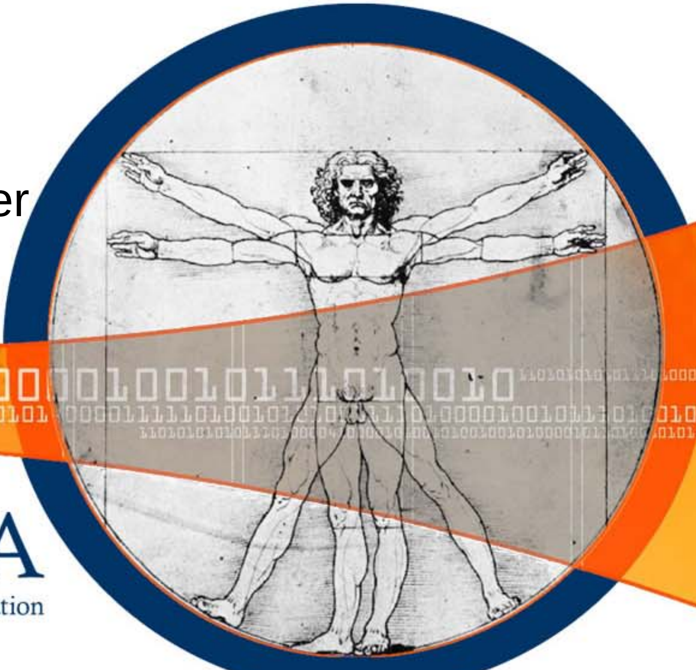
Body-Coupled Communication for Body Sensor Networks

Adam T. Barth, Mark A. Hanson,
Harry C. Powell Jr., Dincer Unluer,
Stephen G. Wilson, John Lach

Department of Electrical and Computer
Engineering University of Virginia



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Integrated Networked Embedded Real-time Technologies In Application
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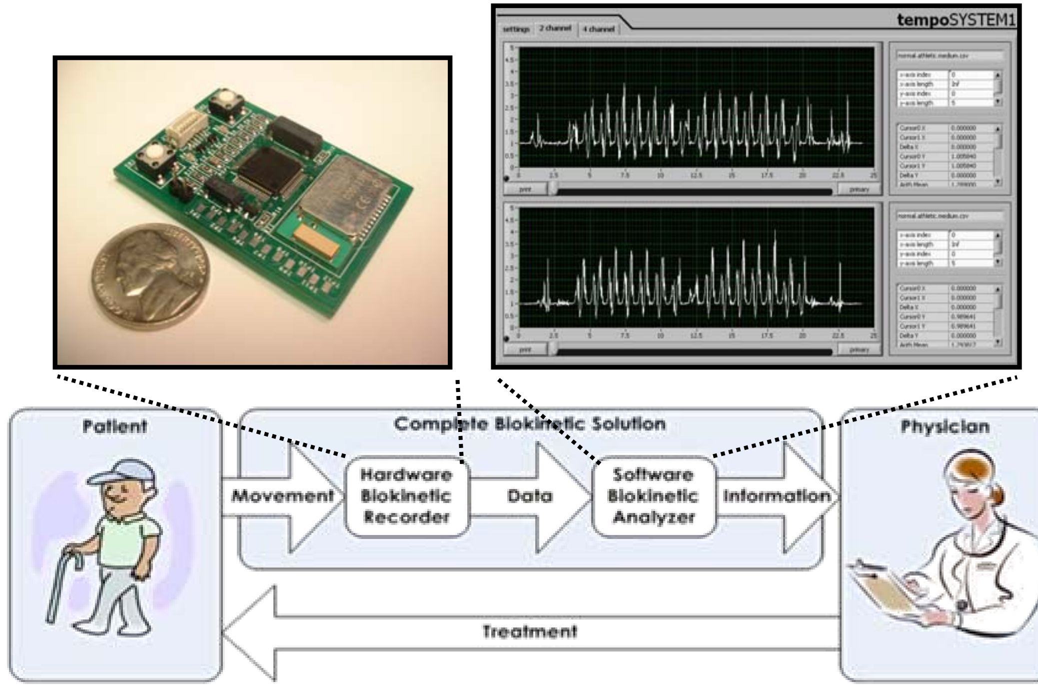
Outline

- 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

- 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



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Electrical Characteristics

	Nordic nRF24AP1	Chipcon CC2420	Chipcon CC1101
Frequency Band	2.4 GHz	2.4 GHz	900 MHz
Volatge Supply	1.9-3.6 V	2.1-3.6 V	1.8-3.6 V
Current Consumption (TX)	13-16 mA	8.5-17.4 mA	12.3-15 mA
Current Consumption (RX)	22 mA	18.8 mA	14.3-16.5 mA
Maximum Data Rate	1 Mbps*	250 kbps	1.2-500 kbps

*over air maximum raw data rate

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

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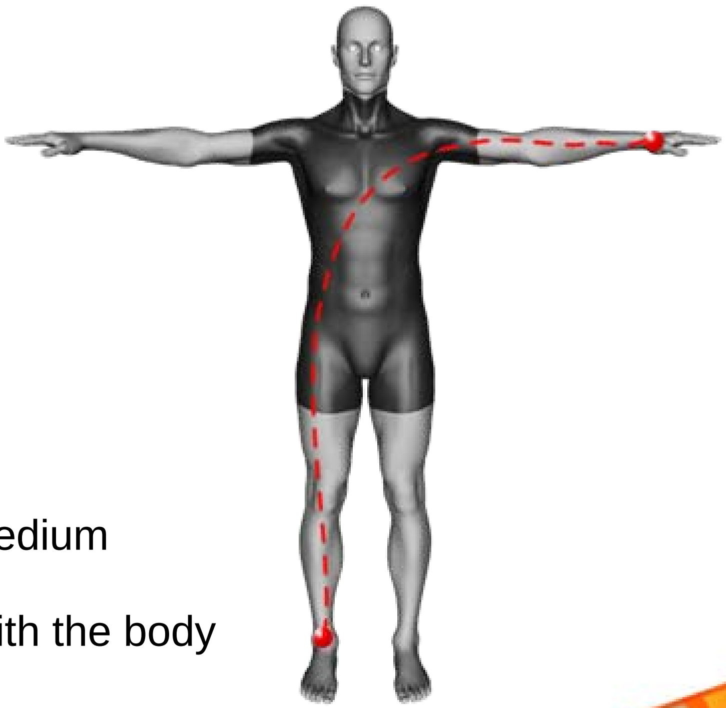
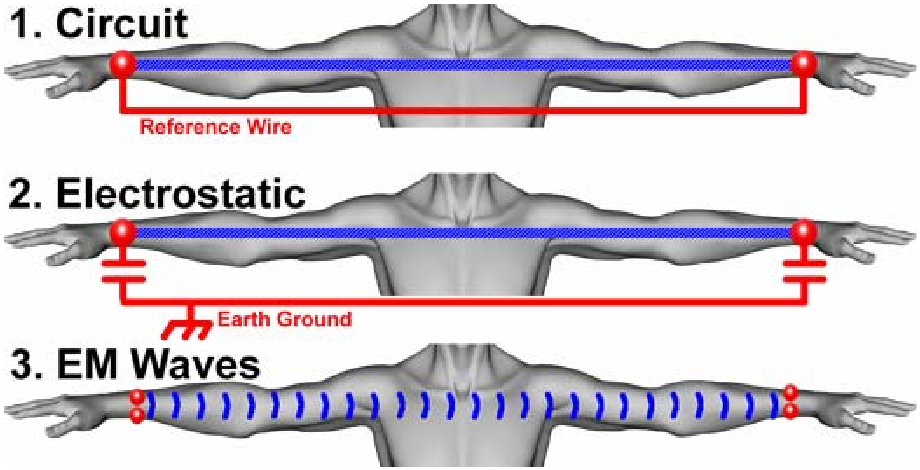
Types of Wireless Communication

- 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

Background | Testing | Comparison | Future | Conclusion



- Which is best for BANs?
  - External dependence
  - System complexity
  - Wearability
- How do they compare to RF communication?

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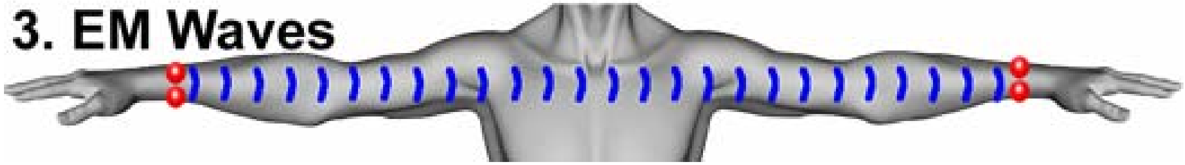
Waveguide BodyComm

Background Testing Comparison Future Conclusion



- 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

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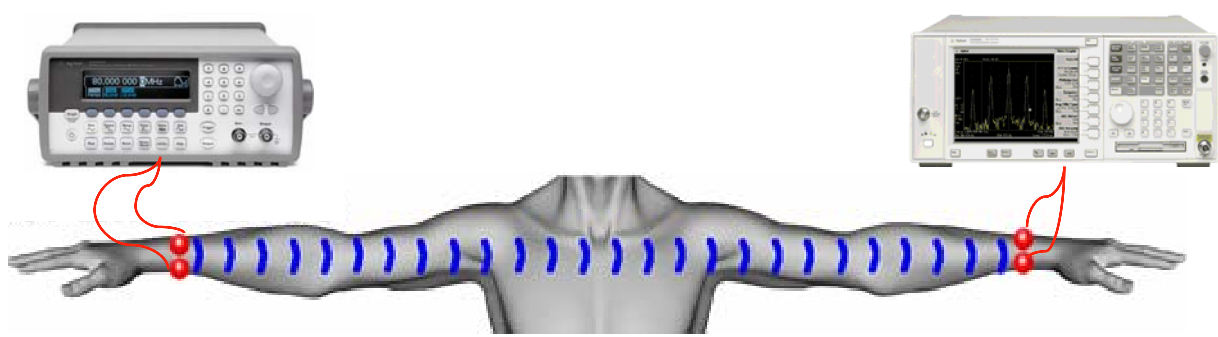
Frequency Tests

- 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



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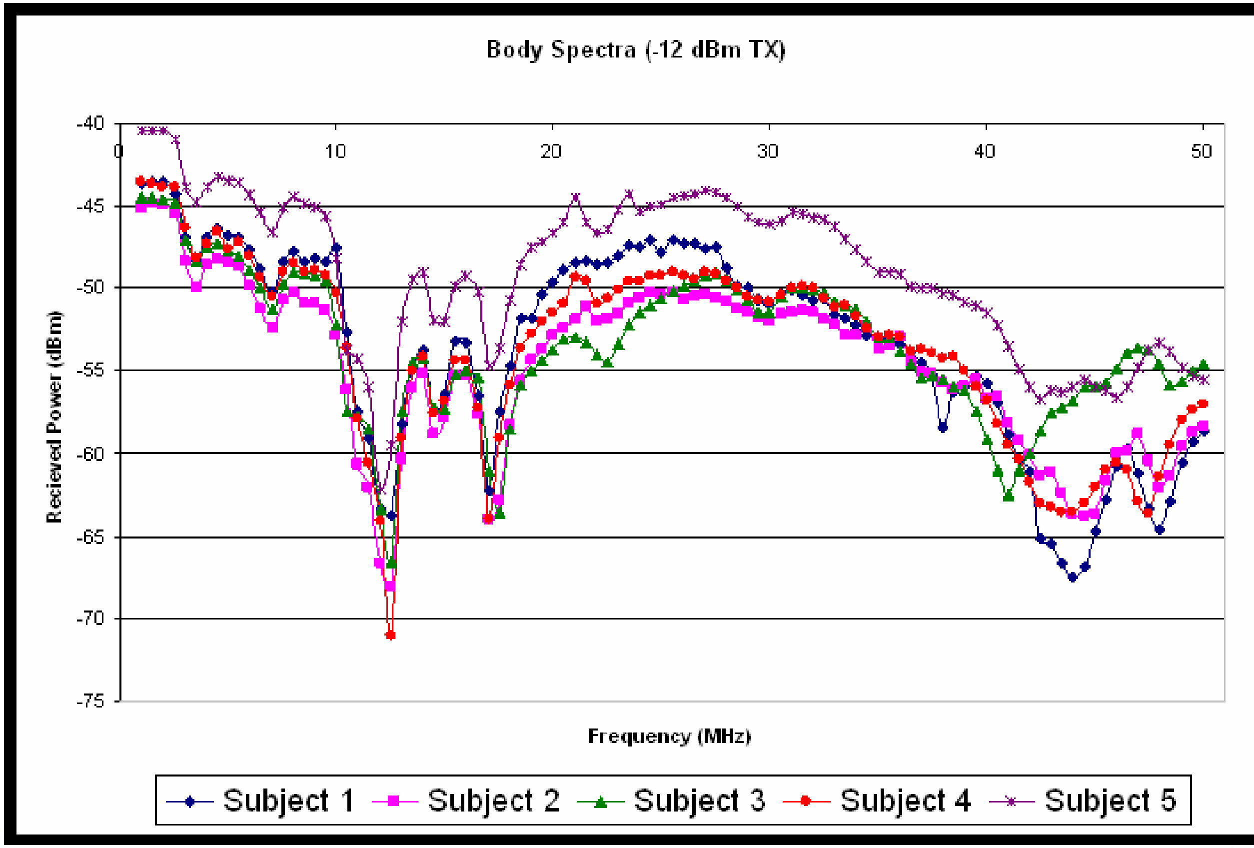
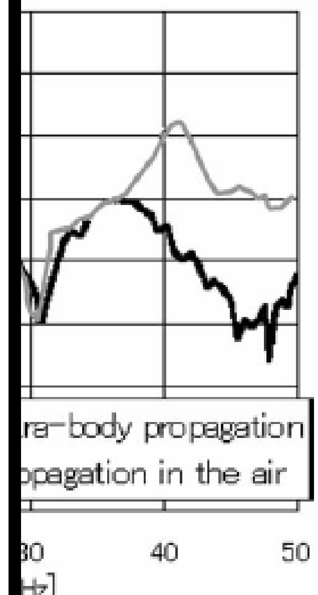
Frequency Results





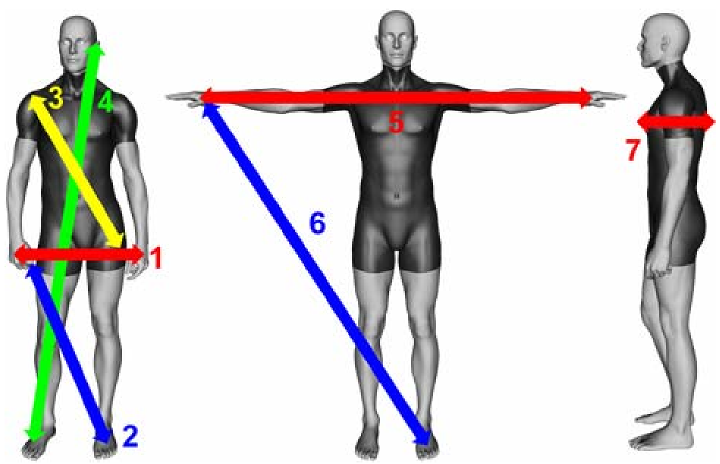
uators,

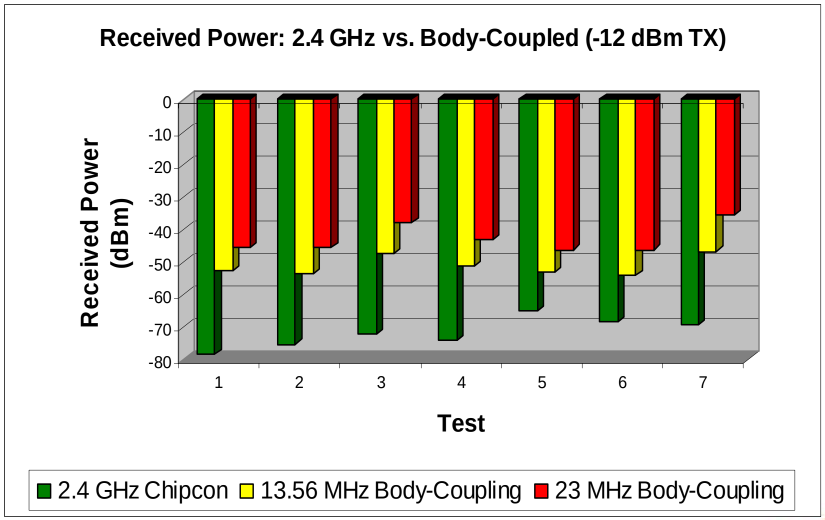
Frequency Results

- 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)

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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:

$$P_p = 1 - \left(1 - P_e\right)^N \quad (1)$$

$$Pe = \frac{1}{2} e^{-\frac{E_b}{2 \cdot N0}} = \frac{1}{2} e^{-\frac{P_r}{2 \cdot N0 \cdot Rb}} \quad (2)$$

- With reasonable assumptions for N_0 and T_{sys}, we could transmit at around -52 dBm and see the same results

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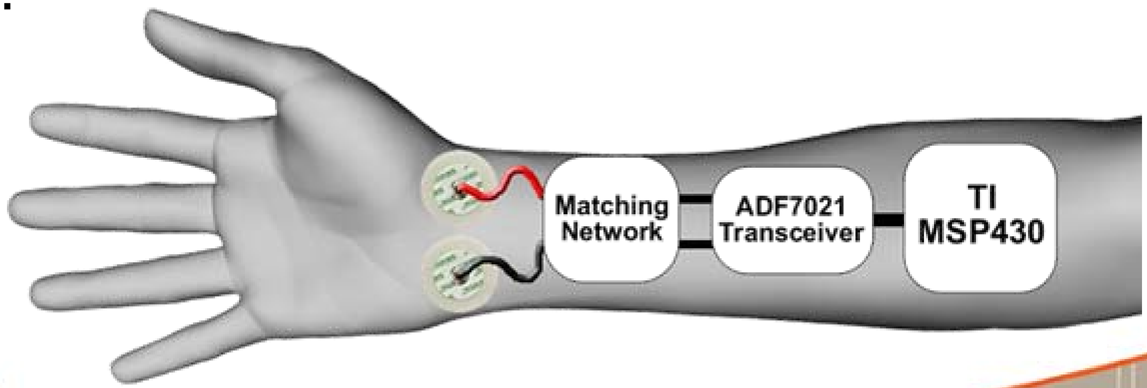
Future Research Opportunities

- 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?



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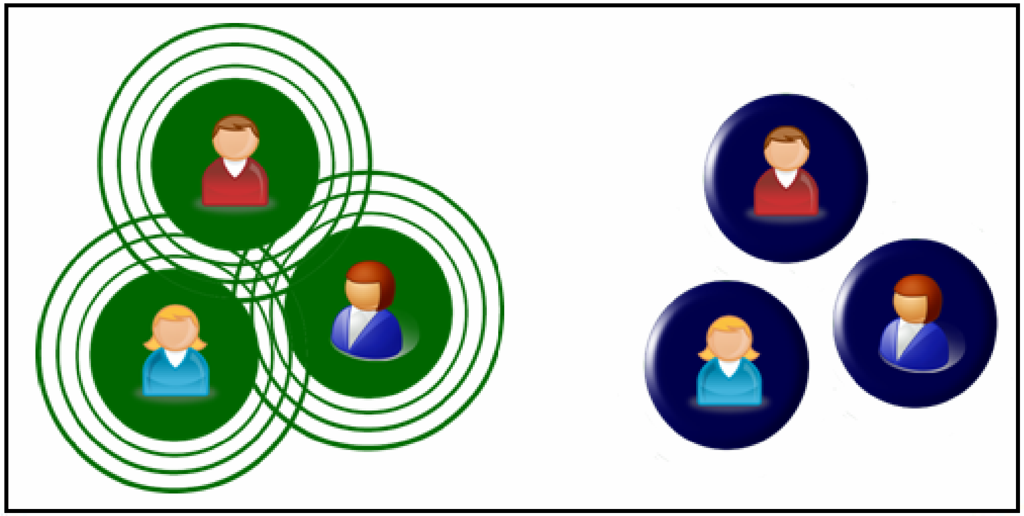
BodyComm Privacy

- 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

RF Radiation



BodyComm “bubbles”

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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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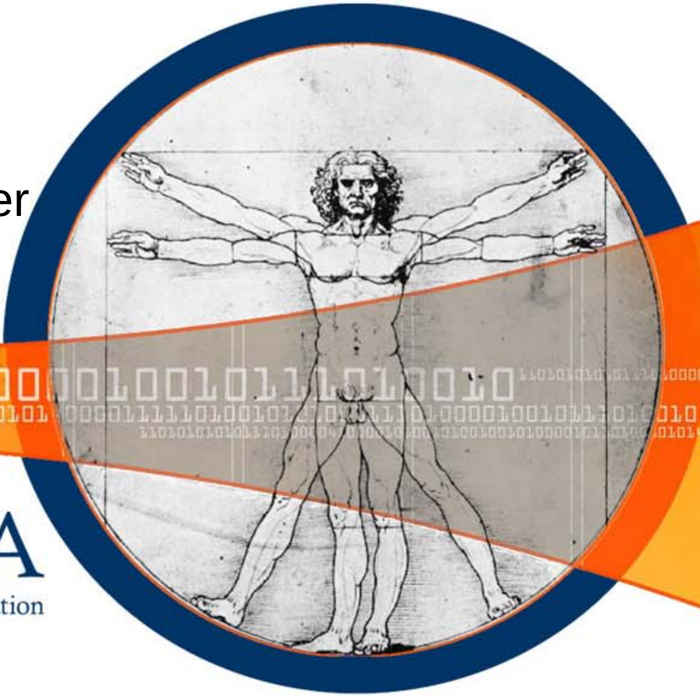

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