Body-Coupled Communication for Body Sensor Networks

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Outline

- Background
  - UVA team
  - What is BodyComm?
  - What are the types of BodyComm?
- BodyComm frequency characteristic testing
- Comparison to 2.4 GHz technology
- Future research and systems
- Conclusion
INERTIA Group at UVA

- **Background**
  - Aging
    - Movement disorders (Parkinson’s Disease, gait disorder, and fall risk behavior) affect mobility and quality of life
  - Collaboration
    - Physicians from UVA Med School and surrounding areas
    - Use feedback to inform engineering decisions
  - Systems
    - Wearable motion acquisition system (TEMPO) already in medical research projects collecting data
### Electrical Characteristics

#### Background
- Nordic nRF24AP1
- Chipcon CC2420
- Chipcon CC1101

#### Frequency Band
- Nordic nRF24AP1: 2.4 GHz
- Chipcon CC2420: 2.4 GHz
- Chipcon CC1101: 900 MHz

#### Voltage Supply
- Nordic nRF24AP1: 1.9-3.6 V
- Chipcon CC2420: 2.1-3.6 V
- Chipcon CC1101: 1.8-3.6 V

#### Current Consumption
- **TX**
  - Nordic nRF24AP1: 13-16 mA
  - Chipcon CC2420: 8.5-17.4 mA
  - Chipcon CC1101: 12.3-15 mA
- **RX**
  - Nordic nRF24AP1: 22 mA
  - Chipcon CC2420: 18.8 mA
  - Chipcon CC1101: 14.3-16.5 mA

#### Maximum Data Rate
- Nordic nRF24AP1: 1 Mbps*
- Chipcon CC2420: 250 kbps
- Chipcon CC1101: 1.2-500 kbps

*over air maximum raw data rate

#### Testing

<table>
<thead>
<tr>
<th></th>
<th>Atmel ATmega128L</th>
<th>MSP430F1611</th>
<th>ARM 920t (Atmel)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voltage Supply</strong></td>
<td>2.7-5.5 V</td>
<td>1.8-3.6 V</td>
<td>3-3.6 V</td>
</tr>
<tr>
<td><strong>Clock Frequency (max)</strong></td>
<td>8 MHz</td>
<td>8 MHz</td>
<td>209 MHz</td>
</tr>
<tr>
<td><strong>Active Mode Current</strong></td>
<td>5.5 mA</td>
<td>450 µA</td>
<td>24.4 mA</td>
</tr>
<tr>
<td><strong>Sleep Mode Current</strong></td>
<td>5-25 µA</td>
<td>0.2-2 µA</td>
<td>520 µA</td>
</tr>
<tr>
<td><strong>RAM</strong></td>
<td>4 KB</td>
<td>10 KB</td>
<td>16 KB</td>
</tr>
</tbody>
</table>

#### Comparison

#### Future

#### Conclusion
Types of Wireless Communication

- Optical/Infrared
  - Requires line of sight
  - Normally not omni-directional

- RF
  - Omni-directional (good/bad?)
  - Received power reduces by $1/r^2$

- Magnetic Induction
  - Normally not omni-directional
  - Received power reduces by $1/r^3$

- Body-Coupled
  - Uses the human body as a transmission medium
    - Health considerations?
  - Limits communication to items in contact with the body
  - Normally operates at low frequencies
Types of BodyComm

- Which is best for BANs?
  - External dependence
  - System complexity
  - Wearability

- How do they compare to RF communication?

1. Circuit

2. Electrostatic

3. EM Waves
Waveguide BodyComm

- Uses the body as a waveguide for EM waves
- Little to no dependence on external environment
- Uses two contacts at each site
- Keisuke Hachisuka (University of Tokyo)
  - Re-validate frequency characteristics for consistency
  - Use carbon conductor electrodes for long-term wearability
  - Compare to current 2.4 GHz (ZigBee) technologies
  - Analyze “what we gain” from BodyComm in BSNs
Frequency Tests

- 5 test subjects
  - 3 males (ages 23, 24, and 54) and 2 females (ages 20 and 23)
- Two carbon conductor electrodes on each wrist
  - One set connected to RF function generator (-12dBm TX power)
  - One set connected to spectrum analyzer
- Frequencies swept from 1-50 MHz
Frequency Results

Comparison

Future

Background

Testing

Conclusion

Hachisuka (Sensors and Actuators, February 2003)
Frequency Results

• What do these results show?
  – Relative consistency across subjects
  – Common resonant frequencies
  – Excellent receive strengths!!
    • Even without matching impedance to body
    • With wireless transmission being the “power hog” in current BSNs, this could extend battery life or reduce form factor dramatically
Comparison to 2.4 GHz

- 13.56 and 23 MHz carriers were selected for comparison
- Conducted tests with various positions on the body of subject 1

13 to 34 dB improvement over 2.4 GHz (between 20X and 2500X better)
Comparison to 2.4 GHz

What do we gain with BodyComm?
ZigBee specs: 1% PER, 1000bits/packet, and 250kbps throughput at -92 dBm RX power
  - Shown in previous tests to be achieved at around -24 dBm TX power

FSK Equations:

\[ P_p = 1 - \left( 1 - P_e \right)^N \]  
\[ P_e = \frac{1}{2} e^{\frac{E_b}{2 \cdot N_0}} = \frac{1}{2} e^{\frac{P_r}{2 \cdot N_0 \cdot Rb}} \]

With reasonable assumptions for \( N_0 \) and \( T_{sys} \), we could transmit at around -52 dBm and see the same results
Future Research Opportunities

• Further theory and modeling
  – Model the human body for low frequency analysis (HFSS?)
    • Is the body really acting as a waveguide at such low frequencies?

• Further Testing
  – Decouple common ground plane
  – Electrodes
    • Feasibility
    • Explore frequency characteristics
  – Use an anechoic chamber to measure radiated energy
Future Research Opportunities

- Build body-worn prototypes
  - Availability of small, low-power transceivers at the frequencies tested
  - Can it be done with COTS components?
  - Can the electrodes be capacitively coupled to the skin?
• What are the implication of a “body-contained” network
  – Malicious attacks are limited to very close proximity
  – Facilitates spatial reuse
  – Reduces interference in dense environments
Conclusions

• Contributions
  – Frequency analysis using wearable electrodes
  – Comparison to 2.4 GHz with equal data-rates

• Implications
  – If wireless transmission consumes over half the power budget for a body node, than a 2000X improvement in TX power could lead to orders of magnitude improvement in battery life
  – Creates opportunities for higher spatial/channel reuse and better awareness of security and privacy issues
  – Could enable long-term medical observation studies previously not possible
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