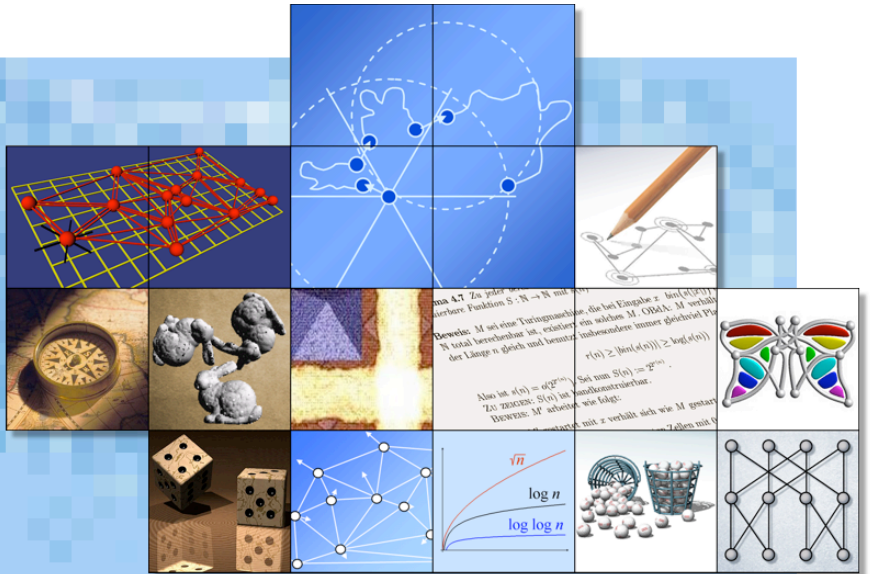
Mobility in Wireless Networks

Invited Talk for SOFSEM 2006
Měřín, Czech Republic
26th January 2006



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Mobility in Wireless Networks

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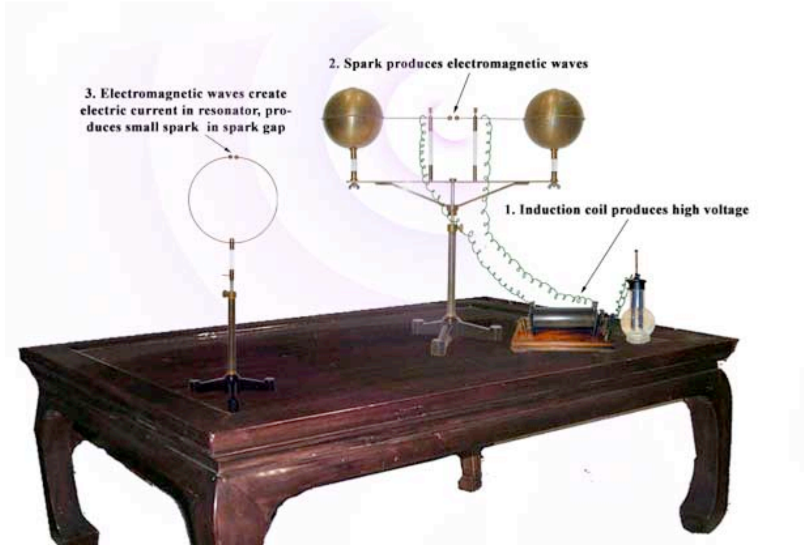
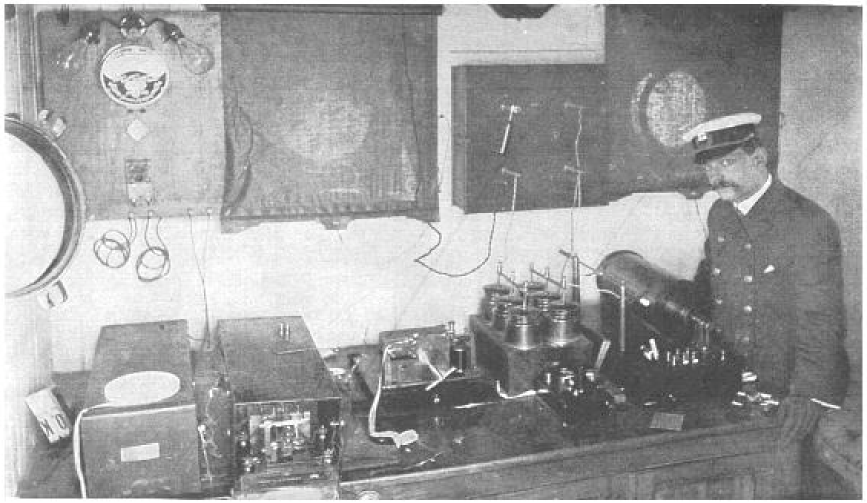
Introduction
The history of Mobile Radio (I)

- 1880s: Discovery of Radio Waves by Heinrich Hertz
- 1900s: First radio communication on ocean vessels
- 1910: Radios requried on all ocean vessels

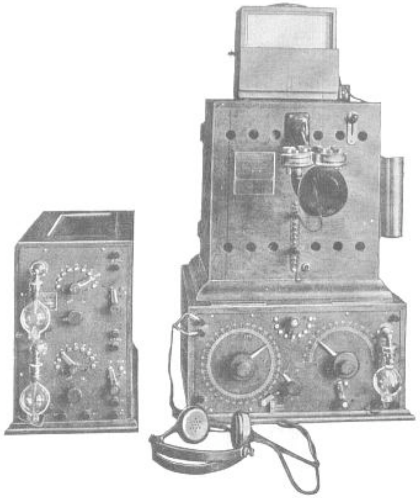




THE "MARCONI MAN" AND HIS INSTRUMENTS

Introduction
The history of Mobile Radio (II)

- 1914: Radiotelephony for railroads
- 1918: Radio Transceiver even in war air plane
- 1930s: Radio transceivers for pedestrians: “Walkie-Talkie”
- 1940s: Handheld radio transceivers: “Handie-Talkie”


RADIOTELEPHONY APPARATUS

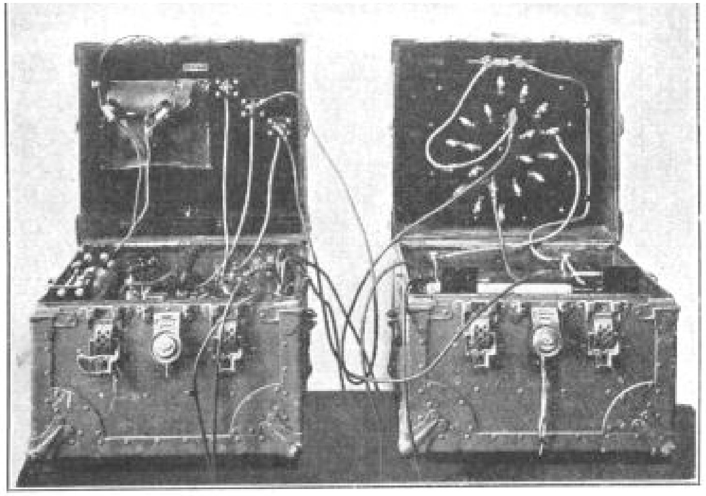
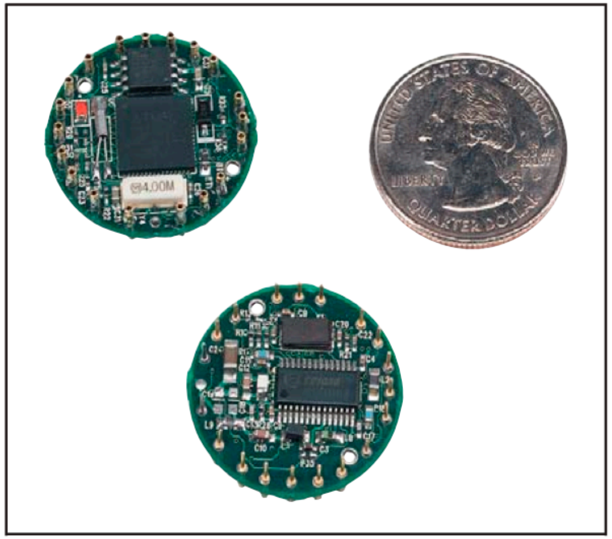


Fig. 108.—U. S. Signal Corps pack sets shown open and closed. Receiving apparatus on the left.

Introduction
The History of Mobile Radio (III)

- 1970s Vint Cerfs Stanford Research Institute (SRI) Van
  – First mobile packet radio tranceivers
- ...

- 2000s Wireless sensor coin sized sensor nodes Mica2dot from California based Crossbow company



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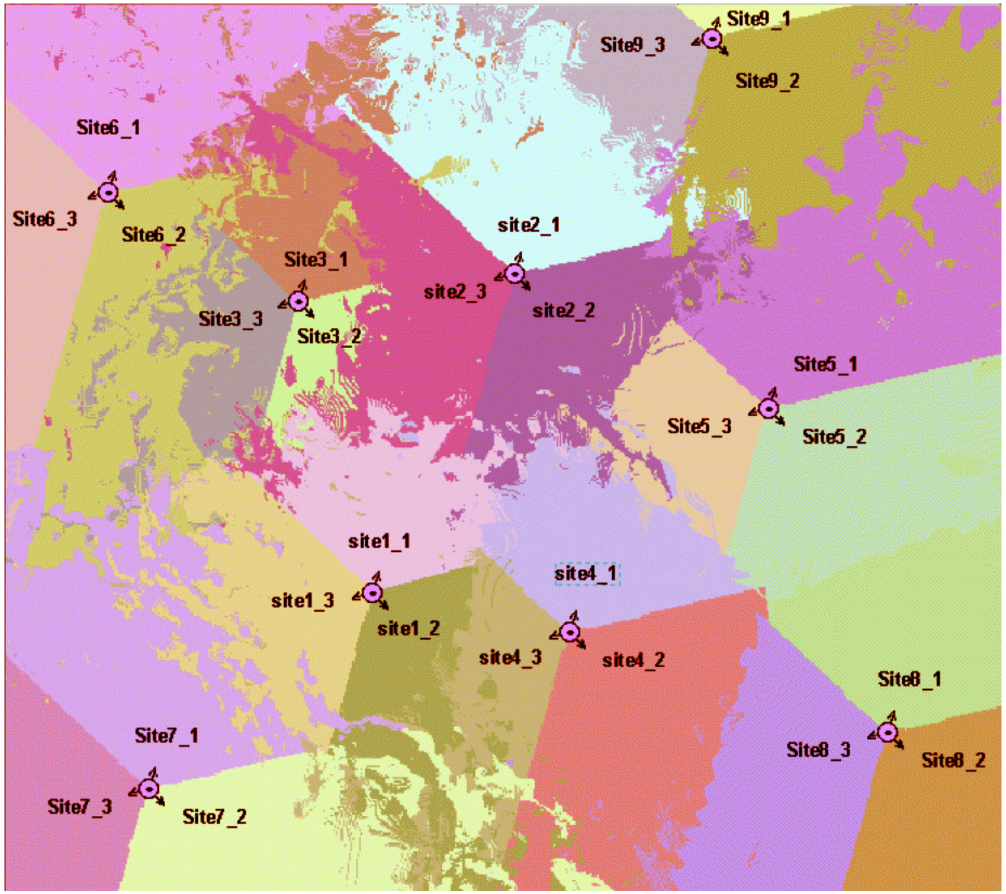
Wireless Networks in a Nutshell
Cellular Networks

- Static base stations
  - devide the field into cells
- All radio communication is only
  - between base station and client
  - between base stations
    - usually hardwired
- Mobility:
  - movement into or out off a cell
  - sometimes cell sizes vary dynamically (depending on the number of clients - UMTS)
- Main problems:
  - Cellular Handoff
  - Location Service



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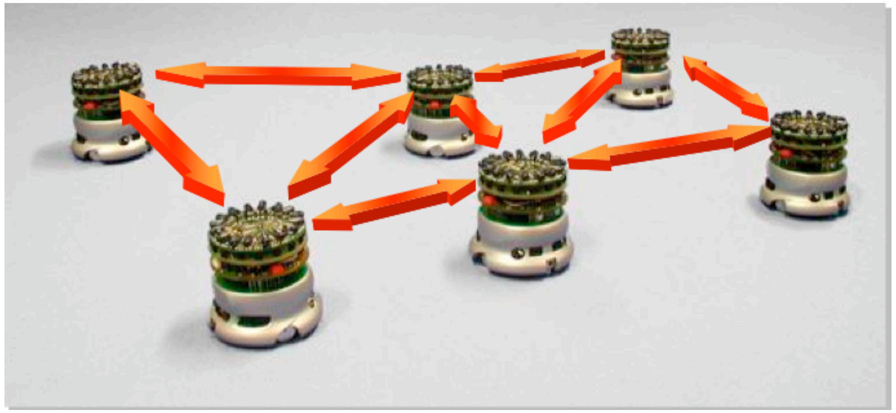
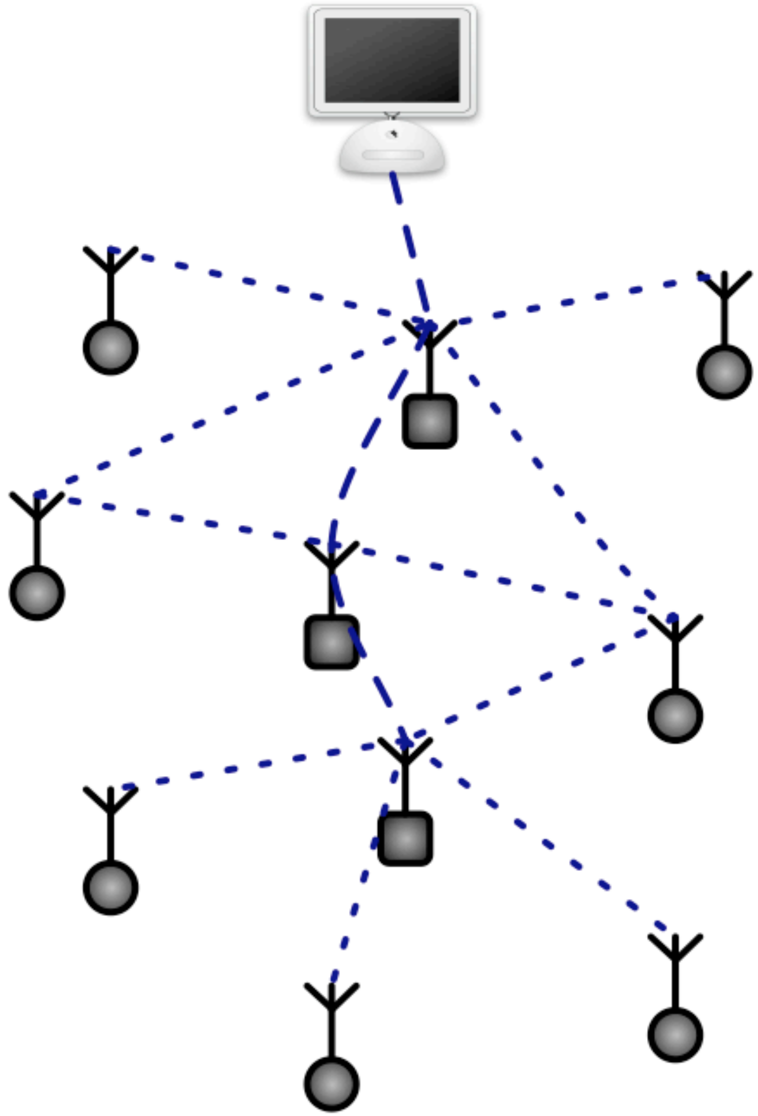
- MANET:
  - self-configuring network of mobile nodes
  - nodes are routers and clients
  - no static infrastructure
  - network adapts to changes induced by movement
- Positions of clients
  - in most applications not available
  - exceptions exist
- Problems:
  - Find a multi-hop route between message source and target
  - Multicast a message
  - Uphold the network routing tables



Wireless Networks in a Nutshelf
Wireless Sensor Networks

- Sensor nodes
  - spacially distributed
  - equipped with sensors for
    - temperature, vibration, pressure, sound, motion, ...
- Base stations
  - for collecting the information and control
  - possibly connected by ad-hoc-network
- Main task
  - Read out the sensor information from the field
- Main problem
  - Energy consumption
    - nodes are sleeping most of the time



Mobility in Wireless Networks

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Mobility Patterns: Pedestrian

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- Characteristics:
  - Slow velocity
  - Dynamics from obstacles obstructing the signal
    - signal change a matter of meters
  - Applies for people or animals
  - Complete use of two-dimensional plane
  - Chaotic structure
  - Possible group behavior
  - Limited energy ressources
- Examples
  - Pedestrians on the street or the mall
  - Wild life monitoring of animals
  - Radio devices for pets

Mobility Patterns: Marine and Submarine

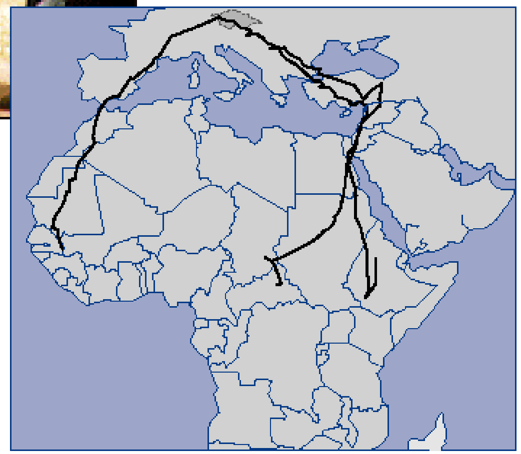
- Characteristics
  - Speed is limited due to friction
  - Two-dimensional motion
    - submarine: nearly three-dimensional
  - Usually no group mobility
    - except conoys, fleets, regattas, fish swarms
- Radio communication
  - On the water: nearly optimal
  - Under the water: terrible
    - solution: long frequencies or sound

Mobility Patterns: Earth bound vehicles

- Mobility by wheels
  - Cars, railways, bicycles, motor bikes etc.
- Features
  - More speed than pedestrians
  - Nearly 1-dimensional mobility
    - because of collisions
  - Extreme group behavior
    - e.g. passengers in trains
- Radio communication
  - Reflections of environment reduce the signal strengths dramatically
    - even of vehicles heading towards the same direction

Mobility Patterns: Aerial Mobility

- Examples:
  - Flying patterns of migratory birds
  - Air planes
- Characteristics
  - High speeds
  - Long distance travel
    - problem: signal fading
  - No group mobility
    - except bird swarms
  - Movement two-dimensional
    - except air combat
- Application
  - Collision avoidance
  - Air traffic control
  - Bird tracking

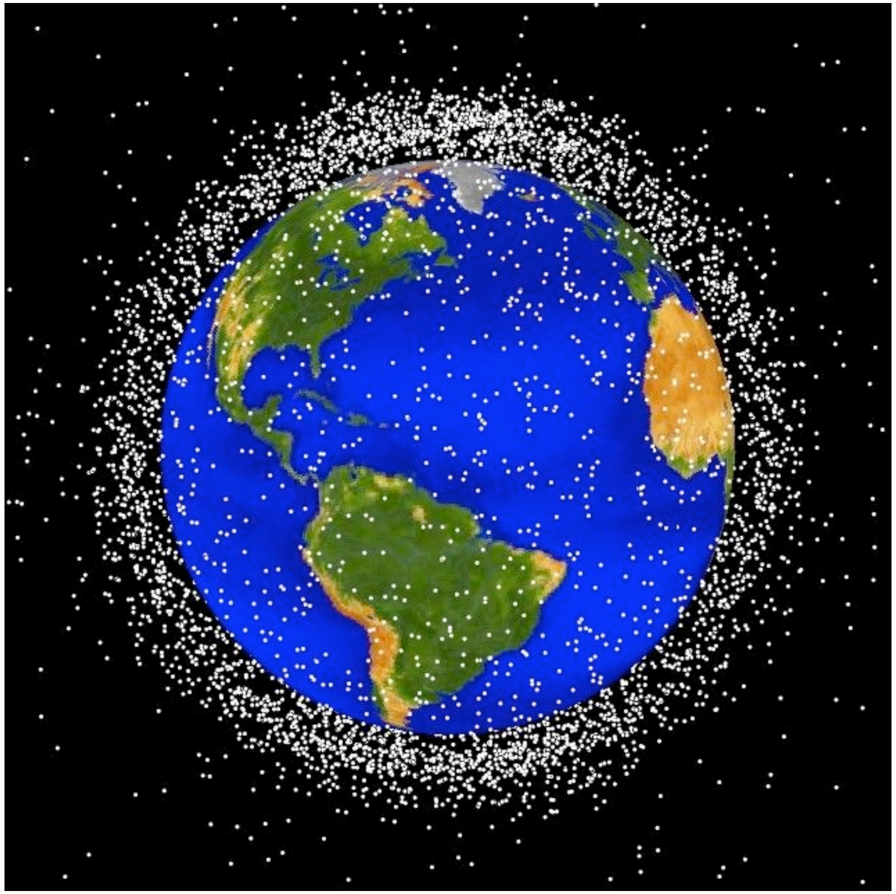


Mobility Patterns: Medium Based

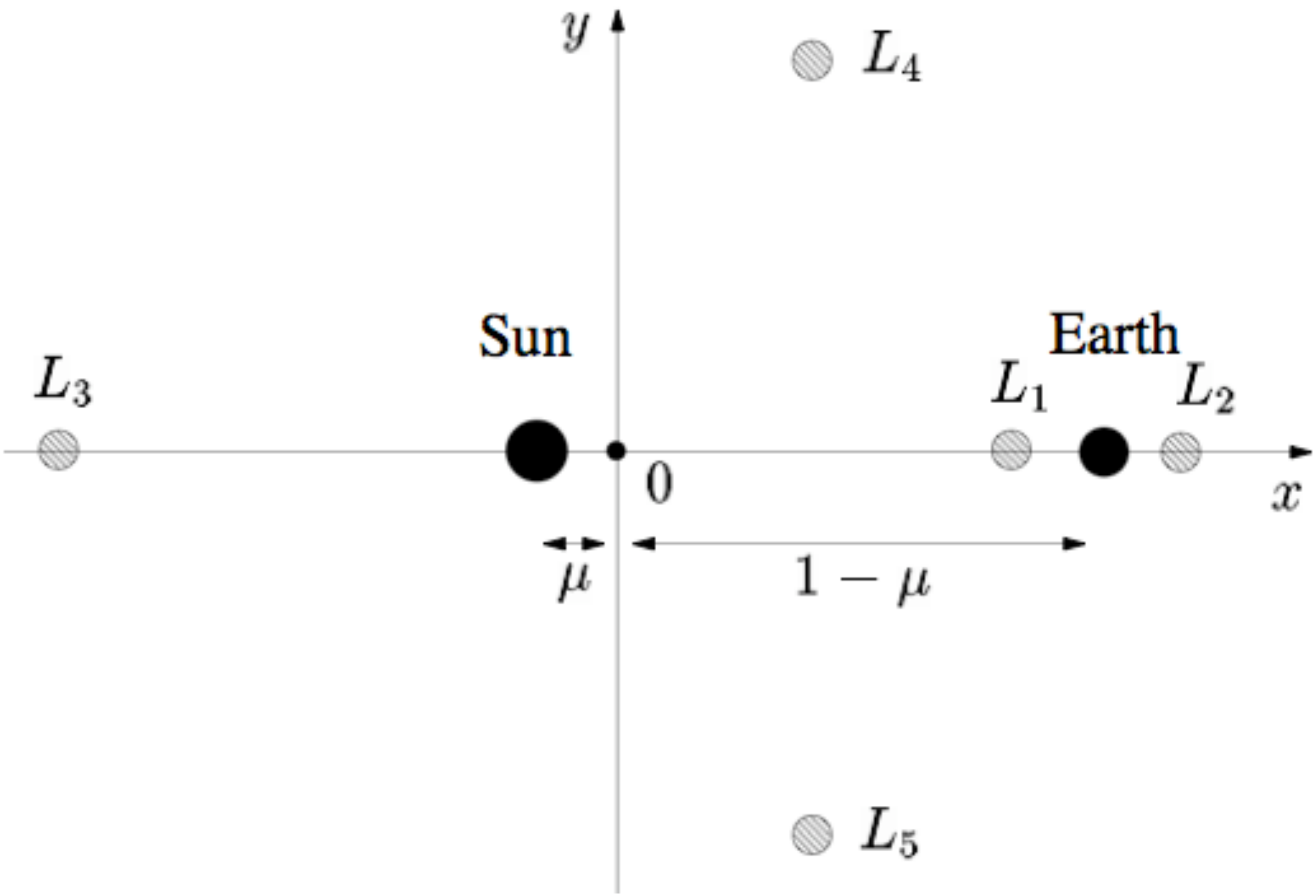
- Examples:
  - Dropwindsondes in tornadoes/hurricanes
  - Drifting buoyes
- Chararcteristics of mobility
  - Determined by the medium
  - Modelled by Navier-Stokes-equations
  - Medium can be 1,2,3-dimensional
  - Group mobility may occur
    - is unwanted, because no information
  - Location information is always available
    - this is the main purpose

Mobility Patterns: Outer Space

- Characterization
  - Acceleration is the main restriction
  - Fuel is limited
  - Space vehicles drift through space most of the time
  - Non-circular orbits possible
  - Mobility in two-planet system is chaotic
  - Group behavior in future systems
- Radio communication
  - Perfect signal transmission
  - Energy supply usually no problem (solar paddles)



Mobility Patterns
Outer Space: Chaotic Mobility



Mobility Patterns
Outer Space: Chaotic Mobility
[Junge et al. 2002]

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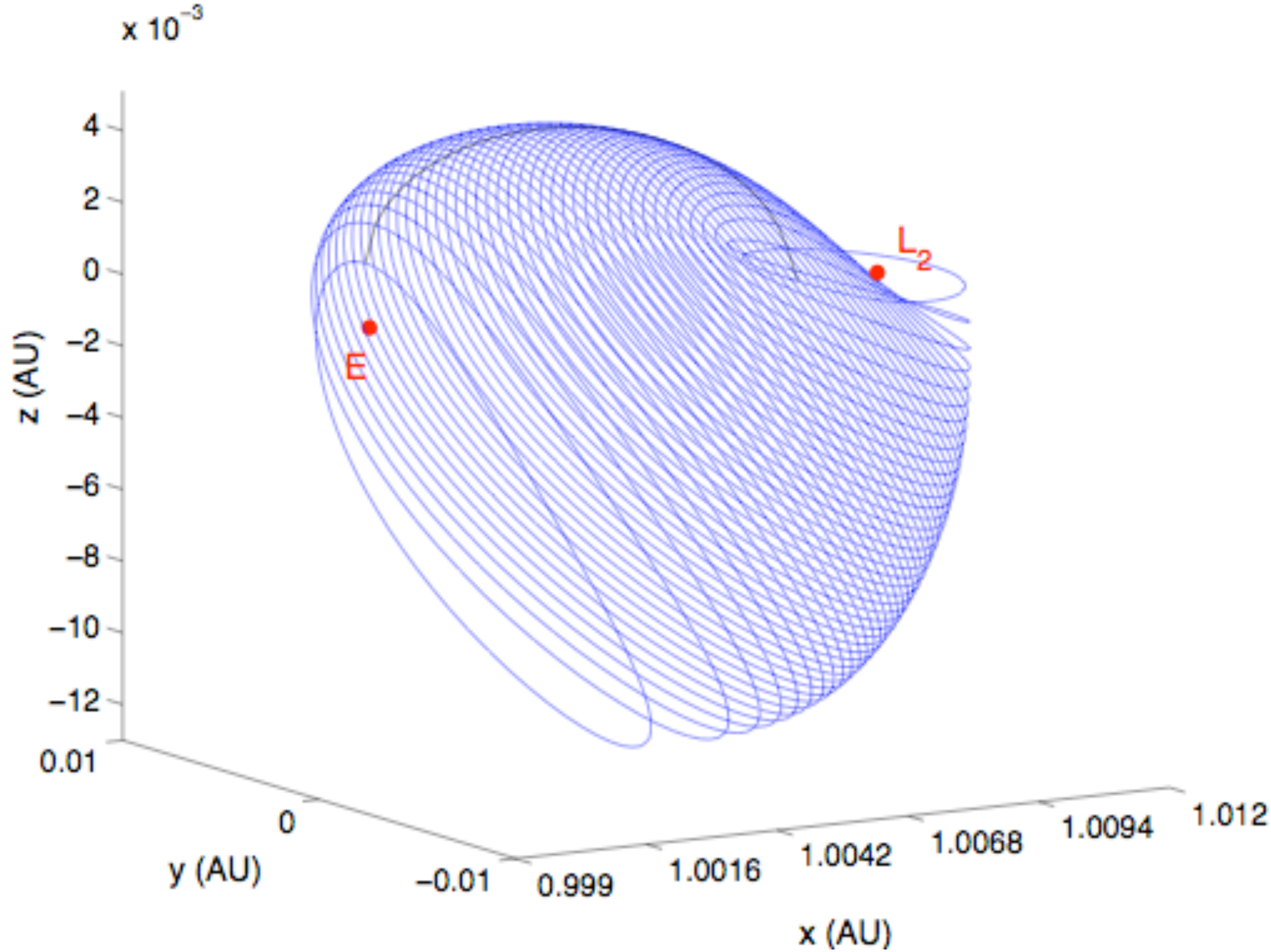
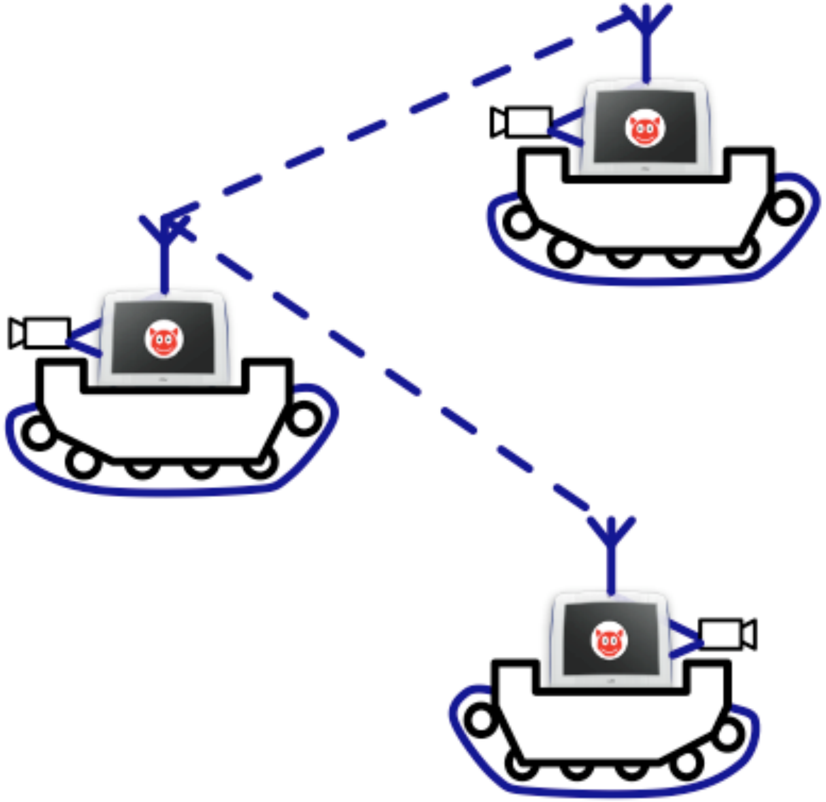


Mobility Patterns: Robot Motion

- Scenario
  - any above
- Main difference
  - Mobility behavior given by the programmer
- Predictability?
  - depends on programmer and environment
- Problem
  - Robot motion designer don't care about communication
  - Robot goals and wireless communication may conflict
- Solution
  - Find a compromise
  - "Smart Team Project"



Mobility Patterns: Characterization

- Group behavior
  - Can be exploited for radio communication
- Limitations
  - Speed
  - Acceleration
- Dimensions
  - 1, 1 1/2, 2, 2 1/2, 3
- Predictability
  - Simulation model
  - Completely erratic
  - Described by random process
  - Deterministic (selfish) behavior

Mobility Patterns: Measuring Mobility

- How to measure mobility?
  - Use a wireless sensor network!
- Localization in wireless networks
  - Signal strength
  - Time of arrival
  - Time difference of arrival
  - Angle of arrival
  - Hop count based techniques
  - Cell information
- Global Positioning System (GPS)
  - (predecessor of Galileo)
  - Works very well on the planet’s surface
    - Perfect for cars, trucks, trains, bikes, pets, cows, zebras,...
    - Not in offices, shopping malls, subway systems, tunnels,underwater
  - Not always available
    - Energy consumption, cost, distances too short

Mobility in Wireless Networks

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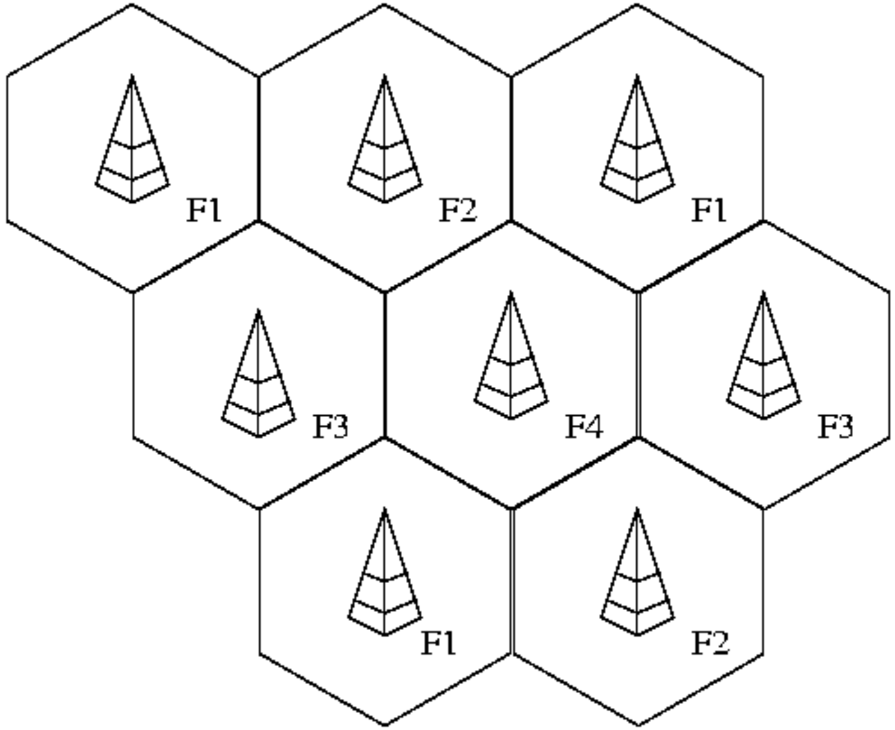
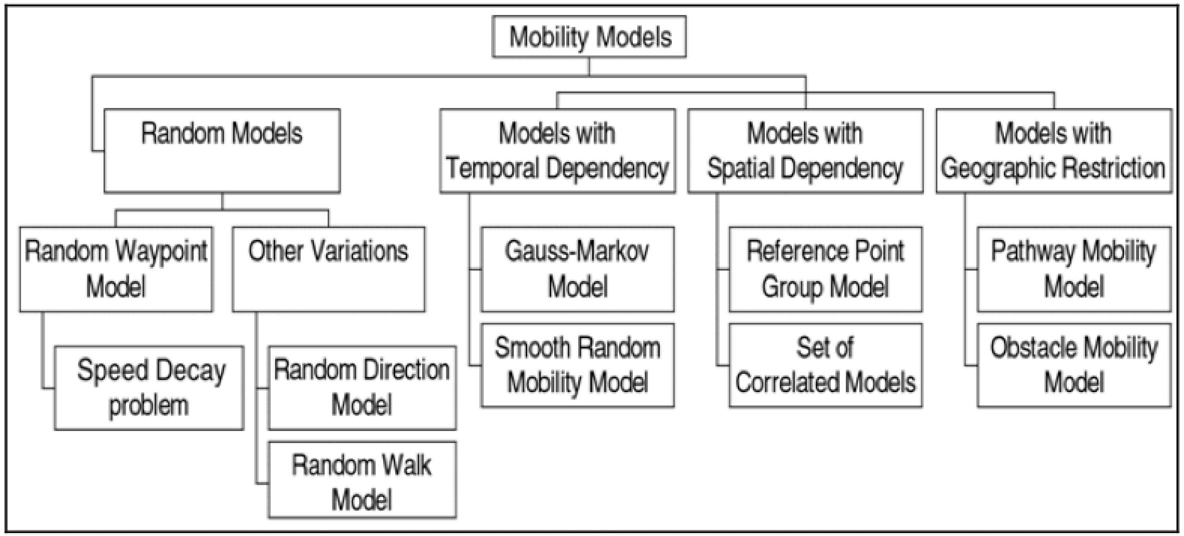
Models of Mobility
Cellular Mobility

- Random Walk
  - A node stays in a cell or changes to a neighbored cell with a given probability
  - Memoryless model for handoff
- Trace Based
  - Large records of real mobility patterns of users
  - Simulate handoff
- Fluid Flow
  - Macroscopic level
  - Mobility is modeled like a fluid/gas in a pipe
  - works very well for highways
  - insufficient for individual movements including stopping and starting



Models of Mobility
Random Trip Mobility

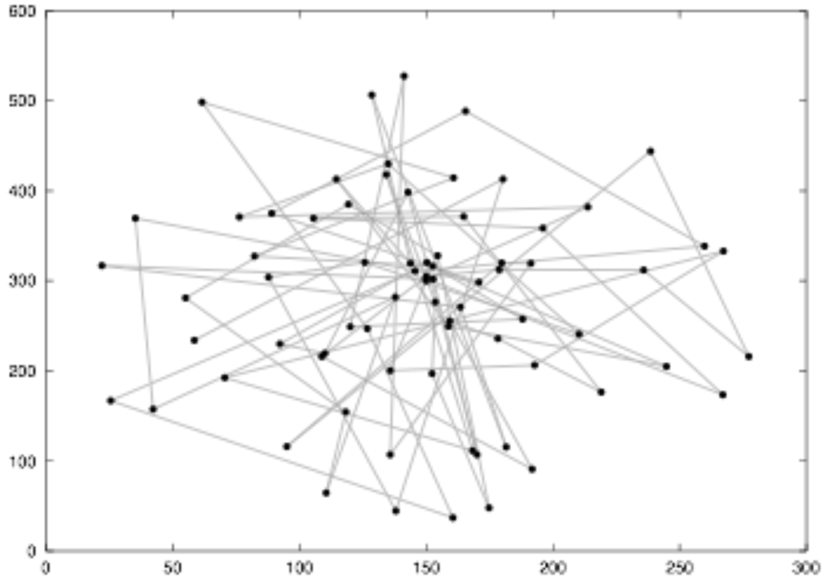
- Random Walk
- Random Waypoint
- Random Direction
- Boundless Simulation Area
- Gauss-Markov
- Probabilistic Version of the Random Walk Mobility
- City Section Mobility Model



[Bai and Helmy in Wireless Ad Hoc Networks 2003]

Models of Mobility
Brownian Motion, Random Walk

- Brownian Motion (microscopic view)
  - speed and direction are chosen randomly in each time step (uniformly from $[v_{\min}, v_{\max}]$ and $[0, \pi]$)
- Random Walk
  - macroscopic view
  - memoryless
  - e.g., for cellular networks
  - movement from cell to cell
  - choose the next cell randomly
  - residual probability



[Camp et al. 2002]

Random Waypoint Mobility Model

[Johnson, Maltz 1996]

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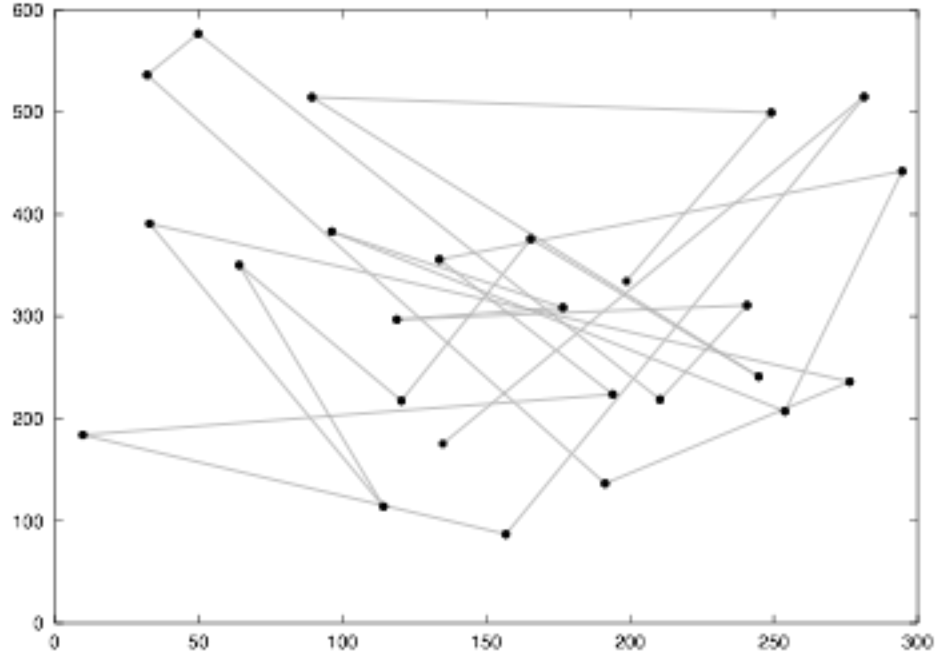
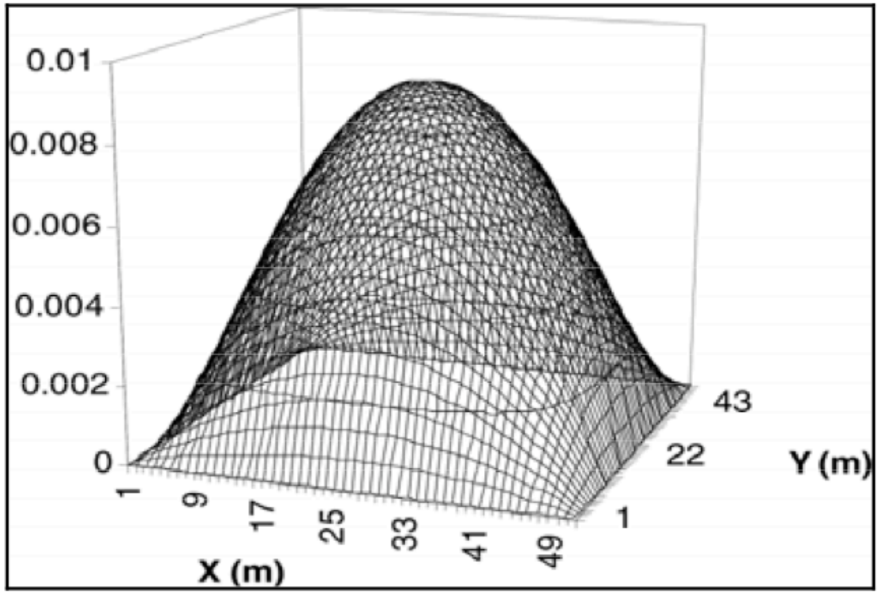
- move directly to a randomly chosen destination
- choose speed uniformly from $[v_{\min}, v_{\max}]$
- stay at the destination for a predefined pause time



[Camp et al. 2002]

Models of Mobility
Problems of Random Waypoint

- In the limit not all positions occur with the same probability
- If the start positions are uniformly at random
  - then the transient nature of the probability space changes the simulation results
- Solution:
  - Start according the final spatial probability distribution

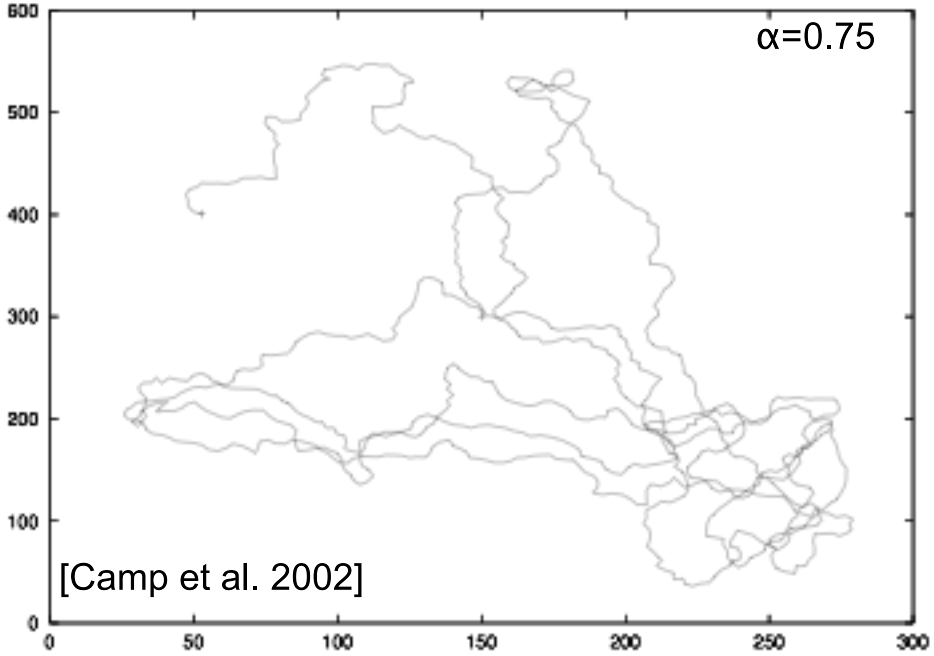


Models of Mobility
Gauss-Markov Mobility Model

[Liang, Haas 1999]

- adjustable degree of randomness
- velocity: $v_n = \alpha v_{n-1} + (1-\alpha)\overline{v} + \sqrt{1-\alpha^2} v_{X_{n-1}}$
- direction: $d_n = \alpha d_{n-1} + (1-\alpha)\overline{d} + \sqrt{1-\alpha^2} d_{X_{n-1}}$

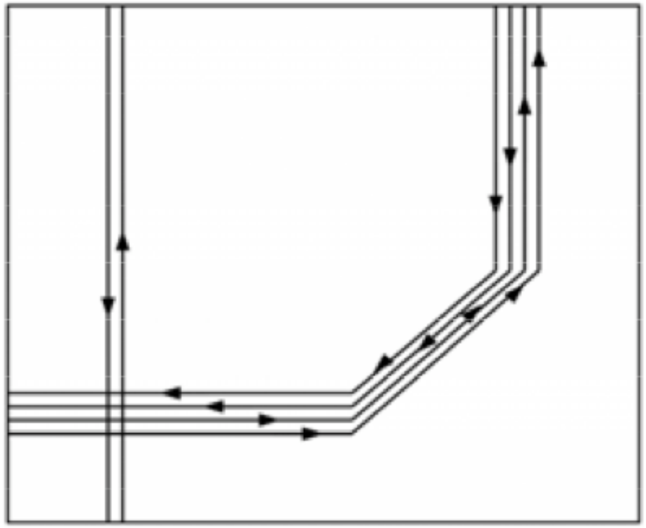
tuning factor — mean — random variable gaussian distribution

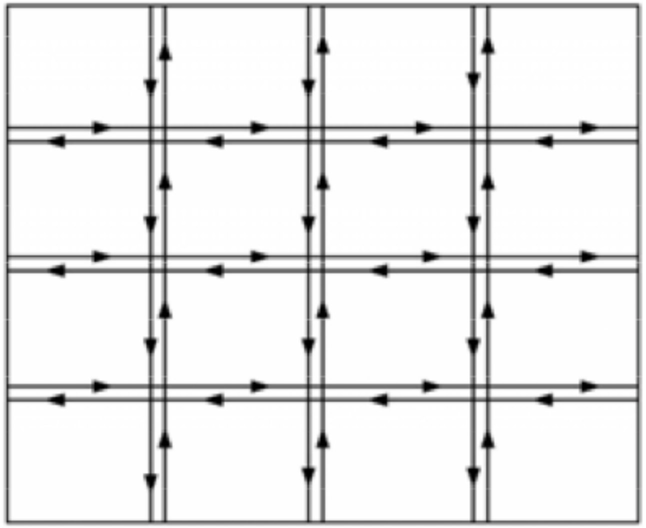


[Camp et al. 2002]

Models of Mobility
City Section and Pathway

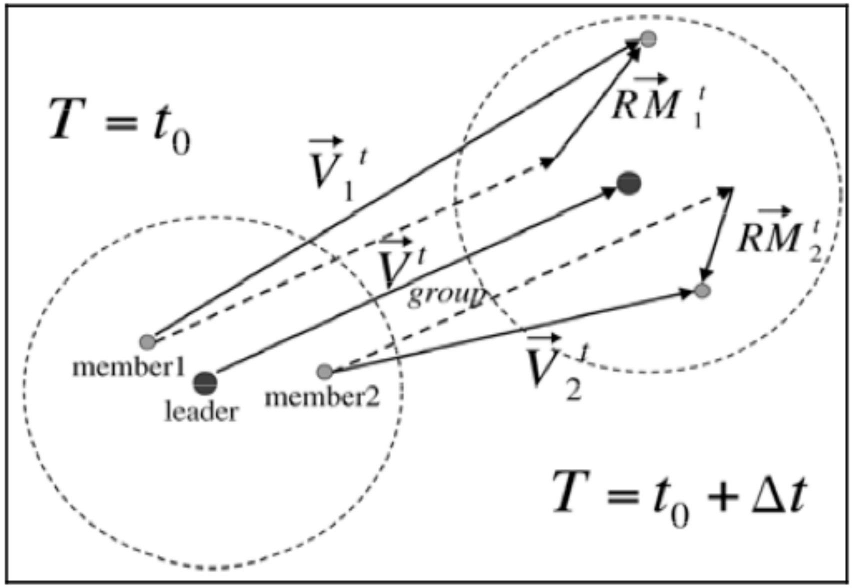
- Mobility is restricted to pathways
  - Highways
  - Streets
- Combined with other mobility models like
  - Random walk
  - Random waypoint
  - Trace based
- The path is determined by the shortest path between the nearest source and target

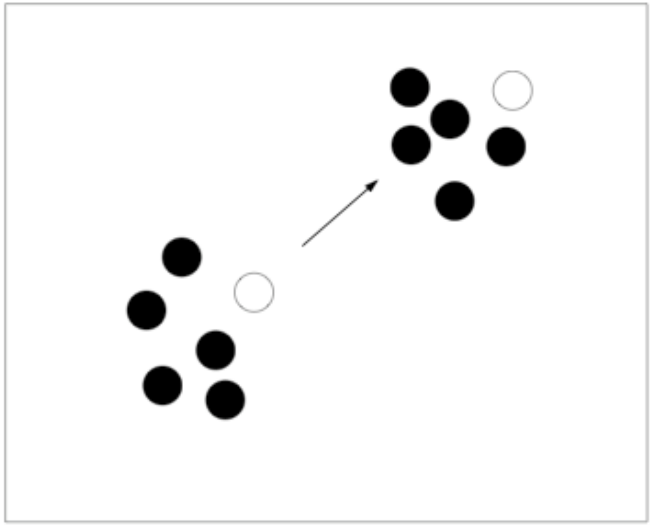




Models of Mobility: Group-Mobility Models

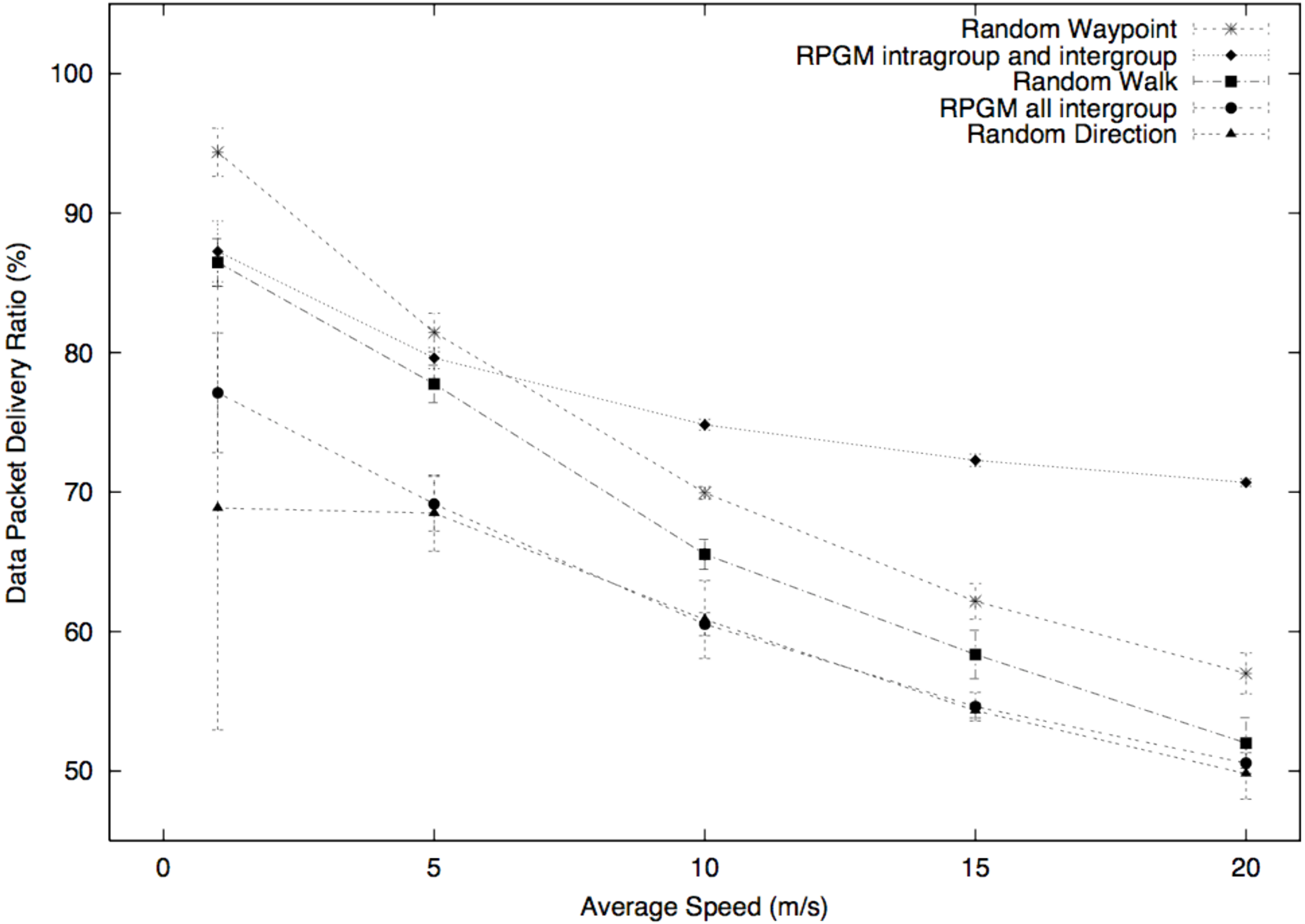
- Exponential Correlated Random
  - Motion function with random deviation creates group behavior
- Column Mobility
  - Group advances in a column
    - e.g. mine searching
- Reference Point Group
  - Nomadic Community Mobility
    - reference point of each node is determined based on the general movement of this group with some offset
  - Pursue Mobility
    - group follows a leader with some offset





Models of Mobility

- The influence of the type of mobility is enormous



Models of Mobility
Combined Mobility Models

[Bettstetter 2001]

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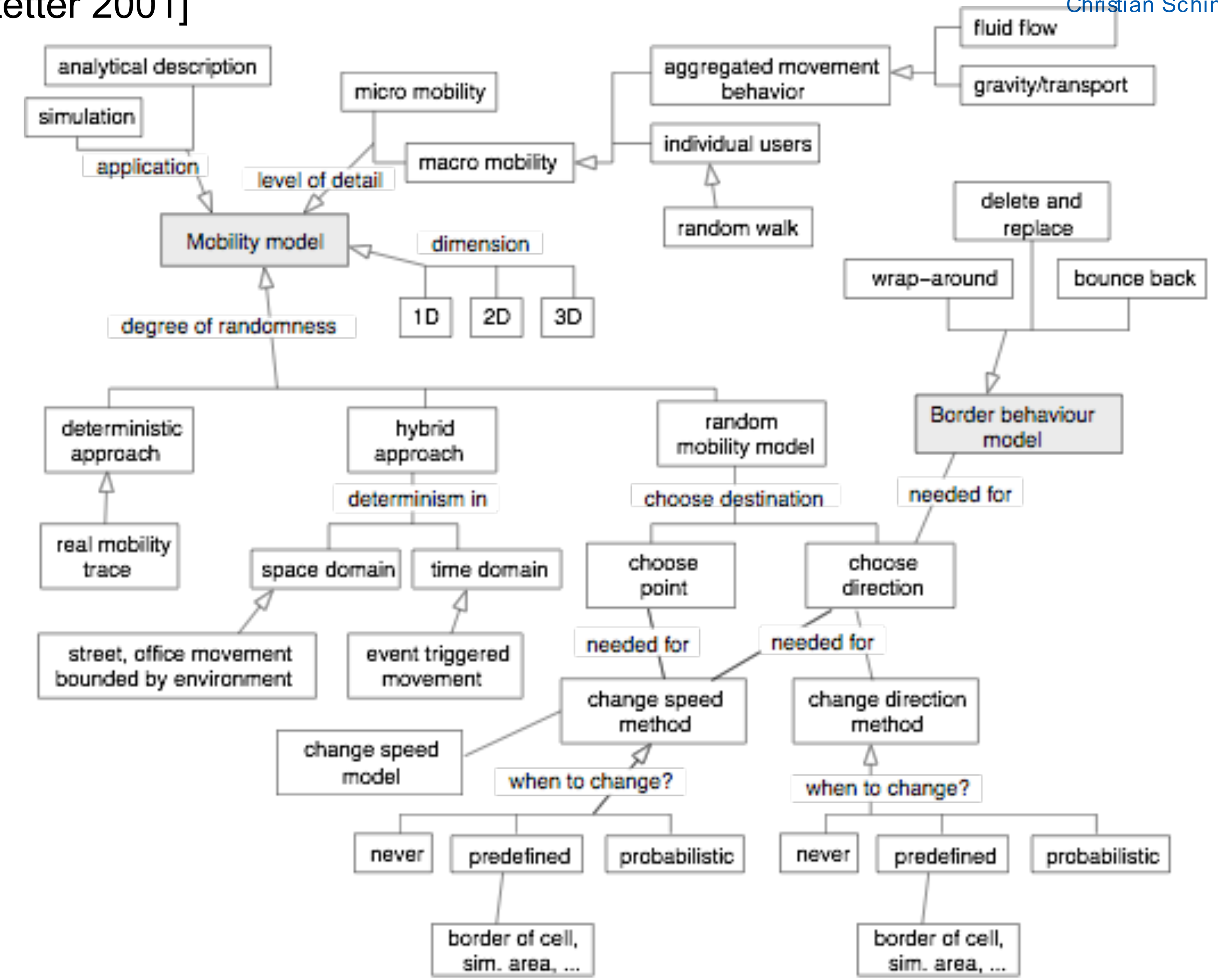
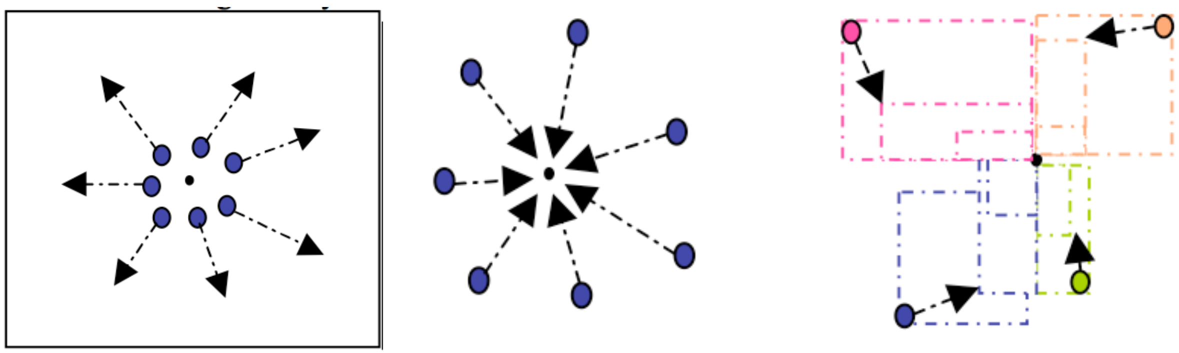


Models of Mobility: Non-Recurrent Models

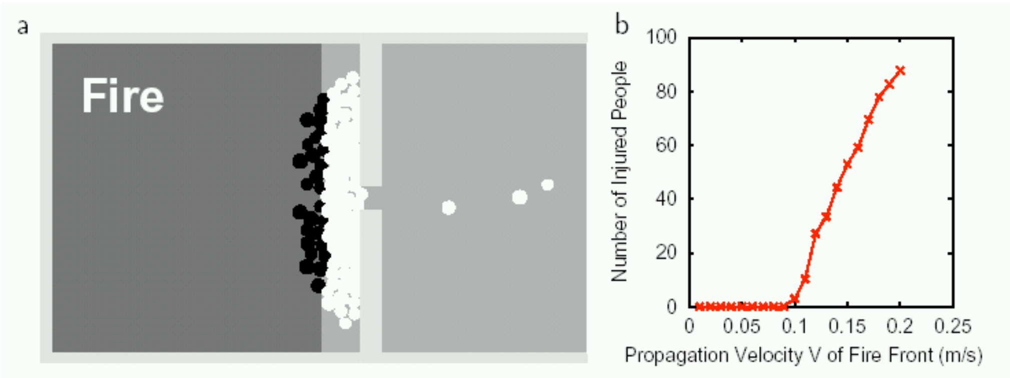
- Kinetic data structures (KDS)
  - framework for analyzing algorithms on mobile objects
  - mobility of objects is described by pseudo-algebraic functions of time.
  - analysis of a KDS is done by counting the combinatorial changes of the geometric structure
- Usually the underlying trajectories of the points are described by polynomials
  - In the limit points leave the scenario
- Other models [Lu, Lin, Gu, Helmy 2004]
  - Contraction models
  - Expansion models
  - Circling models

This room is for rent.



Models of Mobility: Particle Based Mobility

- Motivated by research on mass behavior in emergency situations
  - Why do people die in mass panics?
- Approach of [Helbing et al. 2000]
  - Persons are models as particles in a force model
  - Distinguishes different motivations and different behavior
    - Normal and panic



Models of Mobility: Particle Based Mobility: Pedestrians

- Speed:
  - f: sum of all forces
  - ξ: individual fluctuations

$$v_i(t) := \frac{dx_i(t)}{dt}$$

$$m_i \cdot \frac{dv_i(t)}{dt} = f_i(t) + \xi_i(t) \ ,$$

- Target force:
  - Wanted speed v^0 and direction e^0

$$\frac{v_i^0 e_i^0 - v_i(t)}{\tau_i}$$

- Social territorial force

$$f_{ij}^{soc}(t) = A_i \quad e^{\frac{r_{ij}-d_{ij}}{B_i}} \quad n_{ij} \quad \left(\lambda_i + (1-\lambda_i)\frac{1+\cos(\phi_{ij})}{2}\right)$$

- Attraction force (shoe store)

$$f_{ij}^{att}(t) = -C_i \quad n_{ij}$$

$$n_{ij}(t) = \frac{x_i(t) - x_j(t)}{d_{ij}(t)}$$

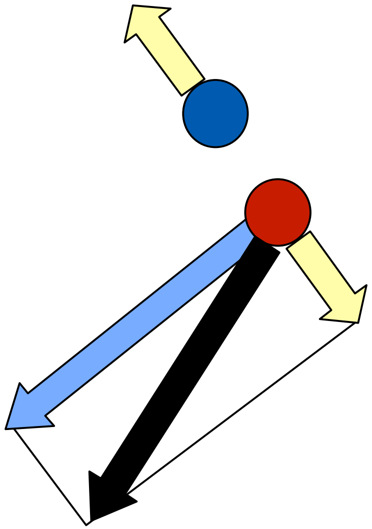
- Pedestrian force (overall):

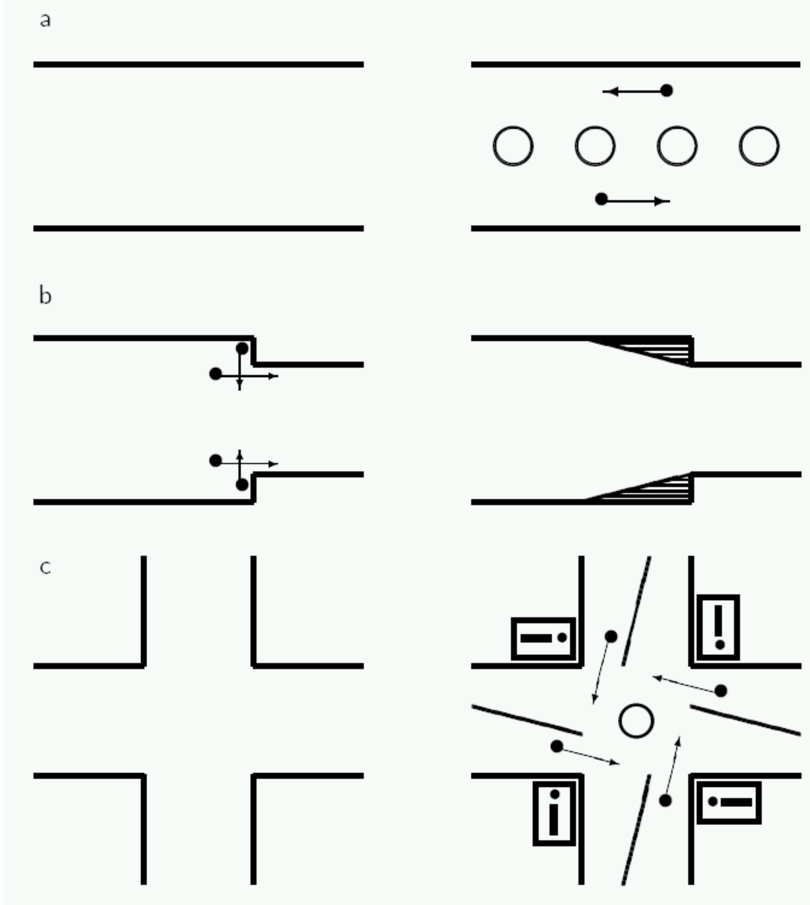
$$f_i(t) = \frac{v_i^0(t)e_i^0(t) - v_i(t)}{\tau_i} + \sum_{j \neq i} f_{ij}^{soc}(t) + \sum_{j \neq i} f_{ij}^{att}(t) + \sum_k f_{ij}^{att}(t) + \sum_b f_{ib}^{obst}(t)$$

Models of Mobility: Particle Based Mobility: Pedestrians

- This particle based approach predicts the reality very well
  - Can be used do design panic-safe areas

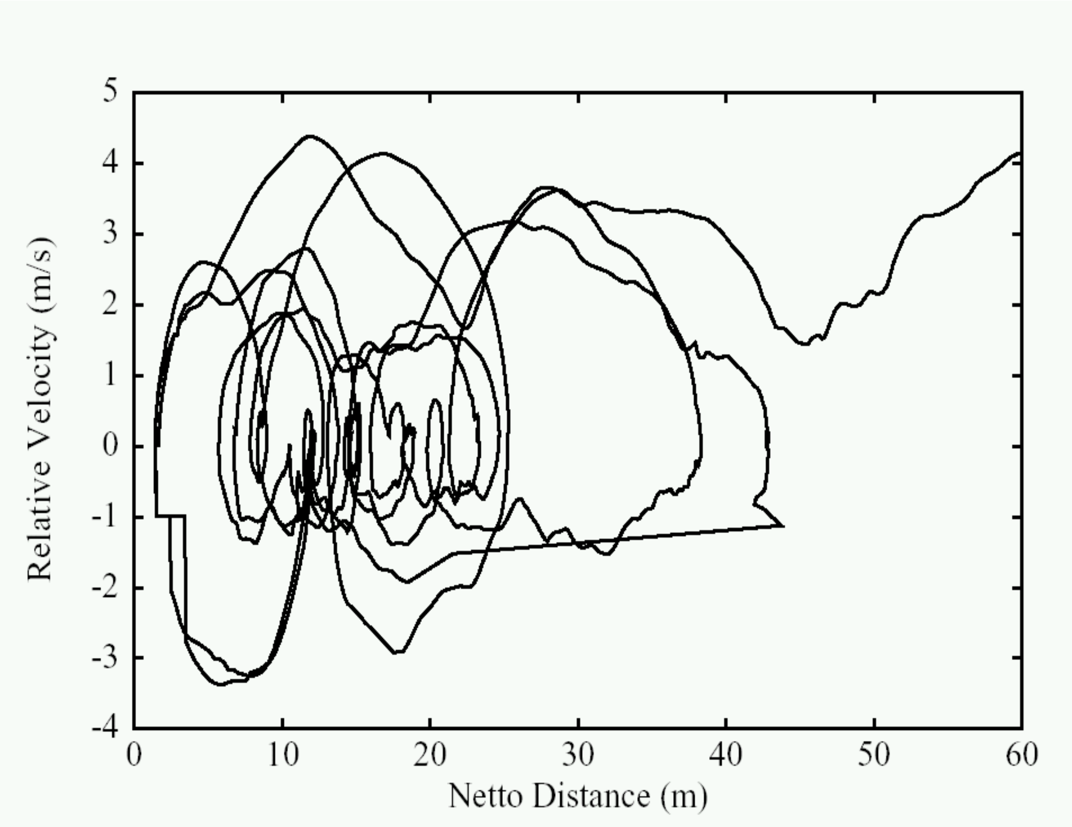
- Bottom line:
  - All persons behave like mindless particles





Models of Mobility
Particle Based Mobility: Vehicles

- Vehicles use 1-dimensional space
- Given
  - relative distance to the predecessor
  - relative speed to the predecessor
- Determine
  - Change of speed



Models of Mobility:
Particle Based Mobility: Pedestrians

- Similar as in the pedestrian model

$$\frac{dv_i(t)}{dt} = f_i^0(t) + \sum_{j \neq i} f_{ij}(x_i(t), v_i(t), x_j(t), v_j(t)) + \xi_i(t)$$

- Each driver watches only the car in front of him
- No fluctuation

$$\frac{dv_i(t)}{dt} = f_i^0(t) + f_{i,i-1}(x_i(t), v_i(t), x_{i-1}(t), v_{i-1}(t))$$

- $s(v_i) = d_i + T_i\, v_i$, d_i is minimal car distance, T_i is security distance
- $h(x) = x$, if $x>0$ and 0 else, R_i is break factor
- $s_i(t) = (x_i(t)-x_{i-1}(t))$ - vehicle length
- $\Delta v_i = v_i - v_{i-1}$

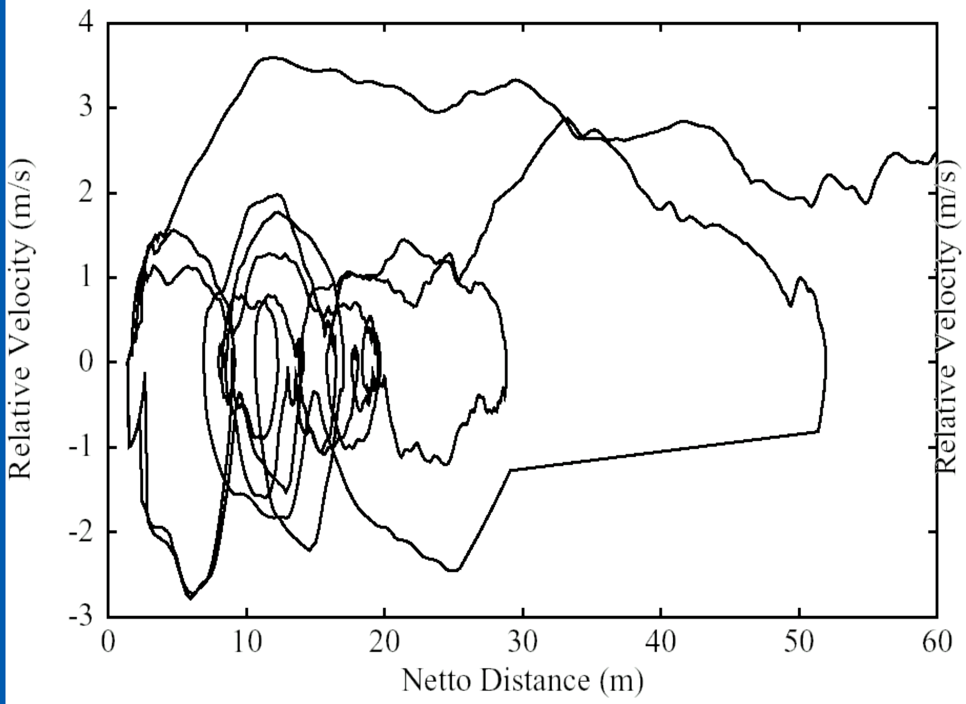
$$f_{i,i-1} = \frac{V_i(t) - v_i^0}{\tau_i} - \frac{\Delta v_i h(\Delta v_i)}{\tau_i'} e^{\frac{s_i(t) - s(v_i)}{R_i'}}$$

- where

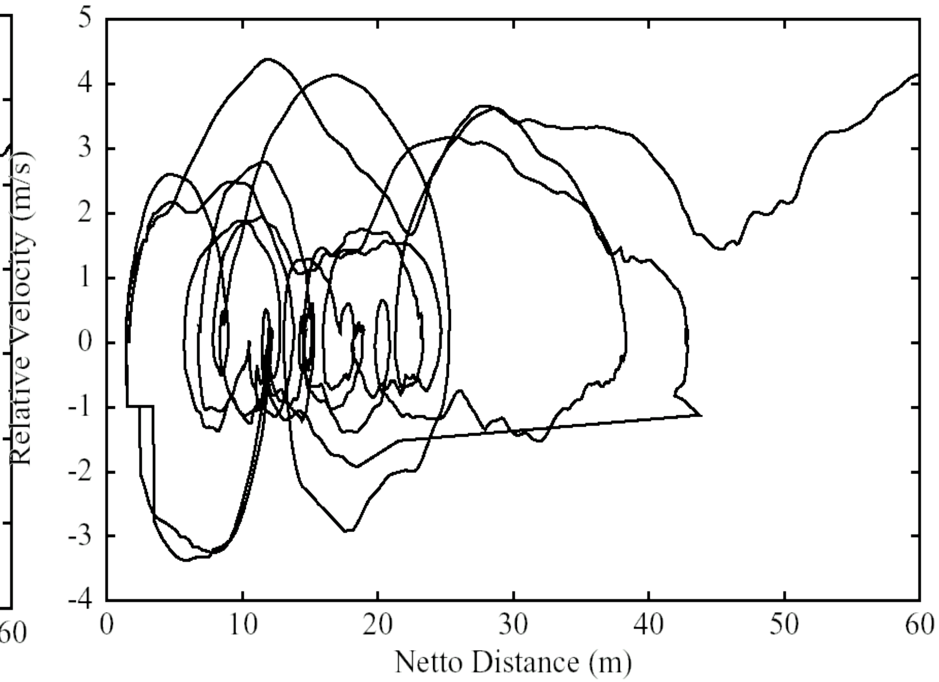
$$V_i(t) = v_i^0 \left((1 - e^{-\frac{s_i(t) - s(v_i(t))}{R_i}} \right)$$

Models of Mobility
Particle Based Mobility: Vehicles

Reality

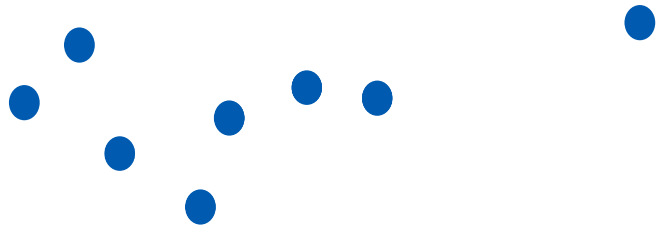


Simulation with GFM

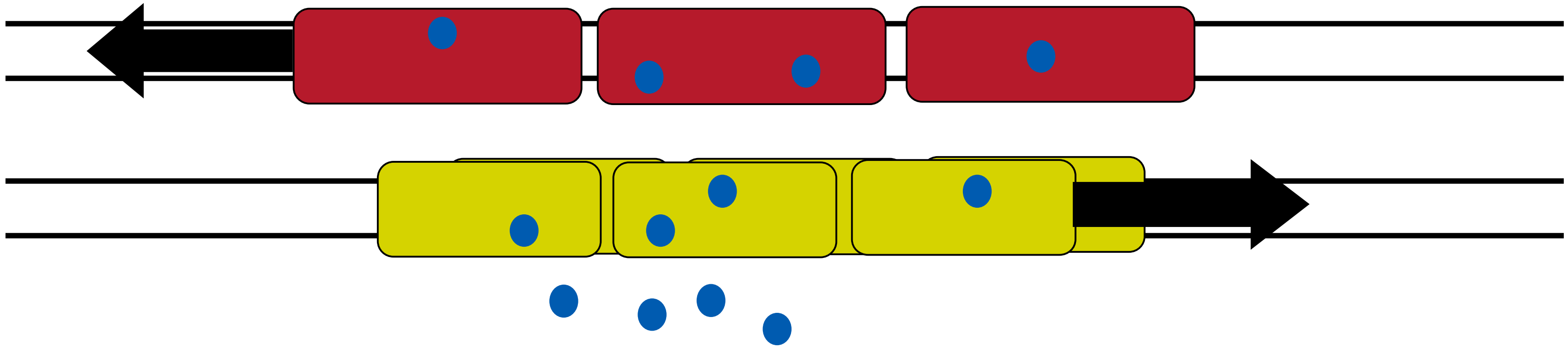


[S., Lukovszki, Rührup, Volbert 2003]

V: Pedestrian Model ↔ Maximum velocity $\leq v_{max}$



A: Vehicular Model ↔ Maximum acceleration $\leq a_{max}$



Modeling
Worst Case Mobility

- Synchronous round model
- In every round of duration Δ
  - Determine positions (speed vectors) of possible comm. partners
  - Establish (stable) communication links
  - Update routing information
  - Do the job, i.e. packet delivery, live video streams, telephone,…

Modeling
Worst Case Mobility: Crowds

- Crowdedness of node set
  - natural lower bound on network parameters (like diversity)

1. Pedestrian (v) model:
   - Maximum number of nodes that can collide with a given node in time span [0,Δ]

$$\text{crowd}_\text{v}(u) := \#\{w \in S \setminus \{u\} \ : \ |u-w|_2 \leq 2v_\text{max}\Delta\}$$

2. Vehicular (a) model:
   - Maximum number of nodes that may move to node u meeting it with zero relative speed in time span [0,Δ]

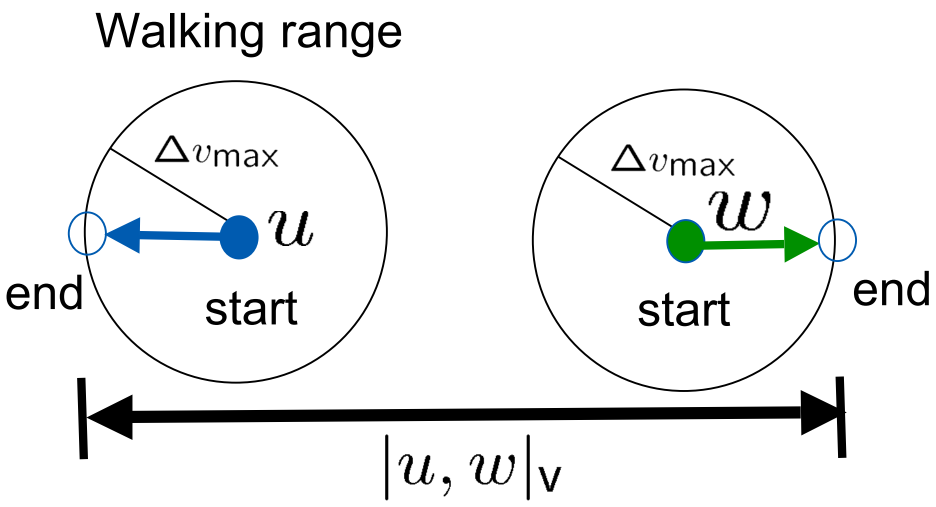
$$\text{crowd}_\text{a}(u) := \#\left\{w \in S \setminus \{u\} \ : \ |u-w|_2 \leq \tfrac{1}{2}a_\text{max}\Delta^2 \text{ and } |u'-w'|_2 \leq \tfrac{1}{2}a_\text{max}\Delta\right\}$$

- $\text{crowd}(S) := \max_{u \in S} \text{crowd}(u)$

Modeling - Worst Case Mobility: Transmission Range of Pedestrian Communication

- Pedestrian model / Velocity bounded model

$$|u,w|_{\mathsf{v}} := 2\Delta v_{\mathsf{max}} + |u-w|_2$$



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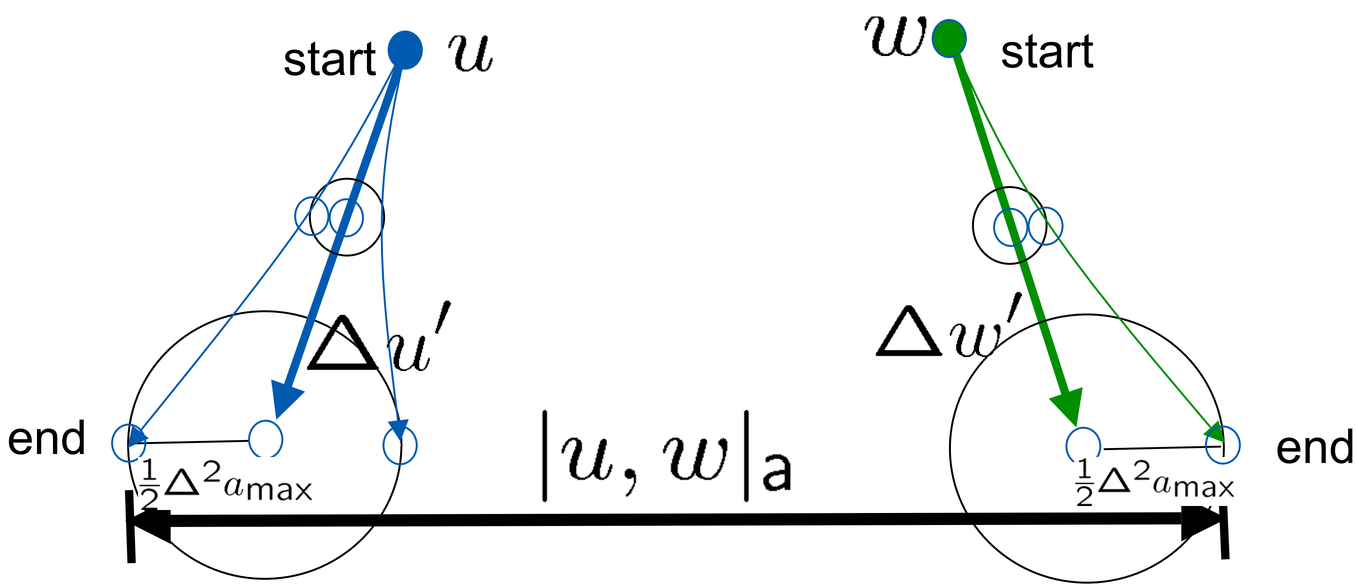
- Vehicular mobility model / Acceleration bounded model

$$|u,w|_{\mathsf{a}} := \max\{|u-w|_2, |u-w+(u'-w')\Delta|_2+a_{\max}\Delta^2\}$$



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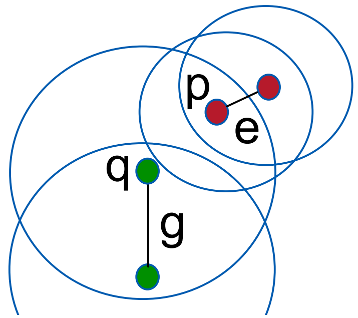
An edge g interferes with edge e in the

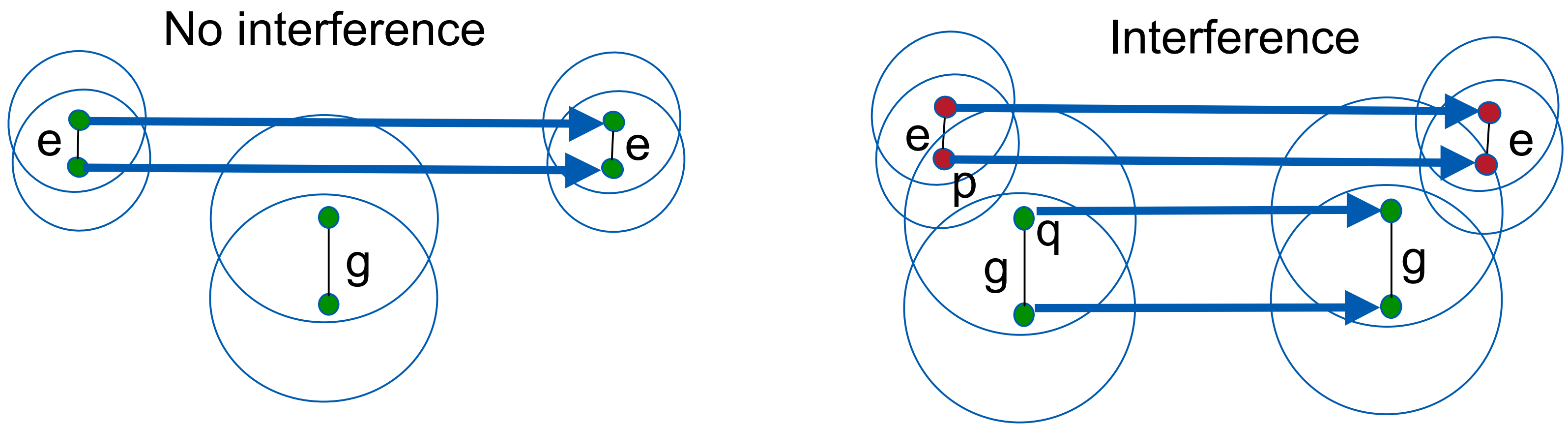
1. Pedestrian (v) model

$$g \in \mathrm{Int}_v(e) \quad :\Longleftrightarrow \quad \exists p \in e, \exists q \in g \ : \ |p-q|_2 \leq |g|_v$$



2. Vehicular (a) model

$$g \in \mathrm{Int}_a(e) \quad :\Longleftrightarrow \quad \exists p \in e, \exists q \in g \ : \ |p-q|_2 \leq |g|_a \text{ and } |p-q+\Delta(p'-q')|_2 \leq |g|_a$$



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Theorem

In both mobility models we observe for all connected graphs G:

$$\mathsf{Int}(G) \;\geq\; \mathsf{crowd}(S) - 1$$

Lemma

In both mobility models α∈{v,a} every mobile spanner is also a mobile power spanner, i.e. for some ß≥1 for all u,w ∈ S there exists a path ($u=p_0,p_1,\ldots,p_k=w$) in G such that:

$$\sum_{i=1}^{k} (|p_{i-1}, p_i|_\alpha)^\beta \;\leq\; c \cdot (|u,w|_\alpha)^\beta$$

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Theorem

Given a mobile spanner G for any of our mobility models then

- for every path system $\mathcal{P}$ in a complete network C
- there exists a path system $\mathcal{P}$‘ in G such that

$$C_{\mathcal{P}'}(G) := \mathcal{O}(C_{\mathcal{P}}(G) \cdot \mathrm{Int}(G) \cdot \log n)$$

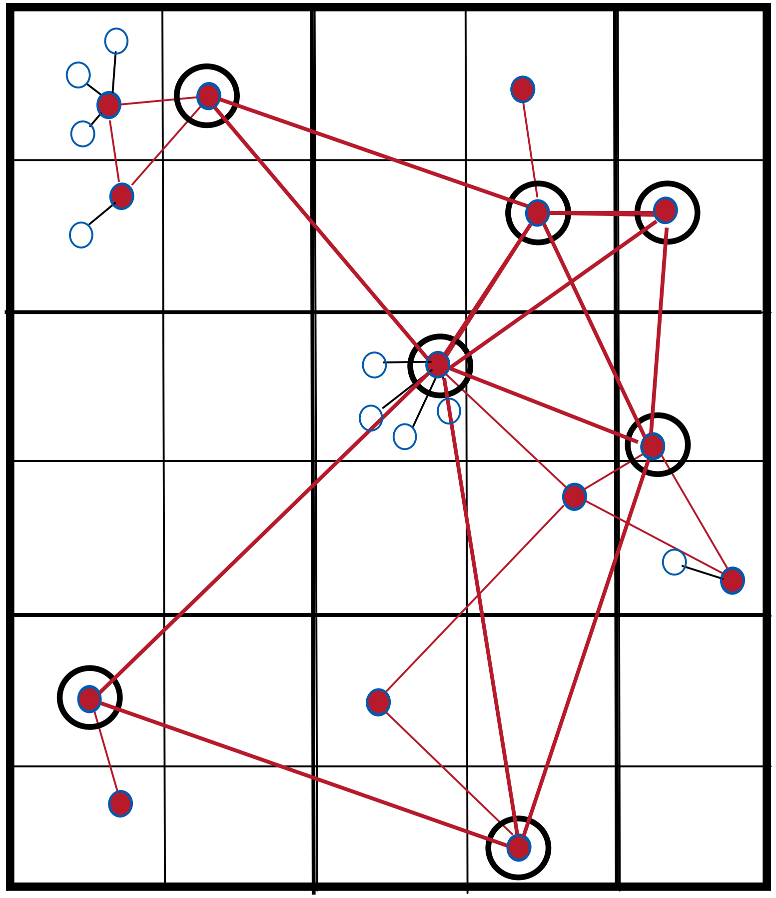
Theorem

The Hierarchical Grid Graph constitutes a mobile spanner with at most O(crowd(V) + log n) interferences (for both mobility models).

The Hierarchical Grid Graph can be built up in O(crowd(V) + log n) parallel steps using radio communication

Modeling - Worst Case Mobility: Hierarchical Grid Graph (pedestrians)

- Start with grid of box size $\Delta\ v_{max}$
- For O(log n) rounds do
  - Determine a cluster head per box
  - Build up star-connections from all nodes to their cluster heads
  - Erase all non cluster heads
  - Connect neighbored cluster heads
  - Increase box size by factor 2
- od



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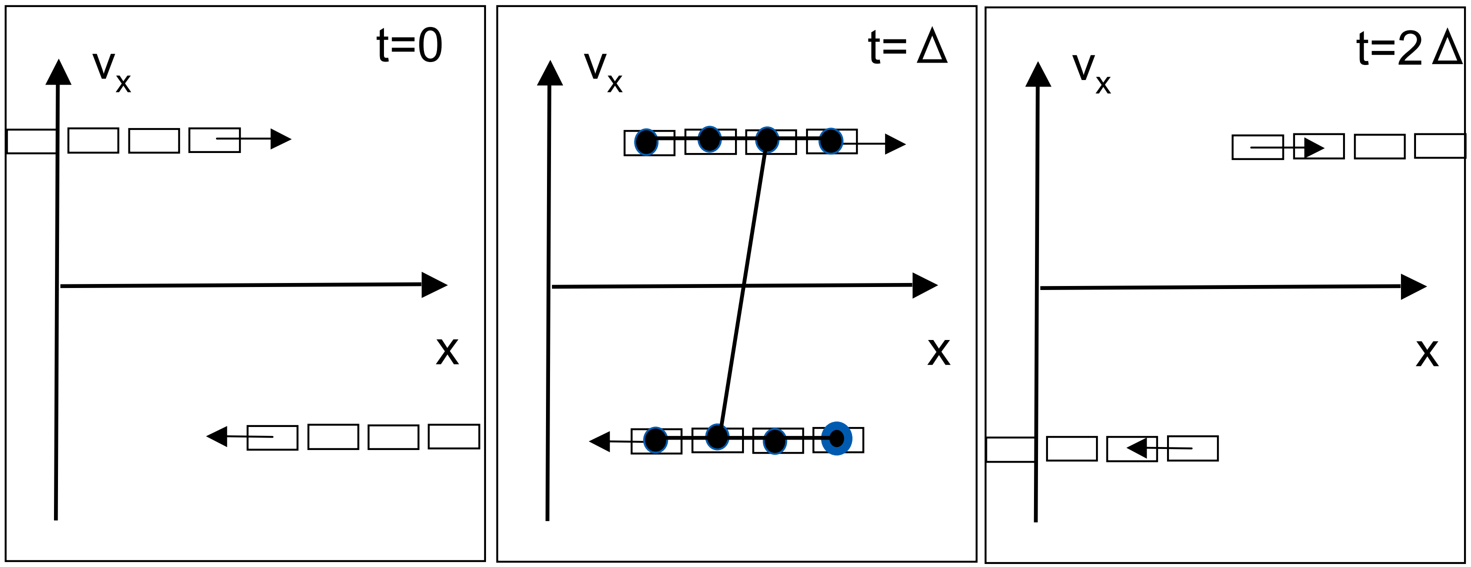
- Algorithm:
  - Consider coordinates $(x(s_i),y(s_i),x(s'_i),y(s'_i))$
  - Start with four-dimensional grid
    - with rectangular boxes of size $(6\Delta^2 a_{max}, 6\Delta^2 a_{max}, 2\Delta v_{max}, 2\Delta v_{max})$
  - Use the same algorithm as before



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Theorem

There exist distributed algorithms that construct a mobile network G for velocity bounded and acceleration bounded model with the following properties:

1. G allows routing approximating the optimal congestion by $O(\log^2 n)$
2. Energy-optimal routing can be approximated by a factor of $O(1)$
3. G approximates the minimal interference number by $O(\log n)$
4. The degree is $O(\text{crowd}(S) + \log n)$
5. The diameter is $O(\log n)$

- Still no routing can satisfy small congestion and energy at the same time!

Mobility in Wireless Networks

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- Introduction
- Wireless Networks in a Nutshelf
  - Cellular Networks
  - Mobile Ad Hoc Networks
  - Sensor Networks
- Mobility Patterns
  - Pedestrian
  - Marine and Submarine
  - Earth bound Vehicles
  - Aerial
  - Medium Based
  - Outer Space
  - Robot Motion
  - Characterization of Mobility Patterns
  - Measuring Mobility Patterns
- Models of Mobility
  - Cellular
  - Random Trip
  - Group
  - Combined
  - Non-Recurrent
  - Particle based
  - Worst Case
- **Discussion**
  - Mobility is Helpful
  - Mobility Models and Reality

Discussion: Mobility is Helpful

- Positive impacts of mobility:
- Improves coverage of wireless sensor networks
- Helps security in ad hoc networks
- Decreases network congestion
  - can overcome the natural lower bound of throughput of $O(\sqrt{n})$
  - mobile nodes relay packets
  - literally transport packets towards the destination node

Discussion: Mobility Models and Reality

- Discrepancy between
  - realistic mobility patterns and
  - benchmark mobility models
- Random trip models
  - prevalent mobility model
  - assume individuals move erratically
  - more realistic adaptions exist
    - really realistic?
  - earth bound or pedestrian mobility in the best case
- Group mobility
  - little known
  - social interaction or physical process?
- Worst case mobility
  - more general
  - gives more general results
  - yet only homogenous participants
  - network performance characterized by crowdedness

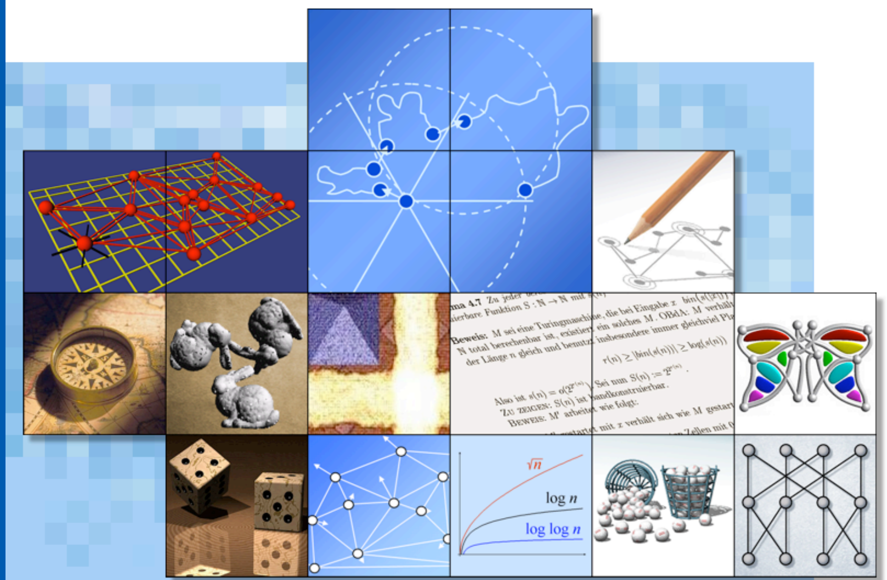
Conclusion: What to do?

- It is possible to formulate mobility models for
  - marine
  - aerial
  - medium based
  - outer space mobility patterns
- Improvements can be expected for
  - pedestrian
  - vehicular mobility models
- Research of mobility models
  - at the beginning
- Todo
  - Find mobility models for specific mobility patterns
  - Prove the validity by comparing with reality
  - Prove the efficiency and reliability of real network protocols with respect to the mobility model

Thanks for your attention!

Mobility in Wireless Networks

Invited Talk for SOFSEM 2006
Mérín, Czech Republic
26th January 2006



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