Mobile Ad Hoc Networks

Mobility (II)

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Christian Schindelhauer
schindel@informatik.uni-freiburg.de

University of Freiburg
Computer Networks and Telematics
Prof. Christian Schindelhauer
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]
Random Waypoint Considered Harmful

- 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

Problem:
- If $v_{\text{min}}=0$ then the average speed decays over the simulation time

[Yoon, Liu, Noble 2003]
Random Waypoint
Considered Harmful

The Random Waypoint \((V_{\text{min}}, V_{\text{max}}, T_{\text{wait}})\)-Model

- All participants start with random position \((x,y)\) in \([0,1]\times[0,1]\)
- For all participants \(i \in \{1, \ldots, n\}\) repeat forever:
  - Uniformly choose next position \((x',y')\) in \([0,1]\times[0,1]\)
  - Uniformly choose speed \(v_i\) from \([V_{\text{min}}, V_{\text{max}}]\)
  - Go from \((x,y)\) to \((x',y')\) with speed \(v_i\)
  - Wait at \((x',y')\) for time \(T_{\text{wait}}\).
  - \((x,y) \leftarrow (x',y')\)

What one might expect

- The average speed is \((V_{\text{min}} + V_{\text{max}})/2\)
- Each point is visited with same probability
- The system stabilizes very quickly

All these expectations are wrong!!!
Random Waypoint Considered Harmful

➢ What one might expect
  – The average speed is \((V_{\text{min}} + V_{\text{max}})/2\)
  – Each point is visited with same probability
  – The system stabilizes very quickly

➢ Reality
  – The average speed is much smaller
    • Average speed tends to 0 for \(V_{\text{min}} = 0\)
  – The location probability distribution is highly skewed
  – The system stabilizes very slow
    • For \(V_{\text{min}} = 0\) it never stabilizes

➢ All these expectations are wrong!!!

➢ Why?
Random Waypoint Considered Harmful
The average speed is much smaller

- Assumption to simplify the analysis:
  1. Assumption:
     - Replace the rectangular area by an unbounded plane
     - Choose the next position uniformly within a disk of radius $R_{\text{max}}$ with the current position as center
  2. Assumption:
     - Set the pause time to 0: $T_{\text{wait}} = 0$
     - This increases the average speed
       - supports our argument
The probability density function of speed of each node is then for

\[ V_{\text{min}} \leq v \leq V_{\text{max}} \]

given by

\[ f_V(v) = \frac{1}{V_{\text{max}} - V_{\text{min}}} \]

since \( f_V(v) \) is constant and

\[
\int_{v=V_{\text{min}}}^{V_{\text{max}}} f_V(v) \, dv = 1
\]
Random Waypoint Considered Harmful
The average speed is much smaller

- The Probability Density Function (pdf) of travel distance $R$:

$$f_R(r) = \frac{2r}{R_{\text{max}}^2} \quad \text{for } 0 \leq r \leq R_{\text{max}}$$

- The Probability Density Function (pdf) of travel time:

$$f_S(s) = \begin{cases} \frac{2s}{3R_{\text{max}}^2}(V_{\text{max}}^2 + V_{\text{min}}^2 + V_{\text{max}}V_{\text{min}}), & 0 \leq s \leq \frac{R_{\text{max}}}{V_{\text{max}}} \\ \frac{2R_{\text{max}}}{3(V_{\text{max}} - V_{\text{min}})} \frac{1}{s^2} - \frac{2V_{\text{min}}^3}{3R_{\text{max}}^2(V_{\text{max}} - V_{\text{min}})}s, & \frac{R_{\text{max}}}{V_{\text{max}}} \leq s \leq \frac{R_{\text{max}}}{V_{\text{min}}} \\ 0, & s \geq \frac{R_{\text{max}}}{V_{\text{min}}} \end{cases}$$
Random Waypoint Considered Harmful
The average speed is much smaller

The Probability Density Function (pdf) of travel time:

\[ f_S(s) = \begin{cases} 
\frac{2s}{3R_{\max}^2}(V_{\max}^2 + V_{\min}^2 + V_{\max}V_{\min}) , \quad 0 \leq s \leq \frac{R_{\max}}{V_{\max}} \\
\frac{2R_{\max}}{3(V_{\max} - V_{\min})} \frac{1}{s^2} - \frac{2V_{\min}^3}{3R_{\max}^2(V_{\max} - V_{\min})} s , \quad \frac{R_{\max}}{V_{\max}} \leq s \leq \frac{R_{\max}}{V_{\min}} \\
0 \quad \text{for} \quad s \geq \frac{R_{\max}}{V_{\min}} .
\end{cases} \]

Expected travel time:

\[ E[S] = \frac{2R_{\max}}{3(V_{\max} - V_{\min})} \ln \left( \frac{V_{\max}}{V_{\min}} \right) \]
Random Waypoint Considered Harmful
The average speed is much smaller

➢ The average speed of a single node:

\[
\bar{V} = \lim_{T \to \infty} \frac{1}{T} \int_0^T \nu(t) dt
\]

\[
= \lim_{T \to \infty} \frac{\sum_{k=1}^{K(T)} \tau_k}{\sum_{k=1}^{K(T)} s_k}
\]

\[
= \lim_{T \to \infty} \frac{\frac{1}{K(T)} \sum_{k=1}^{K(T)} \tau_k}{\frac{1}{K(T)} \sum_{k=1}^{K(T)} s_k}
\]

\[
= \frac{E[R]}{E[S]} = \frac{V_{max} - V_{min}}{\ln \left( \frac{V_{max}}{V_{min}} \right)}
\]
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

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

\( \alpha = 0.75 \)

[Camp et al. 2002]

[Liag, Haas 1999]
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
Combined Mobility Models
[Bettstetter 2001]
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
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
  - \( \xi \): individual fluctuations

- **Target force:**
  - Wanted speed \( v^0 \) and direction \( e^0 \)

- **Social territorial force**

- **Attraction force (shoe store)**
  \[
  f_{ij}^{soc}(t) = A_i \left( \frac{r_{ij} - d_{ij}}{B_i} \right) n_{ij} \left( \lambda_i + (1 - \lambda_i) \frac{1 + \cos(\phi_{ij})}{2} \right)
  \]

- **Pedestrian force (overall):**
  \[
  f_{ij}^{att}(t) = -C_i \quad n_{ij}
  \]
  \[
  n_{ij}(t) = \frac{x_i(t) - x_j(t)}{d_{ij}(t)}
  \]

\[
 f_i(t) = \frac{v_i^0 e_i^0(t) - v_i(t)}{\tau_i} + \sum_{j \neq i} f_{ij}^{soc}(t) + \sum_{j \neq i} f_{ij}^{att}(t) + \sum_k f_{ij}^{att}(t) + \sum_b f_{ib}^{obst}(t)
\]
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
- \(\Delta v_i = v_i - v_{i-1}\)

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

  \[
  V_i(t) = v_i^0 \left( 1 - e^{-\frac{s_i(t) - s(v_i(t))}{R_i}} \right)
  \]
Models of Mobility
Particle Based Mobility: Vehicles
Reality

Simulation with GFM
Thank you!