Competitive MAC under Adversarial SINR

Adrian Ogierman, Andrea Richa, Christian Scheideler,
Stefan Schmid, Jin Zhang

Co MAC

Ac ndrea
St hang

Co IAC

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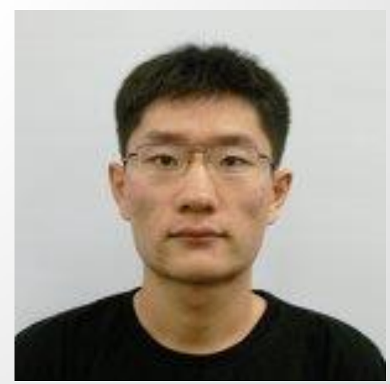

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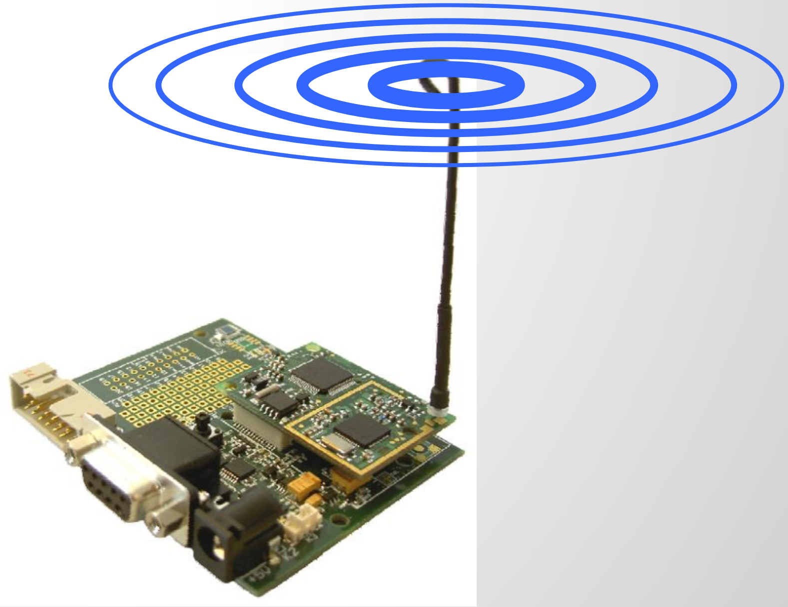
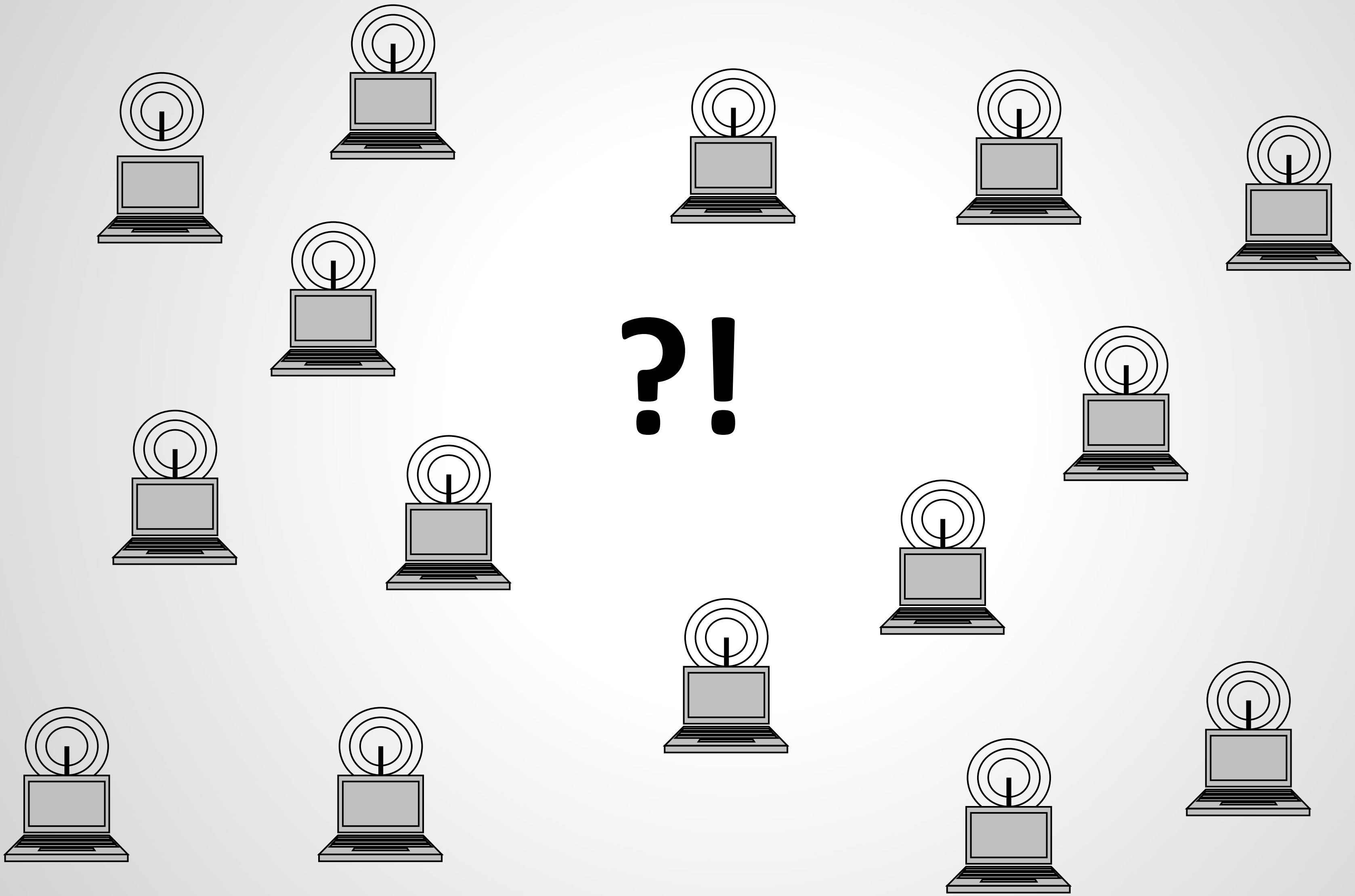
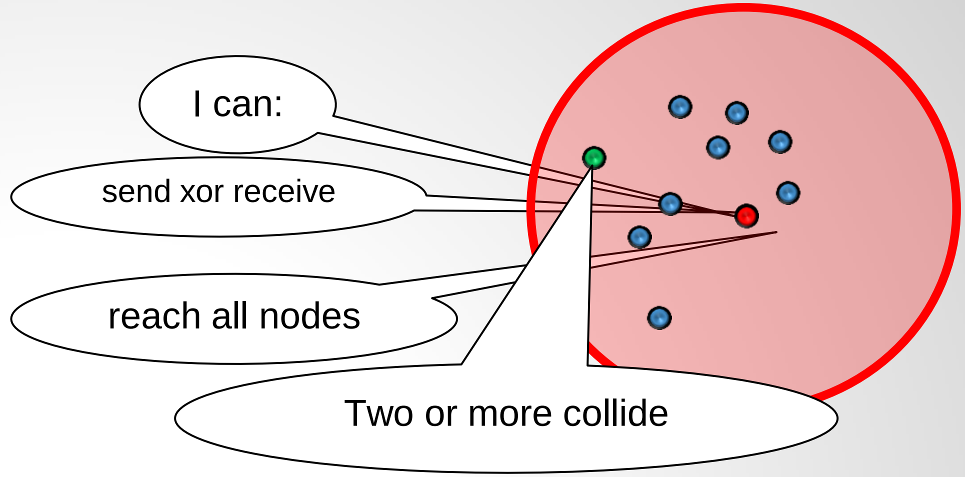


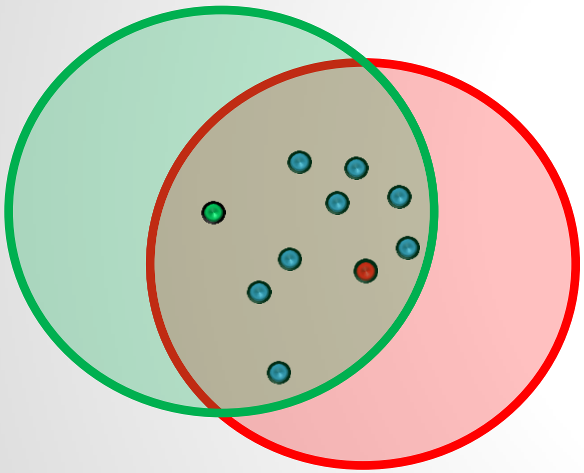
MAC: A Distributed Coordination Problem



Models for Wireless

- The Radio Model
  - All nodes within range

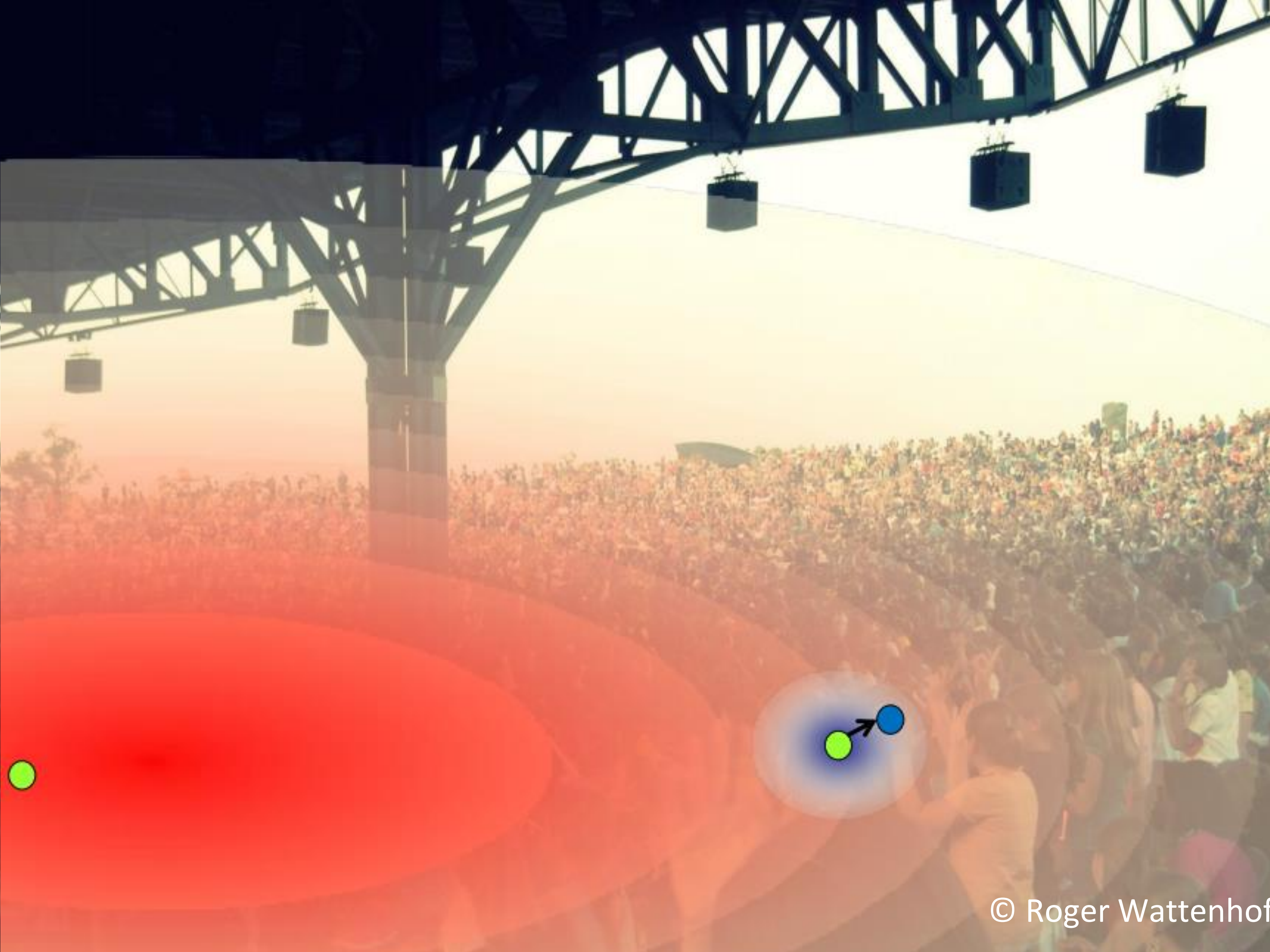


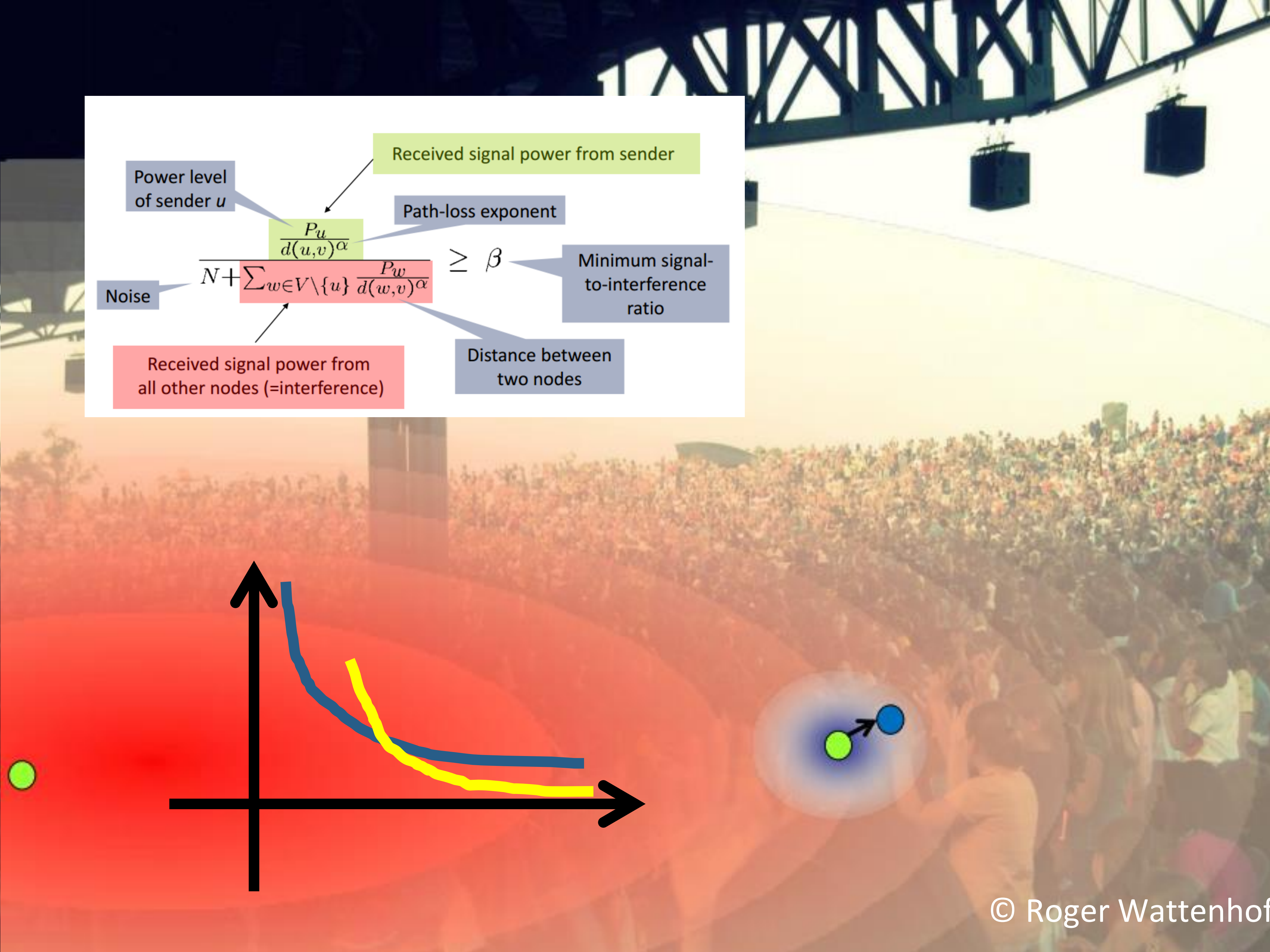


- The Unit Disk Graph Model
  - Unit radius

- The SINR Model
  - Polynomial decay of signal
  - Best explained with a rock concert

$$\frac{P(u)/d(u,v)^{\alpha}}{\mathcal{N} + \sum_{w \in S} P(w)/d(w,v)^{\alpha}} \geq \beta$$


© Roger Wattenhof


Received signal power from sender
Power level of sender *u*
Path-loss exponent
$$\frac{\frac{P_u}{d(u,v)^\alpha}}{N + \sum_{w \in V \setminus \{u\}} \frac{P_w}{d(w,v)^\alpha}} \geq \beta$$
Minimum signal-to-interference ratio
Noise
Received signal power from all other nodes (=interference)
Distance between two nodes
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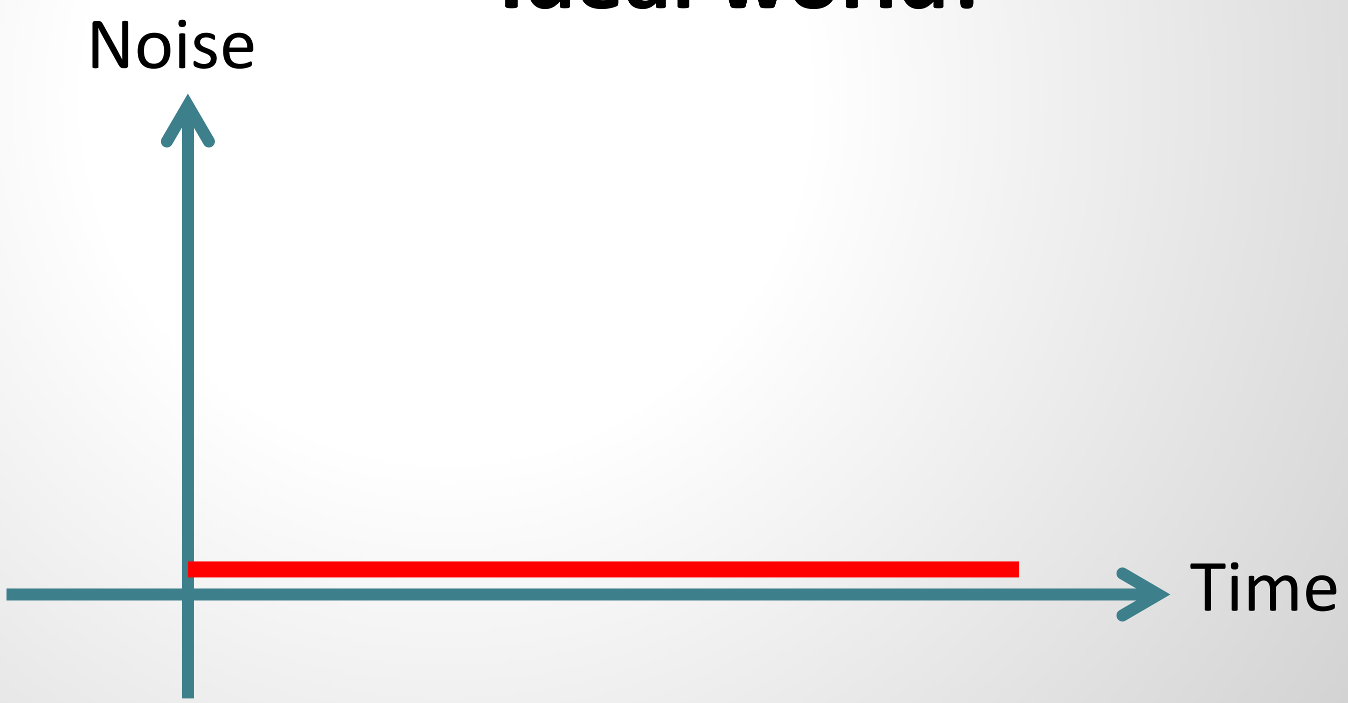
A Tough Model: External Interference

External interference due to:

- Co-existing networks
- Microwave Ovens
- Jammers

Ideal world!



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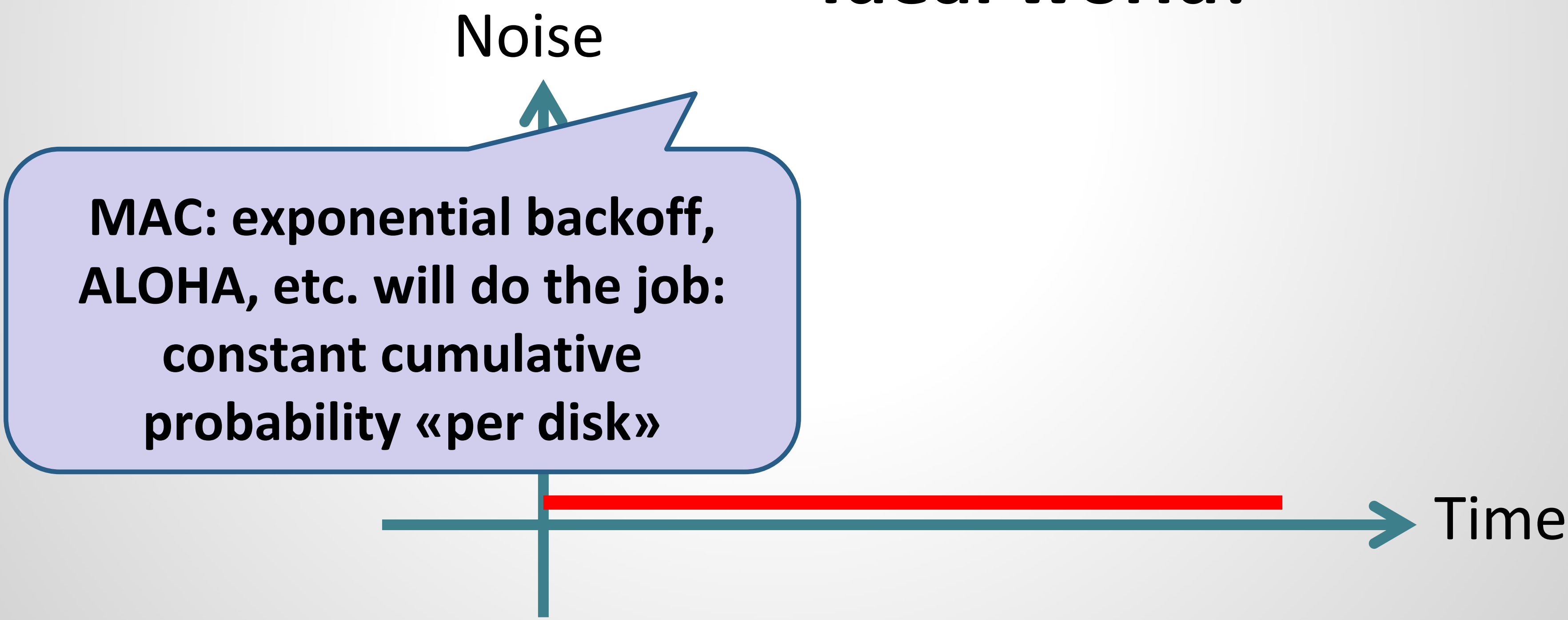
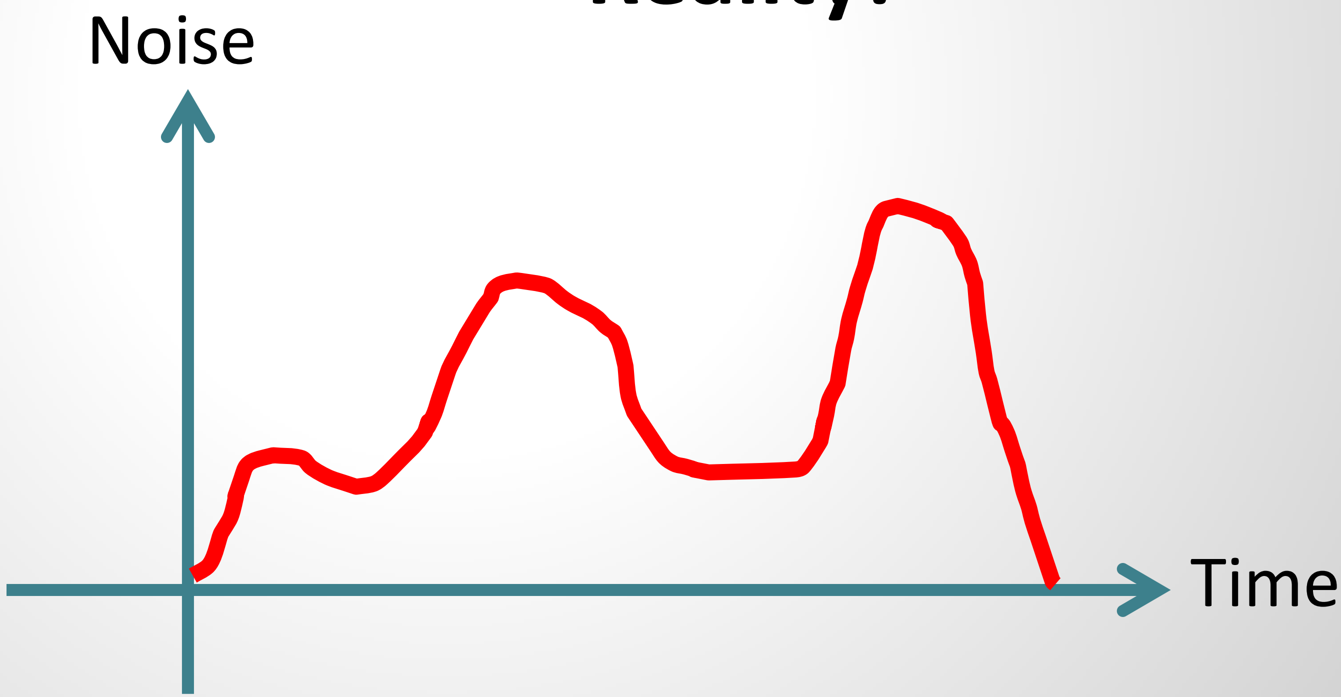


Adding External Interference

External interference due to:

- ❑ Co-existing networks
- ❑ Microwave Ovens
- ❑ Jammers

Reality!



Adding External Interference

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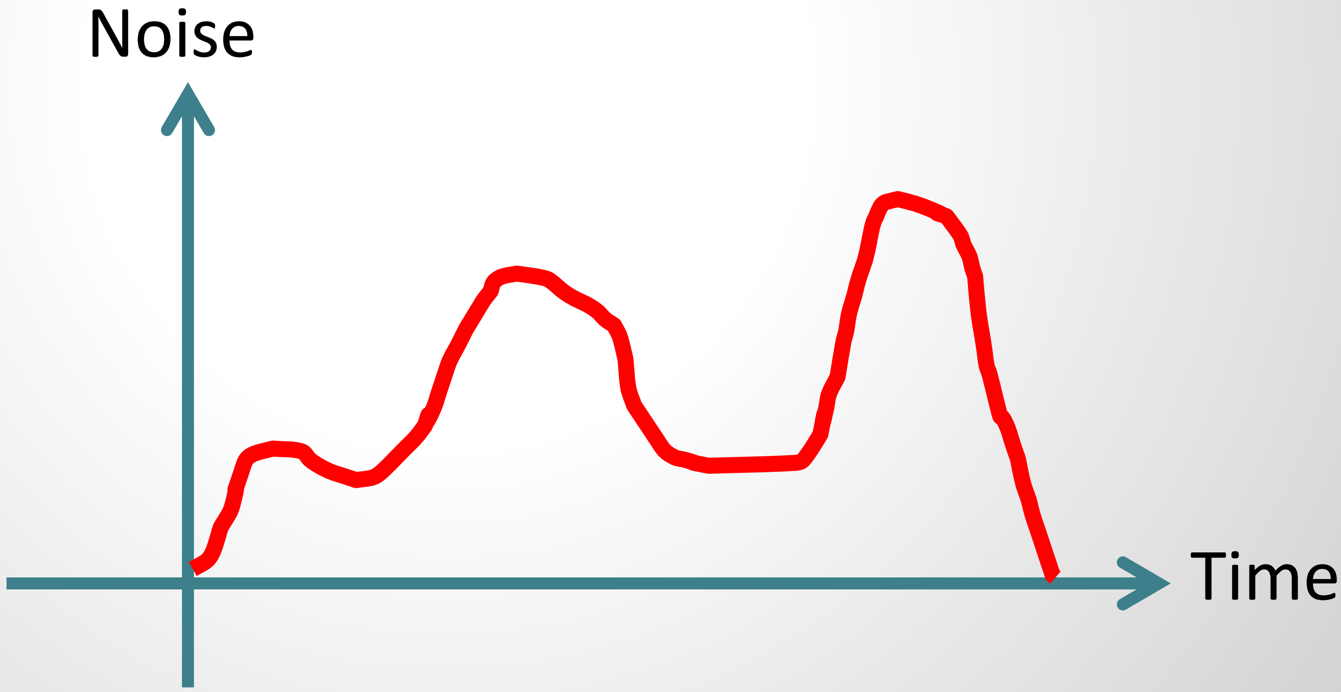
How to model?!



Adding External Interference

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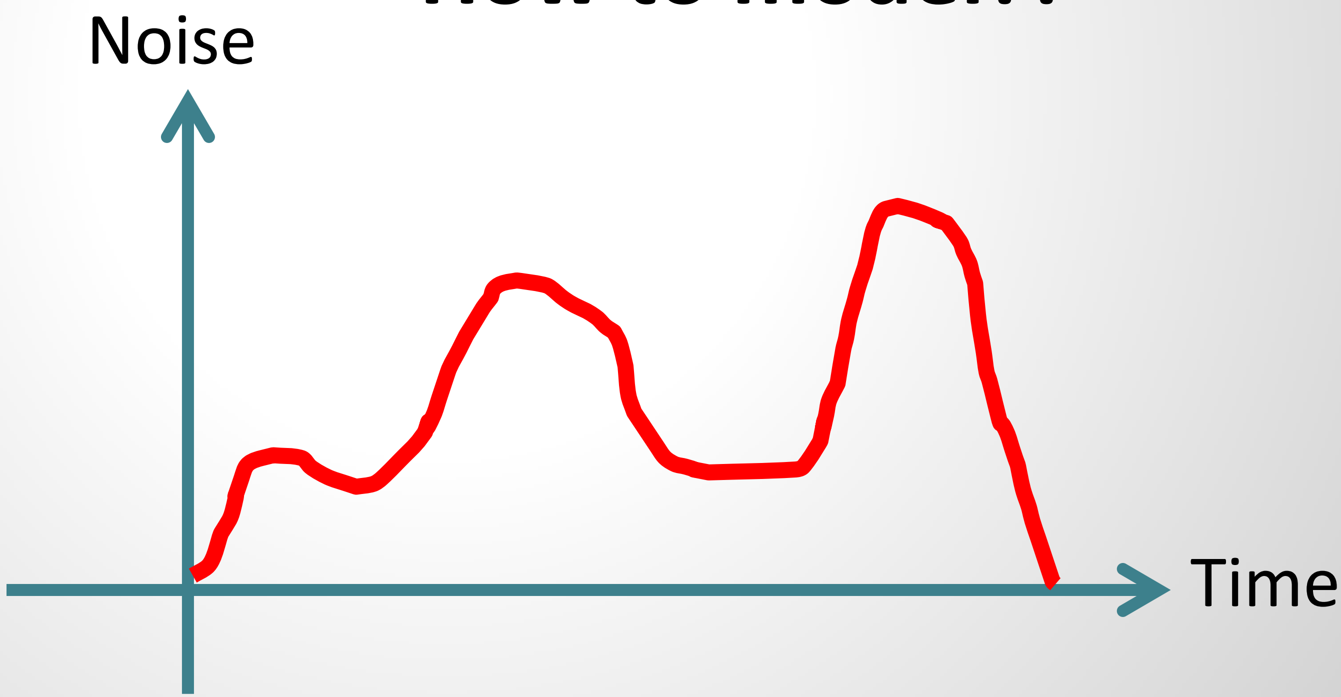
How to model?!

Adversary:



The Adversary Model

$$\frac{P(u)/d(u,v)^\alpha}{\mathcal{N} + \sum_{w \in S} P(w)/d(w,v)^\alpha} \geq \beta$$

Classic SINR

Adversarial SINR

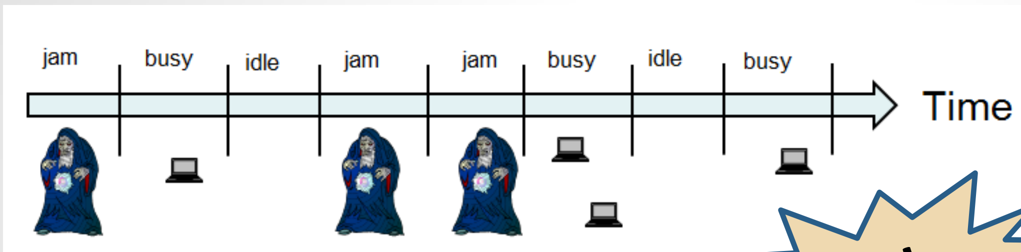
$$\frac{P/d(u,v)^\alpha}{\mathcal{ADV}(v) + \sum_{w \in S} P/d(w,v)^\alpha} \geq \beta$$

worst-case
(e.g., jammer)

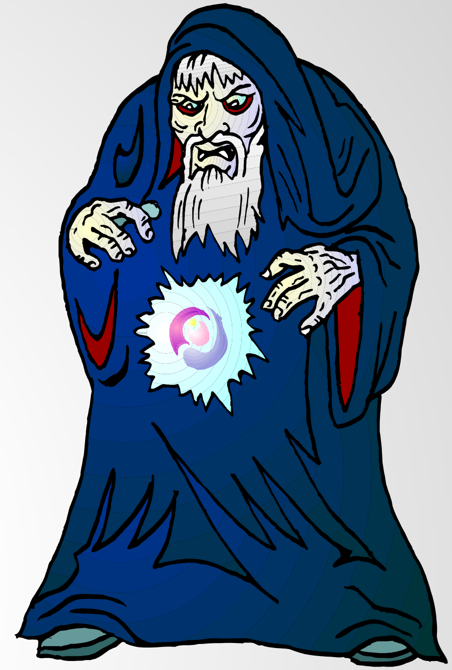
New!

The (B,T)-Adversary Model

- So far: time bounded adversaries



Old



- SINR requires new model!

- Energy-bounded adversary: the (B,T)-adversary
  - In time period of duration T, the adversary can spend a budget of B*T to jam each node arbitrarily («bursty», non-uniform)
  - Theoretically can jam each round «a little bit»

New!

- Adversary is adaptive: knows history and state!

The Model

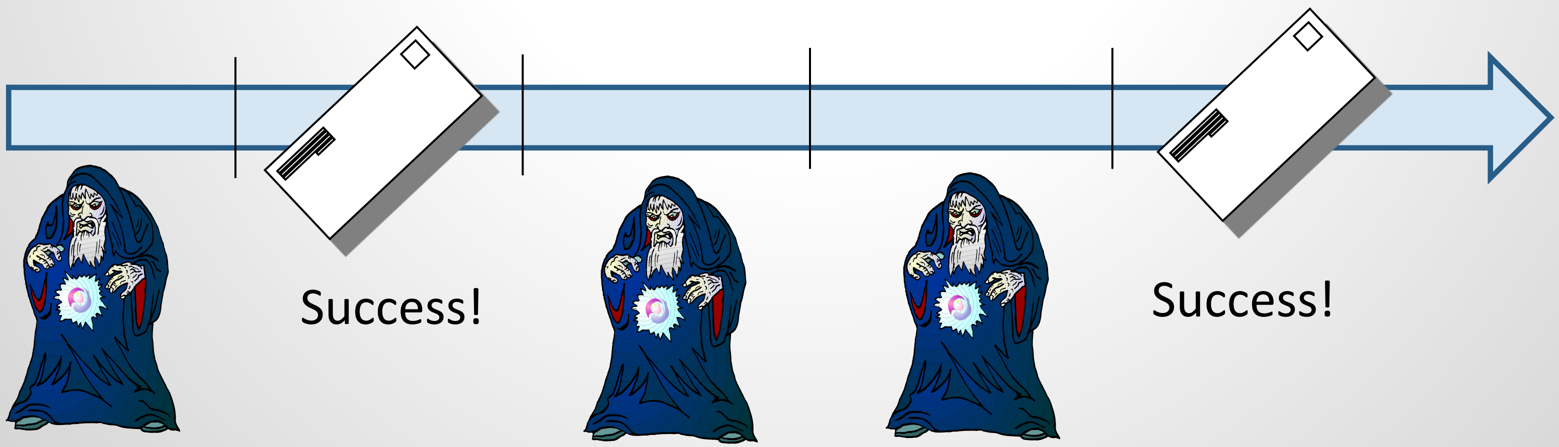
- ❑ Single channel, backlogged, synchronized
- ❑ Protocol is randomized
- ❑ Adversary is adaptive (but not reactive)
- ❑ Nodes cannot distinguish busy from «jammed»
- ❑ Nodes cannot distinguish idle from busy!

The Holy Grail: Constant Competitive Throughput

- Obviously, cannot achieve a throughput if constantly jammed

- Goal hence: Provable throughput in non-jammed rounds!

- **Constant competitive troughput**: in non-jammed rounds, *whenever they occur,* a constant number of messages are successfully transmitted and received



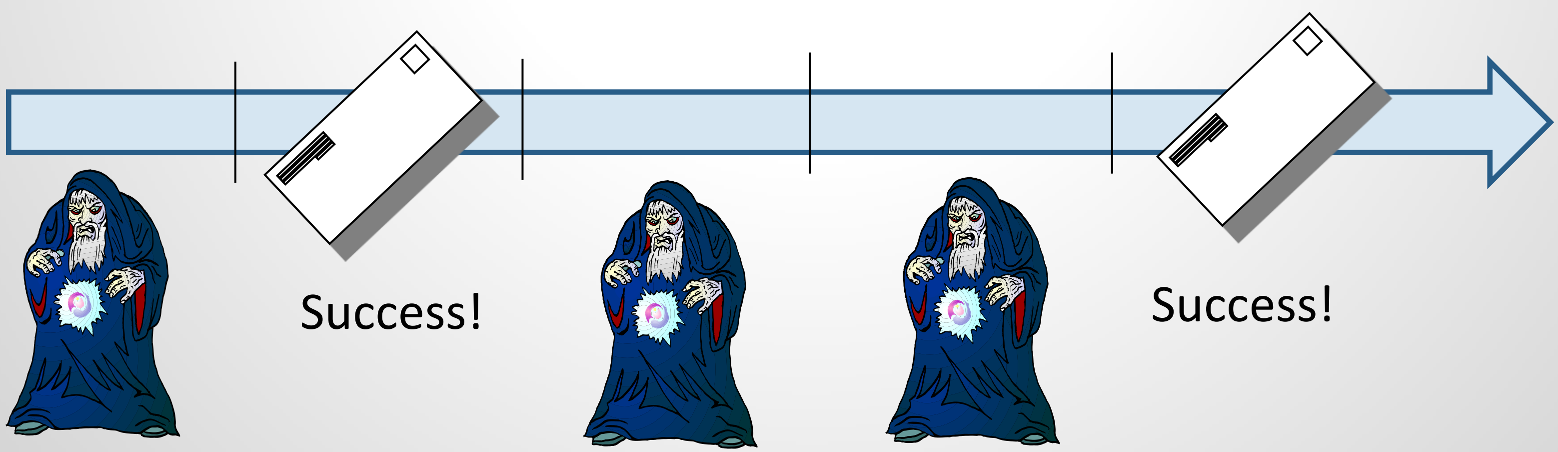
The Holy Grail: Constant Competitive Throughput

- Obviously, cann … med

Non-jammed round: Node within transmission radius, i.e., $P/r^{\alpha} > \beta\nu$ could still successfully send to that node (given no other transmissions).

- Goal hence: Pro …

- **Constant competitive troughput**: in non-jammed rounds, *whenever they occur,* a constant number of messages are successfully transmitted and received



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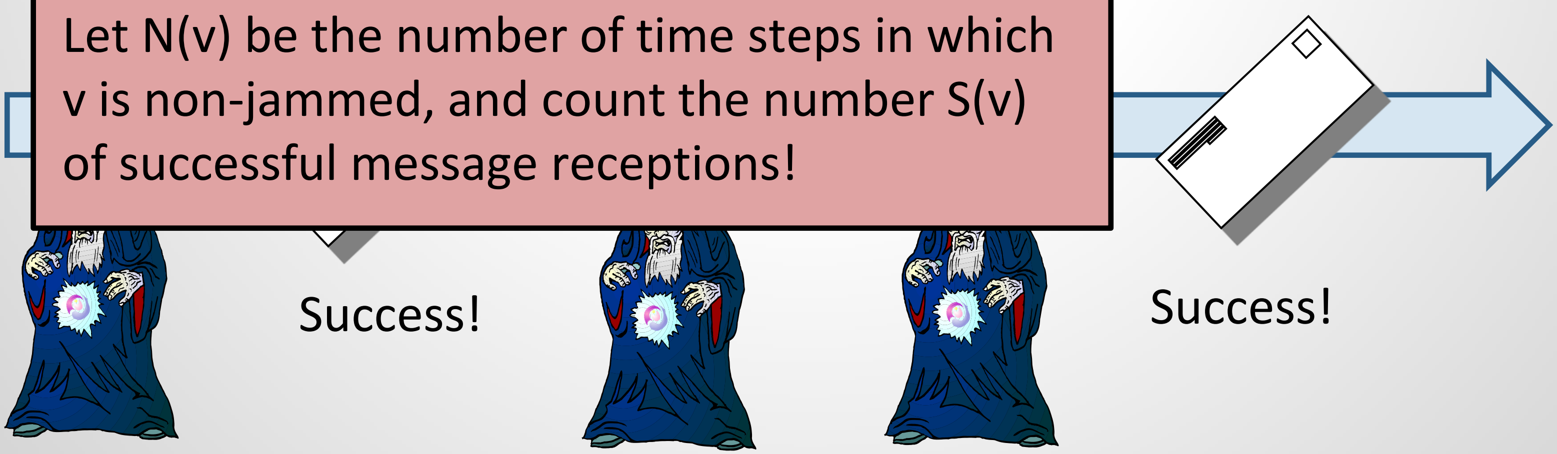
Let N(v) be the number of time steps in which v is non-jammed, and count the number S(v) of successful message receptions!



The Holy Grail: Constant Competitive Throughput

- Ol … onstantly jammed

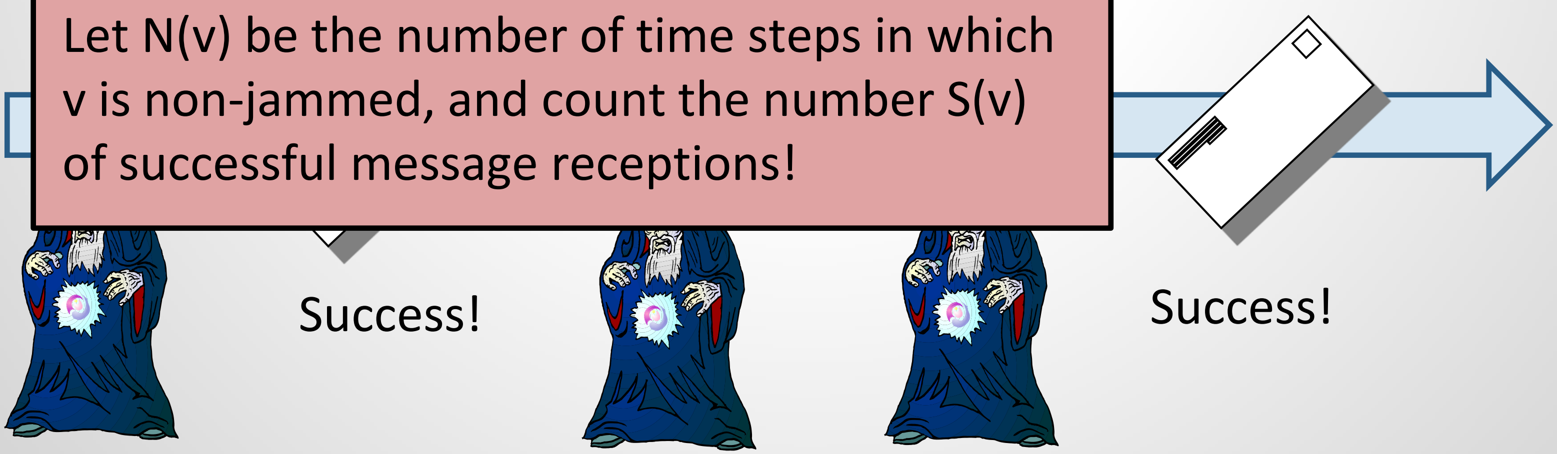
Constant: Sum of all S(v) is at least a constant fraction of N(v):

$$\Sigma\, S(v) \geq const * \Sigma\, N(v)$$

- Go … nmed rounds!

- **Constant competitive troughput**: in non-jammed rounds, *whenever they occur,* a constant number of messages are successfully transmitted and received

Let N(v) be the number of time steps in which v is non-jammed, and count the number S(v) of successful message receptions!



The Result: The Sade Protocol

Theorem 1

Sade has a $2^{-O\left((1/\varepsilon)^{2/(\alpha-2)}\right)}$-competitive throughput if the jammer is uniform or the node density is high! With ε constant, we obtain a constant throughput.

Theorem 2

No MAC protocol can achieve any throughput against a (B,T)-bounded adversary with $B > \vartheta$.

SINR is fundamentally different from UDG: A second lower bound shows that a constant cumulative probability per disk cannot yield a throughput polynomial in ε (for UDG it can).

The MAC Protocol

First idea: “Exponential backoff with state”

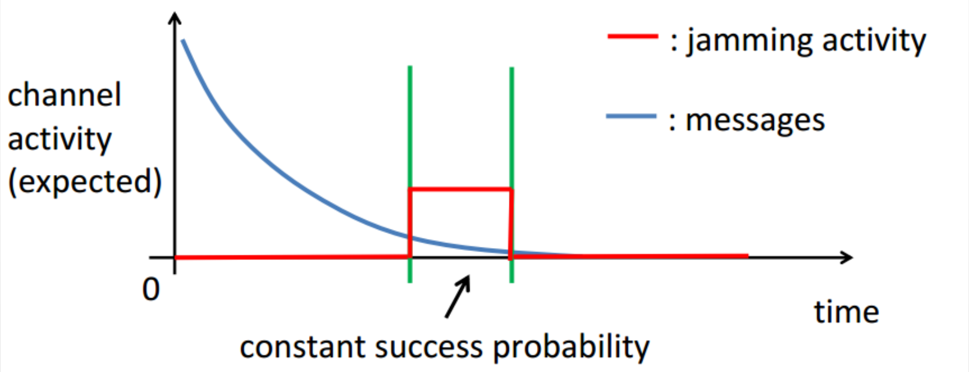
(goal: constant cumulative probability)

If (idle): $p_v := (1+\gamma)\, p_v$

If (success): $p_v := 1/(1+\gamma)\, p_v$

Problem 1: “Idle” is subjective.

Problem 2: Not robust to jamming: May miss “good” cumulative probability.

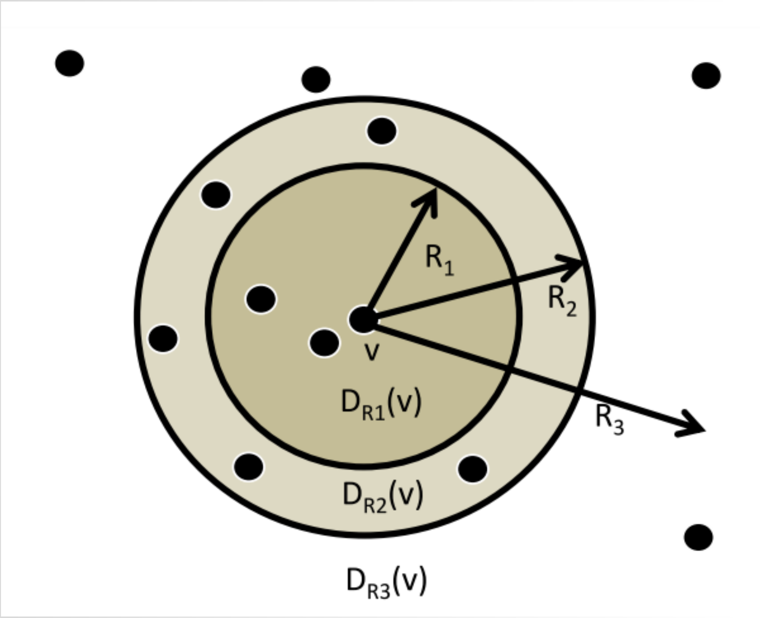


The MAC Protocol SADE

Estimate adversary window: decrease more slowly!

$(T_v, c_v, p_v) = (1,1,p)$, fixed noise threshold $\vee$
With probability p_v, send a message
Else:
if successful reception, $p_v = p_v/(1+\gamma)$
if sense idle channel, $p_v = p_v * (1+\gamma)$, $T_v -$
c_v ++
if $c_v > T_v$: if no idle among last rounds,
$p_v = p_v/(1+\gamma)$, $T_v = T_v + 2$

The Analysis



Zone 1: (transmission range: constant)

- $R_1 := \sqrt[\alpha]{P/(\beta\vartheta)}$
- If there is at least one sender, v will not sense idle
- v successfully receives a message from another node within R_1 provided $ADV(v) \leq \vartheta$ and no collision occurs

Zone 2: (critical interference range: constant)

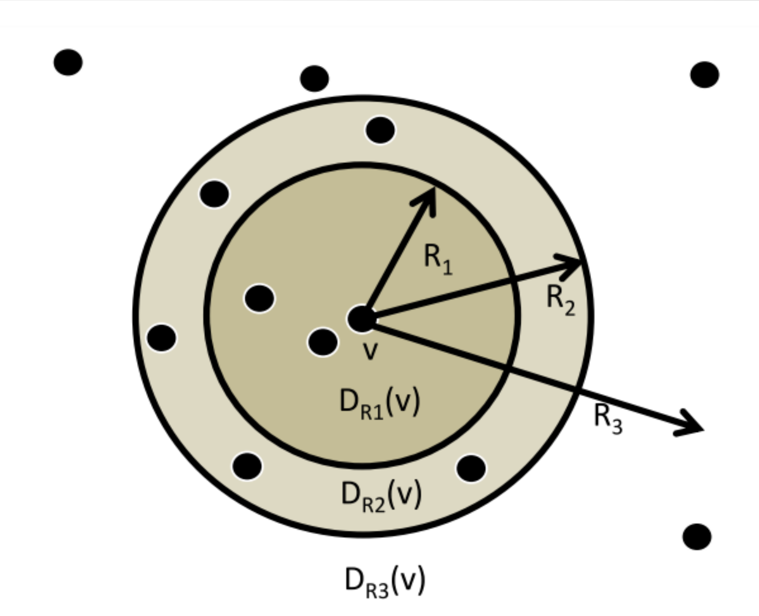
- $R_2 := O\left((1/\varepsilon)^{1/(\alpha-1)} R_1\right)$
- buffer: interference from Zone 3 is at most $\varepsilon\vartheta$

Zone 3: (noncritical interference range)

- every node outside Zone 1 and Zone 2

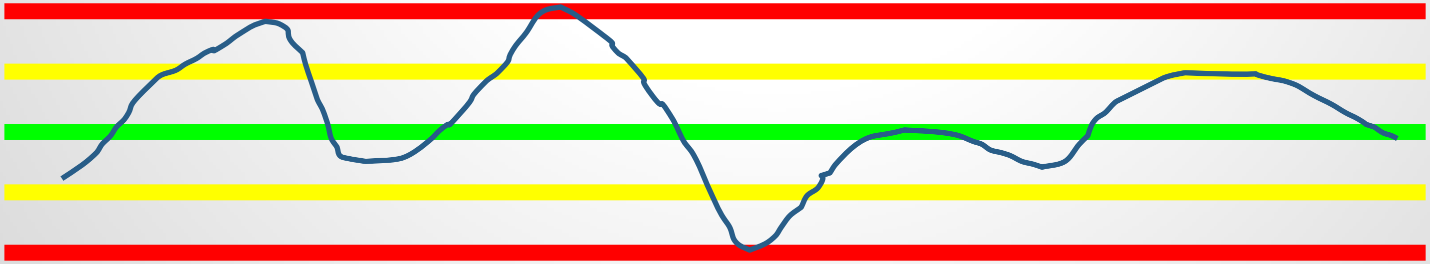
Analysis

- Cumulative sending probabilities in Zone 1 and Zone 2 at most constant

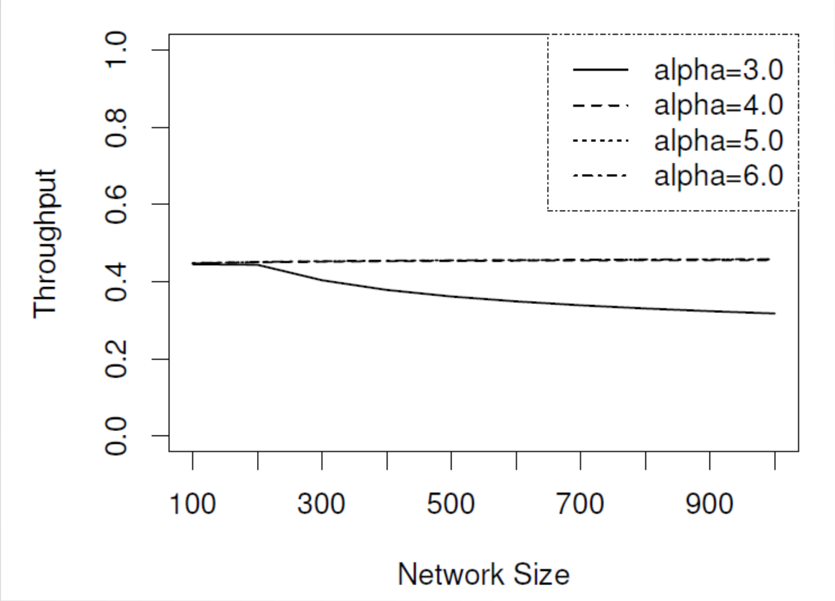


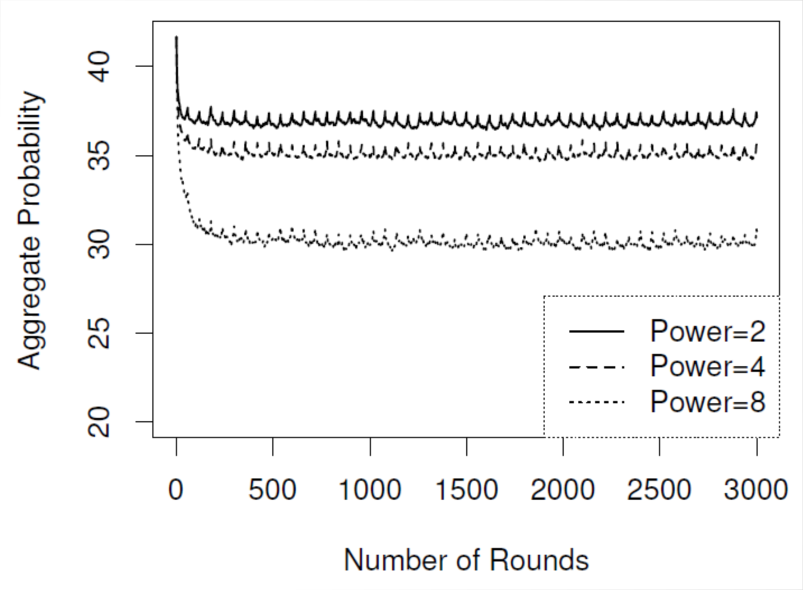
- Power of Zone 3 grows in *n*, but at *v* received power is constant in expectation too

- Analysis over thresholds of cumulative probability:



Simulations





- ❑ Throughput better than what expected from worst-case analysis
- ❑ Fast convergence

Conclusion

- SADE: A very robust MAC protocol with provable throughput guarantees in a harsh and realistic environment
- A new adversary model: energy-constrained
- Future work:
  - Polynomial throughput? Only possible with sub-constant cumulative probability
  - Adaptive power

poly(1/ ε)-competitive?

$2^{-O\left((1/\varepsilon)^{2/(\alpha-2)}\right)}$-competitive

Thank you.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