Mobile Ad Hoc Networks

Mobility (III)

12th Week

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CoNe Freiburg

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Models of Mobility Particle Based Mobility: Vehicles

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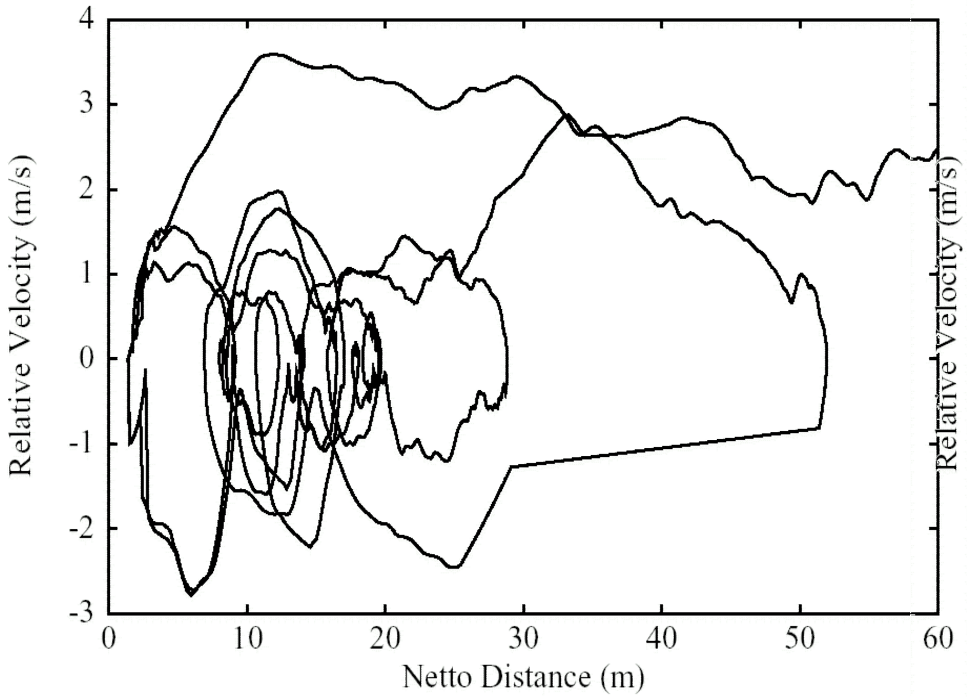
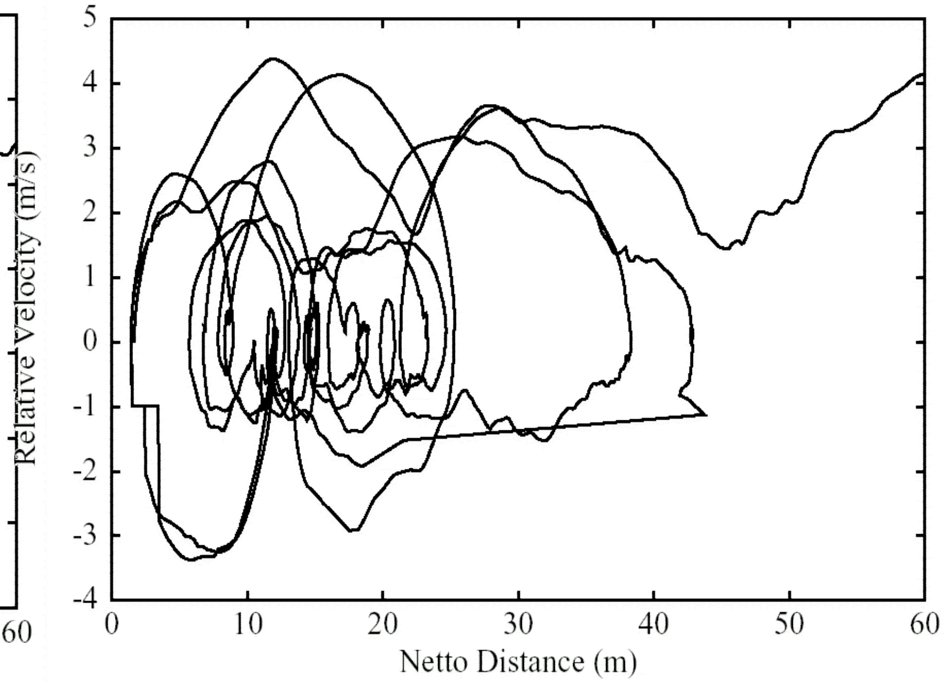
Reality

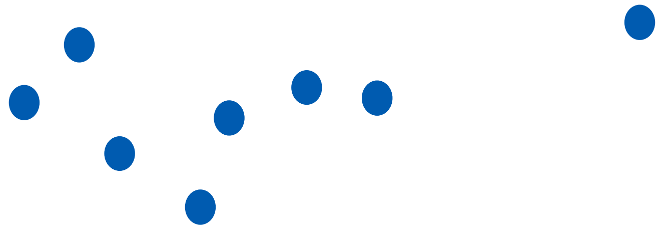


Simulation with GFM

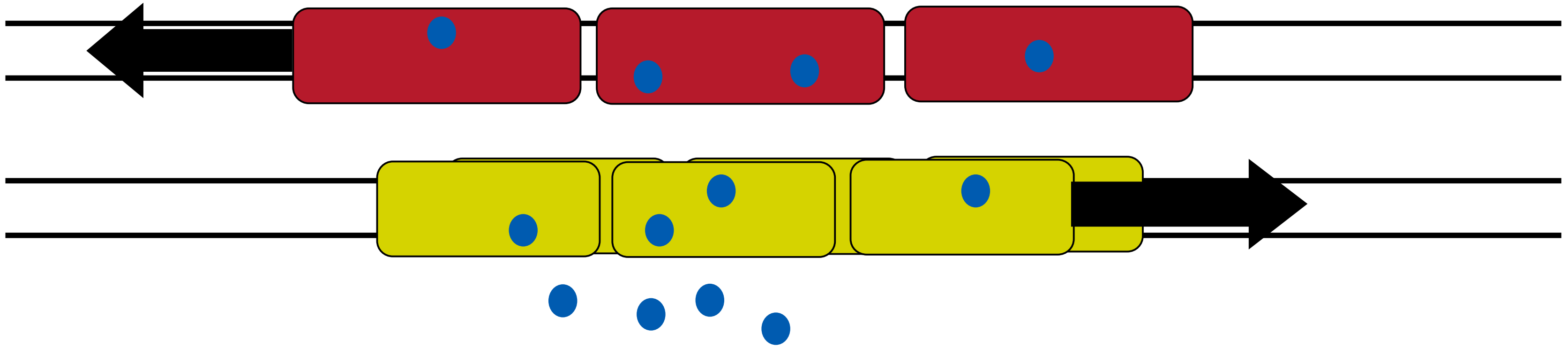


Modeling
Worst Case Mobility
[S., Lukovszki, Rührup, Volbert 2003]

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



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



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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]

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

- **crowd(S) := max$_{u \in S}$ crowd(u)**

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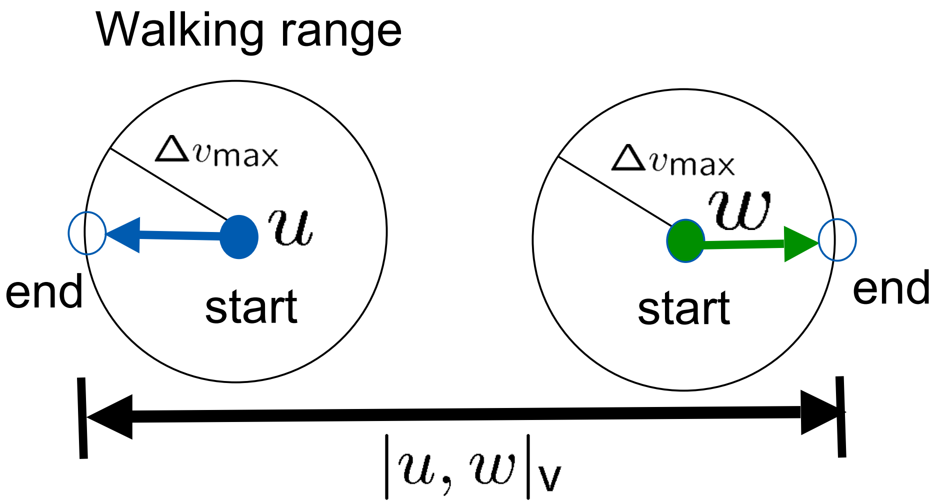
- **Pedestrian model / Velocity bounded model**

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



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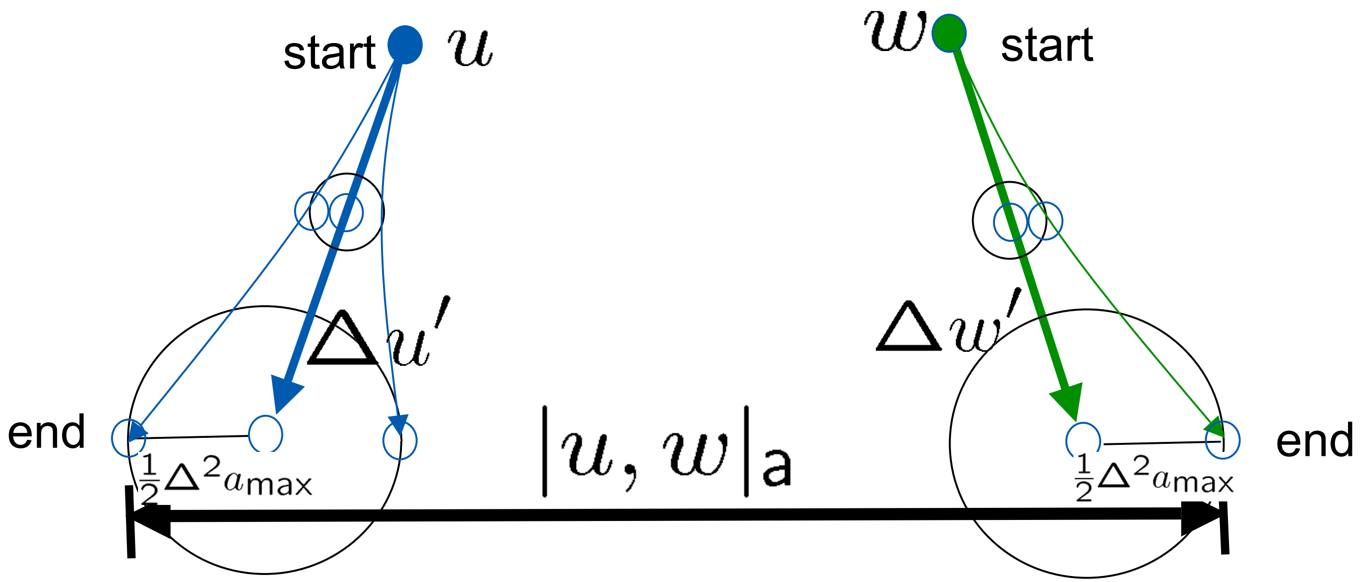
- **Vehicular mobility model / Acceleration bounded model**

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

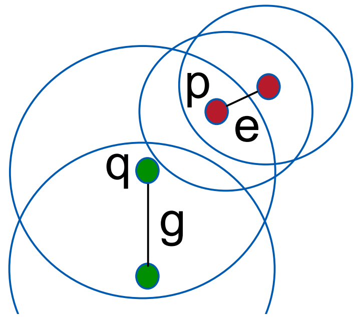


Modeling - Worst Case Mobility
Mobile Radio Interferences

An edge g interferes with edge e in the

1. **Pedestrian (v) model**

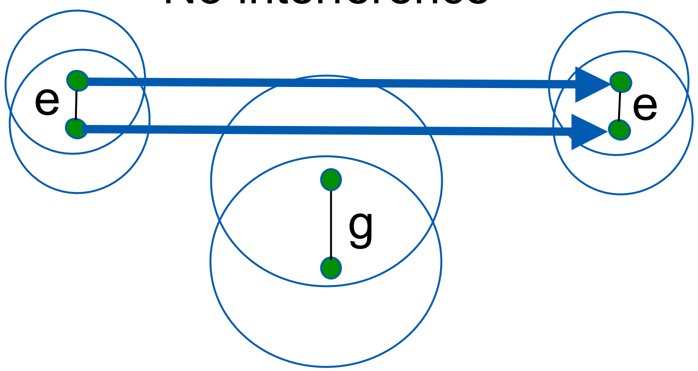
$$g \in \mathrm{Int}_{\mathrm{v}}(e) \quad :\Longleftrightarrow \quad \exists p \in e, \exists q \in g \ : \ |p-q|_2 \leq |g|_{\mathrm{v}}$$



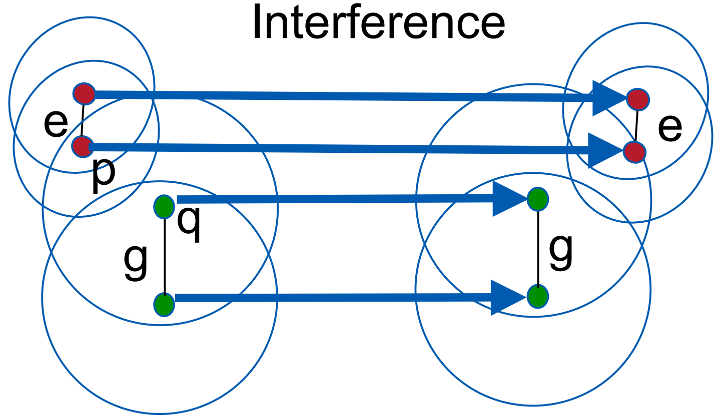
2. **Vehicular (a) model**

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

No interference



Interference



Modeling
Worst Case Mobility: Results (I)

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:

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

Modeling Worst Case Mobility: Results (II)

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

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

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)

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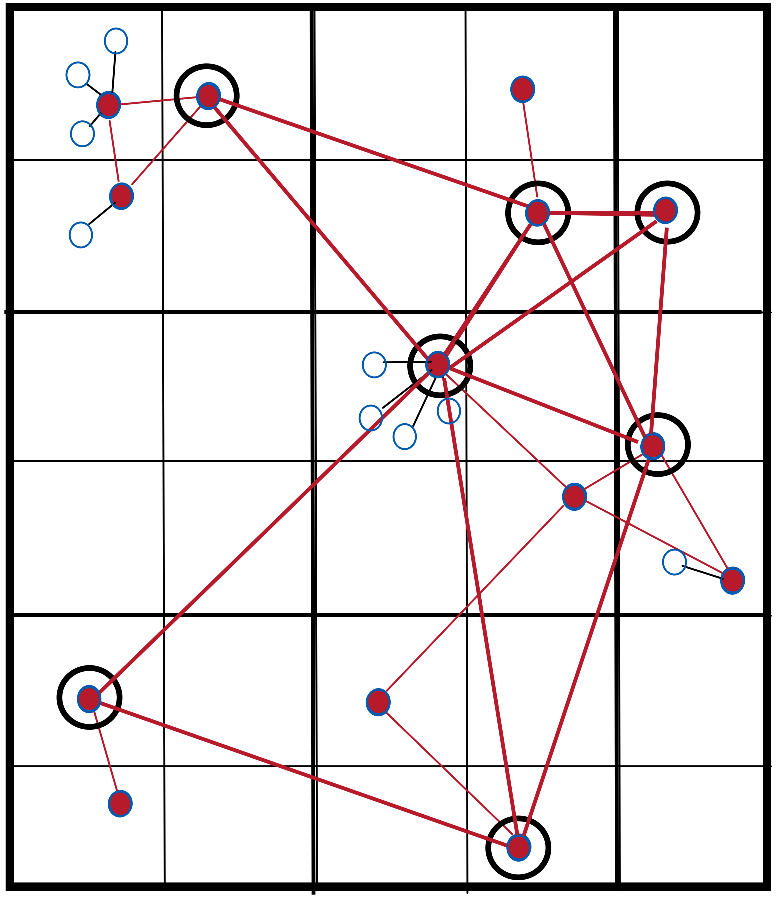
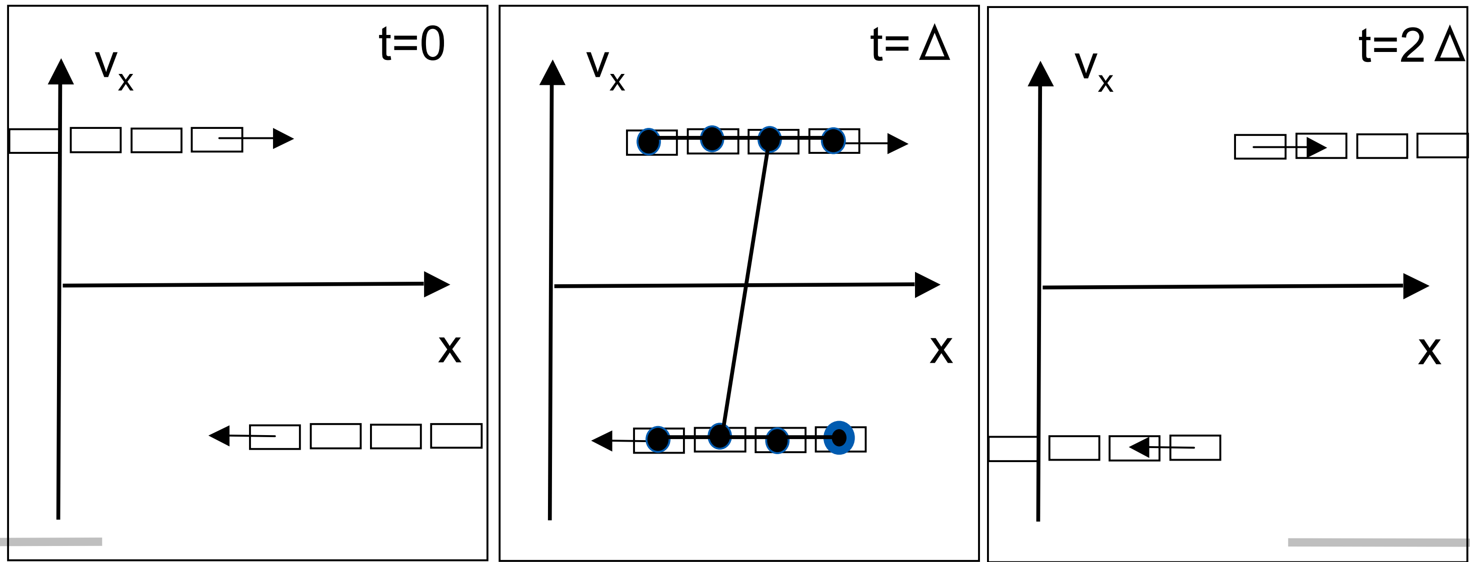
- **Start with grid of box size $\Delta\ v_{max}$**
- **For O(log n) rounds do**
  - Determine a cluster head per box
  - Build up star-connections from all nodes to their cluster heads
  - Erase all non cluster heads
  - Connect neighbored cluster heads
  - Increase box size by factor 2
- **od**



Modeling - Worst Case Mobility: The Hierarchical Grid Graph (vehicular)

- **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



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!

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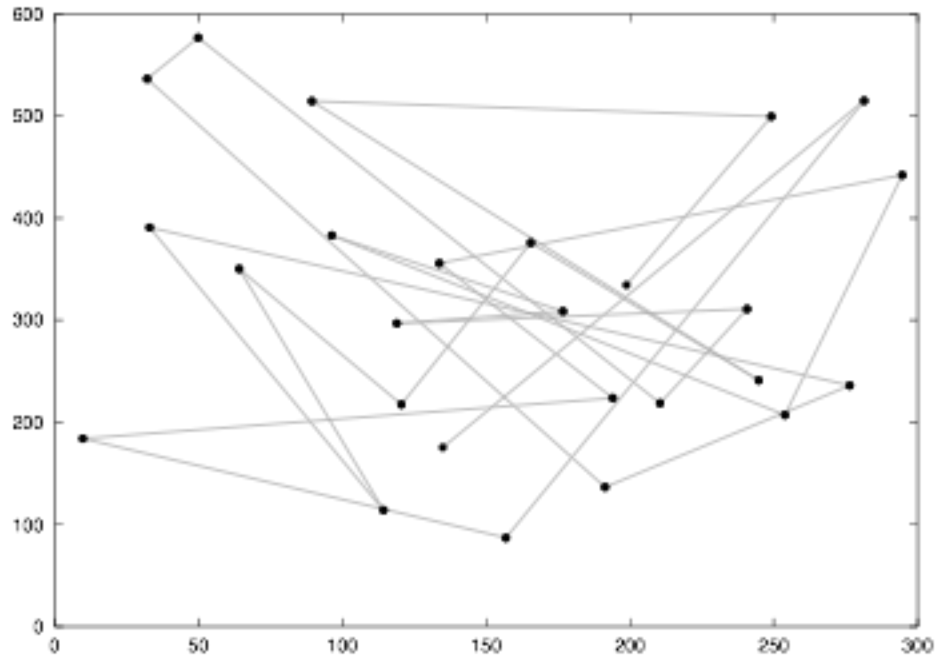
Discussion: Mobility is Helpful

- **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

Models of Mobility
Random Waypoint Mobility Model

[Johnson, Maltz 1996]

- 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]

Mobility Increases the Network Capacity

Grossglauser & Tse 2002

- **Model:**
  - SINR-based communication
  - Scheduling policy without interference
  - Random Waypoint mobility model
  - Complete pair-to-pair communication
- **Without mobility:**
  - The capacity is at least $\Theta(n^{1/2})$
  - and at most $O(n^{1/2} \log n)$
- **Routing**
  - Split packets and send to closeby passing relay node
  - If a relay node is closeby to the destination the packet is transmitted

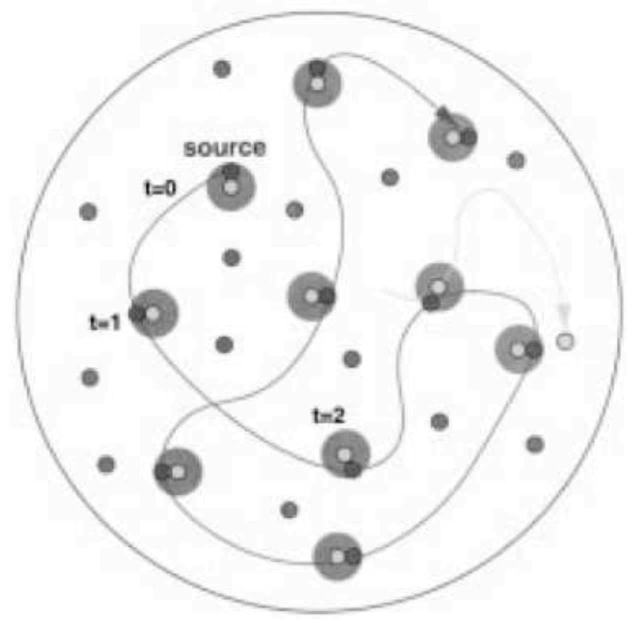


Fig. 1. In phase 1, each packet is transmitted by the source to a close-by relay node.

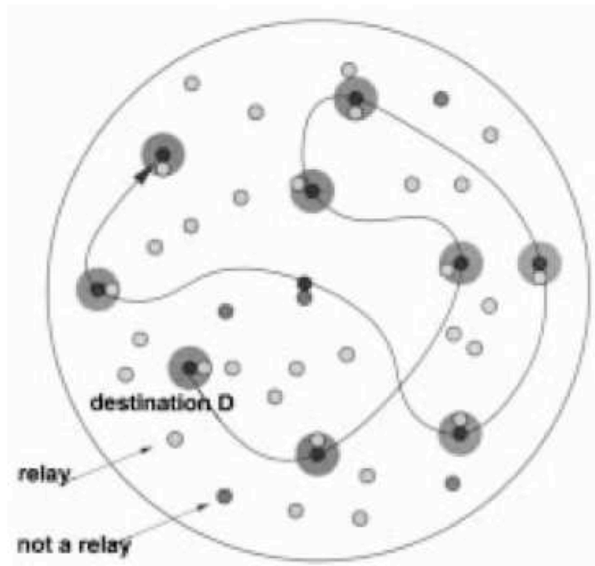


Fig. 2. In phase 2, a packet is handed off to its destination if the relay node is close by.

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Mobility Increases the Network Capacity

Grossglauser & Tse 2002

- **Signal-noise-ratio**
  - Node i transmits packet to node j with power $P_i(t)$ iff

$$\frac{P_i(t)\gamma_{ij}(t)}{N_0 + \frac{1}{L}\sum_{k\neq i} P_k(t)\gamma_{kj}(t)} > \beta$$

  where L=1 is the processing gain
    - L > 1 for CDMA (not considered here)
  - where for $\alpha \geq 2$ the channel gain is

$$\gamma_{ij}(t) = \frac{1}{|X_i(t) - X_j(t)|^\alpha}$$

- **Find a schedule (routing) such that the number of packets $M_i(t)$ reaching destination i at time t is at least $\lambda(n)$ in the limit**
  - If a relay node is closeby to the destination the packet is transmitted

$$\liminf_{T\to\infty} \frac{1}{T}\sum_{t=1}^{T} M_i(t) \geq \lambda(n)$$

Mobility Increases the Network Capacity

Grossglauser & Tse 2002

- **Results without relaying**
  - Sender communicates directly to the destination if the destination is in reach
  - Either long range communication leads to many interferences
  - Or there is only a little chance to meet the destination which leads to small throuhput
- **Capacity for demand R:**

$$\lambda(n) = O\left(R \cdot n^{-\frac{1}{1+\frac{1}{2}\alpha}}\right)$$

- **Remember the channel gain**

$$\gamma_{ij}(t) = \frac{1}{|X_i(t) - X_j(t)|^\alpha}$$

Mobility Increases the Network Capacity

Grossglauser & Tse 2002

- **With relaying**
  - There is a constant portion of feasible relaying nodes
  - This leads to a throughput of cR for demand R for a constant c>0

$$\lambda(n) = \Theta(R)$$

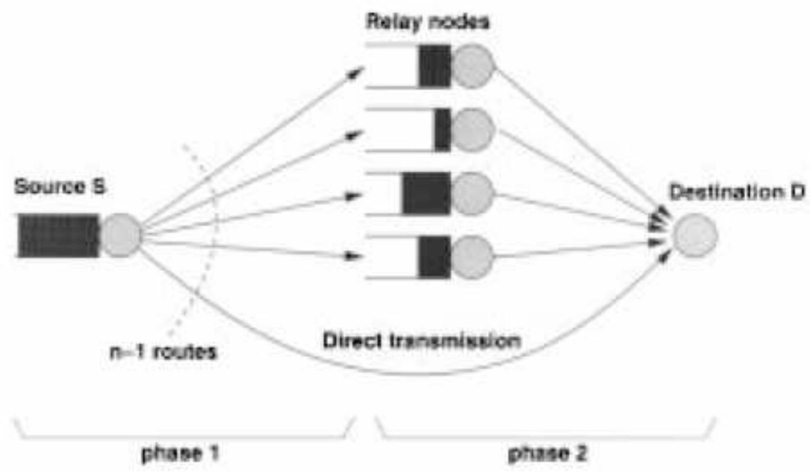

Fig. 3. The two-phase scheduling policy viewed as a queuing system, for a source–destination pair: in phase 1, a packet at S is served by a queue of capacity $\Theta(1)$ and is forwarded either to the destination or to one of $n-2$ relay nodes with equal probability. The service rate at each relay node R is $\Theta(1/n)$, for a total session rate of $\Theta(1)$.

- **Disadvantage**
  - Long delays

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

Thank you!

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