Vehicular Ad-Hoc Networks

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Mobility Modeling for Future Mobile Network Design and Simulation

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Outline

- Mobile Ad Hoc Networks & Mobility Classification
  - Synthetic and Trace-based Mobility Models
  - The Need for Systematic Mobility Framework
- Survey of the Major Mobility Models
  - Random models - Group mobility models – Vehicular (Manhattan/Freeway) models - Obstacle models
- Characterizing the Mobility Space
  - Mobility Dimensions (spatial and temporal dependency, geographic restrictions)
  - Mobility Metrics (spatio-temporal correlations, path and link duration)

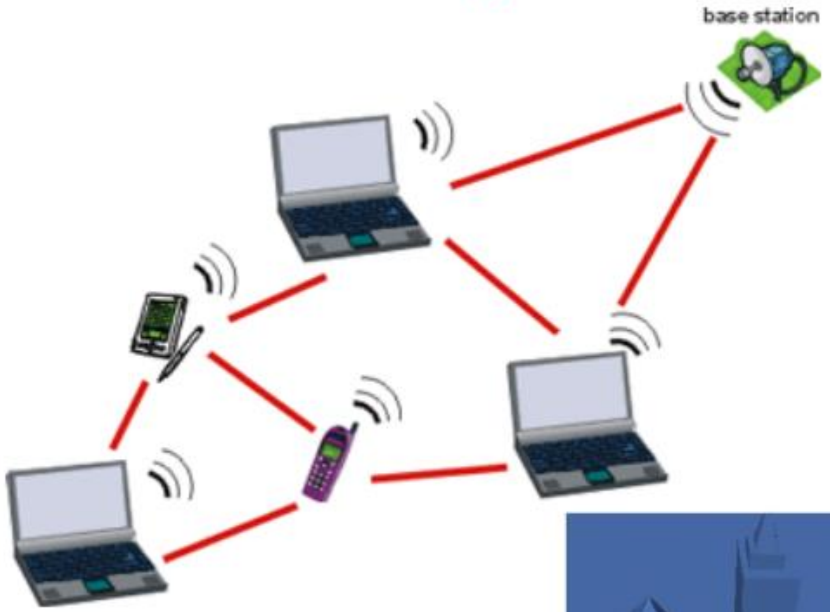
Outline (contd.)

- Mobility-centric framework to analyze ad hoc networks
  - The *IMPORTANT* mobility framework
  - Case Studies: *BRICS*, *PATHS*, *MAID*
- Trace-based mobility modeling
  - Analyzing wireless network measurements and traces
  - The *TVC* model, and *profile-cast*
- Mobility simulation and analysis tools
  - Software packages and tools
  - Resources and related projects

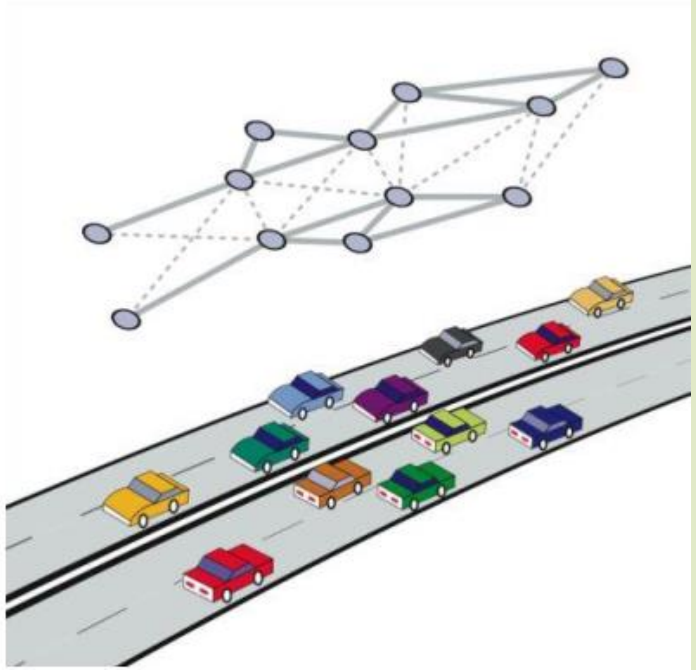
Wireless Mobile Ad hoc Networks (MANETs)

- A Mobile Ad hoc Network (*MANET*) is a collection of mobile devices forming a multi-hop wireless network with minimal (or no) infrastructure
- To evaluate/study adhoc networks mobility and traffic patterns are two significant factors affecting protocol performance.
- Wireless network performance evaluation uses:
  - Mobility Patterns: usually, uniformly and randomly chosen destinations (random waypoint model)
  - Traffic Patterns: usually, uniformly and randomly chosen communicating nodes with long-lived connections
- Impact of mobility on wireless networks and ad hoc routing protocols is significant

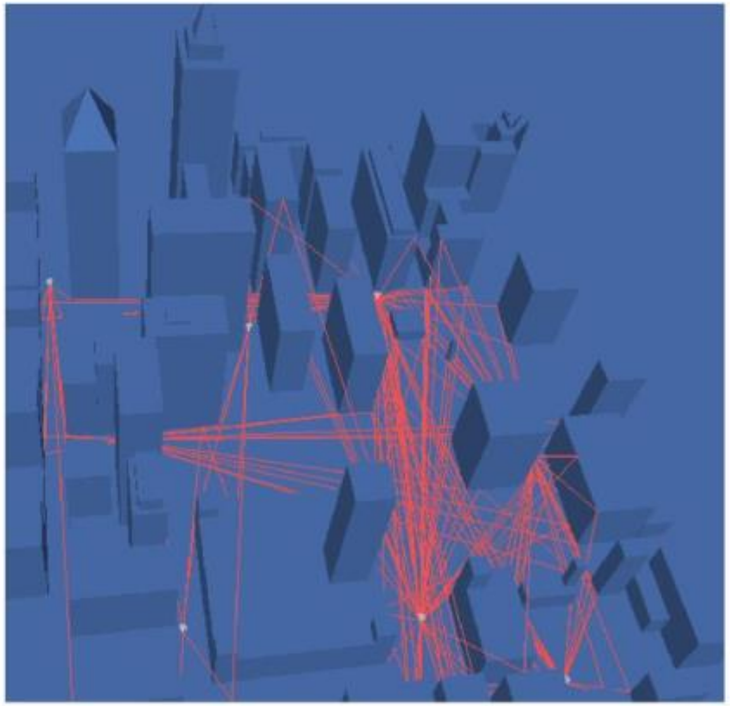
Example Ad hoc Networks



Mobile devices (laptop, PDAs)



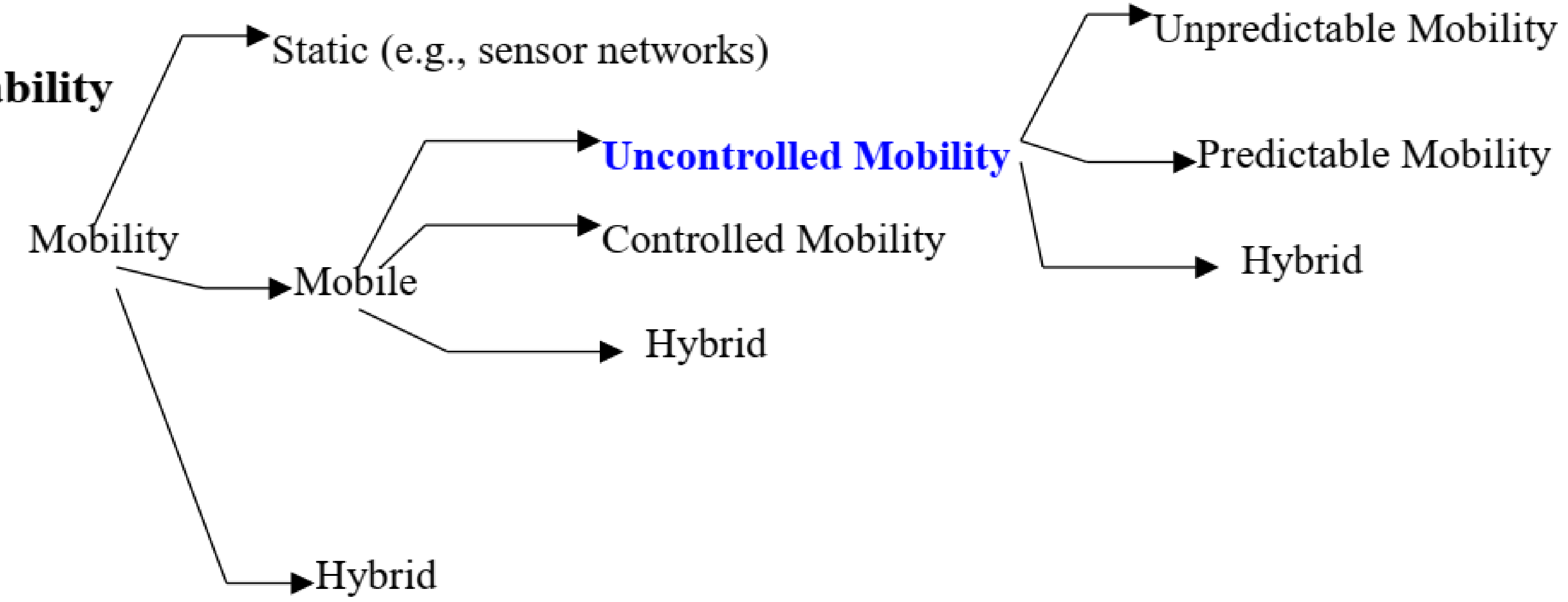
Vehicular Networks on Highways



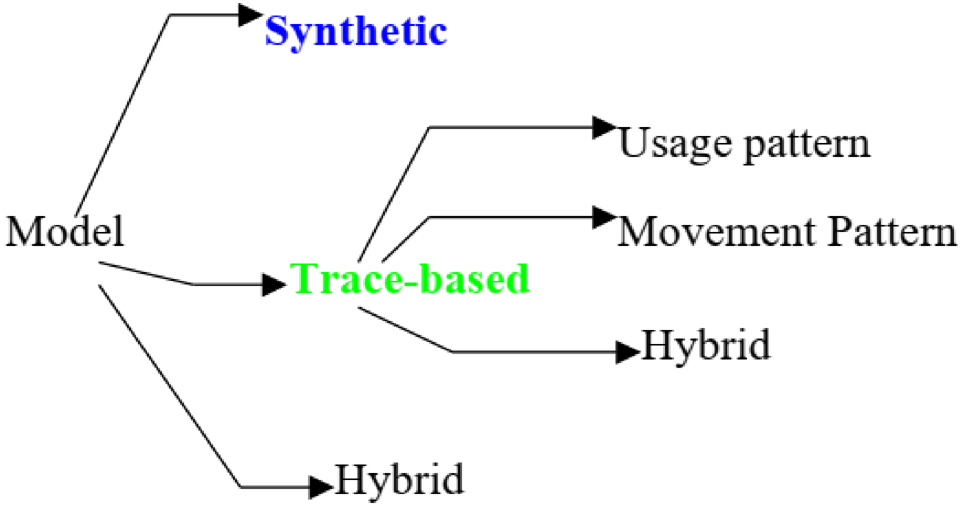
Hybrid urban ad hoc network (vehicular, pedestrian, hot spots,…)

Classification of Mobility and Mobility Models

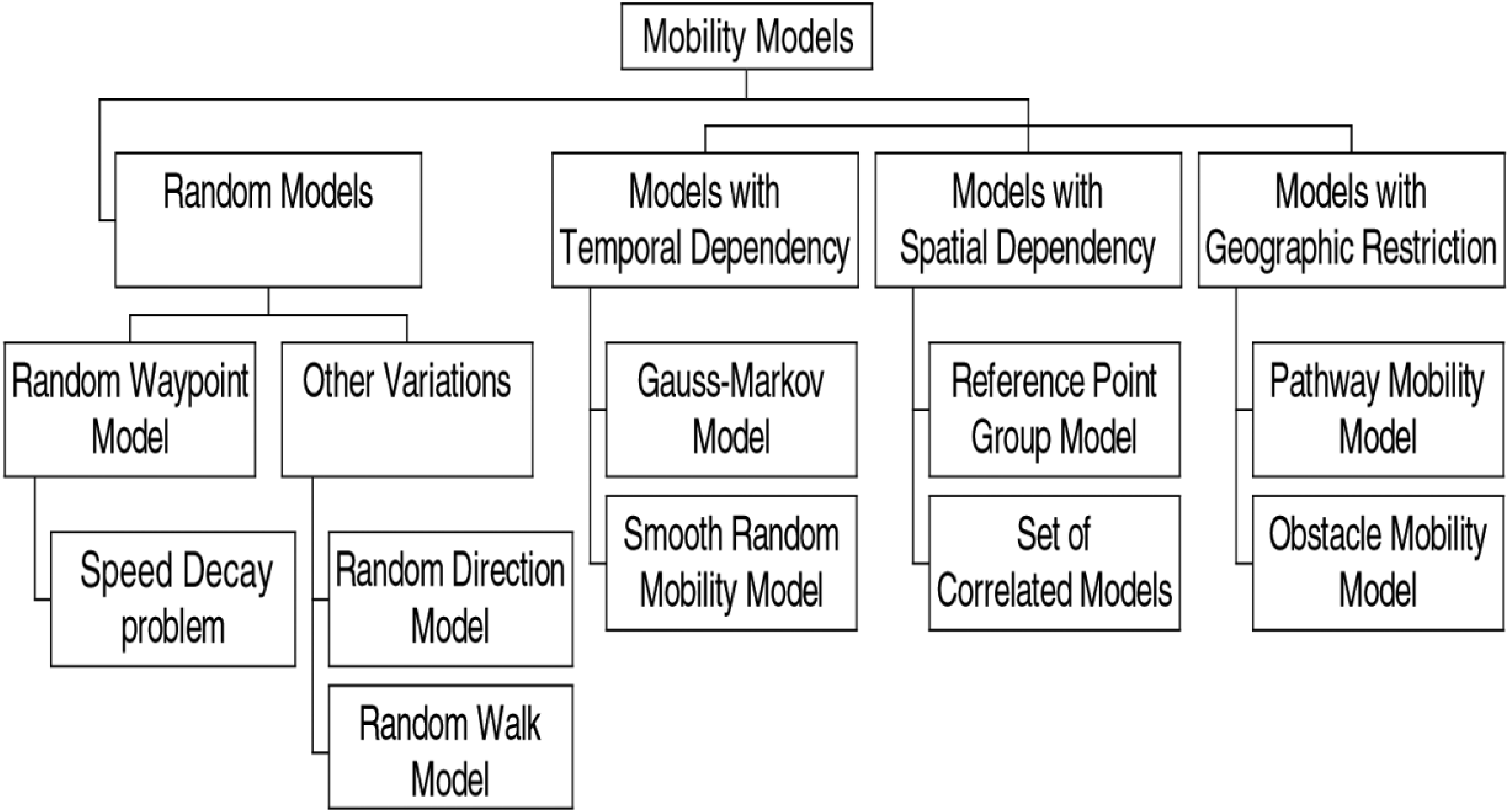
I- Based on Controllability



II- Based on Model Construction



Mobility Dimensions & Classification of Synthetic Uncontrolled Mobility Models



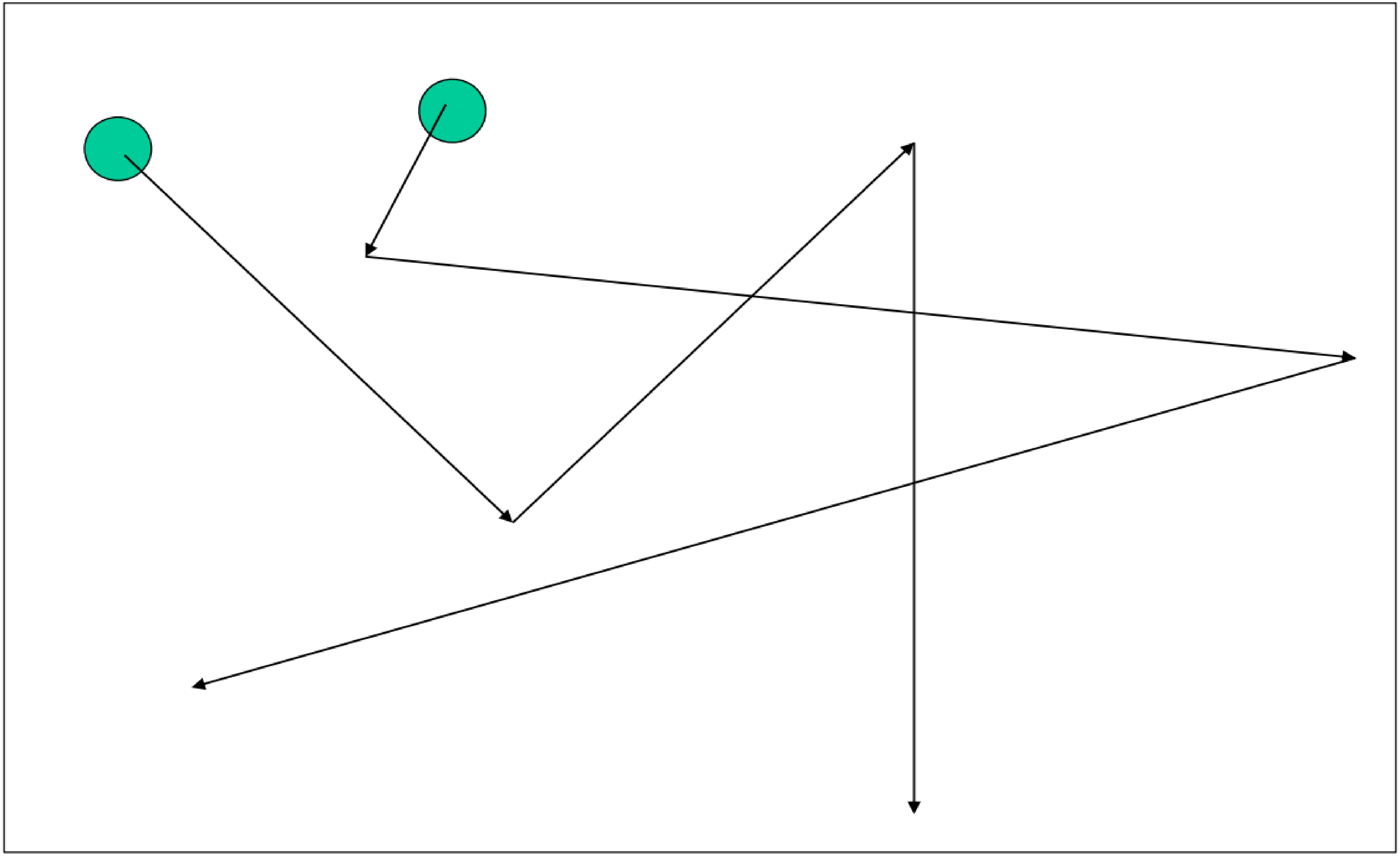
I. Random Waypoint (*RWP*) Model

1. **A node chooses a random destination anywhere in the network field**
2. **The node moves towards that destination with a velocity chosen randomly from [0, *Vmax*]**
3. **After reaching the destination, the node stops for a duration defined by the "pause time" parameter.**
4. **This procedure is repeated until the simulation ends**

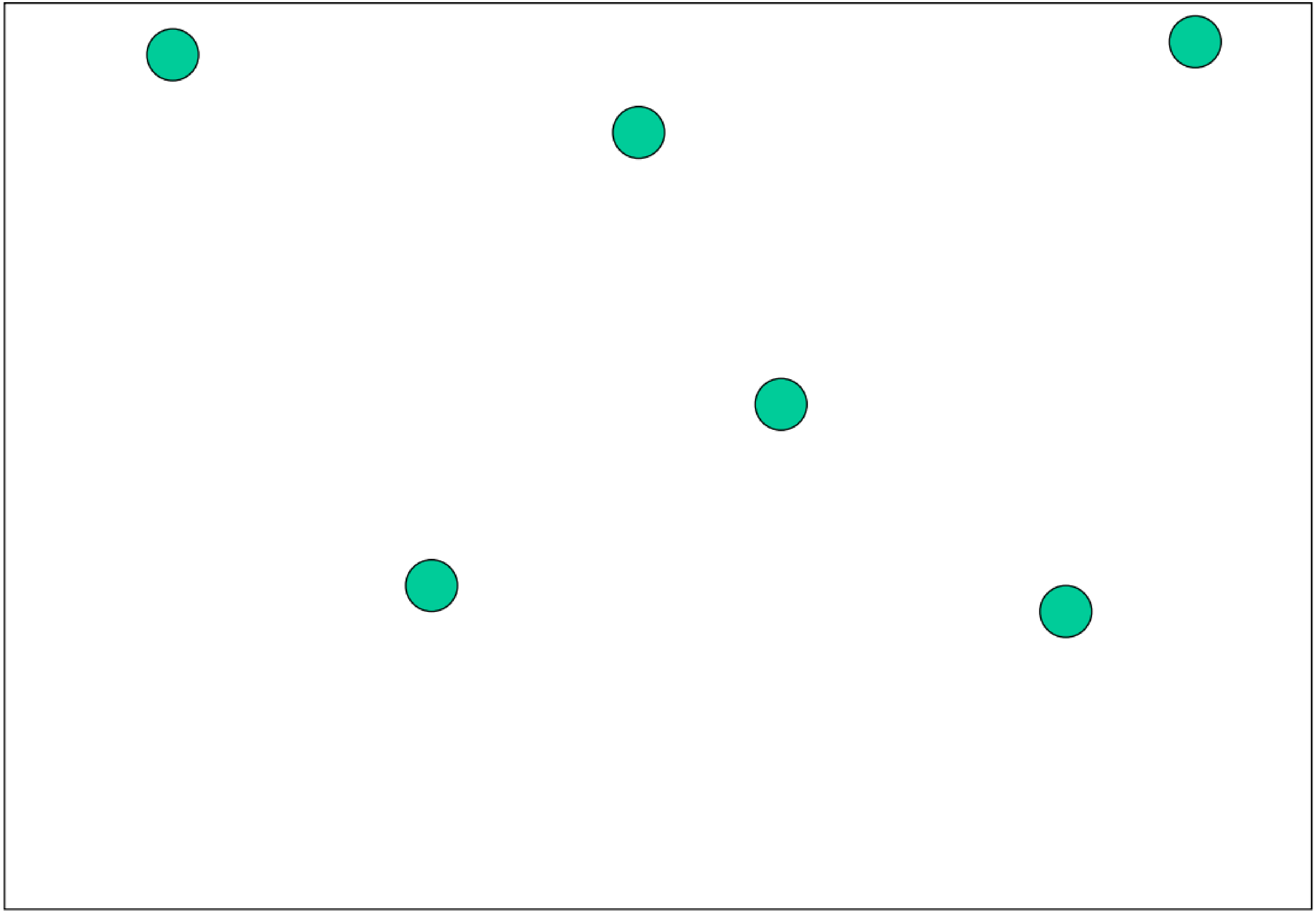
– **Parameters: Pause time T, max velocity *Vmax***

– **Comments:**
  - **Speed decay problem, non-uniform node distribution**
  - **Variants: random walk, random direction, smooth random, ...**

Random Way Point: Basics



Random Way Point: Example



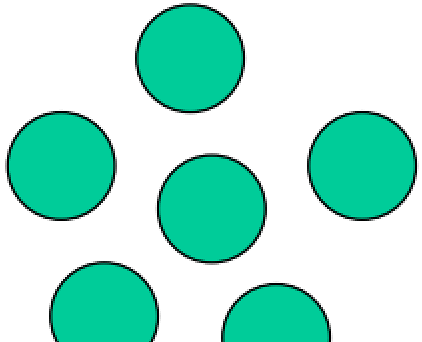
II. Random (*RWK*) Walk Model

- Similar to RWP but
  - Nodes change their speed/direction every time slot
  - New direction θ is chosen randomly between (0,2π]
  - New speed chosen from uniform (or Gaussian) distribution
  - When node reaches boundary it bounces back with (π-θ)

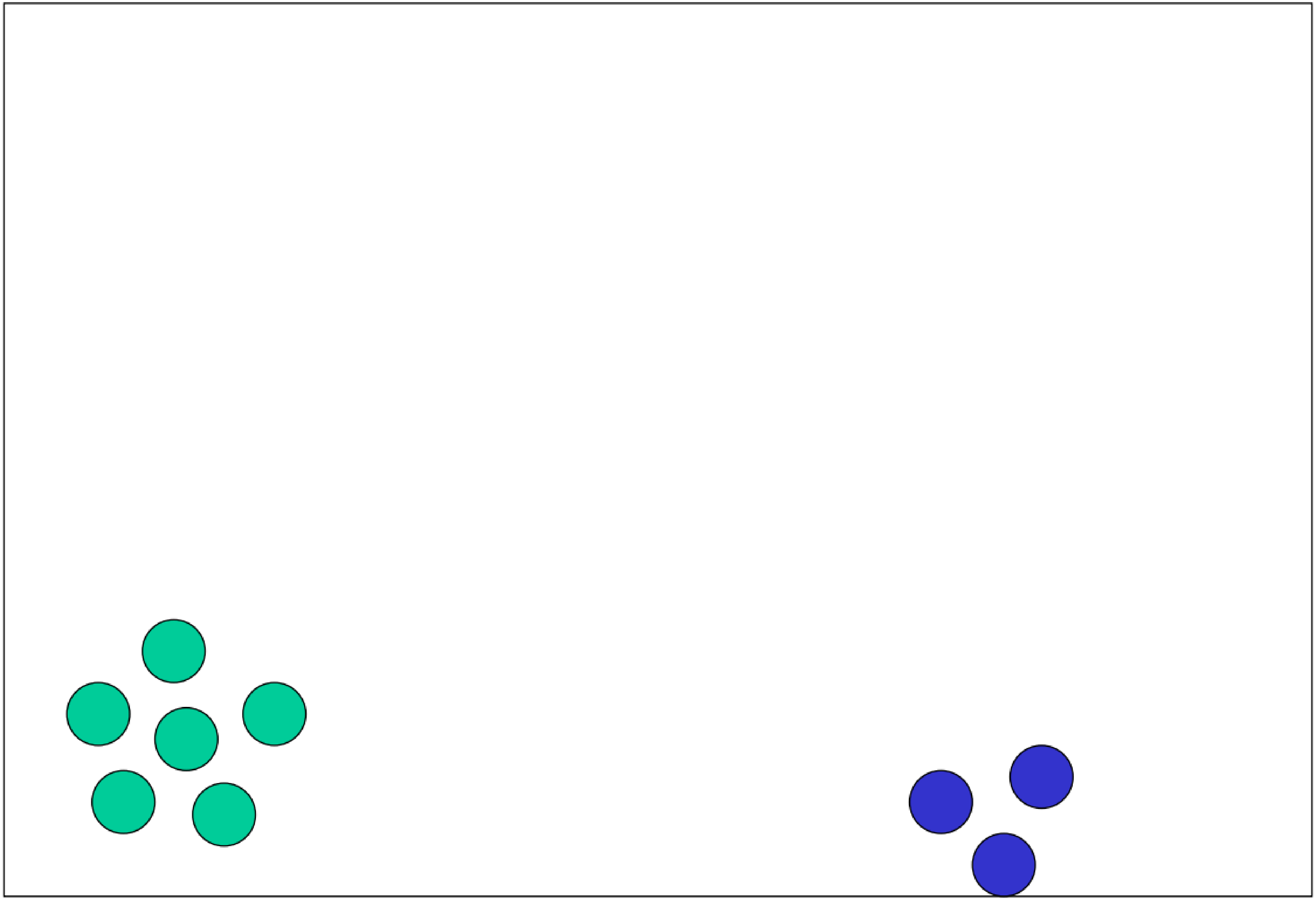
Random Walk

III. Reference Point Group Mobility (*RPGM*)

- Nodes are divided into groups
- Each group has a leader
- The leader's mobility follows random way point
- The members of the group follow the leader's mobility closely, with some deviation
- Examples:
  - Group tours, conferences, museum visits
  - Emergency crews, rescue teams
  - Military divisions/platoons

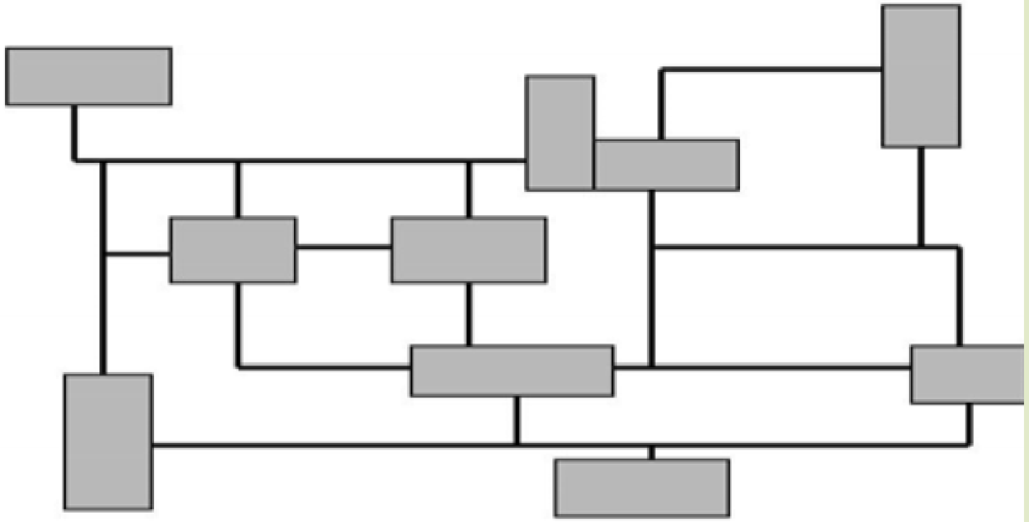


Group Mobility: Multiple Groups



IV. Obstacle/Pathway Model

- Obstacles/bldgs map
- Nodes move on pathways between obstacles
- Nodes may enter/exit buildings



(c) Pathway Graph on a Campus

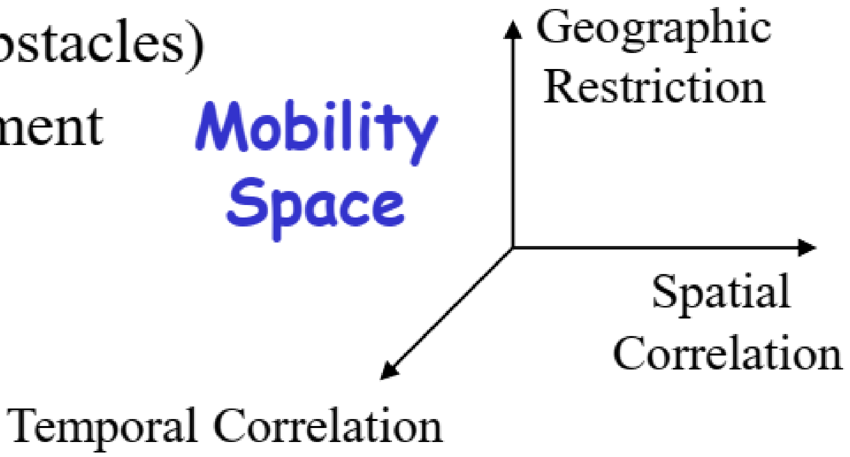
- Pathways constructed by computing Voronoi graph (i.e., pathways equidistant to nearby buildings)
- Obstacles affect communication
  - Nodes on opposite sides (or in/outside) of a building cannot communicate

V. Related Real-world Mobility Scenarios

- Pedestrian Mobility
  - University or business campuses
  - Usually mixes group and RWP models, with obstacles and pathways
- Vehicular Mobility
  - Urban streets (Manhattan-like)
  - Freeways
  - Restricted to streets, involves driving rules

Motivation

- Randomized models (e.g., random waypoint) do not capture
  - (I) Existence of geographic restriction (obstacles)
  - (II) Temporal dependence of node movement (correlation over history)
  - (III) Spatial dependence (correlation) of movement among nodes

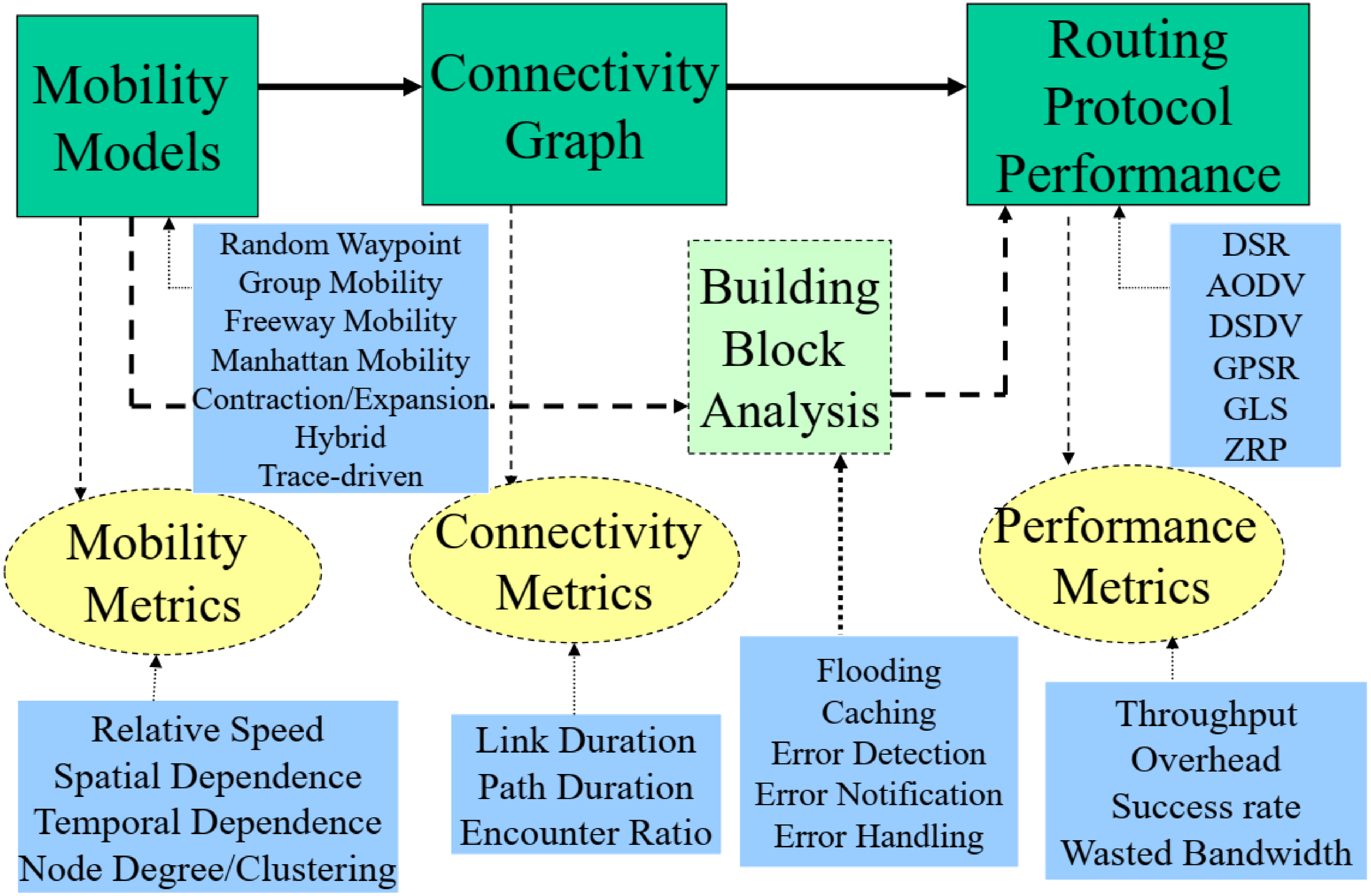


- A systematic framework is needed to investigate the impact of various mobility models on the performance of different routing protocols for MANETs
- This study attempts to answer
  - What are key characteristics of the mobility space?
  - Which metrics can compare mobility models in a meaningful way?
  - Whether mobility matters? To what degree?
  - If the answer is yes, why? How?

Framework Goals (Questions to Answer)

- Whether mobility matters? and How much does it matter?
  - Rich set of mobility models that capture characteristics of different types of movement
  - Protocol independent metrics such as mobility metrics and connectivity graph metrics to capture the above characteristics
- Why?
  - Analysis process to relate performance with a specific characteristic of mobility via connectivity metrics
- How?
  - Systematic process to study the performance of protocol mechanistic building blocks (*BRICS*) across various mobility characteristics

The IMPORTANT Framework Overview



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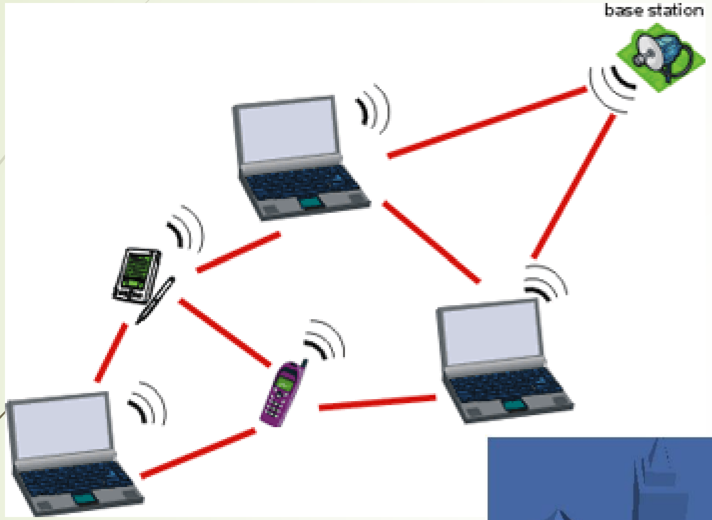

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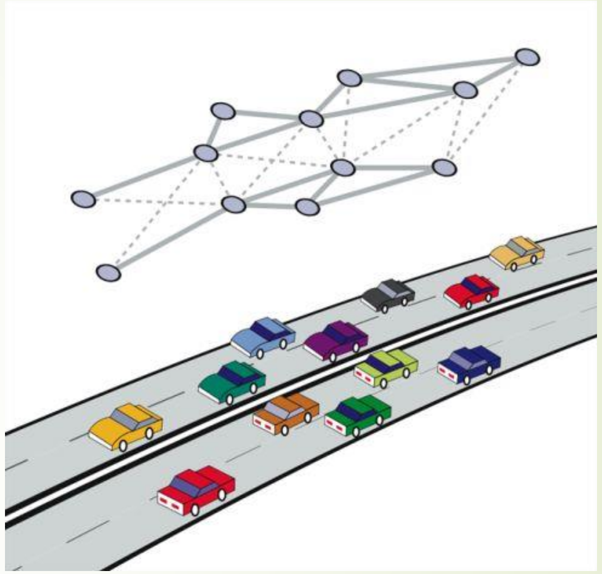

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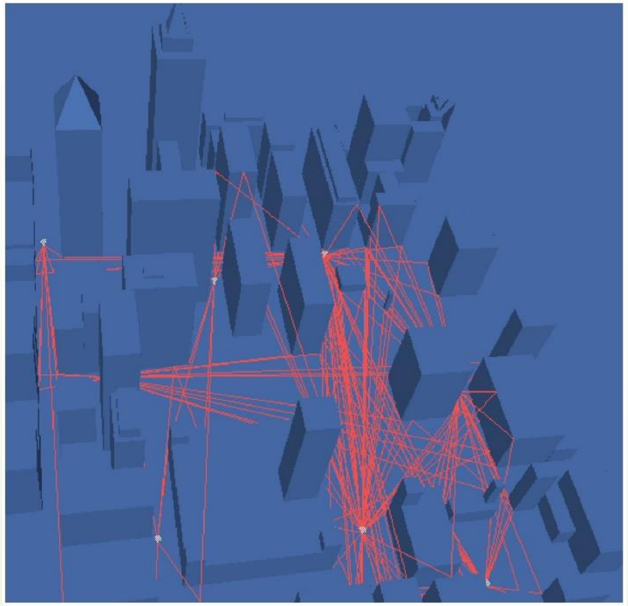


Hybrid urban ad hoc network (vehicular, pedestrian, hot spots,…)

Classification of Mobility and Mobility Models

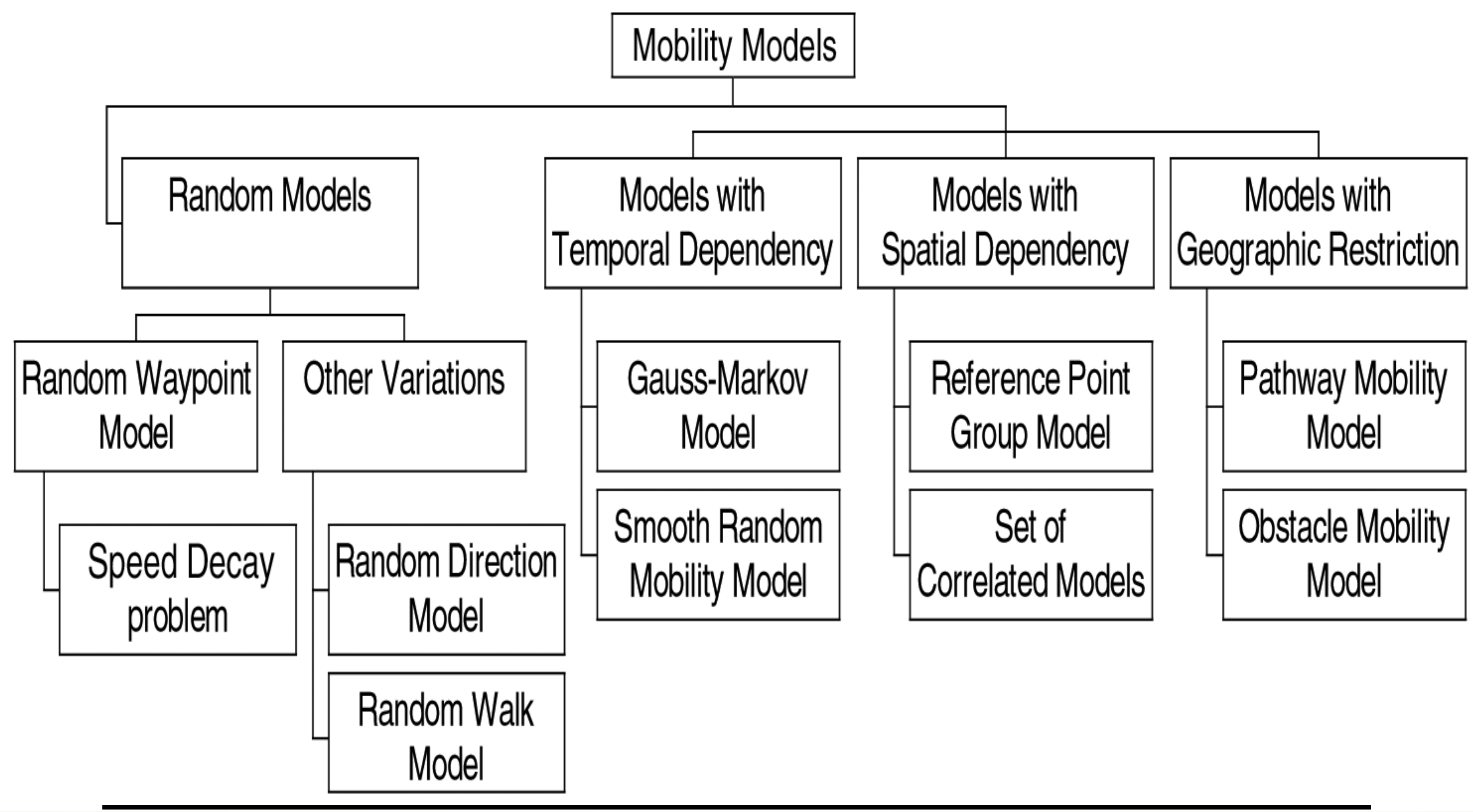
I- Based on Controllability

- Mobility
  - Static (e.g., sensor networks)
  - Mobile
    - **Uncontrolled Mobility**
      - Unpredictable Mobility
      - Predictable Mobility
      - Hybrid
    - Controlled Mobility
    - Hybrid
  - Hybrid

II- Based on Model Construction

- Model
  - **Synthetic**
  - **Trace-based**
    - Usage pattern
    - Movement Pattern
    - Hybrid
  - Hybrid

Mobility Dimensions & Classification of Synthetic Uncontrolled Mobility Models



* F. Bai, A. Helmy, "A Survey of Mobility Modeling and Analysis in Wireles Adhoc Networks", Book Chapter in the book "Wireless Ad Hoc and Sensor Networks", Kluwer Academic Publishers, June 2004.

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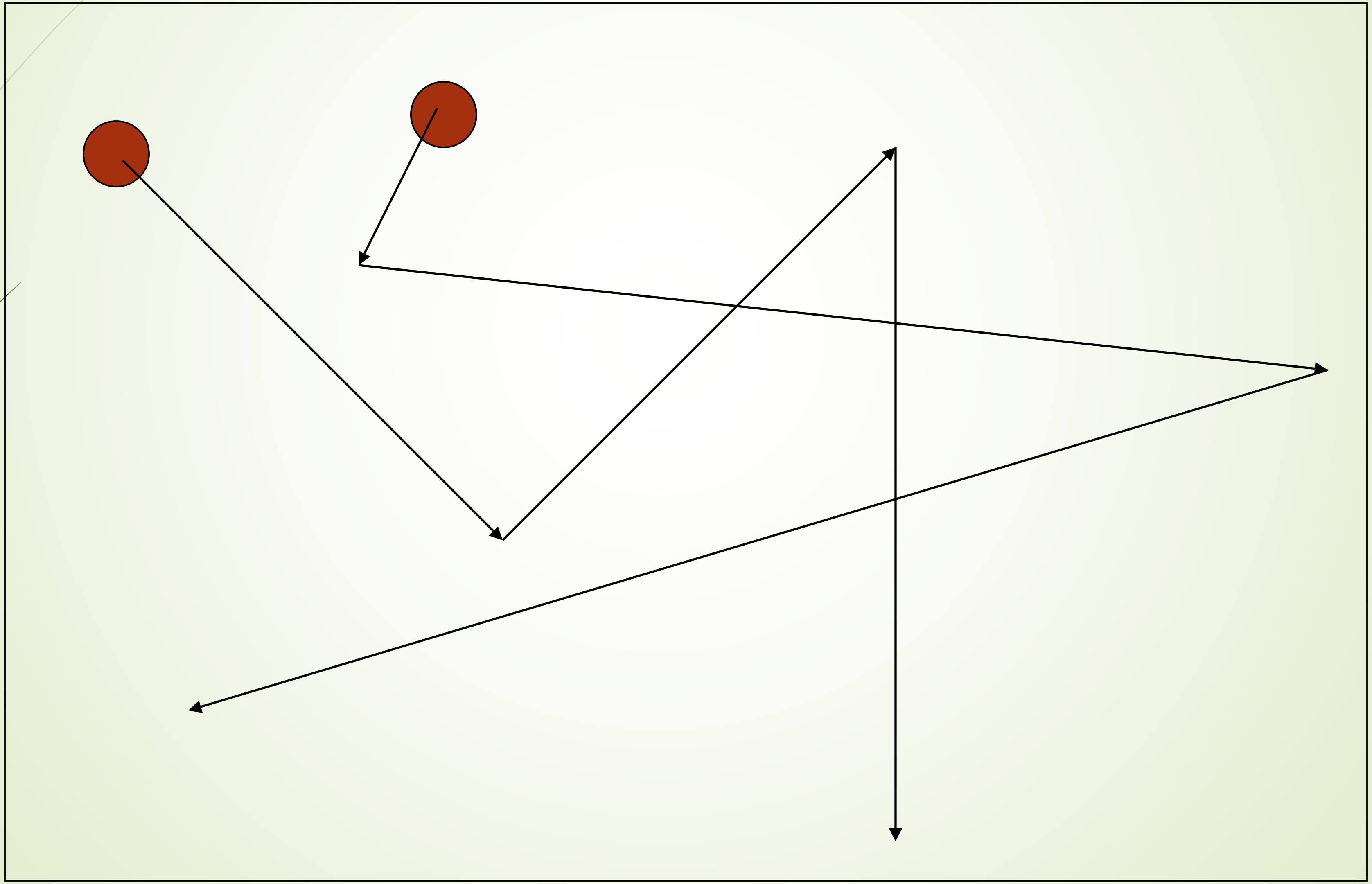

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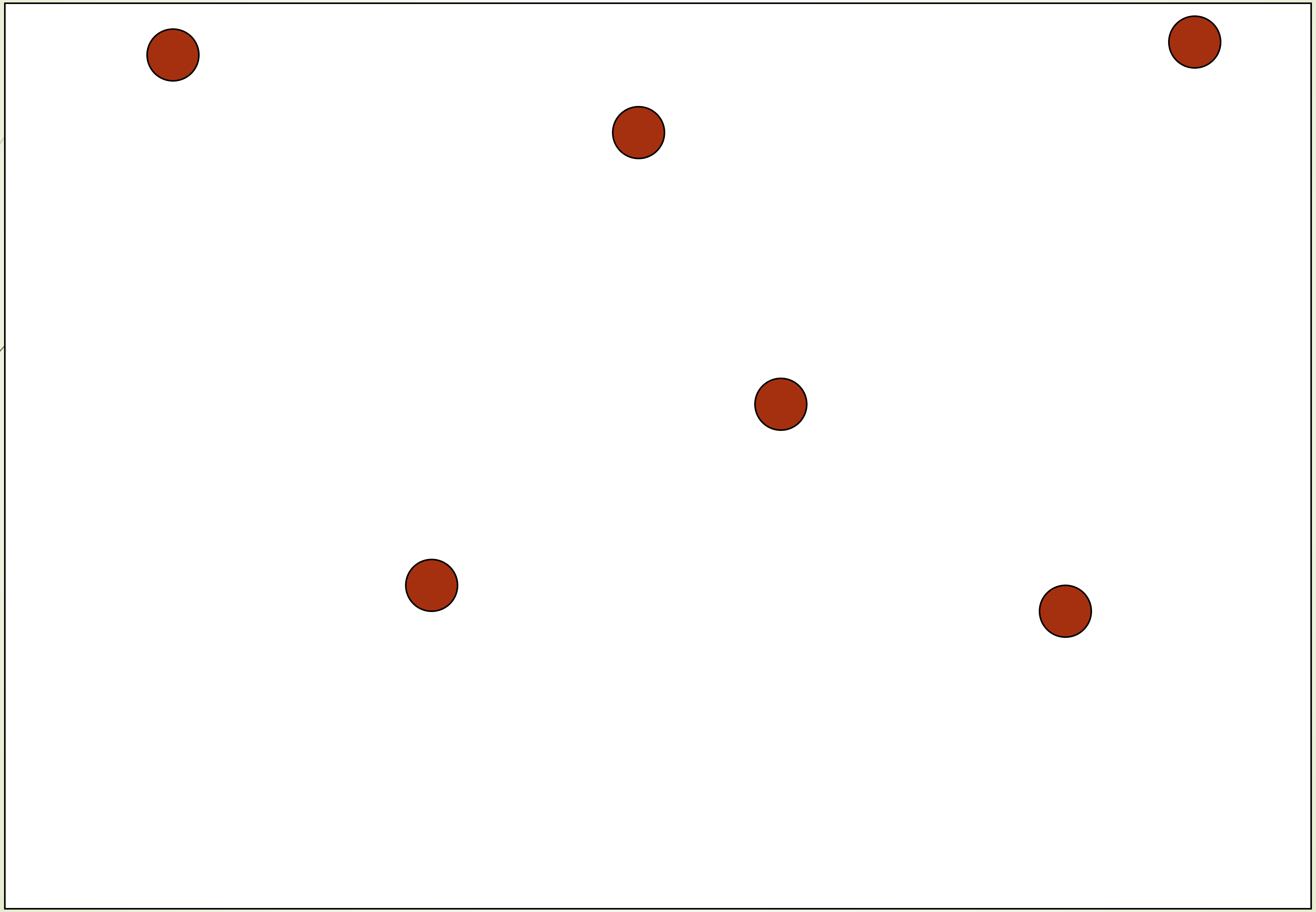

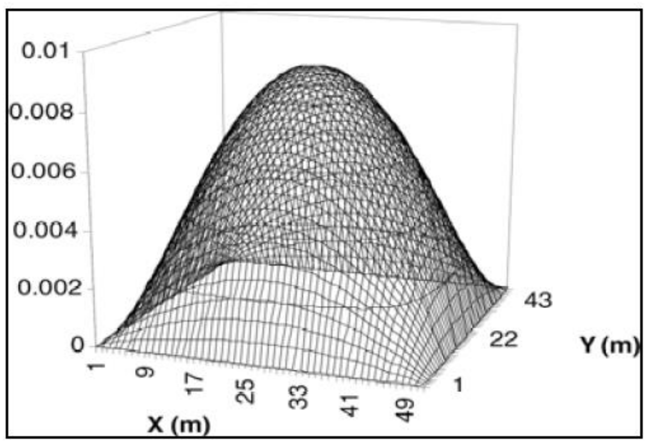

Figure 1-3. Node Spatial Distribution (Square Area)

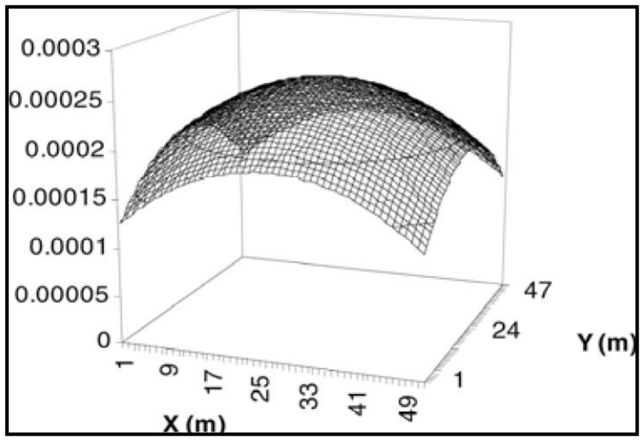

Figure 1-4. Node Spatial Distribution (Circular Area)

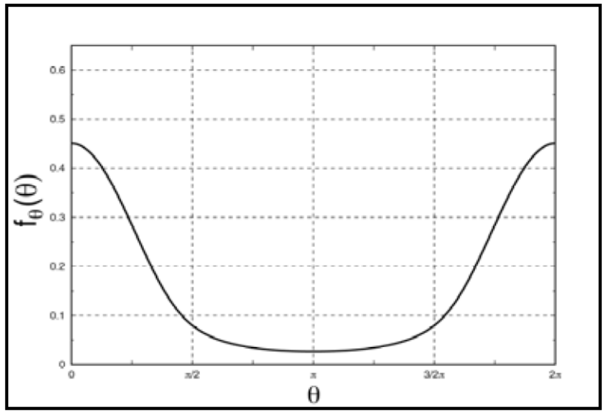

Figure 1-5. The probability distribution of movement direction

-1- *RWP* leads to non-uniform distribution of nodes due to bias towards the center of the area, due to non-uniform direction selection. To remedy this the "random direction" mobility model can be chosen.
-2- Average speed decays over time due to nodes getting 'stuck' at low speeds

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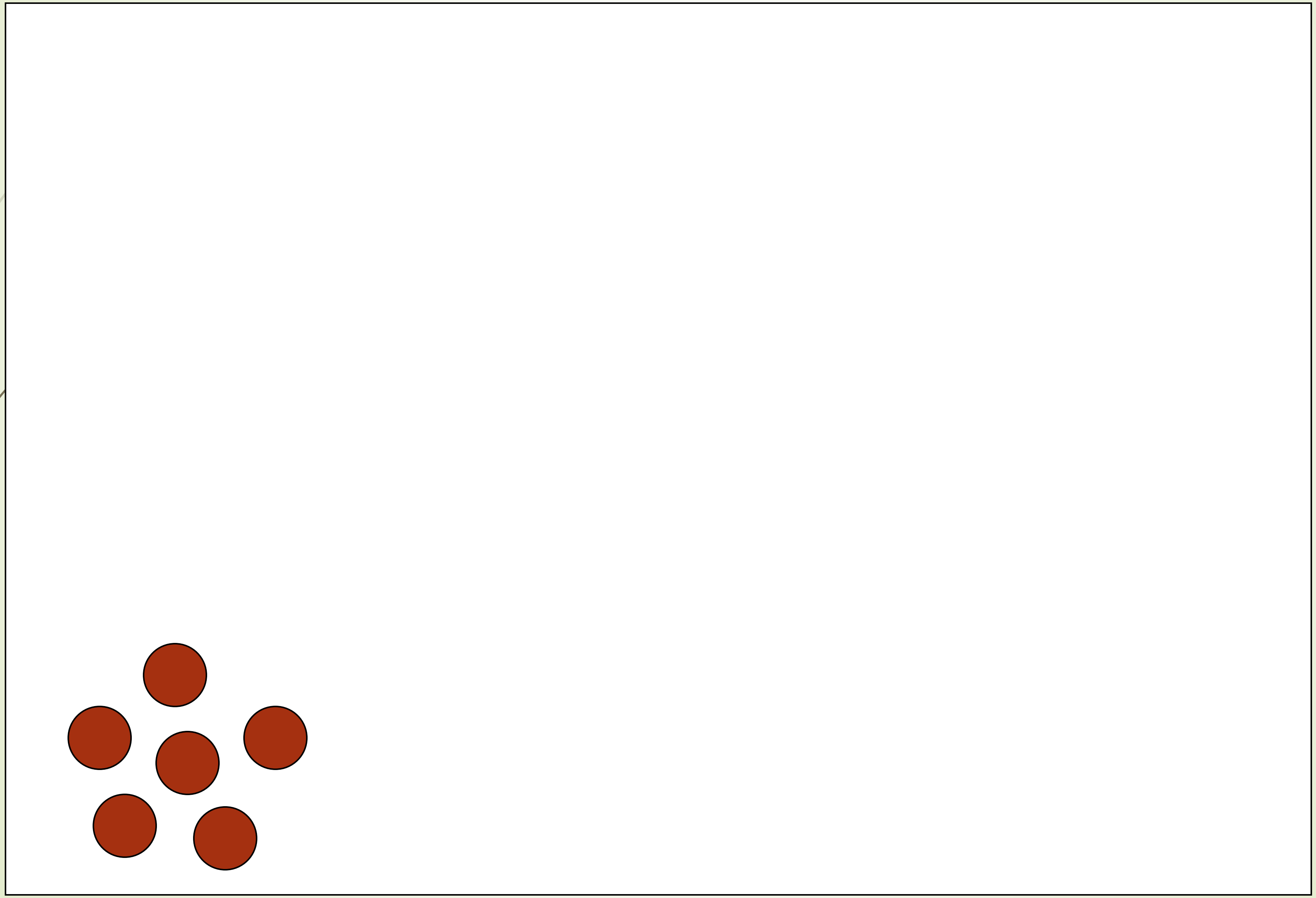
Group Mobility: Single Group



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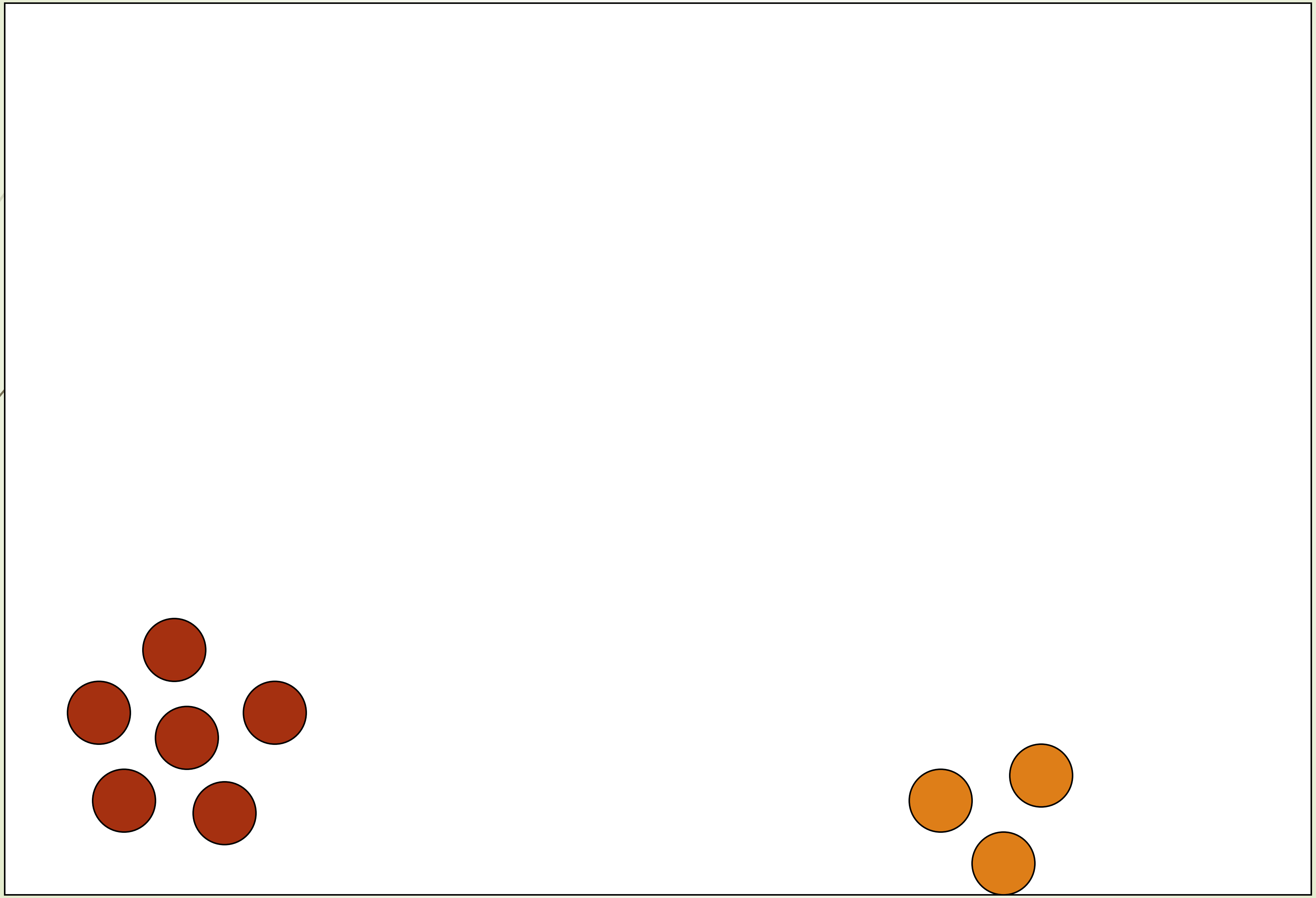

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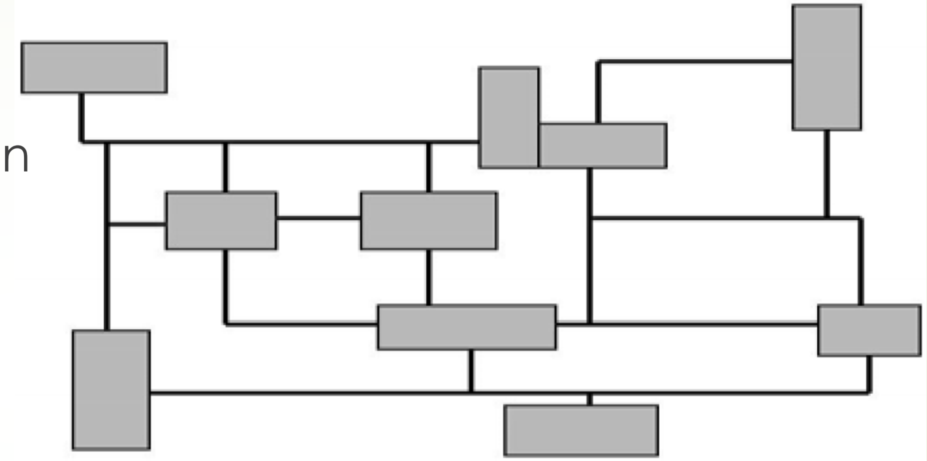

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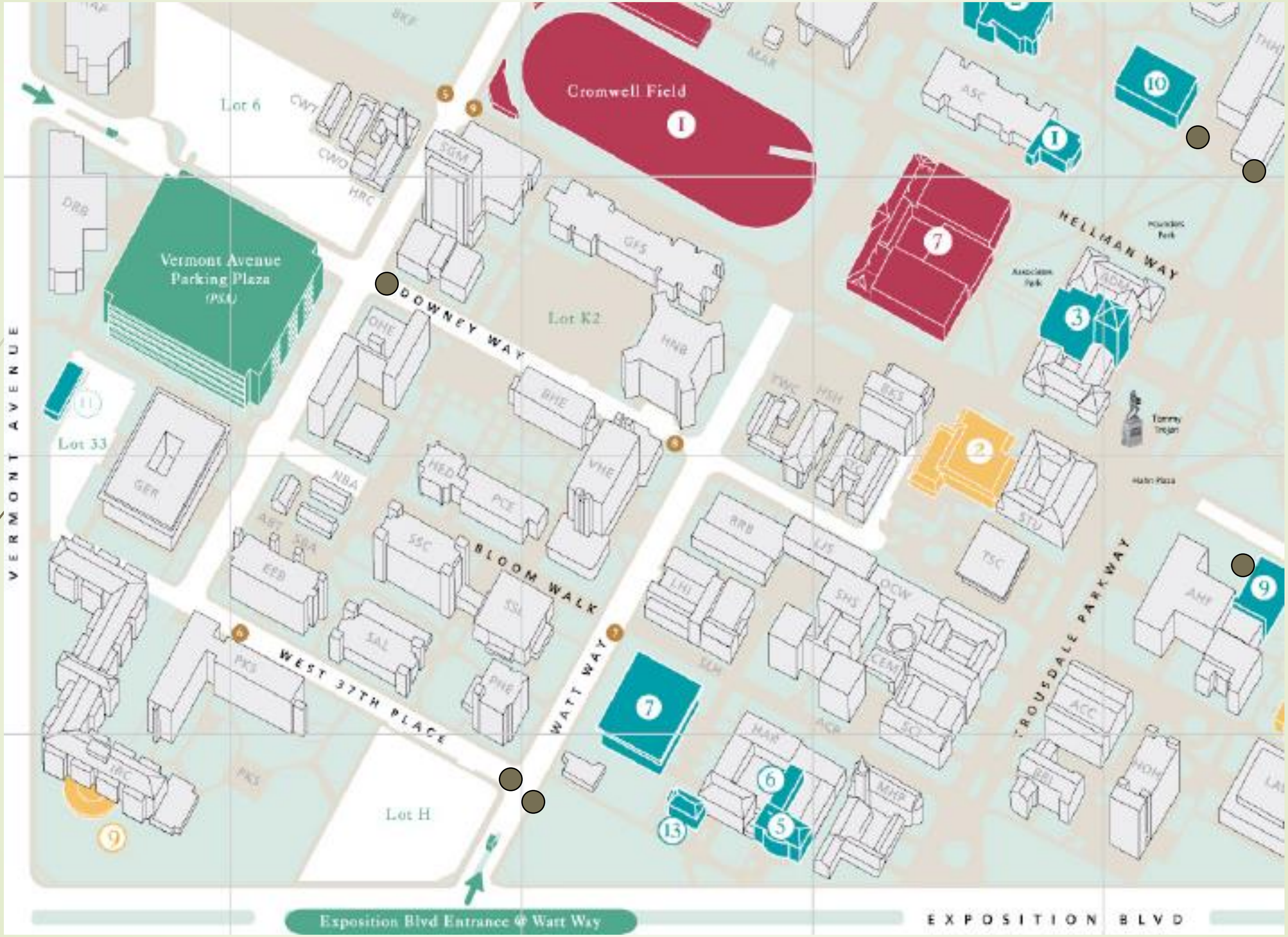
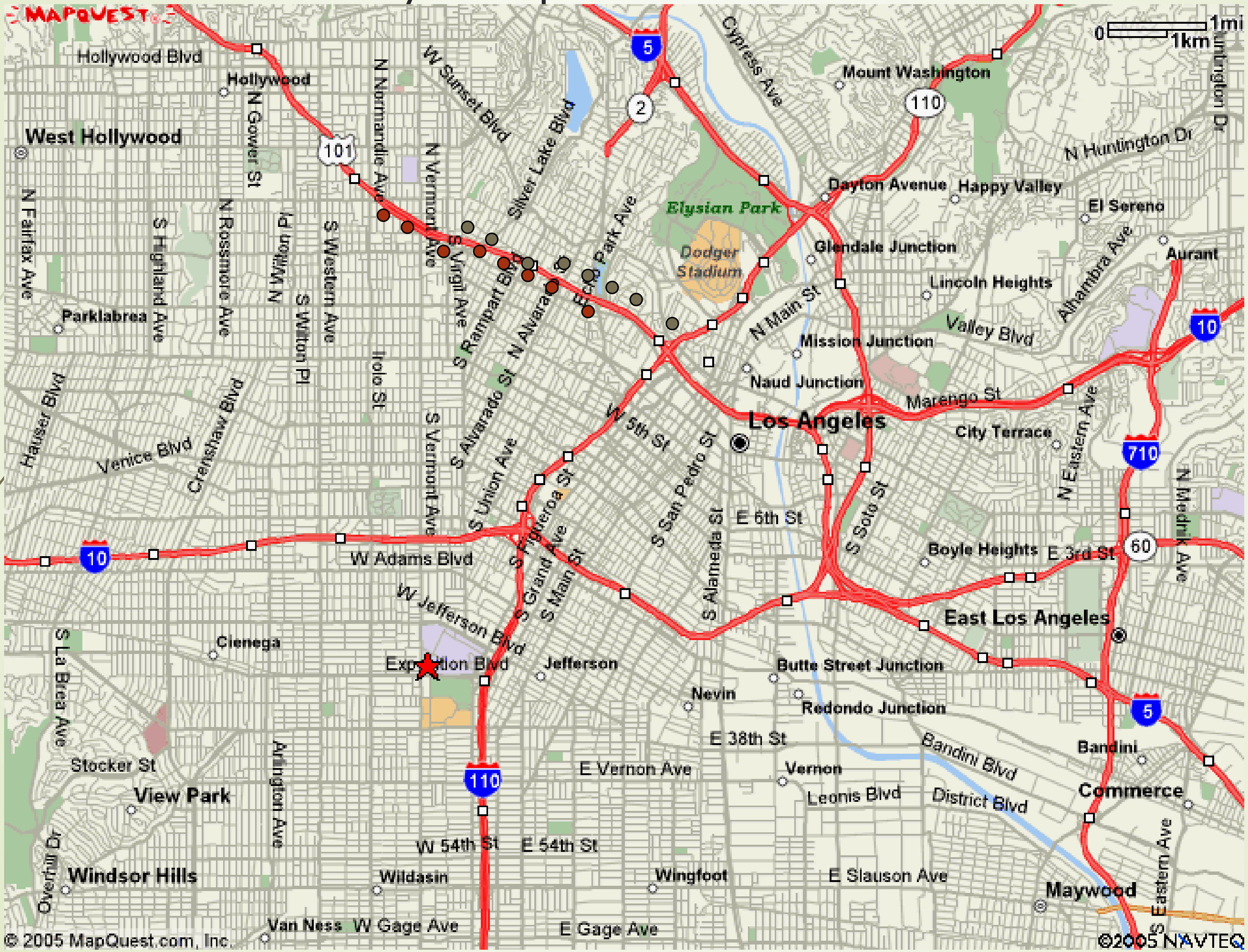


Cromwell Field
Lot 6
Vermont Avenue
Parking Plaza
(PSA)
Lot K2
Lot 33
Lot H
DOWNEY WAY
BLOOM WALK
WEST 37TH PLACE
WATT WAY
HELLMAN WAY
TROUSDALE PARKWAY
VERMONT AVENUE
EXPOSITION BLVD
Exposition Blvd Entrance @ Watt Way

Urban Street

Str

Freeway Map


MAPQUEST
Hollywood Blvd
Hollywood
West Hollywood
Mount Washington
Dayton Avenue
Happy Valley
El Sereno
Elysian Park
Dodger Stadium
Glendale Junction
Lincoln Heights
Aurant
Mission Junction
Naud Junction
Los Angeles
City Terrace
Boyle Heights
East Los Angeles
Parklabrea
Venice Blvd
W Adams Blvd
W Jefferson Blvd
Cienega
Jefferson
Butte Street Junction
Nevin
Redondo Junction
Bandini
Commerce
Vernon
Stocker St
View Park
Windsor Hills
Wildasin
Wingfoot
Maywood
E Vernon Ave
E Slauson Ave
E Gage Ave
W Gage Ave
Van Ness
W 54th St
E 54th St
E 38th St
E 6th St
E 3rd St
Bandini Blvd
District Blvd
Leonis Blvd
Valley Blvd
Marengo St
N Huntington Dr
Alhambra Ave
N Eastern Ave
N Mednik Ave
S Eastern Ave
W Sunset Blvd
Silver Lake Blvd
Echo Park Ave
Cypress Ave
N Main St
W 5th St
S San Pedro St
S Alameda St
S Soto St
S Figueroa St
S Grand Ave
S Main St
S Union Ave
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S Rampart Blvd
S Virgil Ave
N Vermont Ave
S Vermont Ave
N Normandie Ave
S Western Ave
S Wilton Pl
Iolo St
N Rossmore Ave
S Highland Ave
N Fairfax Ave
N Gower St
Hauser Blvd
Crenshaw Blvd
S La Brea Ave
Arlington Ave
Overhill Dr
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110
101
10
710
60
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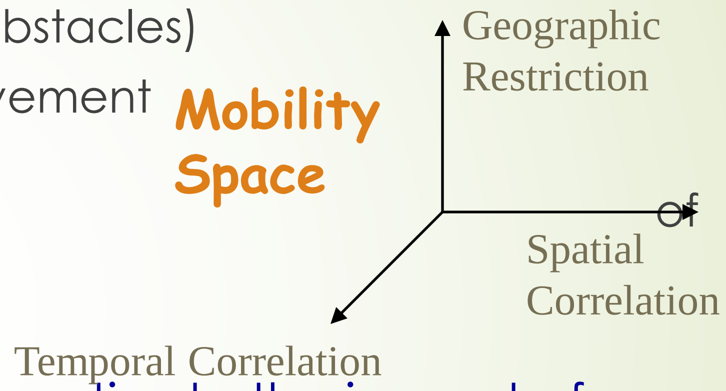

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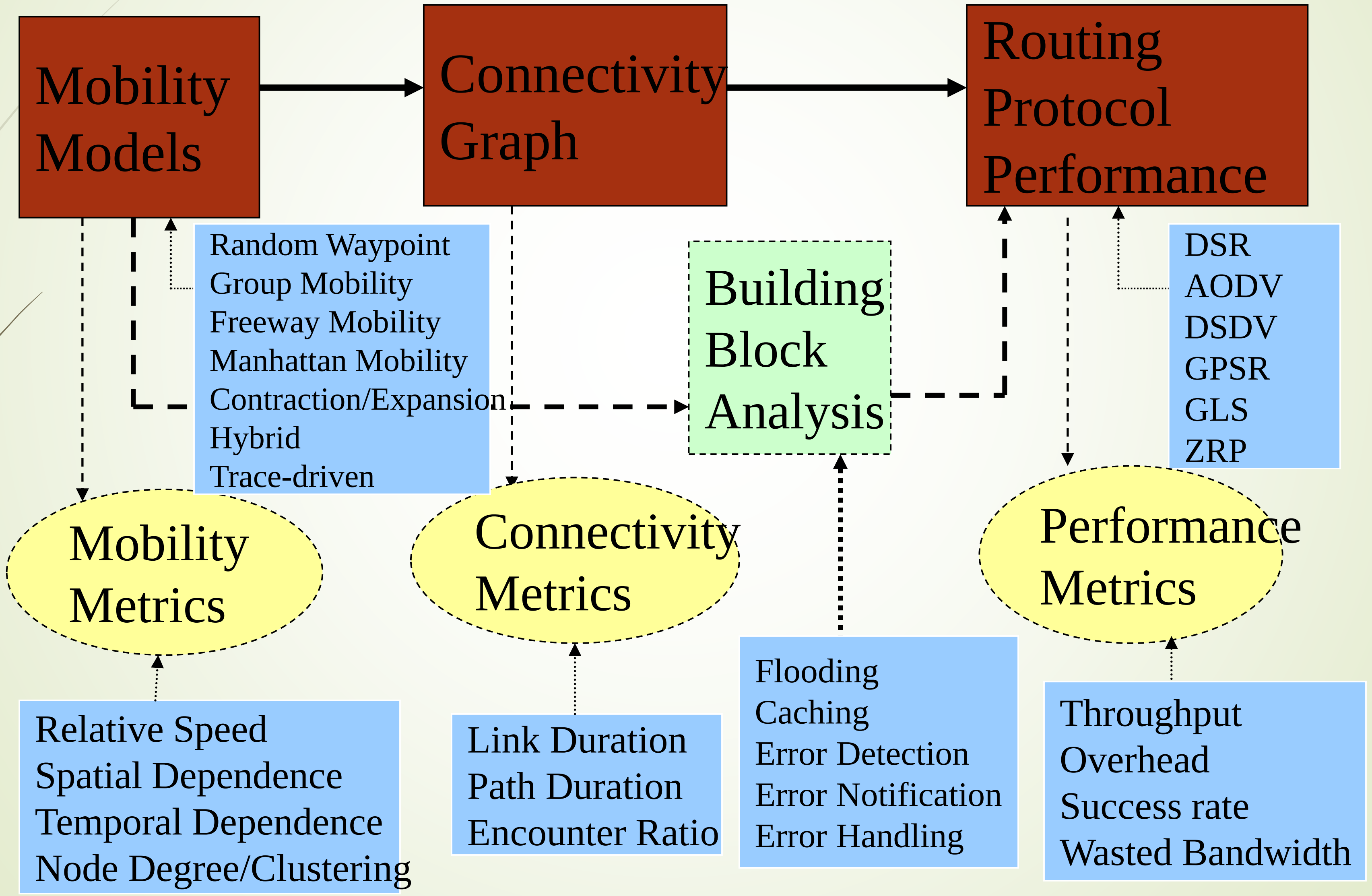


Mobility Metrics

- Relative Speed (mobility metric I)
  - The magnitude of relative speed of two nodes, averaged over all neighborhood pairs and all time

$$\overline{RS} = \frac{1}{P}\sum_{t=0}^{T}\sum_{i=1}^{N}\sum_{\substack{j=1 \\ j\neq i}}^{N} |\vec{v}(i,t) - \vec{v}(j,t)| \quad if\ dist((x_i, y_i),(x_j, y_j)) \leq 2R$$

- Spatial Dependence (mobility metric II)
  - The value of extent of similarity of the velocities/dir of two nodes that are not too far apart, averaged over all neighborhood pairs and all time

$$\overline{D}_{spatial} = \frac{1}{P}\sum_{t=0}^{T}\sum_{i=1}^{N}\sum_{\substack{j=1 \\ j\neq i}}^{N} \frac{\min(\vec{v}(i,t),\vec{v}(j,t))}{\max(\vec{v}(i,t),\vec{v}(j,t))} \times \frac{\vec{v}(i,t)\bullet\vec{v}(j,t)}{|\vec{v}(i,t)\|\vec{v}(j,t)|} \quad if\ dist((x_i, y_i),(x_j, y_j)) \leq 2R$$

For example, RWP model, Vmax=30m/s, RS=12.6m/s, Dspatial=0.03

Connectivity Graph Metrics

- Average link duration (connectivity metric I)
  - The value of link duration, averaged over all nodes pairs

$$\overline{L}\overline{D} = \frac{1}{P}\sum_{i=1}^{N}\sum_{\substack{j=1 \\ j\neq i}}^{N} LD(i,j) \quad if\ there\ is\ a\ link\ between\ i\ and\ j$$

  - Link/Path duration distributions (*PATHS* study)

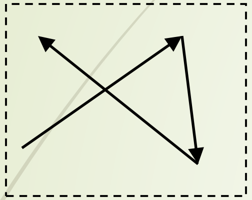
Protocol Performance Metrics

- Throughput: delivery ratio
- Overhead: number of routing control packets sent

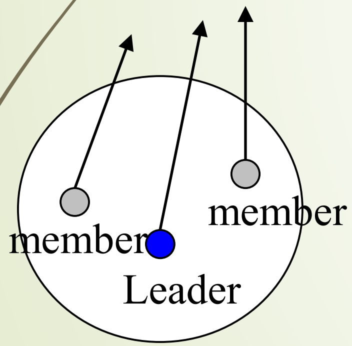
Mobility Models Summary

	Application	Spatial Dependence	Geographic Restriction
Random Waypoint Model	General (uncorrelated straight lines)	No	No
Group Mobility Model	Conventions, Campus	Yes	No
Freeway Mobility Model	Metropolitan Traffic/Vehicular	Yes	Yes
Manhattan Mobility Model	Urban Traffic/Vehicular	No	Yes

Parameterized Mobility Models



- Random Waypoint Model (*RWP*)
  - Each node chooses a random destination and moves towards it with a random velocity chosen from [0, *Vmax*]. After reaching the destination, the node stops for a duration defined by the "pause time" parameter. This procedure is repeated until simulation ends
  - Parameters: Pause time *T*, max velocity *Vmax*



- Reference Point Group Model (*RPGM*)
  - Each group has a logical center (group leader) that determines the group's motion behavior
  - Each nodes within group has a speed and direction that is derived by randomly deviating from that of the group leader

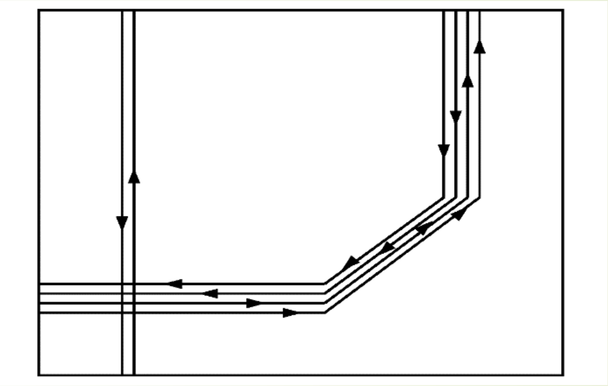
$$|\vec{V}_{member}(t)| = |\vec{V}_{leader}(t)| + random() \times SDR \times V_{\max}$$

$$\theta_{member}(t) = \theta_{leader}(t) + random() \times ADR \times \theta_{\max}$$

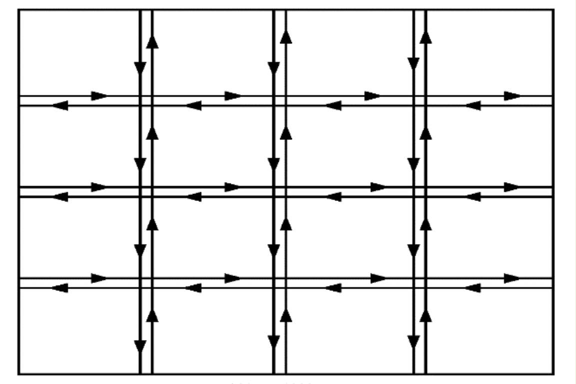
  - Parameters: Angle Deviation Ratio(*ADR*) and Speed Deviation Ratio(*SDR*), number of groups, max velocity *Vmax*. In our study, *ADR*=*SDR*=0.1
  - In our study, we use two scenarios: Single Group (*SG*) and Multiple Group (*MG*)

Parameterized Mobility Models

- Freeway Model (*FW*)
  - Each mobile node is restricted to its lane on the freeway
  - The velocity of mobile node is temporally dependent on its previous velocity
  - If two mobile nodes on the same freeway lane are within the Safety Distance (SD), the velocity of the following node cannot exceed the velocity of preceding node
  - Parameter: Map layout, *Vmax*
- Manhattan Model (*MH*)
  - Similar to Freeway model, but it allows node to make turns at each corner of street
  - Parameter: Map layout, *Vmax*



Map for FW



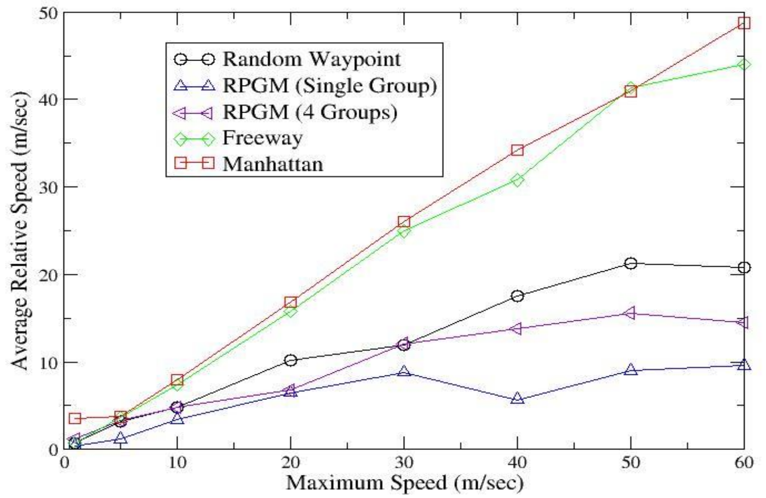
Map for MH

Experiment I: Analysis of mobility characteristics

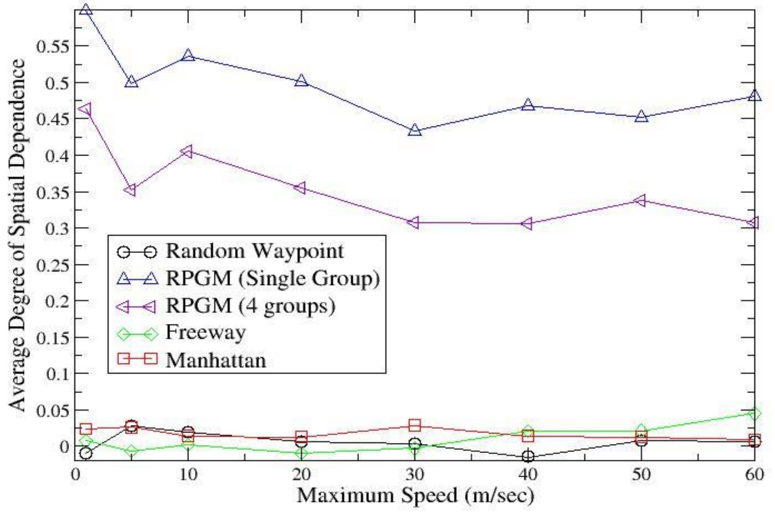
- *IMPORTANT* mobility tool
  - integrated with NS-2 (released Jan '04, Aug '05)
  - *http://nile.cise.ufl.edu/important*
- Simulation done using our mobility generator and analyzer
  - Number of nodes(*N*) = 40, Simulation Time(*T*) = 900 sec
  - Area = 1000m x 1000m
  - *Vmax* set to 1,5,10,20,30,40,50,60 m/sec across simulations
  - *RWP*, pause time T=0
  - *SG/MG*, ADR=0.1, SDR=0.1
  - *FW/MH*, map layout in the previous slide

Mobility metrics

- Objective:
  - validate whether proposed mobility models span the mobility space we explore
- Relative speed
  - For same *Vmax*, *MH/FW* is higher than *RWP*, which is higher than *SG/MG*
- Spatial dependence
  - For *SG/MG*, strong degree of spatial dependence
  - For *RWP/FW/MH*, no obvious spatial dependence is observed



Relative Speed

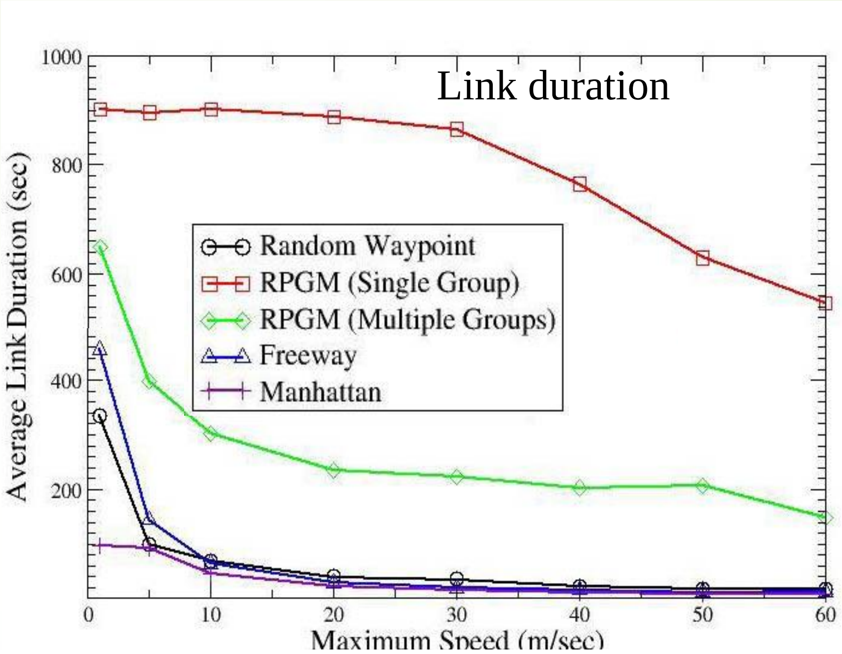


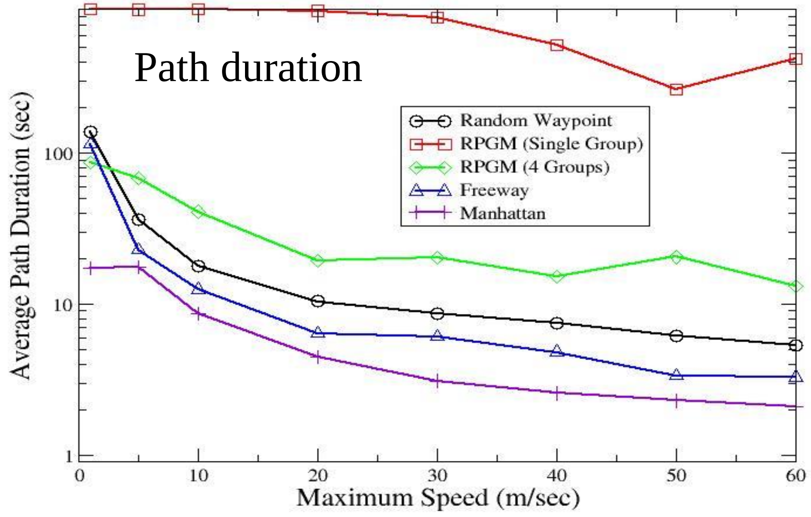
Spatial Dependence

Connectivity Graph Metrics

- Link duration
  - For same Vmax, SG/MG is higher than RWP, which is higher than FW, which is higher than MH
- Summary
  - Freeway and Manhattan model exhibits a high relative speed
  - Spatial Dependence for group mobility is high, while it is low for random waypoint and other models
  - Link Duration for group mobility is higher than Freeway, Manhattan and random waypoint

- Similar observations for Path duration





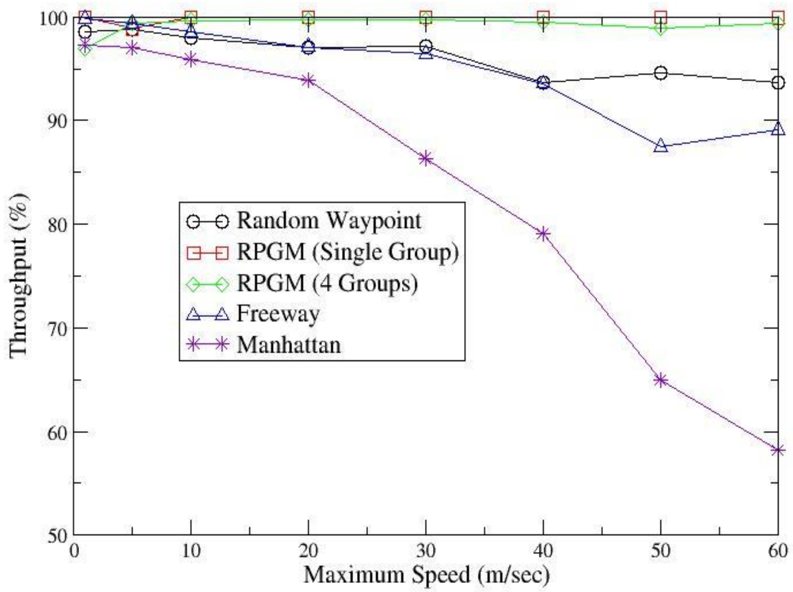
Experiment II: Protocol Performance across Mobility Models

Simulations done in *ns*-2:

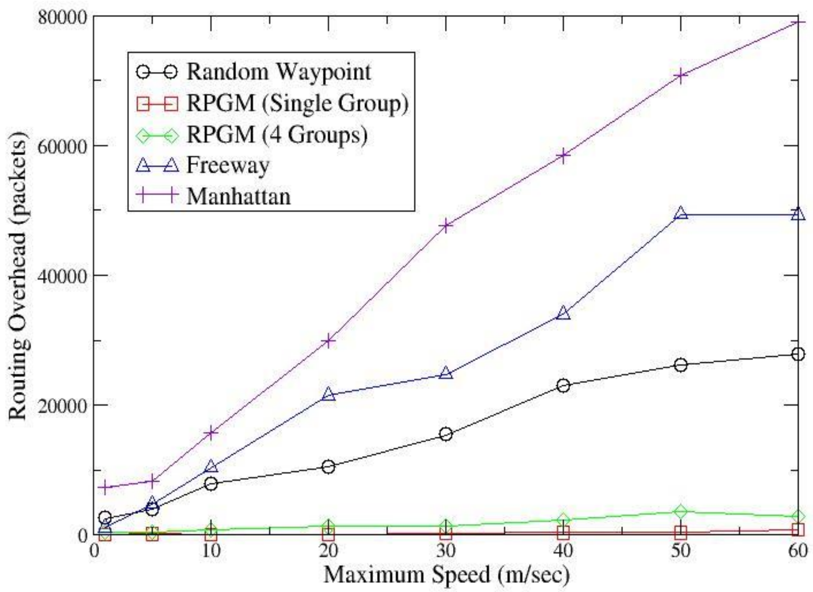
- Routing protocols: DSR, AODV, DSDV
- Same set of mobility trace files used in experiment1
- Traffic pattern consists of source-destination pairs chosen at random
- 20 source, 30 connections, *CBR* traffic
- Data rate is 4packets/sec (low data rate to avoid congestion)
- For each mobility trace file, we vary traffic patterns and run the simulations for 3 times

Results and Observations

- Performance of routing protocols may vary drastically across mobility patterns (Example for DSR)



Throughput

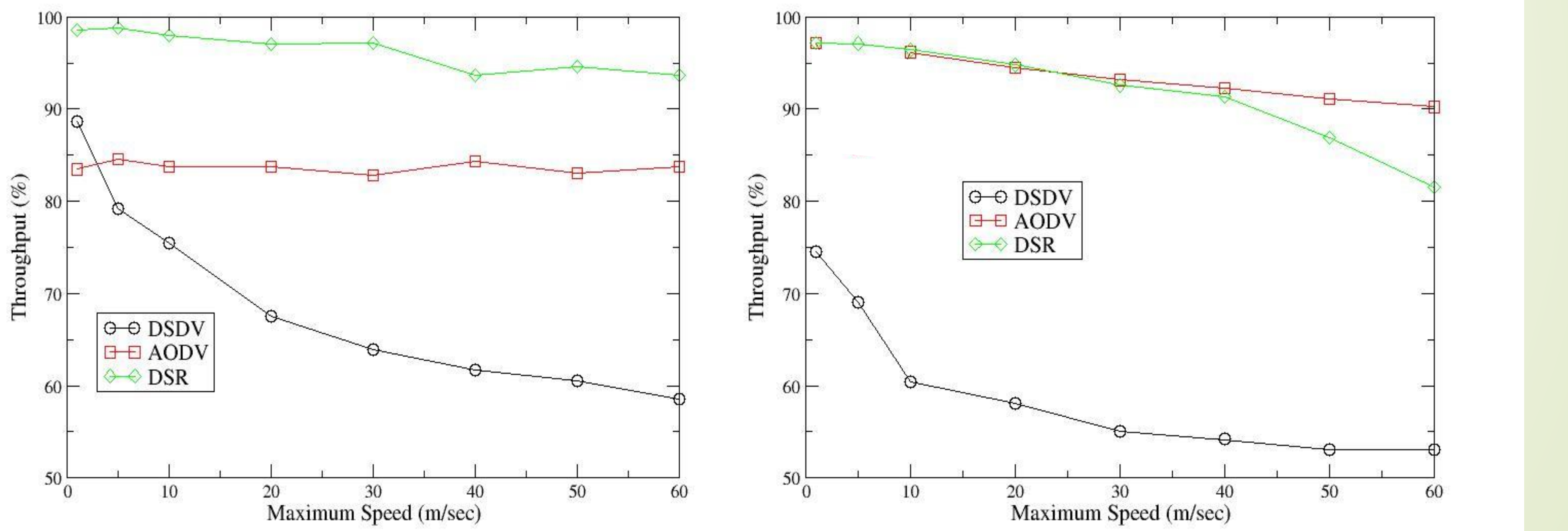


Routing Overhead

- There is a difference of 40% for throughput and an order of magnitude difference for routing overhead across mobility models!

Which Protocol Has the Highest Throughput ?

- We observe that using different mobility models may alter the ranking of protocols in terms of the throughput!

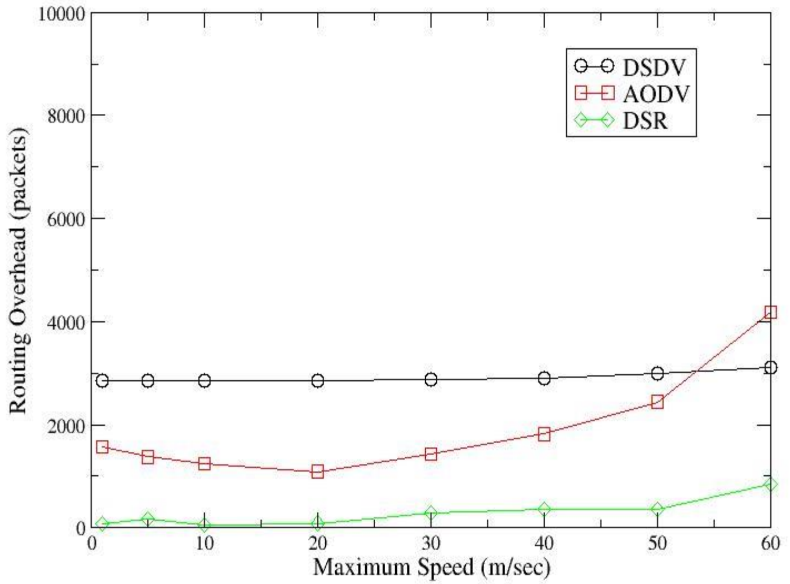


Random Waypoint : DSR

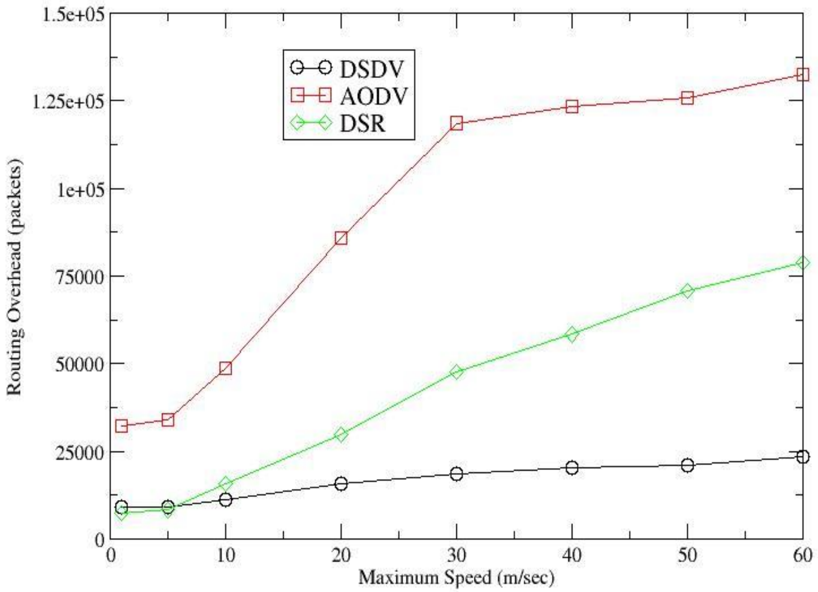
Manhattan : AODV !

Which Protocol Has the Lowest Overhead ?

- We observe that using different mobility models may alter the ranking of protocols in terms of the routing overhead!



RPGM(single group) : DSR



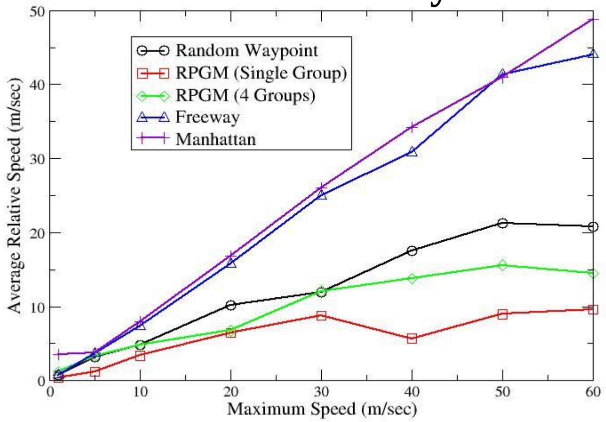
Manhattan : DSDV

Putting the Pieces Together

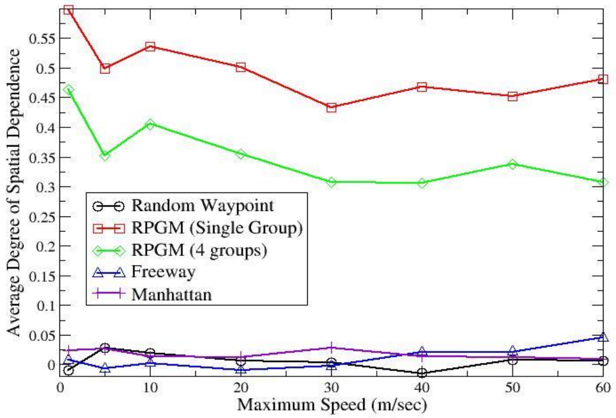
- *Why* does mobility affect protocol performance?
- We observe a very clear trend between mobility metric, connectivity and performance
  - With similar average spatial dependency
    - Relative Speed increases→ Link Duration decreases→ Routing Overhead increases and throughput decreases
  - With similar average relative speed
    - Spatial Dependence increase →Link Duration increases→Throughput increases and routing overhead decreases
- Conclusion: **Mobility Metrics influence Connectivity Metrics which in turn influence protocol performance metrics !**

Putting the Pieces Together

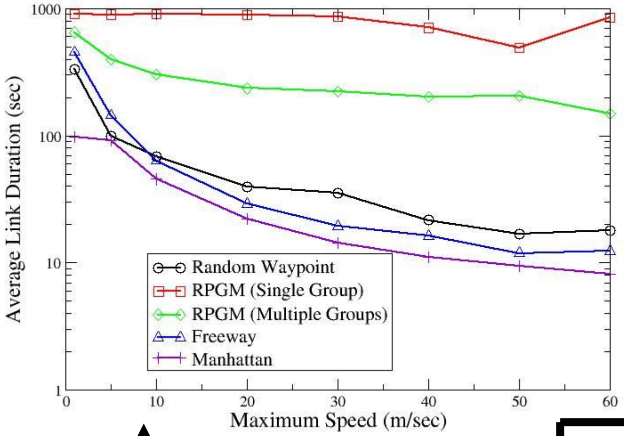
Relative Velocity



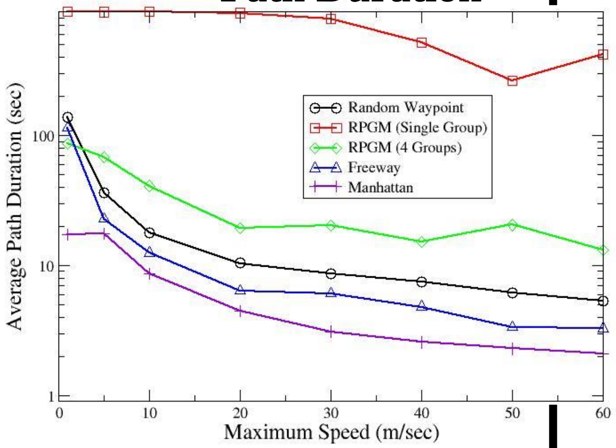
Spatial Dependence



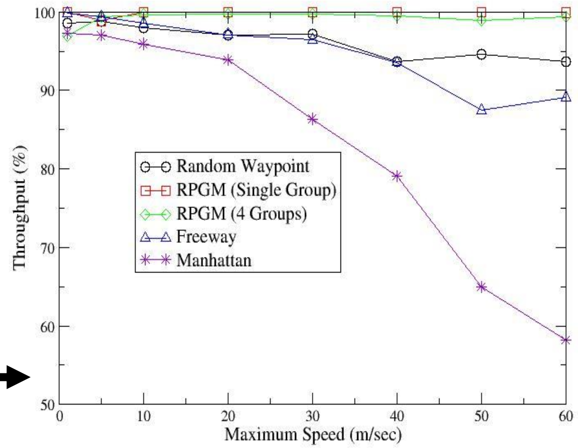
Link Duration



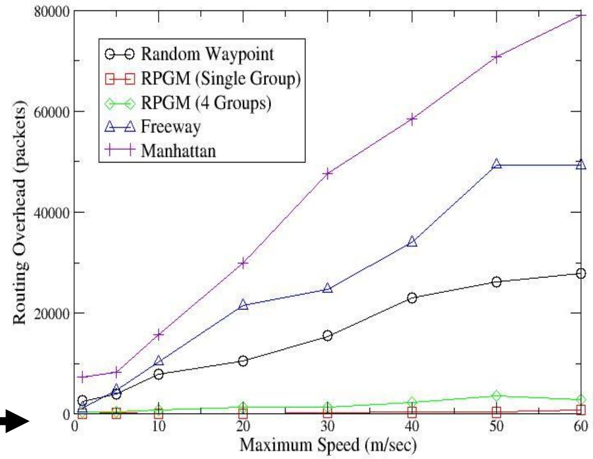
Path Duration



Throughput



Overhead



Mechanistic Building Blocks (BRICS) *

- *How* does mobility affect the protocol performance?
- Approach:
  - The protocol is decomposed into its constituent mechanistic, parameterized building block, each implements a well-defined functionality
  - Various protocols choose different parameter settings for the same building block. For a specific mobility scenario, the building block with different parameters behaves differently, affecting the performance of the protocol
- We are interested in the contribution of building blocks to the overall performance in the face of mobility
- Case study:
  - Reactive protocols (e.g., DSR and AODV)

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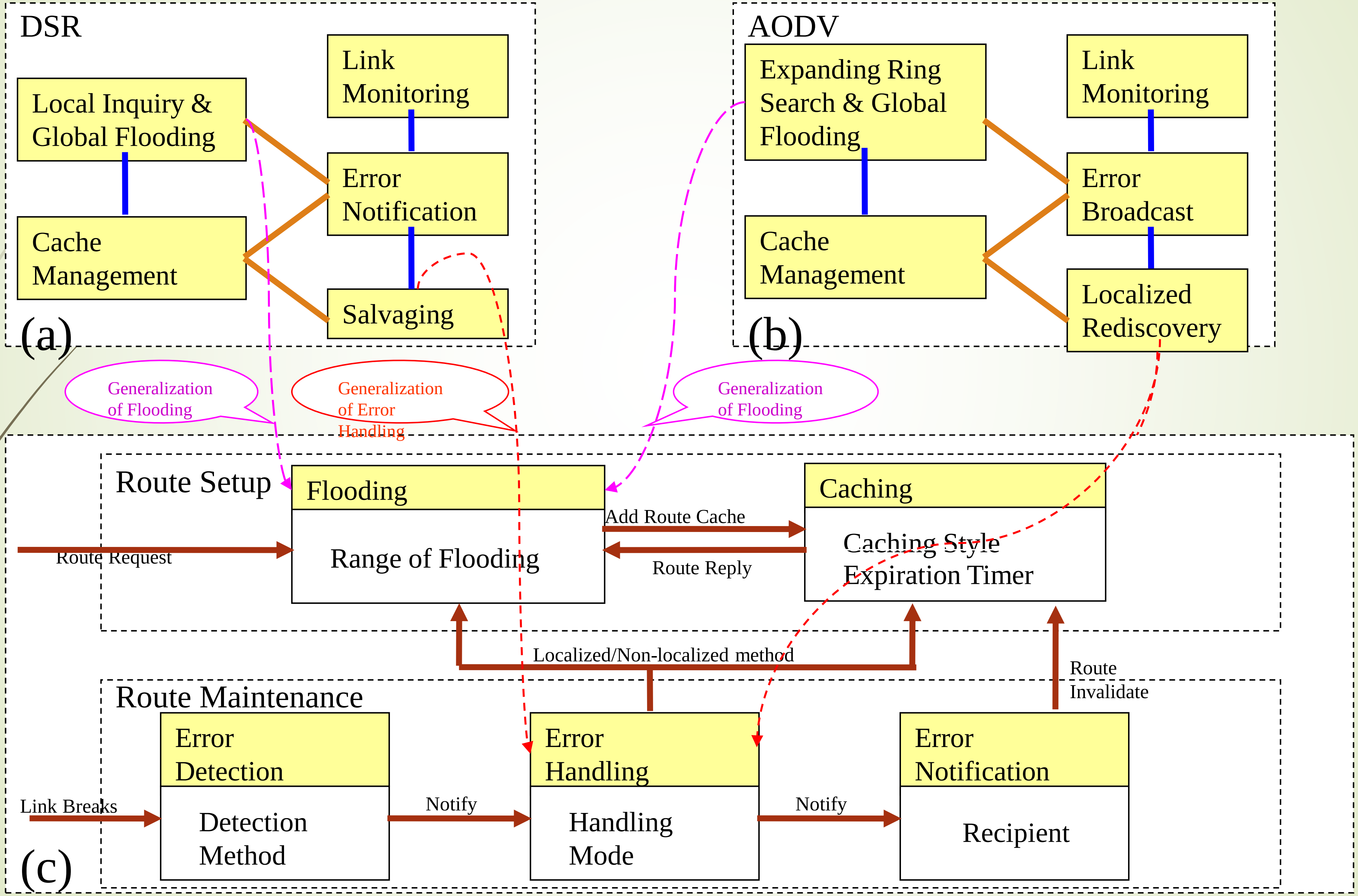
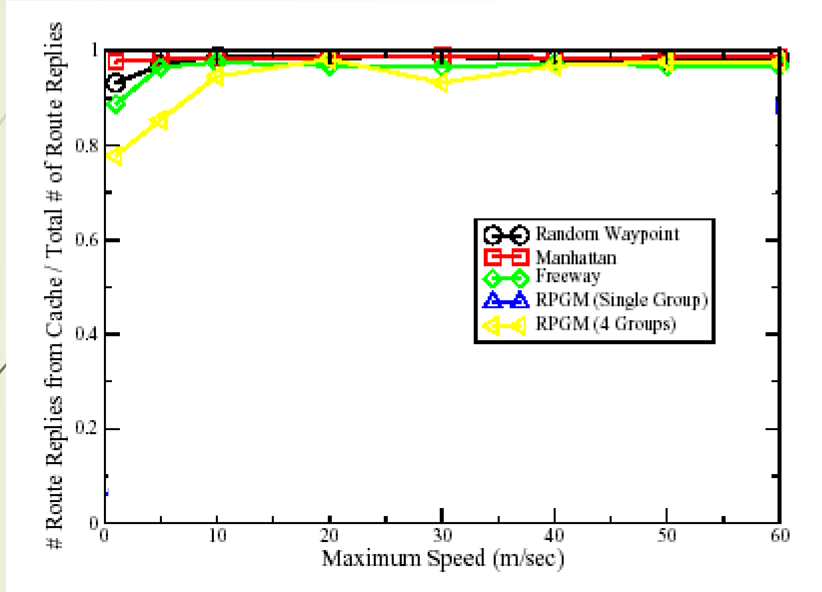
* F. Bai, N. Sadagopan, A. Helmy, "*BRICS*: A Building-block approach for analyzing RoutIng protoCols in Ad Hoc Networks - A Case Study of Reactive Routing Protocols", *IEEE International Conference on Communications (ICC)*, June 2004.

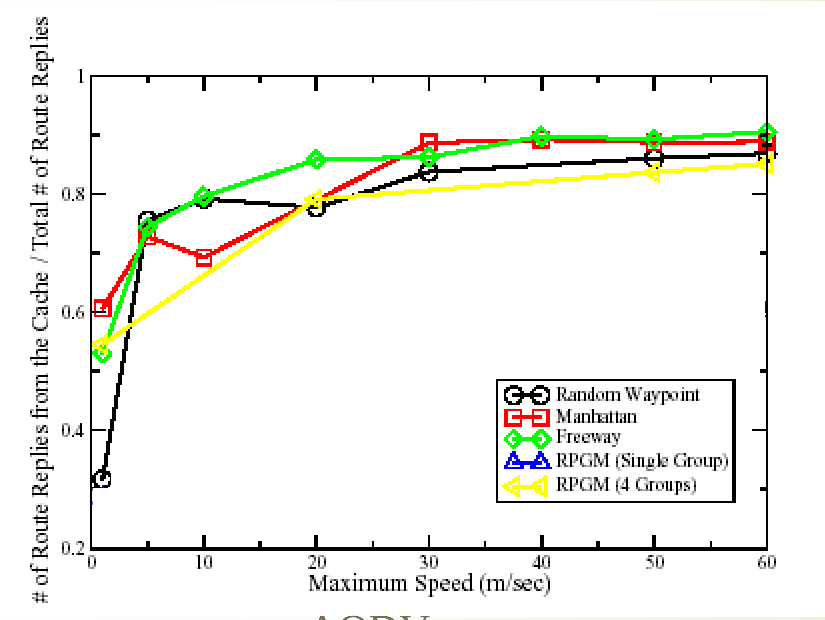
Building Block Diagram for reactive protocols



How useful is caching?



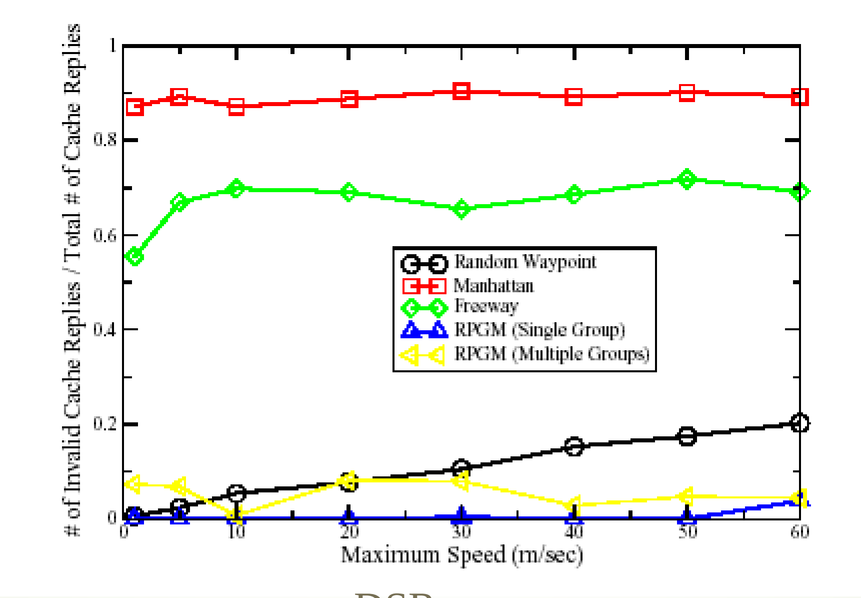
DSR



AODV

- In RW, FW and MH model, most of route replies come from the cache, rather than destination (>80% for DSR, >60% for AODV in most cases)
- The difference in the route replies coming from cache between DSR and AODV is greater than 20% for all mobility models, maybe because of caching mode

Is aggressive caching always good?



DSR

- The invalid cached routes increase from RPGM to RW to FW to MH mobility models
- Aggressive Caching may have adverse effect at high mobility scenarios!

Conclusions

- Mobility patterns are very *IMPORTANT* in evaluating performance of ad hoc networks
- A rich set of mobility models is needed for a good evaluation framework.
- *Richness* of those models should be evaluated using quantitative mobility metrics.

- Observation
  - In the previous study only 'average' link duration was considered.
  - Are we missing something by looking only at averages?
  - Next: We conduct the PATHS study to investigate statistics and distribution of link and path duration.

Duration Statistics and their Impact on Reactive MANET Routing Protocols

Fan Bai, Narayanan Sadagopan,

Bhaskar Krishnamachari, Ahmed Helmy

{fbai, nsadagop, brksihna, helmy}@usc.edu

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* F. Bai, N. Sadagopan, B. Krishnamachari, A. Helmy, "Modeling Path Duration Distributions in MANETs and their Impact on Routing Performance", *IEEE Journal on Selected Areas in Communications (JSAC), Special Issue on Quality of Service in Variable Topology Networks*, Vol. 22, No. 7, pp. 1357-1373, Sept 2004.

•N. Sadagopan, F. Bai, B. Krishnamachari, A. Helmy, "*PATHS*: analysis of PATH duration Statistics and their impact on reactive MANET routing protocols", *ACM MobiHoc*, pp. 245-256, June 2003.

Motivation and Goal

- Mobility affects connectivity (i.e., links), and in turn protocol mechanisms and performance
- It is essential to understanding effects of mobility on link and path characteristics
- In this study:
  - Closer look at the mobility effects on connectivity metrics (statistics of link duration (*LD*) and path duration (*PD*))
  - Develop approximate expressions for *LD* & *PD* distributions (Is it really exponential? When is it exponential?)
  - Develop first order models for Tput & Overhead as *f*(*PD*)

Mobility → Connectivity → Protocol Mechanisms → Performance (Throughput, Overhead)
Connectivity → Performance (Throughput, Overhead)

Connectivity Metrics

- Link Duration (*LD*):
  - For nodes *i,j,* the duration of link *i-j* is the longest interval in which *i* & *j* are directly connected
  - $LD(i,j,t_1)=t_2-t_1$
    - iff $\forall t,\ t_1 \le t \le t_2,\ \exists \in > 0 : X(i,j,t)=1, X(i,j,t_1-\in)=0, X(i,j,t_2+\in)=0$
- Path Duration (*PD*):
  - Duration of path $P=\{n_1,n_2,\ldots,n_k\}$ is the longest interval in which all *k*-1 links exist

$$\mathrm{PD}(P,t_1) = \min_{1\le z\le k-1} \mathrm{LD}(n_z, n_{z+1}, t_1)$$

Simulation Scenarios in *NS*-2

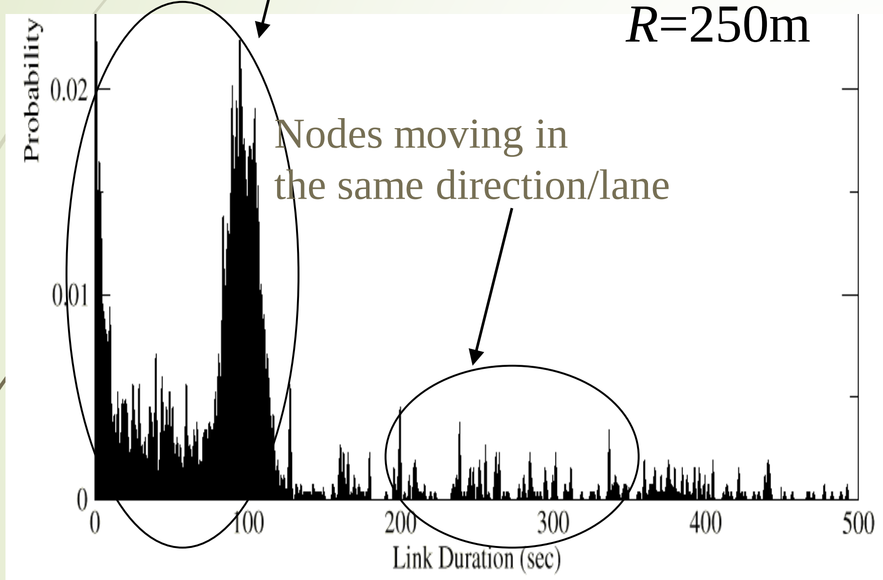
- Path duration computed for the shortest path, at the graph and protocol levels, until it breaks.
- Used the *IMPORTANT* mobility tool:
  - nile.usc.edu/important
- Mobility Parameters
  - *Vmax* = 1,5,10,20,30,40,50,60 m/s,
  - RPGM: 4 groups (RPGM4), Speed/Angle Deviation Ratio=0.1
- 40 nodes, in 1000mx1000m area
- Radio range (*R*)=50,100,150,200,250m
- Simulation time 900sec

Link Duration (*LD*) PDFs

- At low speeds (*Vmax* < 10m/s) link duration has multi-modal distribution for FW and RPGM4
  - In FW due to geographic restriction of the map
    - Nodes moving in *same* direction have *high* link duration
    - Nodes moving in *opposite* directions have *low* link duration
  - In RPGM4 due to correlated node movement
    - Nodes in *same* group have *high* link duration
    - Nodes in *different* groups have *low* link duration
- At higher speeds (*Vmax* > 10m/s) link duration does *not* exhibit multi-modal distribution
- Link duration distribution is *NOT* exponential

FW model
Vmax=5m/s
R=250m

Nodes moving in opposite directions

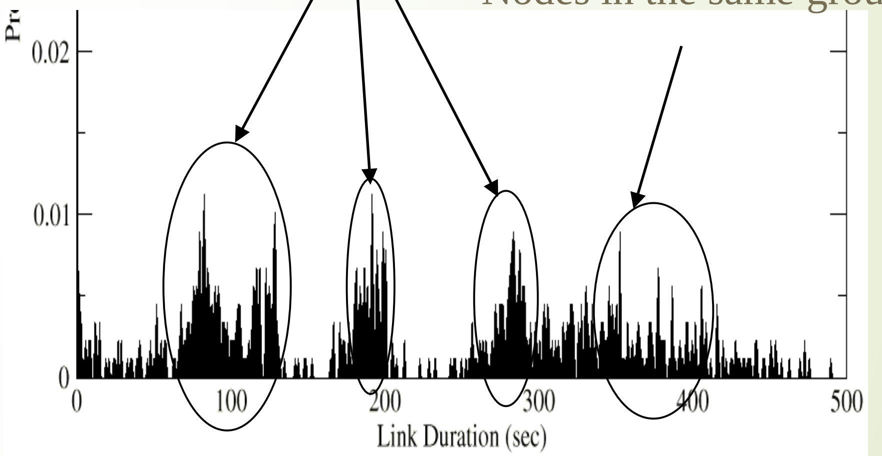


Multi-modal Distribution of Link Duration for Freeway model at low speeds

RPGM w/ 4 groups
Vmax=5m/s
R=250m

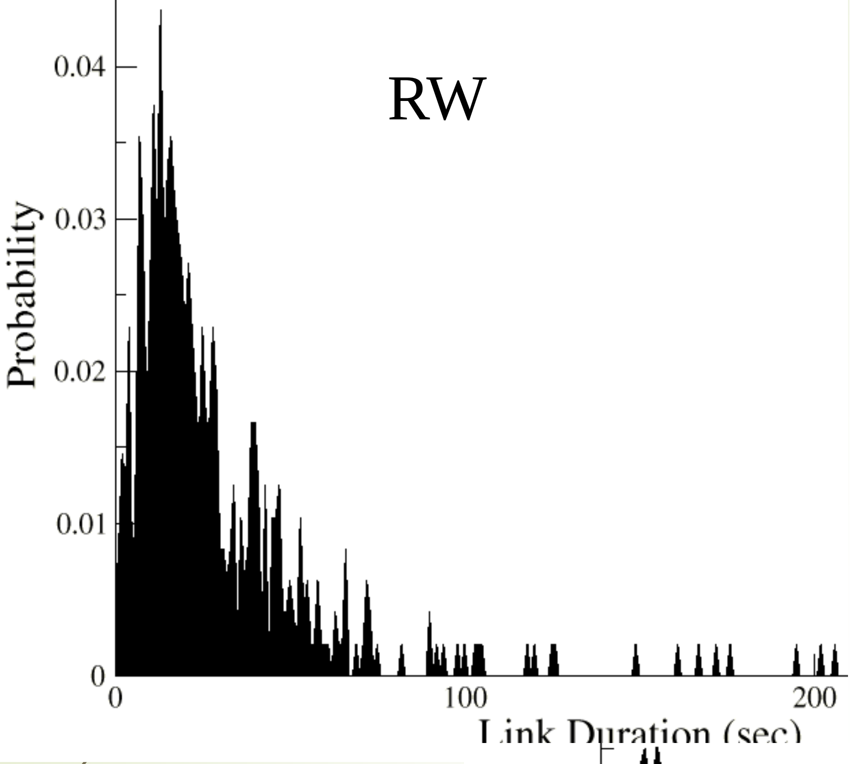
Nodes in different groups

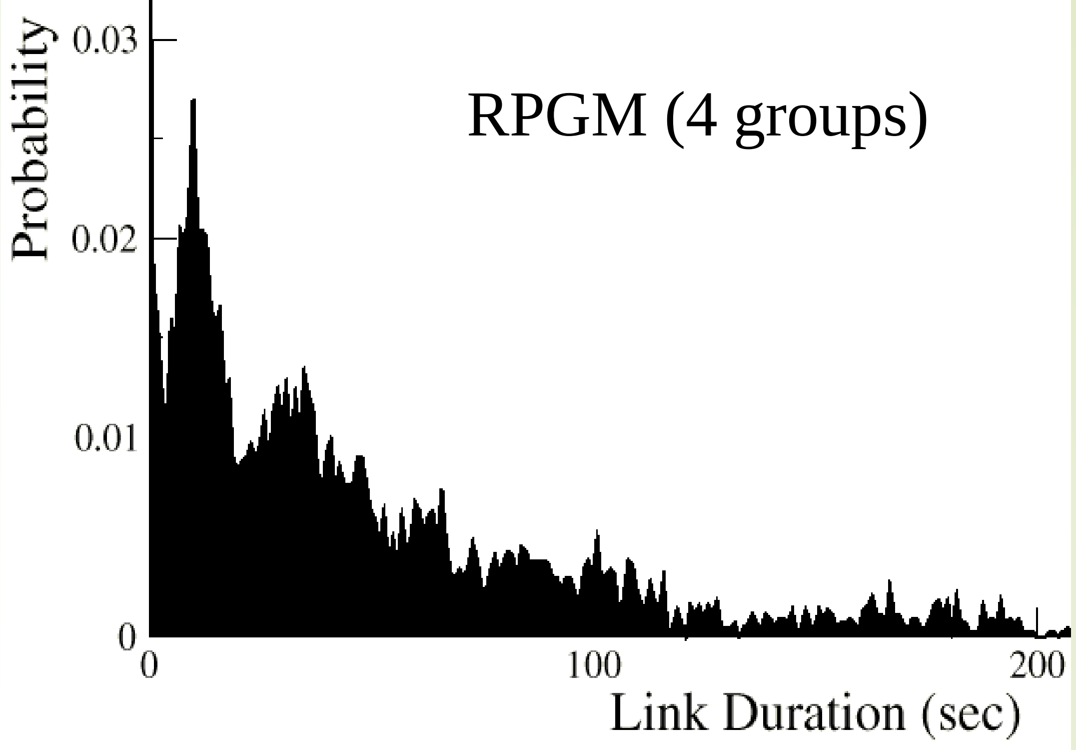
Nodes in the same group

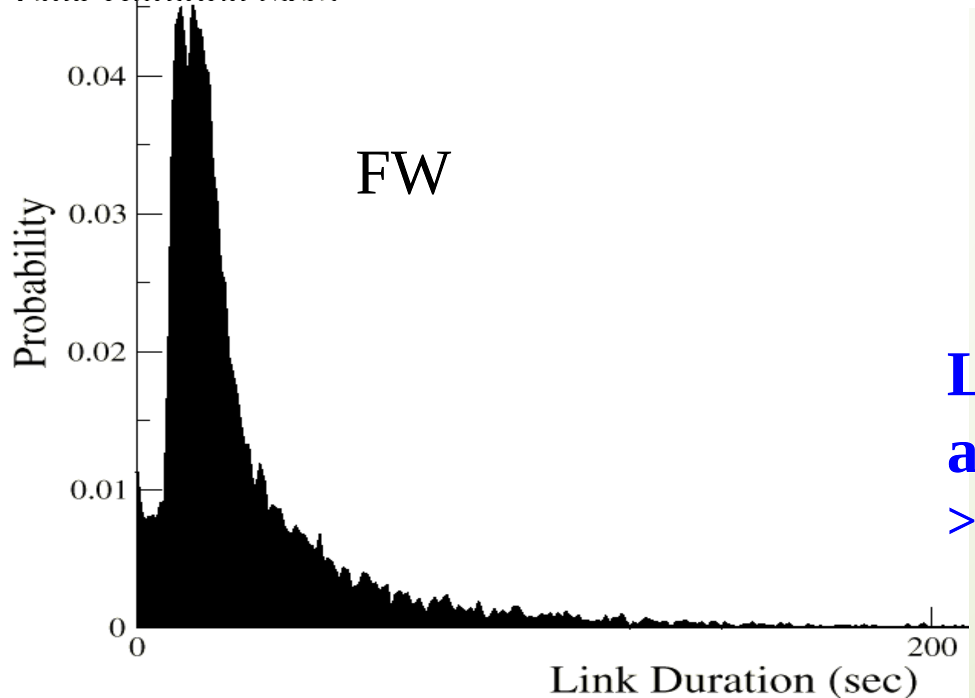


Multi-modal Distribution of Link Duration for RPGM4 model at low speeds

Link Duration (*LD*) distribution at low speeds < 10m/s







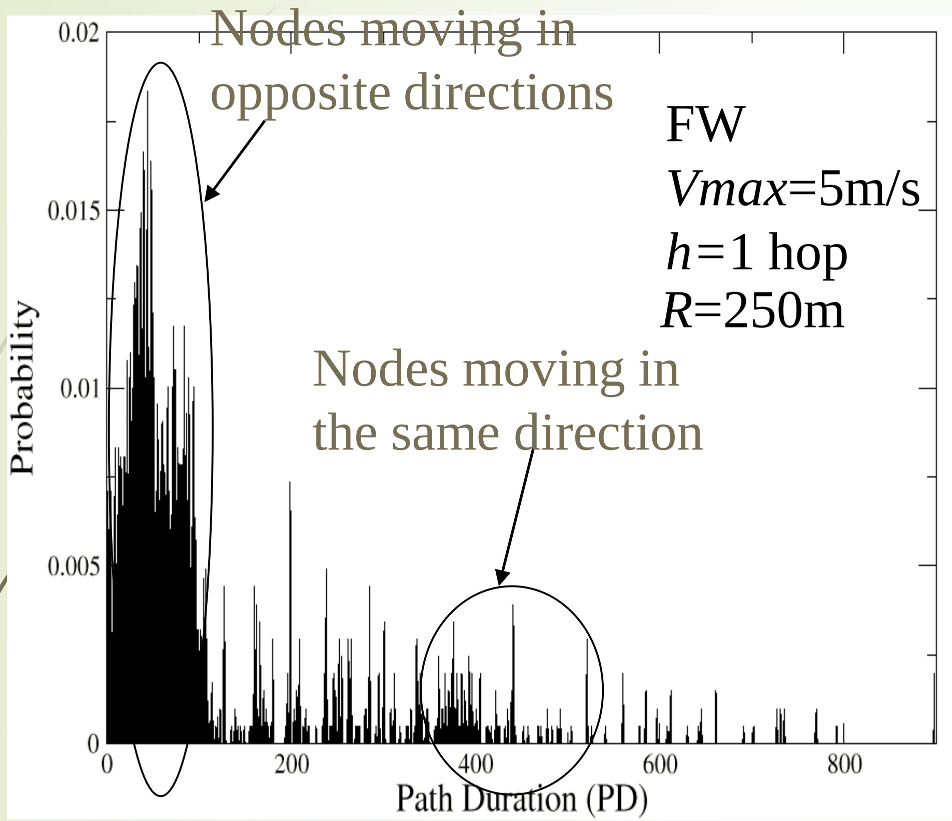
Vmax=30m/s
R=250m

Link Duration at high speeds
> 10m/s

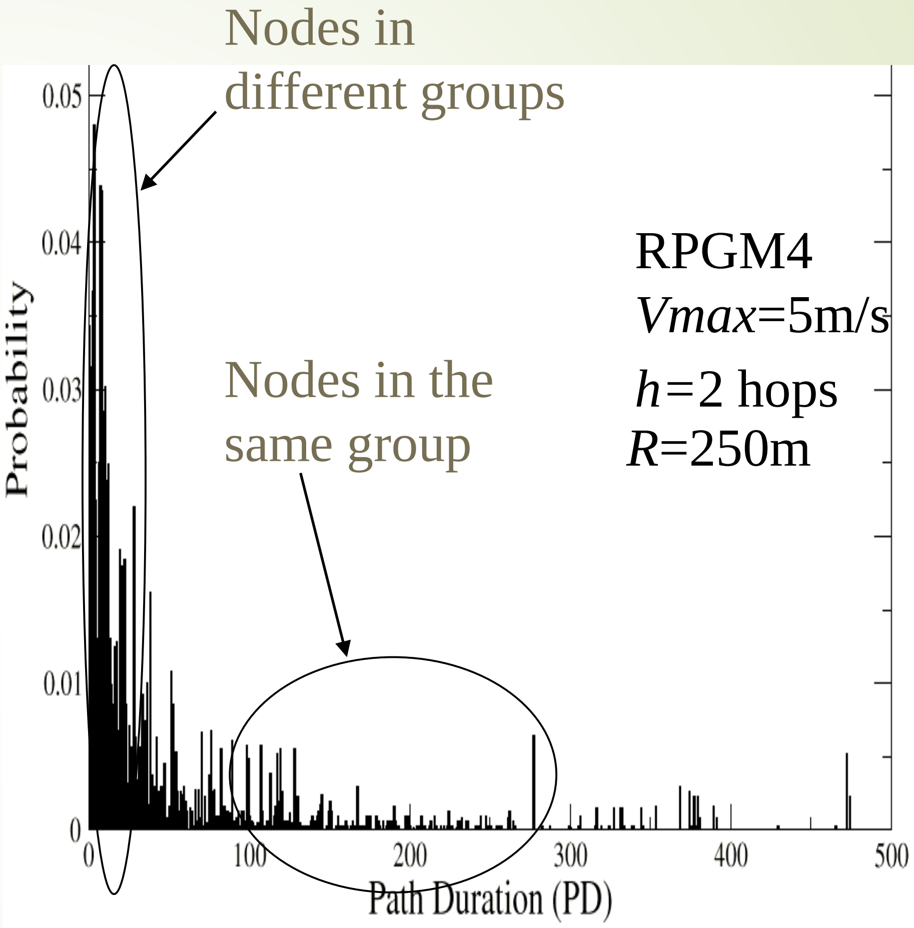
Not Exponential !!

Path Duration (*PD*) PDFs

- At low speeds (*Vmax* < 10m/s) and for short paths ($h \leq 2$) path duration has multi-modal for FW and RPGM4
- At higher speeds (*Vmax* > 10m/s) and longer path length ($h \geq 2$) path duration can be reasonably approximated using *exponential* distribution for RW, FW, MH, RPGM4.

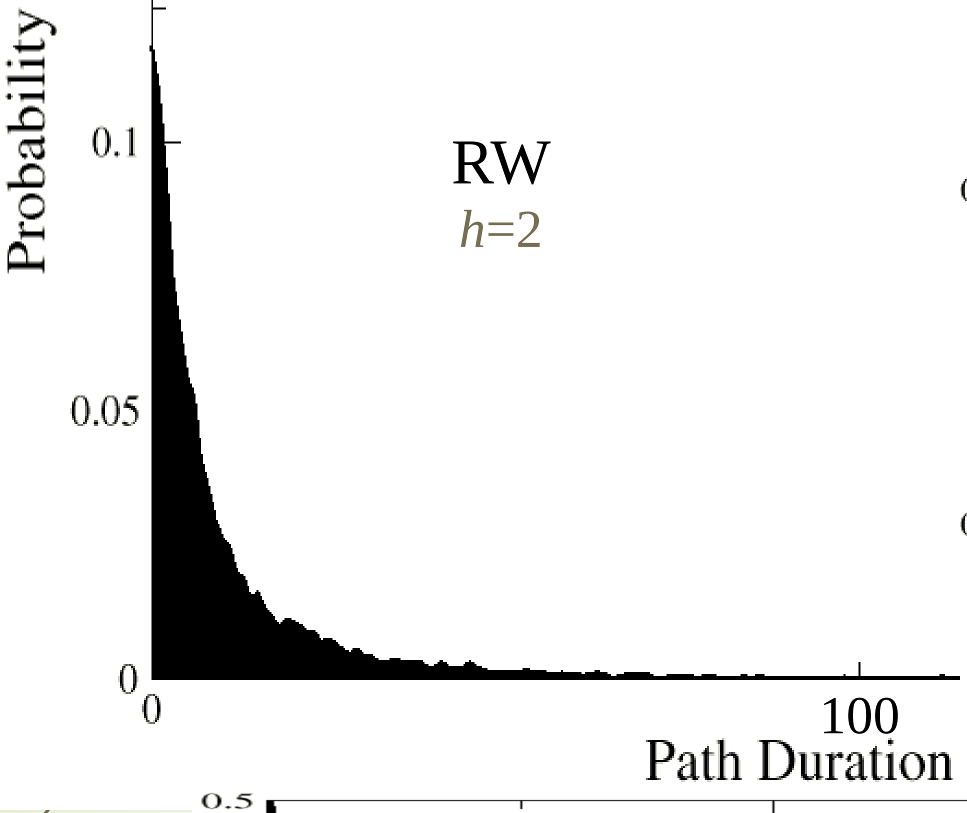


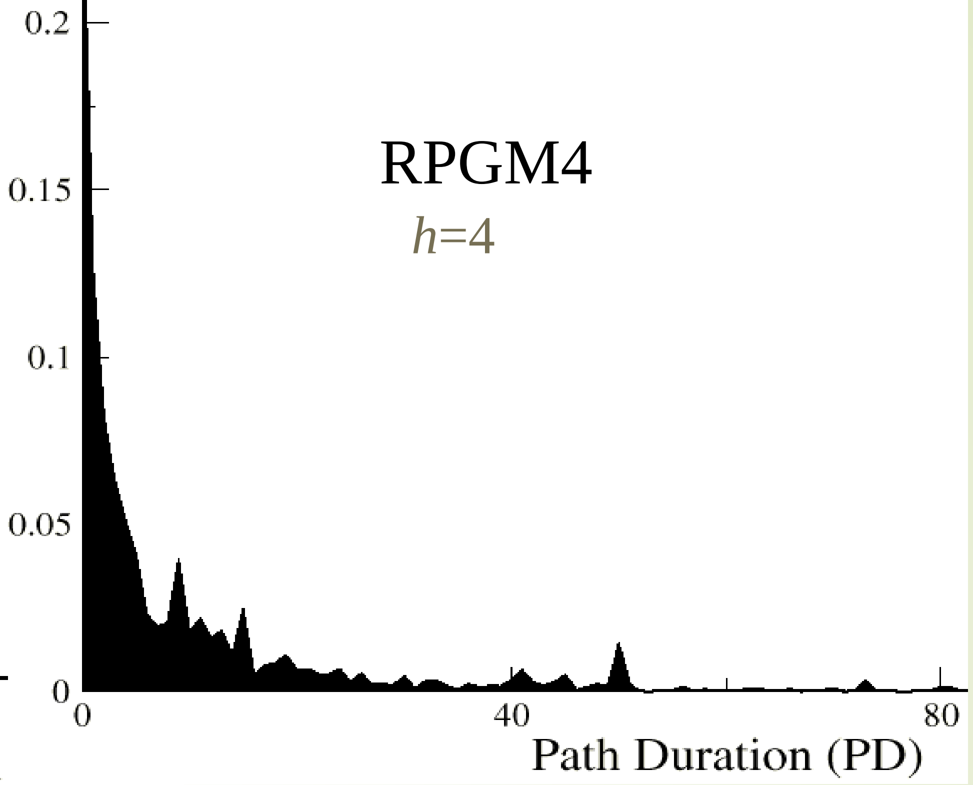
Multi-modal Distribution of Path Duration for Freeway model at low speeds, low hops

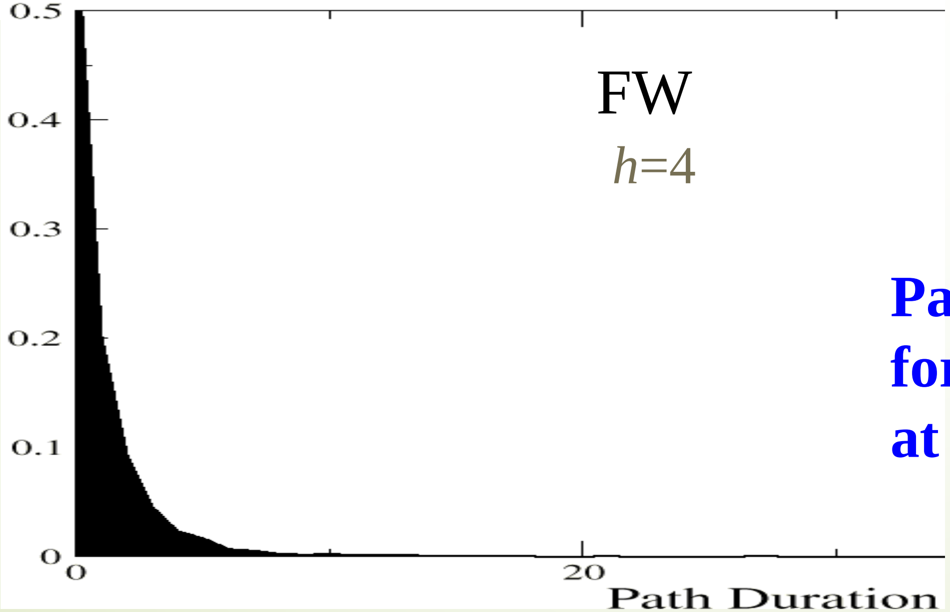


Multi-modal Distribution of Path Duration for RPGM4 model at low speeds, low hops

Path Duration (*PD*) distribution for short paths at low speeds < 10m/s





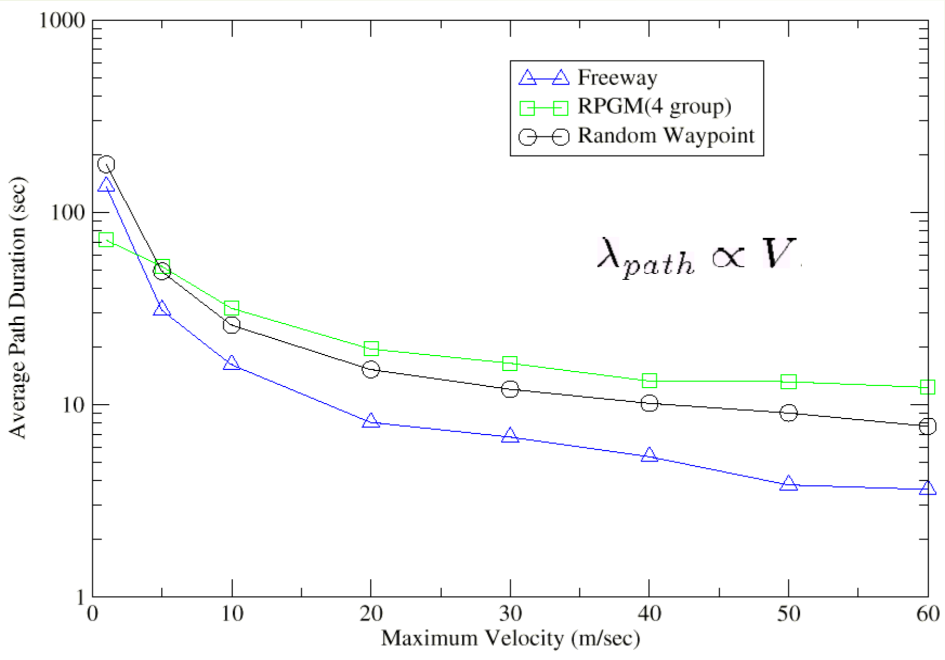


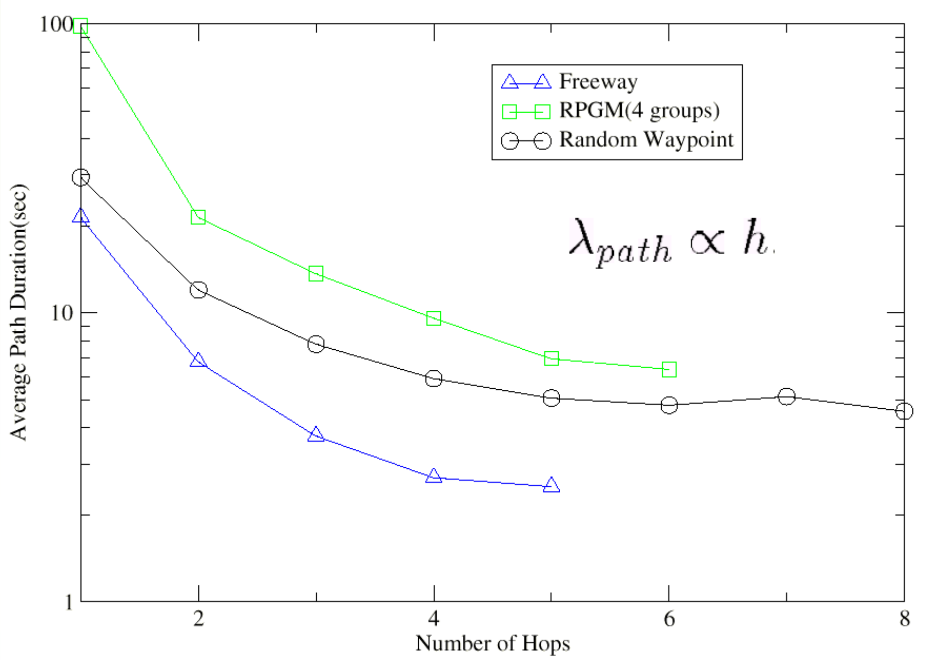
Vmax=30m/s
R=250m

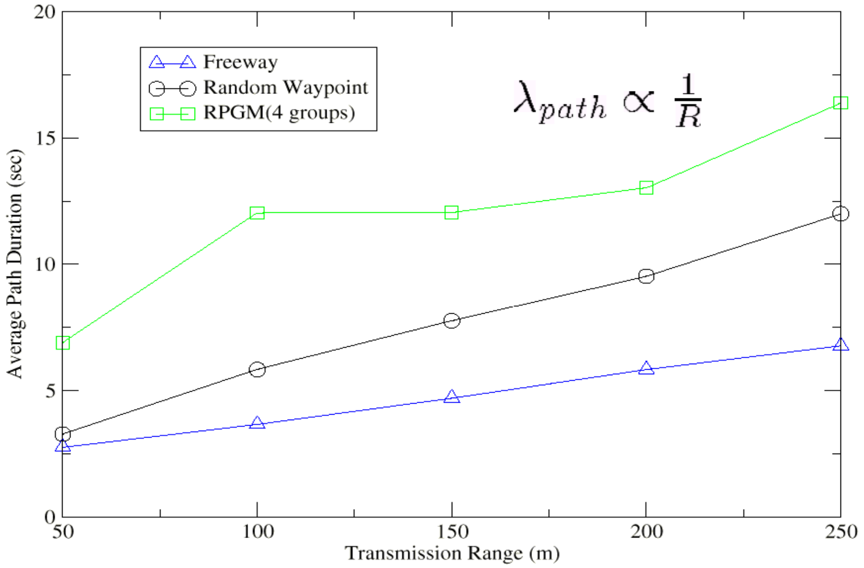
Path Duration (*PD*) distribution for long paths (≥ 2 hops) at high speeds (> 10m/s)

Exponential Model for Path Duration (*PD*)

- Let λ_{path} be the parameter for exponential *PD* distribution:
  - *PD* PDF $f(x) = \lambda_{path}\, e^{-\lambda path\ x}$
  - As λ_{path} increases average *PD* decreases (and vice versa)
- Intuitive qualitative analysis:
  - *PD=f(V,h,R); V* is relative velocity, *h* is path hops & *R* is radio range
  - As *V* increases, average *PD* decreases, i.e., λ_{path} increases
  - As *h* increases, average *PD* decreases, i.e., λ_{path} increases
  - As *R* increases, average *PD* increases, i.e., λ_{path} decreases
- Validate intuition through simulations







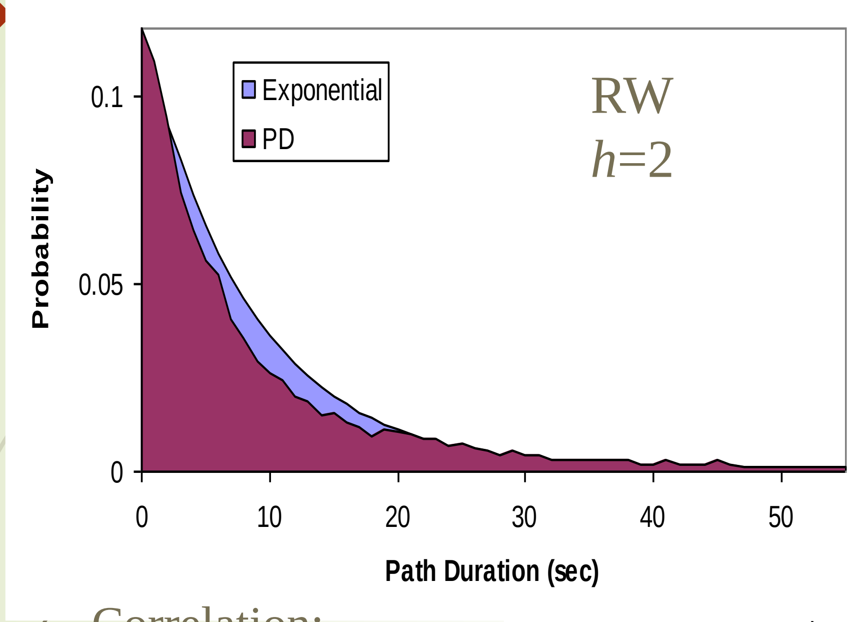
Exponential Model for *PD*

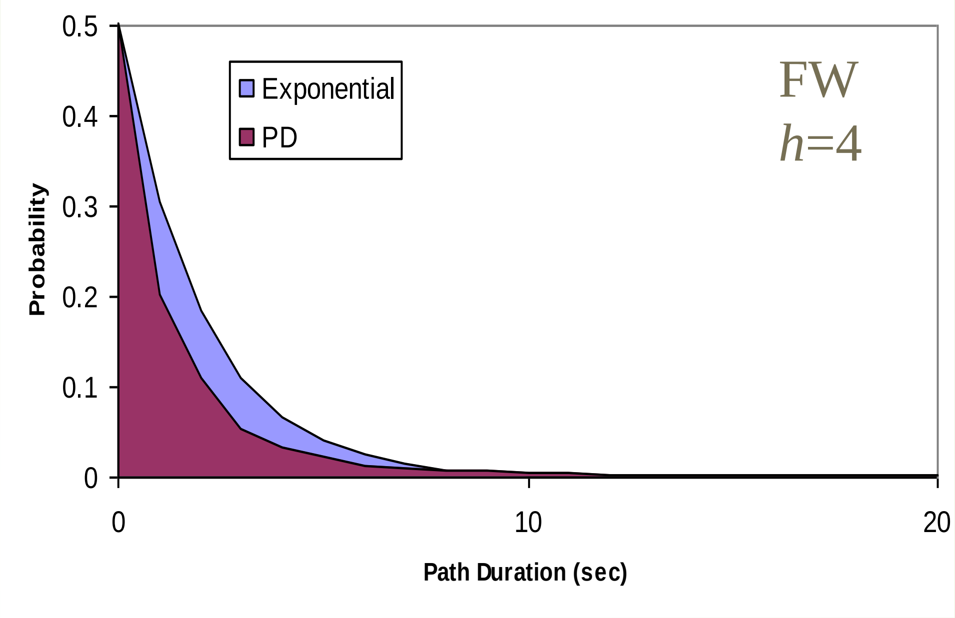
$\boxed{\lambda_{path} \propto h}$ $\boxed{\lambda_{path} \propto V}$ $\boxed{\lambda_{path} \propto \frac{1}{R}}$

$$\lambda_{path} = \lambda_0 \frac{hV}{R}$$

But, *PD* PDF $f(x) = \lambda_{path}\, e^{-\lambda_{path}\, x}$

$$\boxed{f(x) = \frac{\lambda_0 hV}{R} e^{\frac{-\lambda_0 hV}{R} x}}$$

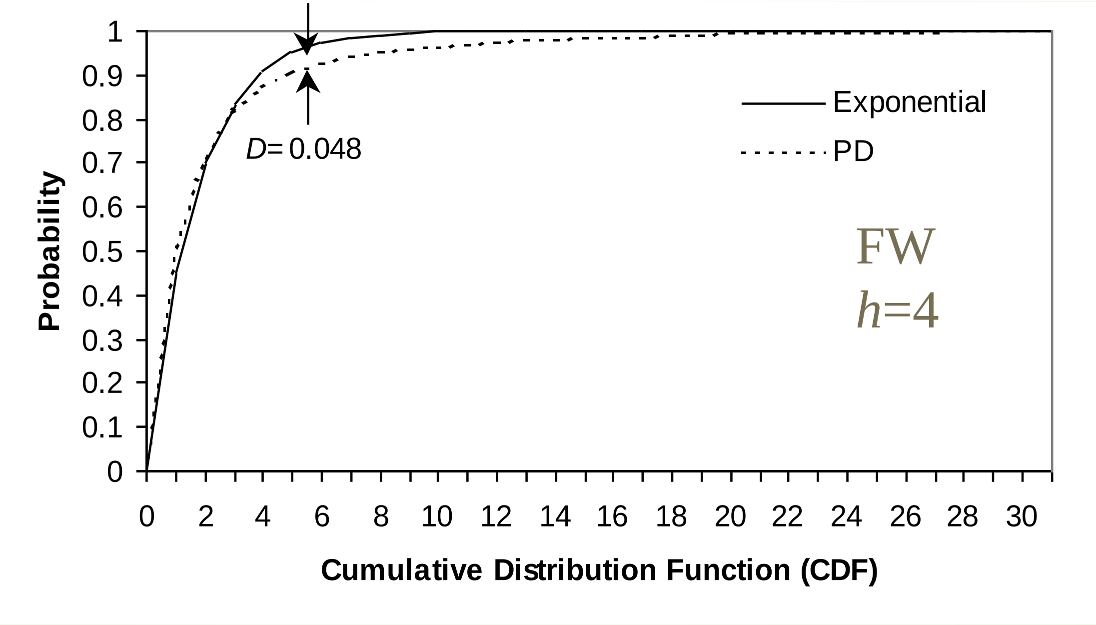




- Correlation: 94.1-99.8%

- Goodness-of-fit Test

	K-S test
RW	0.04-0.065
FW	0.045-0.085
RPGM	0.09-0.12



Vmax=30m/s

R=250m

Effect of Path Duration (*PD*) on Performance: Case Study for DSR

- *PD* observed to have significant effect on performance
- (I) Throughput: First order model
  - *T*: simulation time, *D*: data transferred, T_{flow}: data transfer time, T_{repair}: total path repair time, t_{repair}: av. path repair time, *f*: path break frequency

$$Throughput = \frac{D}{T}$$

$$T = T_{flow} + T_{repair} = T_{flow} + t_{repair}.f.T = T_{flow} + t_{repair}.\frac{1}{PD}.T \quad \Rightarrow \quad T = \frac{T_{flow}}{(1-\frac{t_{repair}}{PD})}$$

$$\boxed{Throughput = (1-\frac{t_{repair}}{PD})\frac{D}{T_{flow}} = (1-\frac{t_{repair}}{PD}).rate} \quad \Rightarrow \quad \boxed{Throughput \alpha (-\frac{1}{PD})}$$

Effect of *PD* on Performance (contd.)

- (II) Overhead: First order model
  - Number of DSR route requests= $\frac{T}{PD}$
  - *p*: non-propagating cache hit ratio, *N*: number of nodes

$$\boxed{Overhead = \frac{T}{PD}((p)1 + (1-p)N)} \Rightarrow \boxed{Overhead \, \alpha \, \frac{1}{PD}}$$

- Evaluation through *NS-2* simulations for DSR

	Random Waypoint (RW)	Freeway (FW)	Manhattan (MH)
Throughput	-0.9165	-0.9597	-0.9132
Overhead	0.9753	0.9812	0.9978

Pearson coefficient of correlation (ρ) with $\frac{1}{PD}$

  - RPGM exhibits low *p*, due to relatively low path changes/route requests

Conclusions

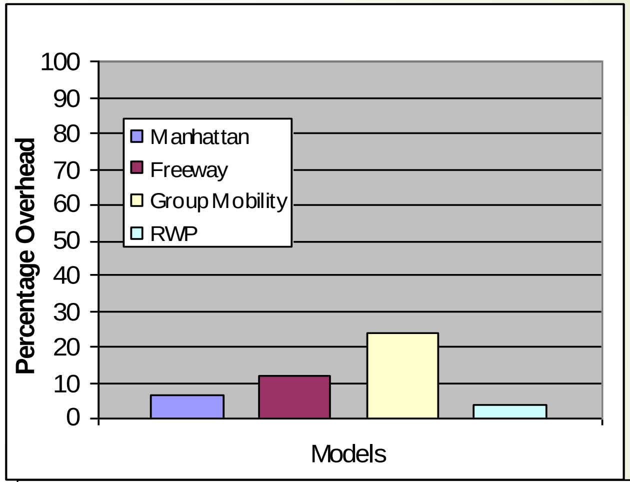
- Detailed statistical analysis of link and path duration for multiple mobility models (RW,FW,MH,RPGM4):
  - Link Duration: multi-modal FW and RPGM4 at low speeds
  - Path Duration PDF:
    - Multi-modal FW and RPGM4 at low speeds and hop count
    - *Exponential-like* at high speeds & med/high hop count for all models
- Developed parametrized exponential model for *PD* PDF, as function of relative velocity *V*, hop count *h* and radio range *R*
- Proposed simple analytical models for throughput & overhead that show strong correlation with reciprocal of average *PD*
- Open Issues:
  - Can we prove this mathematically? Yes
  - Is it general for random and correlated mobility? Yes

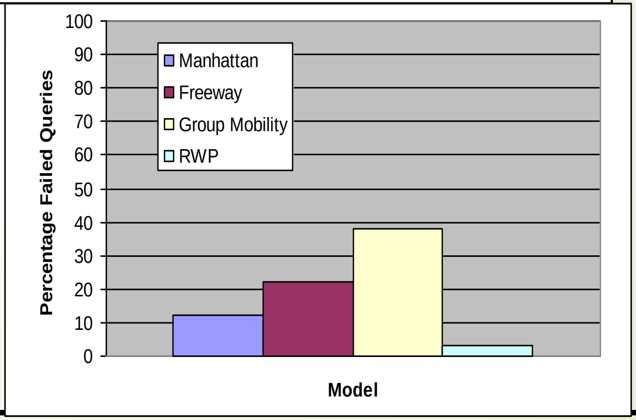
Case Studies Utilizing Mobility Modeling

Case Study on Effects of Mobility on the Grid Location Service (*GLS*)

- Group mobility:
  - prolongs protocol convergence
  - incurs max overhead
  - incurs max query failure rate

* Subtle Coupling between
  - (1) Mobility
  - (2) The Grid Topology
  - (3) Protocol Mechanisms

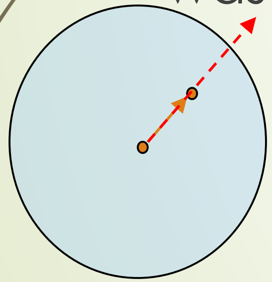


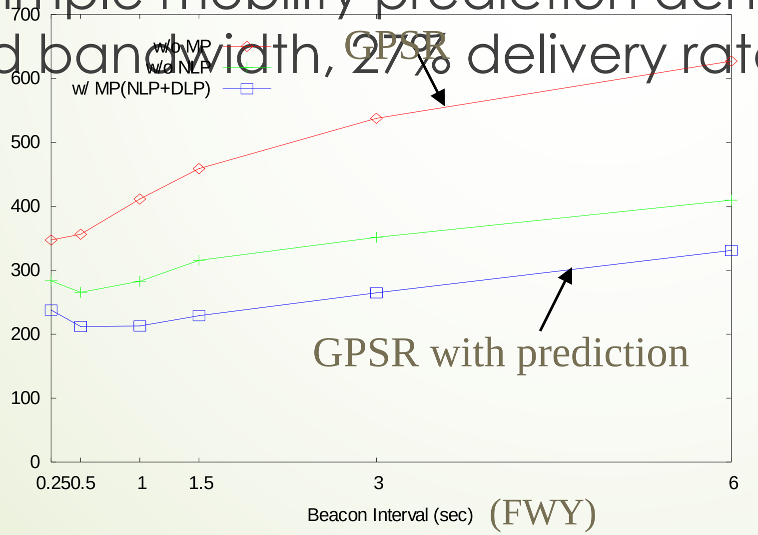


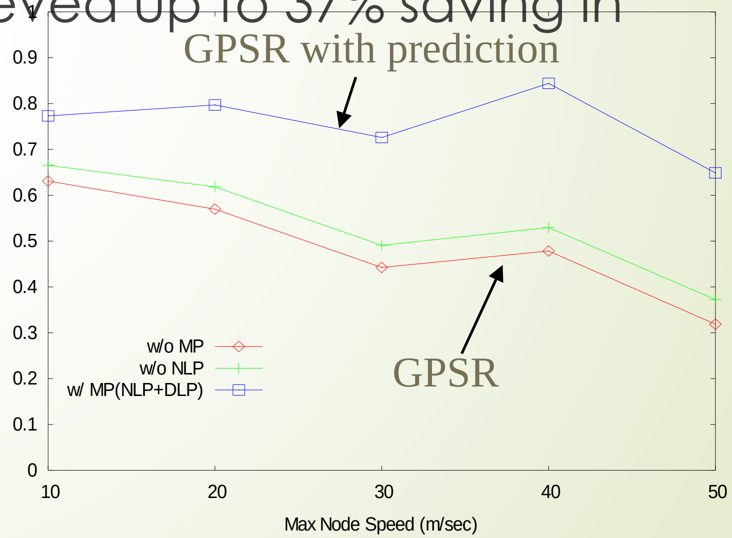
* C. Shete, S. Sawhney, S. Herwadka, V. Mehandru, A. Helmy, "Analysis of the Effects of Mobility on the Grid Location Service in Ad Hoc Networks", *IEEE ICC*, June 2004.

Case Study on *Geo-routing* across Mobility Models

- Depending on beacon frequency location info may be out of date
- Nodes chosen by geographic routing may move out of range before next beacon update.
- Increasing beacon updates does not always help!
- Using simple mobility prediction achieved up to 37% saving in wasted bandwidth, 27% delivery rate



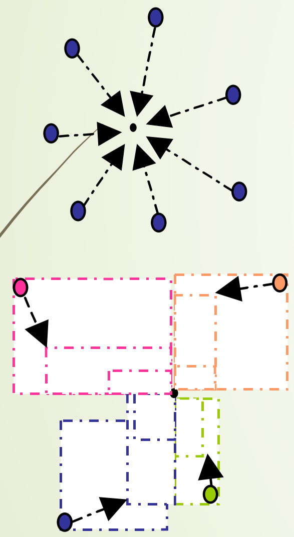




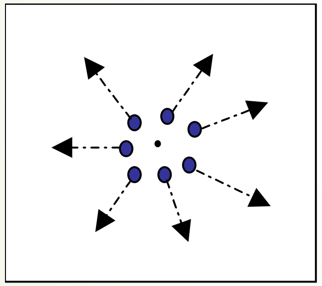
* D. Son, A. Helmy, B. Krishnamachari, "The Effect of Mobility-induced Location Errors on Geographic Routing in Ad Hoc Networks: Analysis and Improvement using Mobility Prediction", *IEEE WCNC*, March 2004, and *IEEE Transactions on Mobile Computing*, *Special Issue on Mobile Sensor Networks*, 3rd quarter 2004.

Contraction, Expansion and Hybrid Models

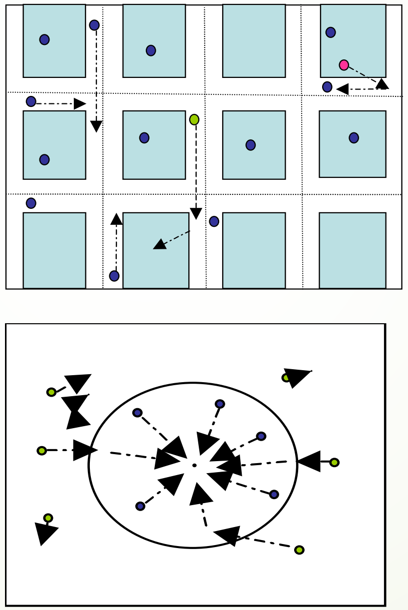
- May be useful for sensor networks
- Contraction models show ‘improved’ performance (e.g., Tput, link duration) with increased velocity



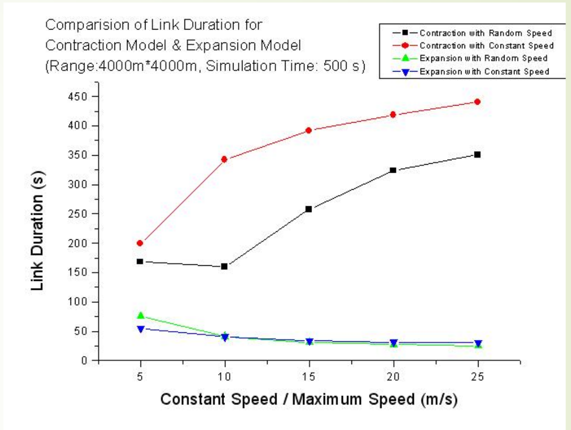
Contraction

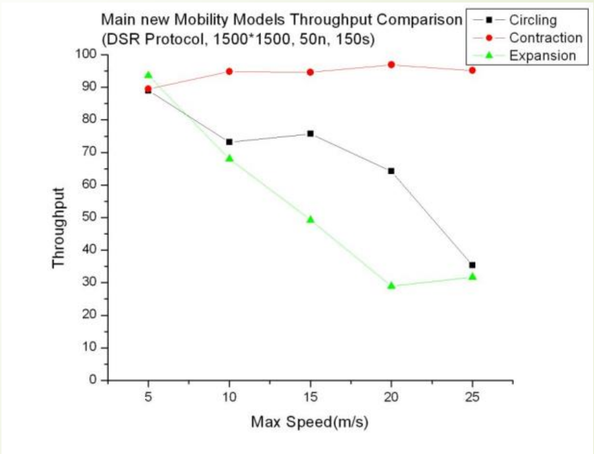


Expansion



Hybrid





* Y. Lu, H. Lin, Y. Gu, A. Helmy, "Towards Mobility-Rich Performance Analysis of Routing Protocols in Ad Hoc Networks: Using Contraction, Expansion and Hybrid Models", *IEEE ICC*, June 2004.

MAID Case Study: Utilizing Mobility

- *MAID*: Mobility Assisted Information Diffusion
- May be used for: resource discovery, routing, node location applications
- MAID uses 'encounter' history to create *age-gradients* towards the target/destination
- MAID uses (and *depends on*) mobility to diffuse information, hence its performance may be quite sensitive to mobility degree and patterns
- Unlike conventional adhoc routing, link/path duration may not be the proper metrics to analyze
- The 'Age gradient tree' and its characteristics determine MAID's performance

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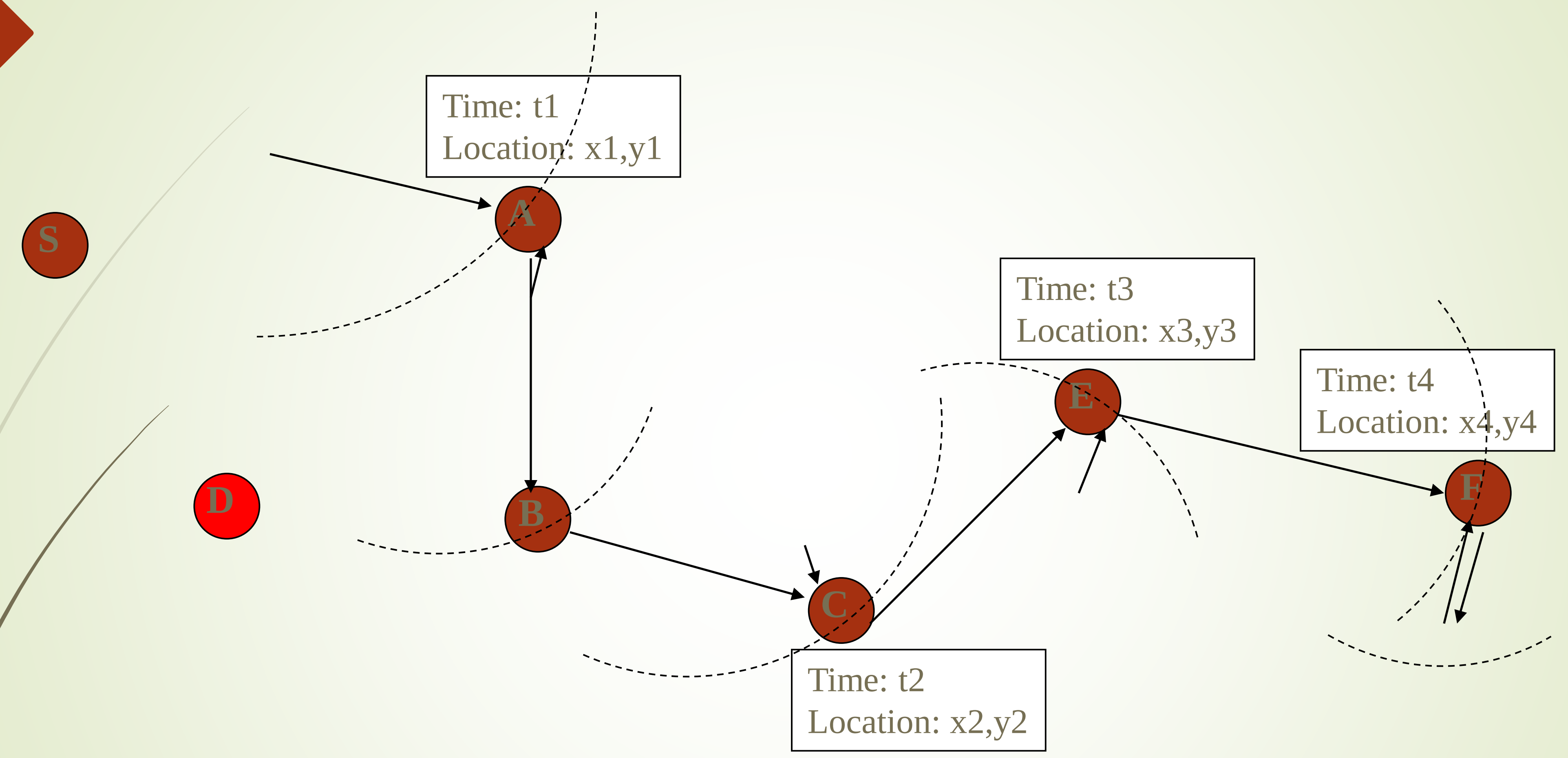
* F. Bai, A. Helmy, "Impact of Mobility on Mobility-Assisted Information Diffusion (*MAID*) Protocols", IEEE SECON, 2007.

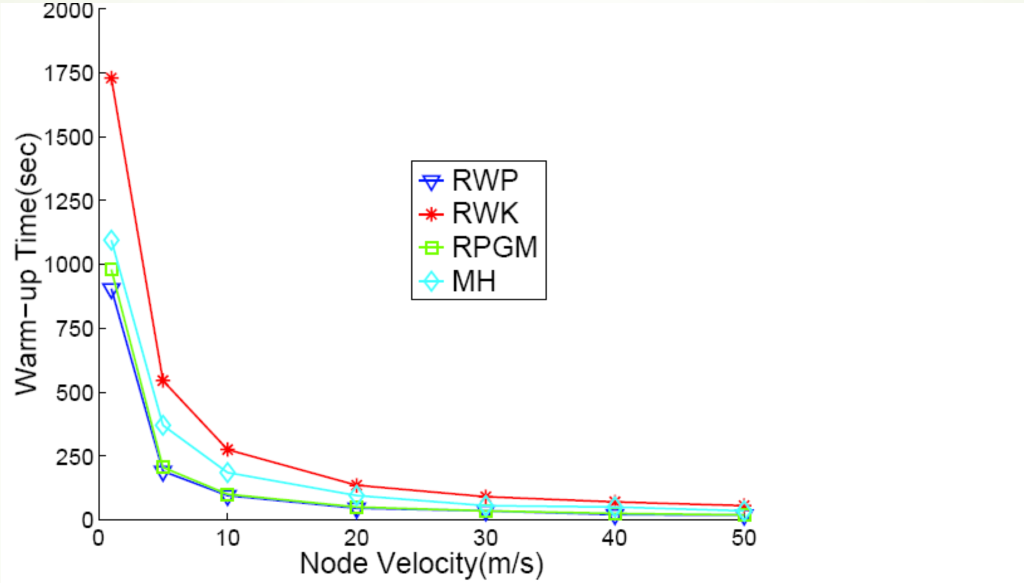


Basic Operation of MAID: Encounter history, search and age gradient tree

MAID protocol phases and metrics

- Cold cache (initial, transient, phase):
  - Encounter cache is empty
  - More encounters ‘warm up’ the cache by increasing the entries
- Warm cache (steady state phase) :
  - Average encounter ratio reaches ~30% of network nodes
  - Age gradient trees are established
- Metrics:
  - Warm up time
  - Average path length to a destination
  - Cost of search to establish the route to the destination

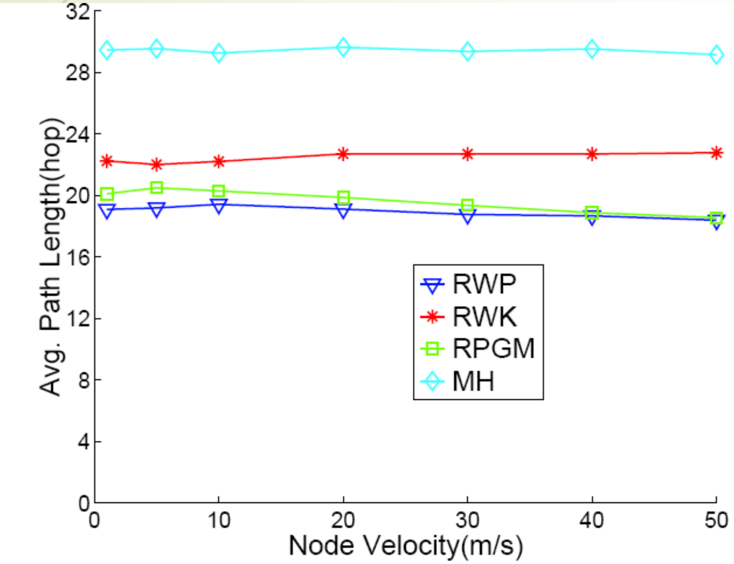
Warm Up Phase



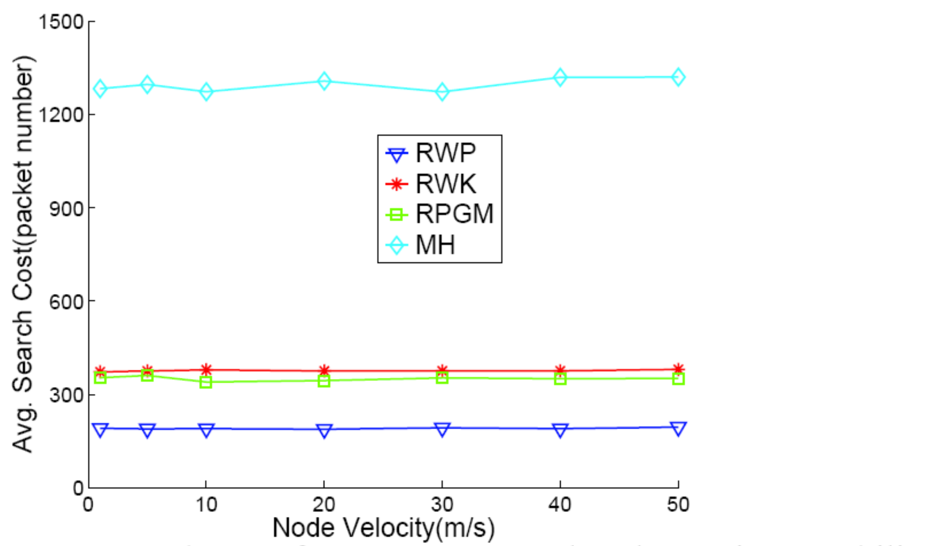
Warm Up Time for MAID Protocol under Various Mobility

The Warm Up Time depends heavily on the Mobility model and the Velocity

Steady State Phase



Average Path Length for MAID Protocol under Various Mobilit

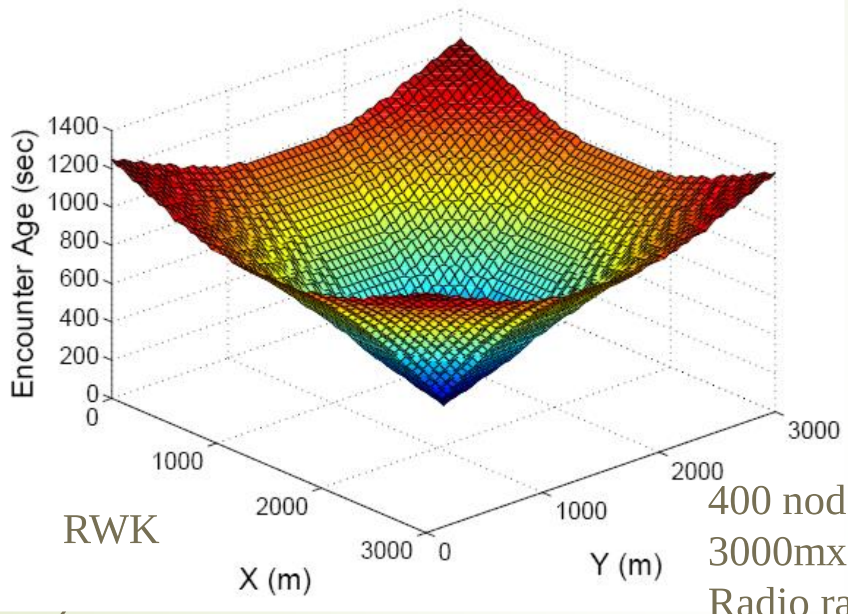


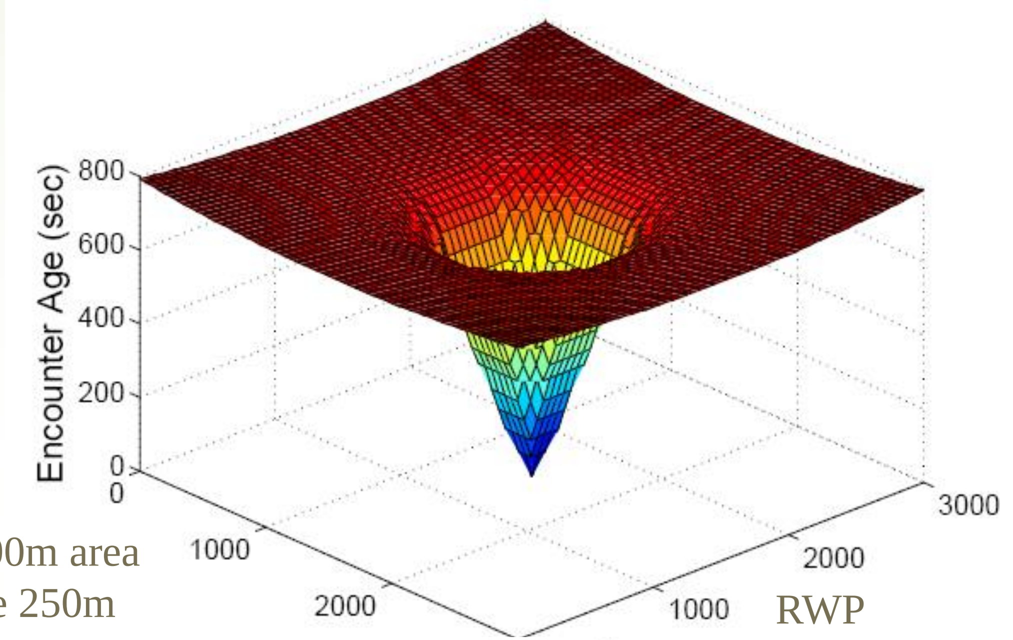
Average Search Cost for MAID Protocol under Various Mobility

Steady State Performance depends only on the Mobility model but NOT on the Velocity

- These metrics reflect the structure of the age-gradient trees (AGTs).
- Hence, MAID leads to stable characteristics of the AGTs.

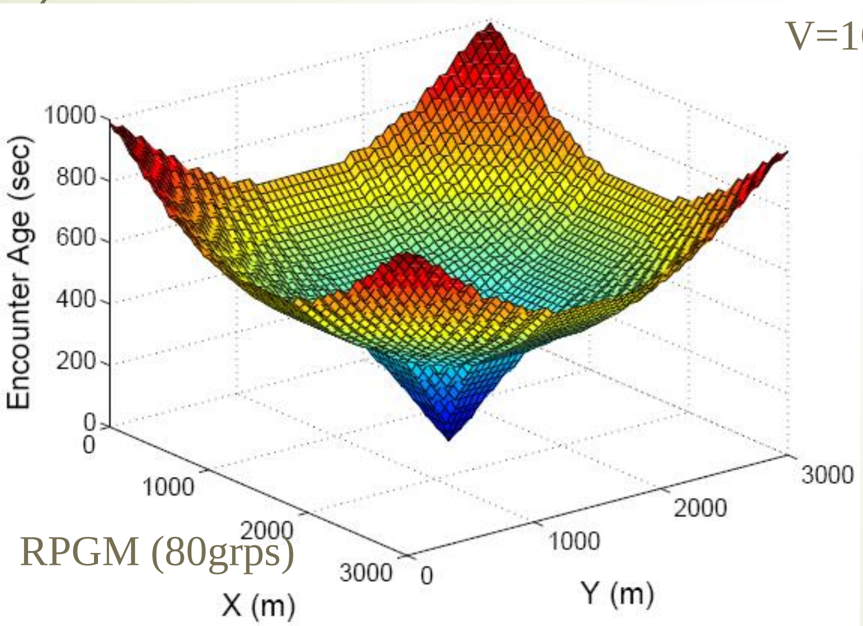
Spatio-Temporal Correlations in the AGT

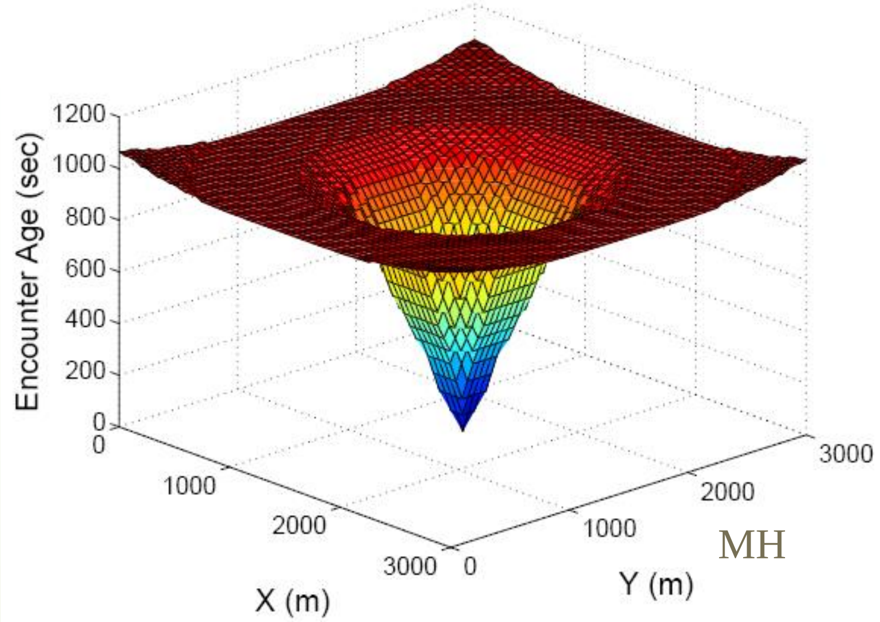


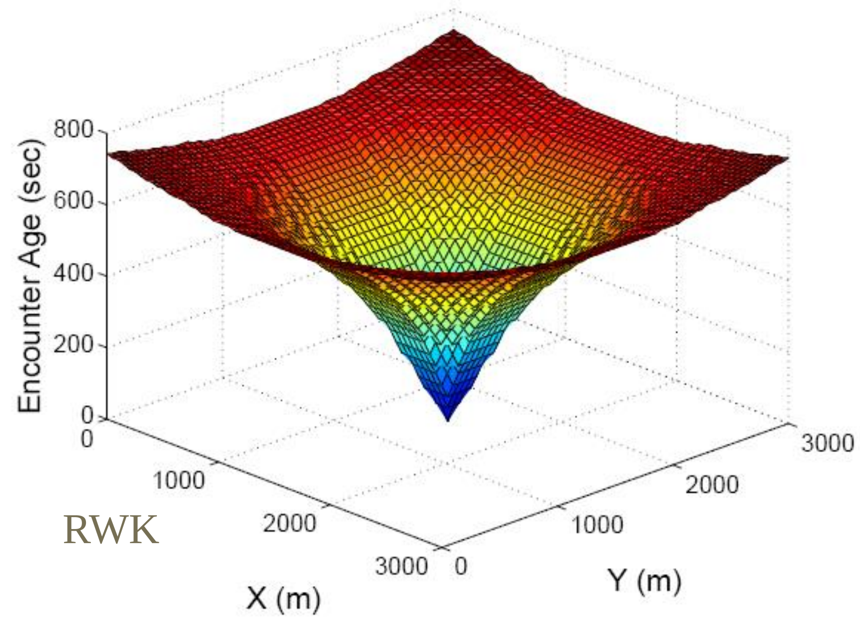


400 nodes
3000mx3000m area
Radio range 250m

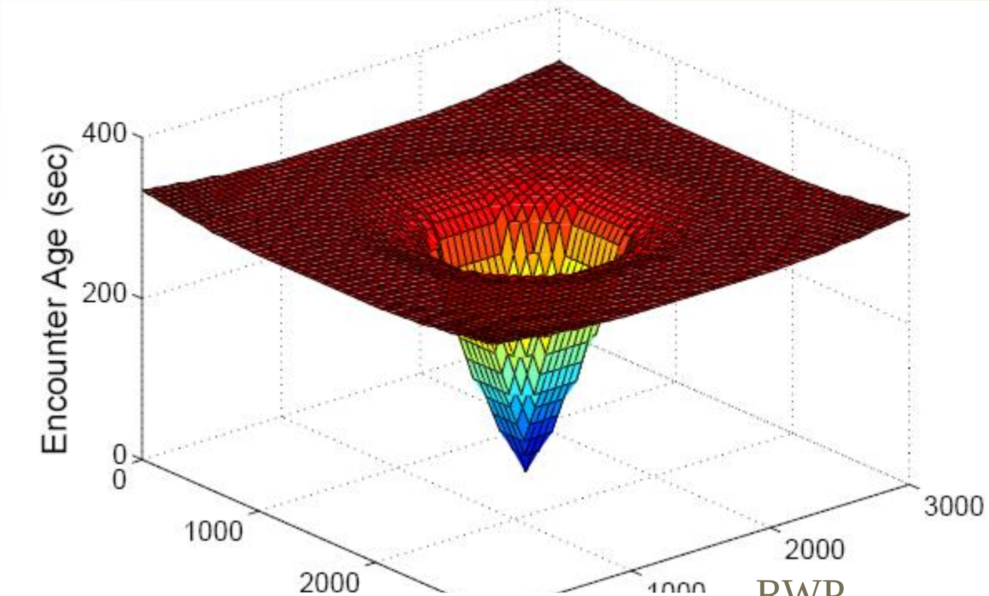
V=10m/s





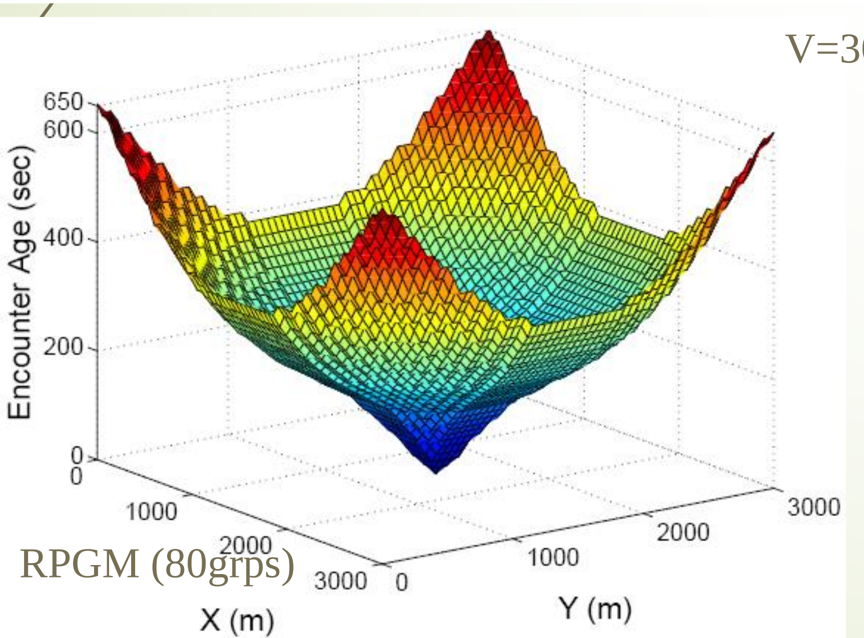


RWK

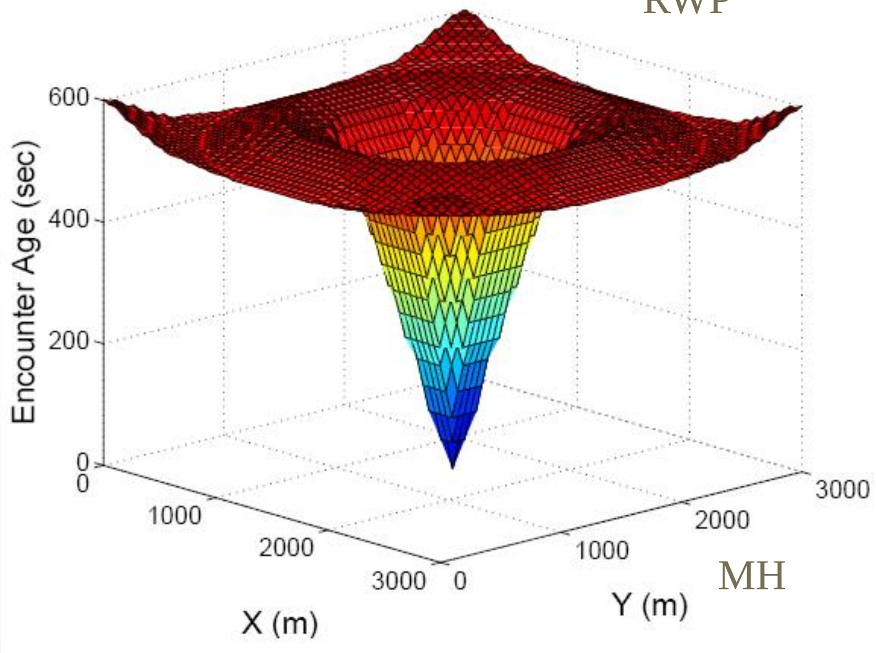


RWP

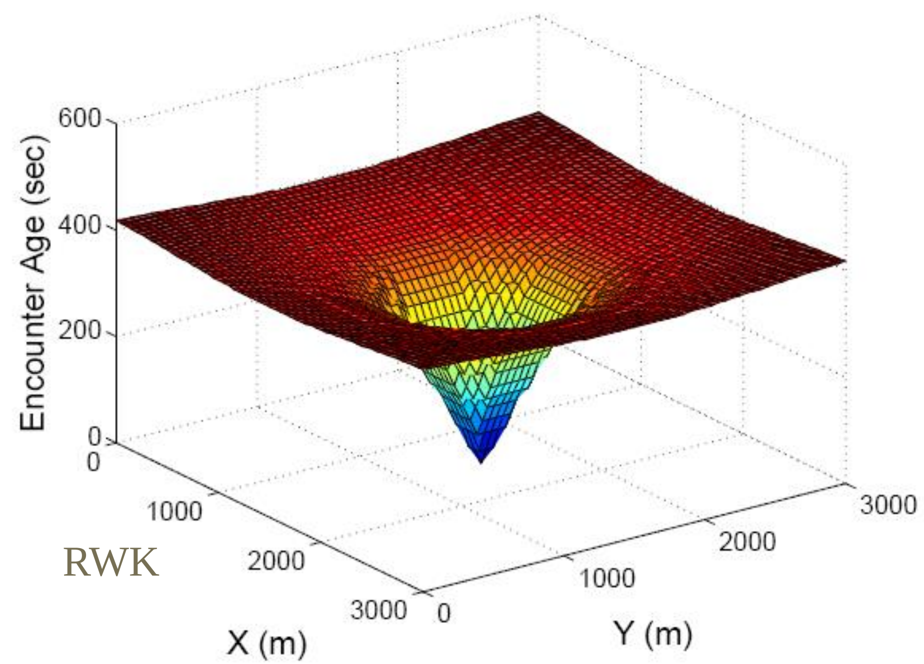
V=30m/s



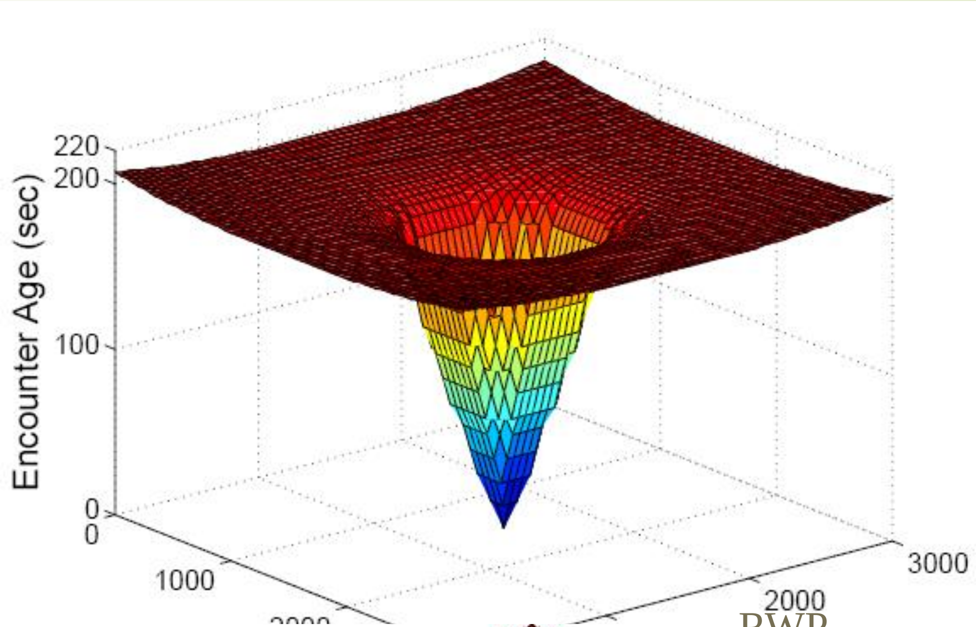
RPGM (80grps)



MH

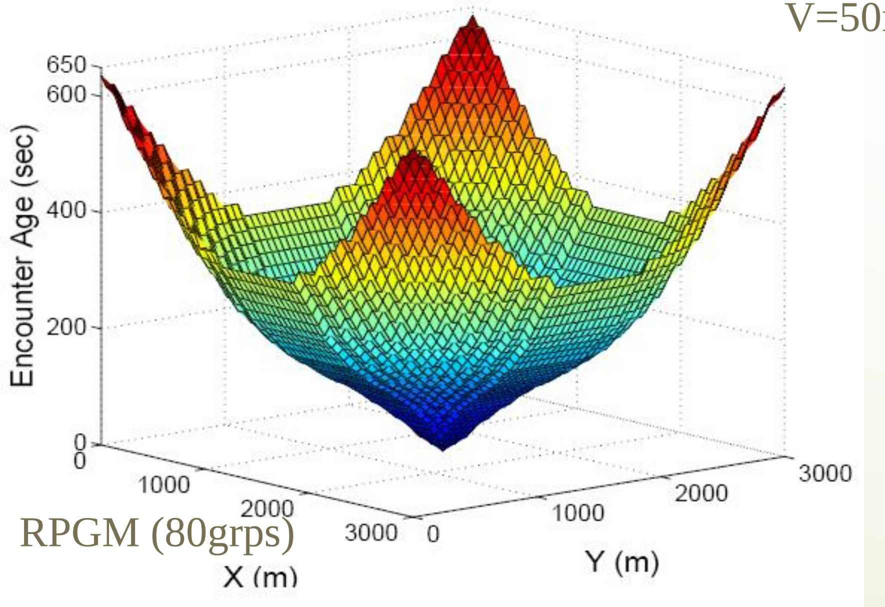


RWK

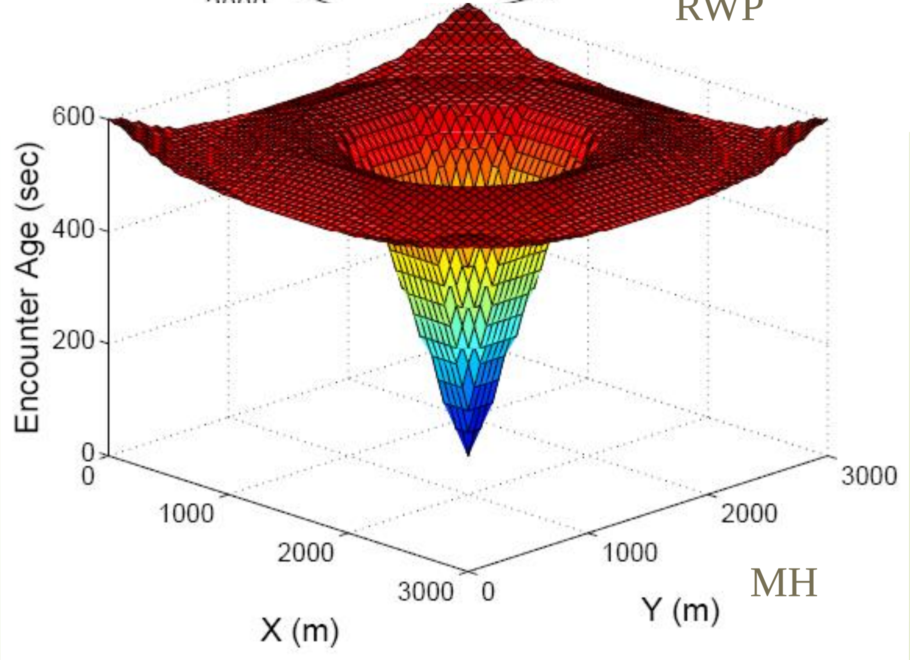


RWP

V=50m/s



RPGM (80grps)



MH

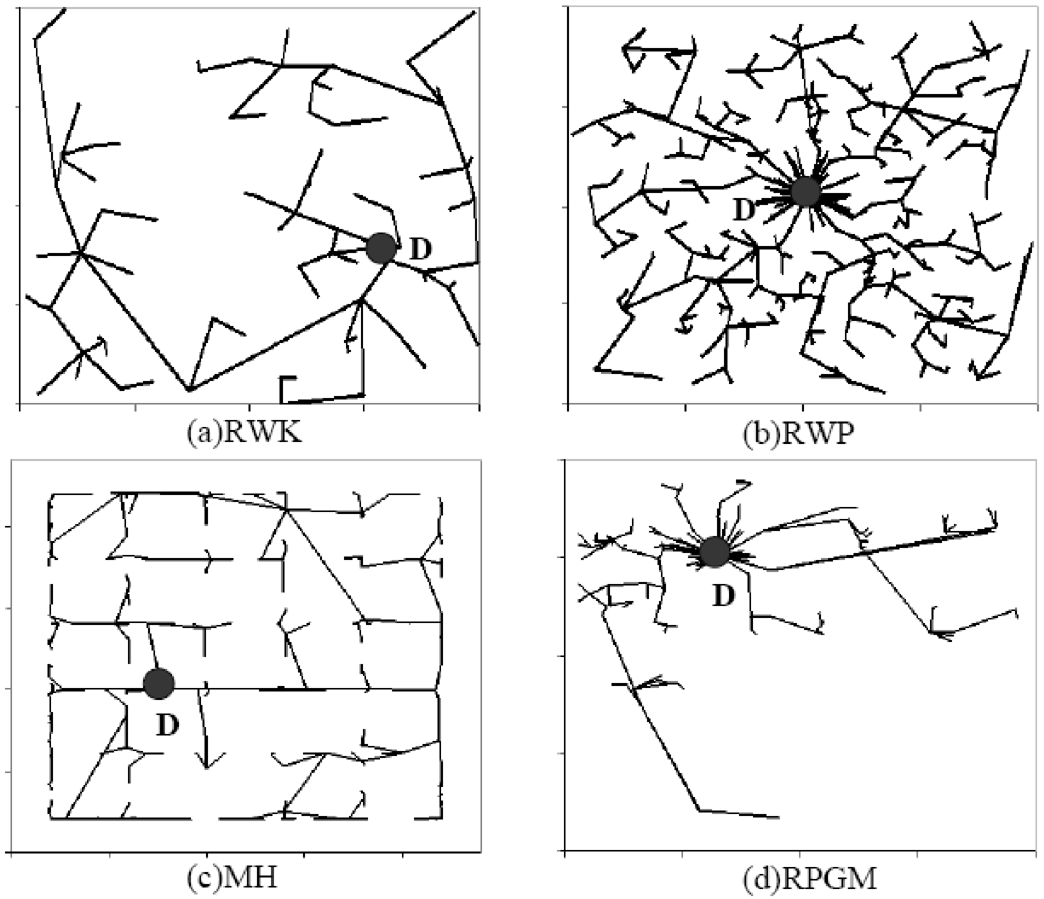


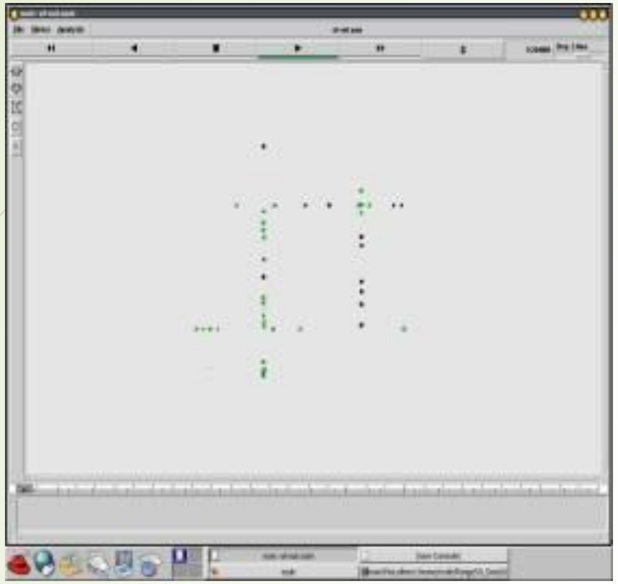
Fig. 13. The Age Gradient Tree (AGT) for RWP, RWK, MH and RPGM models (v=20m/s, t=400sec). Here, D is the destination (also, the root of AGT).

Mobility Simulation Tools

- The Network Simulator (NS-2) (USC/ISI, UCB, Xerox Parc) [wireless extensions CMU/Rice]
  - www.isi.edu/nsnam
- The GloMoSim Simulator (UCLA)/QualNet (Commercial)
- The IMPORTANT Mobility Tool (USC/UF)
  - nile.cise.ufl.edu/important
- Time Variant Community (*TVC*) (UF/USC)
  - nile.cise.ufl.edu/~helmy (click on *TVC* model)
- The Obstacle Mobility simulator (UCSB)
  - moment.cs.ucsb.edu/mobility
- The CORSIM Simulator
- OPNET (commercial)

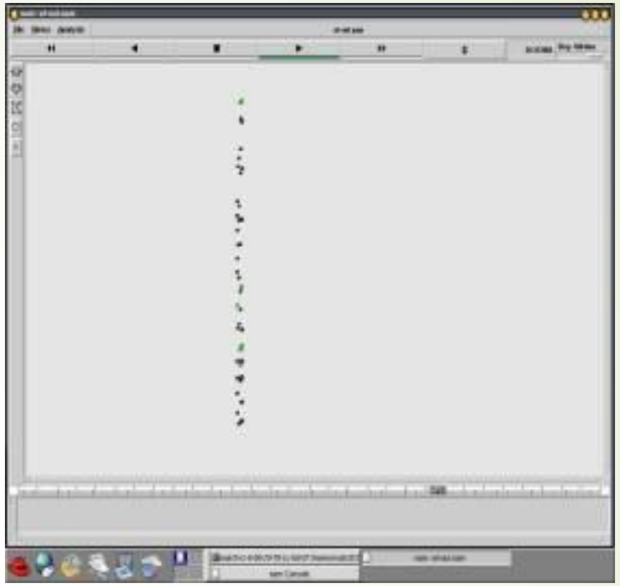
IMPORTANT

- Includes:
  - Mobility generator tools for FWY, MH, RPGM, RWP, RWK (future release), City Section (Rel. Sp 05)
  - Acts as a pre-processing phase for simulations, currently supports NS-2 formats (can extend to other formats)
  - Analysis tools for mobility metrics (link duration, path duration) and protocol performance
  - (throughput, overhead, age gradient tree chars)
  - Acts as post-processing phase of simulations
  - *nile.cise.ufl.edu/important*

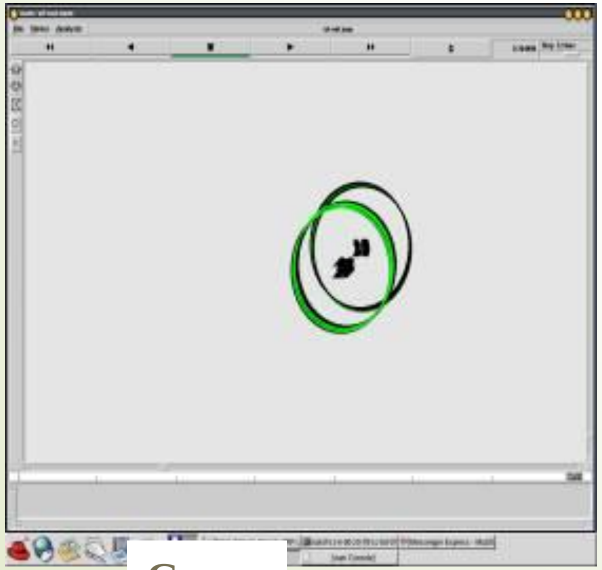


Manhattan

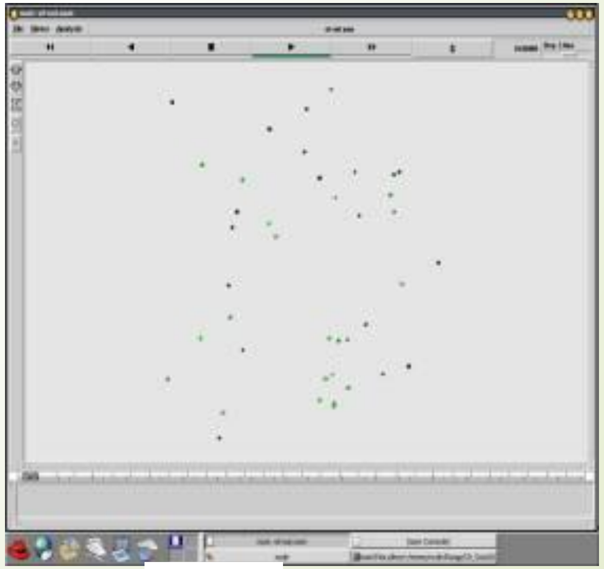
IMPORTANT



Freeway



Group

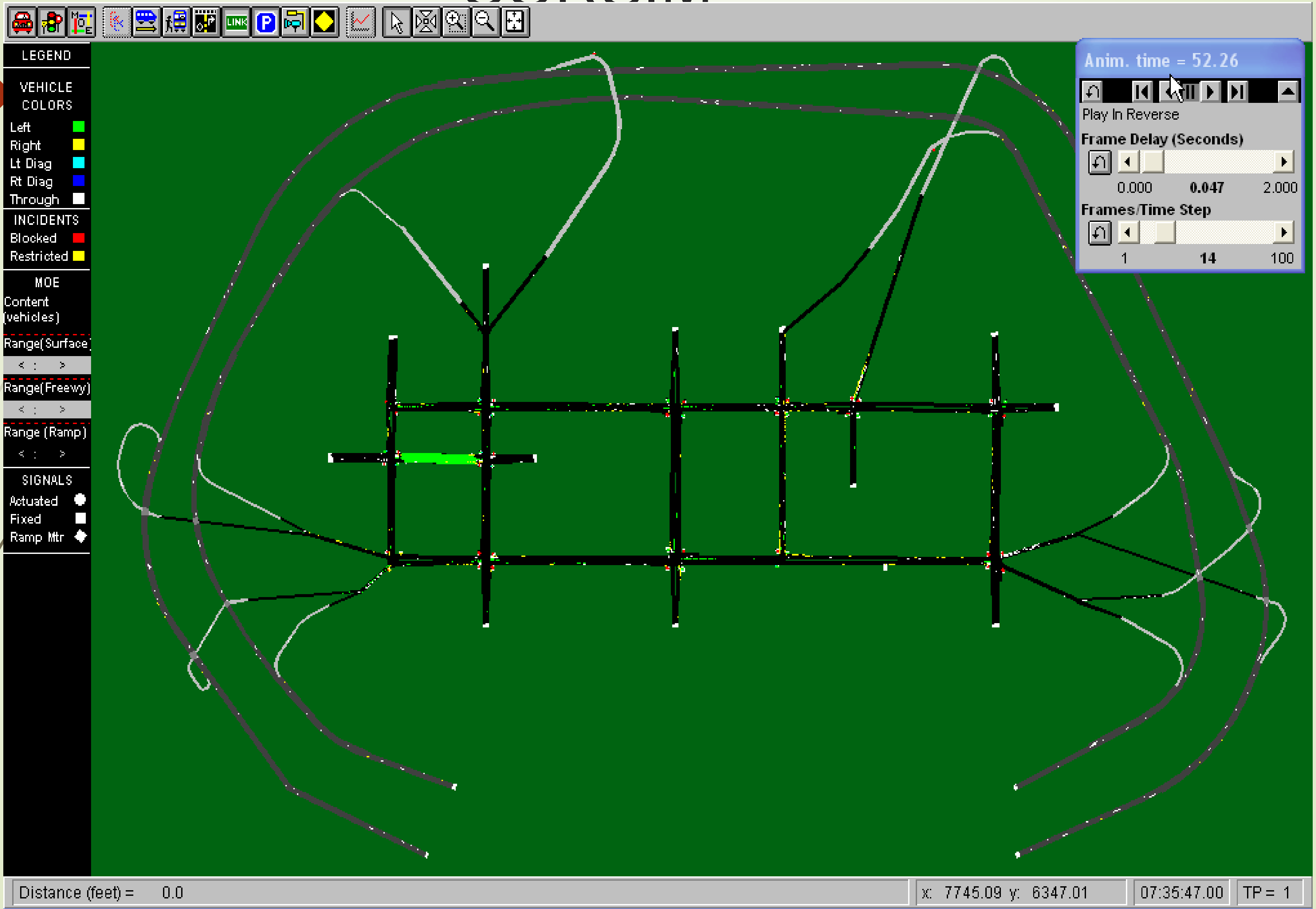


RWP

CORSIM (Corridor Traffic Simulator)

- Simulates vehicles on highways/streets
- Micro-level traffic simulator
  - Simulates intersections, traffic lights, turns, etc.
  - Simulates various types of cars (trucks, regular)
  - Used mainly in transportation literature (and recently for vehicular networks)
  - Does not incorporate communication or protocols
  - Developed through FHWA (federal highway administration) http://ops.fhwa.dot.gov
  - Need to buy license

CORSIM

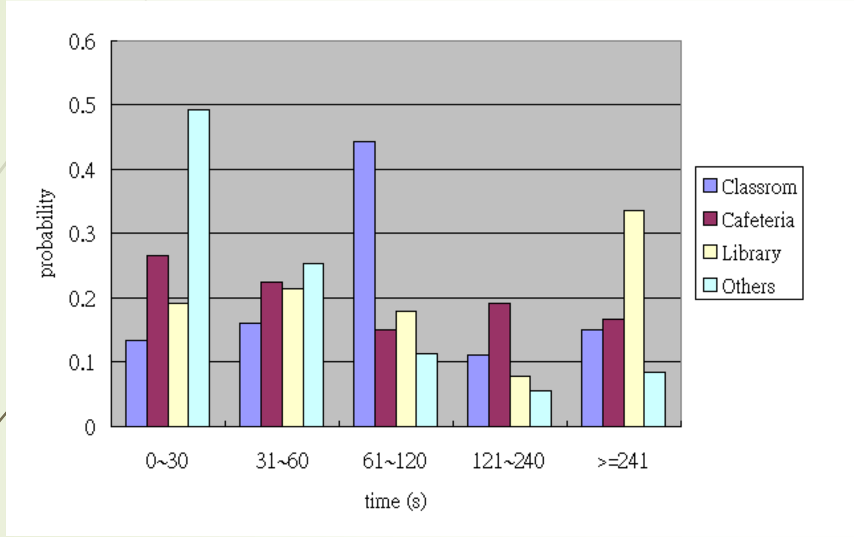


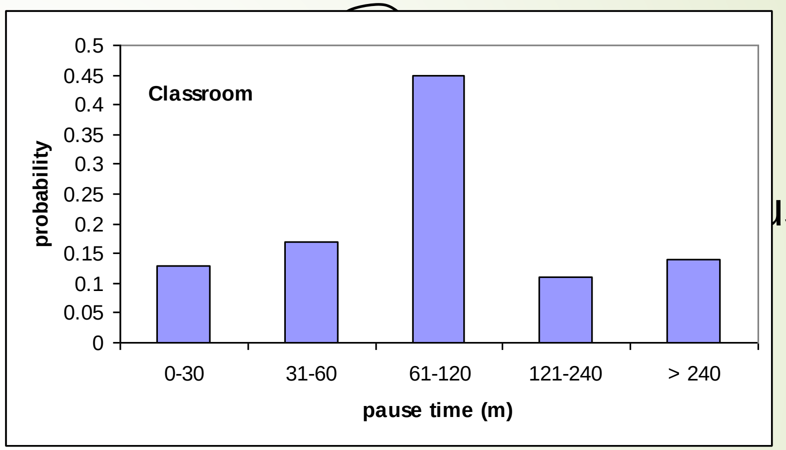
LEGEND
VEHICLE COLORS
Left
Right
Lt Diag
Rt Diag
Through
INCIDENTS
Blocked
Restricted
MOE
Content (vehicles)
Range(Surface)
Range(Freewy)
Range (Ramp)
SIGNALS
Actuated
Fixed
Ramp Mtr
Anim. time = 52.26
Play In Reverse
Frame Delay (Seconds)
0.000
0.047
2.000
Frames/Time Step
1
14
100
Distance (feet) = 0.0
x: 7745.09 y: 6347.01
07:35:47.00
TP = 1

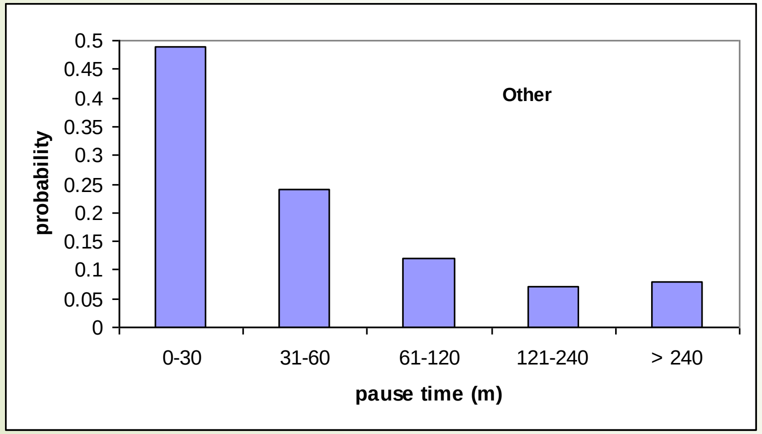
Trace-based Mobility Modeling

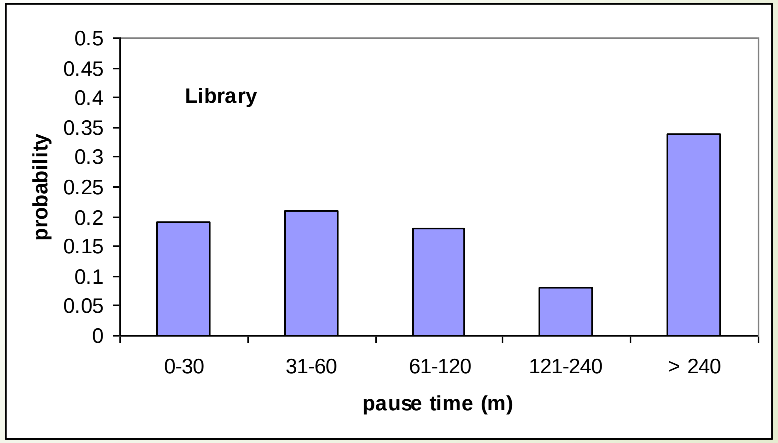
- Extend the *IMPORTANT* mobility tool:
  - URL: *http://nile.cise.ufl.edu/important*
- Trace-based mobility models *nile.cise.ufl.edu/MobiLib*
  - Pedestrians on campus
    - Usage pattern (WLAN traces)
      - USC, MIT, UCSD, Dartmouth,…
    - Student tracing (survey, observe)
  - Vehicular mobility
    - Transportation literature
  - Parametrized hybrid models
    - Integrate Weighted Group mobility with I
    - Derive the parameters based on the trac

Survey based: Weighted Way Point (*WWP*) Model [ACM MC²R 04]









Q1. What is the computational cost and performance metrics of V2V Mobility Modeling and Simulation using Periodic Broadcast (PBC) Messages for Traffic Congestion Control (i.e., Mitigation)? Explain your answer.

The ETSI standardized message set for vehicular communication is Cooperative Awareness Messages (CAM). CAM is a set of VANETs application that intended for the intelligent transportation system using the periodically messaging services that can be used to send and receive notification. The traffic congestion is significant factor in disrupting traffic flows. The CAM notifications are utilized to enhance traffic flow by mitigating traffic congestion through Vehicle to Vehicle (V2V) communication System. The using of CAM notification can parse congestion at high traffic density points.

Q2. Importance of vehicle discovery for V2V (or V2I) communication in VANETs? Explain your answer based on mobility patterns and routing.


THANK
YOU