Introduction

- 5G: Device-to-Device (D2D) networks,
- Security issues: potential strong malware propagation,
- Multi-Agent Simulation for complex systems.

Objectives

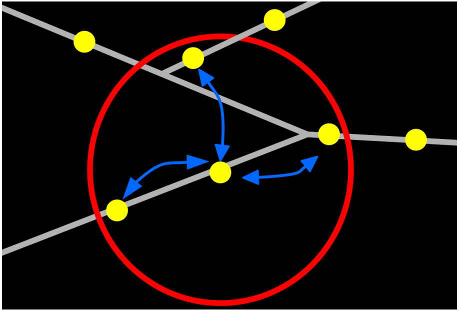
- Build an agent based simulator for the Malware Propagation model,
- Identify the critical relations between the parameters,
- Study the virus propagation by the mean of simulation.

Devices $a_1, a_2, \ldots$ moving on a map.

Connection

Two devices a_i, a_j are connected if

- $d(a_i, a_j) \leq r$,



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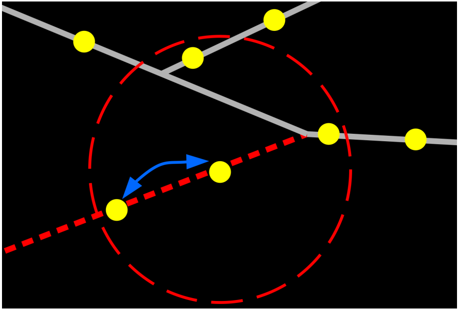

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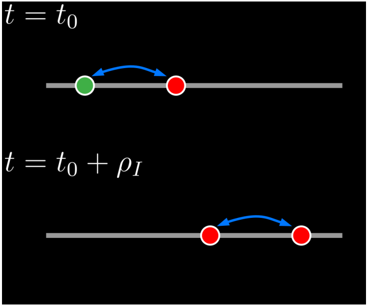
Malware Transmission Rule

Connection time greater than ρ.

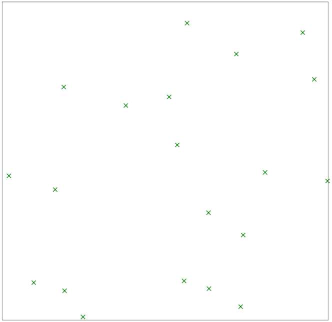
State of a_i at time t

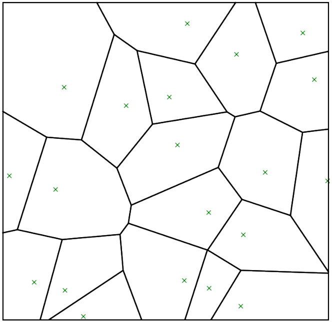
$$\xi_i(t) := (\text{state of device } a_i \text{ at time } t) \in \{\text{susceptible, infected}\}$$



λ : surface intensity of the Voronoi seeds, H : side size of the map.

1. Random Seeds number N : Poisson variable with parameter λH^2,
2. Random Seeds positions $Q_1, \ldots, Q_N \in [0, H] \times [0, H]$,
3. Voronoi cells $C_i := \{X \in [0, H]^2 \mid \forall j \in \{1, \ldots, N\}, \|X - Q_i\| \leq \|X - Q_j\|\}$.



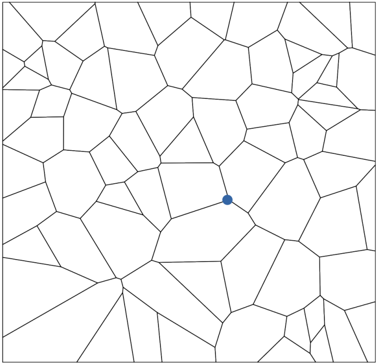


θ : Length intensity of susceptible agents,

- On a street of length L
  1. Random number N_S of agents: Poisson variable with parameter θL,
  2. Random positions on the street $X^{(1)}, \ldots, X^{(N_S)}$,
- One infected agent near the center of the map

Definition (WayPoint)

Each agent has a **Home**, and it moves back and forth between its home and a new destination every **Trip**.



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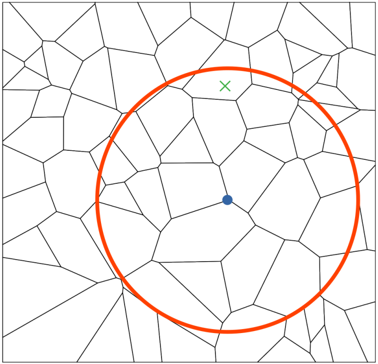
- Sample a point (x_d, y_d) with Gaussian distribution centered at **Home** and with a standard deviation σ_D,



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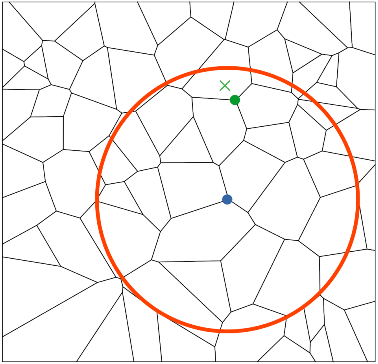
- Set the **destination** as the closest map node to (x_d, y_d),



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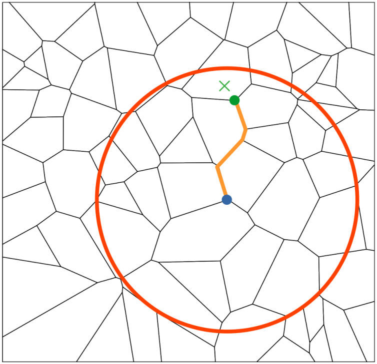
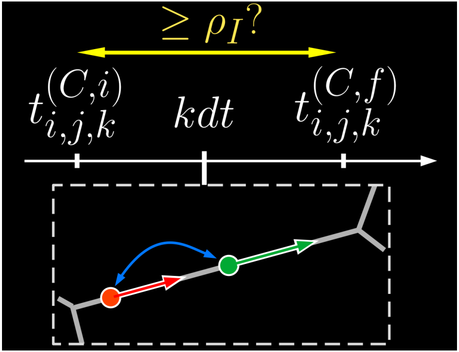
- Sample a point (x_d, y_d) with Gaussian distribution centered at **Home** and with a standard deviation σ_D,
- Set the **destination** as the closest map node to (x_d, y_d),
- Go to **destination** and go back **Home** via a **"good" path**.



The Simulator
Track the Virus Propagation

- If a_i and a_j are connected at kdt, we can compute the connection interval $[t_{i,j,k}^{(C,i)}, t_{i,j,k}^{(C,f)}] \ni kdt$ using their movement equations,
- If a_i is infected, InfectNeighbors(a_i) [Algorithm 2]: updates $T_{j,k}^{(I)}$ for each susceptible neighbor a_j of a_i



Choice of parameters and simulation results

What Values for the Parameters ?

Simplified Model. The initially infected a_{I_0} visits a succession of streets $\hat{\mathcal{E}}_0, \hat{\mathcal{E}}_1, \ldots$, each having an independent length $L_{\lambda,i} \sim f_{\lambda,L}$, where $f_{\lambda,L}$ is the density function of the edges lengths in a PVT having a seeds intensity equal to λ. No white-knights in this model.
(We deduced $f_{\lambda,L}$ from $f_{1,L}$ using a length unit change)

Proposition (Kenneth A. Brakke. "Statistics of Random Plane Voronoi Tessellations")

If $L_\lambda \sim f_{\lambda,L}$, then $\mathbb{E}[L_\lambda] = \dfrac{2}{3\sqrt{\lambda}}$.

What can we say about $T^{(I)} := \inf\{t \geq 0 \mid \exists a_j \neq a_{I_0} \text{ such that } \xi_{j,t} = I\}$?

Lower Bounds for $\mathbb{E}[T^{(I)}]$

$$\mathbb{E}[T^{(I)}] \geq \frac{2}{3\sqrt{\lambda}v} \cdot (e^{\lambda\rho^2 v^2} - 1), \qquad \mathbb{E}[T^{(I)}] \geq \frac{1}{2\sqrt{\lambda}v}(\sqrt{\lambda}/\theta - 4/3).$$

Note. $\sqrt{\lambda}\rho v \gg 1 \iff \rho v \gg \mathbb{E}[L_\lambda], \qquad \sqrt{\lambda}/\theta \gg 1 \iff \theta\mathbb{E}[L_\lambda] \ll 1.$

- $\tau_u := \inf\{t \geq 0 \mid \exists a_j \in \mathcal{I}(t) : \|X_j(t) - X_{I_0}(0)\| \geq u\}$.

Propagation Speed

The speed with which the virus spreads in space.

$$\mathcal{V} := \limsup_{u \to +\infty} u\mathbb{E}[1/\tau_u],$$

Infection Rate

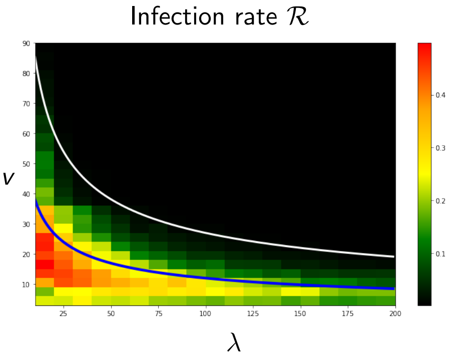
the rate of agents infected inside the area reached by the virus.

$$\mathcal{R} := \limsup_{u \to +\infty} \frac{|\mathcal{I}(\tau_u)|}{|\{X_j(\tau_u) \mid a_j \in \mathcal{A}\} \cap B(X_{I_0}(0), u)|},$$

Unless otherwise stated, the parameters will have the following values
$u = 3.5km, \;\; H = 10km, \;\; \lambda = 50km^{-2},$
$\theta = 3km^{-1}, \;\; v = 5km/h, \;\; \rho = 20s, \;\; r = 200m.$

Let $u_k := \max\{\|X_{j,k} - X_{I_0}(0)\| \mid a_j \in \mathcal{A}\}$, (max propagation radius)

$$\text{Stop at step } k \text{ if :} \quad \left(u_k \geq u \quad \text{or} \quad u_k/(kdt) < 0.05km/h \quad \text{or} \quad |\mathcal{I}_k| = 0\right).$$



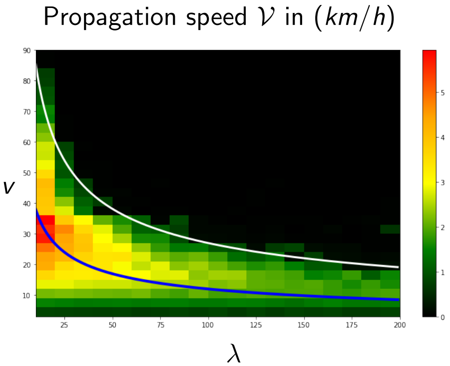
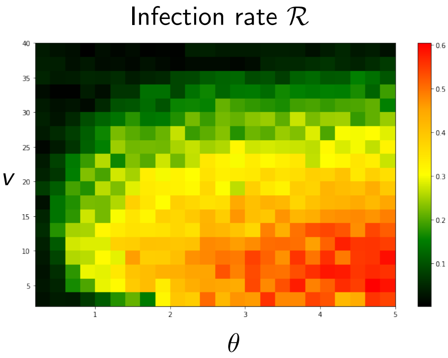


Figure: $\lambda \in [10, 200](km^{-2})$, $v \in [3, 90](km/h)$. The blue curve: $\sqrt{\lambda}\rho v = 2/3\,(\rho v = \mathbb{E}[L_\lambda])$, and the white one: $\sqrt{\lambda}\rho v = 3/2$



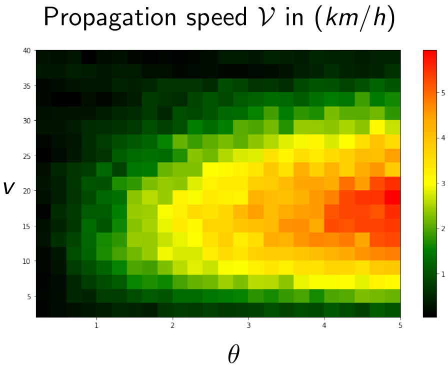


Figure: $\theta \in [0.2, 5](km^{-1})$, $v \in [2, 40](km/h)$.

Conclusion and Future Work

Conclusion

- Agent based simulation is a powerful tool to study D2D network systems,
- The virus does not propagate when $\sqrt{\lambda}\rho v > 1.5$,
- The propagation is maximal for $\sqrt{\lambda}\rho v \approx 2/3$

Future Work

- Introduce "white knights"
- Study the survival/extinction of the malware
- Predict what happens on real maps