IN4316 - Wireless Sensor Networks

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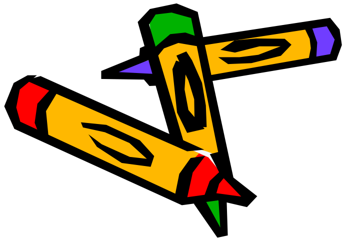
VLSI Trends: Moore's Law

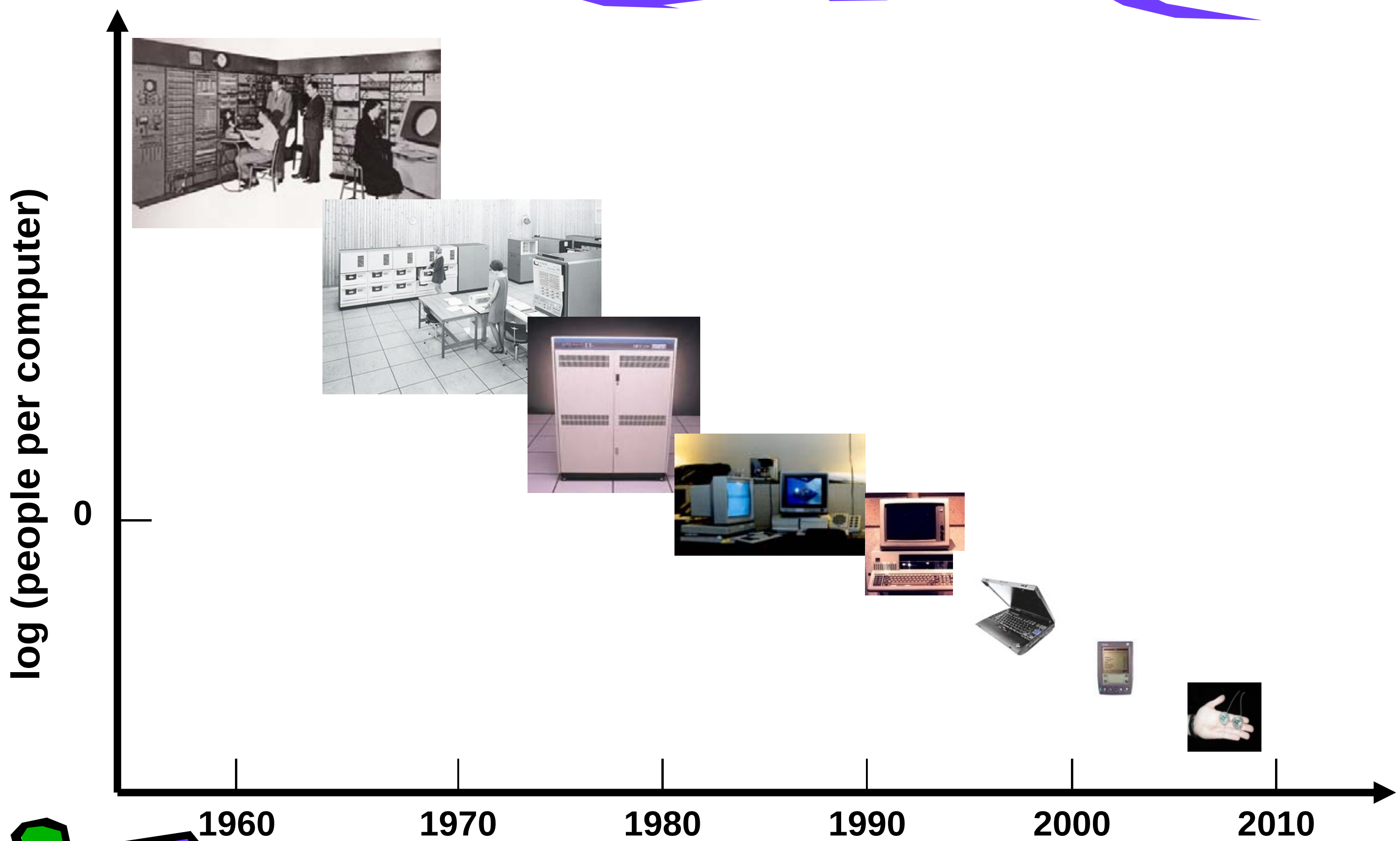
- in 1965, Gordon Moore **predicted** that transistors would continue to shrink, allowing:
  - **doubled** transistor density
  - **doubled** performance

  every 18-24 months

Gordon Moore
Intel Co-Founder

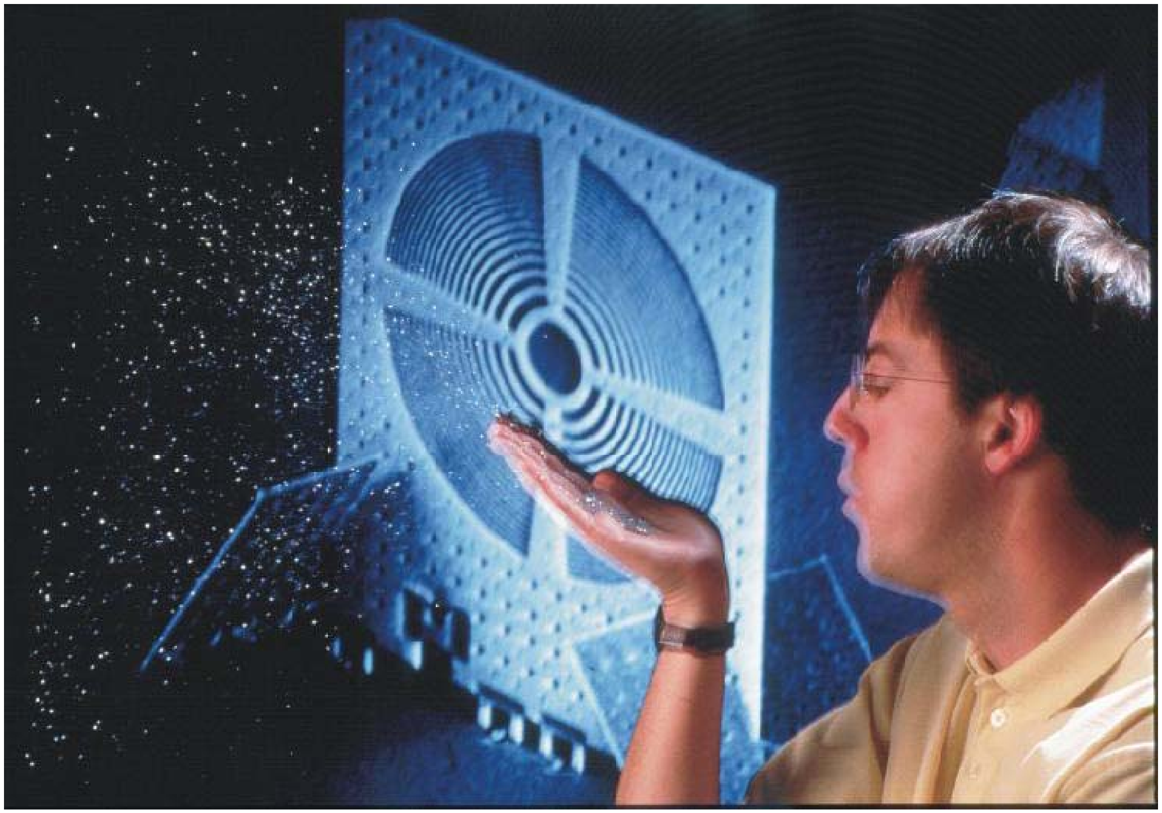


Bell's law:
every decade a new generation



[Culler:2004]

Wireless Sensor Networks
The beginning …



Next Century Challenges: Mobile Networking for "**Smart Dust**"

J. M. Kahn,

R. H. Katz,

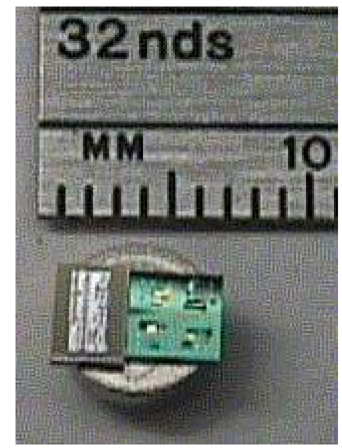
K. S. J. Pister

(MobiCom 1999)

Smart Dust @ UC Berkeley

Advances in digital circuitry will bring us:

- ultra low-power devices, with
- small form factor, at
- very low cost



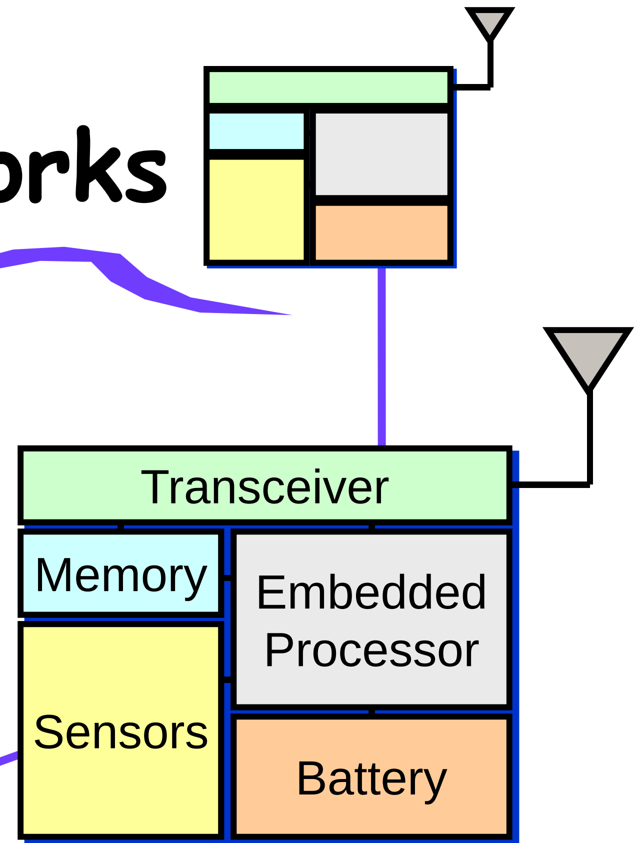
fostering a new range of applications

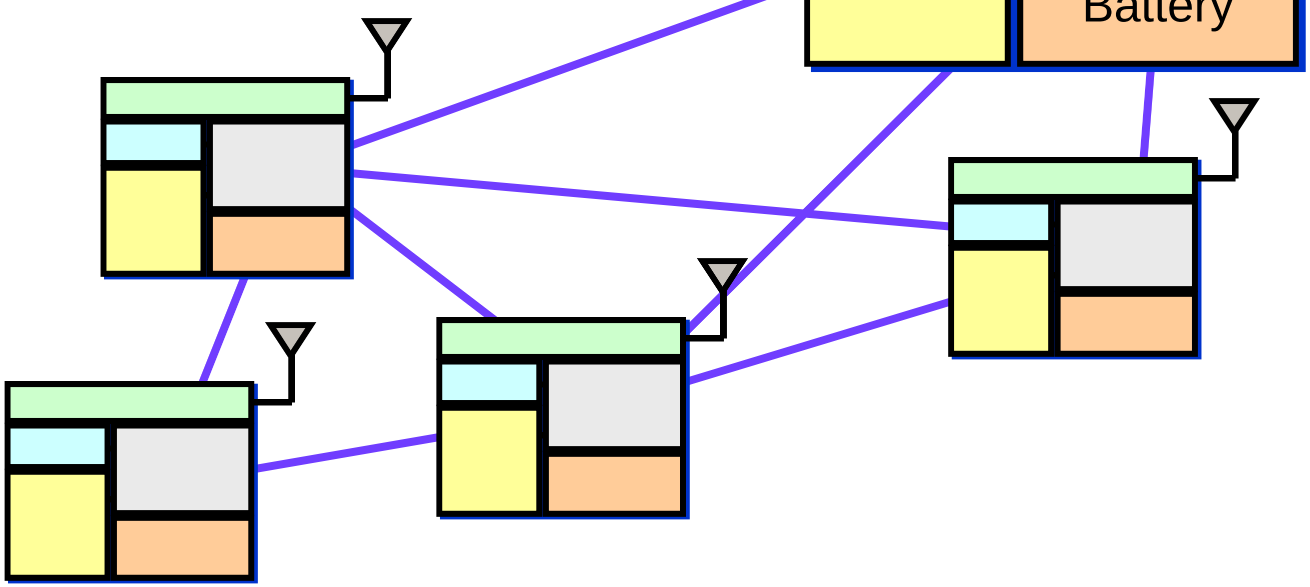
Autonomous sensing and communication
in a cubic millimeter

Wireless sensor networks

Many, cheap nodes

- wireless ⇒ easy to install
- intelligent ⇒ collaboration
- low-power ⇒ long lifetime





Envisioned applications

Fire fighting

Urban warfare

and many more…

Medical

Process industry

Agriculture

The first steps …

- Develop COTS hardware
- Develop software (TinyO
- Run experiments
- Prototype applications

[Vanderbilt, 2003]

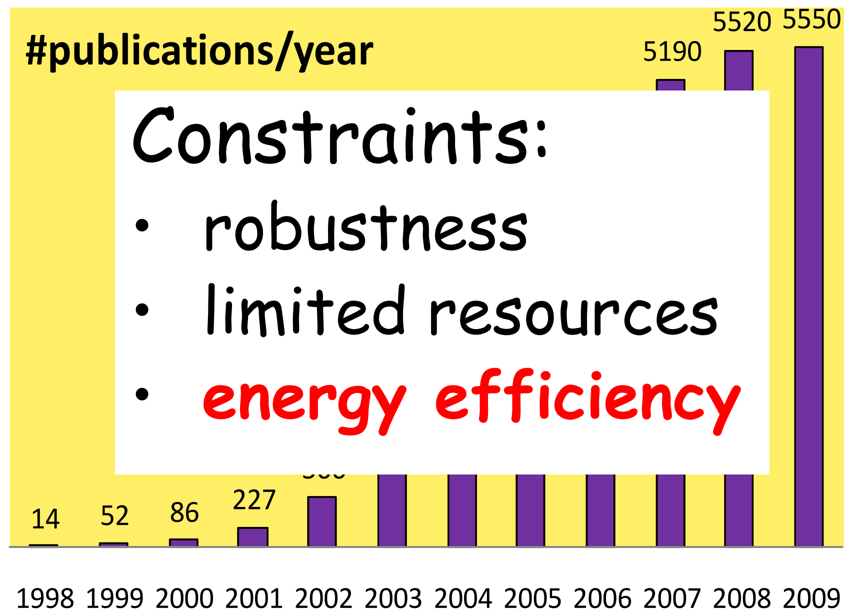
[UCB, 2002]

[Princeton, 2004]

WSN research

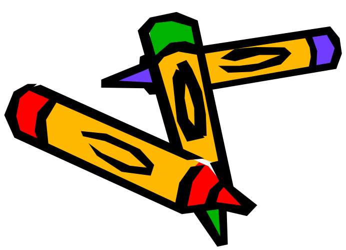
Topics:

- self-configuration
- node localization
- low-bitrate communication
- ad-hoc routing
- in-network data processing
- time synchronization
- ...

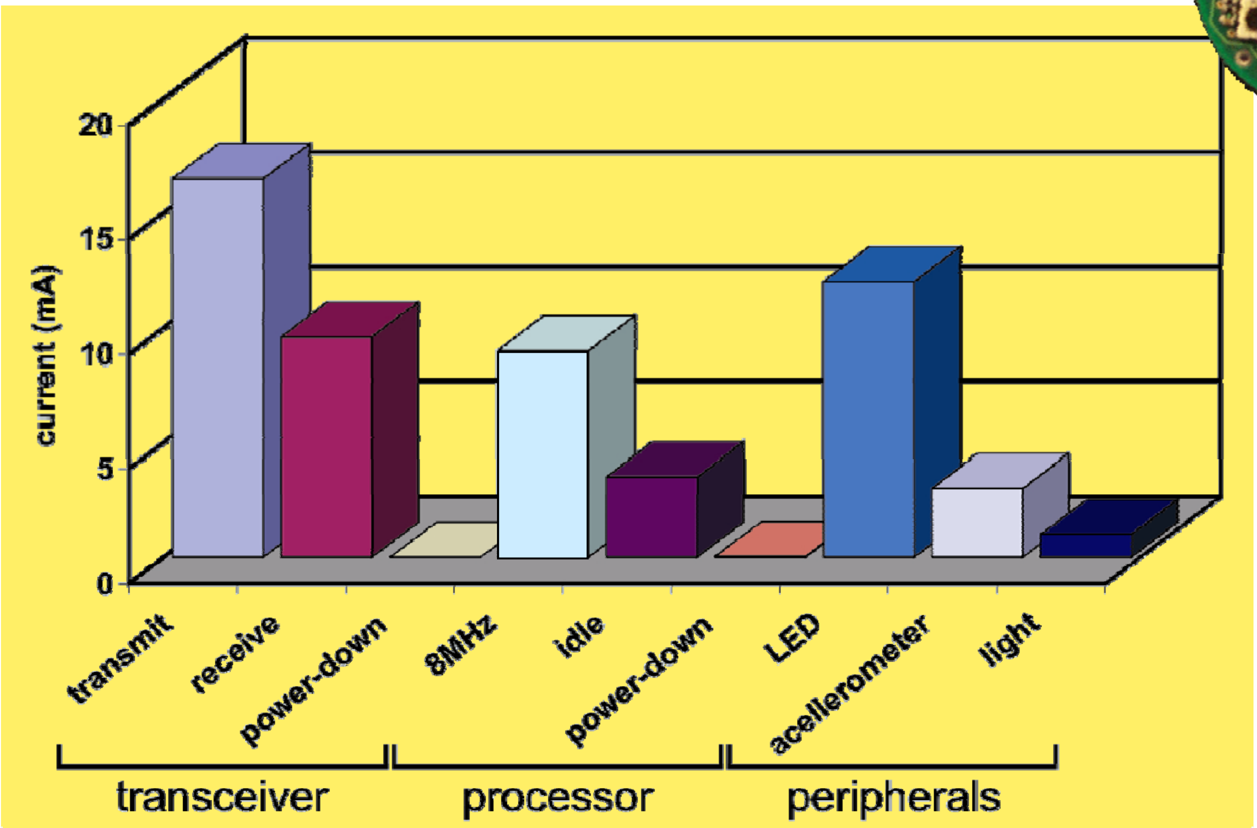


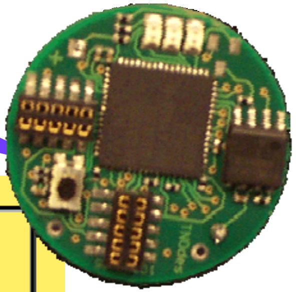
Constraints:

- robustness
- limited resources
- **energy efficiency**

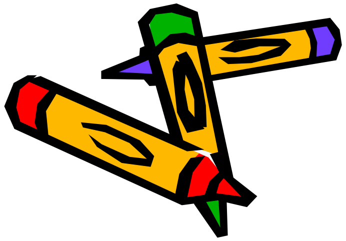


Energy breakdown





TNOdes



The battery crisis
(Moore's law evil twin brother)

Limited capacity

~2 kcal (per battery)

Slow increase of capacity

- ~8% yearly increase (Wh/cm^3)
- doubles every **9** years

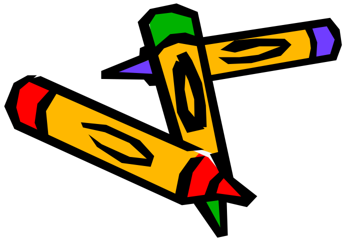
Back to reality

Course information

- Goal:
  - to acquire knowledge and understanding of **Wireless Sensor Networks**, in particular, of how the inherent need for **energy-efficient operation** requires a new approach to distributed computing.
- Means:
  - by reading, presenting, and discussing **state-of-the-art** research papers

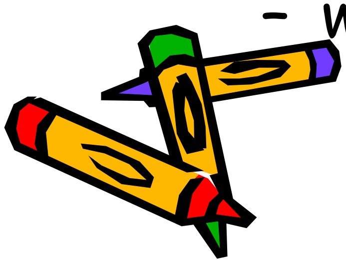
Course contents

- Lectures (2x)
  - wireless communication
  - ad-hoc + sensor networks
- Seminar (5x)
  - **M**edium access control, **L**ocalization, **R**outing, **S**ystems, **P**rogramming
- Darjeeling Lab (1x)
  - hands-on experience



Seminar organization

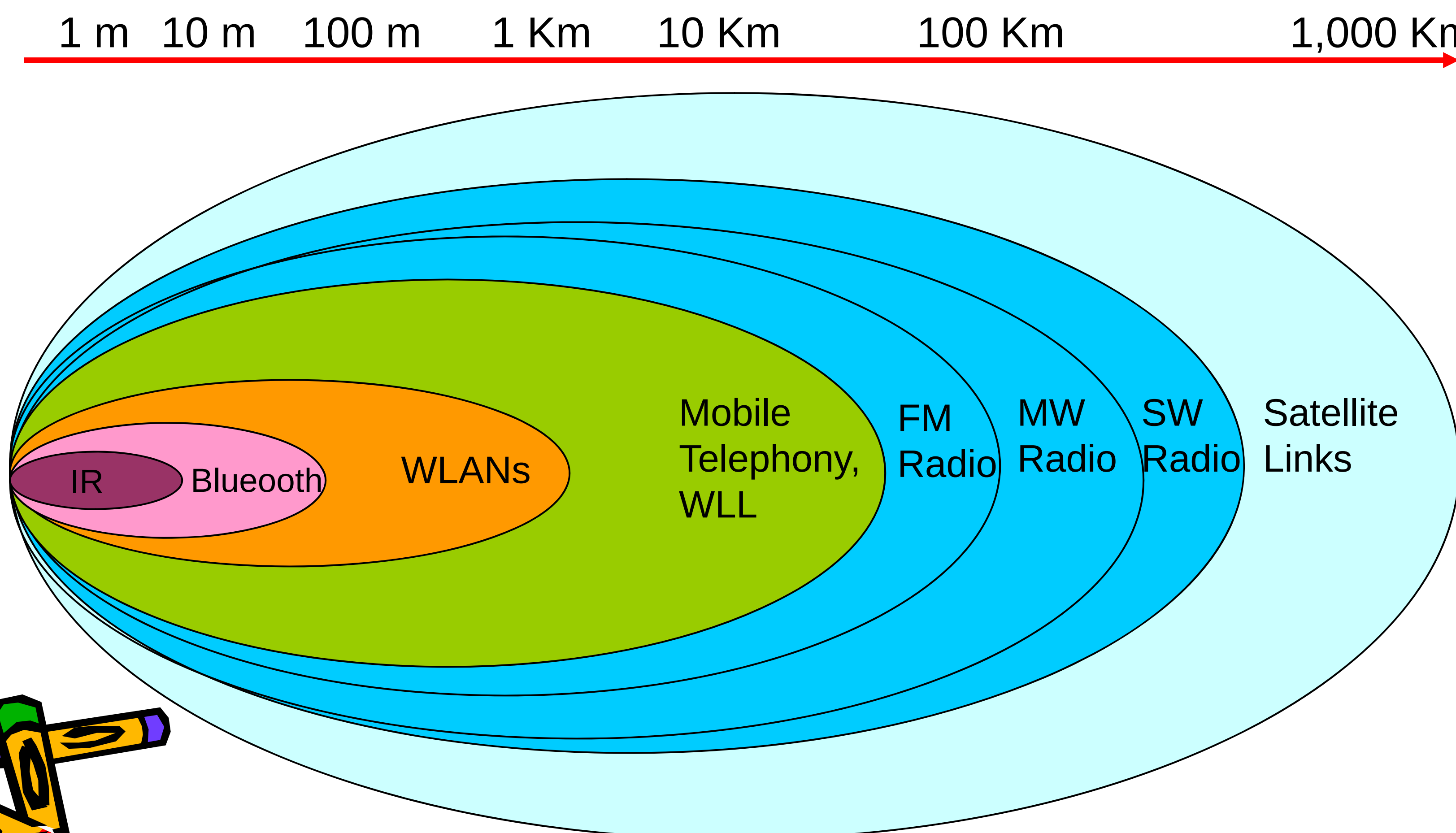
- Audience
  - prepare by reading classic papers
  - submit short summary before class
- Presenters
  - select a special topic (**today**)
  - browse recent literature
  - propose paper for presentation (**-1 week**)
  - prepare Powerpoint slides (**-2 days**)
  - present paper + lead discussion
  - write report (**+2 weeks**)

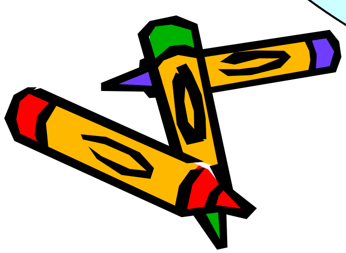


Wireless Communication

crash course

Wireless technologies

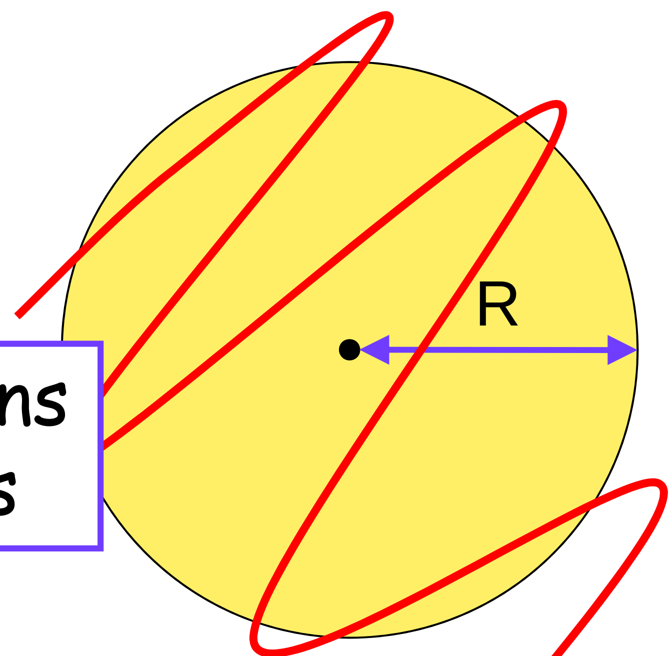




Wireless communication

- Error prone, unpredictable medium
- Impact on protocol stack
  - medium access control
  - localization
  - routing

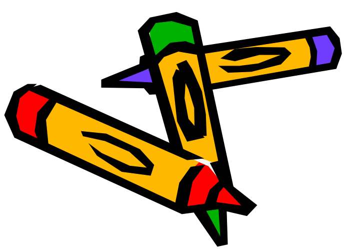
Unrealistic assumptions in many WSN papers



Unit Disk Graph model

Bottom-up approach

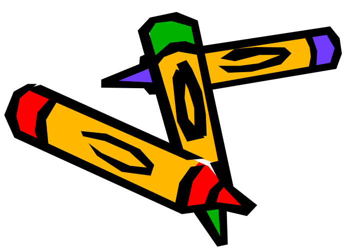
- Wireless channel
  - RF propagation
  - noise & interference
- Physical layer
  - modulation
  - coding

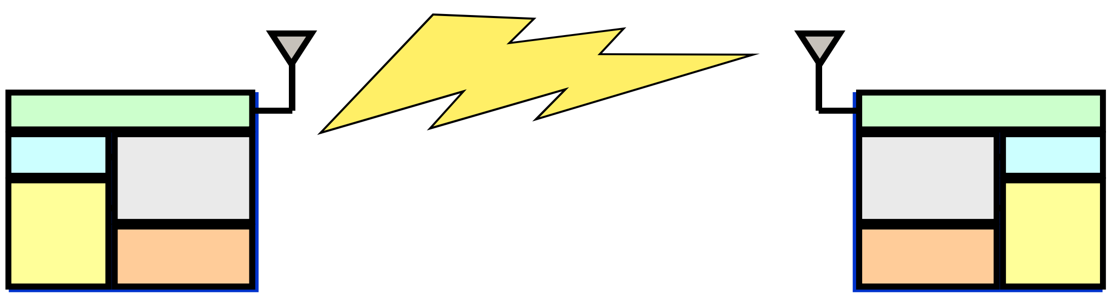


Wireless = Waves

- Electromagnetic radiation
- Sinusoidal wave with a frequency/wavelength
- Emitted by sinusoidal current running through a wire (transmitting antenna)
- Induces current in receiving antenna

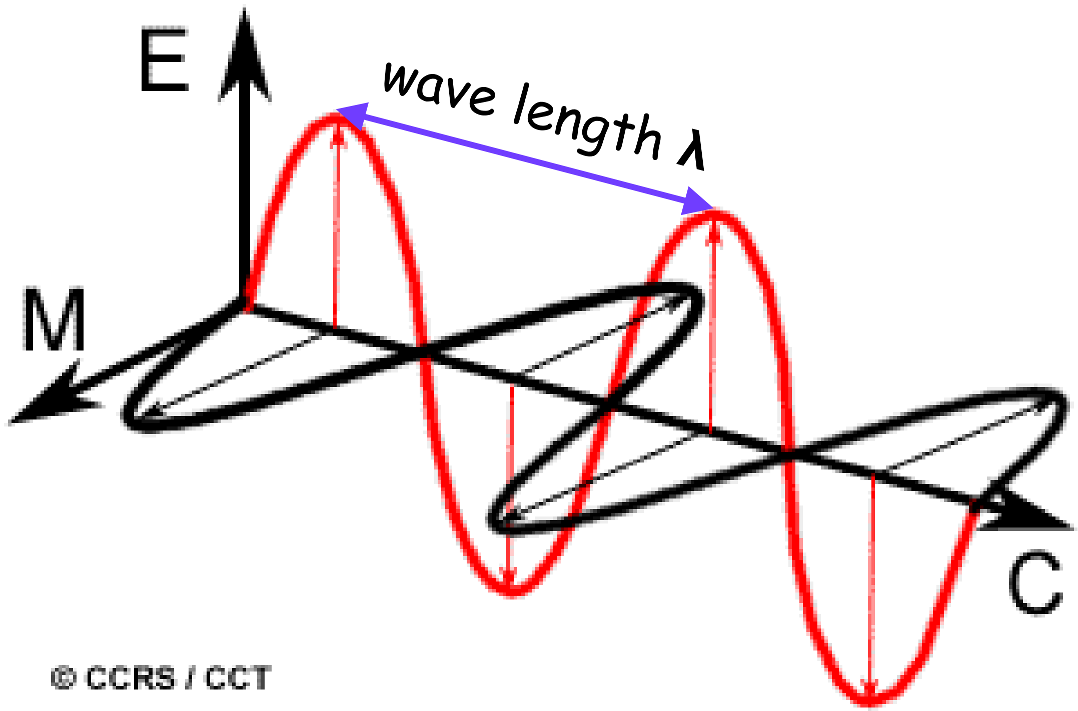
$$f = \frac{c}{\lambda}$$





Electromagnetic waves

- Propagation in vacuum

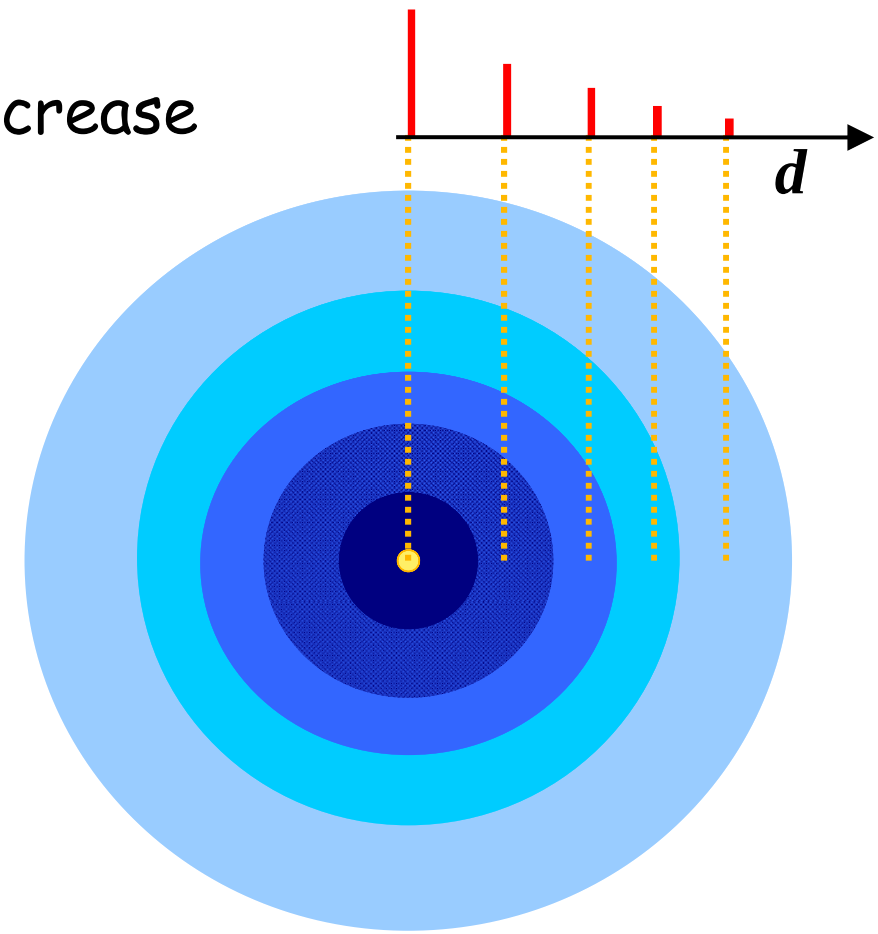


Electromagnetic waves

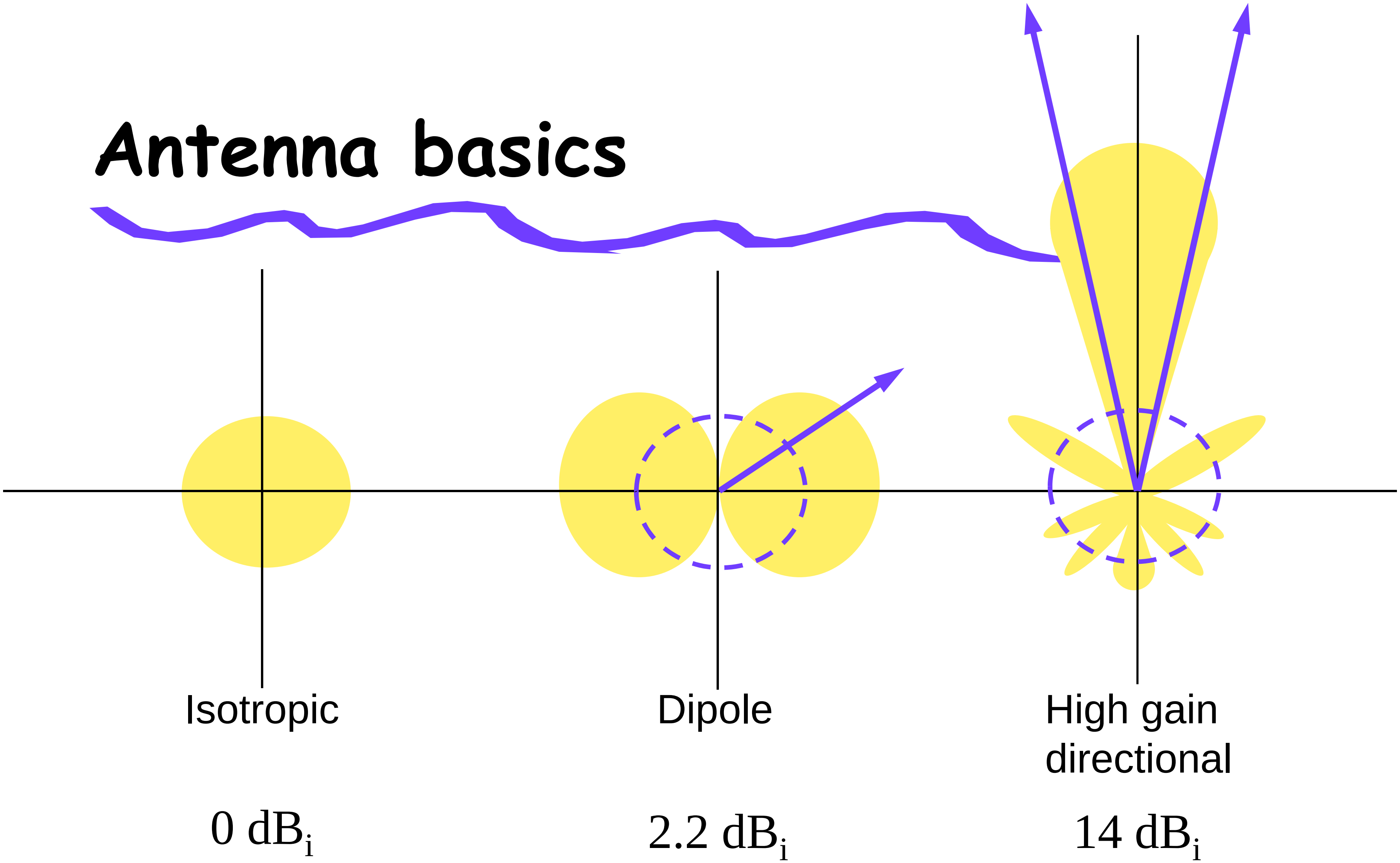
- Free-space loss
  - due to surface area increase

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d} \right)^2$$

Also known as Friis free space formula



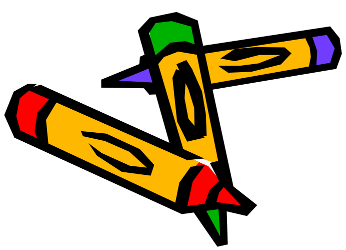
Antenna basics



Antenna gain: $G = \dfrac{P_{directional}}{P_{isotropic}}$

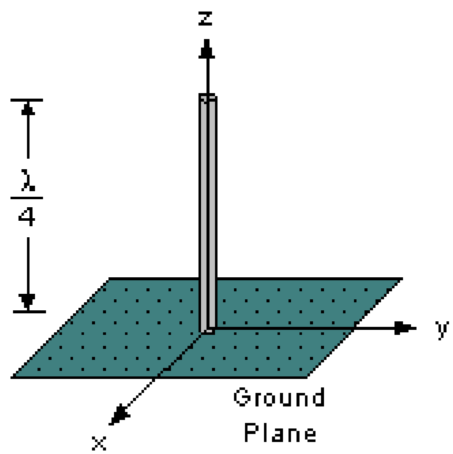
dB and friends

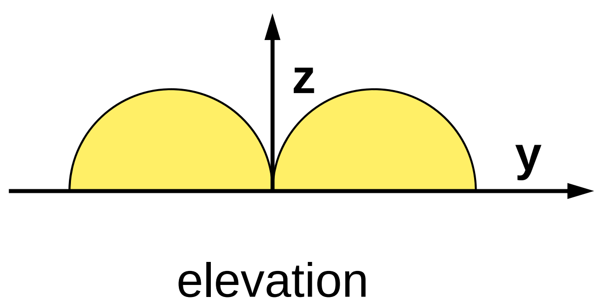
- dB (Decibel)
  - Denote the **difference** between two power levels
  - (P2/P1)[dB] = 10 * $\log_{10}$ (P2/P1)
- dBm (dB milliWatt)
  - Denote the power level relative to 1 mW
  - P[dBm] = 10 * $\log_{10}$ (P/1mW)
- dBi (dB isotropic)
  - Denote the **gain** a given antenna has, as compared to a theoretical isotropic (point source) antenna

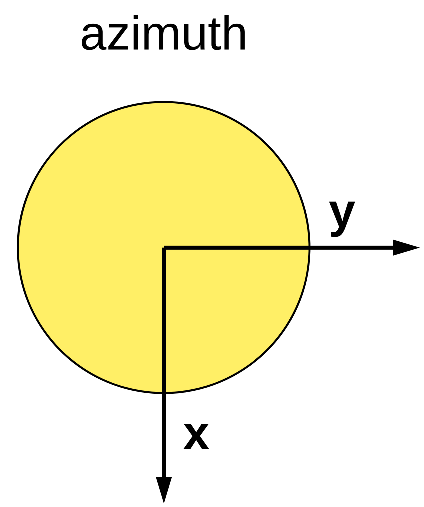


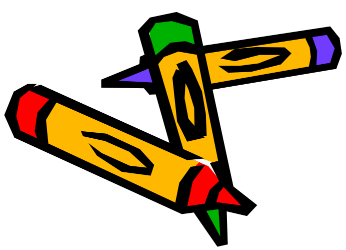
Antenna radiation in theory

Vertical Whip Antenna, 1/4 Wave



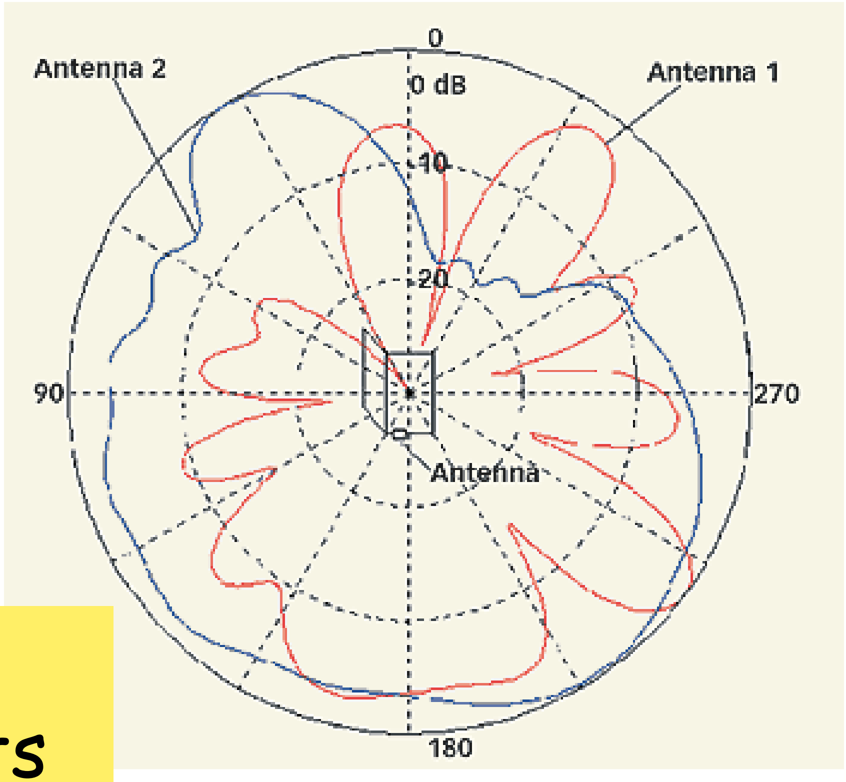






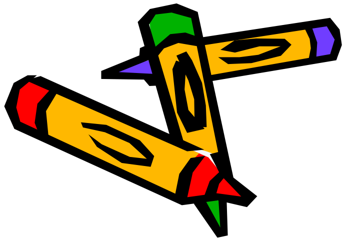
[http://www.rfcafe.com/references/electrical/antenna_patterns.htm]

Antenna radiation in practice



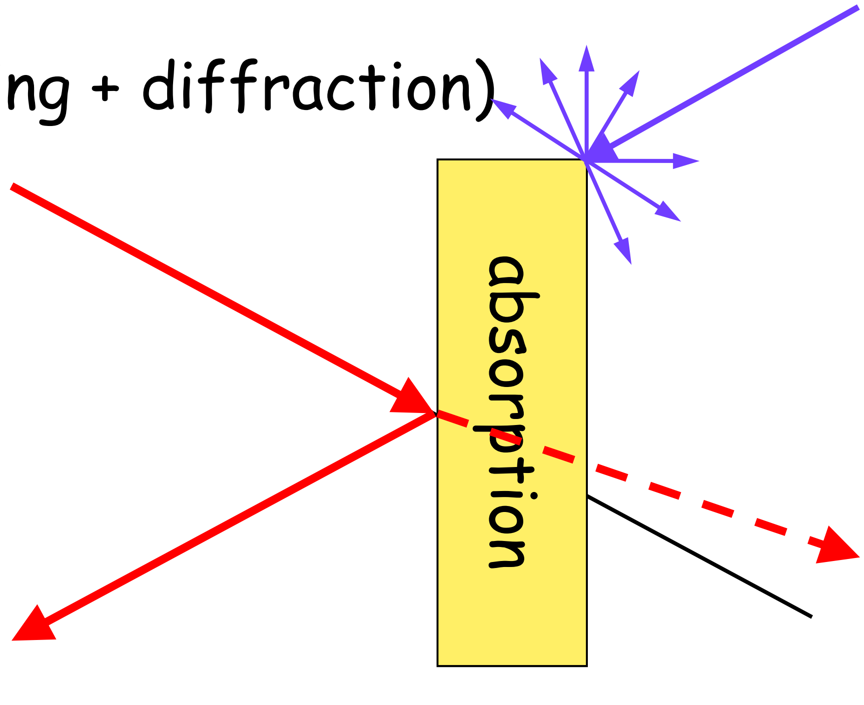
Distortion:
- metal objects
- electronics
- polarization

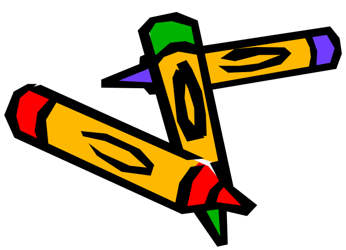
[http://www.mwrf.com/]



Wireless Transmission Impairments

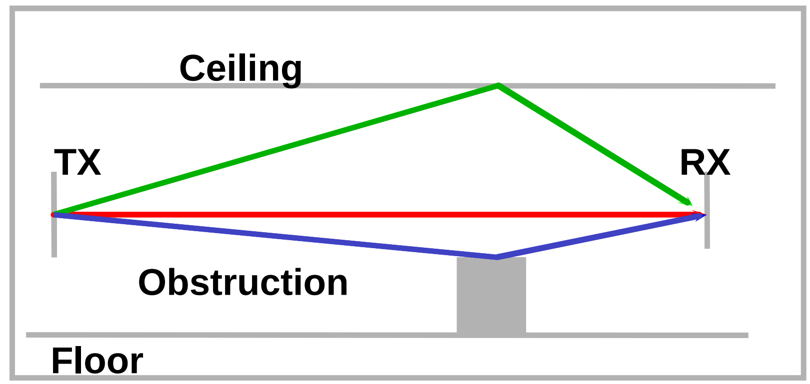
- Attenuation (free space loss, directionality)
- Noise (thermal + impulse)
- Objects
  - **reflection** (+ scattering + diffraction)
  - absorption
  - refraction

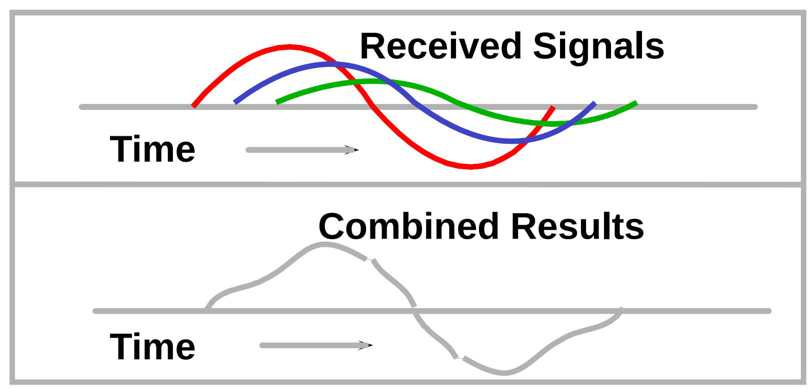


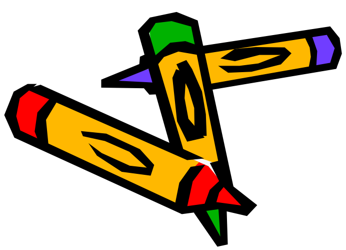


Reflections ⇒ multipath distortion

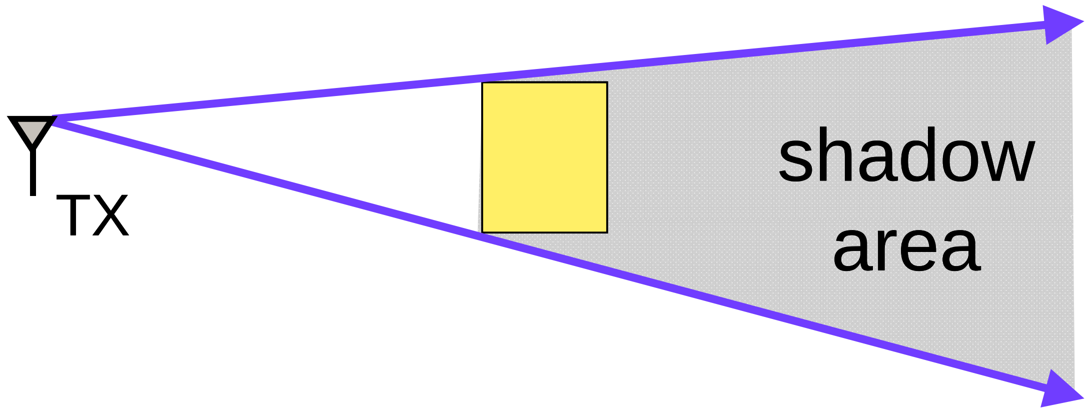
- Propagation along multiple paths leads to self interference
- Unlike attenuation and noise, multipath cannot be handled by increasing the send power ☹



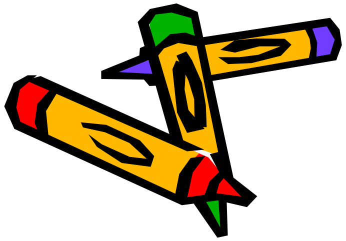




Reflections ⇒ shadowing



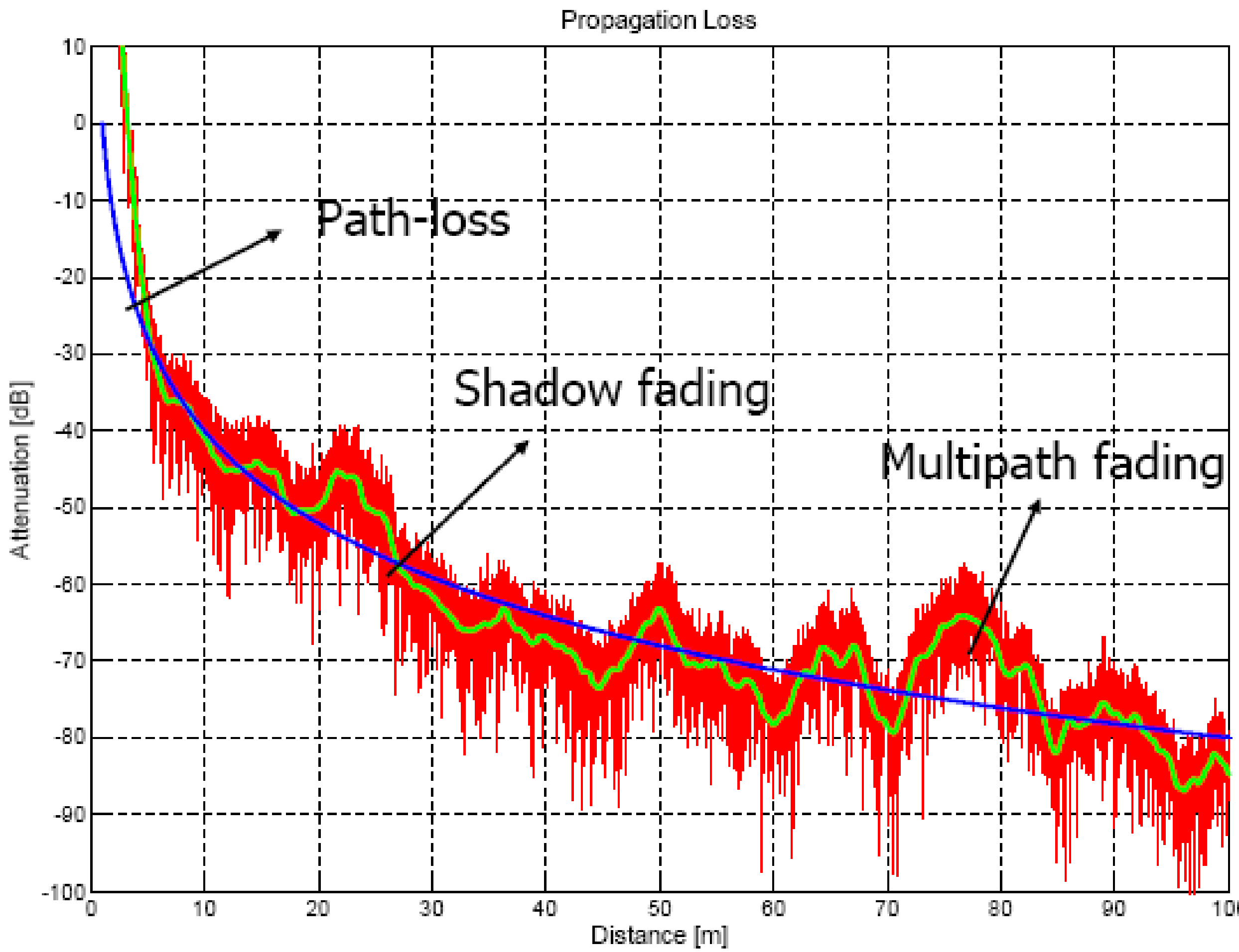
- A large object shields the area behind it
- As for multipath, shadowing cannot be handled by increasing the send power

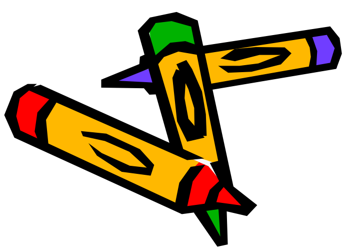


Propagation loss

Attenuation =
  path loss
  + shadowing
  + multipath

Fading depends
- location
- frequency
- time



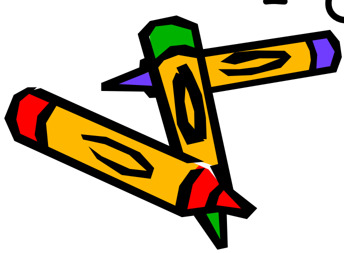


[G. Janssen, ET4358]

Path-loss Exponents

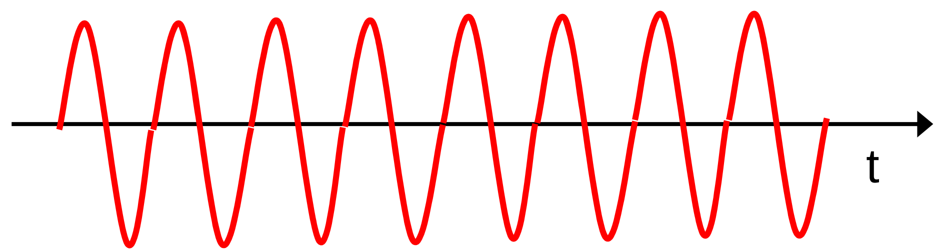
$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d} \right)^2$$

- Depends on environment:
  - Free space 2
  - Urban area cellular 2.7 to 3.5
  - Shadowed urban cell 3 to 5
  - In building LOS 1.6 to 1.8
  - Obstructed in building 4 to 6
  - Obstructed in factories 2 to 3

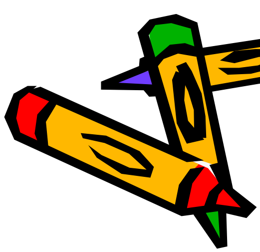


Physical layer

- Encoding information as waves
  - modification of a **carrier** signal
  - high frequency: low loss, small antennas

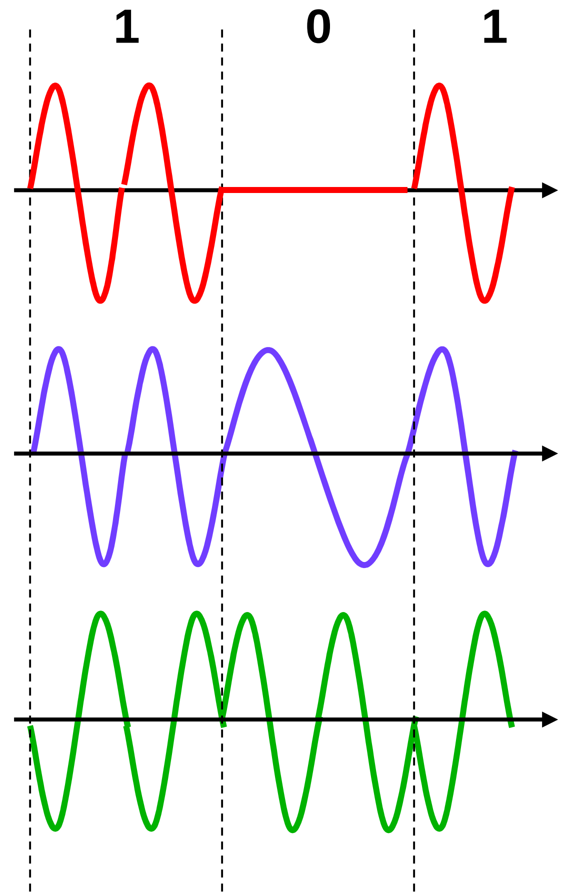


- Modulation
  - digital to analog conversion (and back)
  - options: amplitude, frequency, phase

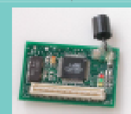
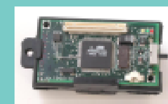
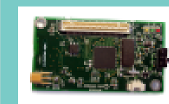


Digital modulation

- Amplitude Shift Keying (ASK):
  - very simple
  - low bandwidth requirements
  - very susceptible to interference
- Frequency Shift Keying (FSK):
  - needs larger bandwidth
- Phase Shift Keying (PSK):
  - more complex
  - robust against interference



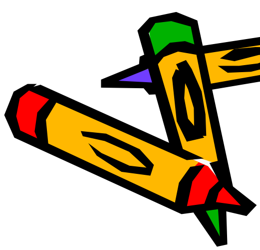
Mote Evolution

Mote Type Year	*WeC* 1998	*René* 1999	*René 2* 2000	*Dot* 2000	*Mica* 2001	*Mica2Dot* 2002	*Mica 2* 2002	*Telos* 2004
								
Microcontroller								
Type	AT90LS8535		ATmega163		ATmega128			TI MSP430
Program memory (KB)	8		16		128			60
RAM (KB)	0.5		1		4			2
Active Power (mW)	15		15		8		33	3
Sleep Power (μW)	45		45		75		75	6
Wakeup Time (μs)	1000		36		180		180	6
Nonvolatile storage								
Chip	24LC256				AT45DB041B			ST M24M01S
Connection type	I^2C				SPI			I^2C
Size (KB)	32				512			128
Communication								
Radio	TR1000				TR1000	CC1000		CC2420
Data rate (kbps)	10				40	38.4		250
Modulation type	OOK				ASK	FSK		O-QPSK
Receive Power (mW)	9				12	29		38
Transmit Power at 0dBm (mW)	36				36	42		35
Power Consumption								
Minimum Operation (V)	2.7		2.7		2.7			1.8
Total Active Power (mW)	24				27	44	89	41
Programming and Sensor Interface								
Expansion	none	51-pin	51-pin	none	51-pin	19-pin	51-pin	10-pin
Communication	IEEE 1284 (programming) and RS232 (requires additional hardware)							USB
Integrated Sensors	no	no	no	yes	no	no	no	yes

Physical layer techniques

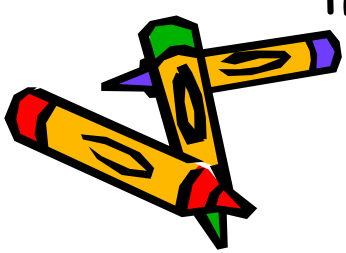
- Handling noise
  - channel coding

- Handling fading
  - location: antenna diversity
  - frequency: hopping, spread spectrum, OFDM, UWB
  - time: (retransmissions; link layer and up)

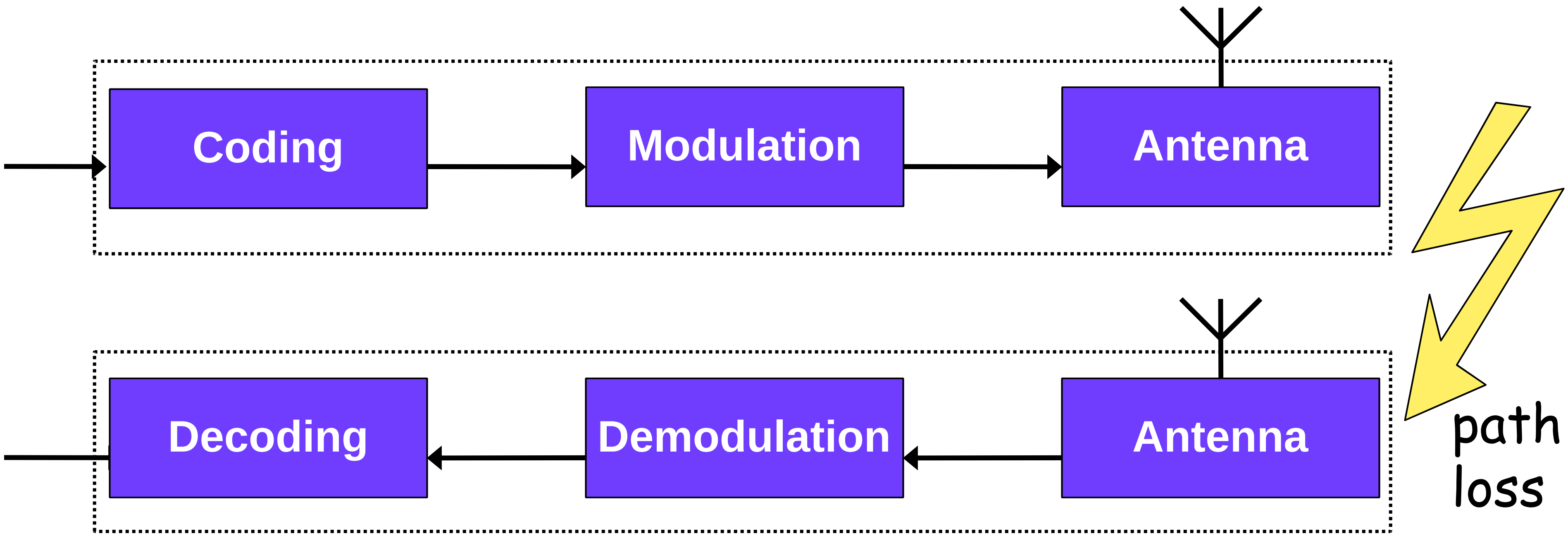


Channel coding

- Forward Error Correction (FEC)
  - add redundant information at sender
  - coding gain vs. overheads (code rate, processing)
- Types
  - block codes (BCH, Reed-Solomon)
  - convolution codes (Viterbi, Turbo)
- Error bursts
  - interleaving (at the expense of latency)

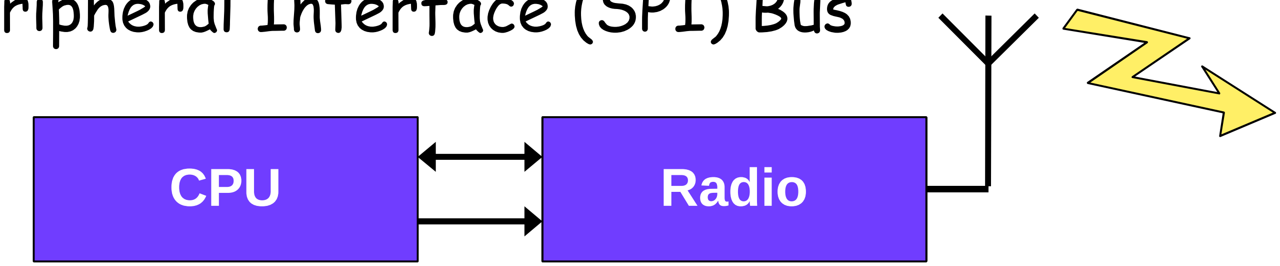


Radio Block Diagram



Radio interface

- Data
  - Serial Peripheral Interface (SPI) Bus



- Control
  - configuration (freq. channel, etc.)
  - TX/RX mode (**half duplex**)
  - power on/off (sleep modes)

Wireless Sensor Networks

- Technology push
  - "Smart Dust: autonomous sensing and communication in a cubic millimeter"
- Novel research area
  - focus on energy efficiency
- Hostile wireless environment
  - channel basics (RF propagation & interference)
  - physical layer (modulation & coding)

Home work

- Check out info on Blackboard

- Register with the CPM submission system
  - send {Name, student nr, NetID} to

    Koen Langendoen <k.g.langendoen@tudelft.nl>

  - try account at

    http://cpm.ewi.tudelft.nl/