

# Speed Dating despite Jammers

*Dominik Meier*

*Yvonne-Anne Pignolet*

*Stefan Schmid*

*Roger Wattenhofer*



**ETH**

Eidgenössische Technische Hochschule Zürich  
Swiss Federal Institute of Technology Zurich

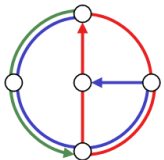
# Wireless Networks

## Radio Communication

- Find communication partner (device discovery)
- Concurrent transmissions disturb each other (Interference)



Device discovery under jamming attacks

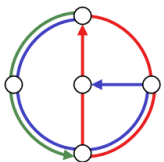
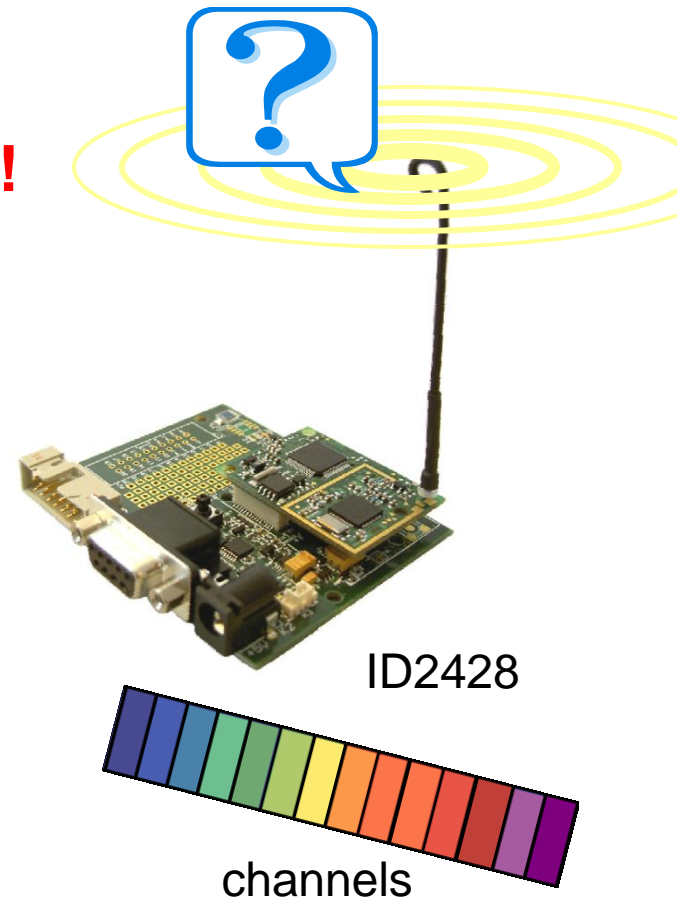
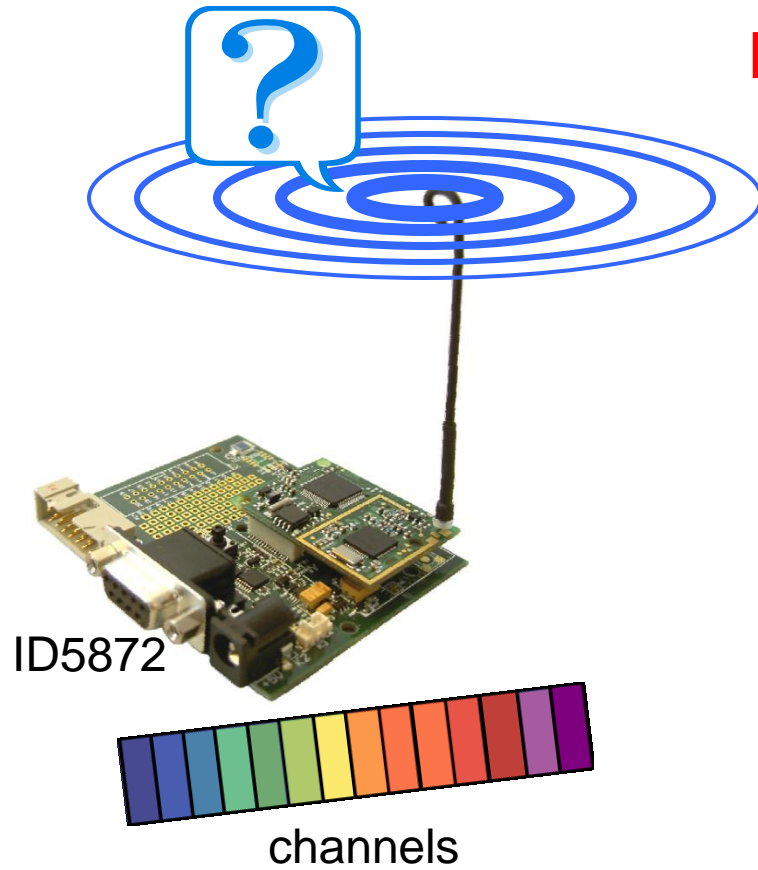


# Adversarial Interference: Jamming



Device Discovery

**No discovery!**

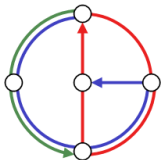
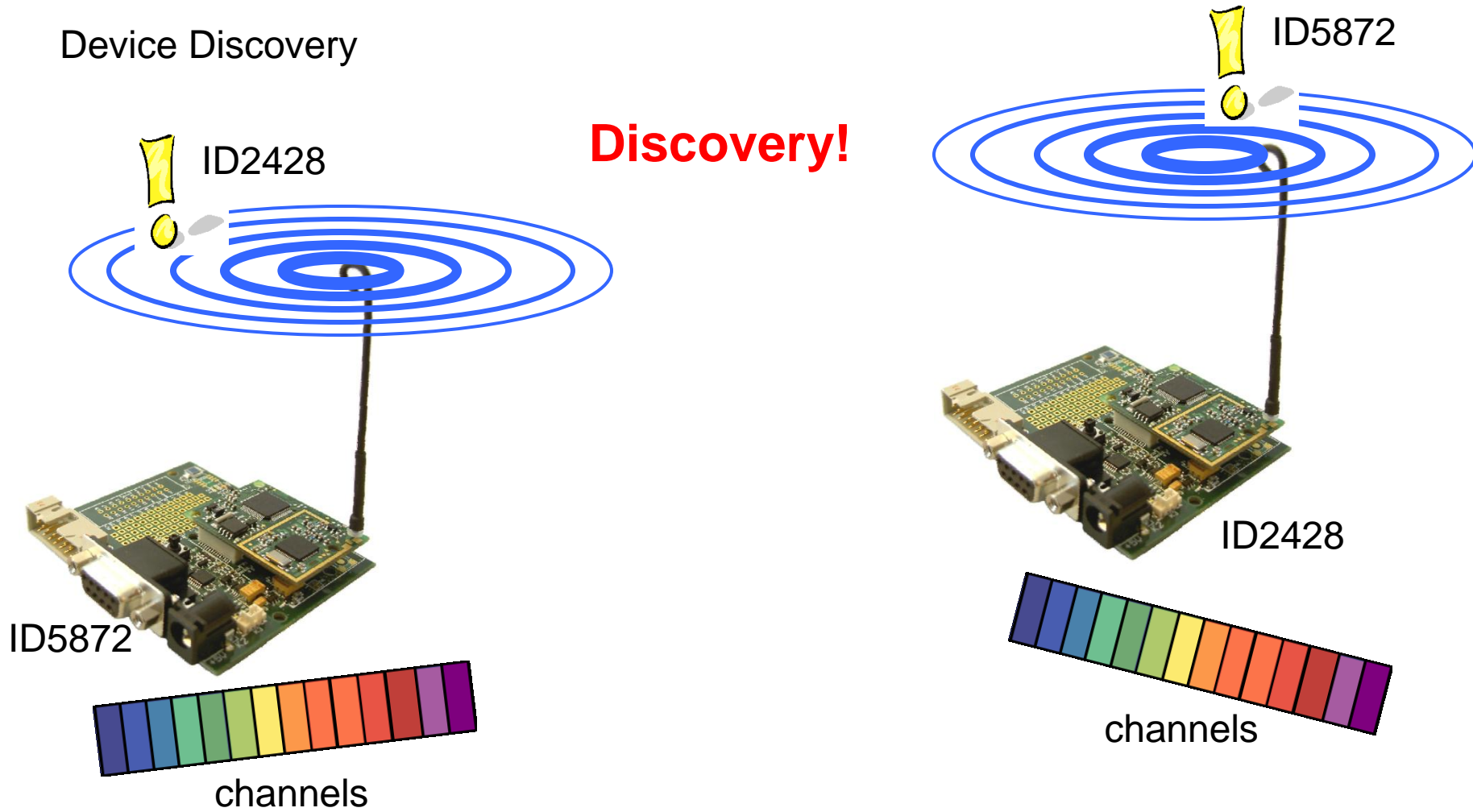


# Adversarial Interference: Jamming



Device Discovery

**Discovery!**

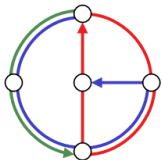
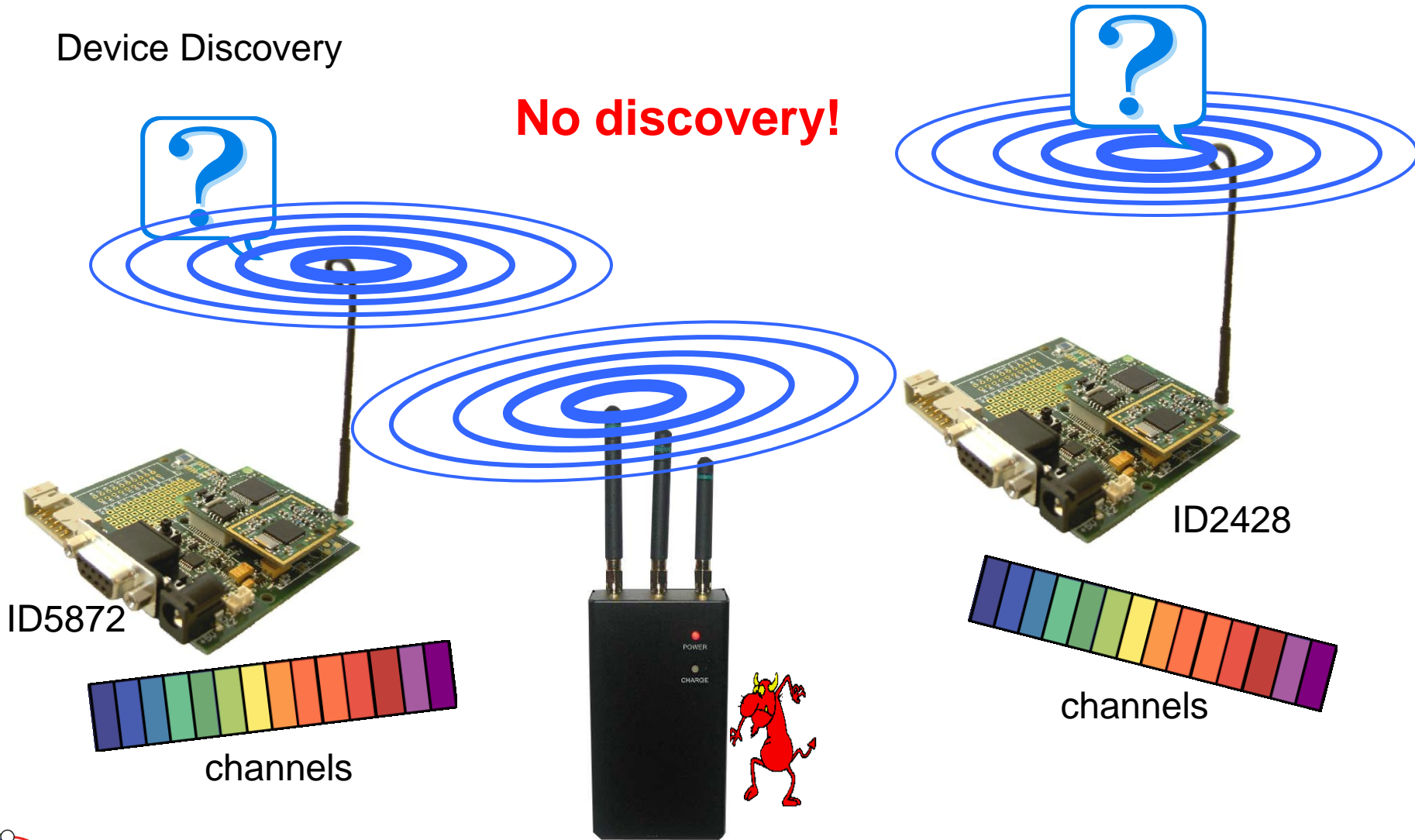


# Adversarial Interference: Jamming



Device Discovery

**No discovery!**



# Model: Device Discovery Problem



## 2 devices



- Want to get to know each other
- $m$  channels
- Listen/send on 1 channel in each time slot



$m$

## Adversary

- Always blocks  $t$  channels
- $t < m$
- Worst case

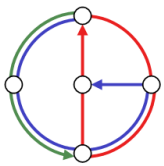


$t$

Quickly?  
Graceful  
degradation

**Goal:**  
Algorithm that lets the devices find each other quickly, regardless of  $t$

Quality:  $\rho := \max_t \frac{E[\text{algo discovery time} \mid t \text{ unknown}]}{E[\text{best discovery time} \mid t \text{ known}]}$



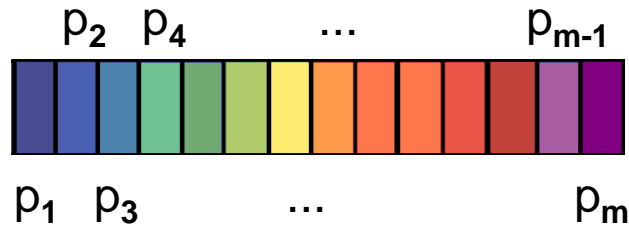
# Algorithms



## Randomized Algorithms

Represented by probability distribution over channels:

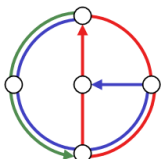
- choose channel  $i$  with probability  $p_i$



## Advantages

- Simple
- Independent of starting time
- Stateless
- Robust against adaptive adversaries

Perfect for sensor nodes because we are rather stupid....



# E[best discovery time | t known ]



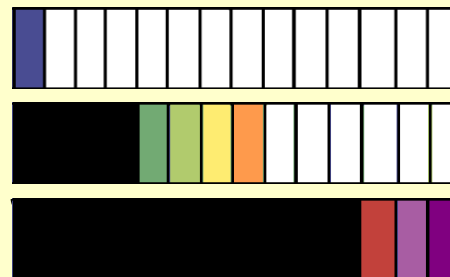
## Best Algorithm

In each time slot

- if  $t = 0$
- if  $t < m/2$
- else

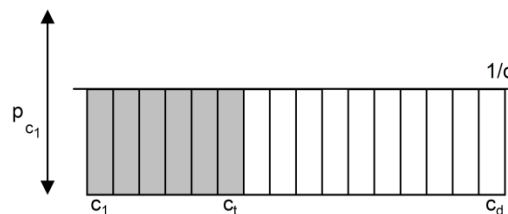
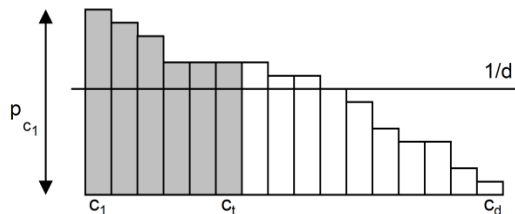


choose channel 1  
 choose random channel in  $[1, 2t]$   
 choose random channel



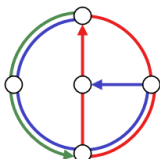
$$E[\text{discovery time knowing } t] = \begin{cases} 1 & \text{if } t=0 \\ 4t & \text{if } t < m/2 \\ m^2/(m-t) & \text{else} \end{cases}$$

$t > 0$  : Why uniform distribution?



Easy!  
 What if we  
 don't know  $t$ ?

Why channel in  $[1, 2t]$  ?  
 $2t$  minimizes discovery time





# E[discovery time NOT knowing t]



## Example Algo<sub>Random</sub>

In each time slot



- choose channel uniformly at random



$$E[\text{time Algo}_{\text{Random}}] = m^2/(m-t)$$

choose  $t=0$

$$\rho_{\text{Random}} = m$$

$$\rho := \max_t \frac{E[\text{algo discovery time} \mid t \text{ unknown}]}{E[\text{best discovery time} \mid t \text{ known}]}$$

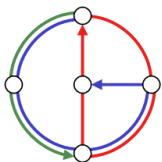
## Example Algo<sub>3</sub>

In each time slot

- with prob  $1/3$  choose channel 1  $\approx$  estimate  $t = 0$
- with prob  $1/3$  choose randomly in  $[1, \sqrt{m}]$   $\approx$  estimate  $t = \sqrt{m}/2$
- with prob  $1/3$  choose randomly in  $[1, m]$   $\approx$  estimate  $t = m/2$

choose  $t = \sqrt{m}$

$$\rho_3 = O(\sqrt{m})$$



# E[discovery time NOT knowing t]



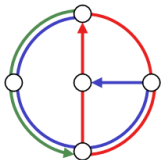
## Example Algo<sub>log m</sub>

In each time slot

- with prob  $1/\log m$  choose channel 1  $\approx$  estimate  $t = 0$
- with prob  $1/\log m$  choose randomly in  $[1,2]$   $\approx$  estimate  $t = 1$
- ...
- with prob  $1/\log m$  choose randomly in  $[1,2^i]$   $\approx$  estimate  $t = 2^{(i-1)}$
- ...
- with prob  $1/\log m$  choose randomly in  $[1,m]$   $\approx$  estimate  $t = m/2$

choose  $t = m$   
 $\rho_{\log m} = O(\log^2 m)$

$$\rho := \max_t \frac{E[\text{algo discovery time} \mid t \text{ unknown}]}{E[\text{best discovery time} \mid t \text{ known}]}$$



# Optimal Algorithm?



## General algorithm

Given probability distribution  $p$ , where  $p_1 \geq p_2 \geq \dots \geq p_m \geq 0$

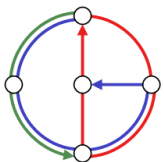
In each time slot

- choose channel  $i$  with probability  $p_i$

$$E[\text{algo discovery time} \mid t] = \frac{1}{\sum_{i=t+1}^m p_i^2}$$

$$\rho := \max_t \frac{E[\text{algo discovery time} \mid t \text{ unknown}]}{E[\text{best discovery time} \mid t \text{ known}]}$$

$$\frac{E[\text{algo discovery time} \mid t \text{ unknown}]}{E[\text{best discovery time} \mid t \text{ known}]} = \begin{cases} \frac{1}{\sum_{i=1}^m p_i^2} & \text{if } t=0 \\ \frac{1}{(4t \sum_{i=t+1}^m p_i^2)} & \text{if } t < m/2 \\ \frac{(m-t)}{(m^2 \sum_{i=t+1}^m p_i^2)} & \text{else} \end{cases}$$



# Optimal Algorithm?

## General algorithm

Given probability distribution  $p$ , where  $p_1 \geq p_2 \geq \dots \geq p_m \geq 0$

In each time slot

- choose channel  $i$  with probability  $p_i$

## Optimization problem

min  $\rho^*$  s.t.

$$t = 0 \quad 1/\rho^* = \sum_{i=1}^m p_i^2$$

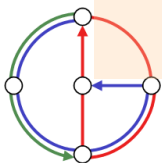
$$1 \leq t \leq m/2 \quad 1/\rho^* = 2 \sum_{i=t+1}^m p_i^2$$

$$t > m/2 \quad 1/\rho^* = m^2 \sum_{i=t+1}^m p_i^2 / (m-t)$$

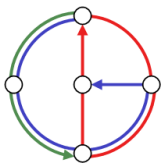
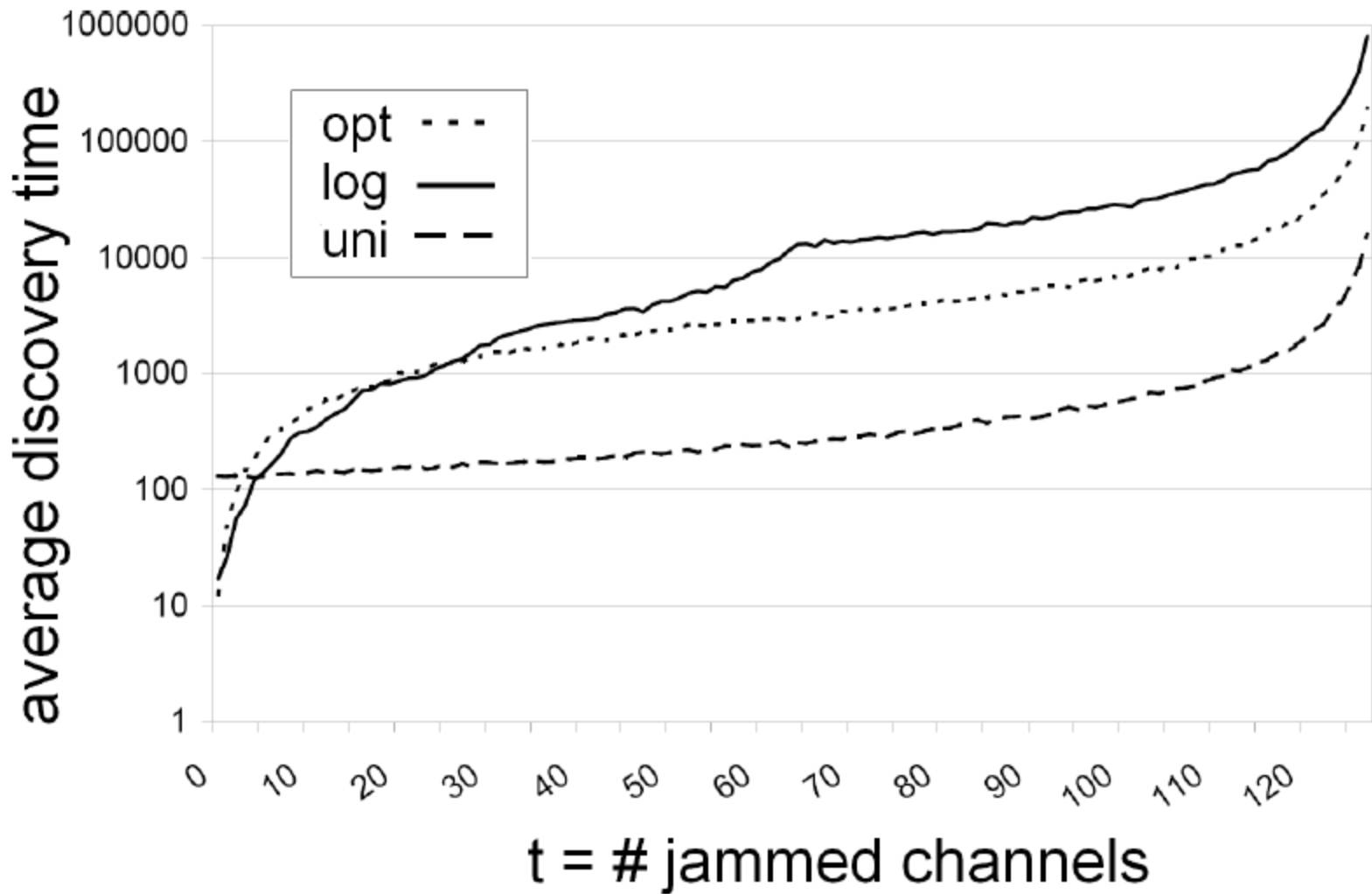
can choose any  $t$



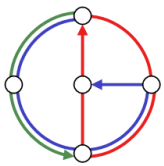
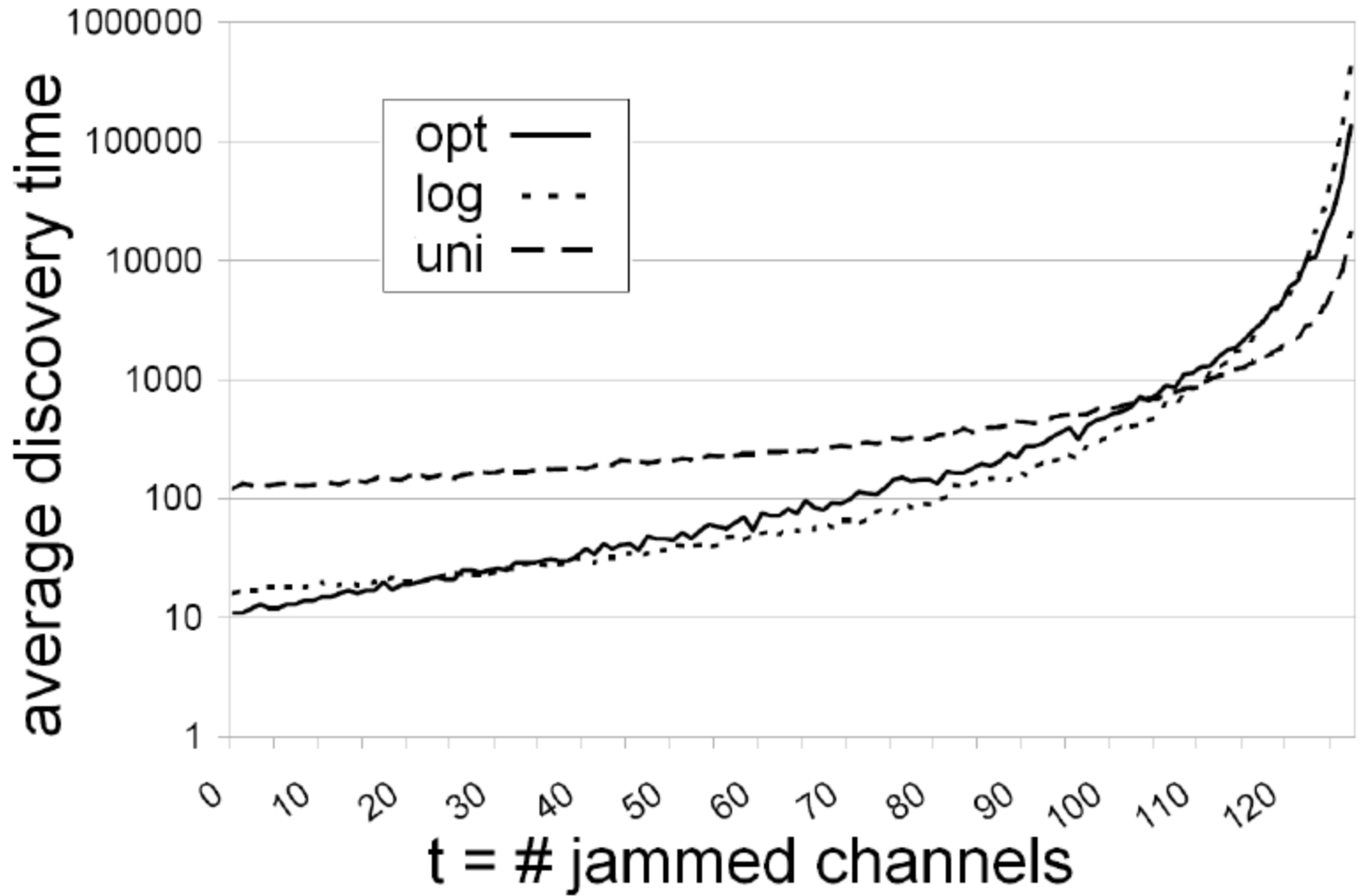
$$\rho^* = \Theta(\log^2 m)$$



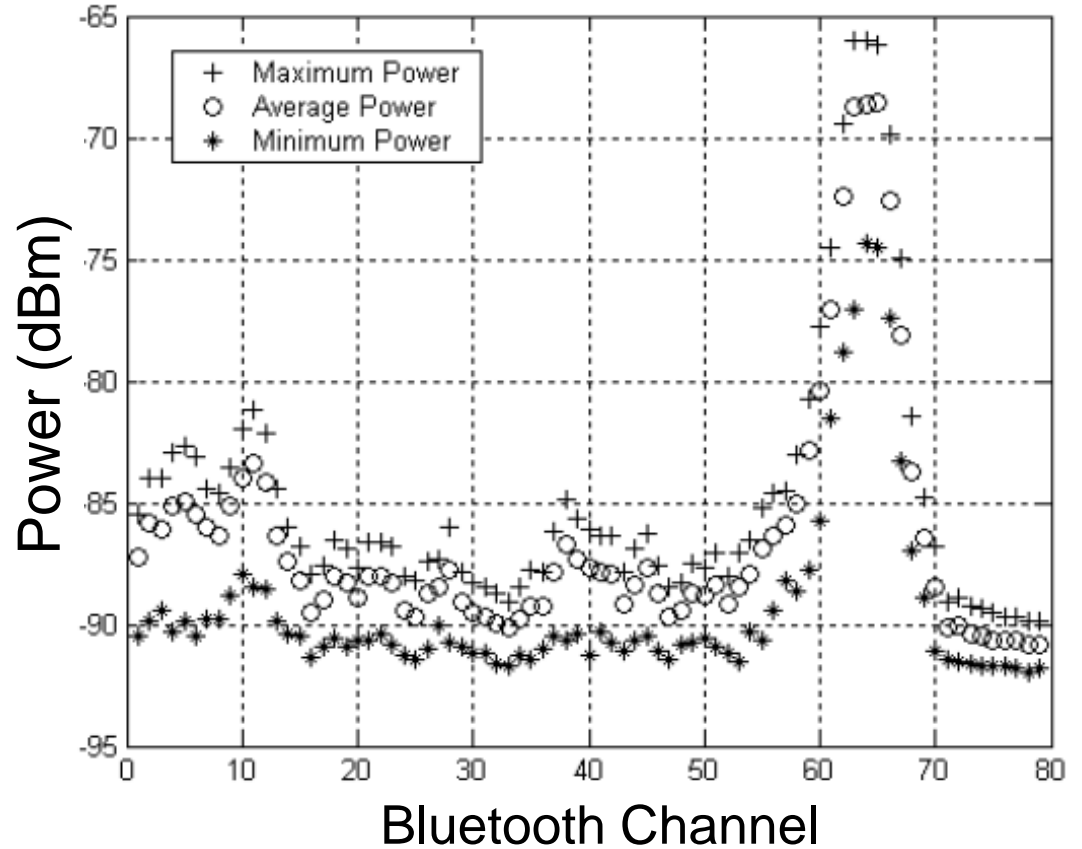
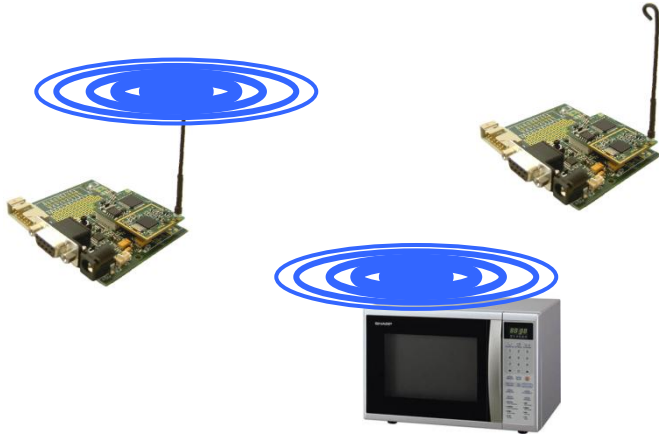
# Simulations: Worst Case Jammer



# Simulations: Random Jammer

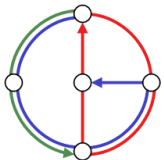


# Case Study: Bluetooth vs Microwave



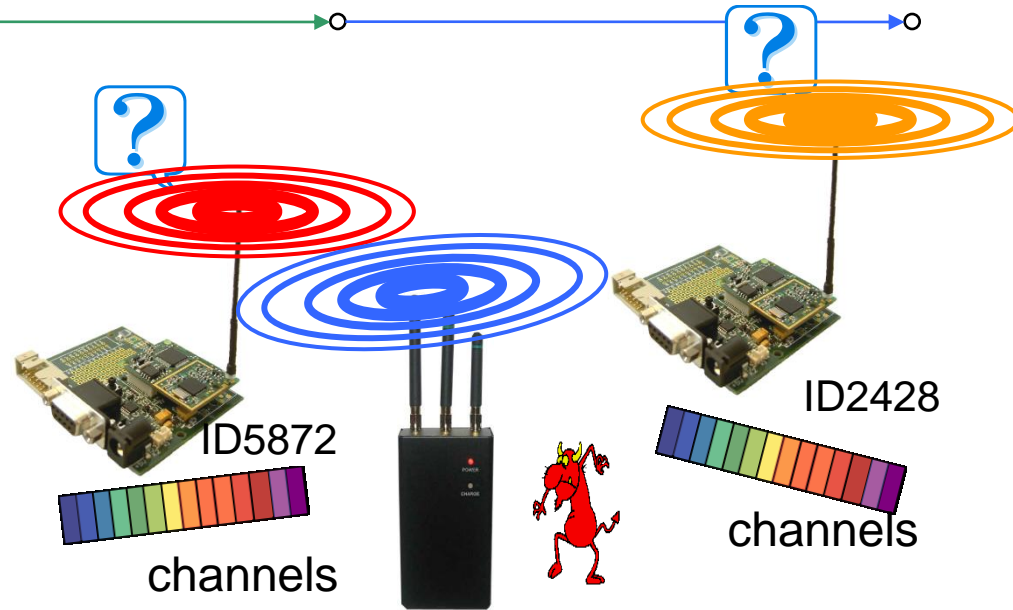
Microwave	BT	OPT
off	34.49	15.16
on	45.76	15.70

**OPT much better than Bluetooth**



# Lessons

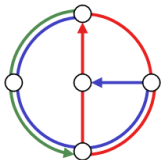
- Interference can prevent discovery
- uniformly random algorithm not always best solution



- best expected discovery time

$$E[\text{Algo}_{\text{opt}}] = \begin{cases} O(\log^2 m) & \text{if } t=0 \\ O(t \log^2 m) & \text{if } t < m/2 \\ O(m^2 \log^2 m / (m-t)) & \text{else} \end{cases}$$

- price for NOT knowing  $t$ :  $\rho^* = \Theta(\log^2 m)$





That's it...



**THANK YOU!**

