Body Coupled Communication

Presentation By:
Adam Barth...Again
Types of Communication

- Optical/Infrared
  - Requires line of sight
  - Omni-directional devices can consume a lot of power

- Far-field (RF)
  - Omni-directional (good/bad?)
  - Received power reduces by $1/r^2$
    - Eavesdropping?
    - Off-body communication?

- Near-field (magnetic/electrostatic)
  - Normally not omni-directional
  - Received power reduces by $1/r^3$
    - Privacy?
    - Distance limitations?
What is BodyComm

- Can be considered near-field or somewhere in between
- Uses the human body as a transmission medium
  - Health concerns?
- Generally limits communication to items in contact to the body
- Normally operates at low frequencies
  - Body absorption
Types of BodyComm

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

- How do they compare to RF communication?
Electrostatic BodyComm

- Zimmerman (1996) MIT and IBM
- Electrostatic coupling
- Relies on small capacitive coupling to common “earth” ground
Electrostatic Models

- Electrostatic circuit with external ground reference
  - What capacitances are assumed?
  - How can they vary?
Electrostatic BodyComm

- **Practicality:**
  - Somewhere with strong “ground” capacitance is recommended
    - Shoe computer?
  - Commercial systems are available
    - RedTacton

- Would this work for BAN application?
  - Entertainment/Gaming
  - Medical
Waveguide BodyComm

- Uses the body as a waveguide for EM waves
- Little to no dependence on external environment
- Uses two transducers at each site
Waveguide BodyComm Research

- Keisuke Hachisuka (University of Tokyo)
- Experiments using Ag-Cl electrodes
  - Frequency characteristics
  - Electrode pair patterns
  - Electrode compositions
  - Electrode placement on body
Frequency Experiments

- Electrodes on a forearm
- Frequency sweep from 1-50 MHz
- Shown to be better than airborne propagation
  - Problems?
  - Ambiguities?
Frequency Results

Hachisuka (Sensors and Actuators, February 2003)

Hachisuka (the 12th International Conference on Solid State Sensors, Actuators and Microsystems, June 2003)
Our Frequency Tests

- 5 test subjects (Harry, Dincer, Mark, Me, and two females 20-23 years of age)
- 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
Our Frequency Results
Our Frequency Results

- What do these results show?
  - Relative consistency across subjects
  - Common resonant frequencies
  - Excellent receive strengths!!
    - Even without matching impedance to body
Waveguide Frequency Tests

- Problems with tests?
  - Common ground plane
  - Electrodes
    - Feasibility
    - Unknown frequency characteristics
  - Availability of small, low-power transceivers at the frequencies tested

- Other tests are needed
  - Some have already been done
Electrode Pair Pattern Tests

Fig. 6. Differences in propagation gain for three patterns of electrodes.
Electrode Impedance Tests
Electrode placement Tests
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?
- FSK Equations:
  \[ P_p = 1 - \left( 1 - P_e \right)^N \]  
  \[ P_e = \frac{1}{2} e^{-\frac{E_b}{2 \cdot N_0}} = \frac{1}{2} e^{-\frac{P_r}{2 \cdot N_0 \cdot R_b}} \] 

- ZigBee boasts 1% PER, 1000bits/packet, and 250kbps throughput at -92 dBm RX power
- With reasonable assumptions for \( N_0 \) and \( T_{sys} \), we could transmit at around -52 dBm and see the same results
BodyComm Prototype

- Analog FM transmission at 10.7 MHz
- Assembled from all COTS components at low cost
BodyComm Theory

- What is actually going on with waveguide BodyComm?
  - $\frac{1}{4}$ wavelength at 10.7 MHz is 28 meters
- How much radiation is there away from the body?
- What accounts for small variations among test subjects?
- What can we gain from knowing all of this?
BodyComm Theory

- One way to answer some of the aforementioned questions is by constructing a model of the human body’s impedance (bio-impedance analysis).
- Most research in this area is somewhat proprietary.
  - Consumer scales that give body fat, etc.
- A simple model can be constructed using HFSS:
  - 3 cylinders (two arms and one body), with input and output ports on the right and left arms.
  - 0.2 Siemens/m was used for the conductivity.
  - 70 was used for the relative permittivity constant.
HFSS simulation

The magnitudes of the E-field inside the body
HFSS Simulation

The magnitudes of the E-field inside the body and the air around the input arm
HFSS Simulation

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Impedance Real and Imaginary</th>
<th>13.56 MHz</th>
<th>23 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Left Wrist</td>
<td>Right Wrist</td>
</tr>
<tr>
<td>Left Wrist</td>
<td></td>
<td>0.982 + j162</td>
<td>1.797E-5 – j463</td>
</tr>
<tr>
<td>Right Wrist</td>
<td></td>
<td>1.799E-5 – j463</td>
<td>0.983 + j163</td>
</tr>
</tbody>
</table>

Table 1. HFSS Impedance results.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>E-Field Magnitude</th>
<th>13.56 MHz</th>
<th>23 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Left Wrist</td>
<td>Right Wrist</td>
</tr>
<tr>
<td>Left Wrist</td>
<td></td>
<td>0.98139</td>
<td>1.80E-05</td>
</tr>
<tr>
<td>Right Wrist</td>
<td></td>
<td>1.80E-05</td>
<td>0.98256</td>
</tr>
</tbody>
</table>

Table 2. HFSS E-Field Magnitude simulation results.
Ideas for More Experiments

- HFSS has a human model built for use in MRIs
  - Using this could get much more accurate simulation results
- Decouple from common ground plane and repeat receive strength measurements
- Use an anechoic chamber to measure radiated energy
- See if it can be capacitively coupled to the skin
BodyComm Privacy

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
BodyComm Applications

- What applications could benefit from BodyComm?
- What applications should remain RF?
- Is there enough demand for a BodyComm bote?
BodyComm Implications

- Should this still be considered a BAN?
  - What is the difference between BSNs, BANs, and PANs

- What will BodyComm do to processor power requirements?
Questions?