DOT3 Radio Stack

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Introduction

• A wireless sensor
  – sample analog signals
  – communicate with other nodes in wireless.

• MICA is the current platform in Berkeley.

• MICA has been useful, but not enough for large scale app due to short range

Outdoor range of MICA (256 packets)
Mote with CC1000 Radio

- DOT3 is a new platform with ChipCon CC1000 radio chip.
- MICA2 is a variation of DOT3 that has full features of MICA.
- We aim to have a working network stack for motes with ChipCon radio in nesC.
Design of Chipcon Radio Stack

- Components accessing the radio were modified
- Components for reliable communication were added.

<table>
<thead>
<tr>
<th>Application</th>
<th>ReliableComm</th>
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<tbody>
<tr>
<td></td>
<td>GenericComm</td>
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<tr>
<td></td>
<td>AMStandard</td>
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<tr>
<td></td>
<td>RadioCrcPacket</td>
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<td>RFCComm</td>
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<td></td>
<td>ChannelMonC</td>
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<td>Chipcon</td>
<td>SecDedEncoding</td>
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<td></td>
<td>SpiByteFifoC</td>
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<td>Radio</td>
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</tbody>
</table>

- Retransmit dropped packets using Acknowledgement
- Calculates CRC.
- Packet decomposition and reassembly
- Sends and receives data in bytes and notifies data arrival

Setting the parameters for CC1000 radio chip

*: newly made or modified from existing network stack
Packet decomposition and reassembly

- The application level uses a packet whereas the underlying radio uses a byte as a data unit.
- Thus, a packet needs to be decomposed to bytes and reassembled from bytes.
- Since a packet is received as a sequence of bytes, we need a way to tell the beginning of the packet.
- The byte data can be transferred in half duplex mode.
Packet decomposition and reassembly

- Packet decomposition and reassembly can be implemented using a state machine in the below:
- Send mode consists of one state
  - IDLE state: sends a byte when the byte buffer is empty
- Receive mode consists of two states
  - FIND_SYNC state: detects the start of a packet using preamble and start symbol
  - READING state: reads the remaining bytes and triggers an event when all the bytes are read.
Interface to CC1000

- Microprocessor transfers data to and from the radio using byte level interface called SPI.
- The microprocessor needs to communicate with CC1000 radio chip to configure or monitor the status of it.
- The properties like operating frequency and power consumption can be set up by changing the CC1000 status registers.
Using multiple channels

- CC1000 can operate in several different bands: 433, 866 and 916 MHz using corresponding capacitors and inductors.
- Within each band, CC1000 can operate in different frequencies according to the status register values.
- Using multiple channels can help reducing the interference between nodes.
- We found working frequencies in 433 MHz band and here are the examples:

<table>
<thead>
<tr>
<th></th>
<th>CH 1</th>
<th>CH 2</th>
<th>CH 3</th>
<th>CH 4</th>
<th>MICA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Frequency(MHz)</td>
<td>433.02</td>
<td>433.64</td>
<td>434.20</td>
<td>434.71</td>
</tr>
<tr>
<td>RX</td>
<td>Frequency (MHz)</td>
<td>433.09</td>
<td>433.71</td>
<td>434.27</td>
<td>434.78</td>
</tr>
</tbody>
</table>
How to transmit messages reliably?

- Add source address and Ack number to packets.
- Receiver keeps track of senders to handle duplicate packets.
Evaluation

• Evaluation Methods
  – Sends a number of packets and counts the packets received as we vary the environment.
  – Ratio of received packets is our metric.
  – In outdoor tests, we vary the distance.
  – In indoor tests, we vary the number of nodes and number of channels used.
Effectiveness of ECC

- Transmission with error correction code, no packets were dropped within 800ft compared to 500ft for non-ECC version.

The effectiveness of ECC (256 packets)
Effectiveness of retransmission

- Retransmission reduced the packet losses with additional time costs.

The effectiveness of retransmission (256 packets)
Multiple Senders

Sender 1

Sender 2

Sender 3

Receiver
Cases with multiple senders

- Retransmission reduced most of the packet losses due to collision.

The effects of retransmission on collisions
(128 packets per node)
Cases with multiple senders

- Retransmission paid a little high costs for increasing packet receiving rate (over 6 times in case of 4 senders).

![Graph showing effects of retransmission on transmission time](image.png)
Multiple Channels

Sender 1 -> Receiver 1
Sender 2 -> Receiver 2
Sender 3 -> Receiver 3
Sender 4 -> Receiver 4
Cases with multiple channels

- Using multiple channels reduced the packet losses due to collision.

The effects of multiple channels on collision
(128 packets per node)
Cases with multiple channels

- Using multiple channels reduced the time cost to achieve high receiving rate

The effects of multiple channels on transmission time (128 packets per node)
Discussion & Future Works

• Comparison with MICA
  – Pros: Better coverage and reliability
  – Cons: Slower transmission (60 sec vs. 9 sec for 512 packets) caused by
    » Slower clock rate of radio (19Kbps vs. 40Kbps)
    » Less efficient interrupt handler
  – Modifying interrupt handler (from SPI to timer interrupt) will address this.
Discussion & Future Works

- Problems with our reliable transmission method
  - Effective for moderate collision, but not for high collision.
  - Introducing exponential back-off is expected to be helpful.
  - Overhead of retransmission is negligible.

<table>
<thead>
<tr>
<th>Best Effort</th>
<th>Retransmission (5 retransmission)</th>
<th>Retransmission (0 retransmission)</th>
</tr>
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<tbody>
<tr>
<td>31 sec</td>
<td>64 sec</td>
<td>32 sec</td>
</tr>
</tbody>
</table>

Time to send/receive 512 packets
Discussion & Future Works

- Using multiple channels
  - Reduces collision.
  - Currently statically determined, vulnerable to misconfiguration.
  - Dynamic frequency allocation is needed.

- Coding with error correction code
  - The theoretical lower bound of code word is 13-bits without considering preamble and start symbol.
  - Existing implementation used 3 byte code word.
  - Reducing the code word to 2 bytes will be helpful.
End

• Questions?
Extra Slides
Overview of existing network stack (MICA)

- Converts a packet to and from raw bytes
- Sends and receives bytes
- Calculates CRC for sanity check
- Codes data with ECC
Data interface to the radio

- Microprocessor transfers data to and from the radio using byte level interface called SPI.
- SPI consists of byte buffer, status register and clock.
- At each clock interrupt, status register is checked for a received byte.

- With no incoming byte, the microprocessor can send a byte into the byte buffer by setting the data direction as send.
Configuring Chipcon Radio

- The microprocessor needs to communicate with CC1000 radio chip to configure or monitor the status of it.
- The properties like operating frequency and power consumption can be set up by changing the CC1000 status registers.

- By setting or clearing three pins, the microprocessor can send or read a byte to a CC1000 status register.
Rayleigh Fading

- The graphs in outdoor tests consistently had dips at 900 ft.
- Radio waves from the sender can take different paths and cancel each other when the waves are of opposite phase.
- This is called Rayleigh Fading.