BLINK: A High Throughput Link Layer for Backscatter Communication

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Why backscatter radio?

Can backscatter replace active radios as the first wireless hop?

- Backscatter can offer **two orders of magnitude** reduction in power consumption compared to active radio.
High Throughput Backscatter Stack

- Burst Round
- Co-ordination
- Duty-cycling

Bulk Transfer MAC

- Rate Adaptation
- Channel Selection
- Mobility Detection

Mobility-aware Link

BLINK

High Throughput PHY
Encoding and Modulation in Backscatter Radio

Reader --> Tag

PIE encoding

Reader

Tag

Complex Decoding at Reader

Simple Decoding at Tag

Carrier Wave

Tag --> Reader

FM0/M2/M4/M8 encoding

000

001

010
Encoding and Modulation in Backscatter Radio

Goal 1: Select optimal bit-rate on tag to reader link

Path loss \( a \frac{1}{d^2} \)

Carrier Wave

Reader

Path loss \( a \frac{1}{d^4} \)

FM0/M2/M4/M8 encoding

Tag

000

001

010
Channel Hopping in Backscatter Radio

FCC regulations: 0.4 channel dwell time within 10s

Goal 2: Design high throughput FCC-compatible channel selection algorithm
BLINK Overview

- Link Metrics
- Design
- Evaluation
- Conclusion
Link Metrics in Backscatter Radio

- Commercial reader exposes RSSI and loss rate
  - In active radio, RSSI is correlated with loss rate. Does this hold true for backscatter radios?

- Expt: Measure RSSI/loss-rate for single tag over distance

![Graph showing RSSI and loss rate over distance]
Link Metrics in Backscatter Radio

- Commercial reader exposes RSSI and loss rate
  - In active radio, RSSI is correlated with loss rate. Does this hold true for backscatter radios?

- Expt: Measure RSSI/loss-rate for single tag over distance

Why is there low correlation between RSSI and loss rate?
Key insight: self-interference causes high losses even if signals interfere constructively i.e. RSSI is high!
**Reason: Multipath Self-interference**

- **Key insight:** self-interference causes high losses even if signals interfere constructively i.e. RSSI is high!
- **Implication:** Use both RSSI (range effects) and lossrate (self-interference effects).
BLINK Overview

- Link Metrics
- Design
  - Mobility Detection
  - Rate Adaptation
  - Channel Switching
- Evaluation
- Conclusion
Mobility Detection

- **Link Signature**: Euclidean distance between successive RSSI/Lossrate scans of 50 channels

- **Result**: Can reliably detect change of tag position and movement pattern with over 90% accuracy.
BLINK Overview

- Link Metrics
- Design
  - Mobility Detection
  - Rate Adaptation
  - Channel Switching
- Evaluation
- Conclusion
Rate Adaptation

**Goal**: choose among six encoding/baudrate combinations based on observed RSSI/loss rate

<table>
<thead>
<tr>
<th>Bitrate (symbol/s)</th>
<th>Throughput (kbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM0/640</td>
<td>640</td>
</tr>
<tr>
<td>FM0/160</td>
<td>160</td>
</tr>
<tr>
<td>Miller4/640</td>
<td>160</td>
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<tr>
<td>Miller4/256</td>
<td>64</td>
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<tr>
<td>FM0/40</td>
<td>40</td>
</tr>
<tr>
<td>Miller8/256</td>
<td>32</td>
</tr>
</tbody>
</table>
Rate Adaptation

**Intuition**: Loss rate increase caused primarily by self-interference, hence choose stronger encoding.
Rate Adaptation

- **Intuition**: RSSI reduction caused primarily by range effects, hence choose the next lower bitrate.
Rate Adaptation

- Does our intuition hold in practice?

![Plot showing packet loss rate vs. RSSI for different encoding schemes.](chart)

- Complex encoding
- Throughput decreases
BLINK Overview

- Link Metrics
- **Design**
  - Mobility Detection
  - Rate Adaptation
  - Channel Switching
- Evaluation
- Conclusion
Channel Switching

Recall: Dwell time of 0.2s - 0.4s per channel. How can we exploit the flexibility?
Channel Switching

- Recall: Dwell time of 0.2s - 0.4s per channel. How can we exploit the flexibility?

- Observation: Channel is bursty i.e. we observe a string of successful packet transmission or losses

Algorithm: switch channels upon single loss

Putting it together

Rate Adaptation Module
- Classifier
- Feature Extraction
- Fast Channel Probe

Mobility Patterns

Passive Channel Monitor

Link Signature

Mobility Detection Module

Channel Switching Runtime
- Channel Switching
- Channel Burstiness Measurement

Mobility Detector
BLINK Overview

- Link Metrics
- Design
- Evaluation
  - Experiment Setup
  - Rate Adaptation
  - Channel Switching
  - Overall System Performance
- Conclusion
Experimental Setup

Impinj Reader

Static tags

Mobile tags

Toy train

Pedestrian

Collected data set

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training data</td>
<td>room/day 1</td>
<td>room/day 1</td>
<td>room/day 1</td>
</tr>
<tr>
<td>Testing data</td>
<td>room/day 2</td>
<td>corridor1/day 3</td>
<td>corridor2/day 4</td>
</tr>
<tr>
<td>Training size</td>
<td>158</td>
<td>158</td>
<td>158</td>
</tr>
<tr>
<td>Test size</td>
<td>347</td>
<td>161</td>
<td>162</td>
</tr>
</tbody>
</table>
Benefits of Rate Adaptation

Blink Rate adaptation is close to optimal bitrate
Benefits of Channel Switching

BLINK improves throughput by 2x through burstiness-aware channel switching.
Impact of Scale: Static Tags

BLINK is 1.3x-1.5x better than SampleRate and 1.4x-1.6x better than AutoSet.
Impact of Scale: Mobile Tags

BLINK is 1.4x-2x better than SampleRate and 2x-2.5x better than AutoSet
Conclusion

- Understand role of multipath self-interference on link metrics for backscatter links.

- Clustering-based rate adaptation and burstiness-aware channel switching.

- Up to $3x$ improvement in throughput over a range of scales, channel conditions and mobility scenarios.

Thank you!
Backup Slides
BLINK Overview

Rate Adaptation Module
- Classifier
- Feature Extraction
- Fast Channel Probe

Channel Selection/Switching Module
- Channel Selection
- Channel Switching
- Burstiness
- Sharp Transition
- Channel Measurement

Mobility Patterns

Mobility Detection Module
- Passive Channel Monitor
- Link Signature
- Mobility Detector
Euclidean distance between RSSI and loss rate vector

- Euclidean distance between link signatures
  - Need to compare both RSSI vector and loss rate vector
  - Exploit only RSSI vector?

- Exploit only loss rate vector?
Channel Probe

- Rate adaptation waits for link metrics to be obtained before selecting best bitrate. How long does this take?
  - 7 queries per channel → 5s probe

- Can we reduce channel Probe time?
  - Observation: Sharp transition between good and bad channels
  - Implication: One packet per channel to probe
  - Result: 5s → 0.7s