Mobile Wireless Networking
The University of Kansas EECS 882
Mobility and Location Management

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LM.1 Mobility models
LM.2 Location management
Mobile Wireless Networking

Cube Model

- Mobility models affect L1→L3 in ns-3

LM.1 Mobility Models

LM.1 Mobility models
  LM.1.1 Entity mobility models
  LM.1.2 Group mobility models

LM.2 Location management
Mobility Models
Overview and Motivation

- **Mobility model**: model of mobility in a real system
- **Motivation?**

- **Mobility model**: model of mobility in a real system
- Understand the behaviour of deployed systems
- Predict the behaviour of proposed systems
  - before deployment
Mobility Models

Classification

- Degree of abstraction
- Number of nodes
- Topology
- Memory

Mobility Models

Classification: Degree of Abstraction

- **Trace-driven**: constructed from measurements
  - useful for well-understood pre-existing scenarios
    - particularly when location measurements are available
  - following the trajectory of a real mobile node
    - important to understand if representative of general scenario
  - may be approximate
    - time sample
    - geographic resolution
- Synthetic mobility model
- Analytical model
Mobility Models
Classification: Degree of Abstraction

- Trace-driven
- Synthetic mobility model: abstract model
  - intended to approximate the real behaviour of a node
  - necessary for new scenarios
  - important to understand applicability to real scenarios
- Analytical model

- mathematical model of mobility
- typically applied to satellite and spacecraft orbits
Mobility Models

Classification: Degree of Abstraction

- Synthetic vs. trace driven choice
  - dictated by availability of traces
  - synthetic model may be less computationally intense
  - trade fidelity of abstraction vs. representativeness of trace

Mobility Models

Classification: Number of Nodes

- **Entity mobility model**: model for a single node
  - example: individual person walking through a city
- **Group mobility model**: model for a group of nodes
  - each of which uses an entity model within the group
  - example: group of people walking through a city
Mobility Models

Classification: Topology

- Unconstrained: arbitrary node movement
  - within a defined geographic area
  - e.g. individual walking in a field
- Constrained: node movement patterns constrained
  - may be constrained to simplify synthetic model
    - e.g. Manhattan grid
  - may be constrained to represent real topology or geography
    - e.g. automobile moving within a road system

Mobility Models

Classification: Memory

- Memoryless: past history not used in model
  - current move or trajectory independent of past
  - e.g. Brownian motion
- Memory: past history used in model
  - current move or trajectory based on past movement
  - e.g. vehicle driving on a road
Mobile Wireless Networking

**LM.1.1 Entity Mobility Models**

**LM.1 Mobility models**

**LM.1.1 Entity mobility models**

**LM.1.2 Group mobility models**

**LM.2 Location management**

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**Entity Mobility Models**

**Example Scenarios**

- Entity mobility model: a *single* node
- Examples of entity movement:
  - individual person walking through a city
  - individual soldier on special operations mission
  - individual vehicle trajectory
  - solitary animal movements
Entity Mobility Models

Example Models

- Memoryless
  - random walk
  - random waypoint
- Memory
  - Gauss-Markov
  - Probabilistic random walk

Example Models: Random Walk

- Random walk: random choice of distance & direction
  - modelled after Brownian motion [Einstein 1926]
Entity Models: Random Walk

Algorithm

- Random walk: random choice of distance & direction
  - choose starting position $(x_0, y_0)$
  - choose random direction $\theta_1 = [0, 2\pi)$
Entity Models: Random Walk

Algorithm

- Random walk: random choice of distance & direction
  - choose starting position $(x_0, y_0)$
  - choose random direction $\theta_1 = [0, 2\pi)$
  - choose random speed $s_1 = [s_{\text{min}}, s_{\text{max}}]$
  - travel at constant speed $s_1$ for constant time $t$ or distance $d$
• Random walk: random choice of distance & direction
  - choose starting position \((x_1, y_1)\)
  - choose random direction \(\theta_2 = [0, 2\pi)\)
  - choose random speed \(s_2 = [s_{\text{min}}, s_{\text{max}}]\)
  - travel at constant speed \(s_2\) for constant time \(t\) or distance \(d\)
  - immediately repeat from current position to \(i=2\)

• Random walk: random choice of distance & direction
  - choose starting position \((x_2, y_2)\)
  - choose random direction \(\theta_3 = [0, 2\pi)\)
  - choose random speed \(s_3 = [s_{\text{min}}, s_{\text{max}}]\)
  - travel at constant speed \(s_3\) for constant time \(t\) or distance \(d\)
  - immediately repeat from current position to \(i=3\)
**Entity Models: Random Walk**

**Algorithm**

- **Random walk:** random choice of distance & direction
  - choose starting position $(x_i, y_i)$
  - choose random direction $\theta_{i+1} = [0, 2\pi)$
  - choose random speed $s_{i+1} = [s_{\text{min}}, s_{\text{max}}]$  
  - travel at constant speed $s_{i+1}$ for constant time $t$ or distance $d$
  - immediately repeat from current position $i$ to $i+1$ ...

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**Entity Models: Random Walk**

**Example Path**

- **Random walk:** random choice of distance & direction

[Camp Boleng Davis 2002 Fig. 1]
Advantages?

Advantages:
- simple memoryless model
Entity Models: Random Walk

Advantages and Disadvantages

• Advantages
  – simple memoryless model

• Problems
  – nodes walk randomly around origin; never stay far
    • $\Pr[\text{moving away from origin}] = \Pr[\text{moving toward origin}]$

  Disadvantages?

• Disadvantages
  – most real network-node scenarios not Brownian
  – rapid, random, disruptive turns in path
Entity Mobility Models

Example Models: Random Waypoint

- Random waypoint: move between *waypoints* [Johnson-Maltz 1996]
  - one of the most widely used mobility models

Entity Models: Random Waypoint

Algorithm

- Random waypoint: move between waypoints
  - choose starting position 
  \((x_0, y_0)\)
Entity Models: Random Waypoint

Algorithm

- Random waypoint: move between waypoints
  - choose starting position
    \((x_0, y_0)\)
  - choose random waypoint
    \((x_1, y_1)\)
  - choose random speed
    \(s_1 = [s_{\text{min}}, s_{\text{max}}]\)

*
Entity Models: Random Waypoint

Algorithm

- Random waypoint: move between waypoints
  - choose starting position $(x_0, y_0)$
  - choose random waypoint $(x_1, y_1)$
  - choose random speed $s_1 = [s_{\text{min}}, s_{\text{max}}]$
  - travel to waypoint at constant speed $s_1$

- pause for a specified time $p_1$
Entity Models: Random Waypoint

Algorithm

- Random waypoint: move between waypoints
  - choose starting position $(x_1, y_1)$
  - choose random waypoint $(x_2, y_2)$
  - choose random speed $s_3 = [s_{\text{min}}, s_{\text{max}}]$
  - travel to waypoint at constant speed $s_3$
  - pause for a specified time $p_3$
  - repeat from current position to $i=3$
Entity Models: Random Waypoint

**Algorithm**

- Random waypoint: move between waypoints
  - choose starting position 
    \((x_i, y_i)\)
  - choose random waypoint 
    \((x_{i+1}, y_{i+1})\)
  - choose random speed 
    \(s_{i+1} = [s_{\text{min}}, s_{\text{max}}]\)
  - travel to waypoint at constant speed \(s_{i+1}\)
  - pause for a specified time 
    \(P_{i+1}\)
  - repeat from current position 
    \(i\) to \(i+1\) ...

Example Path

- Random waypoint: move between waypoints

[Camp Boleng Davis 2002 Fig. 3]
Advantages?

• Advantages
  – relatively simple memoryless model
  – more realistic than random walk for many scenarios

• Problem: average node velocity decreases over time
  – due to steps over long distance with very low speed
  – takes some time to stabilise
  – problem reduced by large enough choice of $s_{\text{min}}$

Disadvantages?
Entity Models: Random Waypoint

Advantages and Disadvantages

- Advantages
  - relatively simple memoryless model
  - more realistic than random walk for many scenarios
- Problem: average node velocity decreases over time
- Disadvantages
  - still has sharp sudden turns
  - may not realistically represent real mobility patterns
  - but may be good enough to model
    - mobility effects including need for rerouting and handoffs
    - disconnectivity when nodes out of range

Entity Mobility Models

Example Models: Gauss-Markov

- Gauss-Markov: gradually vary trajectory over time
  [Garcia-Luna-Aceves Madruga 1999]
Entity Models: Gauss-Markov Algorithm

- Gauss-Markov: gradually vary trajectory over time
  - choose starting position \((x_0, y_0)\)
  - choose mean direction and initial random direction \(\theta_0 = [0, 2\pi)\)
  - choose mean speed and initial random speed \(s_0 = [s_{\text{min}}, s_{\text{max}}]\)
  - travel at constant speed \(s_0\) until next timestep \(t_n\)
• Gauss-Markov: \textit{gradually} vary trajectory over time
  – at each timestep $n$
  – new speed
  – new direction
  – tuning parameter $0 \leq \alpha \leq 1$
    \begin{align*}
    \alpha = 0 & : \text{Brownian} \\
    \alpha = 1 & : \text{linear}
    \end{align*}
  – memory from last timestep
Entity Models: Gauss-Markov

Algorithm

- Gauss-Markov: gradually vary trajectory over time
  - at each timestep $n$
  - new speed
  - new direction
  - tuning parameter $0 \leq \alpha \leq 1$
    - $\alpha = 0$: Brownian
    - $\alpha = 1$: linear
  - memory from last timestep

Example Path

- Gauss-Markov: gradually vary trajectory over time

[Camp Boleng Davis 2002 Fig. 10]
Entity Models: Gauss-Markov

**Advantages**

- no sudden turns
- more realistic than random waypoint for some scenarios

**Disadvantages?**
Entity Models: Gauss-Markov

Advantages and Disadvantages

- Advantages
  - no sudden turns
  - more realistic than random waypoint for some scenarios
- Disadvantages
  - more computationally intensive than random waypoint
  - more parameters to understand and tune

Entity Mobility Models

Example Models: City Section

- City section: constrained to paths (streets)
  [Davies 2000]
**Entity Models: City Section**

**Algorithm Overview**

- Motion constrained to street paths
  - streets assigned speed limits
- Nodes choose random destination
  - shortest time computed
  - nodes maintain safe spacing
Group Mobility Models

Example Scenarios

- Group mobility model: a *coördinated set* of nodes
- Examples of group movement:
  - group of people walking through a city
  - military unit
  - search-and-rescue team
  - caravan of vehicles trajectory
  - herd, flock, or school of animals

Group Mobility Models

Group and Entity Sub-Models

- Group mobility model consists of two sub-models
  - mobility model for group
  - mobility model for entities within group
  - may use same or different models for each
Entity Mobility Models

Example Models: Column

- Column: nodes follow reference point along a line
  [Sanchez Manzoni Anejos 2001]

Example Models: Nomadic Community

- Nomadic: nodes move with respect to reference point
  [Sanchez Manzoni Anejos 2001]
  - entity model for nodes with respect to reference point
  - entity model for reference points
Entity Mobility Models

Example Models: Pursue

- Pursue: nodes follow reference point
  [Sanchez Manzoni Anejos 2001]

Example Models: Reference Point

- RPGM (reference point group model):
  nodes move with respect to center of group
  [Hong Gerla Pei Chiang 1999]
Location Management

Introduction

- Fixed networks: static nodes
  - address related to topology (e.g. IP LPM) or
  - address bound to device (e.g. Ethernet)
- Mobile networks: modes move problem?
Location Management

Introduction

• Mobile networks: nodes *move*
  – problem: *how to find the destination node for communication?*

Introduction and Definition

• Mobile networks: nodes *move*
• *Location management* tracks movements of MNs
  – also {location|mobility}{management|tracking}
  – maintains binding between node identifier and location
  – note: "*address*" is overloaded and can mean either
Location Management

Introduction and Definition

- Mobile networks: nodes move
- **Location management** tracks movements of MNs
  - also {location|mobility}{management|tracking}
  - maintains binding between node identifier and location
  - note: “address” is overloaded and can mean either
- **Location database** maintains these bindings
  - typically distributed set of agents or registries

Location Management

Networks based on Geographic Location

- Location management consists of
  - tracking and disseminating geo-coordinates
  - predicting trajectories in case of high-velocity mobility
Mobile ad hoc networks (MANETS)
  - significant mobility
  - no dependence on infrastructure
Location management consists of
  - mapping identifiers to current topological location
  - reassigning identifiers based on topological location and providing translation mechanism to new address
Both of these are very hard problems
  - especially in large geographically distributed networks

LM.1 Mobility models
LM.2 Location management
  LM.2.1 Taxonomy and strategies
  LM.2.2 Internet and PSTN location management
Location Management

Alternative Strategies

- Flooding
  - proactive vs. reactive
- Quorum / rendezvous
  - explicit vs. implicit
  - flat vs. hierarchical

Flooding

- each node floods its location to other nodes

*Advantages and disadvantages?*
Location Management

Flooding: Advantages vs. Disadvantages

- Flooding
  - each node floods its location to other nodes
- Advantages
  - simple scheme
  - guarantees dissemination if connectivity exists
- Disadvantages
  - overhead
  
  Optimisations?

Location Management

Flooding: Optimisations

- Flooding
  - each node floods its location to other nodes
- Advantages
  - simple scheme
  - guarantees dissemination if connectivity exists
- Disadvantages
  - overhead
- Optimisations
  - decrease accuracy of dissemination with distance
  - limit hop count or decreased frequency with hop count
Location Management

Flooding: Proactive vs. Reactive

- Proactive flooding
  - each node periodically floods its location to other nodes

  *Reactive flooding?*

- Reactive flooding
  - nodes that don't know location of destination flood *query*
Location Management

**Quorum / Rendezvous**

- Flooding
  - proactive vs. reactive
- **Quorum / rendezvous**
  - explicit vs. implicit
  - flat vs. hierarchical

**Quorum-based location management**

- **quorum** of location servers capable of finding all nodes
- location server nodes serve location requests
- location server nodes serve update requests
Location Management

**Quorum / Rendezvous**

- Quorum-based location management
  - quorum of location servers capable of finding all nodes
  - nodes serve location requests
  - nodes serve update requests

- Rendezvous
  - rendezvous servers
  - handle both location and update are rendezvous

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Location Management

**Quorum: Explicit**

- Explicit quorum-based location management
  - explicit set of servers designated as location servers
  - intersecting set of *query quorum* and *update quorum*
Location Management

**Quorum: Implicit**

- Implicit quorum-based location management
  - implicit set of servers selected by DHT lookup

**Quorum: Flat vs. Hierarchical**

- Flat quorum-based location management
  - all servers serve same role
- Hierarchical quorum-based location management
  - hierarchy of servers
  - sub-grid one approach for implicit approach
Location Management

LM.2.2 Internet and PSTN

LM.1 Mobility models
LM.2 Location management
  LM.2.1 Taxonomy and strategies
  LM.2.2 Internet and PSTN location management

- Networks with limited mobility capabilities
  - occasional handoffs and roaming
    - e.g. mobile cellular telephony and mobile IP
Location Management
Internet and Mobile Cellular Telephony

- Networks with limited mobility capabilities
  - occasional handoffs and roaming
    - e.g. mobile cellular telephony and mobile IP
- Mobile nodes
  - assigned to home network
  - move to visited network

<table>
<thead>
<tr>
<th></th>
<th>Internet (agent)</th>
<th>Mobile PSTN (location registry)</th>
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<tbody>
<tr>
<td>Home Network</td>
<td>HA</td>
<td>HLR</td>
</tr>
<tr>
<td>Visited / Foreign Network</td>
<td>FA</td>
<td>VLR</td>
</tr>
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Location Management

Internet: Mobile IP

- Location management performed by Mobile IP **agents**
  - HA (home agent): maintains binding to MN care-of address
  - FA (foreign agent): assigns care-of addr when MN registers

**Lecture WI**

- **Home Net**
  - AP
  - MN

- **Visited Net**
  - AP
  - MN

Mobile Telephone Network

- Location management performed by PSTN **registries**
  - HLR (home location register): binding to VLR of MN
  - VLR (visitor location register): authentication, service profile

**Lecture MT**
Further Reading


Acknowledgements

Some material in these foils is based on the textbook

- Murthy and Manoj, *Ad Hoc Wireless Networks: Architectures and Protocols*

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