Mobile Ad Hoc Networks
Mobility (III)
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Models of Mobility
Particle Based Mobility: Vehicles
Reality

Simulation with GFM

![Graphs showing relative velocity vs netto distance for vehicles in reality and simulation.](image-url)
Modeling Worst Case Mobility

[S., Lukovszki, Rührup, Volbert 2003]

V: Pedestrian Model  ↔  Maximum velocity \( \leq v_{\text{max}} \)

A: Vehicular Model  ↔  Maximum acceleration \( \leq a_{\text{max}} \)
Modeling
Worst Case Mobility

- Synchronous round model
- In every round of duration $\Delta$
  - 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 \([0, \Delta]\)
   \[
   \operatorname{crowd}_v(u) := \# \{ w \in S \setminus \{u\} : |u - w|_2 \leq 2v_{\max}\Delta \}
   \]

2. Vehicular (a) model:
   - Maximum number of nodes that may move to node \(u\) meeting it with zero relative speed in time span \([0, \Delta]\)
   \[
   \operatorname{crowd}_a(u) := \# \{ w \in S \setminus \{u\} : |u - w|_2 \leq \frac{1}{2}a_{\max}\Delta^2 \text{ and } |u' - w'|_2 \leq \frac{1}{2}a_{\max}\Delta \}
   \]

\[
\operatorname{crowd}(S) := \max_{u \in S} \operatorname{crowd}(u)
\]
Pedestrian model / Velocity bounded model

\[ |u, w|_v := 2\Delta v_{\text{max}} + |u - w|_2 \]
Vehicular mobility model / Acceleration bounded model

\[ |u, w|_a := \max\{|u-w|_2, |u-w+(u'-w')\Delta|_2+a_{\text{max}}\Delta^2\} \]
An edge $g$ interferes with edge $e$ in the

1. Pedestrian ($v$) model

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

2. Vehicular ($a$) model

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

No interference

Interference
Theorem

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

\[ \text{Int}(G) \geq \text{crowd}(S) - 1 \]

Lemma

In both mobility models \( \alpha \in \{v, a\} \) every mobile spanner is also a mobile power spanner, i.e. for some \( \beta \geq 1 \) for all \( u, w \in S \) 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

$$C_{\mathcal{P}'}(G) \equiv O(C_\mathcal{P}(G) \cdot \operatorname{Int}(G) \cdot \log n)$$

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

The Hierarchical Grid Graph can be built up in $O(\operatorname{crowd}(V) + \log n)$ parallel steps using radio communication
Modeling - Worst Case Mobility: Hierarchical Grid Graph (pedestrians)

- Start with grid of box size $\Delta v_{\text{max}}$
- 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 \((6\Delta^2 a_{\text{max}}, 6\Delta^2 a_{\text{max}}, 2\Delta v_{\text{max}}, 2\Delta v_{\text{max}})\)
- 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!
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

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

[Johnson, Maltz 1996]

[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.
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

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

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 \(c > 0\)

\[
\lambda(n) = \Theta(R)
\]

- Disadvantage
  - Long delays

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 \(\Theta(1)\).
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 adaptations 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!