Physical Layer I

Lecture #7

Prof. Raj Rajkumar

Outline of Previous Lecture

- Basic Terms and Building Blocks
- Sensor Taxonomy
- Some Sensor Principles and Types
- Some Actuator Types

Administrivia

- Quiz #1 next Wednesday?
- All materials through Monday's lecture

Readings

- Required Reading On Piazza
  - "Physical Layer"
  - Regulatory Considerations: An Easy Read
- Optional Readings
  - "*The* Physical Layer"

Outline of Today's Lecture

- Communication Schemes
  - Propagation Modes
  - Fading
  - Encoding Schemes
  - Spread Spectrum

Communication Schemes

Topics

- OSI Physical Layer
- Frequency
- Propagation Modes
- Encoding Techniques
- Spread Spectrum

- References

[1] W. Stallings, *Wireless Communications & Networks* , 2nd Ed, Prentice Hall, 2005

[2] Holger Karl, Andreas Willig, *Protocols and Architectures for Wireless Sensor Network*, Wiley, 2005

[3] Simon Haykin, *Communications Systems*, 4ed ,Wiley 2000

OSI Physical Layer

- Concerned with the transmission of unstructured bit streams over the physical medium
- Deals with accessing the physical medium
  - Mechanical characteristics
  - Electrical characteristics
  - Functional characteristics
  - Procedural characteristics

Is the WSN Physical Layer compatible with the OSI Physical Layer?

Frequency

3kHz	30kHz	300kHz	3MHz	30MHz	300MHz	3GHz	30GHz	300GHz
VLF	LF	MF	HF	VHF	UHF	SHF	EHF	
100 km	10 km	1 km	100 m	10 m	1 m	10 cm	1 cm	1 mm

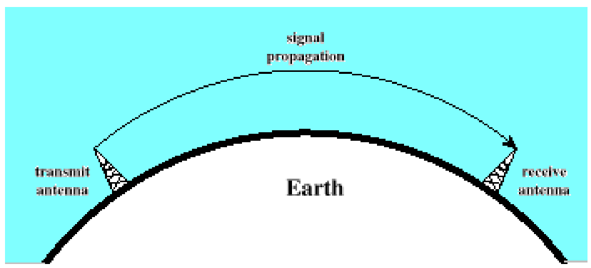
Frequency	Allowed ISM Bands
13.553 - 13.567 MHz	
26.957 – 27.283 MHz	
40.66 – 40.70 MHz	
433 – 464 MHz	Europe
902 -928 MHz	Americas
2.4 – 2.5 GHz	Used by WLAN/WPAN technologies
5.725 – 5.875 GHz	Used by WLAN
24 – 24.25 GHz	

Propagation Modes

- Ground-wave propagation
- Sky-wave propagation
- Line-of-sight propagation

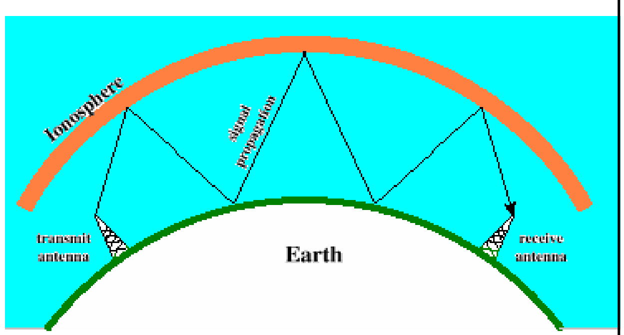
Ground Wave Propagation

- Follows the contour of the earth
- Can propagate considerable distances
- Frequencies up to 2 MHz
- Example
  - AM radio



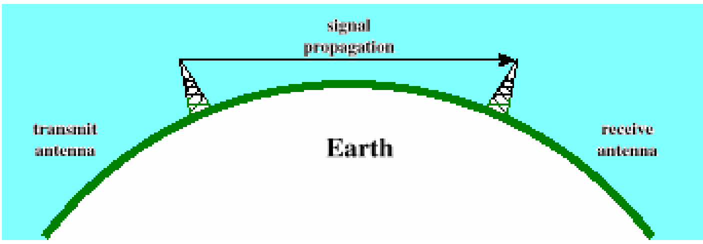
Sky Wave Propagation

- Signal reflected from the ionized layer of atmosphere back down to earth
- Signal can travel a number of hops, back and forth between ionosphere and earth's surface
- Reflection effect caused by refraction
- Examples
  - Amateur radio
  - CB radio



Line-of-Sight Propagation

- Transmitting and receiving antennas must be within line of sight
  - Satellite communication – signal above 30 MHz *not* reflected by ionosphere
  - Ground communication – antennas within *effective* line of sight due to refraction
- Refraction – bending of microwaves by the atmosphere
  - Velocity of electromagnetic wave is a function of the density of the medium
  - When wave changes medium, speed changes
  - Wave bends at the boundary between two media



Line-of-Sight Impairments

- Impairments
  - Attenuation
  - Free space loss
  - Noise
  - Atmospheric absorption
  - Fading
    - Large-scale fading: Multi-path
    - Small-scale fading
  - Refraction

Free Space Loss

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2}$$

where,

- P_t = signal power at transmitting antenna
- P_r = signal power at receiving antenna
- λ = carrier wavelength
- d = propagation distance between antennas

Thus, as the wavelength goes up, the signal loss is reduced and as the distance goes up, the signal loss is increased.

Noise Sources

- Thermal Noise
  - Noise seen in switching circuits due to electrons
  - Function of temperature

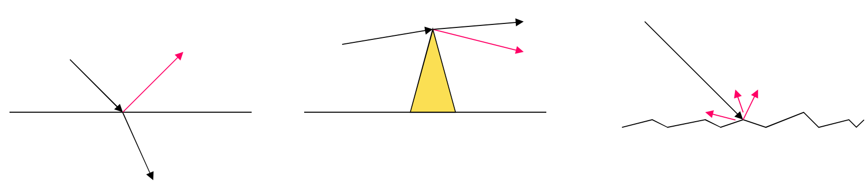
$$N = kTB$$

  - N: Noise, k: Boltzmann constant, T: Temperature, B: Bandwidth
- Inter-modulation noise
  - Noise caused by signals at different frequencies on the same medium
- Crosstalk
  - Coupling between signal paths
- Impulse Noise
  - Power spike (e.g. from thunder)

Large-Scale Fading: Multi-path (1 of 4)

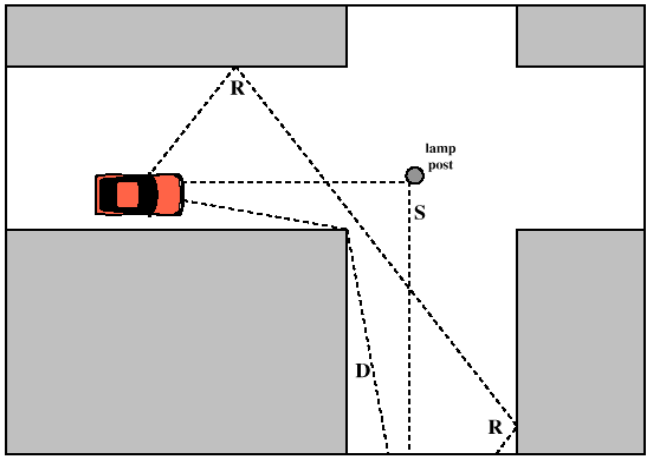
- **Multi-path**: obstacles reflect signals so that multiple copies with varying delays are received
  - Reflection – occurs when signal encounters a surface that is large relative to the wavelength of the signal
  - Diffraction – occurs at the edge of an impenetrable body that is large compared to the wavelength of radio wave
  - Scattering – occurs when incoming signal hits an object whose size in the order of the wavelength of the signal or less

Large-Scale Fading: Multi-path (2 of 4)



Reflection (R) Diffraction (D) Scattering (S)

Large-Scale Fading: Multi-path (3 of 4)



Andersen, JB, T.S. Rappaport and S. Yeshiva, “Propagation Measurements and Models for Wireless Communications Channels”, *IEEE Communications Magazine*, 1995, pp. 42-49.

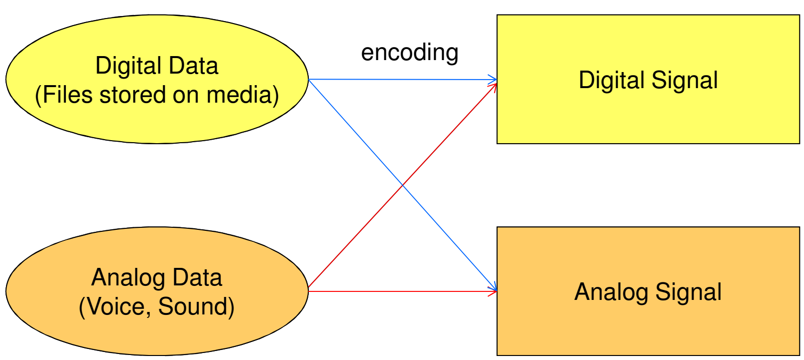
Large-Scale Fading: Multi-path (4 of 4)

- Effects of Multi-path
  - Multiple copies of a signal may arrive at different phases
    - If phases add destructively, the signal level relative to noise declines, making signal detection more difficult
  - Inter-symbol interference (ISI)
    - One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit

Small-Scale Fading

- Distortion of Signal
  – Time-spreading of the underlying digital pulses in signal
- Motion
  – Time-variant behavior of the channel due to motion

Encoding Techniques (1 of 2)



Why?

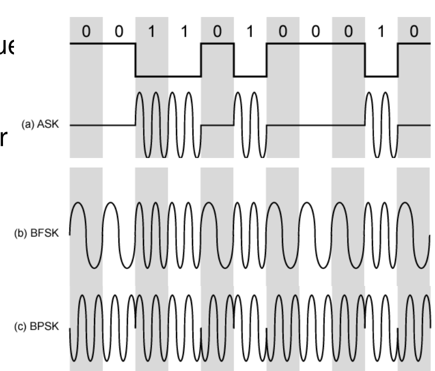
Need to change types of signaling according to channel bandwidth.

Encoding Techniques (2 of 2)

- Digital data → digital signal
  - e.g. Moving logic (digital data) between ICs on LVTTL level (digital signal)
- Analog data → digital signal
  - e.g. Voice (analog data) converted by ADC to TTL level (digital signal)
- Digital data → analog signal
  - e.g. ASCII files (digital data) on LAN cables (analog signal)
- Analog data → analog signal
  - e.g. Music (analog data) over AM Radio (analog signal)

Digital Data to Analog Signal (1 of 2)

- ASK: Amplitude Shift Key
  - Amplitude difference of carrier freque
- FSK: Frequency Shift Key
  - Frequency difference around carrier
- PSK: Phase Shift Key
  - Phase change on carrier frequency



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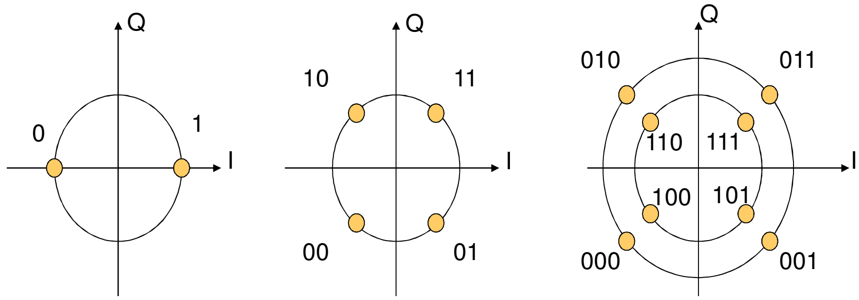
Digital Data to Analog Signal (2 of 2)

- QPSK: Quadrature PSK
- QAM: ASK + PSK

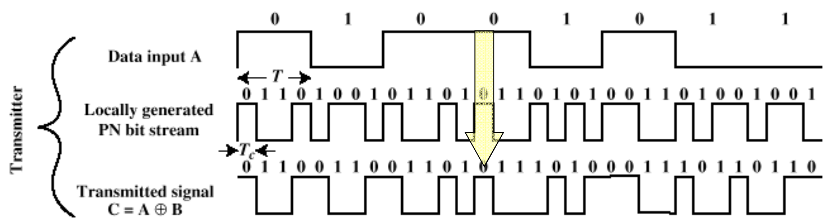


(a) BPSK (b) QPSK (c) QAM

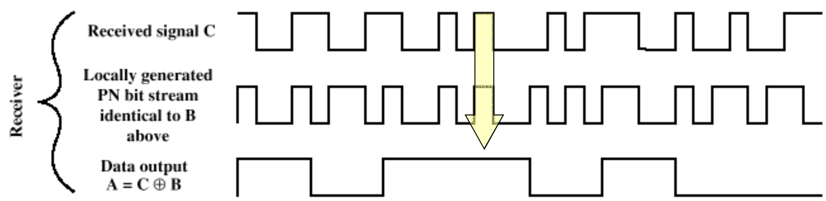
Spread Spectrum

- Concept
  - Effect of increasing bandwidth of signal to be transmitted by modulating the signal with a sequence of digits
    - Spreading code or spreading sequence
    - Generated by pseudo-noise, or pseudo-random number generator
- Benefits
  - Immunity from various kinds of noise and multi-path distortion
  - Used for hiding and encrypting signals
  - Several users can independently use the same higher bandwidth with very little interference
- Types
  - Direct Sequence Spread Spectrum (DSSS)
  - Frequency Hopping Spread Spectrum (FHSS)

DSSS

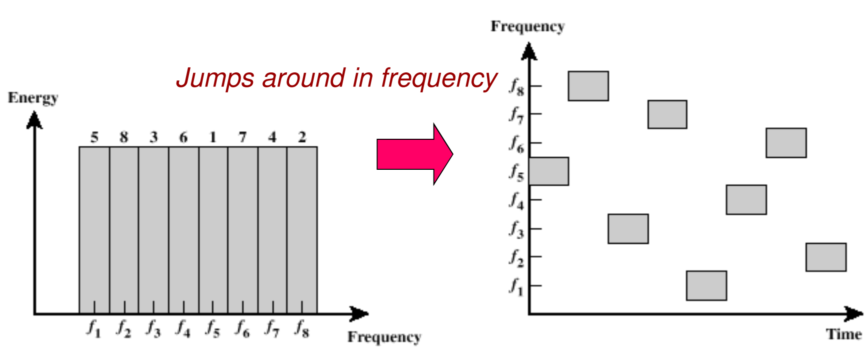


Required bandwidth jumps up with modulation



Original signal recovered with demodulation

FHSS



(a) Channel assignment (b) Channel use

Physical Layer for Wireless Communications

Topics

- Physical Layers for various Wireless Applications
- Examples of Wireless Sensor Networks
  - PicoRadio
  - WINS
  - µAMPS
- Constraints on Wireless Sensor Networks
  - Cost
  - Power

References

[1] Thomas H. Lee, *The Design of CMOS Radio-Frequency Integrated Circuits*, Cambridge, 2004

[2] Holger Karl, Andreas Willig, *Protocols and Architectures for Wireless Sensor Network*, Wiley, 2005

[3] Edgar H. Callaway, *Wireless Sensor Networks: Architectures and Protocols*, Auerbach, 2003

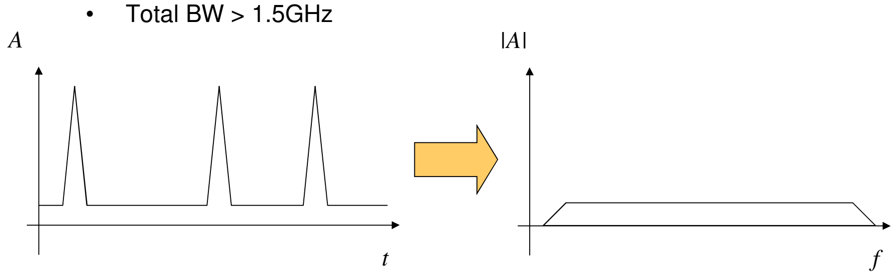
Physical Layer for Various Wireless Applications (1 of 3)

Parameter	CDMA 1900MHz	802.11.b	802.11.a	Bluetooth	IEEE 802.15.4	
Frequency range	1850-1990 MHz	2400-2483.5 MHz	5150-5350MHz 5725-5825MHz	2402-2480 MHz	2402-2480 MHz	902-928 MHz
Channel spacing	1250kHz	FHSS: 1MHz DSSS: 25MHz	OFDM: 20MHz	1MHz	5MHz	5MHz
Number of channels	48	3 non-overlapping	12 non-overlapping	79	16	10
Multiple access method	CDMA/FDM	CSMDA/CA	CSMA/CA	Frequency hop	CSMA/CA	CSMA/CS
Duplex method	FDD	TDD	TDD	TDD	FDD	FDD
Modulation	QPSK/OQPSK	FHSS:GFSK	OFDM:64 QAM	GFSK	OQPSK	OQPSK
Bit or symbol rate	1.2288Mb/s	1,2, or 11Mbps	5.5-54Mb/s	1MS/s	250kb/s	250kb/s
Applications	Mobile phones	WiFi	WiFi	Power on wireless	Home automation	

From Thomas H. Lee, *The Design of CMOS Radio-Frequency Integrated Circuits*, Cambridge, 2004

Physical Layer for Various Wireless Applications (2 of 3)

- Ultra-Wideband (UWB)
  - How: *Use impulse-like spark transmissions.*
    - Small spike in time domain → Large spectrum in frequency domain
  - Common Definition
    - If transmitted signal's fractional bandwidth > 25%
    - Total BW > 1.5GHz

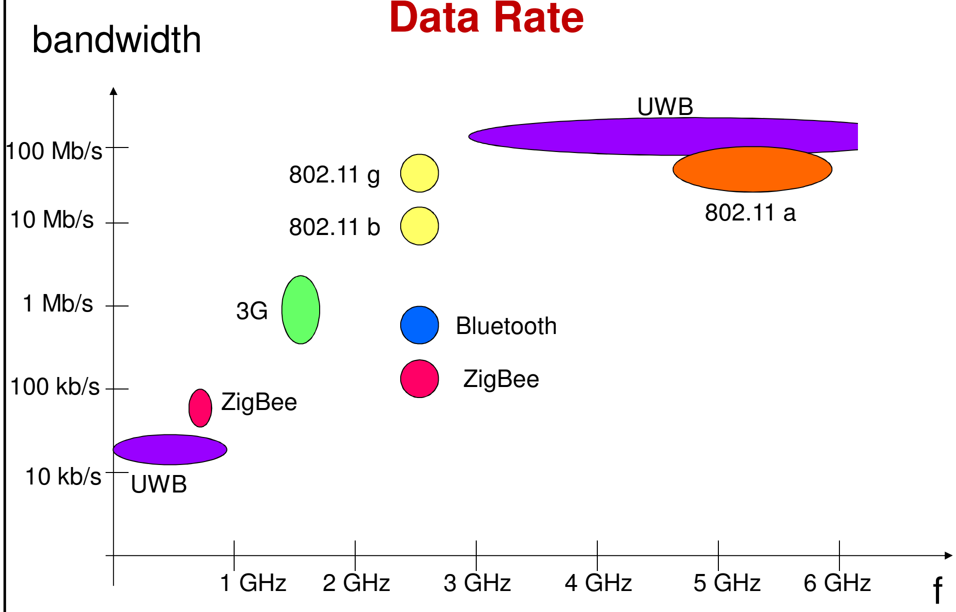


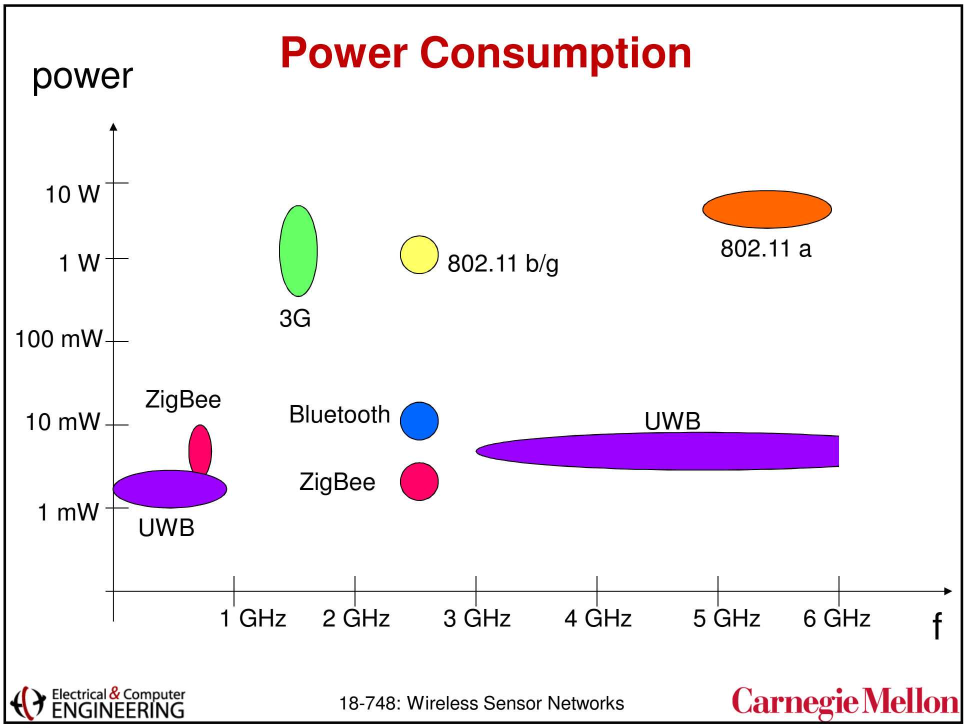
Fractional bandwidth = the bandwidth of a device divided by its center frequency.
- a device that has a bandwidth of 1 MHz with center frequency 10 MHz has a fractional bandwidth of 1/10, or 10%.

Physical Layer for Various Wireless Applications (3 of 3)

- UWB Advantages
  - Low power consumption
  - Low cost: Nearly "all digital" with minimal RF electronics
  - A low probability of signature detection (noise-like)
- UWB Applications
  - Wireless USB
  - …

Data Rate




Power Consumption
power
10 W
1 W
100 mW
10 mW
1 mW
3G
802.11 b/g
802.11 a
ZigBee
Bluetooth
ZigBee
UWB
UWB
1 GHz
2 GHz
3 GHz
4 GHz
5 GHz
6 GHz
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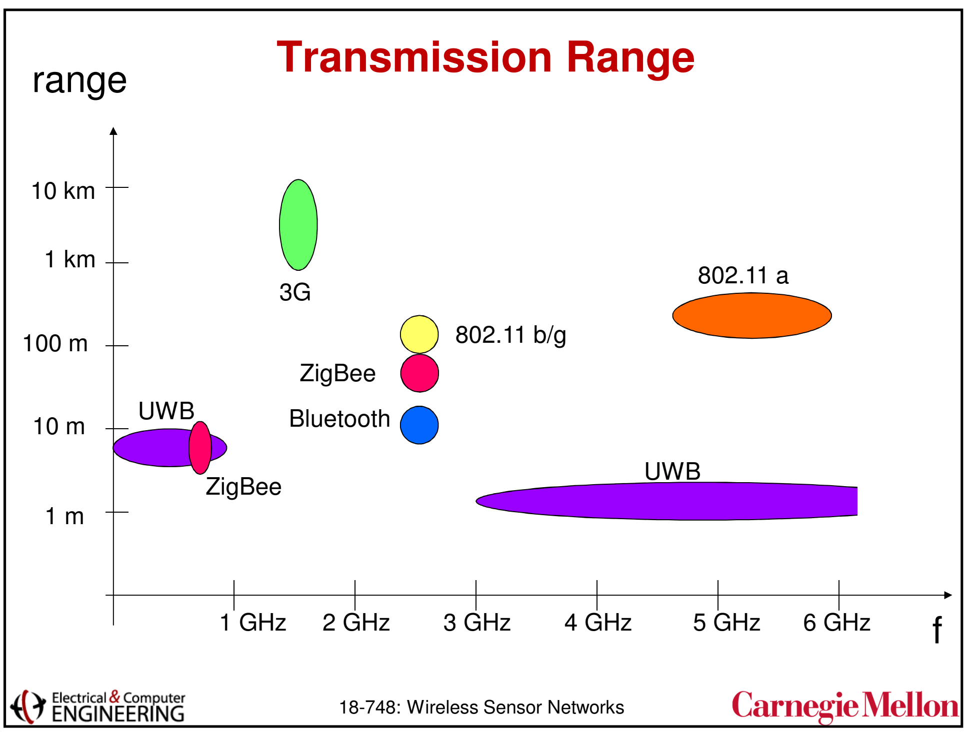
Transmission Range
range
10 km
1 km
100 m
10 m
1 m
3G
802.11 a
802.11 b/g
ZigBee
Bluetooth
UWB
ZigBee
UWB
1 GHz
2 GHz
3 GHz
4 GHz
5 GHz
6 GHz
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Examples of Wireless Sensor Networks

Name	From	Focus
PicoRadio	UC Berkeley	**Power**: Wakeup radios **Cost**: Use easier integration at the cost of bandwidth http://bwrc.eecs.berkeley.edu/research/Pico_Radio/Publications.htm
WINS	UCLA	**Cost**: Low-cost fabrication with CMOS circuit technology **Power**: Low power http://www.janet.ucla.edu/WINS/
µAMPS	MIT	**Power**: Multi-level signaling to minimize network time http://mtlweb.mit.edu/researchgroups/icsystems/**uamps**/

Constraints of Physical Layer in WSN

- Cost
  - Digital Circuits or Analog Circuits?
    - Digital circuits get cheaper with technology advance
    - Analog circuits are harder to develop with reducing feature size
    - It turns out more chip area and power is devoted to the analog circuits!

    → All digital-circuit approach is becoming the preferred method

Constraints of Physical Layer in WSN

- Power supply & Power consumption
  - Power supply is hard to increase
    - Battery development cycle
  - Power consumption can be reduced by
    - Pulsating power
      - Charge recovery by small amounts of power consumption.
    - Choosing the right communication frequency
    - Choosing the distance between WSN Nodes
    - Choosing the Modulation/Demodulation method

Modulation/Demodulation

- For high data rates at low symbol rates
  - *m*-ary modulation
    - *m*-ary PSK or *m*-ary FSK
  - Tradeoffs
    - More complex digital and analog circuitry
    - Requires a higher E_b/N_o ratio
    - *m*-ary modulation only efficient when startup time is small

m		2	4	8	16	32	64
m-ary PSK	Bandwidth efficiency	0.5	1.0	1.5	2.0	2.5	3.0
	E_b/N_o	10.5	10.5	14.0	18.5	23.4	28.5
m-ary FSK	Bandwidth efficiency	0.40	0.57	0.55	0.42	0.29	0.18
	E_b/N_o	13.5	10.8	9.3	8.2	7.5	6.9

Bandwidth efficiency is the information rate that can be transmitted over a given bandwidth in a specific communication system (often measured in bits/Hz).

Summary of Today's Lecture

- Communication Schemes
  - Propagation Modes
  - Fading
  - Encoding Schemes
  - Spread Spectrum