A Jamming-Resistant MAC Protocol for Multi-Hop Wireless Networks

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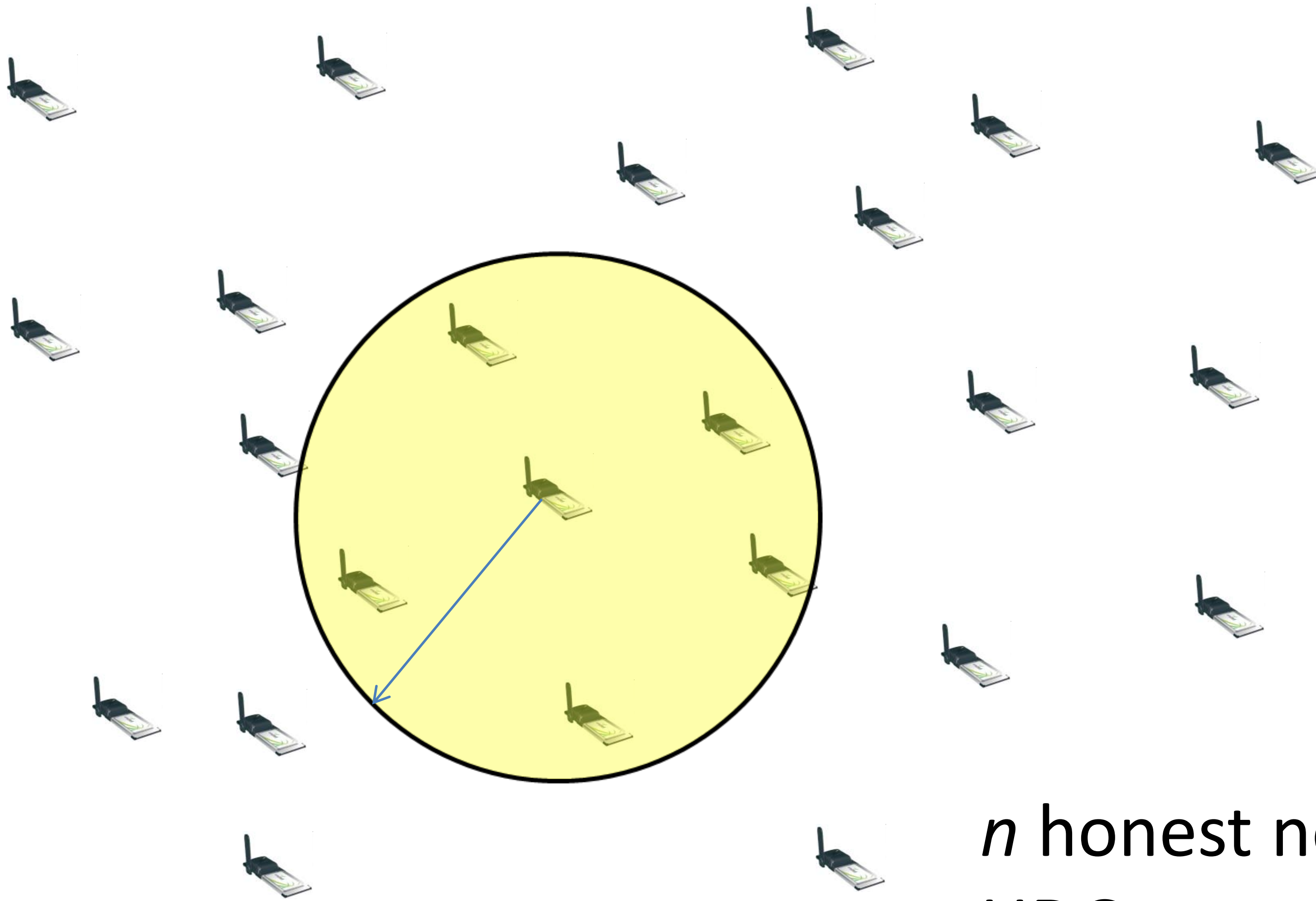
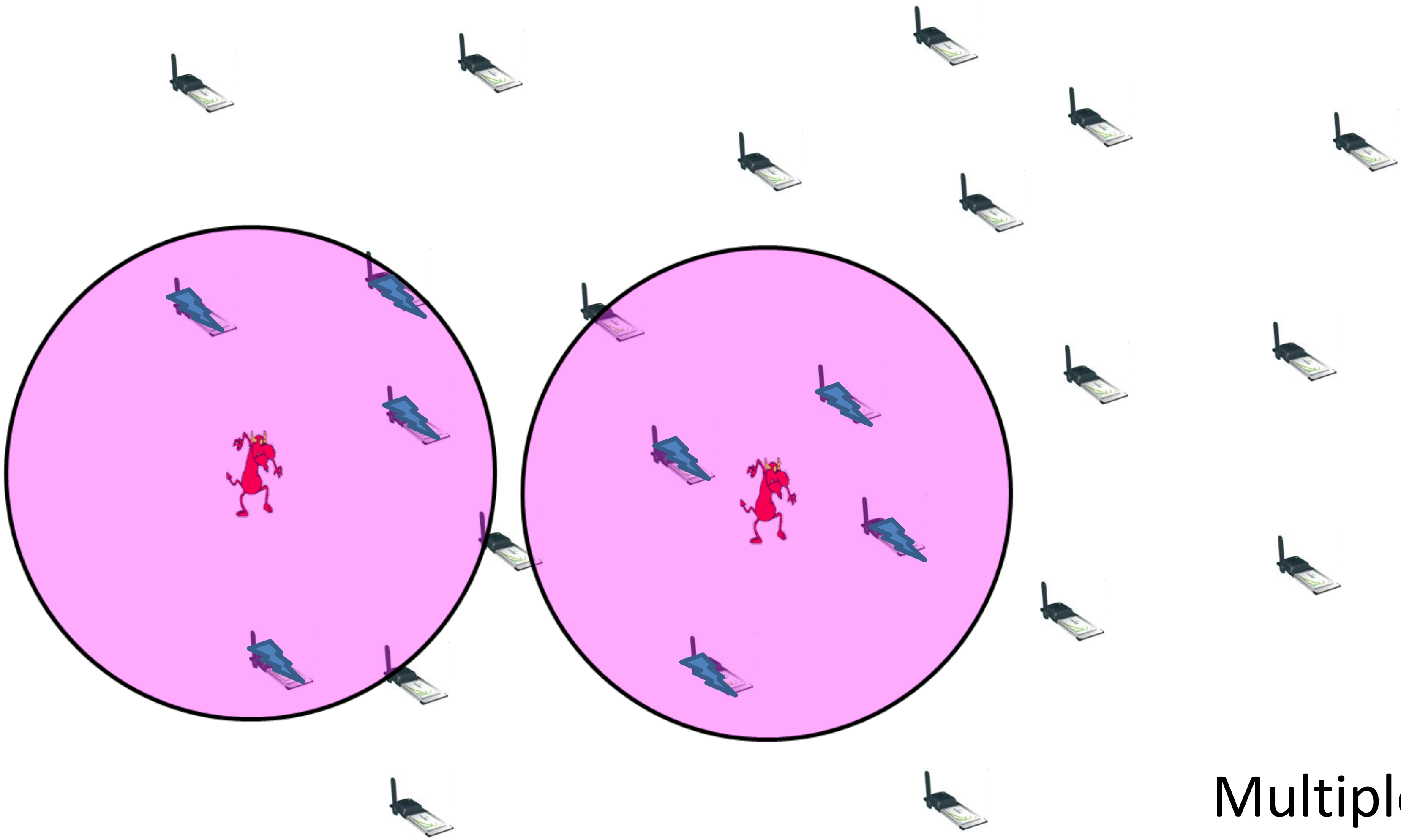
Multihop Wireless Network



n honest nodes

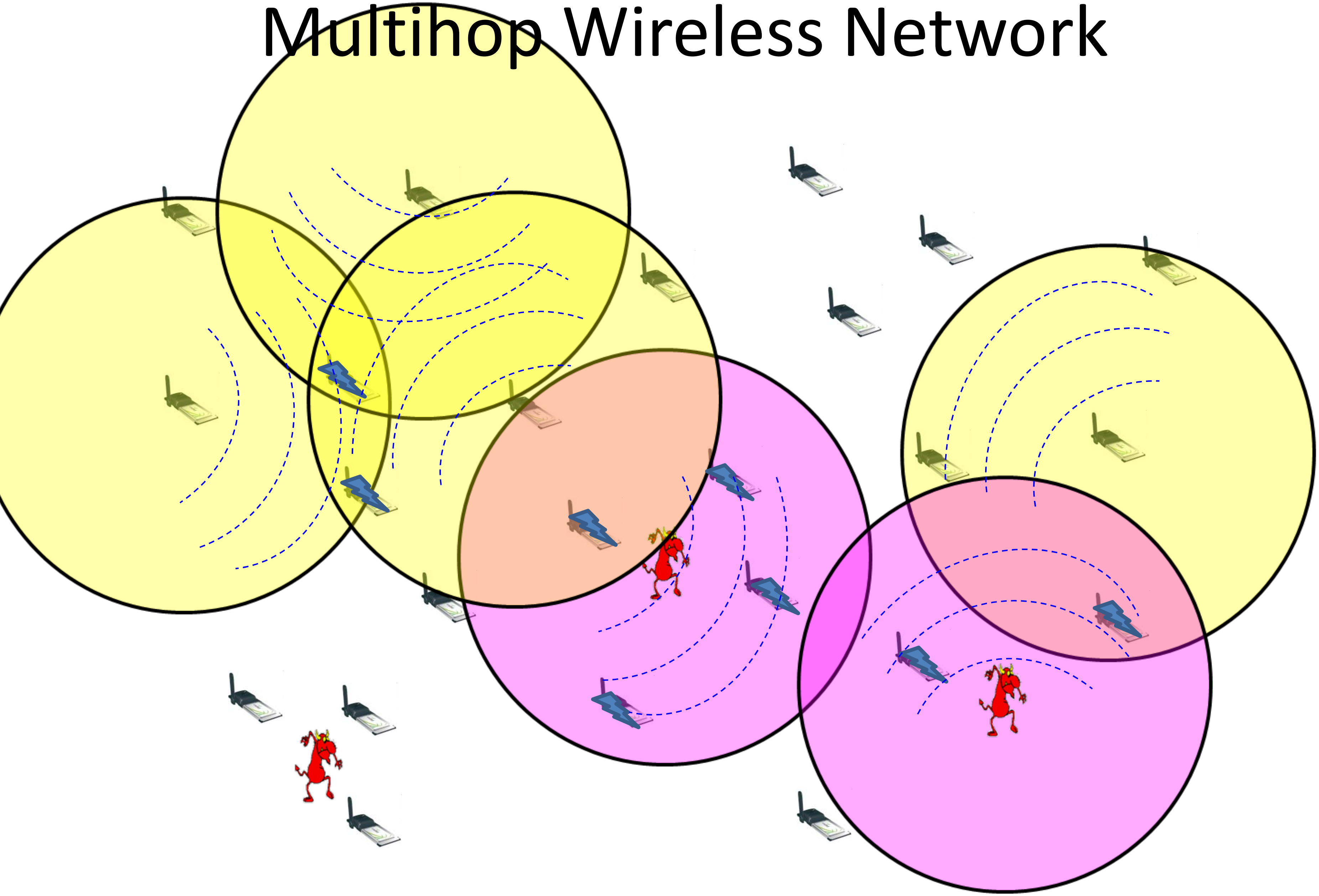
UDG

Multihop Wireless Network



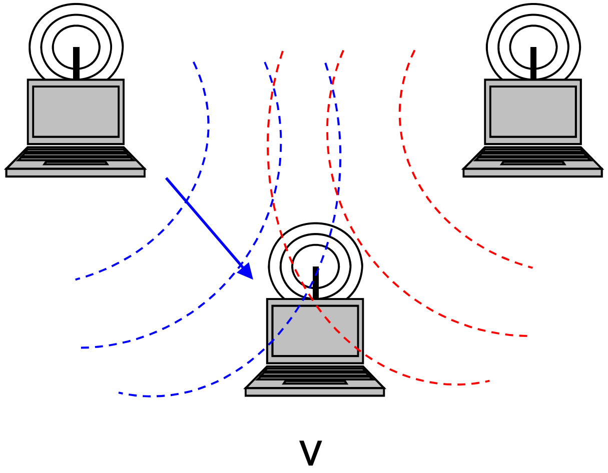
Multiple jamming devices

Multihop Wireless Network



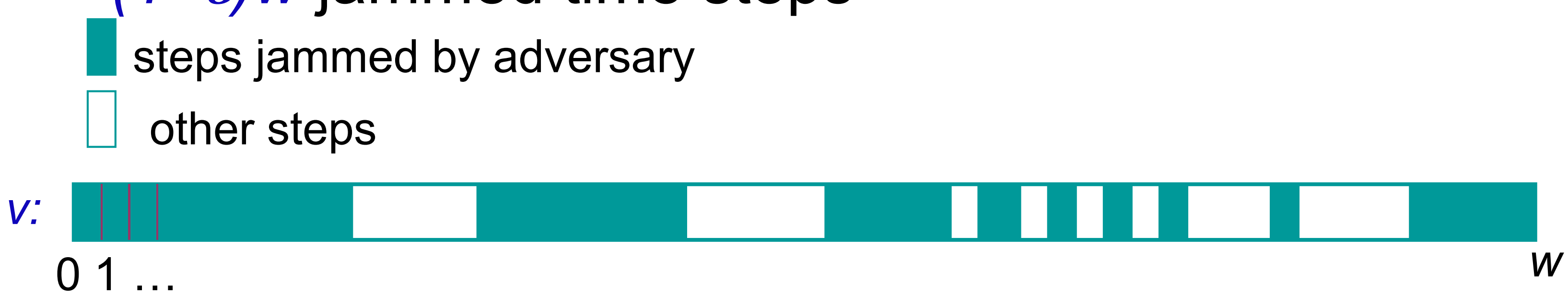
Wireless communication model

- at each time step, a node may decide to transmit a packet (nodes continuously contend to send packets)
- a node may transmit *or* sense the channel at any time step (half-duplex)
- when sensing the channel a node *v* may
  - sense an idle channel
  - receive a packet
  - sense a busy channel



Adaptive adversary

- knows protocol and entire history
- nodes cannot distinguish between adversarial jamming or a message collision
  - i.e., a node senses a busy channel in both cases
- controls all jamming devices
- $(T, 1-\varepsilon)$-bounded adversary, $0 < \varepsilon < 1$: For every node v and every time window of size $w \geq T$, v experiences $\leq (1-\varepsilon)w$ jammed time steps



Constant-competitive throughput

- A MAC protocol is called constant-competitive against a $(T, 1\text{-}\varepsilon)$-bounded adversary if, for any sufficiently large time interval I,

Throughput:
$$\frac{\sum_{v} \#\text{successful transmissions for v}}{\sum_{v} \#\text{non-jammed time steps for v}} \geq c$$

where c is a constant.

Our Main Contribution

Our MAC protocol, Jade, has a constant competitive throughput for any case in which

(a) The jamming pattern is uniform (i.e., every node experiences the same jamming pattern), or

(b) The node density is sufficiently high.

Related Work

- spread spectrum & frequency hopping:
  - rely on broad spectrum. However, sensor nodes or common wireless devices based on 802.11 have very narrow bandwidths.
  - Our approach is orthogonal to broad spectrum techniques, and can be used in conjunction with those.
- random backoff:
  - adaptive adversary too powerful for MAC protocols based on random backoff or tournaments (including the standard MAC protocol of 802.11 [BKLNRT’08])
- jamming-resistant MAC for single-hop [ARS’08]:
  - can achieve constant throughput but only in single-hop wireless networks.

Simple idea

- each node v sends a message at current time step with probability $p_v \leq p_{max}$, for constant $0 < p_{max} << 1$.

$p = \sum_{w \in D(v) \backslash v} p_w$, where $D(v)$ is the unit disk centered at node v

q_{idle} = probability the channel is idle around v

$q_{success}$ = probability that only one node is transmitting around v (successful transmission)

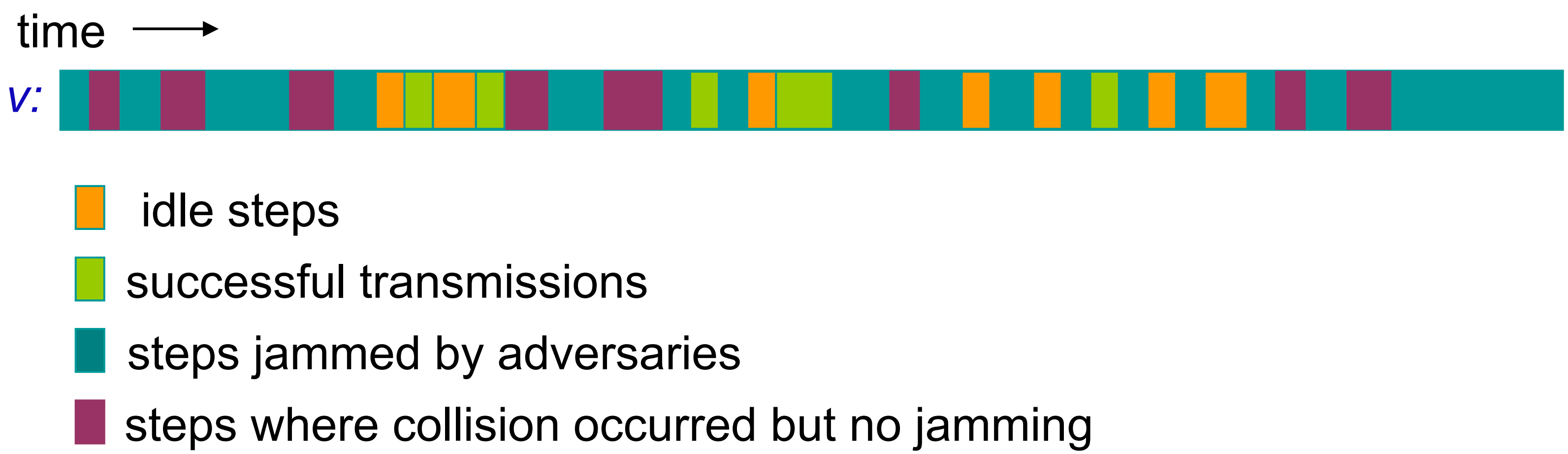
- Claim. $q_{idle} \cdot p \leq q_{success} \leq (q_{idle} \cdot p) / (1 - p_{max})$

$\therefore$

if (number of times the channel is idle) $\tilde{=}$ (number of successful transmissions) $\rightarrow$ $p = \theta(1)$! $\rightarrow$ $q_{success} = \theta(1)$! (what we want!)

Basic approach

- a node *v* adapts p_v based only on steps when an idle channel or a successful message transmission are observed, ignoring all other steps (including all the blocked steps when the adversary transmits!) and what happens in the rest of the network!



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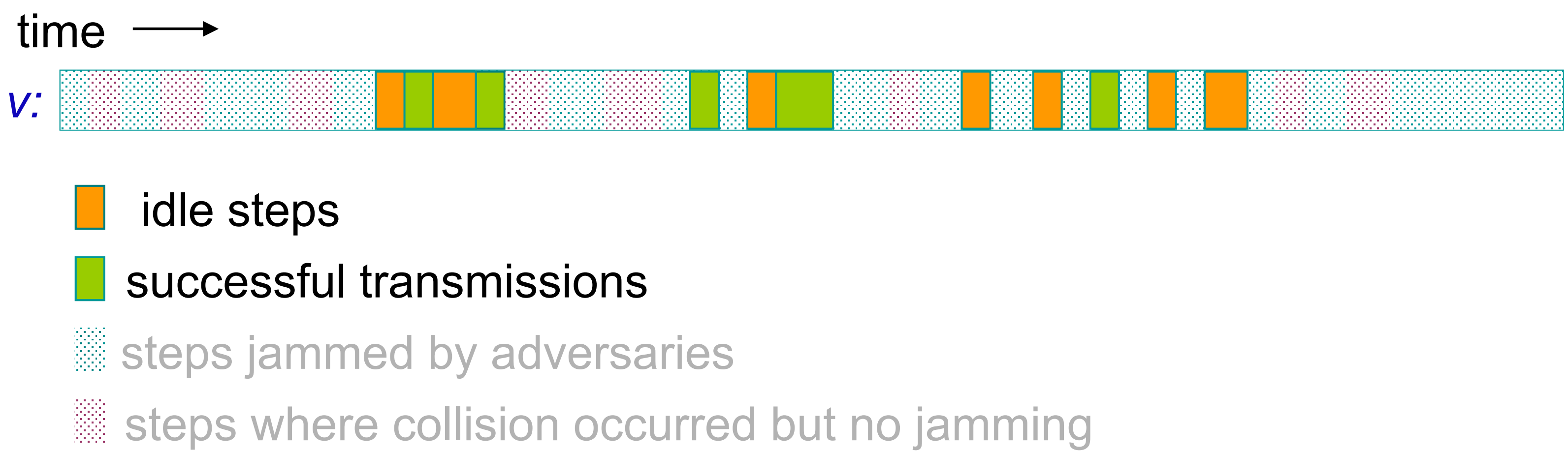

The Jade Strategy for UDGs

The Jade protocol (Naïve protocol):

$p_v = p_{max}$;
In each round:
    decide to send with prob p_v;
    if decide not to send:
        if sense *idle channel*: $p_v = (1+\gamma)\ p_v$;
        if *succ* reception: $p_v = 1/(1+\gamma)\ p_v$;

- Nodes know a common parameter $\gamma > 0$

Problem: p too high

- Basic problem: Cumulative probability *p* in a unit disk centered at *v* could be too large.
  - all time steps blocked due to message collisions w.h.p.

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idle steps

successful transmissions

steps jammed by adversary

steps where collision occurred but no jamming

Problem: p too high

- Basic problem: Cumulative probability p in a unit disk centered at v could be too large.
  - all time steps blocked due to message collisions w.h.p.
- Idea: If more than T consecutive time steps without successful transmissions, then reduce probabilities, which results in fast recovery of p.
- Problem: Nodes do not know T. How to learn a good time window threshold?
  - It turns out that additive-increase additive-decrease is the right strategy!

The Jade Strategy for UDGs

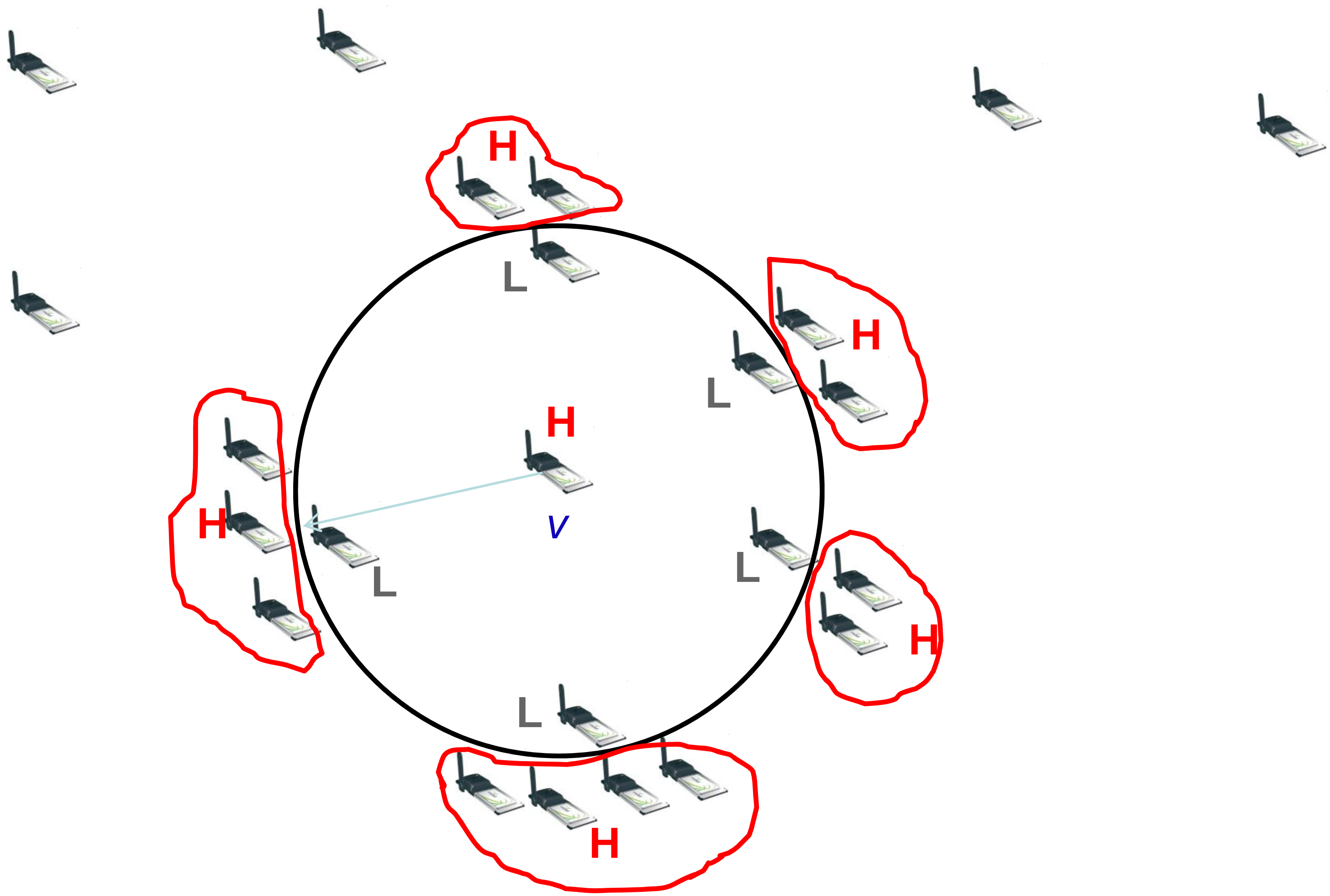
The Jade protocol:

$T_v=1$, $c_v=1$, $p_v = p_{max}$;
In each round:
    decide to send with prob p_v;
    if decide not to send:
        if sense *idle channel*: $p_v = (1+\gamma)\, p_v$;
        if *succ* reception: $p_v = 1/(1+\gamma)\, p_v$; T_v--;
    c_v++;
    if ($c_v > T_v$)
        $c_v = 1$;
        if no *idle* nor *succ* in last T_v steps:
            $p_v = 1/(1+\gamma)\, p_v$; $T_v = T_v + 1$;

Problem: T_v too high

- Basic problem: T_v could become too high.
  - very inaccurate estimation of T
  - only happens in multi-hop networks

Problem: T_v too high



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    if ($c_v > T_v$)
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        if no *idle* nor *succ* in last T_v steps:
            $p_v = 1/(1+\gamma)\, p_v$; $T_v = \min(T_v + 1, 2^{1/(4\gamma)})$;

Our results

- Theorem 1. When running Jade for at least $\tilde{\Omega}(T/\varepsilon)$ steps, Jade has a constant competitive throughput for any $(T,1\text{-}\varepsilon)$-bounded adversary and any UDG w.h.p. as long as $\gamma = O(1/(\log T + \log\log n))$ and
  - (a) The jamming pattern is uniform, and UDG is connected, or
  - (b) There are at least $2/\varepsilon$ nodes within the transmission range of every node

Proof Sketch

- An *open* round: a node v and at least one other node in its neighborhood are non-jammed at round t.
- Weakly $(T, 1-\varepsilon)$-bounded adversary: if the adversary is $(T, 1-\varepsilon)$-bounded, and at least a constant fraction of the non-jammed rounds at each node are *open* in every time interval of size $w \geq T$.

Proof Sketch

- We study the competitiveness of the protocol for a single frame $F = \tilde{\theta}(T/\varepsilon)$, then we show that our competitive throughput result can be extended to any sequence of F.

- Lemma: Jade is constant competitive under the weakly $(T, 1-\varepsilon)$-bounded adversary.

Proof Sketch

- We show that the cumulative probability of a *unit disk* centered at node *u*, as well as the *unit disks* centered at the neighbors of *u*, are upper bounded by a constant for at least a constant fraction of the non-jammed *open* rounds (good) at *u* in time frame *F*.
- Within these many good rounds, *u* has a constant probability to transmit a message and every node *v*, which is *u*'s neighbor, has a constant probability of receiving it.
- If we charge ½ of each successfully transmitted message to the sender and ½ to the receiver, then a constant competitive throughput can be identified for every node, so Jade is constant competitive in *F*.

Proof Sketch

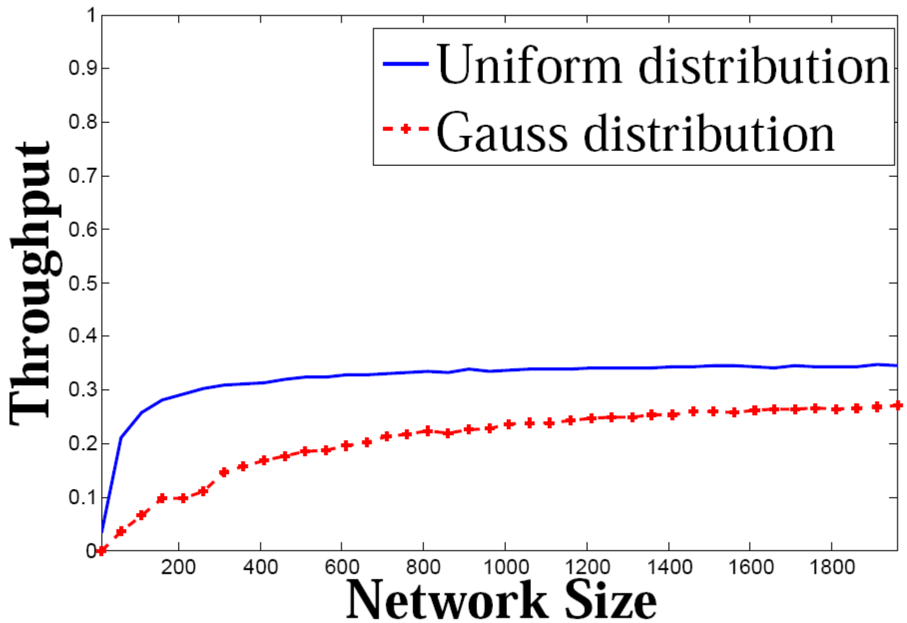
Back to arbitrary $(T,1\text{-}\varepsilon)$-bounded adversaries:

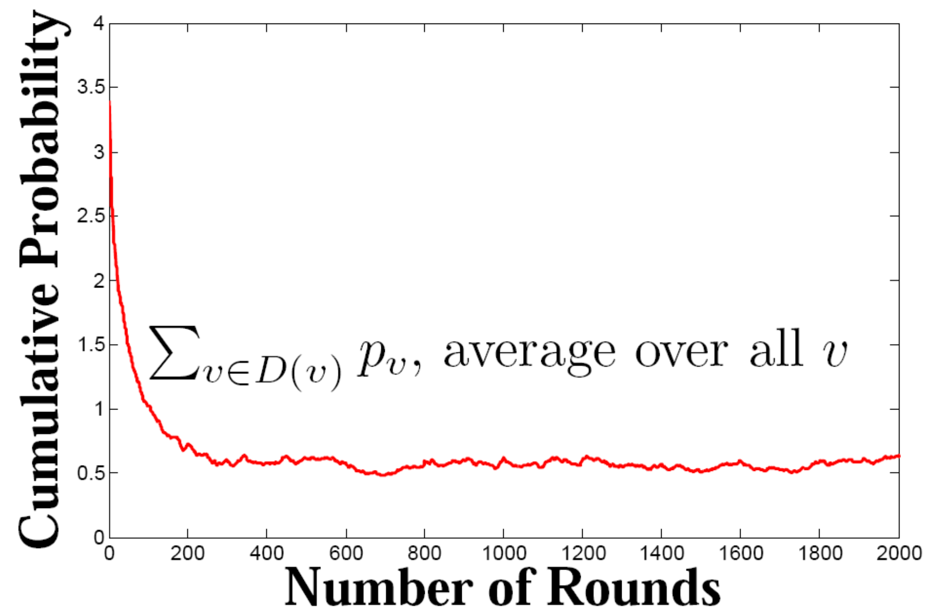
(a) When the jamming pattern is uniform, and UDG is connected, or

(b) When there are at least $2/\varepsilon$ nodes within the transmission range of every node (together with the geometric feature of Unit Disk Graph),

we can show that the adversary is also weakly bounded,
hence the constant competitiveness shown in the Lemma applies.

Simulations



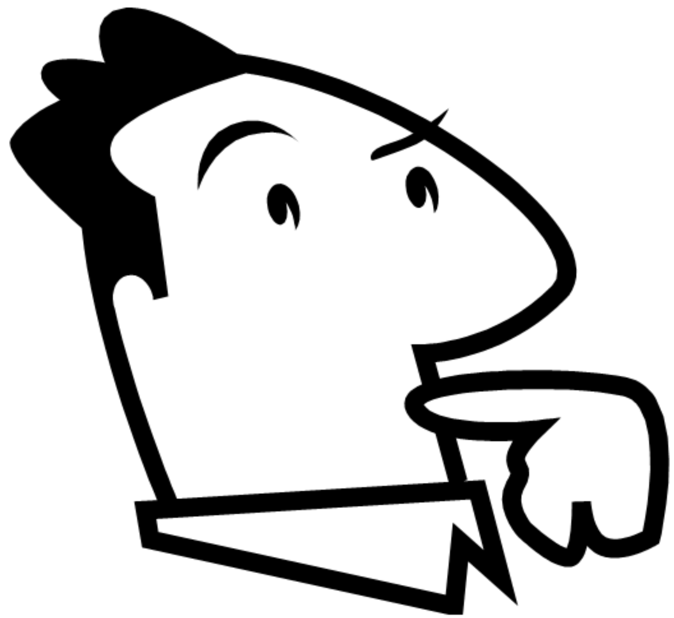


Future Work

- Can Jade perform well in physical interference model, i.e., SINR?

$$\frac{P_v(u)}{N + \sum_{w \in S} P_v(w)} \geq \beta$$

- What if the jammer is not only adaptive but also reactive, where the jammer make its jamming decision after the nodes decide whether to transmit a message at current time step?



Questions?