Speed Dating despite Jammers

Dominik Meier
Yvonne-Anne Pignolet
Stefan Schmid
Roger Wattenhofer

Distributed Computing Group

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

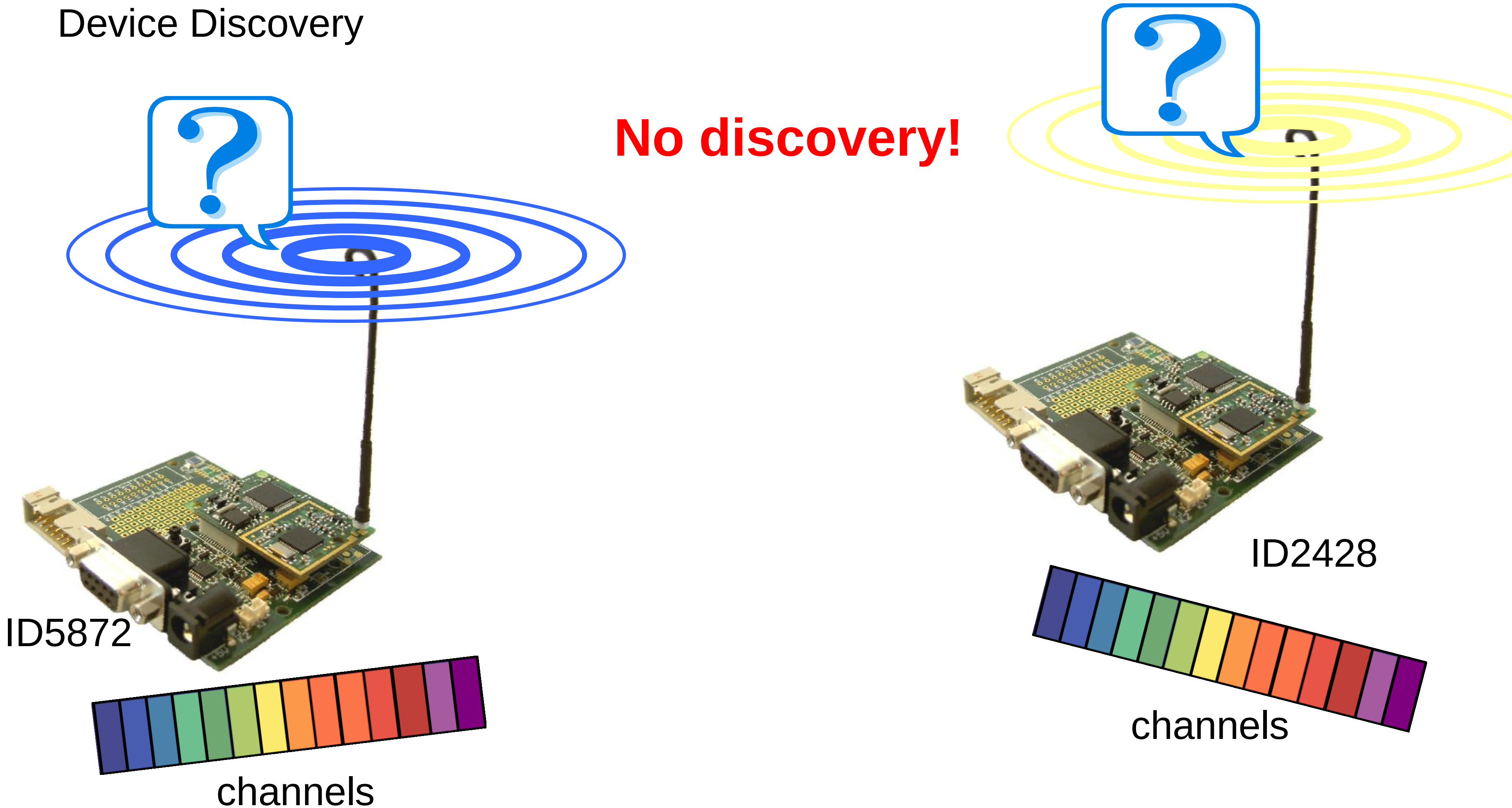
Wireless Networks

Radio Communication

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

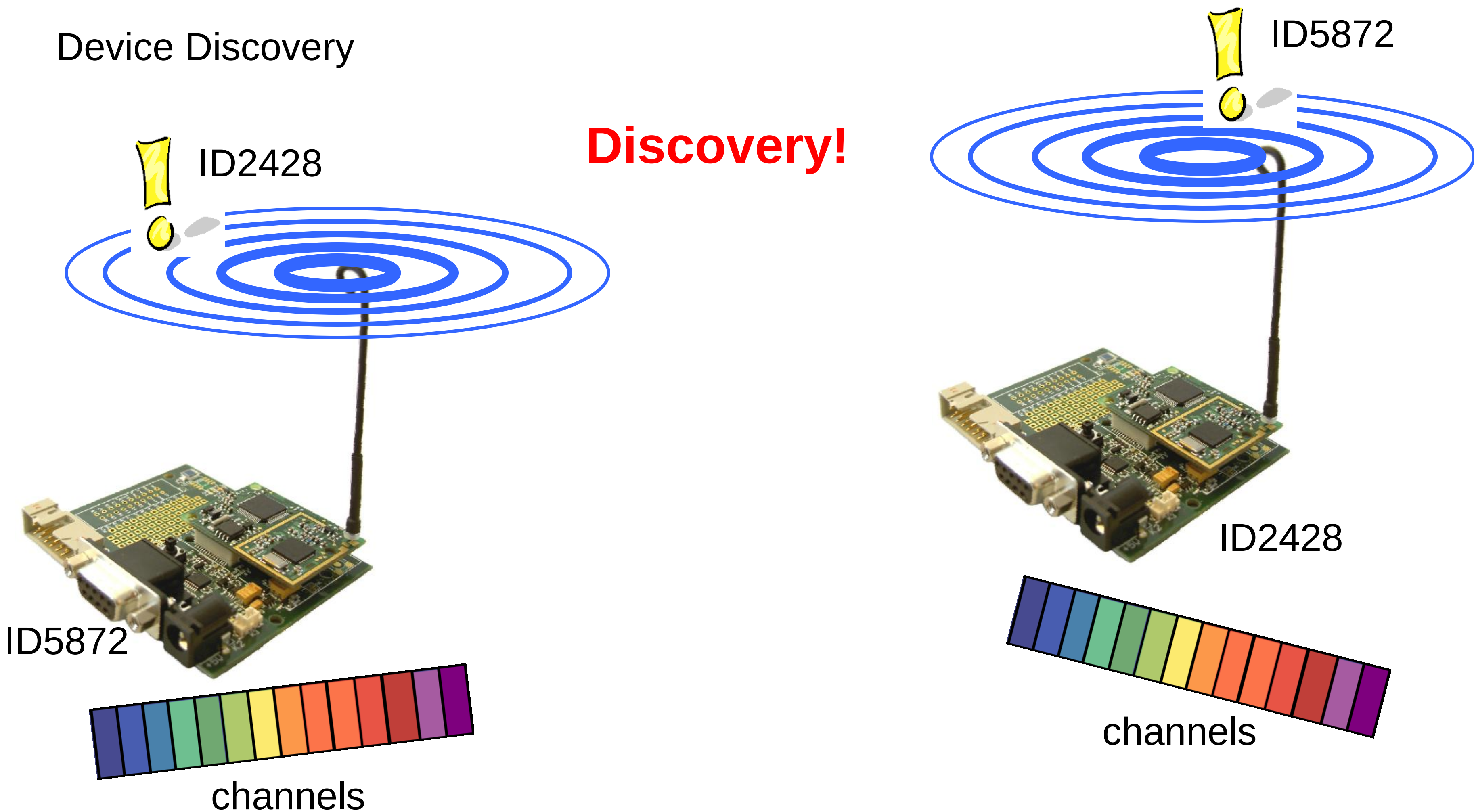
Device discovery under jamming attacks

Adversarial Interference: Jamming



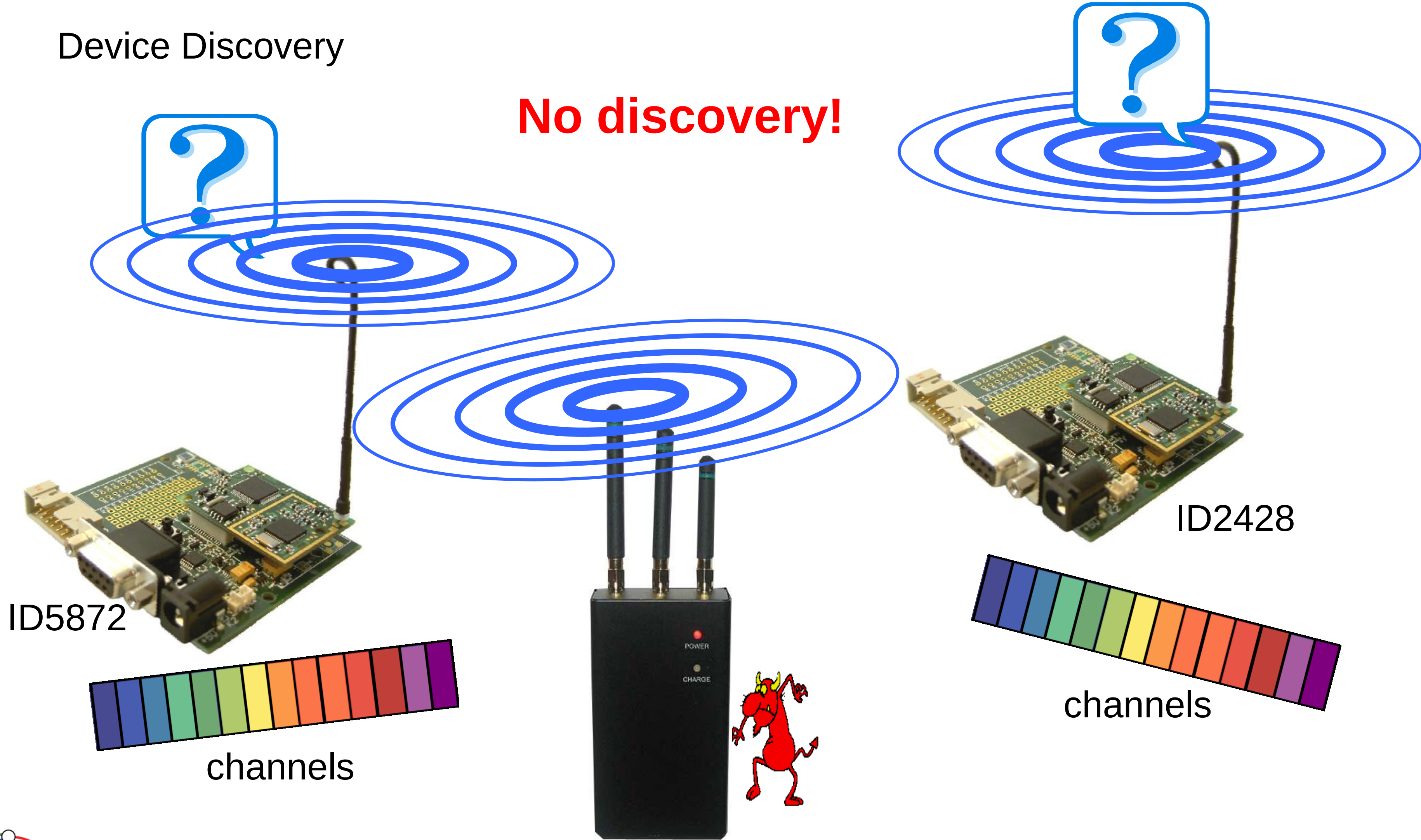
Adversarial Interference: Jamming

Device Discovery



Adversarial Interference: Jamming

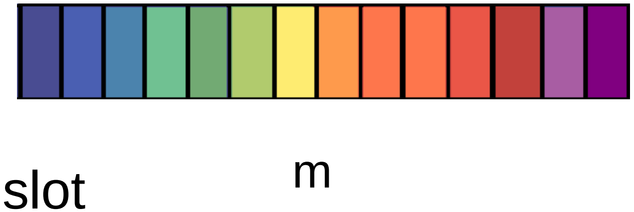
Device Discovery



Model: Device Discovery Problem

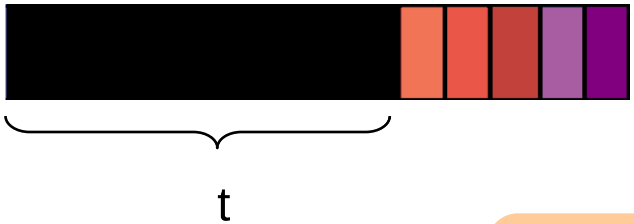
2 devices 

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



Adversary

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



Quickly?
Graceful degradation

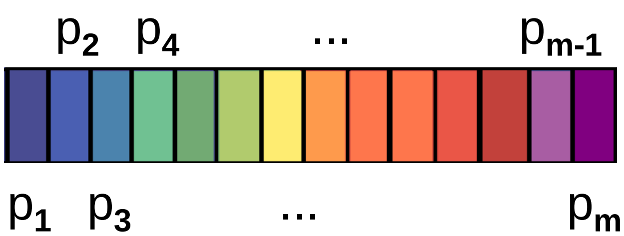
Goal:
Algorithm that lets the devices find each other quickly, regardless of t

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

Randomized Algorithms

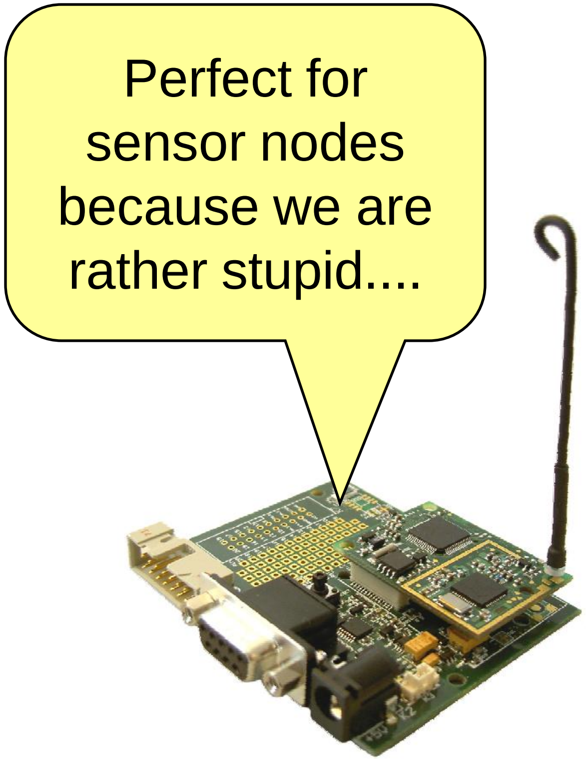
Represented by probability distribution over channels:

- choose channel i with probability p_i



Advantages

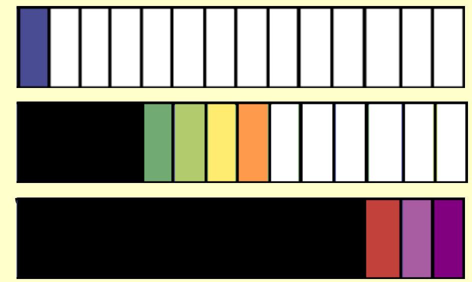
- Simple
- Independent of starting time
- Stateless
- Robust against adaptive adversaries



E[best discovery time | t known]

Best Algorithm

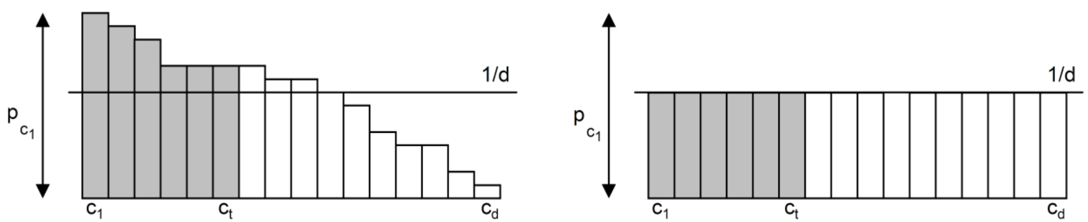
In each time slot



- if $t = 0$ choose channel 1
- if $t < m/2$ choose random channel in [1,2t]
- else 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?



Why channel in [1,2t] ?

2t minimizes discovery time

Easy!
What if we don't know t?

E[discovery time NOT knowing t]

Example $\text{Algo}_{\text{Random}}$

In each time slot

- choose channel uniformly at random

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

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_3

In each time slot

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

choose $t = \sqrt{m}$

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

E[discovery time NOT knowing t]

Example Algo$_{\log m}$

In each time slot

- with prob 1/log m   choose channel 1   ≈ estimate t = 0
- with prob 1/log m   choose randomly in [1,2]   ≈ estimate t = 1

...

- with prob 1/log m   choose randomly in [1,2^i]   ≈ estimate t = 2^(i-1)

...

- with prob 1/log m   choose randomly in [1,m]   ≈ estimate t = m/2

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

choose t= m

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

Optimal Algorithm?

General algorithm

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

In each time slot

- choose channel i with probability p_i

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

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

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

Optimal Algorithm?

General algorithm

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

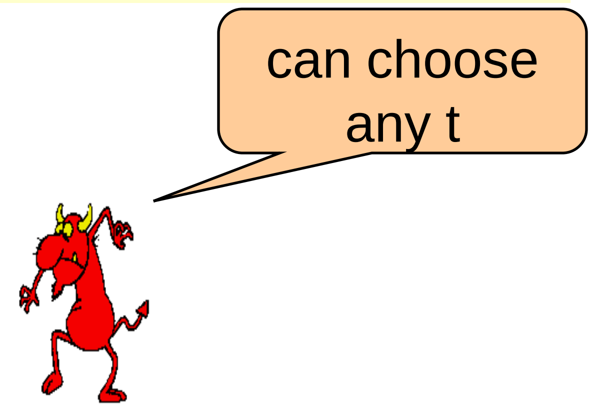
In each time slot

- choose channel i with probability p_i

Optimization problem

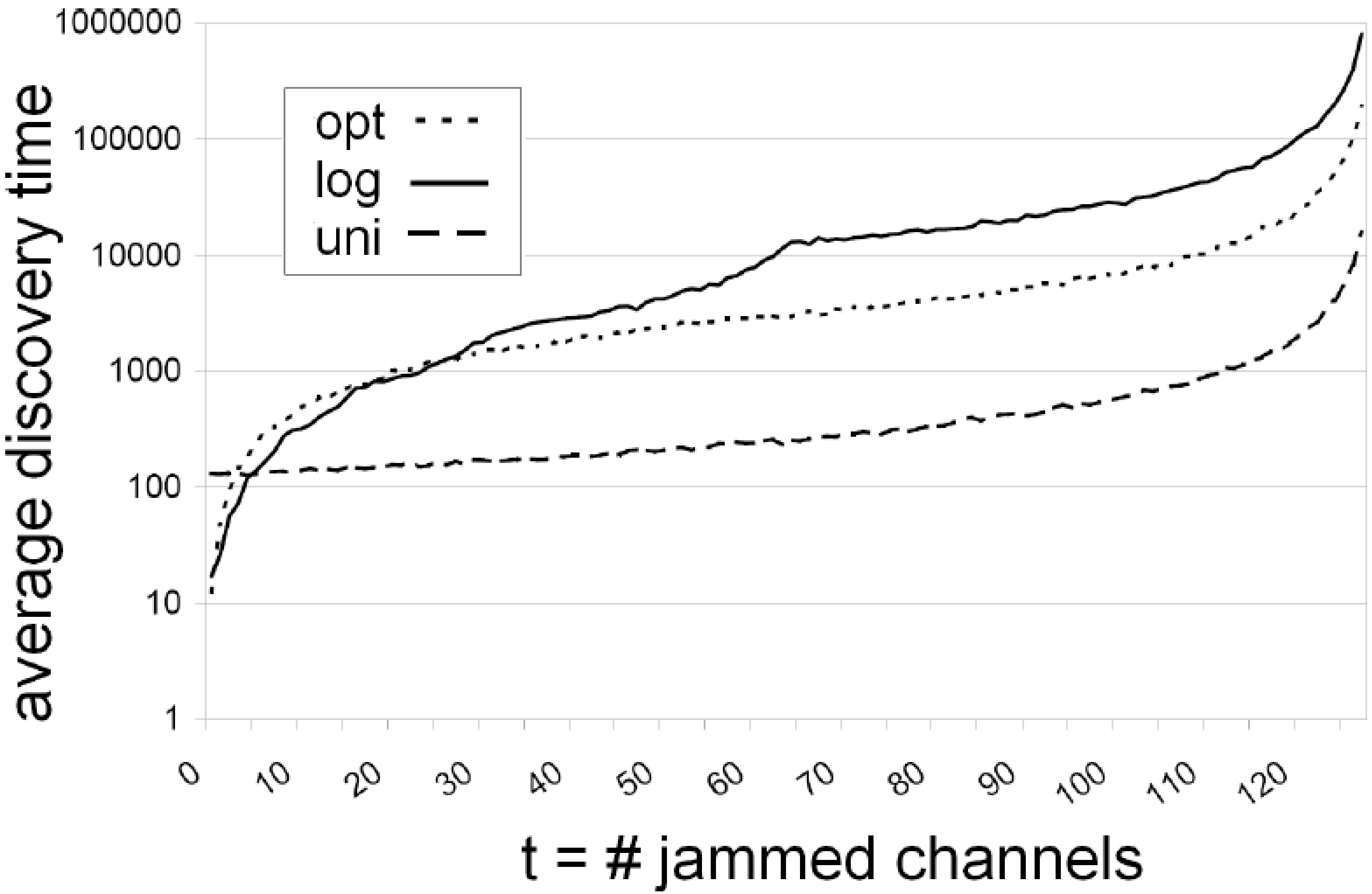
min ρ^* s.t.

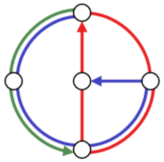
$t = 0$	$1/\rho^* = \sum_{i=1}^{m} p_i^2$
$1 \leq t \leq m/2$	$1/\rho^* = 2t \sum_{i=t+1}^{m} p_i^2$
$t > m/2$	$1/\rho^* = m^2 \sum_{i=t+1}^{m} p_i^2 / (m-t)$



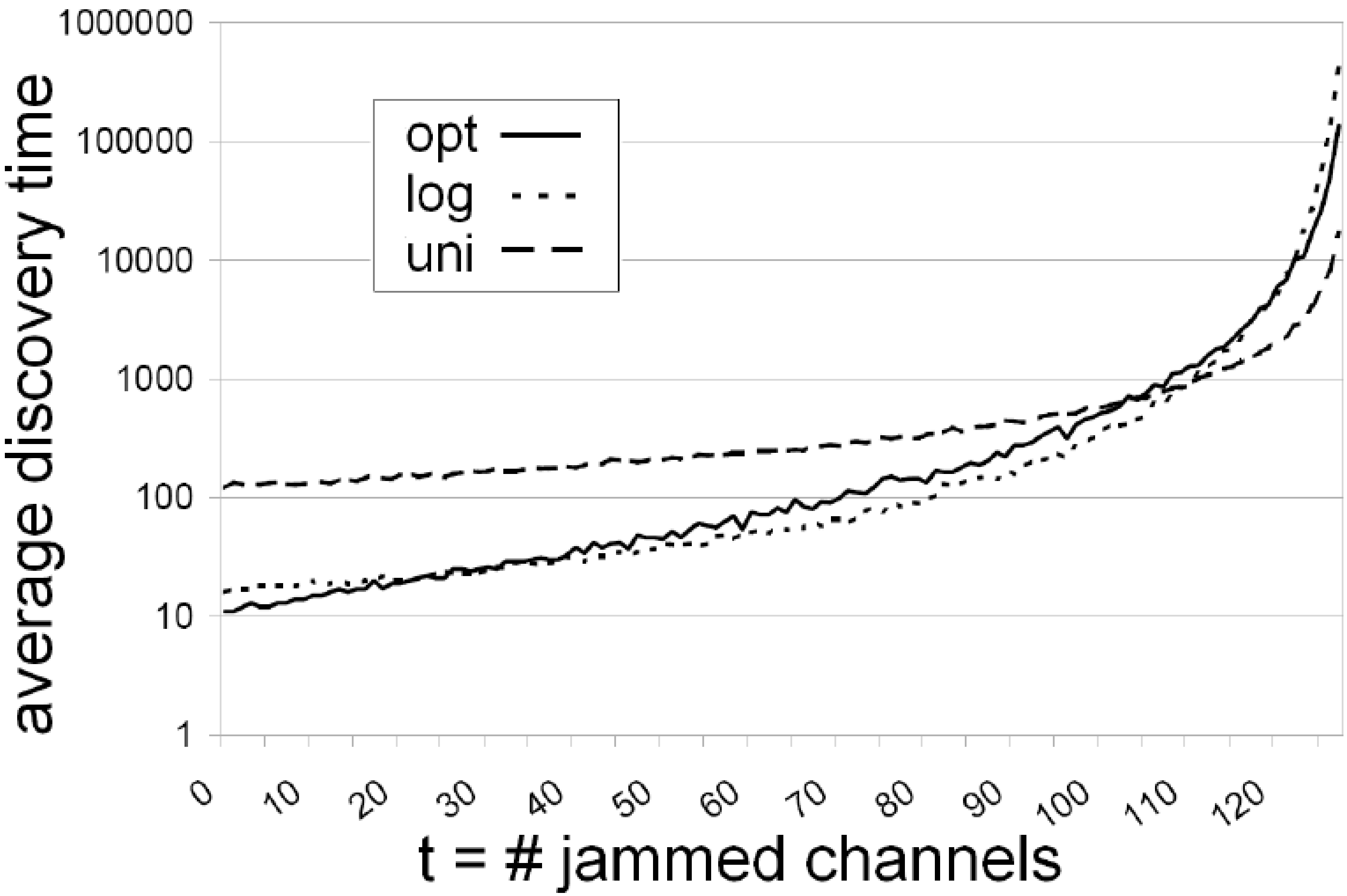
$\rho^* = \Theta(\log^2 m)$

Simulations: Worst Case Jammer

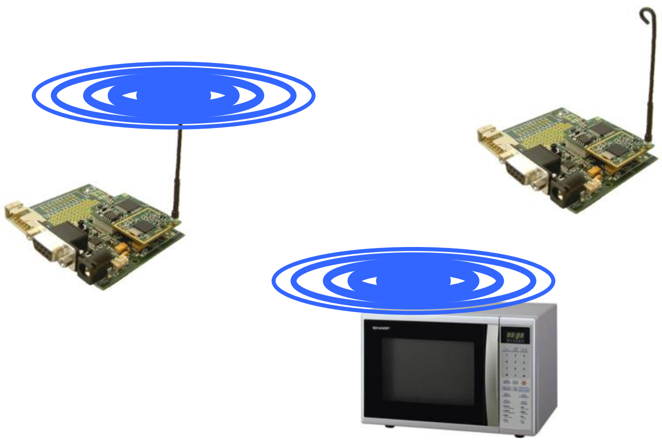




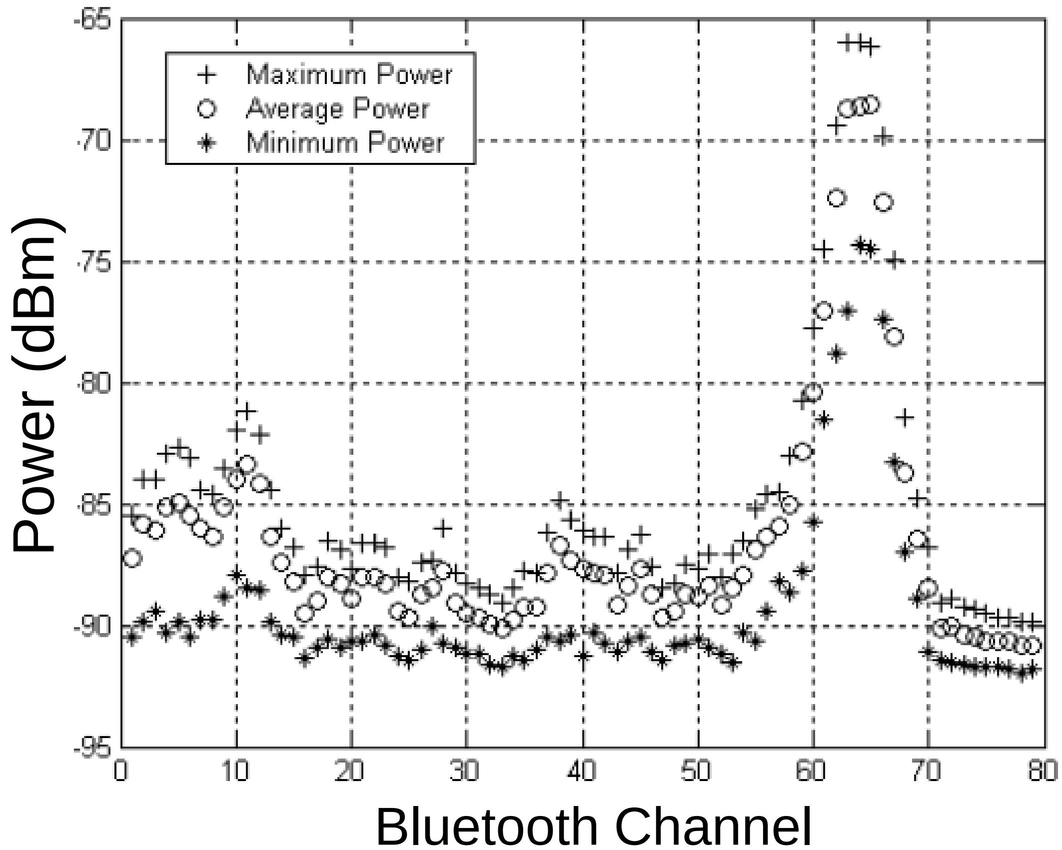
Simulations: Random Jammer



Case Study: Bluetooth vs Microwave

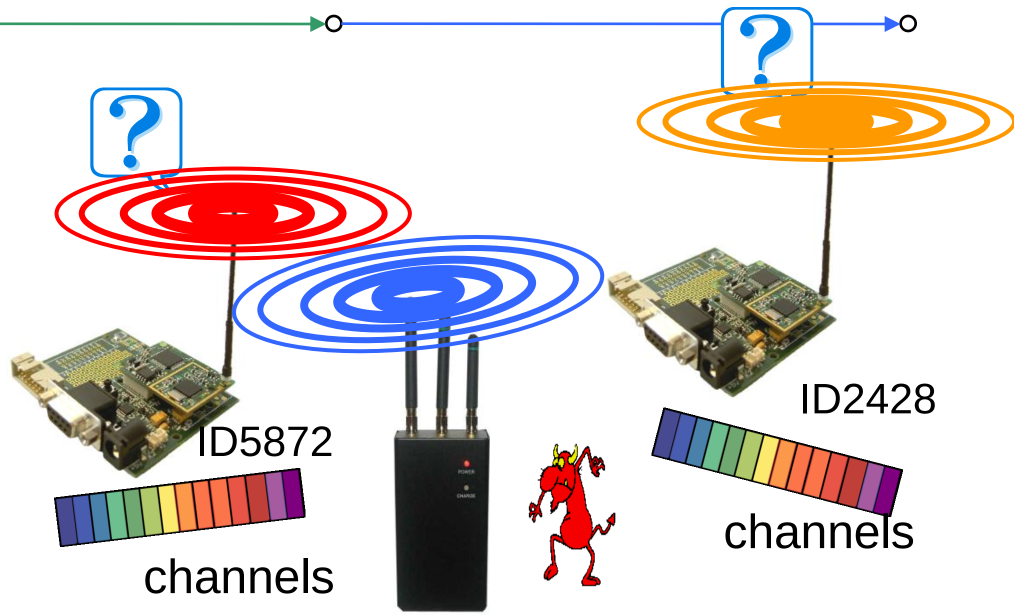


Microwave	BT	OPT
off	34.49	15.16
on	45.76	15.70



OPT much better than Bluetooth

Lessons



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

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

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

That's it…

THANK YOU!