Recorp: Receiver-Oriented Policies for Industrial Wireless Networks

Ryan Brummet*, Octav Chipara, Ted Herman

THE UNIVERSITY OF IOWA
Industrial Wireless Networks

• **Applications**
  – process control systems

• **Workload**
  – stable periodic flows
  – known period, deadline, and phase

• **Strict performance requirements**
  – predictability
  – high reliability
  – real-time
Challenges: Network Dynamics

- **Moving machinery**
  - Tesla Automation

- **Outdoor environments**
  - Automation.com

- **Moving workers**
  - Ford Motor Company
• **Time Slotted Channel Hopping**
  – time division multiple access with channel hopping
  – predictable
  – centralized

• **Limited Flexibility**
  – overprovisioned retransmissions to handle link variability

**TSCH Schedules**

<table>
<thead>
<tr>
<th>Slot</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH 0</td>
<td>F₀: AB</td>
<td></td>
<td>F₁: CB</td>
<td></td>
</tr>
<tr>
<td>CH 1</td>
<td>F₀: AB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH 2</td>
<td></td>
<td></td>
<td>F₁: CB</td>
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TSCH Schedules

- **State of the art**
  - sacrifice predictability for flexibility
  - examples
    - (1) slot stealing
    - (2) hybrid TDMA with CSMA
    - (3) low likelihood transmissions in the same slot

- **Can we do better?**
Allow transmissions to be reallocated conditioned on the local state at runtime
Key Insight

• **Coordinator initiates transmissions**
  – coordinator pulls for packets
  – packet transmitted upon pull reception

• **Transmissions selected via local state**
  – selections prioritized via a priority ordered service list of transmissions

• **Offline synthesis**
  – coordinators and service lists ensure reliable packet delivery
Run-Time Adaptation

• **Schedule**
  – packets dropped in two traces

<table>
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<tr>
<th>Spec</th>
<th>$F_0$: AB</th>
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<th>$F_1$: CB</th>
<th>$F_1$: CB</th>
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<tr>
<td>Slot</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Trace 1</td>
<td>$F_0$: AB</td>
<td>--</td>
<td>$F_1$: CB</td>
<td>--</td>
</tr>
<tr>
<td>Trace 2</td>
<td>$F_0$: AB</td>
<td>$F_0$: AB</td>
<td>$F_1$: CB</td>
<td>--</td>
</tr>
<tr>
<td>Trace 3</td>
<td>$F_0$: AB</td>
<td>--</td>
<td>$F_1$: CB</td>
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• **Recorp policy**
  – no packets dropped

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Recorp Design

Offline synthesis

- Workload
- Routes
- Min. Link Quality

Policy Evaluator

Pull operations

Runtime adaptation (§3.A)

Policy Builder

Pull operations

Current state

Unschedulable

Policy

Workload

(§3.B.1)

(§3.B.2)

Unschedulable

Runtime adaptation (§3.A)
Evaluation

- **Simulation**
  - 41 nodes, 1 base station
  - 50 flows
  - 3 flow periods
  - 3 different workload scenarios
  - 100 runs
  - ensure 99% end-to-end reliability

- **Workload Scenarios**
  - collection (COL)
  - dissemination (DIS)
  - route through the base station (RTB)

- **Comparison**
  - schedules
  - flow centric policies (FCP)

- **Measurement**
  - real-time capacity
  - relative to schedule performance
Conclusion

• **Recorp policies**
  – distribute retransmissions at run-time in response to network dynamics
  – utilize local adaptation to distribute allocated transmissions

• **Significant performance improvement compared to state-of-the-art**
  – 1.63 to 2.44 times median increase in real-time capacity

• **For more details please see our paper**
Worst-Case Response Time

The diagram shows the max flow class response time ratio for different classes and scenarios. The classes are represented by different colors:
- Class 1 (blue)
- Class 2 (green)
- Class 3 (black)

The scenarios include:
- COL
- DIS
- RTB

The graph compares the response times across these classes and scenarios, illustrating the variability and performance characteristics.
State Example

Slot 0
$\text{PL}_A(F_0)$

Slot 1
$\text{PL}_A(F_0,F_1)$

Slot 2
$\text{PL}_A(F_0,F_1)$

Slot 3
$\text{PL}_A(F_1)$

1

$1$ $2P_sP_f$ $3P_sP_f^2$ $3P_sP_f^3 + P_f^4$

$F_0: F$
$F_1: F$

$F_0: S$
$F_1: F$

$F_0: F$
$F_1: F$

$F_0: S$
$F_1: F$

$F_0: F$
$F_1: F$

$F_0: S$
$F_1: F$

$F_0: F$
$F_1: S$

$F_0: F$
$F_1: S$

Release $F_0, F_1$

Complete $F_0$

Complete $F_1$