Dealing with
Bad Vibes
in Open Airwaves

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The Dilemma of Shared Resources

• Can „theoretically“ be accessed by everybody!

• How to coordinate (efficient and/or fair) access?
Wireless Networks

- Communication „over the air“
- Can be accessed by everybody...
Wireless Networks

- Can be accessed by everybody...
  - Thus: collisions...
Wireless Networks

- Can be accessed by everybody...
- Thus: collisions... interference...
Wireless Networks

- Can be accessed by everybody...
  - Thus: collisions... interference... jammers
Jammers

• **Medium access protocols** often not robust (e.g., 802.11)

• Problem: often easy and „cheap“ to implement:
Model

- Clique and UDG
More on the Model

• One communication channel

• Nodes:
  - **Cannot send and listen** concurrently (*one* antenna!)
  - Cannot distinguish between collision and jamming
  - Can recognize an **idle channel**
  - **Backlogged:** Always s.th. to send

• **Adversary:**
  - Can jam a \((1-\varepsilon)\) fraction of all time slots at all positions in the plane
  - Bursty (in time interval \(T\), at most \(\varepsilon T\))
  - **Adaptive:** Knows entire history (but not whether nodes will send in *this* round)
Goal for the Clique?

Each node $v$ has sending probability $p_v$ (adjusted dynamically):

When is throughput good?
Property of $p_v$s?

Too high $\rightarrow$ collisions
Too low $\rightarrow$ idle slots

$$\sum_{v \in D(u)} p_v = \Theta(1)$$

... is a good choice.
The MacJam Strategy

Motivation: if \# idle slots = \# success slots (exactly one transmission) ...

... cumulative probability is around 1!

- Can be observed locally
- Strategy independent of blocked slots!

(Too) simple MAC protocol (for some $\gamma > 0$):

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

Problem?
The MacJam Strategy

(Too) simple MAC protocol (for some $\gamma > 0$):

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

Problem: if $p_v$ initially very high, there are hardly any idling or successful slots to observe!

Therefore: introduce a threshold $T_v$
- if no successful transmission within $T_v$, decrease $p_v$

"Constant competitive throughput against strong adaptive jammer!" (PODC)
"Competitive Throughput"

C-competitive = For any sufficiently large number of time steps, the nodes manage to perform successful message transmissions in at least a c-fraction of the non-jammed time steps (w.h.p.)
Singlehop vs Multihop

Different nodes in different situations (jammed, collisions, idle, successful reception...)!
Clique Strategy Does not Work!

Example:
All neighbors may be jammed, so center node increases probability!
But: no successful reception with $T_v$, so decrease!
The MacJam Strategy for UDGs

- The MacJam protocol:

\[ T_v = 1, \; c_v = 1, \; p_v = p_{\text{max}}; \]

In each round:
- decide to send with prob \( p_v \);
- if decide not to send:
  - if sense idle channel: \( p_v = (1+\gamma) \; p_v; \; T_v --; \)
  - 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 or succ in last \( T_v \) steps:
  - \( p_v = 1/(1+\gamma) \; p_v; \; T_v = T_v + 2; \)

New: idle is okay, too!

New: +2 (not +1)
Analysis

- Some „ideas“ only

- Protocol is interplay of many dependent randomized local algorithms

- Cumulative probability thresholds: $\rho_{\text{green}}, \rho_{\text{yellow}}, \rho_{\text{red}}$

  Show that beyond „good cumulative probabilities“, there is a high drift towards „better values“

- Techniques: Martingale theory, stochastic dominance, etc.
Simulations

- 500 nodes uniformly at random in 4x4 plane, $\epsilon \ldots 0.5$
- Converges fast to good cumulative probabilities
- Around 30% of unjammed slots are successful transmissions
- $T_v$ values around 2 or 3

![Graph showing cumulative probability per unit disk and average successful ratio over number of rounds.](image)
Ideas for Extensions/Applications

• How to make it fair?
  - Problem: When a node is successful, other nodes will reduce $p_v \Rightarrow$ node may be even more successful in future
  - Solution: Nodes remember number of nodes seen so far, and maintain a counter for successful transmissions.
  - Adapt their probabilities in a more equal manner (all around $1/n$ in clique)!

• Leader Election
  - Contention resolution with MacJam
  - Leaders increase sending probability faster (to constant!)
  - Dedicated leader slots determined online
  - When leader offline: new one is selected (self-stabilization property)

See also the upcoming talk by Marek!
Leader Election (Ideas only)

- Initially: arbitrary situation!

<table>
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<th>Node</th>
<th>c_v</th>
<th>ls_1</th>
<th>ls_2</th>
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<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Stefan Schmid @ “DISC”, 2009
Leader Election (Ideas only)

Goal: one leader, „synchronous“ nodes!

Stefan Schmid @ “DISC”, 2009
Leader Election (Ideas only)

Mc = 0

Collision!
Leader Election (Ideas only)

\[ c_v = 6 \]
\[ ls_1 = 1 \]
\[ ls_2 = 3 \]

\[ c_v = 6 \]
\[ ls_1 = 1 \]
\[ ls_2 = 3 \]

\[ c_v = 6 \]
\[ ls_1 = 1 \]
\[ ls_2 = 3 \]

\[ c_v = 6 \]
\[ ls_1 = 1 \]
\[ ls_2 = 3 \]

\[ c_v = 6 \]
\[ ls_1 = 1 \]
\[ ls_2 = 3 \]

\[ c_v = 6 \]
\[ ls_1 = 1 \]
\[ ls_2 = 3 \]

\[ Mc = 1 \]

LEADER alive!
Leader Election (Ideas only)

$c_v = 6$
ls$_1 = 1$
ls$_2 = 3$

Mc = 2

Follower message gets through!
Leader Election (Ideas only)

LEADER alive, but jammed (no problem)!

Mc = 3

F

LEADER alive, but jammed (no problem)!

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Analysis

• Leaders soon have a high sending probability
  - Higher increase of sending probability

• Nodes synchronize after short time

• When a leader message gets through, we are done!

\[ P_L = \Theta(1) \]

\[ P_F = O(1) \]
Conclusion & Future Work

- Jammers exciting research challenge
  - May improve robustness and performance in existing networks

- Many open questions
  - Provable MAC performance
  - Multihop networks
  - SINR networks
  - Fairness
  - Energy efficiency
  - Applications (do everything again, and MAC alone is not enough...)

- But we are working on it... 😊

Thank you for your attention!
Questions and Inputs?