Side Channel: 
Bits over Interference

Kaishun Wu, Haoyu Tan, Yunhuai Liu, Jin Zhang, 
Qian Zhang and Lionel M. Ni

Department of Computer Science and Engineering, 
Hong Kong University of Science and Technology

September 21, 2010
Outline

1. Introduction
   - Interference Management
   - The Coordination Problem
2. Side Channel Design
   - Observations
   - System architecture
   - Modulation/Demodulation Schemes
3. DC-MAC
   - DC-MAC Principles
4. Evaluation
   - Side Channel and DC-MAC
5. Conclusion & Future Work
Outline

1. **Introduction**
   - Interference Management
   - The Coordination Problem

2. **Side Channel Design**
   - Observation
   - System architecture
   - Modulation/Demodulation Schemes

3. **DC-MAC**
   - DC-MAC Principles

4. **Evaluation**
   - Side Channel and DC-MAC

5. **Conclusion & Future Work**
Interference Management

- Broadcast nature
- CDMA, TDMA, FDMA, CSMA/CA
- Interference cancellation
The Coordination Problem

Traditional coordinate scheme is costly

- In-band: Back-off, DIFS and SIFS in CSMA
- Out-of-band: Dedicated control radio/channel

Main Question

Can we coordinate among multiple nodes without significantly wasting system resources?

Side Channel:

an in-band and coordination free channel
Outline

1. Introduction
   - Interference Management
   - The Coordination Problem

2. Side Channel Design
   - Observation
   - System architecture
   - Modulation/Demodulation Schemes

3. DC-MAC
   - DC-MAC Principles

4. Evaluation
   - Side Channel and DC-MAC

5. Conclusion & Future Work
ZigBee PHY (DSSS)

Sender:

Binary Date (4 bits) ➔ Symbol ➔ Chips (32 bits)

1001 ➔ Bit to Symbol conversion ➔ 9 ➔ Symbol to chip conversion ➔ 1011100......

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Chip sequence (C0, C1, C2, ..., C31)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11011001110000110101001000101110</td>
</tr>
<tr>
<td>1</td>
<td>1110110111001111000011010100100010</td>
</tr>
<tr>
<td>2</td>
<td>0010111101101100111000011010100010</td>
</tr>
<tr>
<td>3</td>
<td>001000101110110110011100001101011</td>
</tr>
<tr>
<td>4</td>
<td>0101001000010111101101010011000011</td>
</tr>
<tr>
<td>5</td>
<td>0011010010010001101101011011001100</td>
</tr>
<tr>
<td>6</td>
<td>1100001101010001000101110110110001</td>
</tr>
<tr>
<td>7</td>
<td>1001110000110101001000010111101101</td>
</tr>
<tr>
<td>8</td>
<td>1000110010010110000001110111011011</td>
</tr>
<tr>
<td>9</td>
<td>101110001100100101100000011101111011</td>
</tr>
<tr>
<td>10</td>
<td>01111011110010010110000111011000011</td>
</tr>
<tr>
<td>11</td>
<td>0111011111011000110010010111100000</td>
</tr>
<tr>
<td>12</td>
<td>0000111101111011011000110010010110</td>
</tr>
<tr>
<td>13</td>
<td>011000000110111111100111000011001001</td>
</tr>
<tr>
<td>14</td>
<td>100101100000011101011101110011001100</td>
</tr>
<tr>
<td>15</td>
<td>1100100101100000011110111101110000</td>
</tr>
</tbody>
</table>

ACM MobiCom 2010
Receiver:

Chips (32 bits) → Symbol → Binary Date (4 bits)

Symbol: 100110......

Symbol to chip: 9

Bit to Symbol: 1001

Chip error information:
The number of differences

Redundancy
Radio interference pattern is identifiable.
System Architecture

Traditional communication

Side Channel-enabled communication
Illustrated Example

Main channel

"Hello, Bob!"
Alice

Hello, Bob!
Bob

Hello, Bob!
From Alice

260
Carol

Side channel

Hello, Bob!
From Carol
Design Principles

\[
P_{SEP} = \sum_{j=\delta(f)+1}^{n} \sum_{r=0}^{h} \binom{h}{r} P_{I}^{r} (1 - P_{I})^{h-r} \binom{n-h}{j-r} P_{N}^{j-r} (1 - P_{N})^{(n-h)-(j-r)}
\]

The relation between the number of intended interfered chips \( h \), SEP and the PRR, assuming each packet has 2000 symbols (1000 bytes).
Modulation Schemes

- Pulse-position Modulation (PPM)

- \( C_{\text{PPM}} = 129 \text{ kbps} \)
Modulation Schemes

- Pulse-interval Modulation (PIM)

![Diagram of Pulse-interval Modulation (PIM)]

- \( C_{\text{PIM}} = 15 \text{ kbps} \)
ACM MobiCom 2010

Outline

1. Introduction
   - Interference Management
   - The Coordination Problem
2. Side Channel Design
   - Observation
   - System architecture
   - Modulation/Demodulation Schemes
3. DC-MAC
   - DC-MAC Principles
4. Evaluation
   - Side Channel and DC-MAC
5. Conclusion & Future Work
DC-MAC Principles

[Diagram showing network topology with nodes A, B, and C communicating with an access point (AP). The diagram illustrates the concept of token assignment and downlink/uplink data transmission.]

Main Channel
Side Channel
Request

Token assign.

Data

Uplink

Next
down

Down
link

16/26
Outline

1. Introduction
   - Interference Management
   - The Coordination Problem

2. Side Channel Design
   - Observation
   - System architecture
   - Modulation/Demodulation Schemes

3. DC-MAC
   - DC-MAC Principles

4. Evaluation
   - Side Channel and DC-MAC

5. Conclusion & Future Work
Evaluation

- Implementation
  - IEEE 802.15.4 PHY in GNU Radio
  - Side Channel & DC-MAC
  - CSMA/CA for comparison

- Testbed
  - Room 4205 at HKUST
  - 7 USRP2 nodes
  - IEEE 802.15.4

- Evaluation Metrics
  - Side Channel: Capacity, False negative (Side Channel Erase Rate)
  - DC-MAC: Throughput and PRR (Packet Loss Rate)
PER, SER and CER of normal transmission under different SNR

Effect of different duration of Interfered chips to Main Channel
Experimental Results (2)

Capacity with different modulation schemes in Side Channel

False negative with different modulation schemes in Side Channel
Performance Gain (1)

DC-MAC performance in a saturated network

DC-MAC performance in an unsaturated network
Performance Gain (2)

DC-MAC performance under different traffic loads

Packet loss rate of DC-MAC and CSMA under different traffic loads
Outline

1. Introduction
   • Interference Management
   • The Coordination Problem
2. Side Channel Design
   • Observation
   • System architecture
   • Modulation/Demodulation Schemes
3. DC-MAC
   • DC-MAC Principles
4. Evaluation
   • Side Channel and DC-MAC
5. Conclusion & Future Work
Conclusion

- Intended interference patterns → a "free" in-band control channel, Side Channel

- A new DC-MAC with Side Channel and original Channel

- USRP-based testbed and experiments
  - 7 USRP nodes
  - Implement Side Channel
  - Implement DC-MAC
  - Implement CSMA
  - 250% throughput gain from DC-MAC over CSMA
Future Work

- Limitations
  - IEEE 802.15.4
  - External interference

- Future Work
  - More efficient modulation schemes
  - General Side Channel technique
Questions?

Thank You!

Contact:
Kaishun Wu(kwinson@cse.ust.hk)