N^2)(C_c^2/N^2),$$



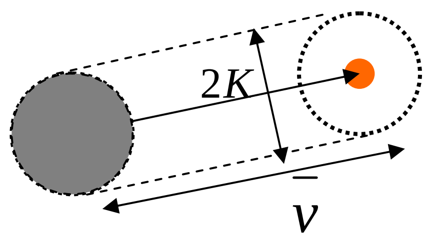
Theory Derivation – Hitting Time

- (Step2) Unit time hitting probability

Local epoch

$$P_{h,n} = \boxed{I(target\ in\ comm.\ in\ NMP) P_{move,l,n} 2K\overline{v_{l,n}}/C_n^2} + \boxed{P_{move,r,n} 2K\overline{v_r}/N^2},$$

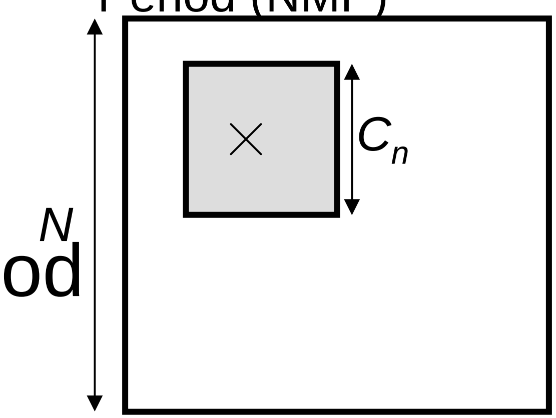
Roaming epoch



Consider the movement in one time unit

  - Random direction movement cover the whole area equal likely

Normal Movement Period (NMP)



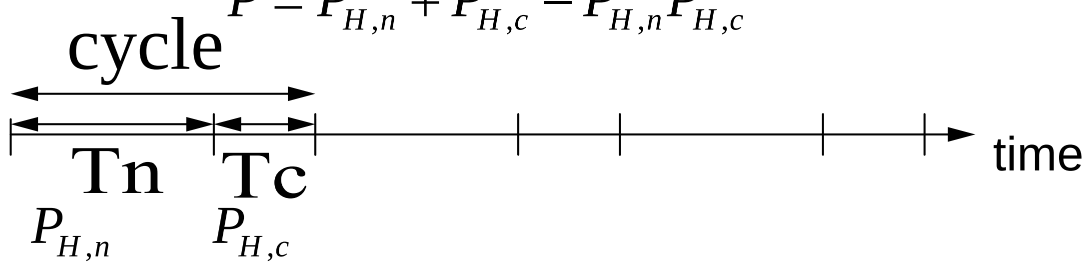
- Each time unit is an *i.i.d.* Bernoulli trial to discover the target, so hitting prob. for the whole time period

$$P_{H,n} = 1 - (1 - P_{h,n})^{T_n}$$

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.

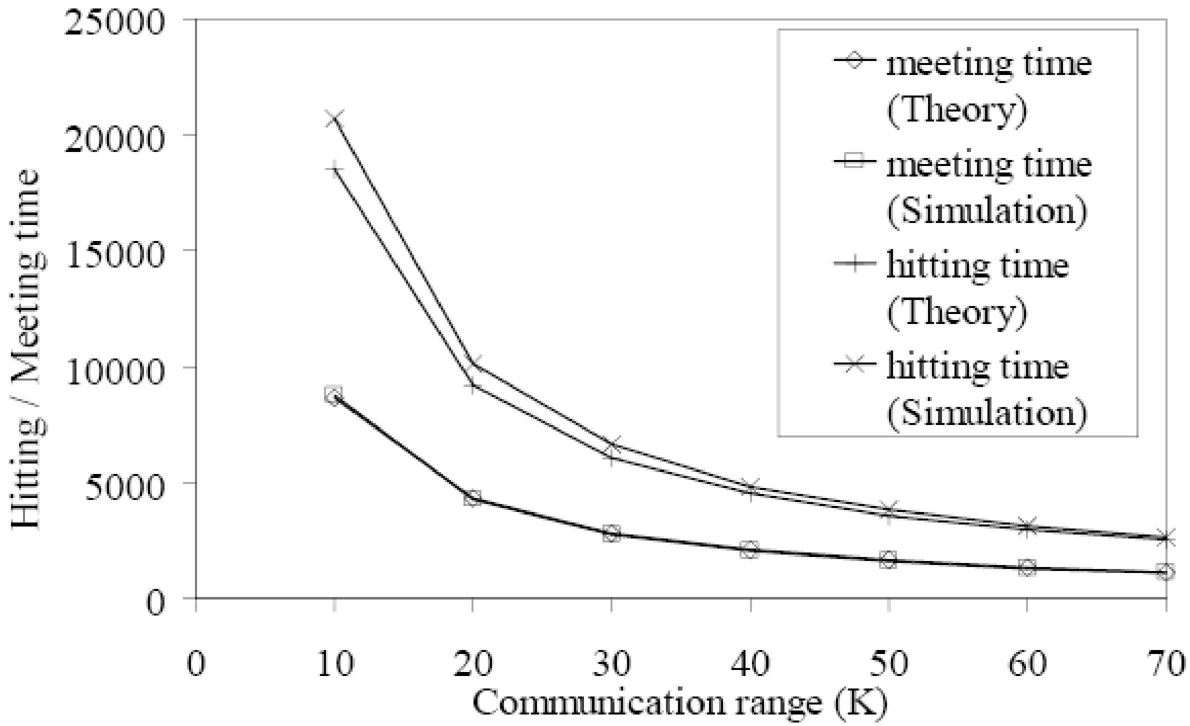
Simulation

- 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)

Model name	Description	N	C_n	C_c	v_{max}, v_{min}	$T_{max,n}$	$T_{max,c}$	$\overline{L_r}$	$\overline{L_l}$	$p_{l,n}$	$p_{r,n}$	$p_{l,c}$	$p_{r,c}$	T_n	T_c
Model 1	Match with the MIT trace	1000	100	100	15, 5	100	50	520	80	0.5	0.2	0.8	0.2	5760	2880
Model 2	Highly attractive communities	1000	200	50	15, 5	100	200	520	52	0.6	0.3	0.8	0.1	3000	2000
Model 3	Not attractive communities	1000	100	100	15, 5	50	200	800	80	0.5	0.5	0.6	0.3	2000	1000
Model 4	Large-size communities	1000	200	250	15, 5	50	100	800	200	0.7	0.3	0.8	0.1	2000	1000

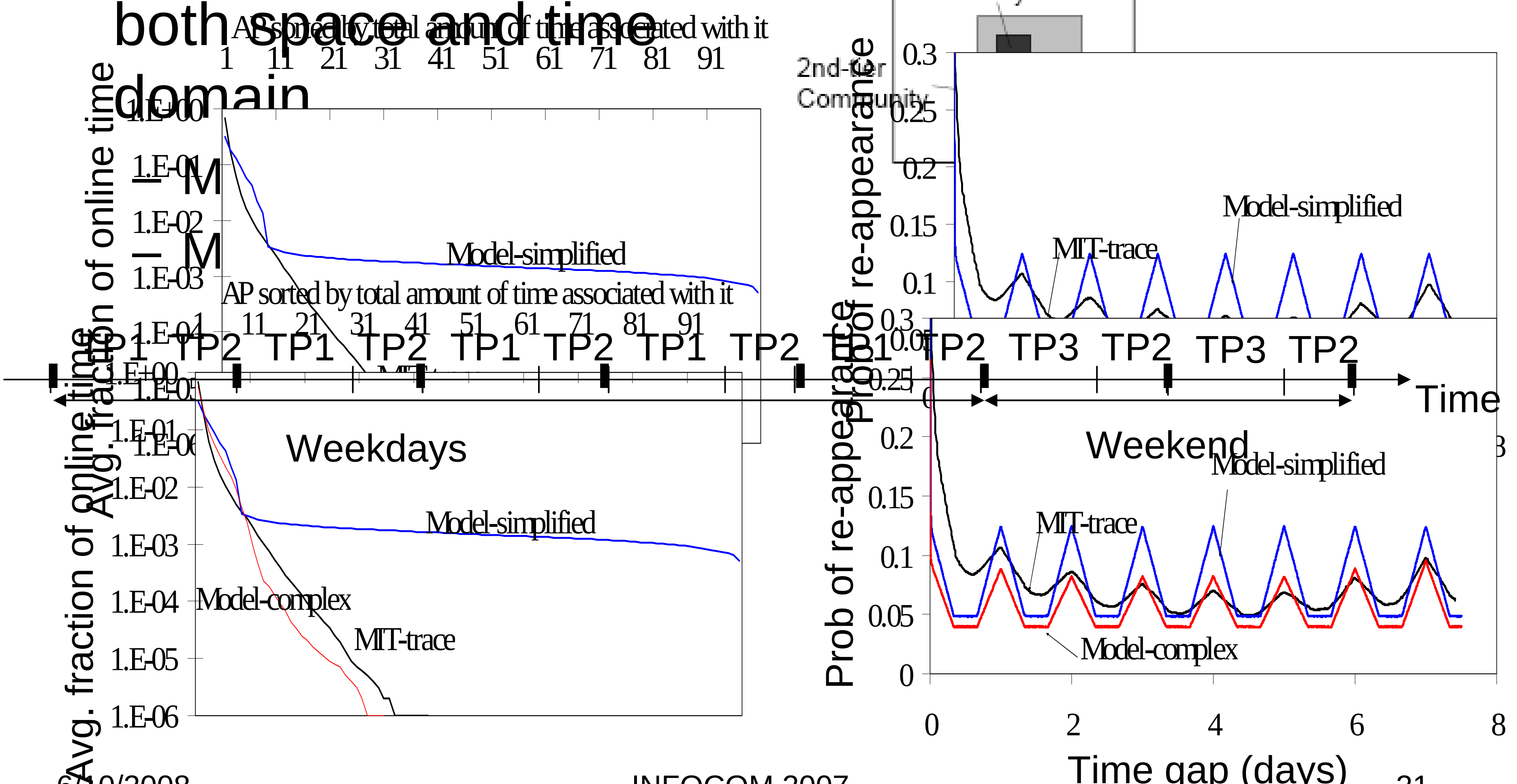
Simulation

- Good match between theoretical and simulation results



Extension of Model

- Richer granularity in both space and time domain
  - M
  - M



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

[1] A. Jindal and K. Psounis, “Fundamental Mobility Properties for Realistic Performance Analysis of Intermittently Connected Mobile Networks,” IEEE PerCom Workshop on Intermittently Connected Mobile Ad Hoc Networks (ICMAN), 2007.

[2] T. Spyropoulos, K. Psounis, and C. Raghavendra, “Efficient Routing in Intermittently Connected Mobile Networks: The Multi-copy Case,” to appear in ACM/IEEE ToN, 2007.

[3] T. Spyropoulos, K. Psounis, and C. Raghavendra, “Efficient Routing in Intermittently Connected Mobile Networks: The Single-copy Case,” to appear in ACM/IEEE ToN, 2007.

[4] W. Hsu and A. Helmy, "On Nodal Encounter Patterns in Wireless LAN Traces," IEEE WiOpt Workshop On Wireless Network Measurement (WiNMee 2006), 2006.

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!!

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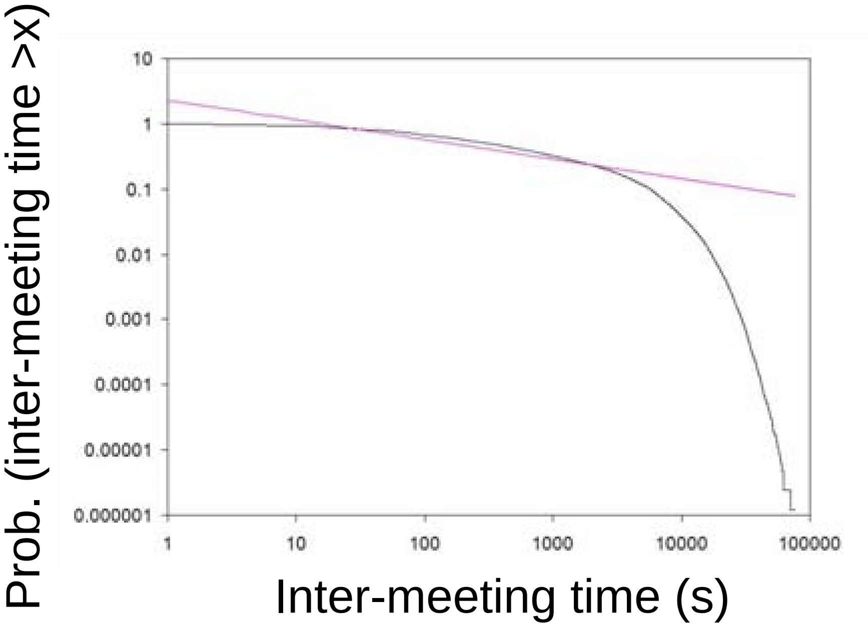
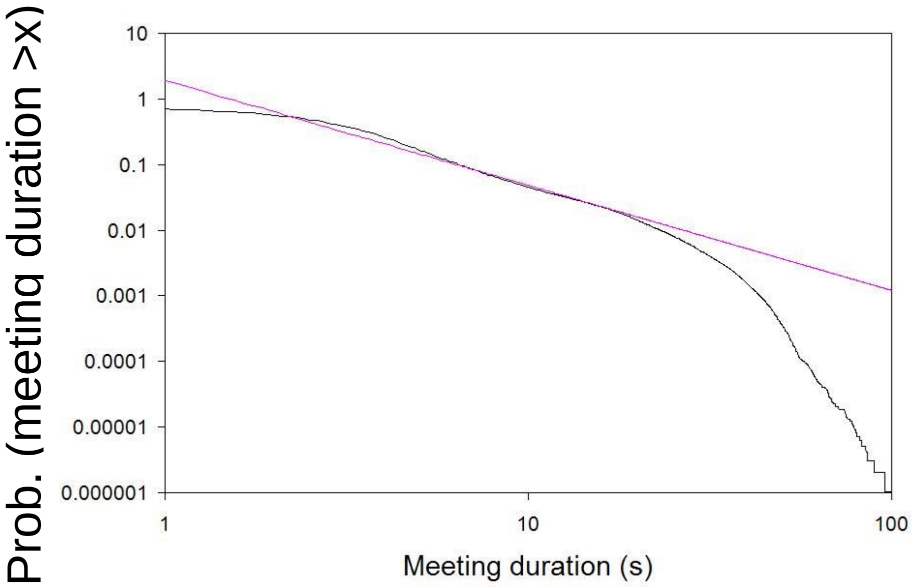
Backup Slides

Other quantities of interest

- Inter-meeting time
- Meeting duration



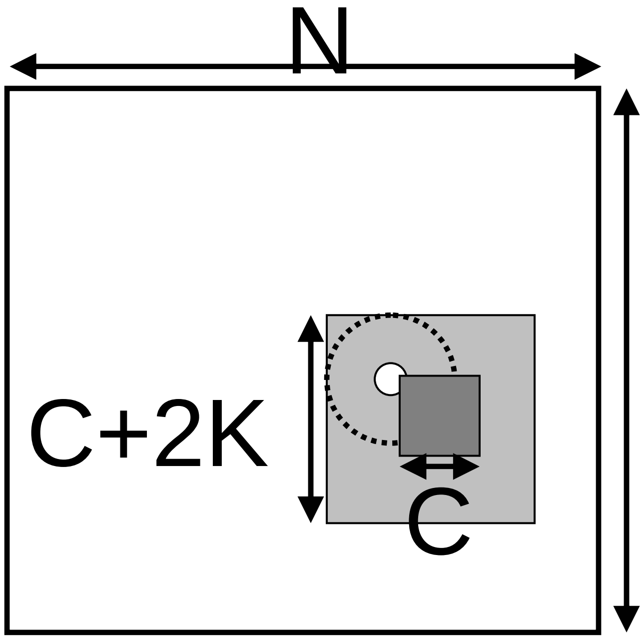


Both quantities follow power-law distributions

Theory Derivation – Meeting Time

- (Step1) 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)

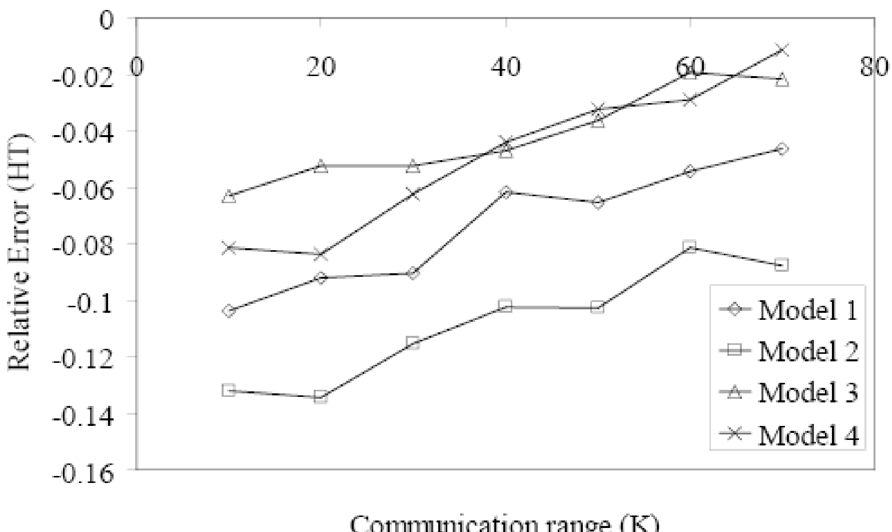
$$P_{m,ov} = \frac{2K\overline{v_l}\hat{v}P_{move,l}^2}{C^2} + \frac{2K\overline{v_l} \times 2P_{move,l}P_{pause,l}}{C^2} + \frac{2K\overline{v_r} \times 2P_{move,r}(P_{pause,r} + P_{pause,l})}{N^2} + \frac{2K\overline{v_l} \times 2P_{move,l}P_{pause,r}}{C^2} \times \frac{C^2}{N^2} + \frac{2K\overline{v}\hat{v}((P_{move,r} + P_{move,l})^2 - P_{move,l}^2)}{N^2}.$$

$$P_{m,no\_ov} = \frac{2K\overline{v_r} \times 2P_{move,r}(P_{pause,r} + P_{pause,l})}{N^2} + \frac{2K\overline{v_l} \times 2P_{move,l}P_{pause,r}}{C^2} \times \frac{C^2}{N^2} + \frac{2K\overline{v}\hat{v}((P_{move,r} + P_{move,l})^2 - P_{move,l}^2)}{N^2},$$

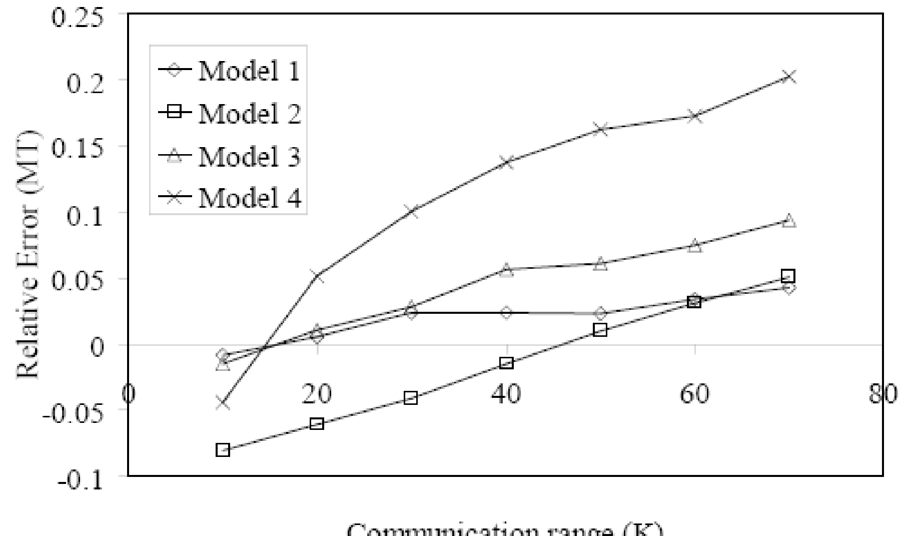
Common terms for both cases (at least one node is in roaming state)

Simulation

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



(a) Hitting time.



(b) Meeting time.

Relative error = (Theory – Simulation) / Simulation