EECS 507: Introduction to Embedded Systems Research
Wireless Communication and Power Consumption

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Outline

Deadlines and announcements

6 Oct: "Research challenges for energy-efficient computing in automated vehicles," *IEEE Computer*, 2022, to appear. No student presentation for this one, but come prepared to discuss.

11 Oct.: E. Ronen, A. Shamir, A.-O. Weingarten, and C. O'Flynn, "IoT goes nuclear: Creating a ZigBee chain reaction," in *Proc. Symp. on Security and Privacy*, May 2017.

13 Oct.: Project checkpoint 1.

20 Oct.: R. P. Dick, L. Shang, M. Wolf, and S.-W. Yang, "Embedded Intelligence in the Internet-of-Things," *IEEE Design & Test of Computers*, Dec. 2019. I will present this one.

25 Oct.: Midterm exam.

Early December: Project presentations.

9 Dec.: Project deadline.

Context

Wireless (sensor) networks / IoT.

Reliability.

Transition to efficient embedded machine learning portion of course.

Outline

Communication reliability

Cannot rely on wireless communication.

Failure rates of 10% are common in practice.

Can compensate.

- Forward error correction: computationally expensive.
- Error detection with retransmission: introduces timing variation.

Power values for Crossbow MICAz

Description	Power
Mote radio transmitting	3.0×10^{-2} W
Mote CPU active	2.4×10^{-2} W
Mote CPU sleeping	3.0×10^{-5} W
Primary sensor and DAQ	5.7×10^{-3} W

Roughly 16 k-words/s transfer for 16-bit words.

Some retransmissions required.

8 M-words/s computation for 16-bit words.

Transmit–compute energy ratio $\geq 625\times$.

Communication energy model types

Ideal: No energy or time cost. Almost never useful.

Quantity-based: Energy cost per bit. Useful only if receive power considered.

Distance based: $\propto k + d^{\alpha}$ where generally $2 \leq \alpha \leq 6$. Surprisingly misleading if k ignored.

For a single transmitter, common for short-range to have similar energy to long-range.

Large variation across transmitter types.

Implications of inappropriate models

Much research on multihop to reduce energy.

- Energy superlinear in distance so...
- take more (linear increase) shorter (superlinear decrease) hops.
- Reduces net energy.
- ...but it doesn't.

Even the shortest hop for a particular transceiver often has an energy cost similar to the longest.

Outline

1. Deadlines and announcements
2. Communication reliability and energy consumption
3. Wireless communication standards

Wireless communication standards

Technology	Power (mW)	Range (m)	Typical rate (kb/s)
4G	1,000	70,000	10,000
5G	1,000	40,000	100,000
WiFi / 802.11x	250	140	20,000
Zigbee / 802.15.4	1–100	10–1,500	20–200
LoRaWAN	10	15,000	20
NB-IoT	100	15,000	250

Great variation in power, range, and data rate.

Efficiency commonly between 1/100 and 1/2, depending on data rate and encoding.

Many other LPWAN technologies.

Timing synchronization

Sleep everything, including wireless interface.

Will miss transmissions by other nodes.

Can use timer to wake up at same time.

Synchronization?

Compression and aggregation

Reduce amount of transmitted data to reduce energy cost.

Can tolerate 100–10,000 instructions per transmitted word, depending on environment.

In-network: Exploit similarities in data from region to reduce transmitted data.

Can aggregate data in field to reduce energy cost.

Antenna environment

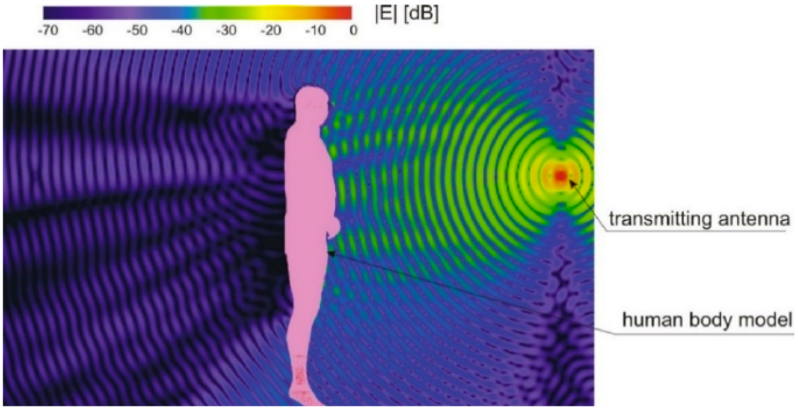
Antennas designed for particular operating environment.

Putting them next to conductive planes changes their behavior.

Transceivers adapt to wireless channel conditions.

Motion: constantly changing conditions make this difficult.

Antenna environment



Credit to Lukasz Januszkiewicz, "Analysis of Human Body Shadowing Effect on Wireless Sensor Networks Operating in the 2.4 GHz Band," *Sensors*, Oct. 2018.