Speed Dating despite Jammers

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Wireless Networks

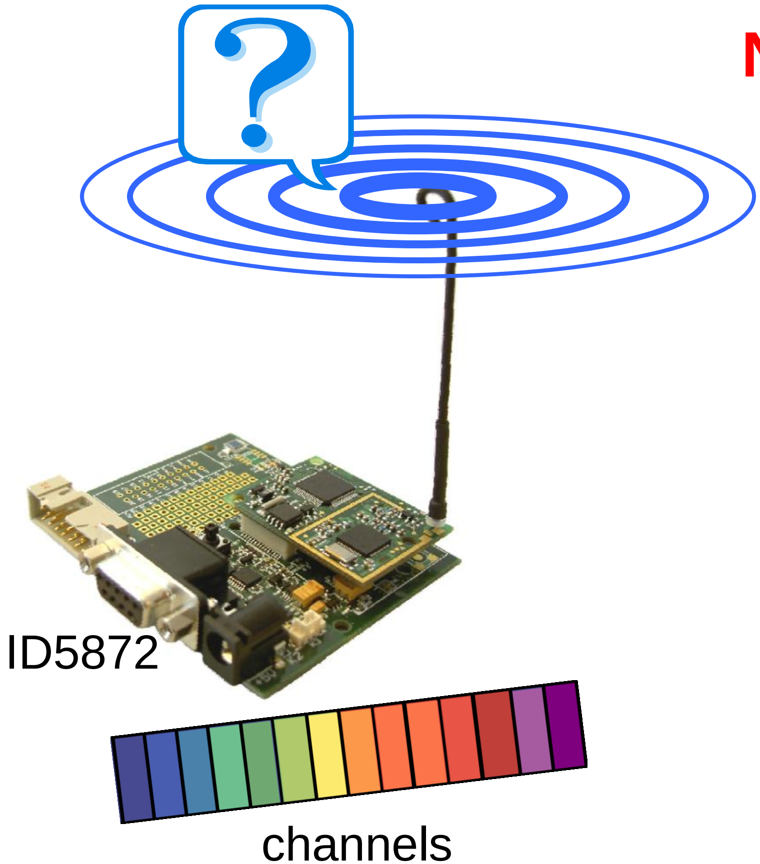
Radio Communication

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

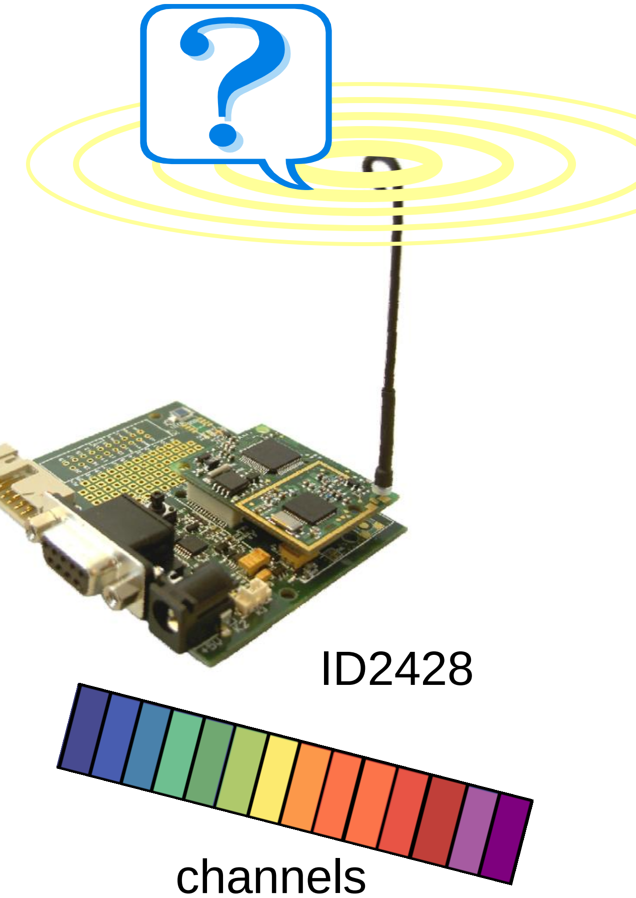
Device discovery under jamming attacks

Adversarial Interference: Jamming

Device Discovery

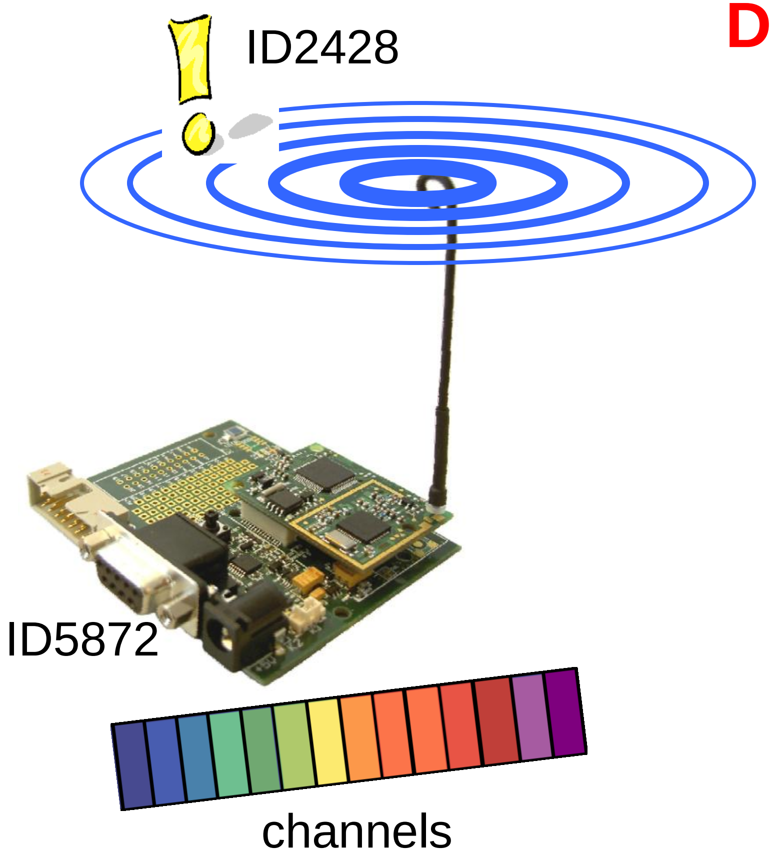


No discovery!

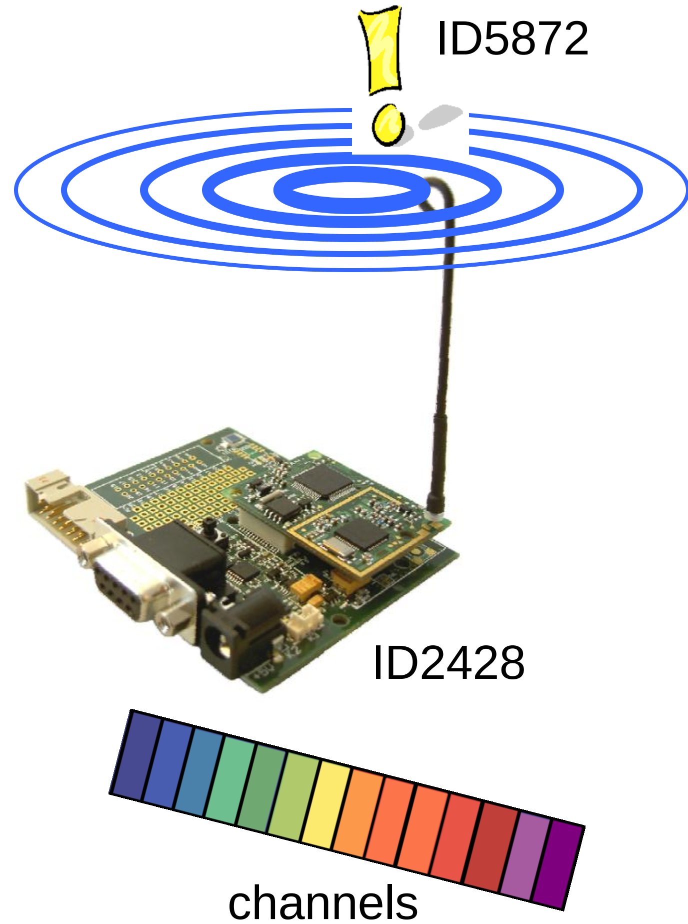


Adversarial Interference: Jamming

Device Discovery

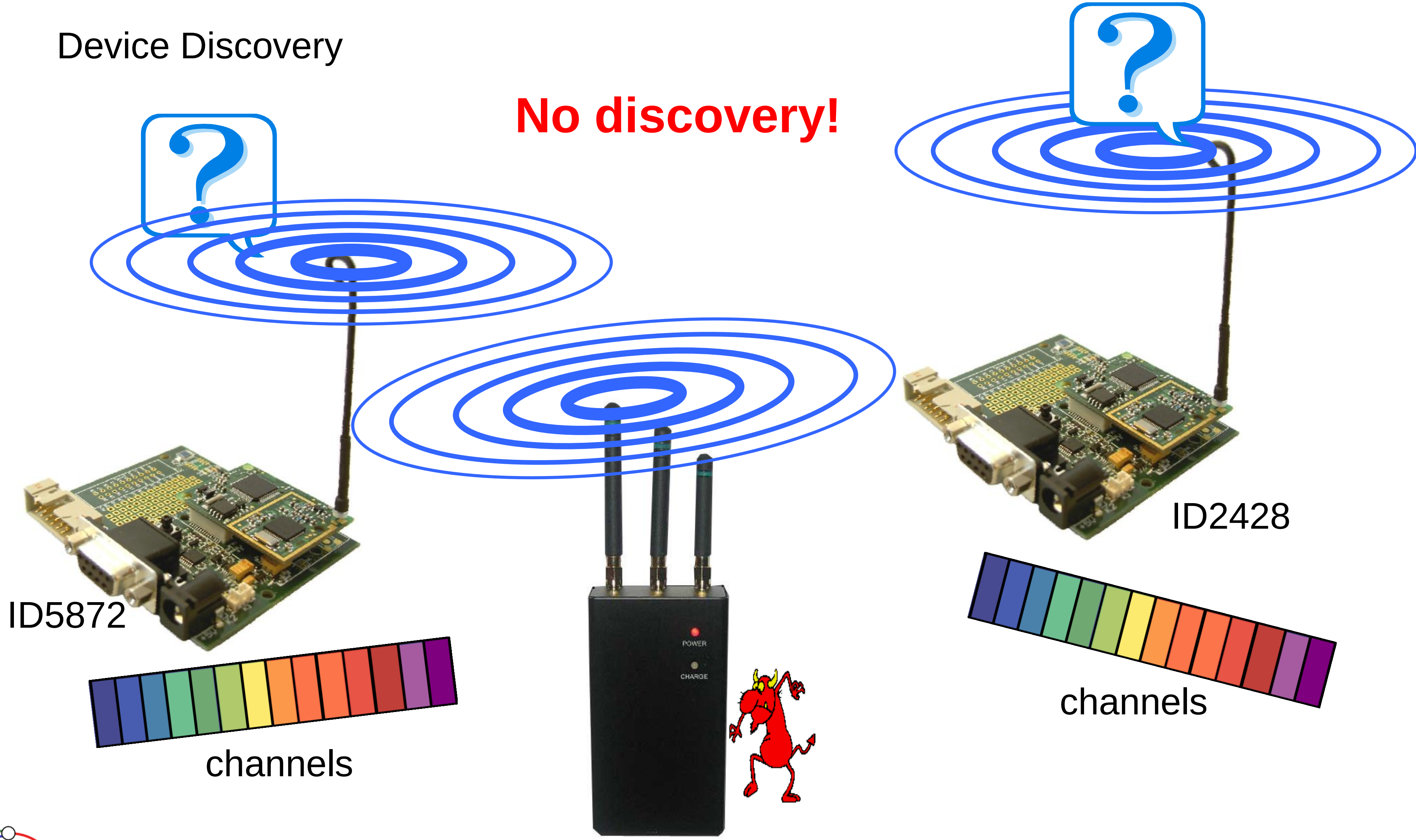


Discovery!



Adversarial Interference: Jamming

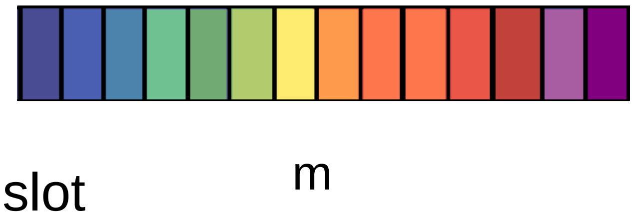
Device Discovery



Model: Device Discovery Problem

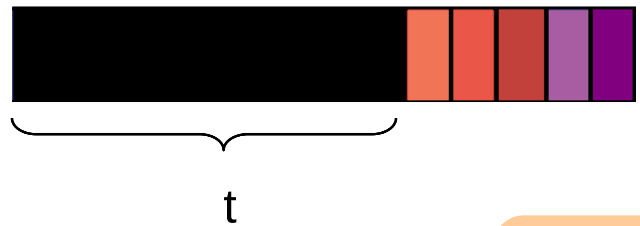
2 devices 

- 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

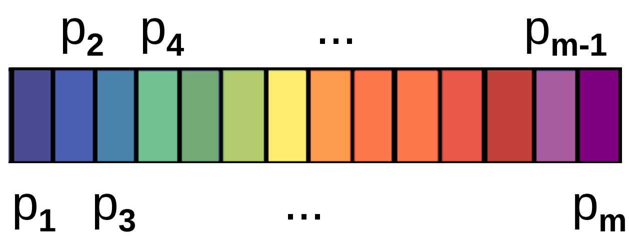
Quality: $$\rho := \max_{t} \frac{E[\text{algo discovery time} \mid t \text{ unknown}]}{E[\text{best discovery time} \mid t \text{ known}]}$$

Algorithms

Randomized Algorithms

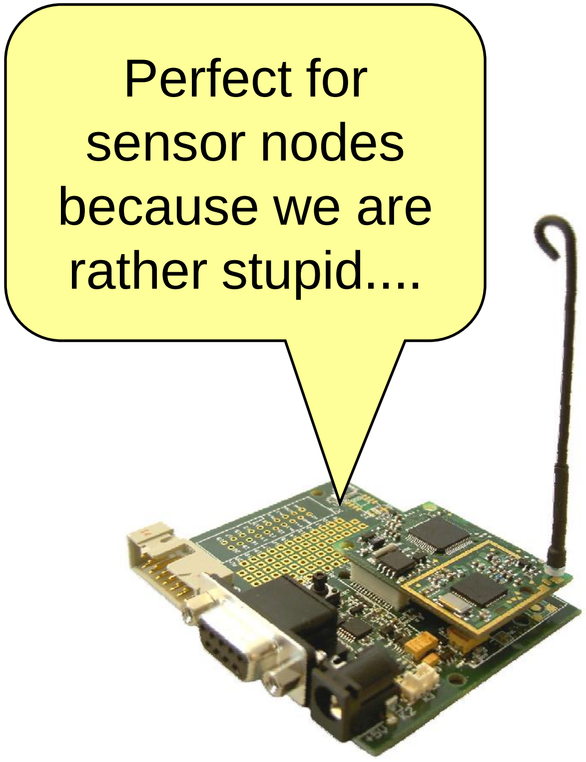
Represented by probability distribution over channels:

- choose channel i with probability p_i



Advantages

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

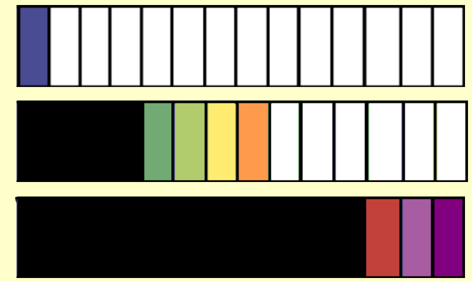


E[best discovery time | t known]

Best Algorithm

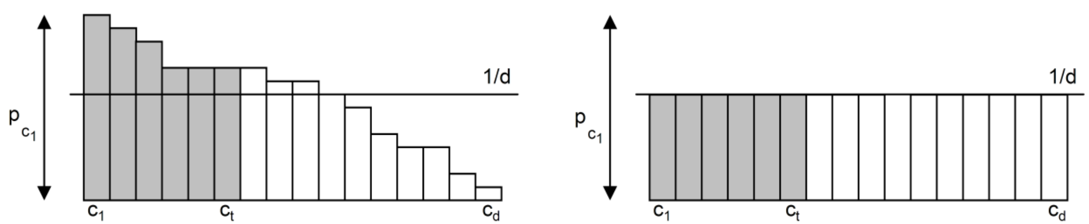
In each time slot

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

In each time slot

- choose channel uniformly at random

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

choose t=0
$\rho_{\text{Random}} = m$

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

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,√m] ≈ estimate t = √m/2
- with prob 1/3 choose randomly in [1,m] ≈ estimate t = m/2

choose t= √m
$\rho_3 = O(\sqrt{m})$

E[discovery time NOT knowing t]

Example $\text{Algo}_{\log m}$

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

choose t= m

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

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

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.

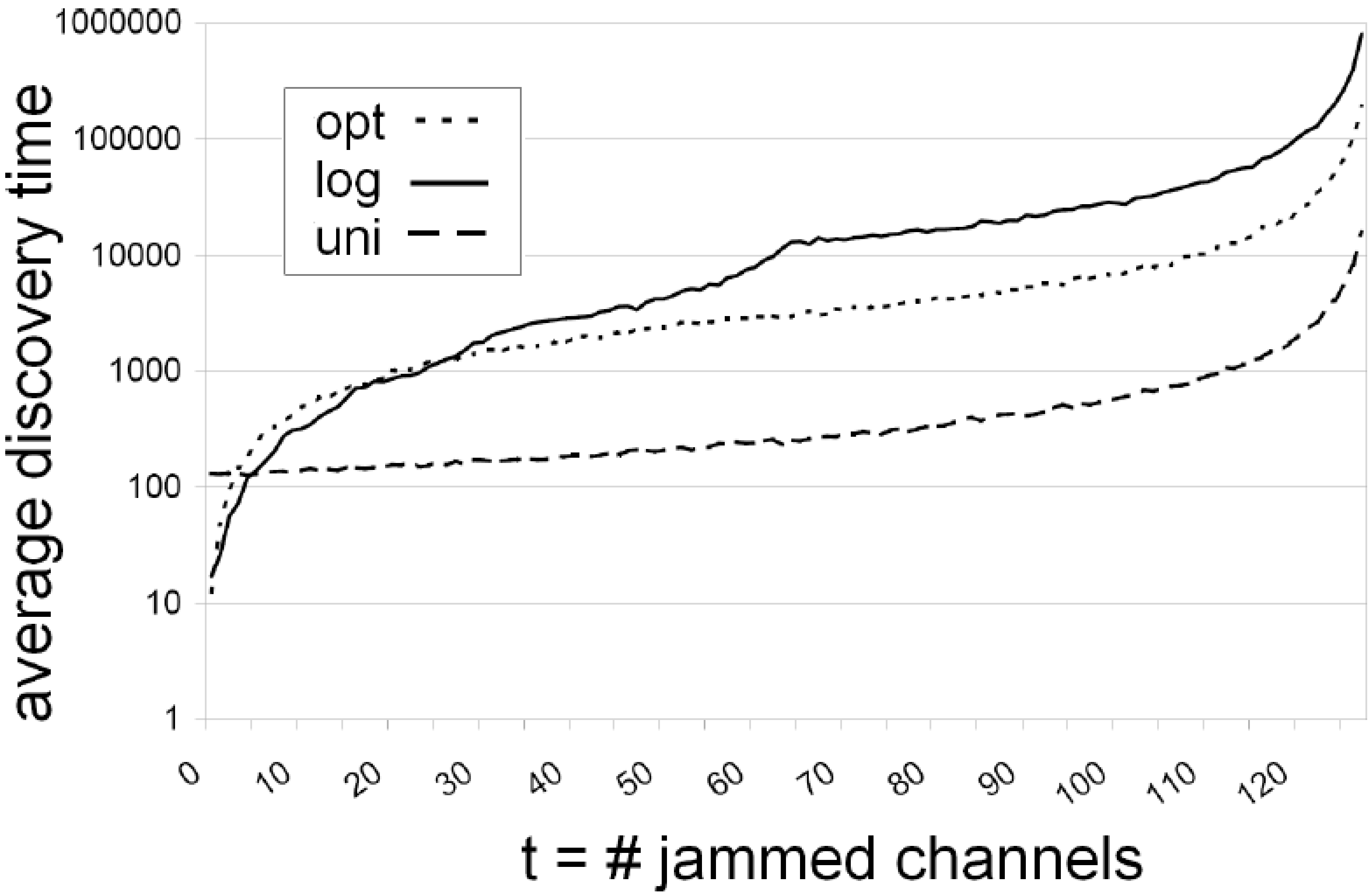
t = 0: $1/\rho^* = \sum_{i=1}^{m} p_i^2$

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

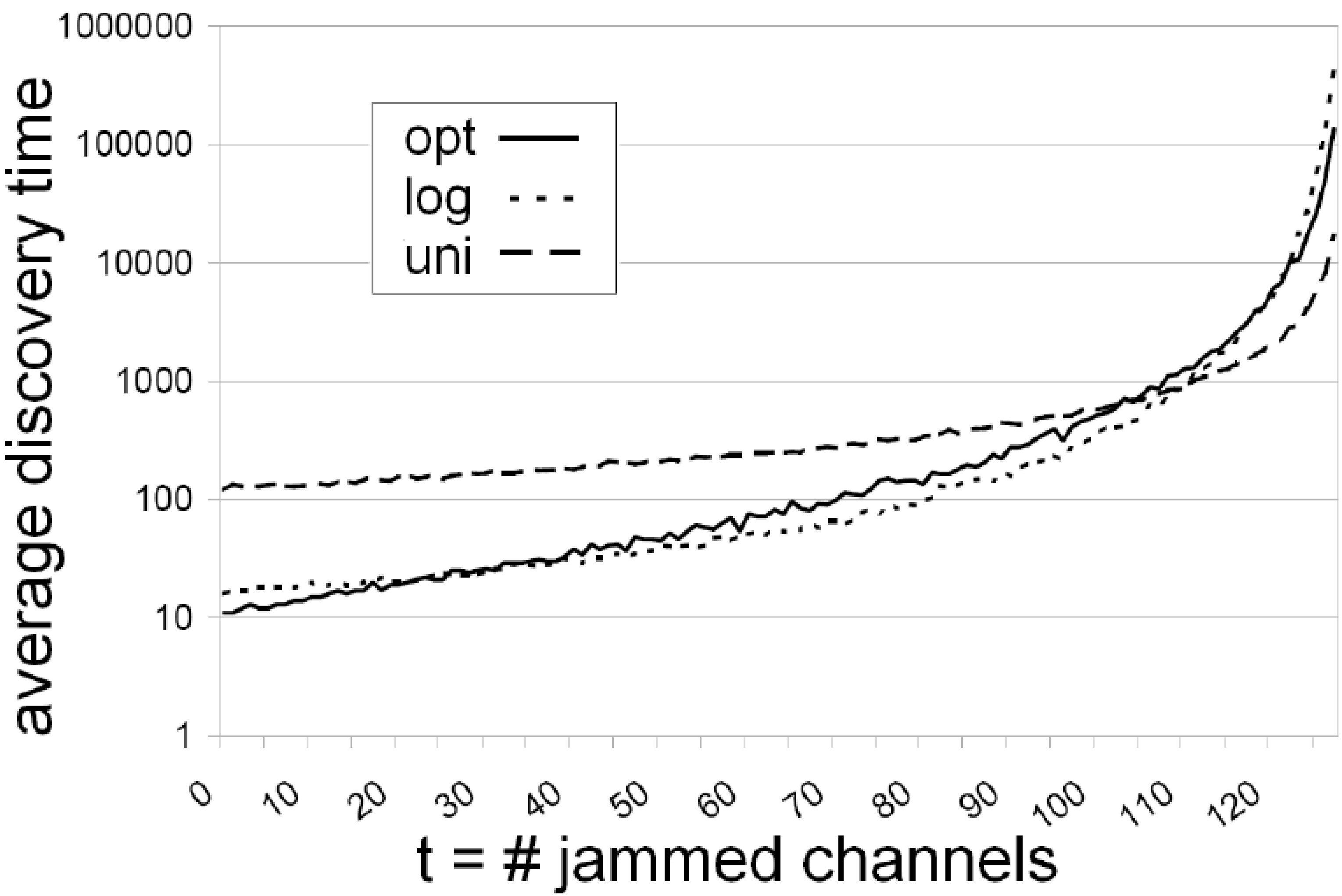
t > m/2: $1/\rho^* = m^2 \sum_{i=t+1}^{m} p_i^2 /(m-t)$

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

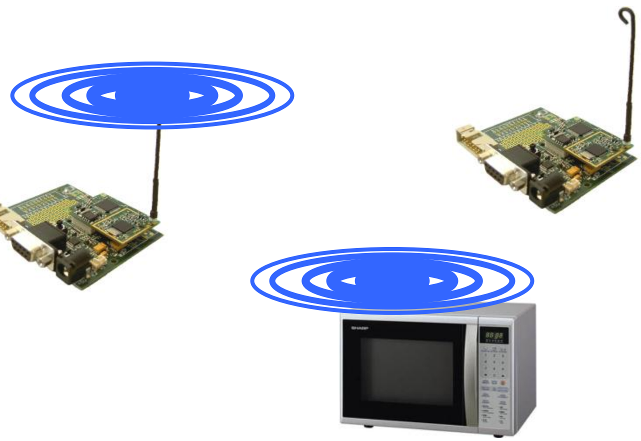
Simulations: Worst Case Jammer



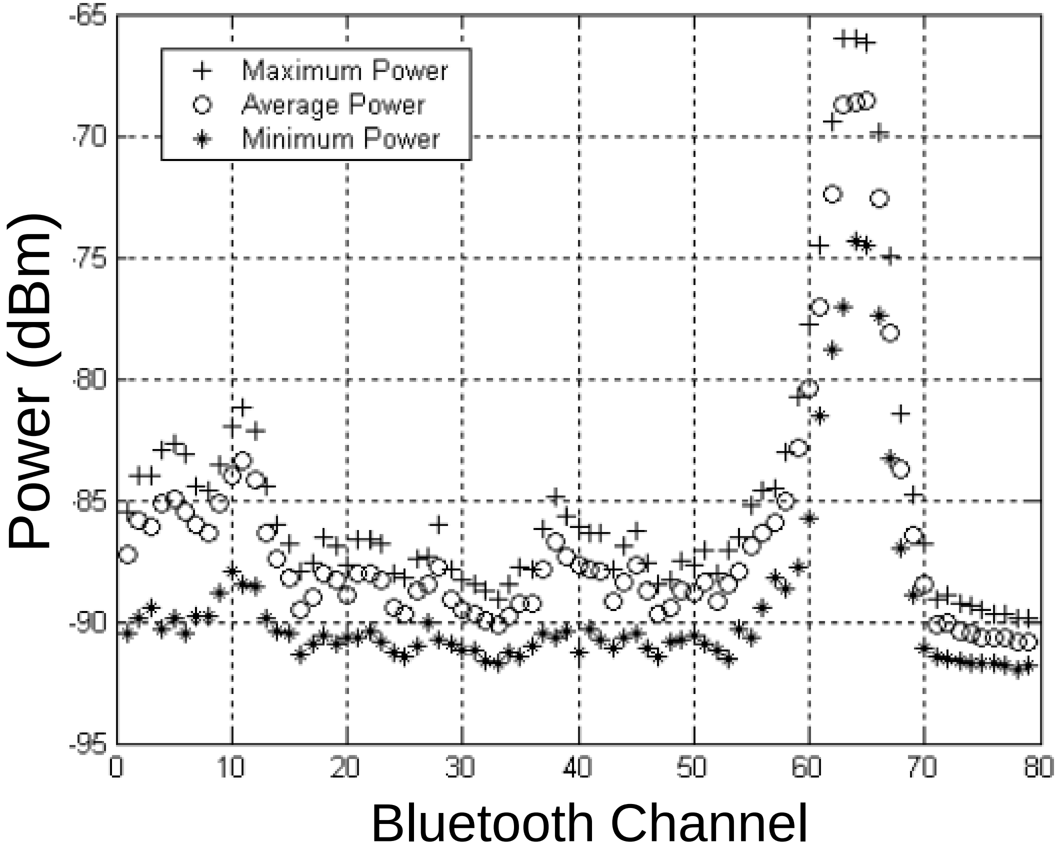
Simulations: Random Jammer



Case Study: Bluetooth vs Microwave



Microwave	BT	OPT
off	34.49	15.16
on	45.76	15.70

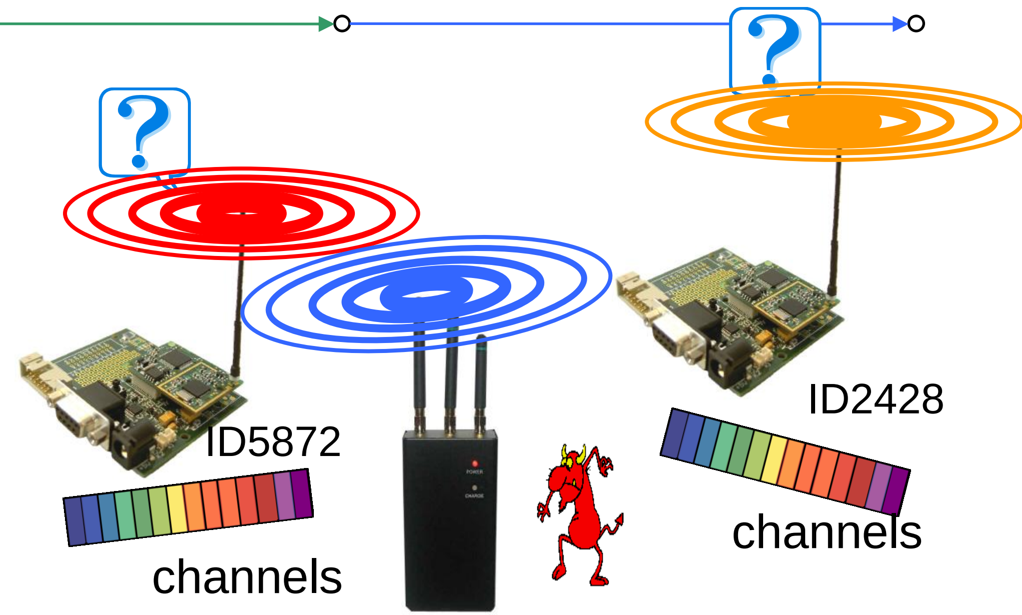


OPT much better than Bluetooth

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!