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Algorithms for Radio Networks

Random Waypoint Considered Harmful

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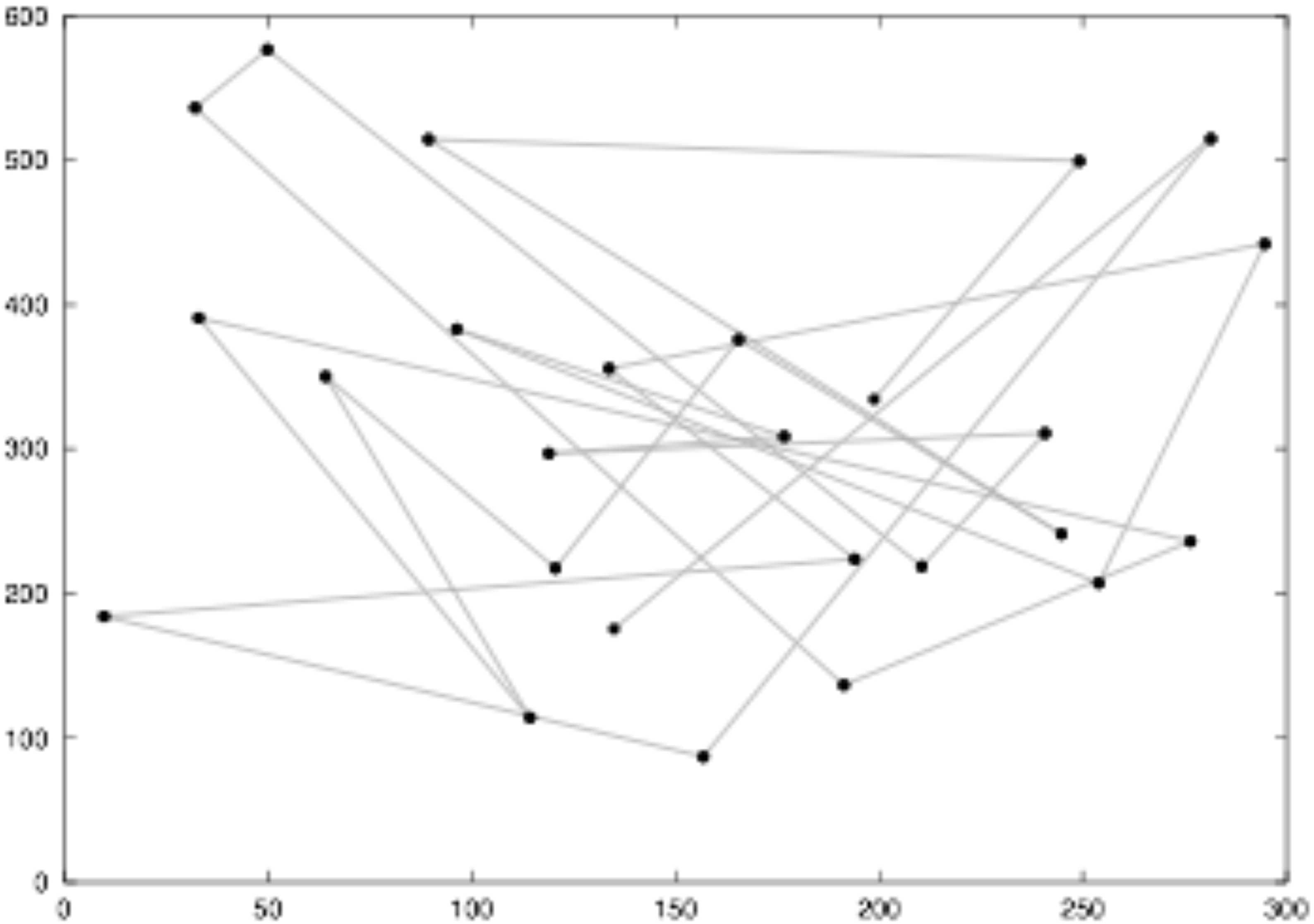
Random Waypoint Mobility Model

- **Move directly to a randomly chosen destination**
- **Choose speed uniformly from [V_{min}, V_{max}]**
- **Stay at the destination for a predefined pause time**
- **Repeat from the beginning**

[Camp et al. 2002]



Broch, J; Maltz DA, Johnson DB, Hu Y-C, and Jetcheva J (1998). "A performance comparison of multi-hop wireless ad hoc network routing protocols" in P*roceedings of the Fourth Annual ACM/IEEE International Conference on Mobile Computing and Networking (Mobicom98), ACM, October 1998*

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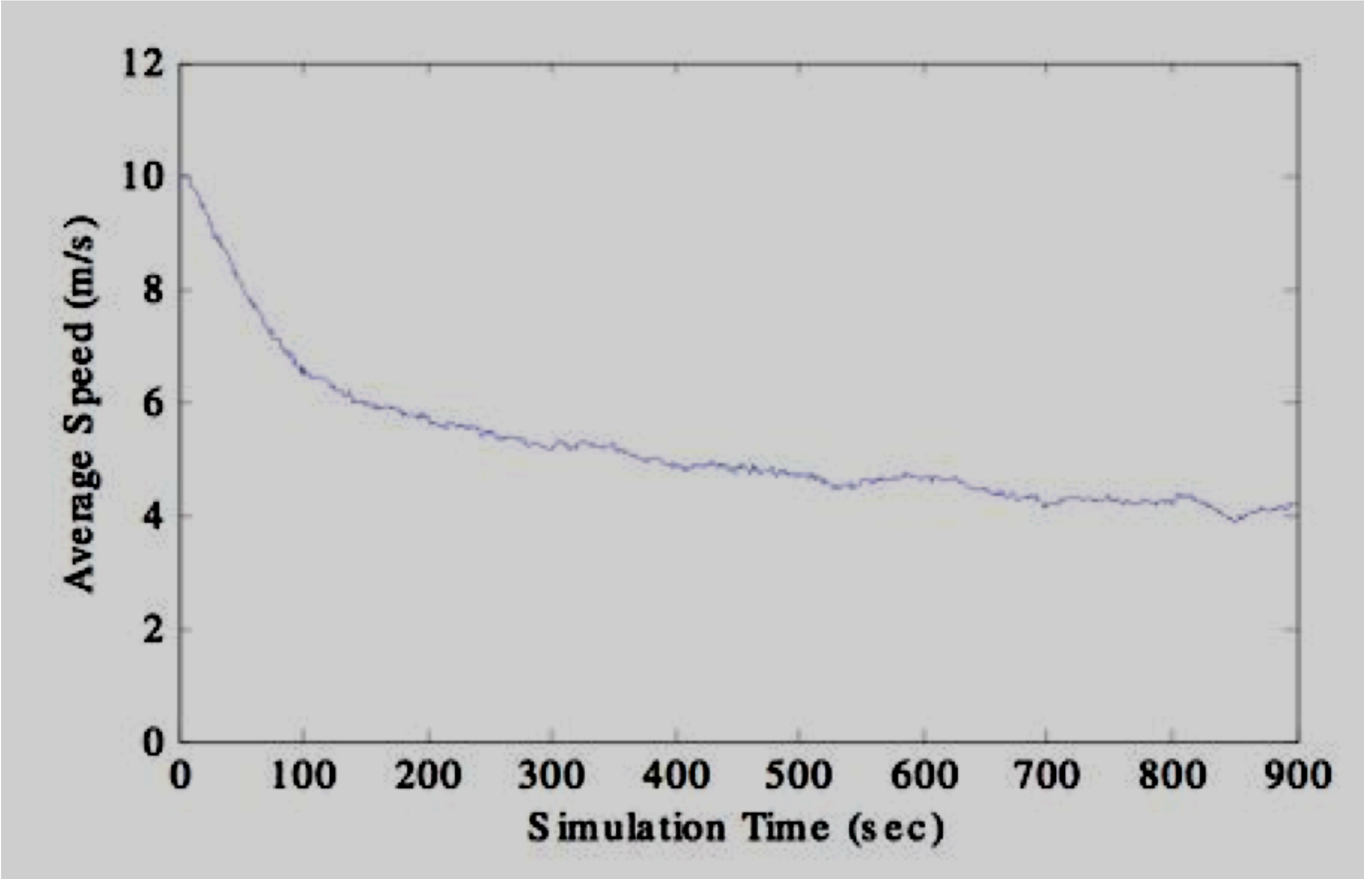
- **Yoon, Liu, Noble**
  - Random Waypoint Considered Harmful, INFOCOM 2003, S. 1312-1321
- **Problem:**
  - If v_{min}=0 then the average speed decays over the simulation time



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

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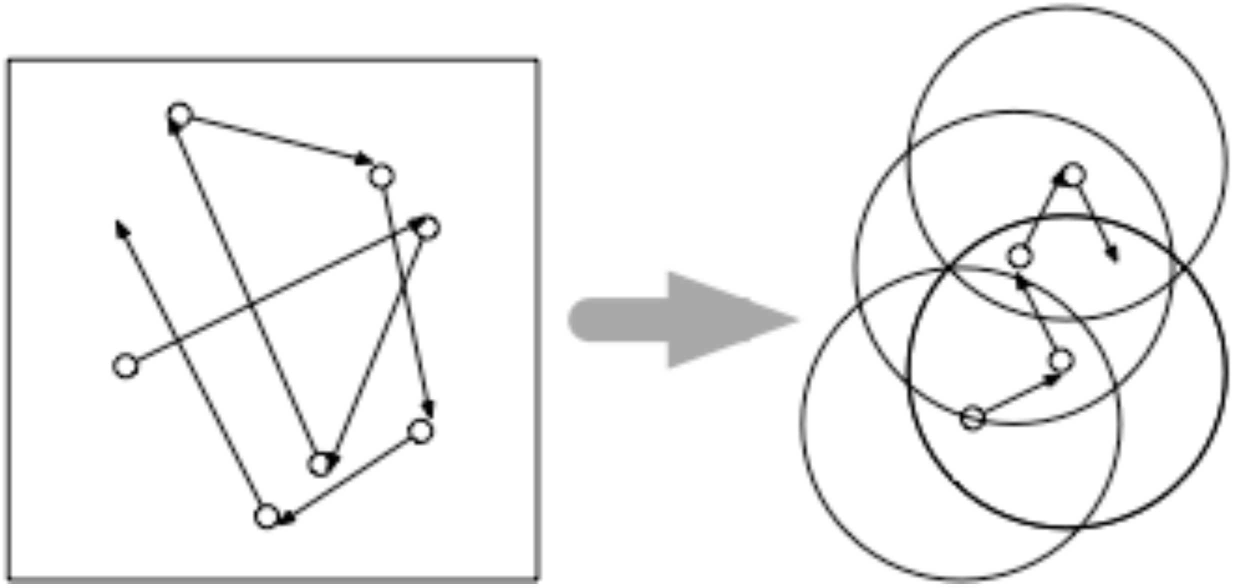
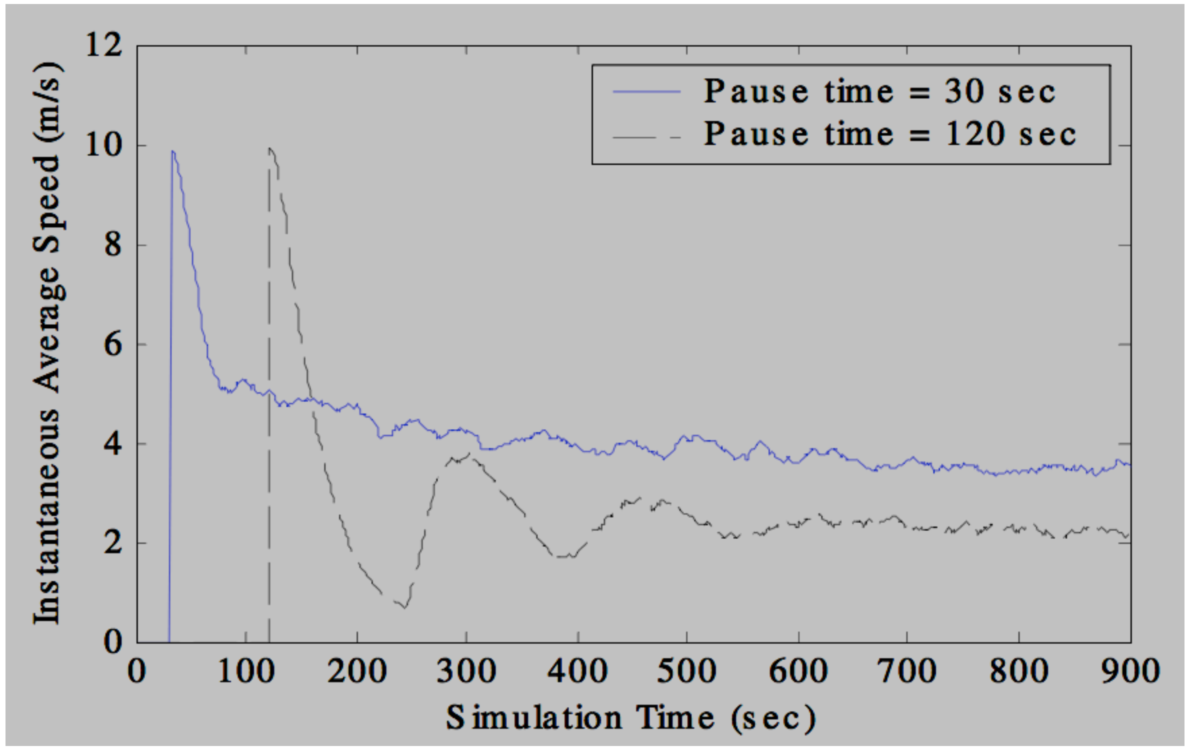
- **What one might expect**
  - The average speed is $(V_{min} + V_{max})/2$
  - Each point is visited with same probability
  - The system stabilizes very quickly
- **All these expectations are wrong!!!**
- **Reality**
  - The average speed is much smaller
  - Average speed tends to 0 for $V_{min} = 0$
  - The location probability distribution is highly skewed
  - The system stabilizes very slow
  - For $V_{min} = 0$ it never stabilizes
- **Why?**

The Average Speed is much Smaller

- **Assumption to simplify the analysis:**
  - Replace the rectangular area by an unbounded plane
  - Choose the next position uniformly within a disk of radius R_{max} with the current position as center
  - Set the pause time to 0: $T_{wait} = 0$
  - This increases the average speed
    - supports our argument





The Average Speed is much Smaller

- **The probability density function of speed of each node**

$$V_{\min} \leq v \leq V_{\max}$$

- **Given by**

$$f_V(v) = \frac{1}{V_{\max} - V_{\min}}$$

- **since $f_V(v)$ is constant and**

$$\int_{v=V_{\min}}^{V_{\max}} f_V(v)\ dv = 1$$

The Average Speed is much Smaller

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

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

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

$$f_S(s) = \begin{cases} \frac{2s}{3R_{\max}^2}(V_{\max}^2 + V_{\min}^2 + V_{\max}V_{\min}) \ , & 0 \leq s \leq \frac{R_{\max}}{V_{\max}} \\ \frac{2R_{\max}}{3(V_{\max} - V_{\min})}\frac{1}{s^2} - \frac{2V_{\min}^3}{3R_{\max}^2(V_{\max} - V_{\min})}s \ , & \frac{R_{\max}}{V_{\max}} \leq s \leq \frac{R_{\max}}{V_{\min}} \\ 0 & s \geq \frac{R_{\max}}{V_{\min}} \ . \end{cases}$$

The Average Speed is much Smaller

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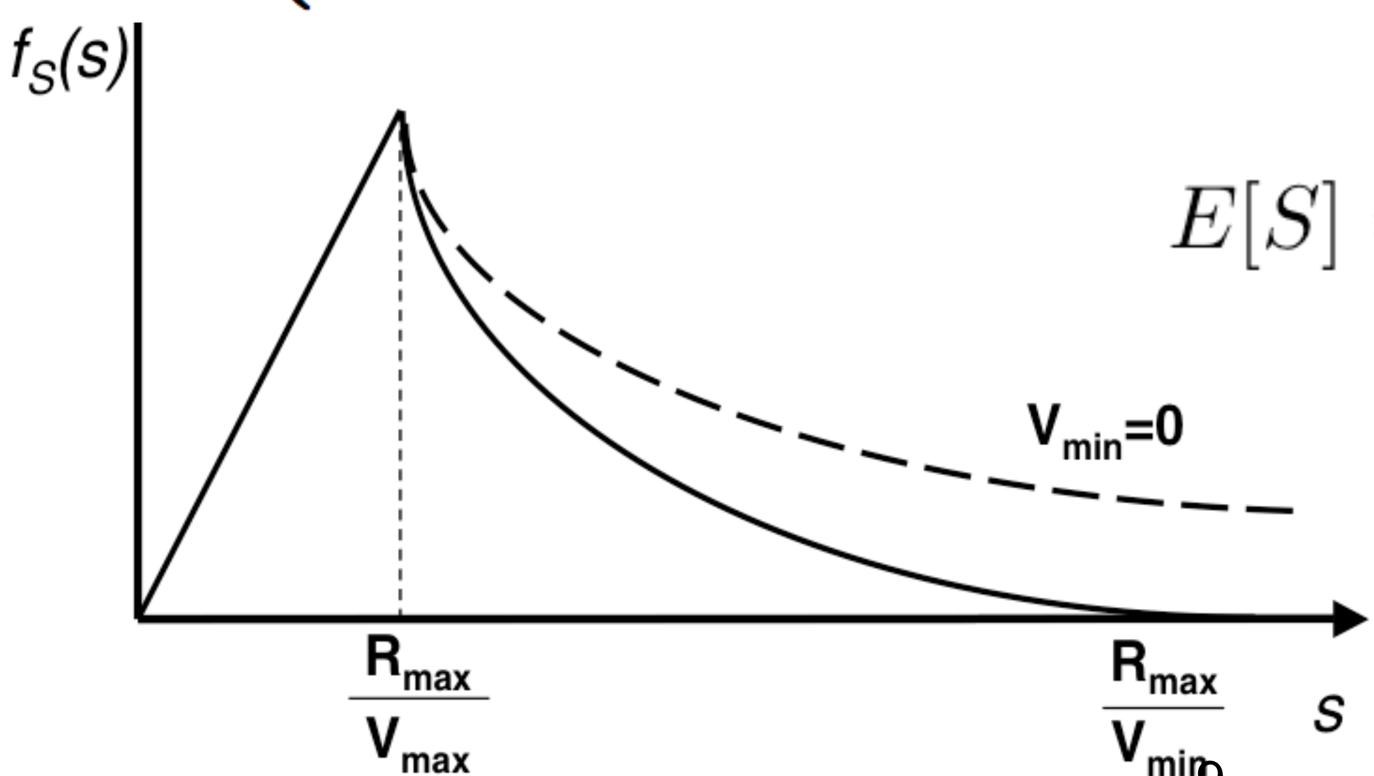


$$E[S] = \frac{2R_{\max}}{3(V_{\max} - V_{\min})} \ln\left(\frac{V_{\max}}{V_{\min}}\right)$$

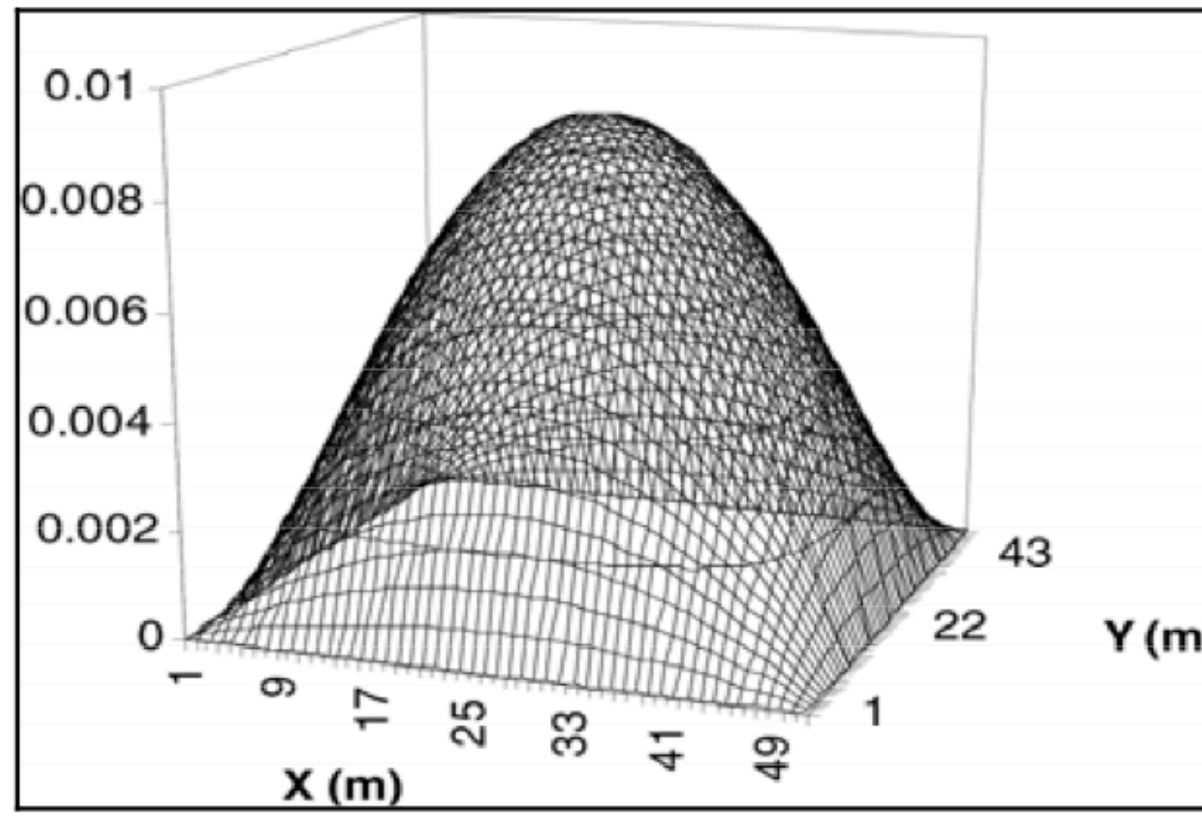
The Average Speed is much Smaller

- **Average speed of a node**

$$
\begin{aligned}
\bar{V} &= \lim_{T \longrightarrow \infty} \frac{1}{T} \int_0^T v(t)dt \\
&= \lim_{T \longrightarrow \infty} \frac{\sum_{k=1}^{K(T)} r_k}{\sum_{k=1}^{K(T)} s_k} \\
&= \lim_{T \longrightarrow \infty} \frac{\frac{1}{K(T)} \sum_{k=1}^{K(T)} r_k}{\frac{1}{K(T)} \sum_{k=1}^{K(T)} s_k} \\
&= \frac{E[R]}{E[S]} = \frac{V_{max} - V_{min}}{\ln\left(\frac{V_{max}}{V_{min}}\right)}.
\end{aligned}
$$

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



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