CRYSTAL CLEAR
MAKING INTERFERENCE TRANSPARENT

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Crystal was designed for *aperiodic unpredictable* data collection traffic

- Little overhead when the traffic is sparse
  - per-mille radio duty cycle in some real-world applications
- Low latency at delivering data bursts
- "5 nines" reliability under Wi-Fi interference of an office building

**Q:** Can Crystal be used (almost) unmodified in the challenging competition setting?
# CRYSTAL IN A NUTSHELL

Each Crystal timeslot is a Glossy flood

<table>
<thead>
<tr>
<th>sensor node 1</th>
<th>sink</th>
<th>sensor node 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S</strong></td>
<td><strong>T</strong></td>
<td><strong>A</strong></td>
</tr>
<tr>
<td><strong>sync</strong></td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

- **T**: contention data slot
- **S**: synchronization slot
- **A**: acknowledgement slot

TA pair

- sleep after observing R=2 empty T slots

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TA pair

- sleep after observing R=2 empty T slots
CRYSTAL UNDER NOISE

Data packet loss can cause premature termination

The messages will be delayed till the next epoch
TIME SLOT CHANNEL HOPPING

Try to escape noise: change the channel every TA pair

We set Crystal to hop over all 16 IEEE 802.15.4 channels
Defer going to sleep if there is strong noise in the channel

<table>
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<tr>
<th>Sensor Node 1</th>
<th>SEND: Sync</th>
<th>SEND: X</th>
<th>SEND: X</th>
<th>SEND: ✓</th>
<th>SEND: ✓</th>
<th>SEND: ✓</th>
</tr>
</thead>
</table>

| Sink          | SEND: Sync | —      | SEND: X | SEND: X | SEND: ✓ | SEND: ✓ |

| Sensor Node 2 | SEND: Sync | SEND: X | SEND: X | SEND: ✓ | SEND: ✓ | SEND: ✓ |

|   | S | T | A | T | A | T | A |

Strong noise: CCA is above –60 dBm during T or A slots
1. Collect sensor readings to a dedicated sink node
   - unmodified Crystal (T slots)
   - 1-2 bits per message

2. Flood the network with the global sensor state
   - piggyback on Crystal control messages (S & A)
   - 11 bits
PROBLEMS WE FACED

Could we go decentralized? We tried…

- Allowing the actuators react on the information received directly from sensors in T slots
- That resulted in superfluous events under noise

Concurrent events

- Packet reordering causes superfluous/missed events

Topology and noise

- Isolated nodes on some channels even without noise
- Noise Level 3 almost blocks our Glossy floods: difficulties in bootstrapping and data delivery

Further modifications would make a new protocol while the goal was to test the original Crystal
THANK YOU! QUESTIONS?

Crystal is Open Source: github.com/d3s-trento/crystal
GLOSSY IN A NUTSHELL

Network flooding + synchronization

- Fastest possible propagation by design
- Very reliable

Efficient network flooding and time synchronization with Glossy, F. Ferrari, M. Zimmerling, L. Thiele and O. Saukh, Information Processing in Sensor Networks (IPSN), 2011
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