Internet of Things

Wireless Transmission Fundamentals (Physical Layer)

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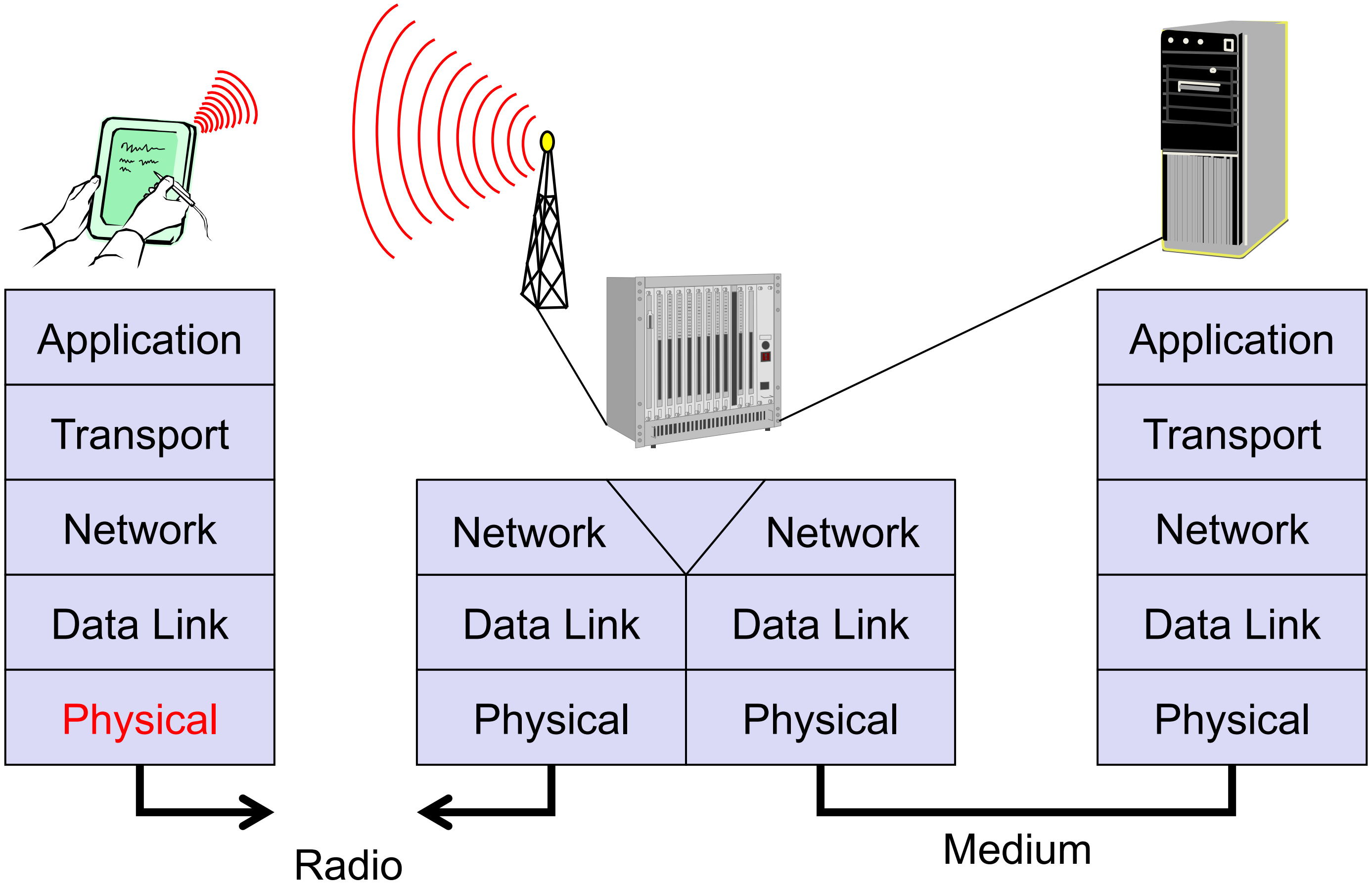
The Layered Reference Model



Application
Transport
Network
Data Link
Physical

Network | Network
Data Link | Data Link
Physical | Physical

Application
Transport
Network
Data Link
Physical

Radio

Medium

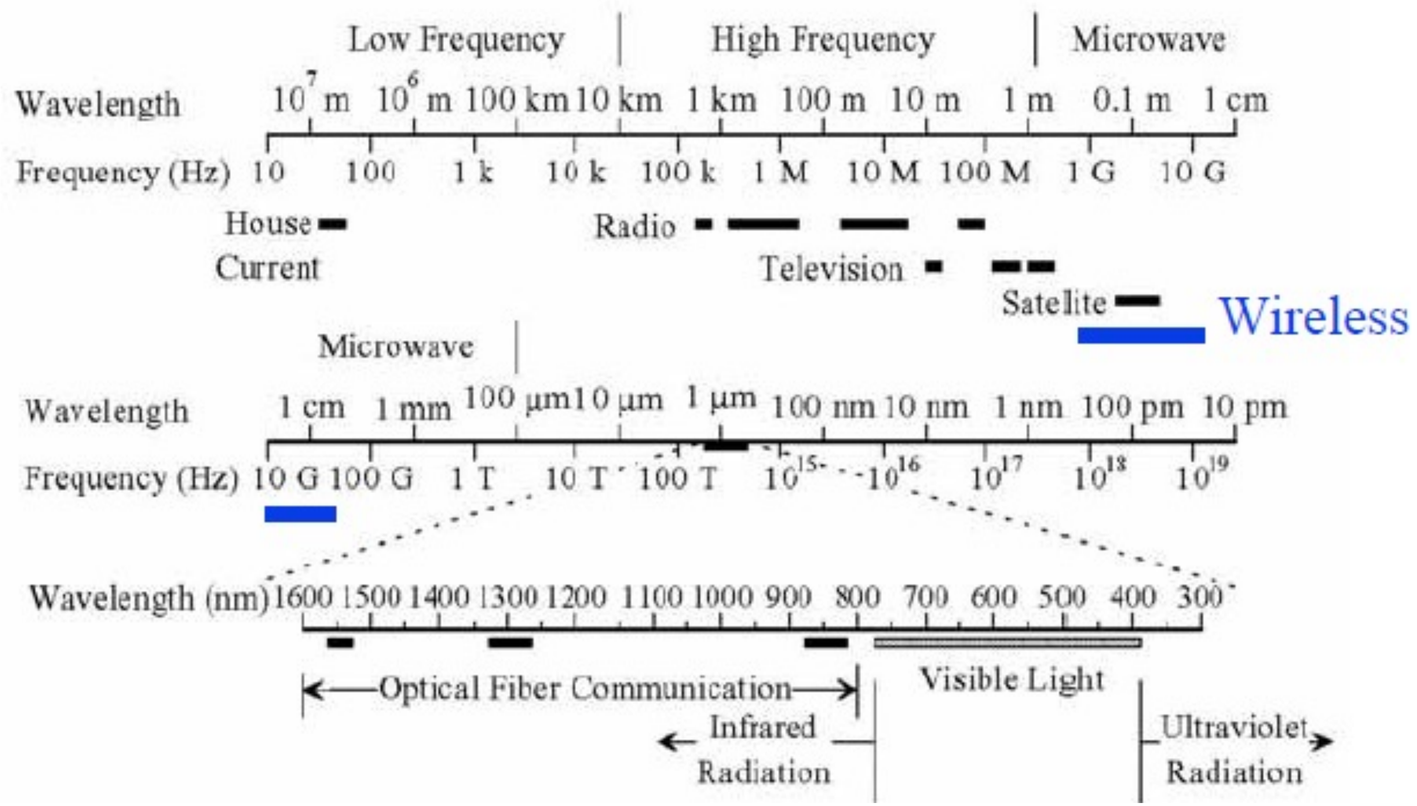
Outline

- RF introduction
- Wireless Terminology
- Antennas and signal propagation
  - How do antennas work
  - Propagation properties of RF signals

- Modulation and channel capacity

Electromagnetic Spectrum

- Wireless communication uses 100 kHz to 60 GHz



Frequencies are Assigned and Regulated

	Europe	USA	Japan
Cellular Phones	**GSM** 450 - 457, 479 - 486/460 - 467,489 - 496, 890 - 915/935 - 960, 1710 - 1785/1805 - 1880 **UMTS** (FDD) 1920 - 1980, 2110 - 2190 **UMTS** (TDD) 1900 - 1920, 2020 - 2025	**AMPS**, **TDMA**, **CDMA** 824 - 849, 869 - 894 **TDMA**, **CDMA**, **GSM** 1850 - 1910, 1930 - 1990	**PDC** 810 - 826, 940 - 956, 1429 - 1465, 1477 - 1513
Cordless Phones	**CT1+** 885 - 887, 930 - 932 **CT2** 864 - 868 **DECT** 1880 - 1900	**PACS** 1850 - 1910, 1930 - 1990 **PACS -UB** 1910 - 1930	**PHS** 1895 - 1918 **JCT** 254 - 380
Wireless LANs	**IEEE 802.11** 2400 - 2483 **HIPERLAN 2** 5150 - 5350, 5470 - 5725	902 - 928 **I EEE 802.11** 2400 - 2483 5150 - 5350, 5725 - 5825	**IEEE 802.11** 2471 - 2497 5150 - 5250
Others	**RF - Control** 27, 128, 418, 433, 868	**RF - Control** 315, 915	**RF - Control** 426, 868

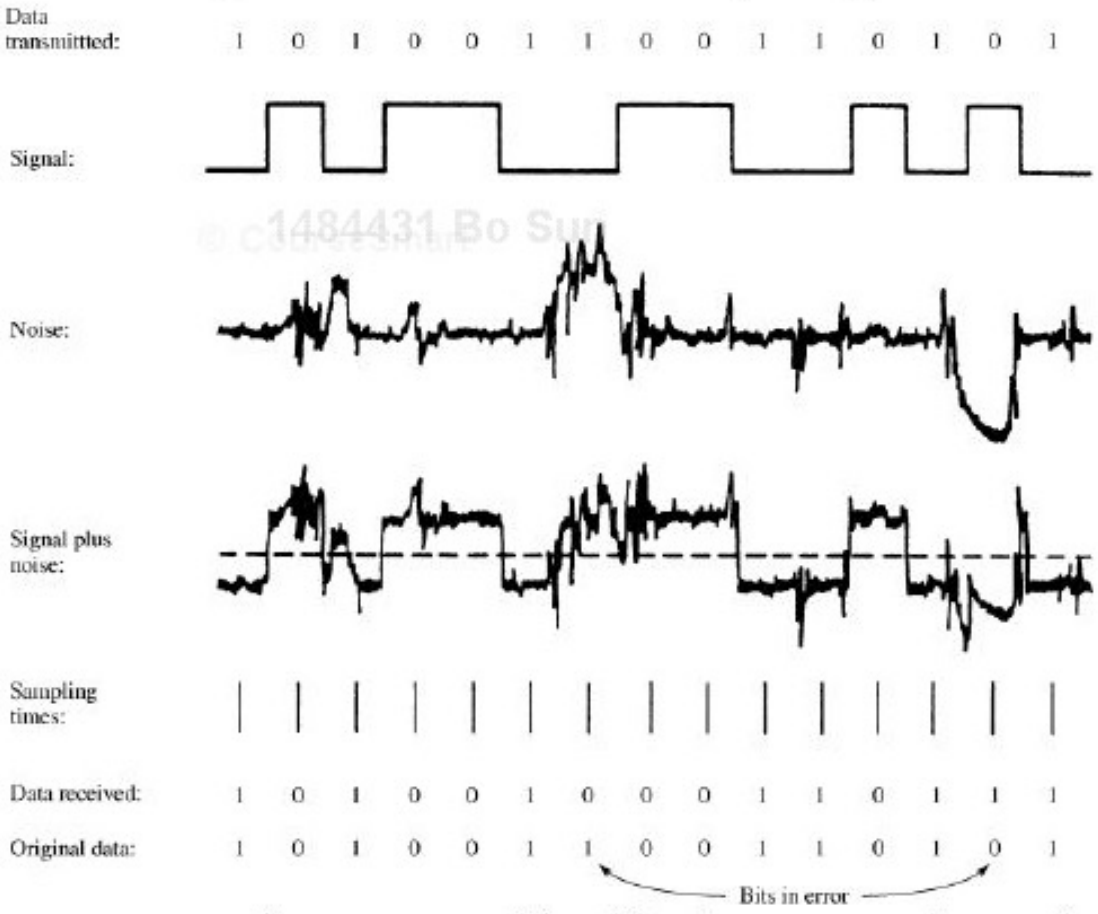
US operator: http://wireless.fcc.gov/uls

Some Basic Concepts

- RSSI
- dbm
- Noise floor: see wikipedia
- CCA thresholding algorithms
- Duty cycle
- LPL

Signal Transmission

Figure 2.9. Effect of Noise on a Digital Signal



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Ref: Fig. 2.9 of "**Wireless Communications and Networks**" by William Stallings

Packet Reception and Transmission

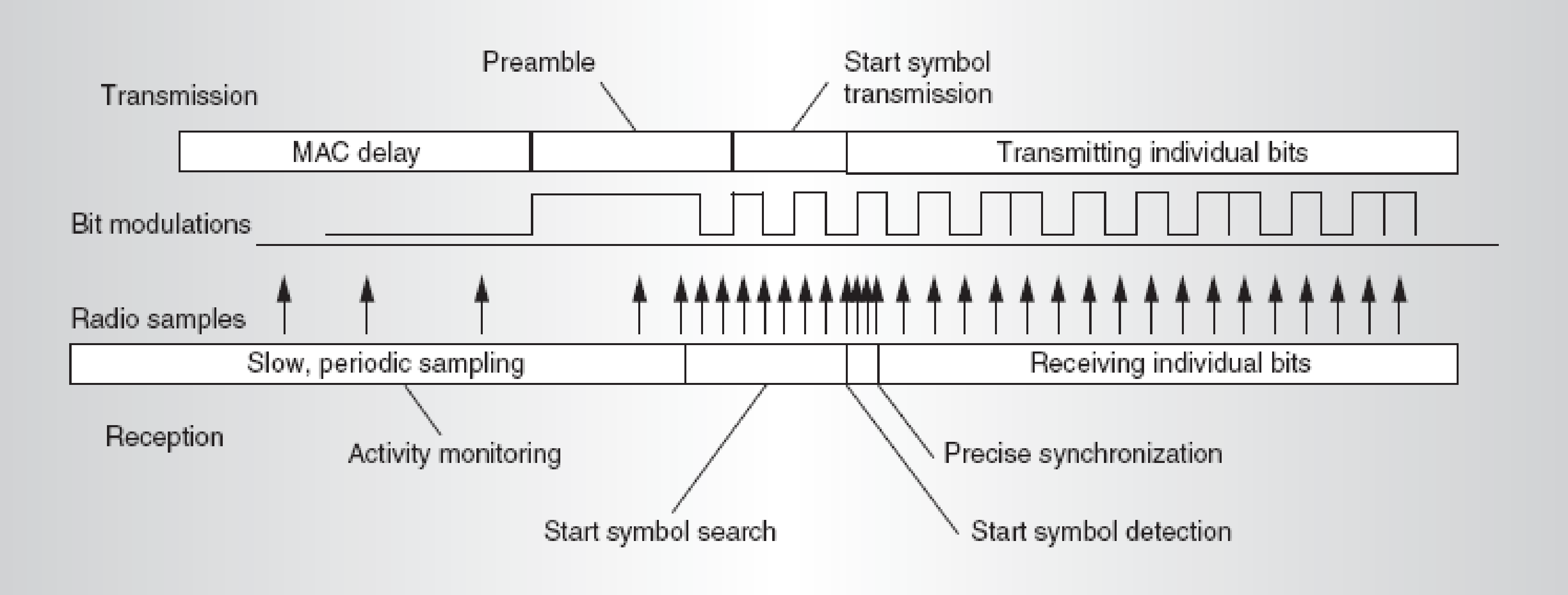
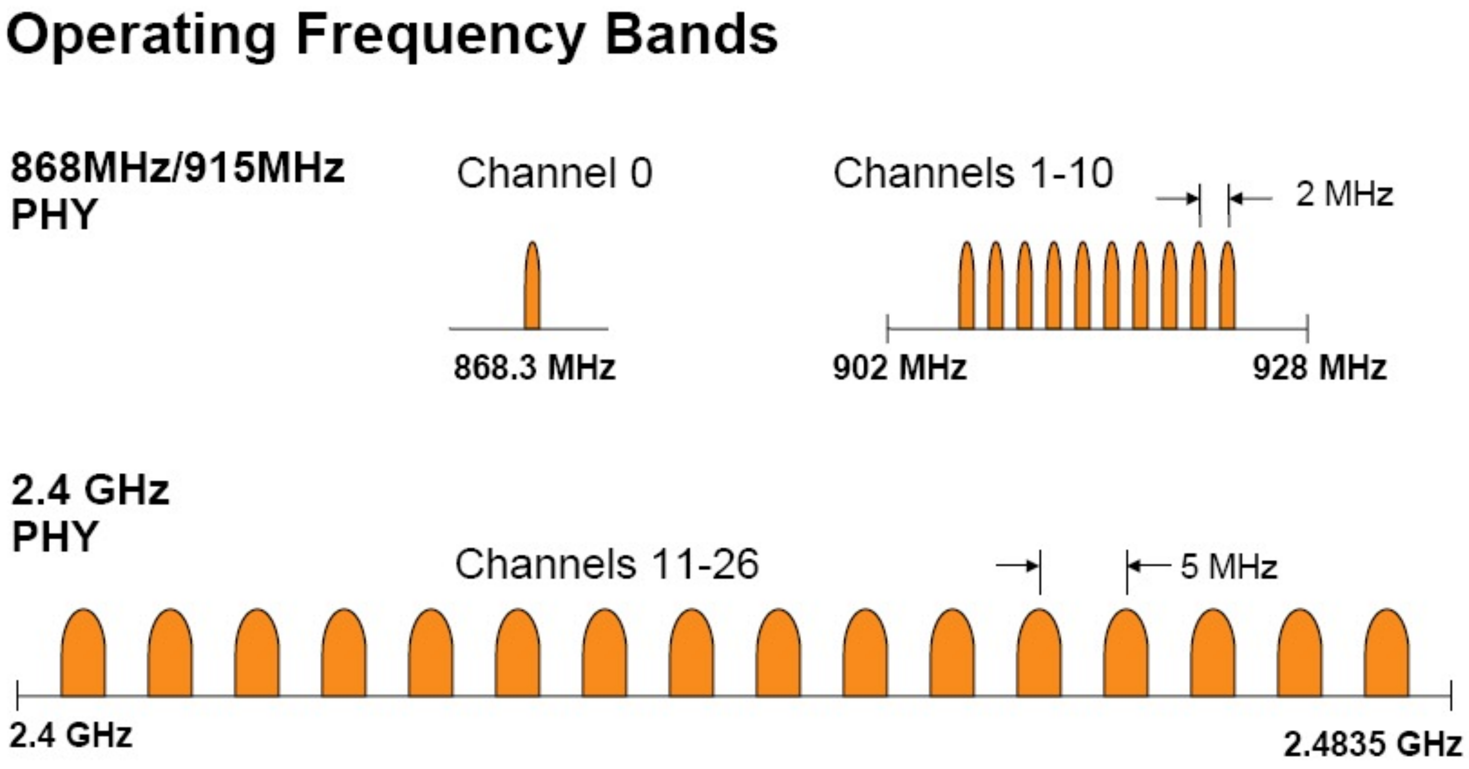


Figure 5. Anatomy of packet reception and transmission. For reception, slow sampling detects arrival of a 10-kilobits-per-second (Kbps) start signal. The receiver must determine the packet's precise timing to synchronize for the 50-Kbps data payload. Data sample timing for the entire packet is based on the initial synchronization. For transmission, after a short random delay, the preamble, then a start symbol, and then the data are sent.

Signal

- An electromagnetic signal
  - – A function of time
  - – Also a function of frequency
    - The signal consists of components of different frequencies

802.15.4 Physical Layer



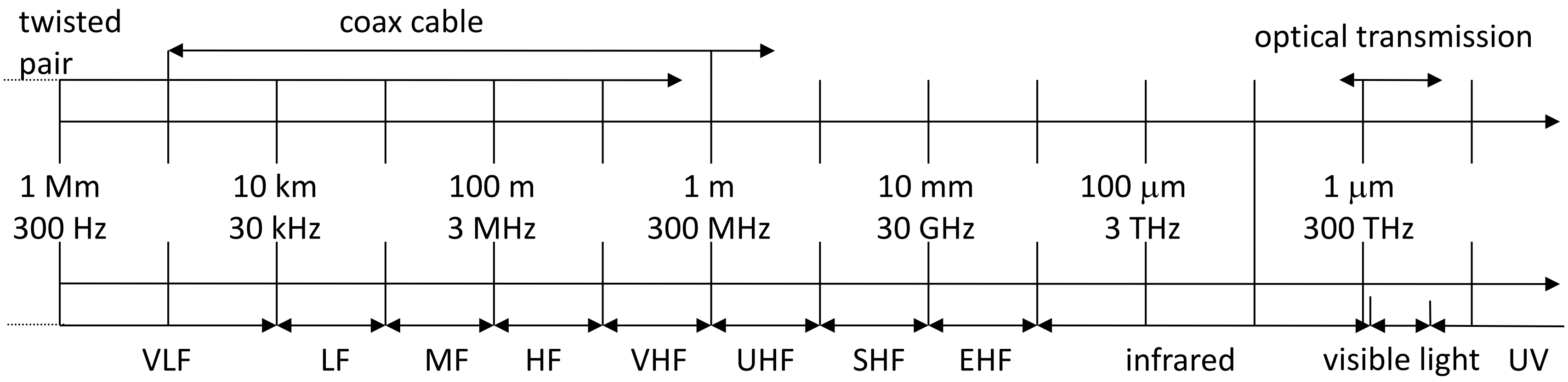
Spectrum and Bandwidth: Shannon Channel Capacity

The maximum number of bits that can be transmitted per second by a physical channel is:

$$\boxed{W \log_2 (1 + \frac{S}{N})}$$

where W is the frequency range of the channel, and S/N is the signal noise ratio, assuming Gaussian noise

Frequencies for Communications



twisted pair

coax cable

optical transmission

1 Mm
300 Hz

10 km
30 kHz

100 m
3 MHz

1 m
300 MHz

10 mm
30 GHz

100 μm
3 THz

1 μm
300 THz

VLF LF MF HF VHF UHF SHF EHF infrared visible light UV

VLF = Very Low Frequency

LF = Low Frequency

MF = Medium Frequency

HF = High Frequency

VHF = Very High Frequency

UHF = Ultra High Frequency

SHF = Super High Frequency

EHF = Extra High Frequency

UV = Ultraviolet Light

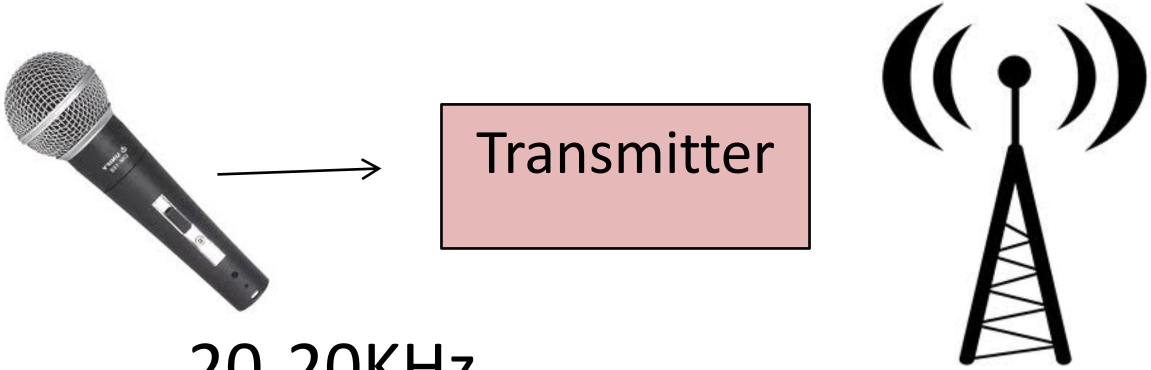
Frequency and wave length:

$$\lambda = c/f$$

wave length λ, speed of light $c \cong 3x10^8 m/s$, frequency f

Why Not Send Digital Signal in Wireless Communications?

voice



Transmitter

20-20KHz

Antenna:
size ~ wavelength

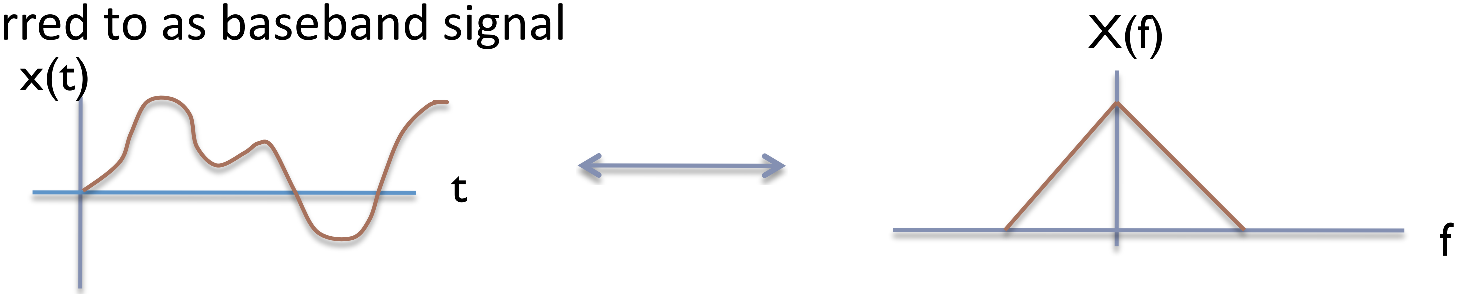
At 3 KHz,

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{3\times10^3} = 100km$$

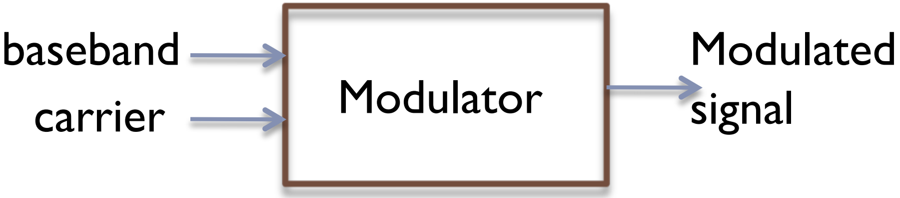
Antenna too large!
Use modulation to transfer to higher frequency

Basic Concepts of Modulation

- The information source
  - Typically a low frequency signal
  - Referred to as baseband signal



- Carrier
  - A higher frequency sinusoid
  - Example cos(2π10000t)



- Modulated signal
  - Some parameter of the carrier (amplitude, frequency, phase) is varied in accordance with the baseband signal

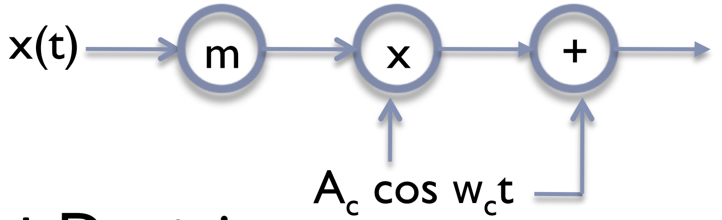
Types of Modulation

- Analog modulation
  - Amplitude modulation (AM)
  - Frequency modulation (FM)
  - Double and signal sideband: DSB, SSB

- Digital modulation
  - Amplitude shift keying (ASK)
  - Frequency shift keying: FSK
  - Phase shift keying: BPSK, QPSK, MSK
  - Quadrature amplitude modulation (QAM)

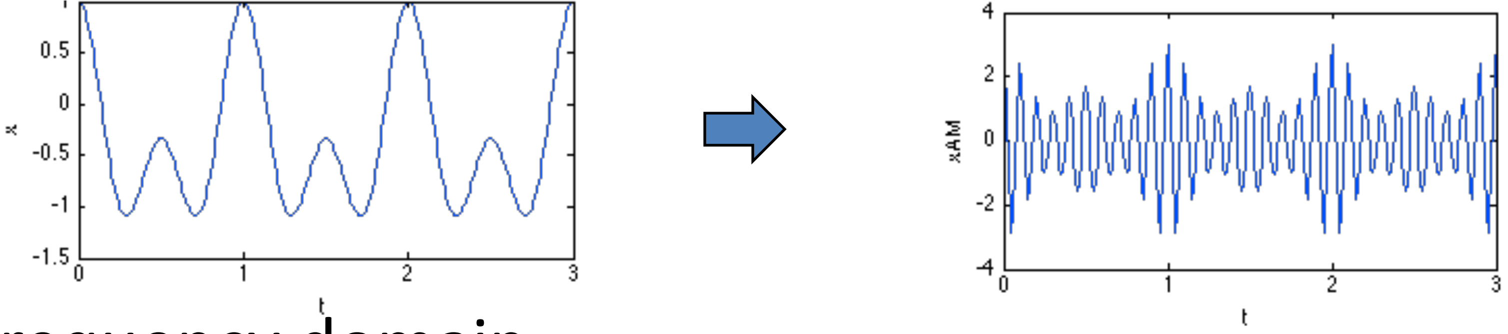
Example: Amplitude Modulation (AM)

- Block diagram

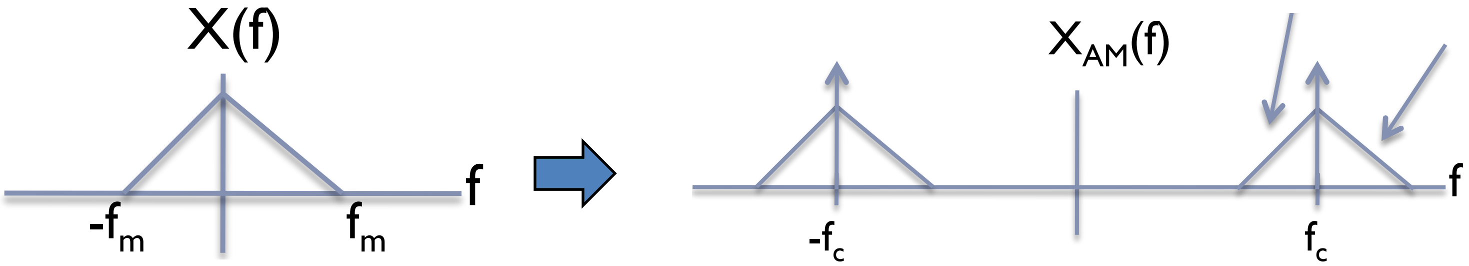


$x_{AM}(t)=A_c\,[1+mx(t)]\cos w_c t$

- Time domain



- Frequency domain



Wireless Terms

- Decibel (dB). Ratio of two powers

$$\text{Ratio of } P_1 \text{ to } P_2 \text{ in dB} = 10\log_{10}\left(\frac{P1}{P2}\right)$$

- dBm. The reference power is in mW
- SNR. Signal-to-Noise Ratio. Power, expressed in dB
- Attenuation. Power loss (dB)
- CDMA. Code Division Multiple Access
- Simplex communication. One direction at a time
- Duplex communication . Transmit and receive simultaneously
- FCC. Federal Communications Commission
- Antenna gain. How much more power the antenna received compared to reference (half wave). Expressed in dB
- MAC. Medium/Media Access Control

Wireless Terms

- Circuit Switched. Dedicated (virtual) link between parties. Connection held even when no data transmitted.
- Packet Data. Split information into packets and route independently through network. Use of spectrum only when data are transmitted.
- Spread Spectrum. A wideband modulation which imparts noise-like characteristics to an RF signal.
- Frequency-hopping and Direct Sequence Examples of Spread Spectrum
- TDMA. Time-Division Multiple Access
- FDMA. Frequency Division Multiplex Access

BER and Effective Channel Capacity

- Analog vs. Digital links
- BER – Bit Error Rate increases as SNR decreases
  - Error detection and correction mechanisms
  - Repeated transmission
  - Reduce channel capacity

Radio Propagation Mechanisms

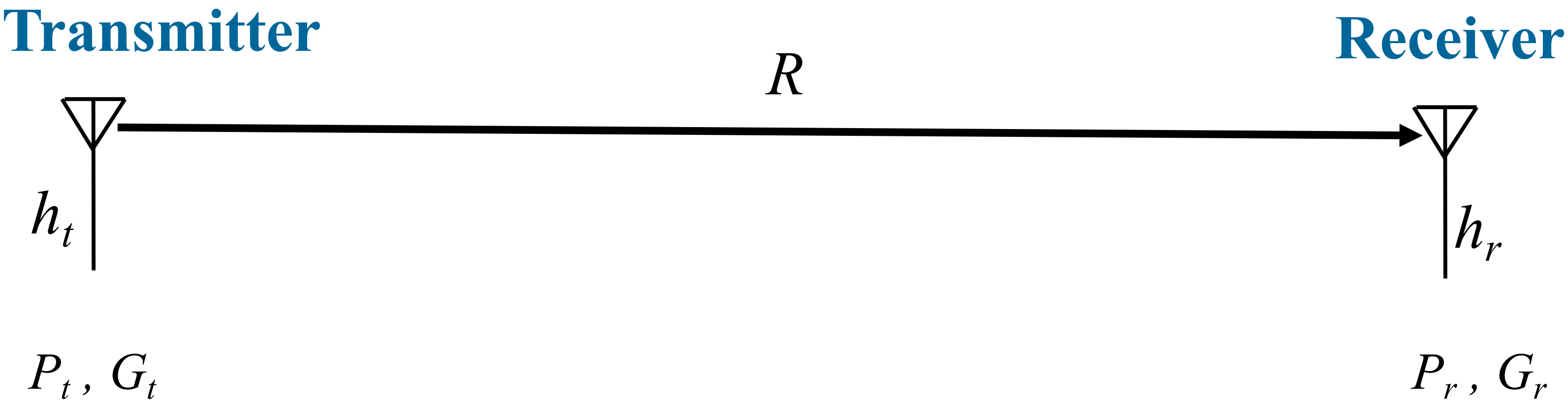
- Free Space
- Reflection
  - Wave impinges on large (compared to wavelength) objects.
- Diffraction
  - Waves bends around obstacle (no LOS)
- Scattering
  - Objects much smaller that wavelength

Radio Propagation

- Simple (but useful) models exist for
  - Free Space
  - Common geometries (flat, curved earth, wall)
- Radio propagation in many real environments is complex
  - Multipath propagation
  - Shadowing
  - Attenuation
- Environment changes => fluctuations in received power

Radio Propagation

- Free space model



$$\boxed{P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2}$$

Free-Space Isotropic Signal Propagation

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

- P_r: received power
- P_t: transmitted power
- G_r, G_t: receiver and transmitter antenna gain
- λ (=c/f): wave length

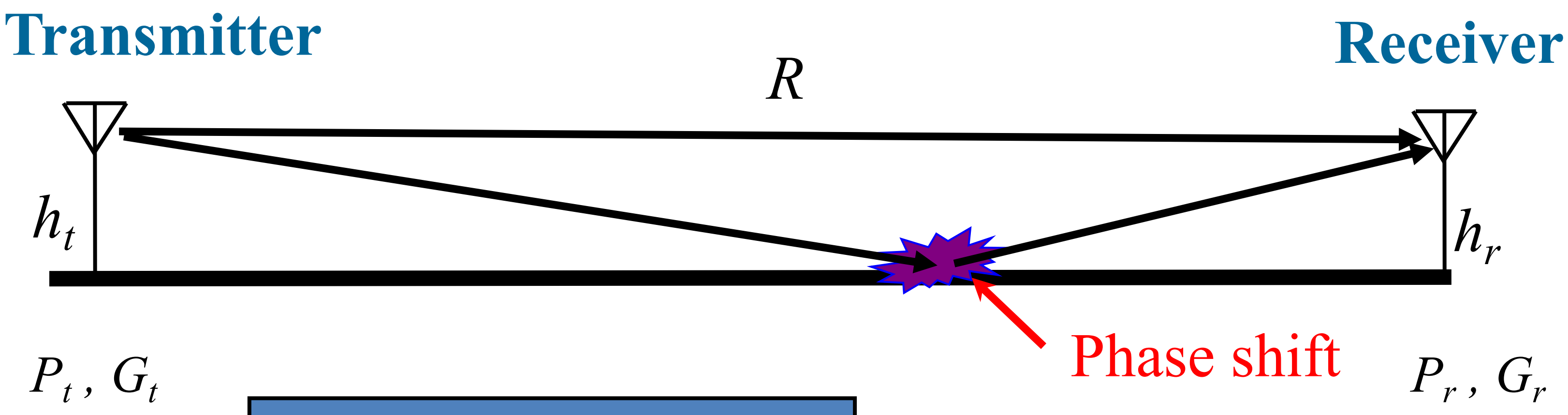
- In free space, receiving power proportional to $1/d^2$
(d = distance between transmitter and receiver)
- Suppose transmitted signal is x, received signal y = h x, where h is proportional to $1/d^2$
- Loss depends on the frequency: Higher loss with higher frequency
- Loss increase quickly with distance (d^2)

Sometime we write path loss in log scale:

$$Lp = 10 \log(Pt) - 10\log(Pr)$$

Radio Propagation

- Two-beam/ray ground *reflection* model, large R

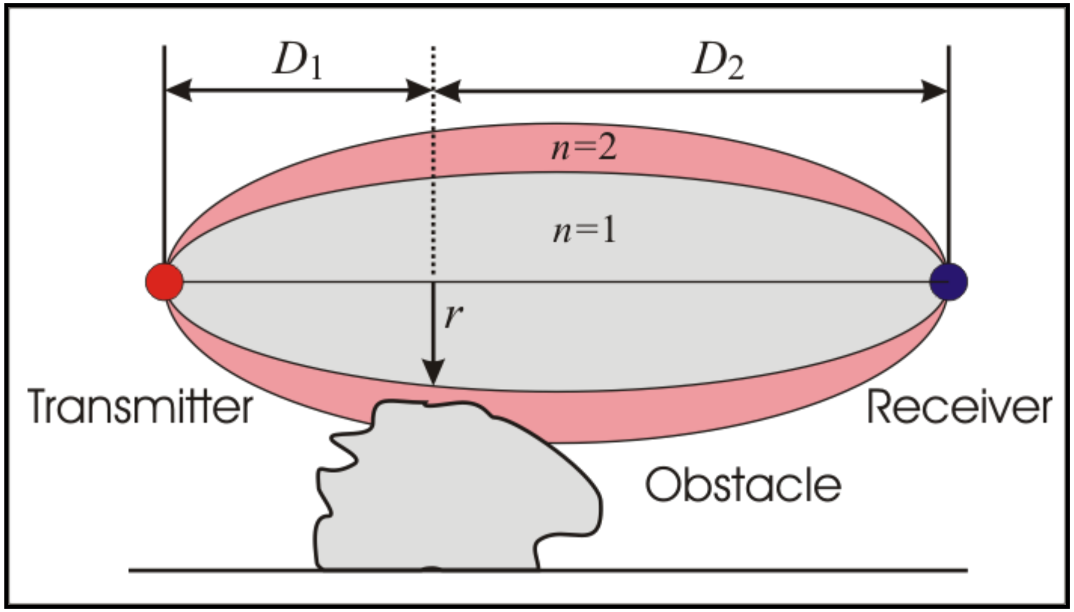


$$\boxed{P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{R^4}}$$

- The “breakpoint” distance R at which the model changes from $1/R^2$ to $1/R^4$ is $\approx 4\pi h_t h_r/\lambda$

Fresnel Zone and LOS

- Diffraction



$$F_n = \sqrt{\frac{n\lambda D_1 D_2}{D_1 + D_2}}$$

Consistent Units

60% rule-of-thumb

Example

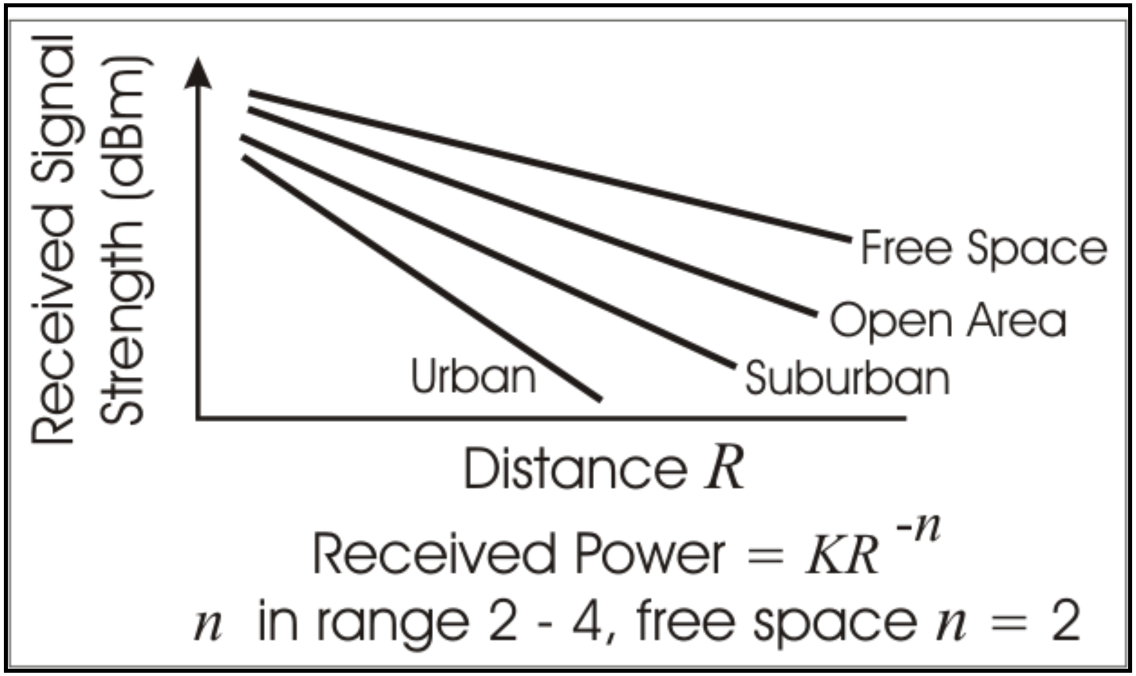
- A 1-km 2.4 GHz link has two antennas that are 2 m above the ground. Do we have LOS?

$$F_n = \sqrt{\frac{n\lambda D_1 D_2}{D_1 + D_2}} = \sqrt{\frac{1 \times 0.125 \times 500 \times 500}{500 + 500}} = 5.59\ \text{m}$$

60% of this is 3.3 m, so we don't have clearance. Answer is "NO"

Loss Models

- Why need model?
- Hybrid models (physics and empirical)



This graph does not reflect temporal changes

Indoor Propagation

- Signal decays much faster
- Coverage contained by walls (waveguides)
- Very complicated dynamic (people move) attenuation and multipath

Path Loss = Unit Loss + $10n\log(R) = kF + lW$

- Unit Loss = power loss @ 1 m (say 30 dB)
- n = power delay index
- R
- k = # of floors, F = # of floors
- l = # of walls, W = loss per wall

Indoor Propagation

$$\text{Path Loss} = \text{Unit Loss} + 10n\log(R) = kF + lW$$

Building	Freq (MHz)	*n*	Sigma (dB)
Retail Store	914	2.2	8.7
Grocery Store	914	1.8	5.2
Office	1500	3.0	7.0
Textile Factory	1300	2.0	3.0
Home	900	3.0	7.0

dB

- dB (Decibel)
  - Express relative differences in signal strength
  - dB = 10 $\log_{10}$ (p1/p2)
  - dB = 0: no attenuation. p1 = p2
  - 1 dB attenuation: 0.79 of the input power survives: 10 * $\log_{10}(1/0.79)$
  - 3 dB attenuation: 0.5 of the input power survives: 10 * $\log_{10}(1/0.5)$
  - 10 dB attenuation: 0.1 of the input power survives: 10 * $\log_{10}(1/0.1)$
- http://en.wikipedia.org/wiki/Decibel
- http://www.sss-mag.com/db.html

Decibels

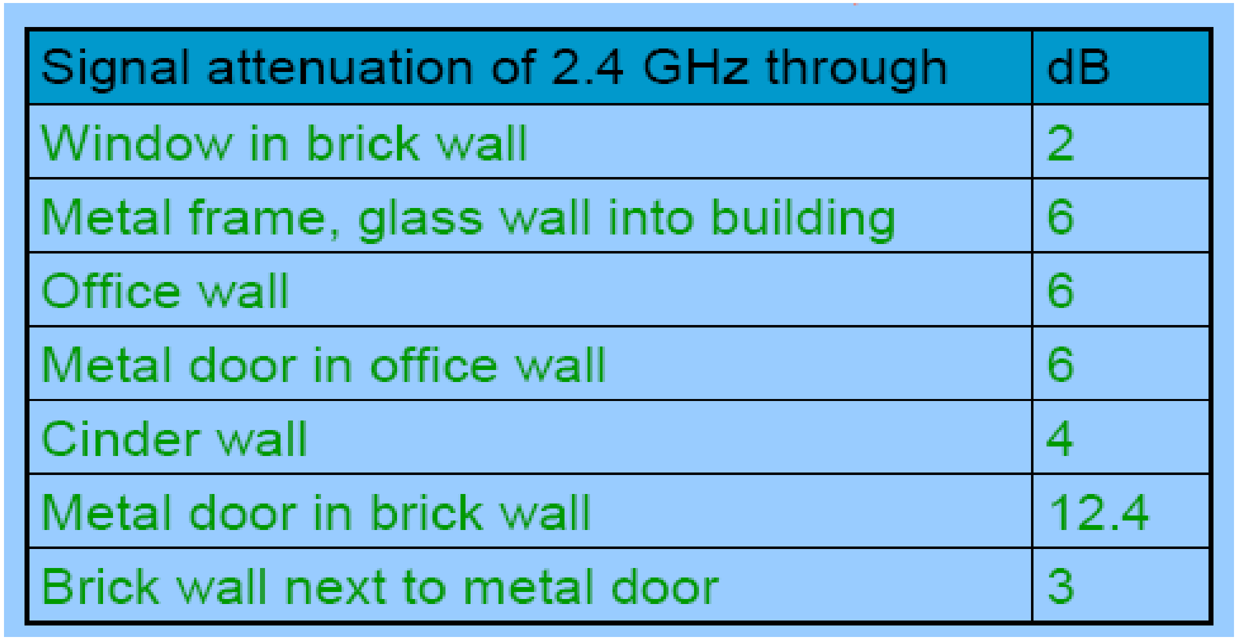
- Attenuation = 10 Log10 (Pin/Pout) decibel
- Attenuation = 20 Log10 (Vin/Vout) decibel

- **Example 1: Pin = 10 mW, Pout=5 mW**
  - Attenuation = 10 log 10 (10/5) = 10 log 10 2 = 3 dB

- **Example 2: Pin = 100mW, Pout=1 mW**
  - Attenuation = 10 log 10 (100/1) = 10 log 10 100 = 20 dB

Shadowing

- Signal strength loss after passing through obstacles
- Some sample numbers



Signal attenuation of 2.4 GHz through	dB
Window in brick wall	2
Metal frame, glass wall into building	6
Office wall	6
Metal door in office wall	6
Cinder wall	4
Metal door in brick wall	12.4
Brick wall next to metal door	3

i.e. reduces to ¼ of signal

$10 \log(1/4) = -6.02$

dBm

- The referenced quantity is one milliwatt(mW)
- dBm = 10 $\log_{10}$ (p1/1mW)
- 0 dBm: p1 is 1 mW
- -80 dBm: p1 is 10^{-11}W = 10pW

- http://en.wikipedia.org/wiki/DBm

Received Signal Strength Indicator (RSSI)

- The strength of a received RF signal
- Many current platforms provide hardware indicator
  - CC2420, the radio chip of MicaZ and TelosB, provides RSSI indicator and LQI (Link Quality Indicator)

LQI (Link Quality Indicator)

- A measure of chip error rate
- Error rate
  - The rate at which errors occur
  - Error
    - 0 is transmitted while 1 is received
    - 1 is transmitted while 0 is received

Noise Floor

- The measure of the signal created from the sum of all the noise sources and unwanted signals

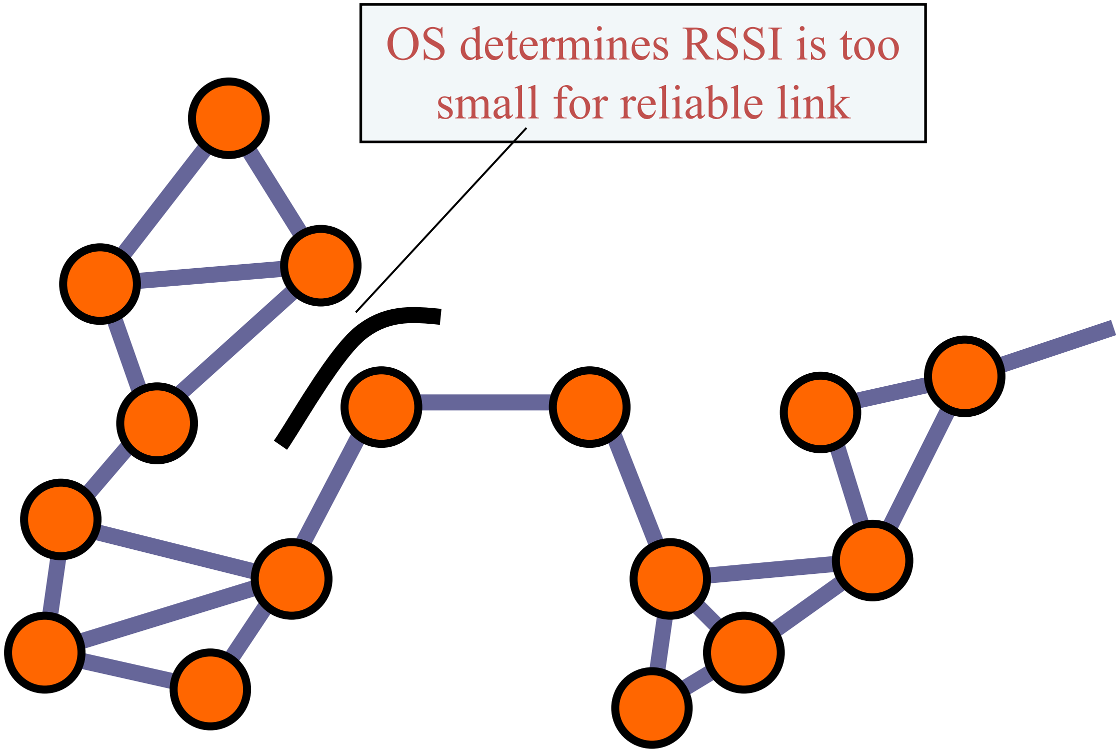
Signal Noise Ratio (SNR)

- The ratio of the power in a signal to the power contained in the noise that is present
- Typically measured at the receiver
- Take CC2420 as the example:
  - Noise Floor: the RSSI register from the CC2420 chip when not receiving a packet
    - For example -98dBm
  - The strength field from the received packet: RSSI of the received packet

Received Signal Strength Indicator (RSSI)

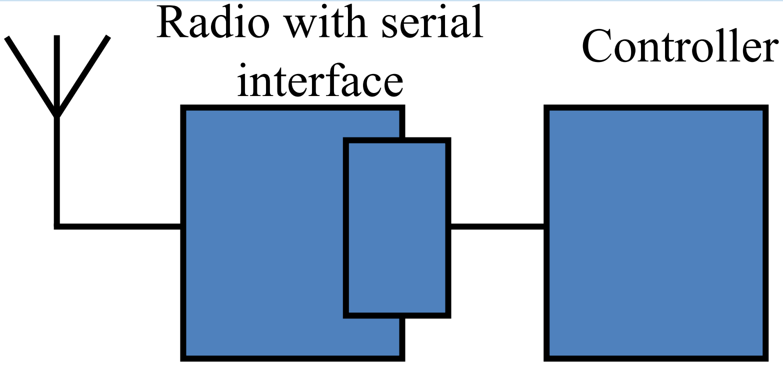
- Measure of received signal strength of radio
- Indicator of link quality
- Radio can be interrogated for RSSI
- On-board Software use RSSI
- Typically a number 23, 19, etc.
- Consult manufacturer for mapping to power level dBm

RSSI



OS determines RSSI is too small for reliable link

RSSI



```
+++
ATRS<CR>
ATCN<CR>
```

```
40
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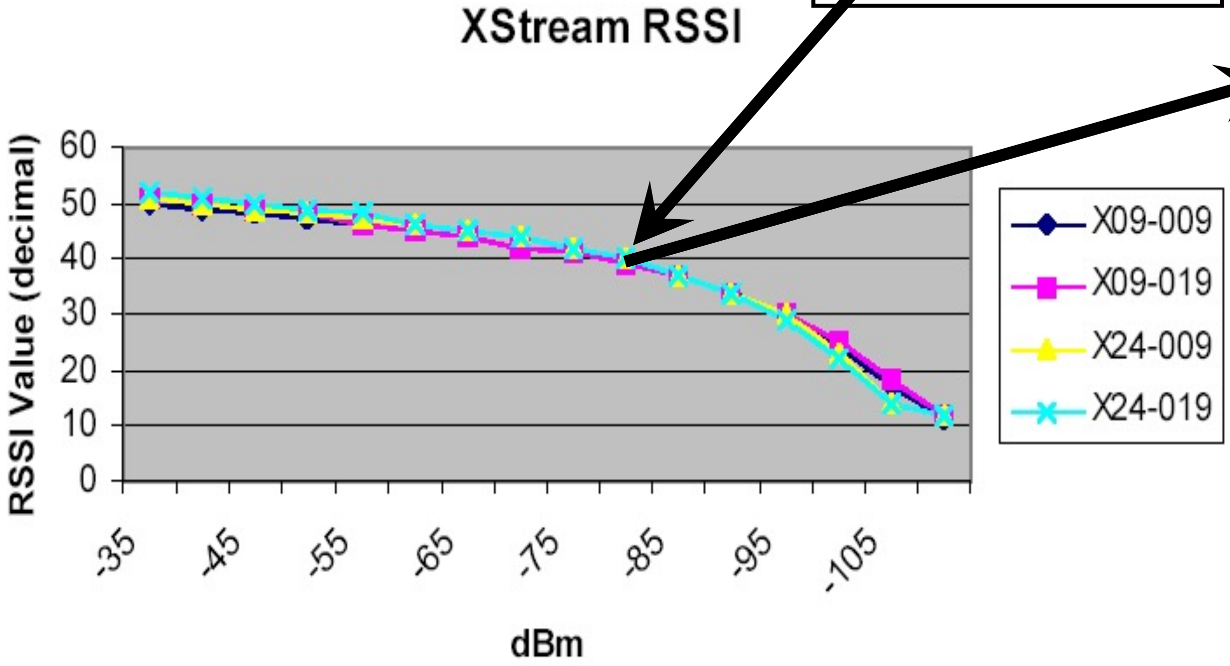


$$
\begin{aligned}
-80\ \text{dBm} &= 10^{-8}\ \text{mW} \\
&= 10^{-11}\ \text{W} \\
&= 0.01\ \text{nW}
\end{aligned}
$$

Small!

What is an Antenna

- Conductor that carries an electrical signal and radiates an RF signal.
  - The RF signal “is a copy of” the electrical signal in the conductor
- Also the inverse process: RF signals are “captured” by the antenna and create an electrical signal in the conductor.
  - This signal can be interpreted (i.e. decoded)
- Efficiency of the antenna depends on its size, relative to the wavelength of the signal.
  - e.g. half a wavelength

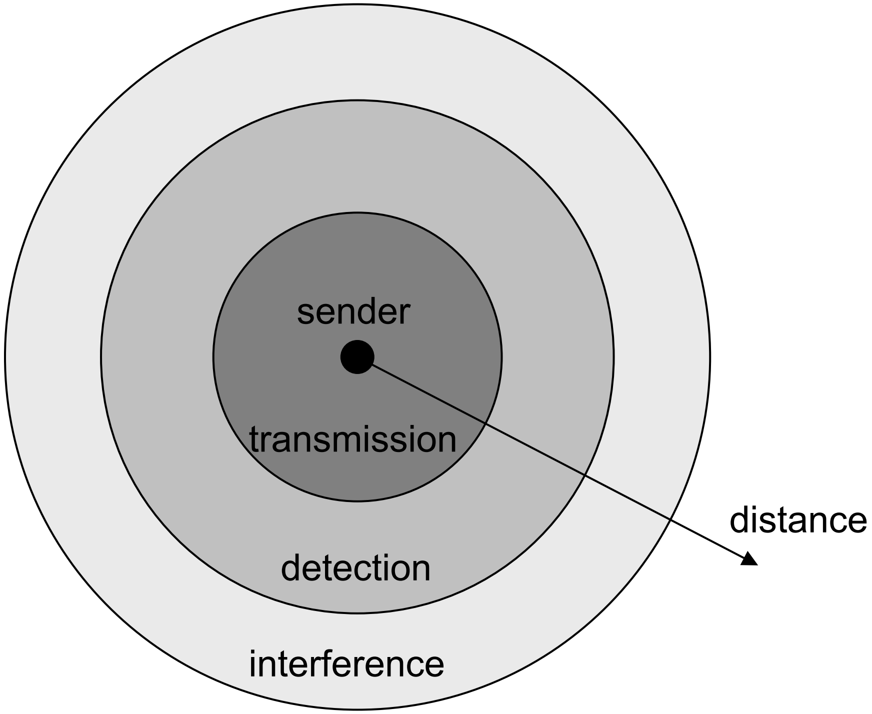
Types of Antennas

- Antenna is a point source that radiates with the same power level in all directions – omni-directional or isotropic
  - An antenna that transmits equally in all directions (isotropic)
  - Shape of the conductor tends to create a specific radiation pattern
- Common shape is a straight conductor
- Shaper antennas can be used to direct the energy in a certain direction
  - Well-know case: a parabolic antenna

A parabolic antenna

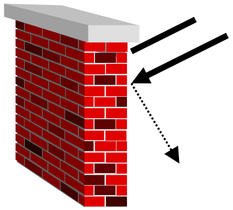
Signal Propagation Ranges

- Transmission range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible
  - no communication possible
- Interference range
  - signal may not be detected
  - signal adds to the background noise

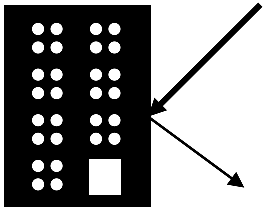


Signal propagation

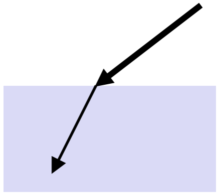
- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$ in vacuum – much more in real environments
  (d = distance between sender and receiver)
- Receiving power additionally influenced by fading (frequency dependent)
- Shadowing
- Reflection at large obstacles
- Refraction depending on the density of a medium
- Scattering at small obstacles
- Diffraction at edges



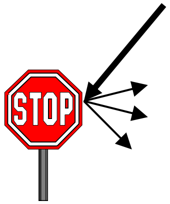
shadowing



reflection



refraction

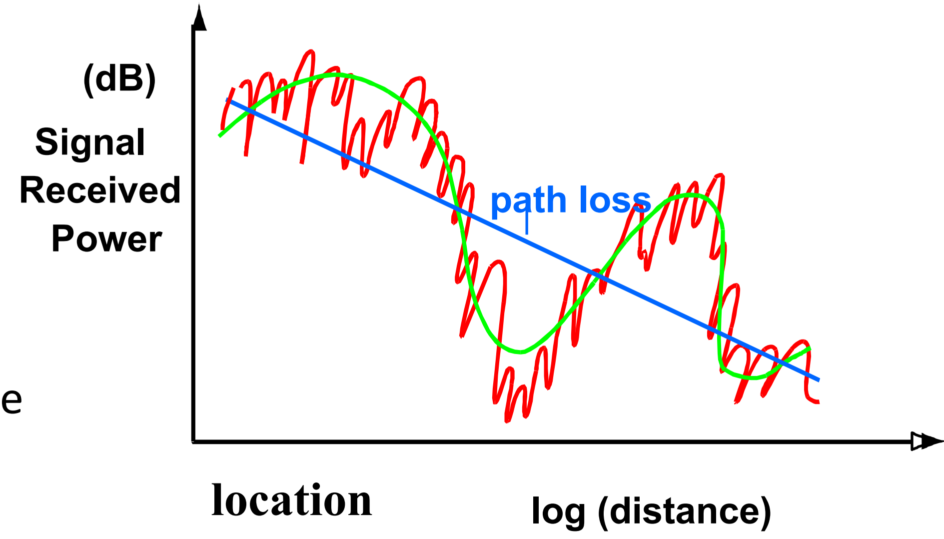


scattering

diffraction

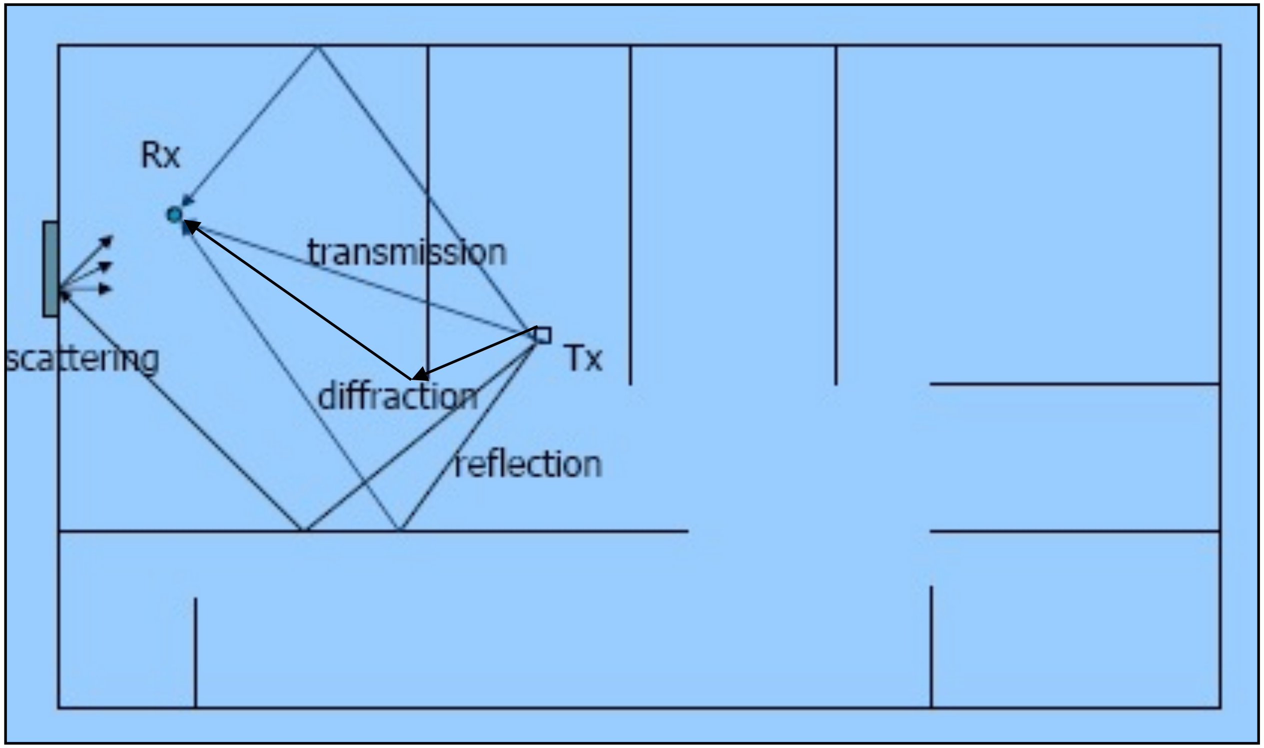
Propagation Degrades RF Signal

- Attenuation in free space
  - Signal gets weaker as it travels over longer distance
  - Free space loss- Signal spreads out
  - Refraction and absorption in the atmosphere
- Obstacle can weaken signal through absorption or reflection.
  - Part of the signal is re-directed.
- Multiple path effects
  - Multiple copies of the signal interfere with each other
- Mobility
  - Moving receiver causes another form of self interference
  - Node moves ½ wavelength cause big change in signal strength



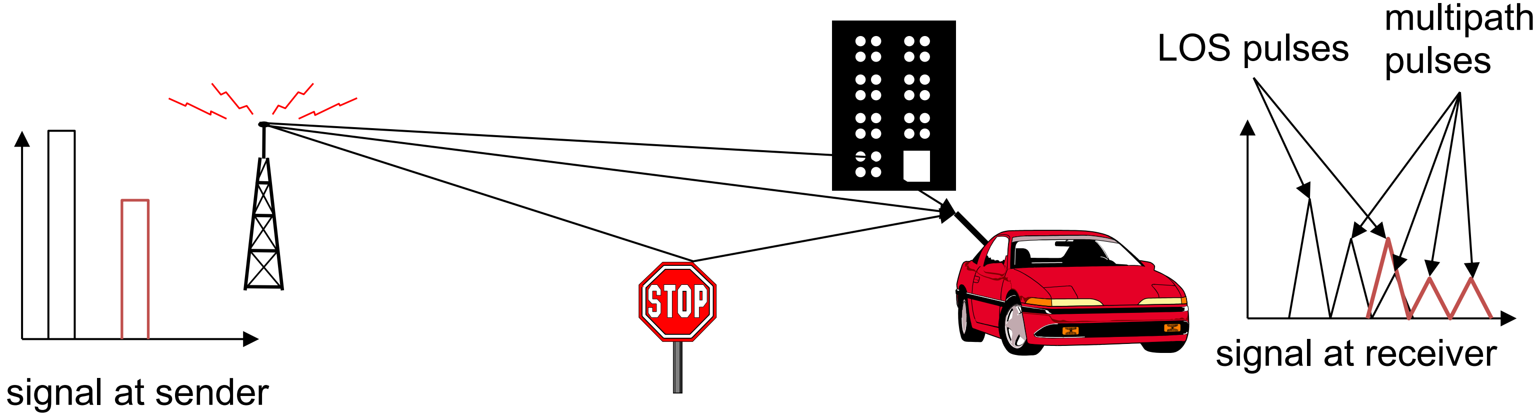
Multipath

- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction



Multipath propagation

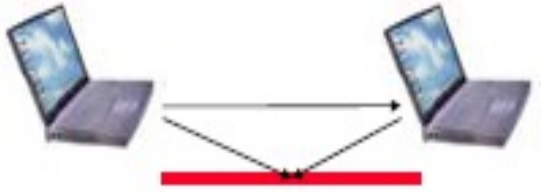
- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction

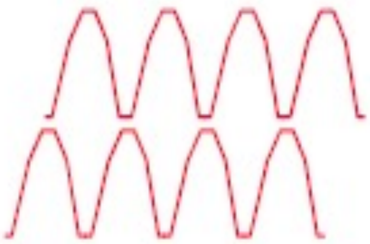


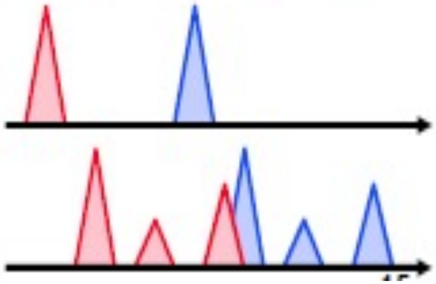
- Time dispersion: signal is dispersed over time
  - interference with “neighbor” symbols, Inter Symbol Interference (ISI)
- The signal reaches a receiver directly and phase shifted
  - distorted signal depending on the phases of the different parts

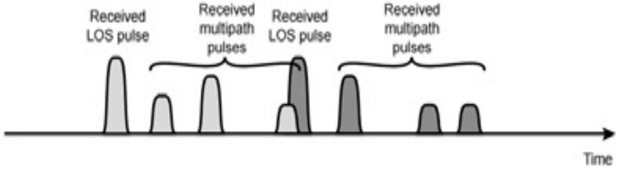
Multipath Effects

- Receiver receives multiple copies of the signal, each following a different path
- Copies can either strengthen or weaken each other
  - Depends on whether they are in our out of phase
- Small changes in location can result in big changes in signal strength
- Larger difference in path length can cause intersymbol interference (ISI)
  - More significant for higher bit rates (shorter bit times)







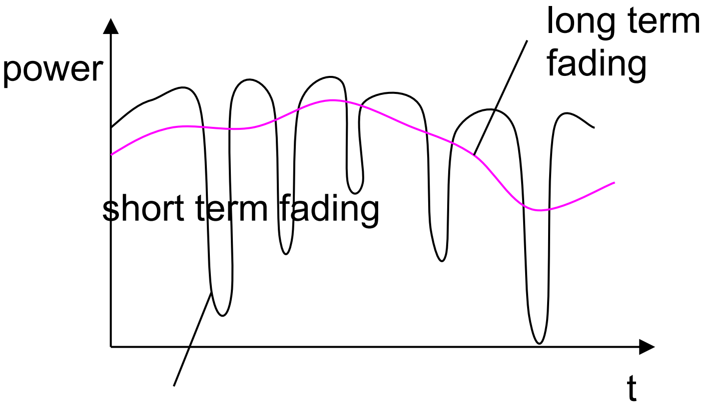


Effects of mobility

- **Channel characteristics change over time and location**
  - signal paths change
  - different delay variations of different signal parts
  - different phases of signal parts
  - quick changes in the power received (short term fading)

- **Fading: time variation of the received signal strength caused by changes in the transmission medium or paths.**
  - Rain, moving objects, moving sender/receiver, …

- **Additional changes in**
  - distance to sender
  - obstacles further away
  - slow changes in the average power received (long term fading)



Radio Irregularity

- Spherical radio range is not valid
- When an electromagnetic signal propagate, the signal may be
  - Diffracted
  - Reflected
  - Scattered
- Radio irregularity and variations in packet loss in different directions

ref: [radio_1]

Radio Signal Property

- Anisotropic Signal Strength: Different path losses in different directions

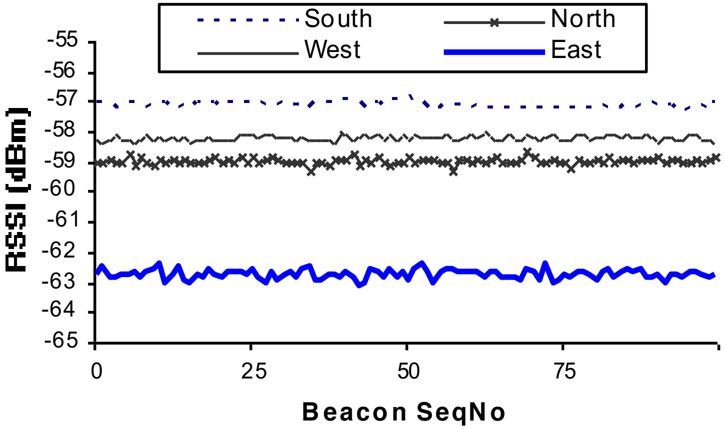


Figure 1: Signal Strength over Time in Four Directions

Radio Signal Property

- Anisotropic Packet Loss Ratio: Packet Reception Ratio (PRR) varies in different directions

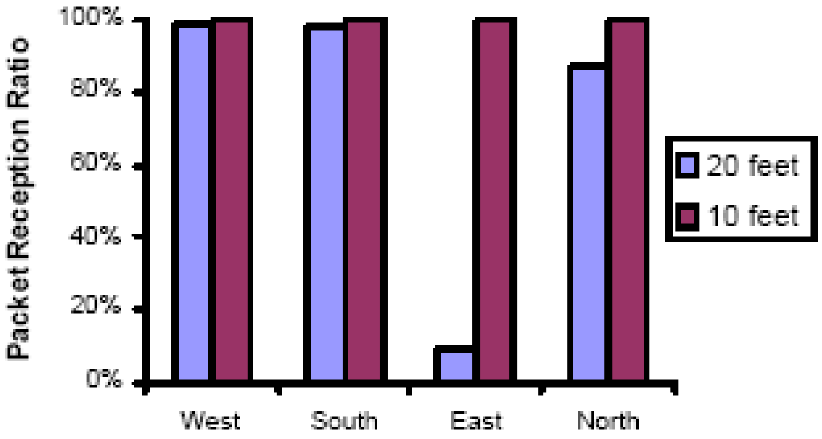


Fig. 3. Anisotropic Packet Reception

[Radio_1]: Figure 3

Radio Signal Property

- Anisotropic Radio Range: The communication range of a mote is not uniform

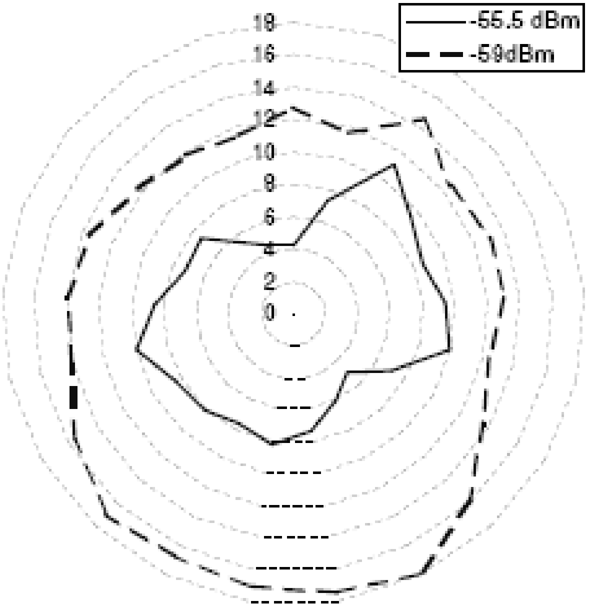


Fig. 4. Anisotropic Range

[Radio_1]: Figure 4

Radio and Medium Access Control

Radio Properties

Medium Access Control (MAC)

Introduction

- A radio channel cannot be accessed simultaneously by two or more nodes that are in a radio interference range
  - Nodes may transmit at the same time on the same channel
- Medium Access Control
  - On top of Physical layer
  - Control access to the radio channel

MAC Protocol Requirements

- Energy Efficiency
  - Sources of energy waste
    - Collision, Idle Listening, Overhearing, and Control Packet Overhead
- Effective collision avoidance
  - When and how the node can access the medium and send its data
- Efficient channel utilization at low and high data rates
  - Reflects how well the entire bandwidth of the channel is utilized in communications
- Tolerant to changing RF/Networking conditions
- Scalable to large number of nodes

Ref: [MAC_2] Section I, II

Two Basic Classes of MAC Protocol – Slotted and Sampling

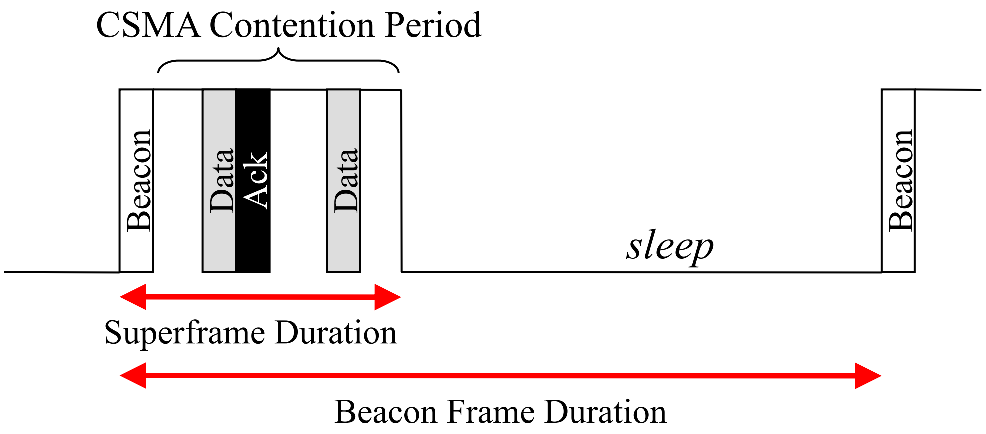
- Slotted Protocols
  - Nodes divides time into slots
  - Radio can be in receive mode, transmit mode, or powered off mode
  - Communication is synchronized
  - Data transfers occur in “slots”
  - TDMA, IEEE 802.15.4, S-MAC, T-MAC, etc.
- Also Ref: J. Polastre Dissertation – Section 2.4: http://www.polastre.com/papers/polastre-thesis-final.pdf

Two Basic Classes of MAC Protocol – Slotted and Sampling

- Sampling Protocols
  - Nodes periodically wake up, and only start receiving data if they detect channel activity
  - Communication is unsynchronized
  - Data transfer wakes up receiver
  - Must send long, expensive messages to wake up neighbors
  - B-MAC, Preamble sampling, LPL, etc.

Slotted Protocol Example: 802.15.4

- Each node beacons on its own schedule
- Other nodes synchronize with the received Beacons



IEEE 802.15.4 Superframe

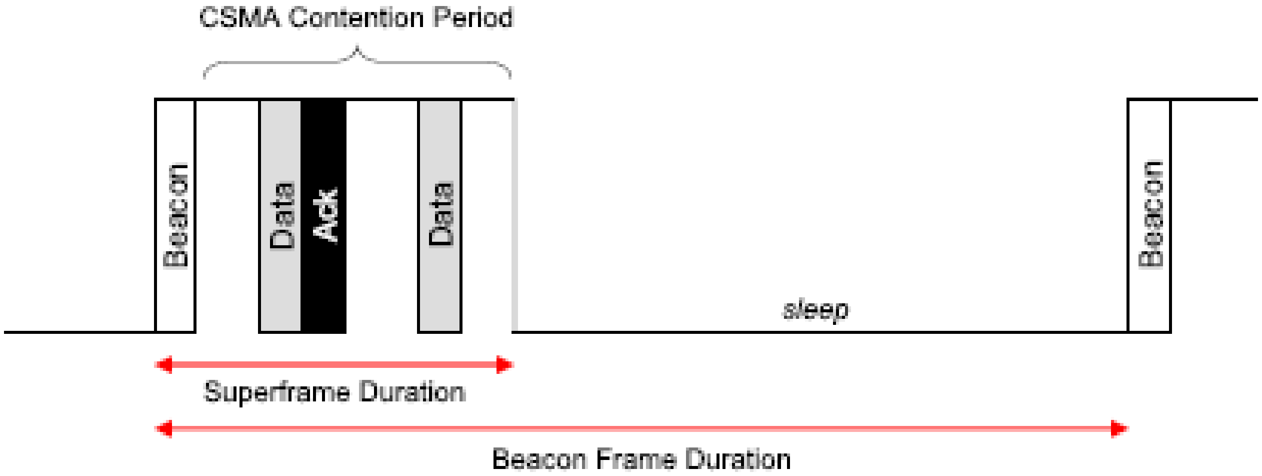
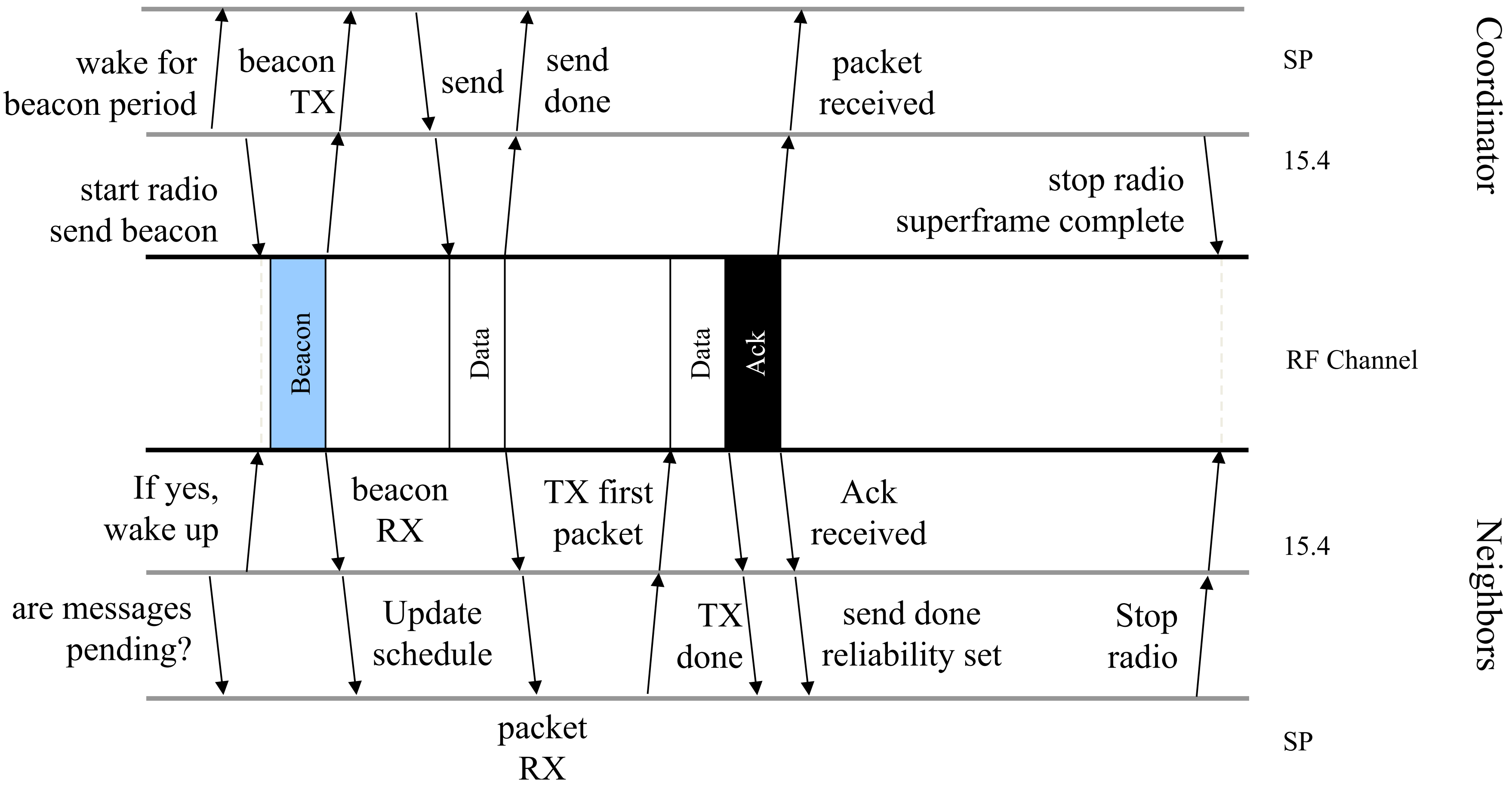


Figure 6: An IEEE 802.15.4 superframe consists of a MAC beacon message followed by a CSMA contention period for other traffic. The duty cycle is bounded by superframe to beacon frame ratio.

Using 802.15.4



wake for beacon period

beacon TX

send

send done

packet received

SP

Coordinator

start radio send beacon

stop radio superframe complete

15.4

Beacon

Data

Data

Ack

RF Channel

If yes, wake up

beacon RX

TX first packet

Ack received

15.4

Neighbors

are messages pending?

Update schedule

TX done

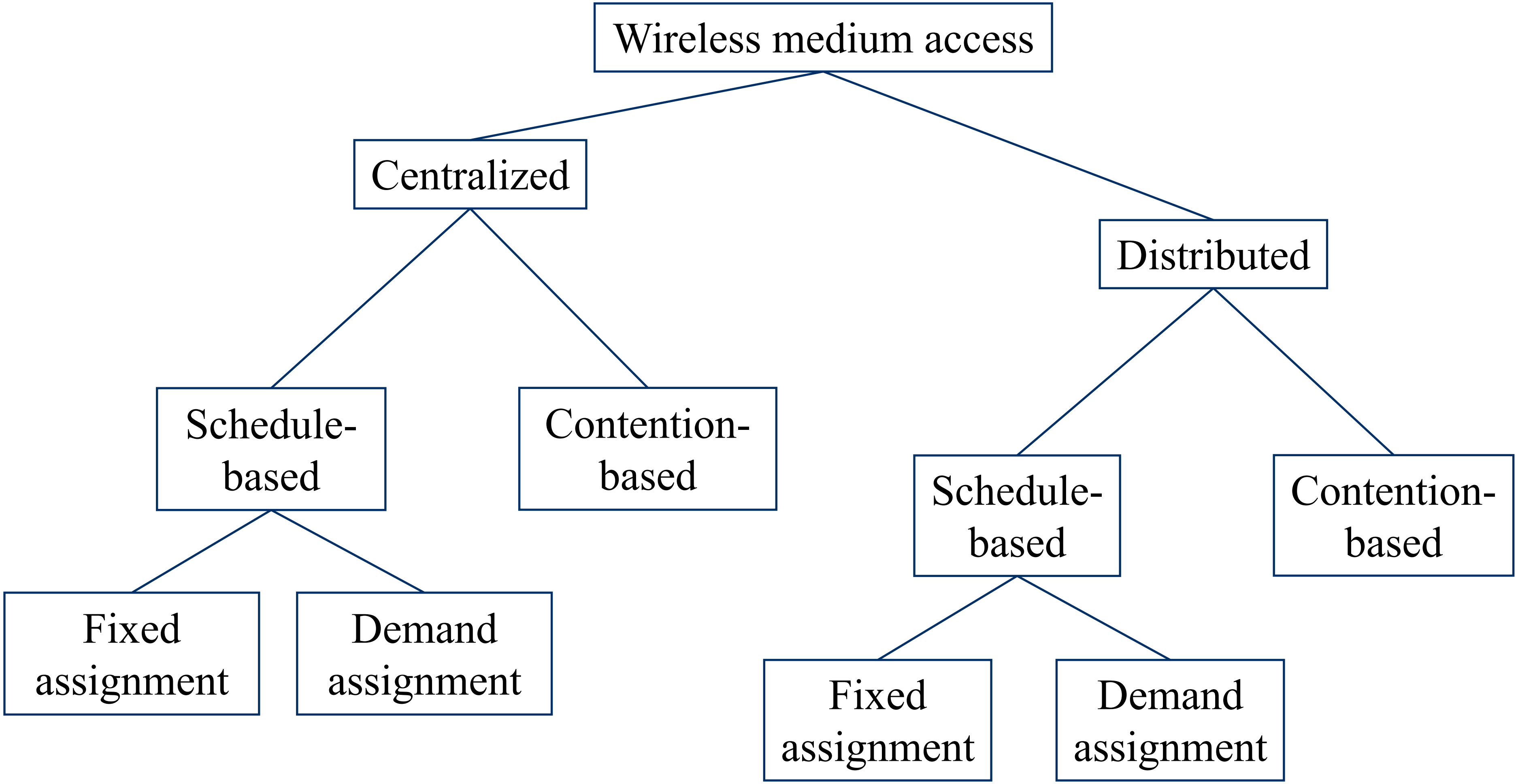
send done reliability set

Stop radio

packet RX

SP

Main MAC Protocols



Scheduled Protocols

- TDMA divides the channel into N time slots

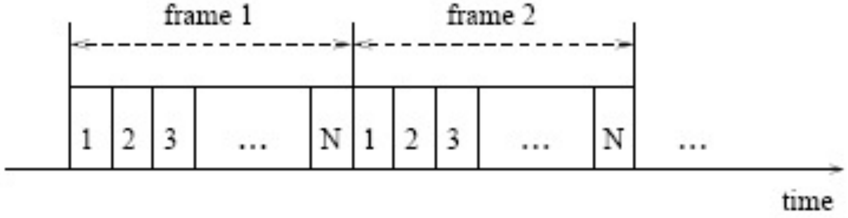


Fig. 1. TDMA divides the channel into *N* time slots.

Contention-based Protocols

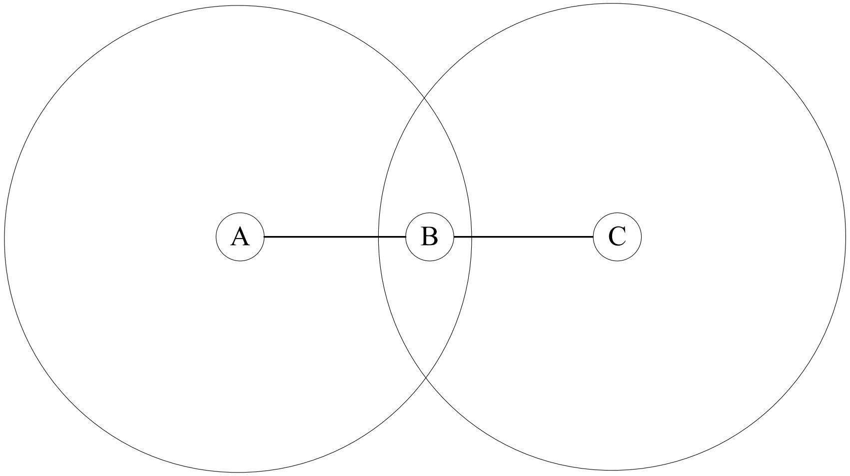
- A common channel is shared by all nodes and it is allocated on-demand
- A contention mechanism is employed
- Advantages over scheduled protocols
  - Scale more easily
  - More flexible as topologies change
  - No requirement to form communication clusters
  - Do not require fine-grained time synchronization
- Disadvantage
  - Inefficient usage of energy
    - Node listen at all times
    - Collisions and contention for the media

CSMA

- Listening before transmitting
- Listening (Carrier Sense)
  - To detect if the medium is busy
- Hidden Terminal Problem

Hidden Terminal Problem

- Node A and C cannot hear each other
- Transmission by node A and C can collide at node B
- On collision, both transmissions are lost
- Node A and C are hidden from each other



CSMA-CA

- CA
  - Collision Avoidance: to address the hidden terminal problem
- Basic mechanism
  - Establish a brief handshake between a sender and a receiver before transmission
  - The transmission between a sender and a receiver follows RTS-CTS-DATA-ACK

Centralized Medium Access

- Idea: Have a central station control when a node may access the medium
    - Example: Polling, centralized computation of TDMA schedules
    - Advantage: Simple, quite efficient (e.g., no collisions), burdens the central station
- Not directly feasible for non-trivial wireless network sizes
- But: Can be quite useful when network is somehow divided into smaller groups
    - Clusters, in each cluster medium access can be controlled centrally – compare Bluetooth piconets, for example

! Usually, distributed medium access is considered

Schedule- vs. Contention-based MACs

- ***Schedule-based*** MAC
  - A ***schedule*** exists, regulating which participant may use which resource at which time (TDMA component)
  - Typical resource: frequency band in a given physical space (with a given code, CDMA)
  - Schedule can be ***fixed*** or computed ***on demand***
    - Usually: mixed – difference fixed/on demand is one of time scales
  - Usually, collisions, overhearing, idle listening no issues
  - Needed: time synchronization!

Schedule- vs. Contention-based MACs

- ***Contention-based*** protocols
  - – Risk of colliding packets is deliberately taken
  - – Hope: coordination overhead can be saved, resulting in overall improved efficiency
  - – Mechanisms to handle/reduce probability/impact of collisions required
  - – Usually, ***randomization*** used somehow

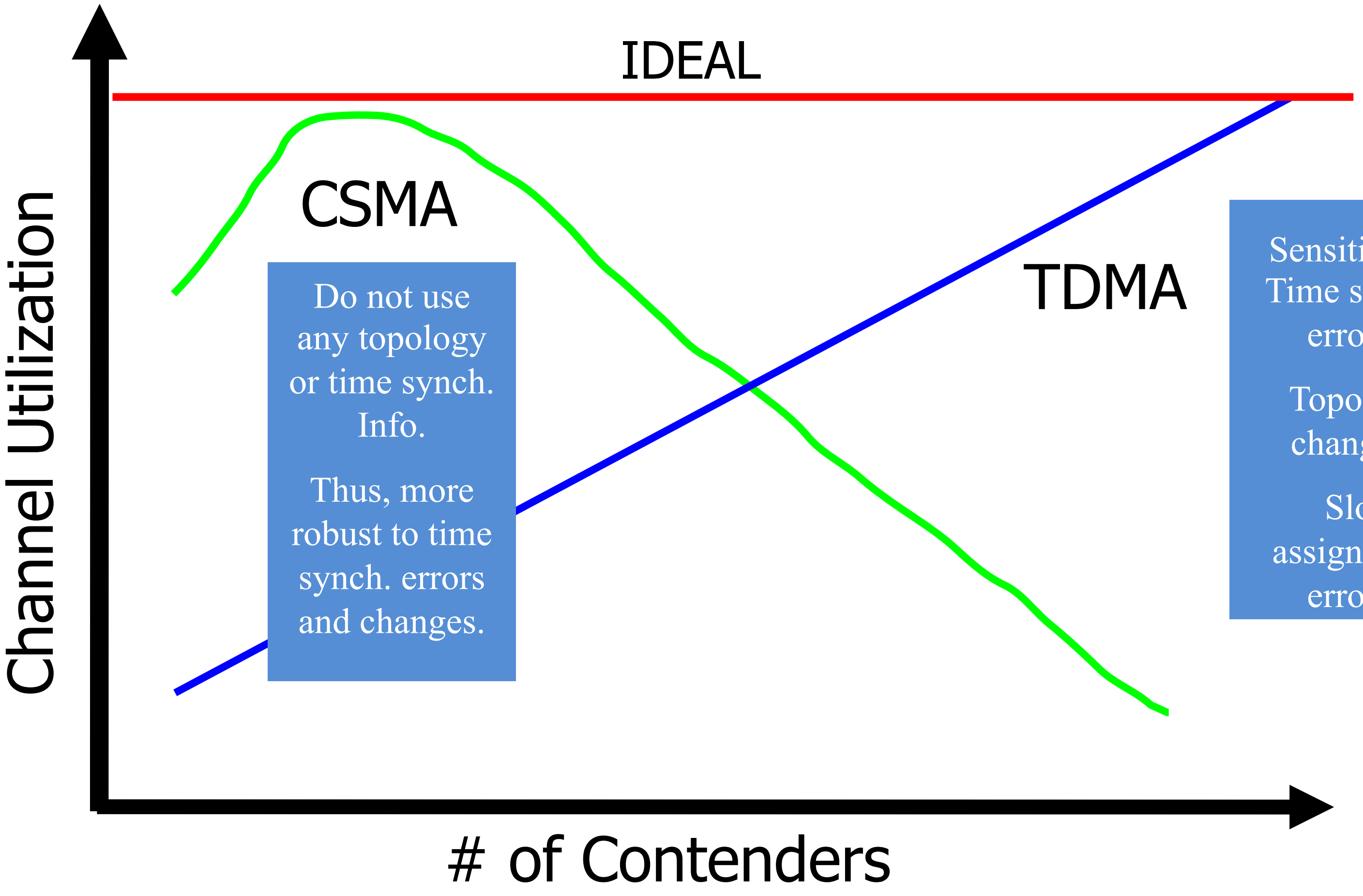
Possible Solutions

- CSMA (Carrier Sense Multiple Access)
  - Advantage:
    - No clock synchronization required
    - No global topology information required
  - Disadvantage
    - Hidden terminal problem: serious throughput degradation
    - RTS/CTS can alleviate hidden terminal problem, but incur high overhead

Possible Solutions

- TDMA (Time-division multiple access)
  - Advantage
    - Solve the hidden terminal problem without extra message overhead
  - Disadvantage
    - It is challenging to find an efficient time schedule
    - Need clock synchronization
      - High energy overhead
    - Handling dynamic topology change is expensive
    - Given low contention, TDMA gives much lower channel utilization and higher delay

Effective Throughput CSMA vs. TDMA



Do not use any topology or time synch. Info.

Thus, more robust to time synch. errors and changes.

Sensitive to Time synch. errors,

Topology changes,

Slot assignment errors.

MAC Energy Usage

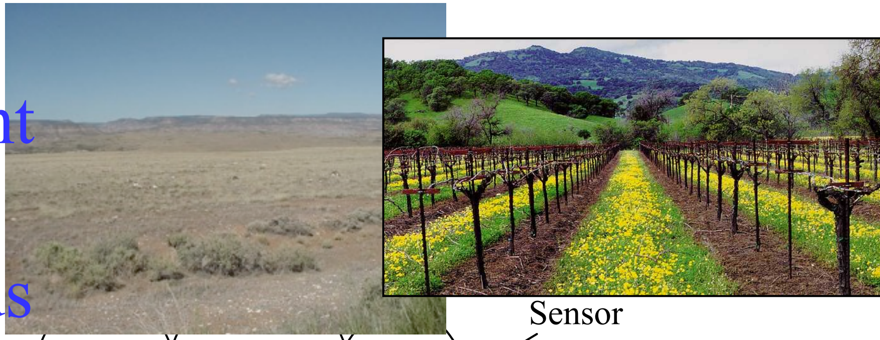
Four important sources of wasted energy in WSN:

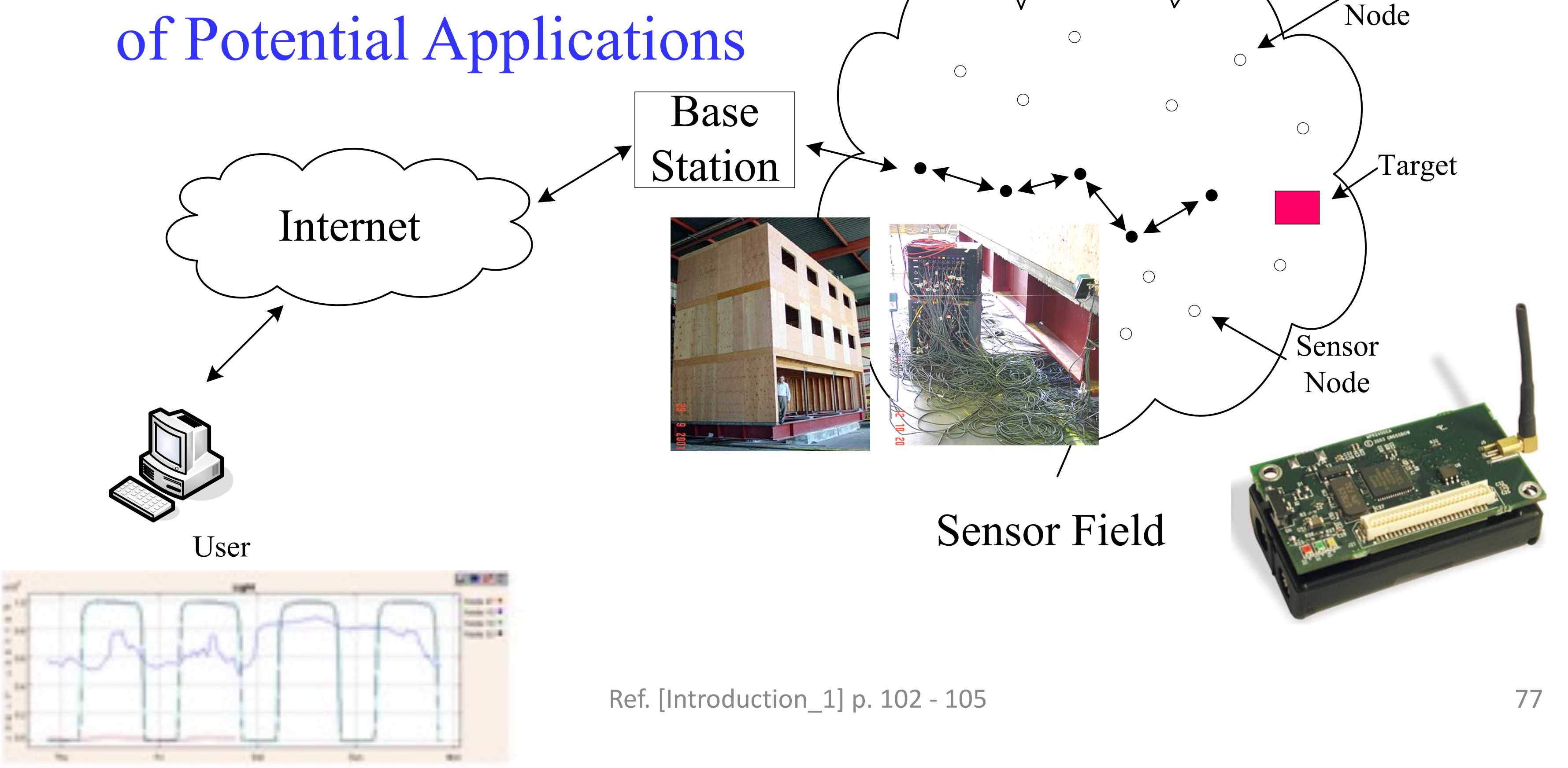
- Idle Listening (required for all CSMA protocols)
- Overhearing (since RF is a broadcast medium)
- Collisions (Hidden Terminal Problem)
- Control Overhead (e.g. RTS/CTS or DATA/ACK)

Wireless Sensor Networks (WSNs)

- Many simple nodes with sensors deployed throughout an environment

Sensing + CPU +Radio = Thousands of Potential Applications

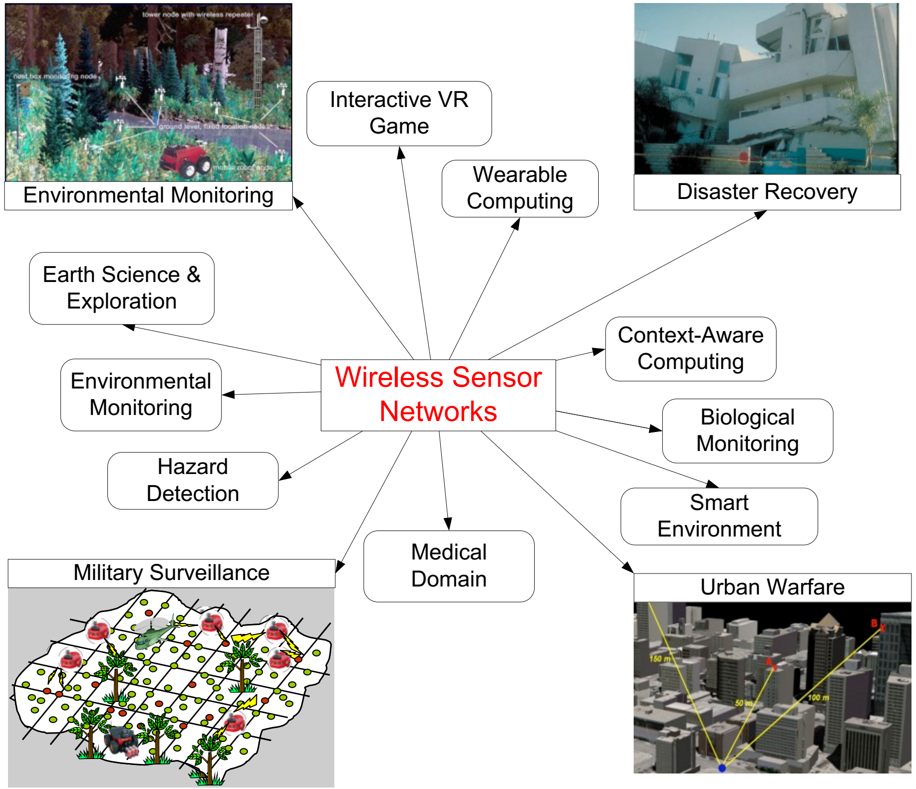




Ref. [Introduction_1] p. 102 - 105

WSN Applications

- Indoor/Outdoor Environmental Monitoring
  - Habitat Monitoring
  - Structural Monitoring
  - Precision Agriculture
- Triggered Events
  - Detection/Notification
- Military Applications
  - Battlefield Surveillance
- Health Monitoring



Wireless Sensor Networks

Environmental Monitoring

Interactive VR Game

Wearable Computing

Disaster Recovery

Earth Science & Exploration

Context-Aware Computing

Environmental Monitoring

Biological Monitoring

Hazard Detection

Smart Environment

Military Surveillance

Medical Domain

Urban Warfare

Ref. [Introduction_1] p. 102 - 105

Some Existing Applications

- Create a macroscope
  - Deployed on Redwood Trees
  - Great Duck Island
  - Tracking zebra
  - Monitor volcanic eruptions

Operational Challenges of Wireless Sensor Networks

- Energy Efficiency
- Limited storage and computation
- Low bandwidth and high error rates
- Errors are common
  - Wireless communication
  - Noisy measurements
  - Node failure are expected
- Scalability to a large number of sensor nodes
- Survivability in harsh environments
- Experiments are time- and space-intensive

Ref. [Introduction_1] p. 102 - 105

Characteristics of Wireless Sensor Networks

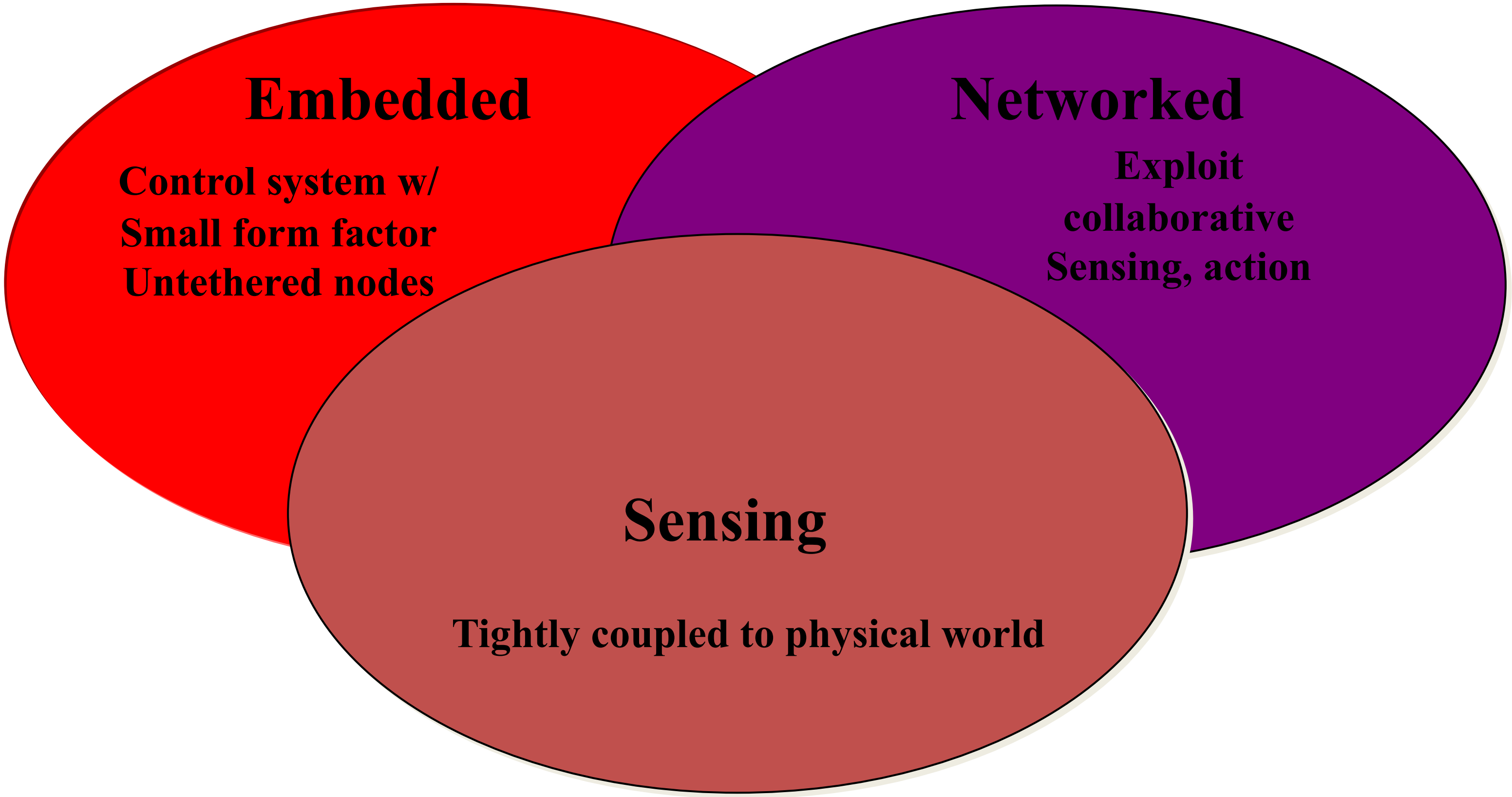
- Limited in
  - Energy
  - Computation
  - Storage
  - Transmission Range
  - Bandwidth
- Characteristics
  - Self-organize
  - Random Deployment
  - Cooperating
  - Local Computation

Ref. [Introduction_1] p. 102 - 105

Enabling Technologies

Embed numerous distributed devices to monitor and interact with physical world

Network devices to coordinate and perform higher-level tasks



Embedded

Control system w/
Small form factor
Untethered nodes

Networked

Exploit
collaborative
Sensing, action

Sensing

Tightly coupled to physical world

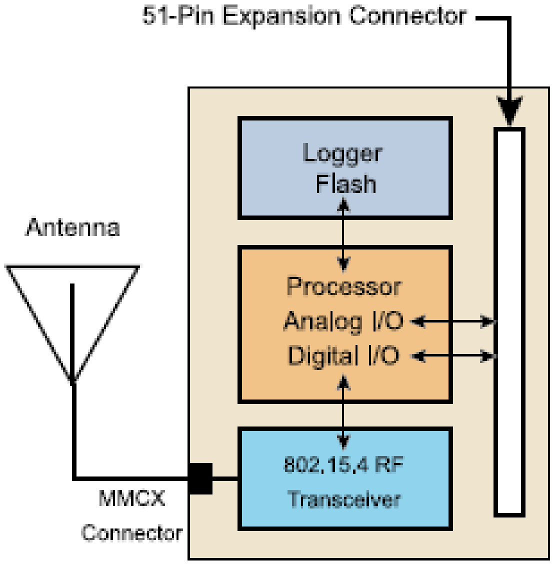
Exploit spatially and temporally dense, in situ, sensing and actuation

Hardware Constraints

- Power, size, and cost constrained
  - Small memory
  - Slow clock cycles of microcontroller

One Example Sensor Node - *MicaZ* Mote

- Developed at UC Berkeley
- Fabricated by Crossbow Inc.
- Integrated Wireless Transceiver
- CPU
  - MPR2400, based on Atmega128L
  - 8MHz
- Memory
  - 4KB of primary memory (SRAM)
  - 128KB of program space (ROM)
  - 512KB Flash Memory
- Transmit Data Rate
  - 250kbps
- Transmission Range
  - Outdoor: 75m – 100m
  - Indoor: 20m - 30m
- Frequency Band
  - 2.4GHz

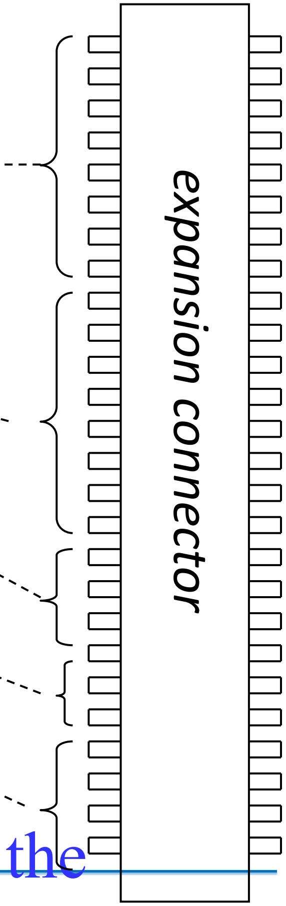


MPR2400 Block Diagram

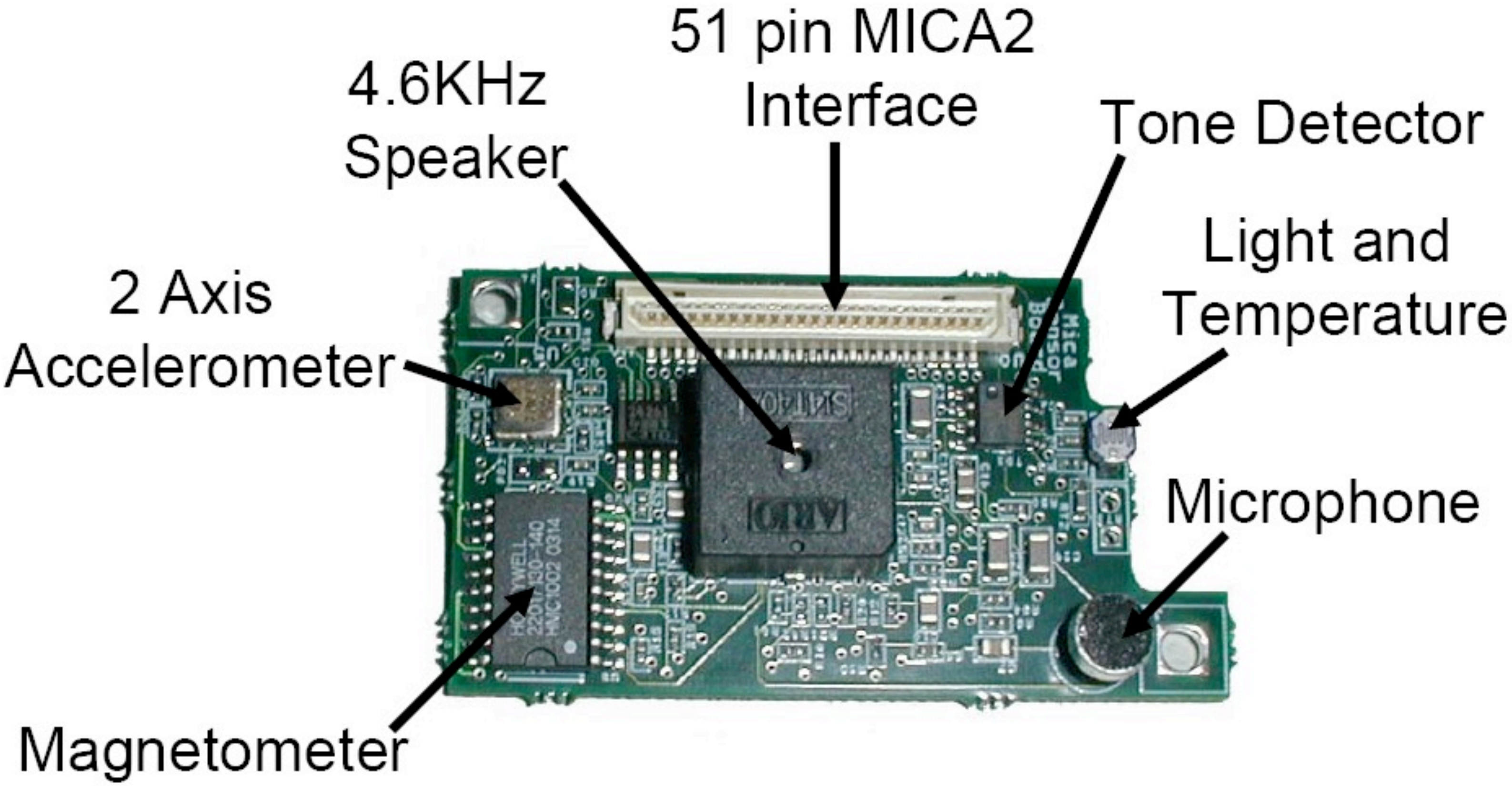
http://www.xbow.com/Products/productdetails.aspx?sid=164

I/O Sub-System

- The I/O subsystem interface consists of a 51-pin expansion connector
  - eight analog lines,
  - eight power control lines,
  - three pulse-width-modulated lines,
  - two analog compare lines,
  - four external interrupt lines,
  - an I2C-bus from Philips Semiconductor,
  - an SPI bus,
  - a serial port,
  - a collection of lines dedicated to programming the microcontrollers.



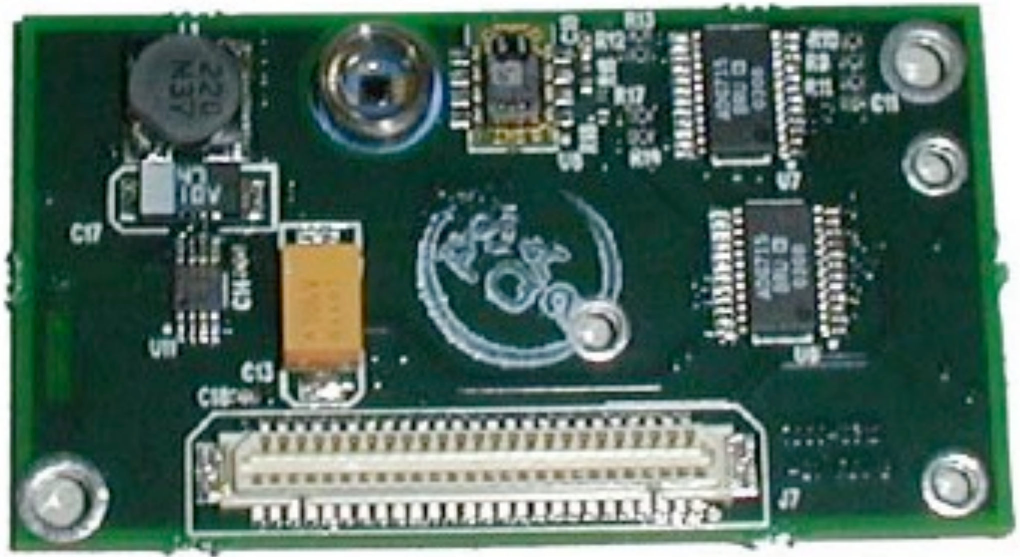
One Example Sensor Board - MTS310



http://www.xbow.com/Products/productdetails.aspx?sid=177

One More Example of Sensor Board - MTS400/420

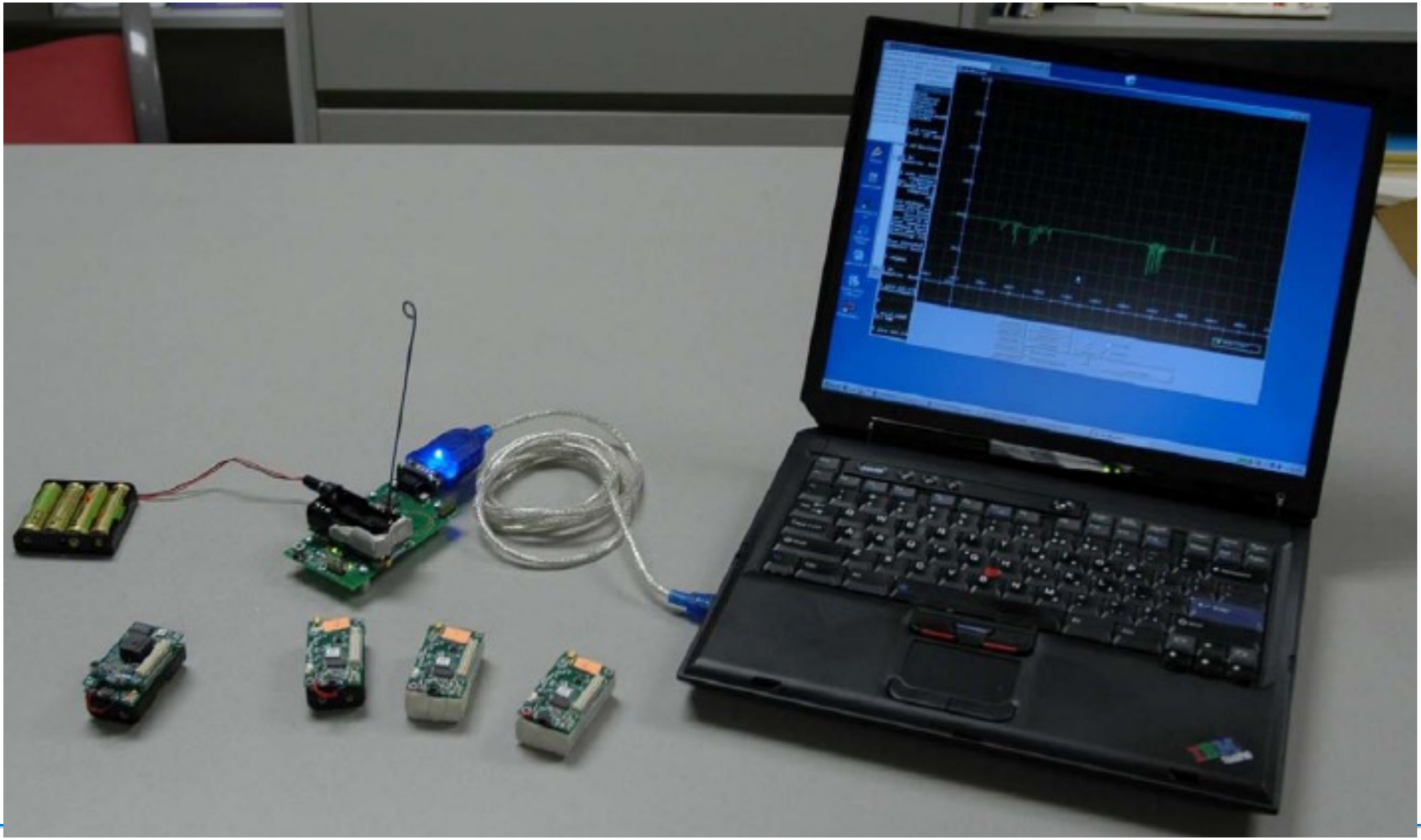
- Besides the functions of MTS 300, it mainly adds GPS functionality



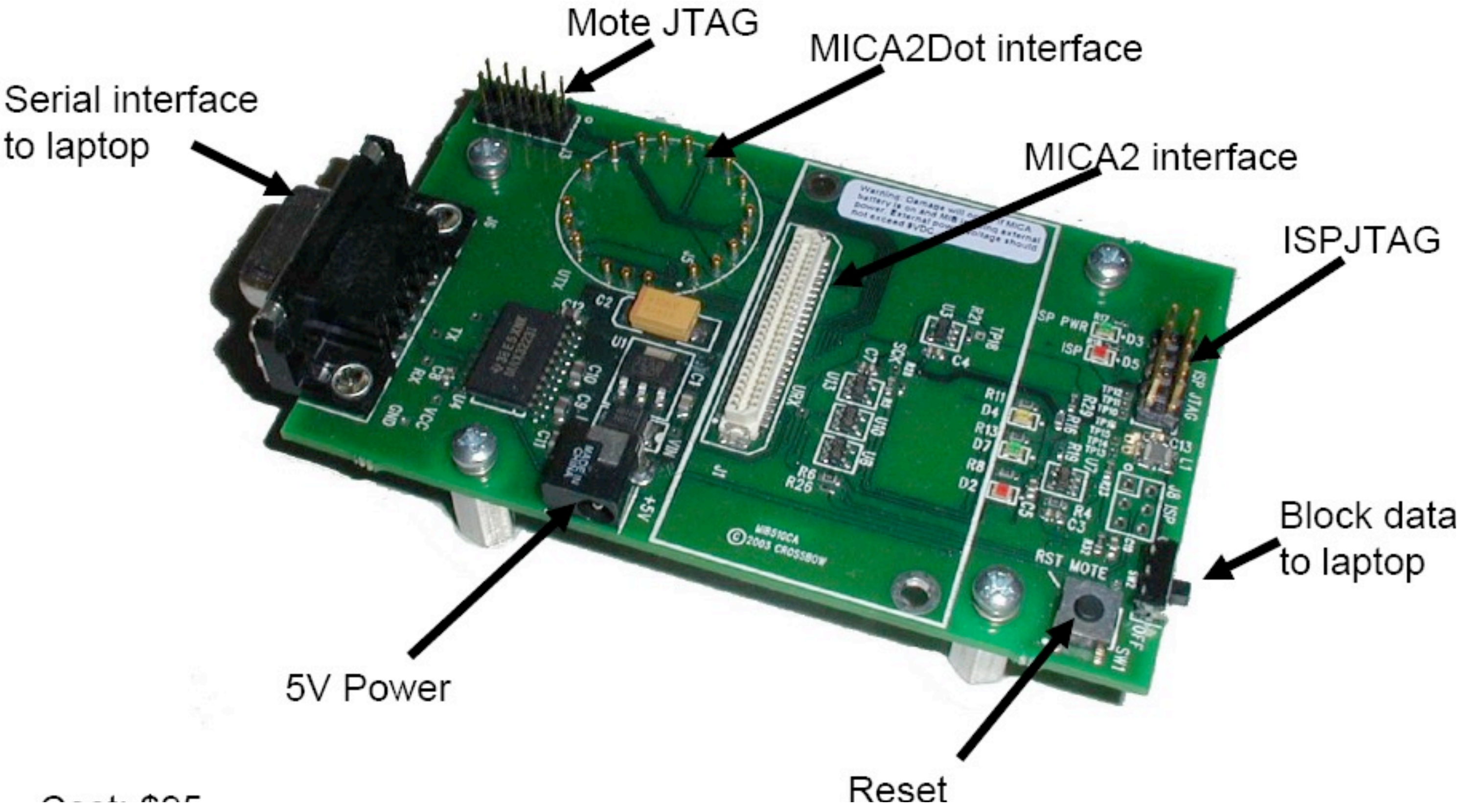
- Example GPS Reading
  - http://firebug.sourceforge.net/gps_tests.htm

http://www.xbow.com/Products/productdetails.aspx?sid=177

Hardware Setup Overview



Programming Board (MIB520)



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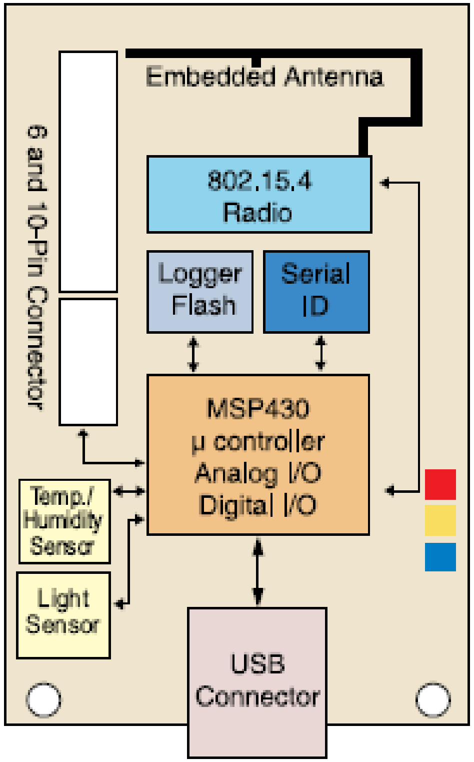
TelosB



- http://www.xbow.com/Products/productdetails.aspx?sid=252

TelosB Architecture

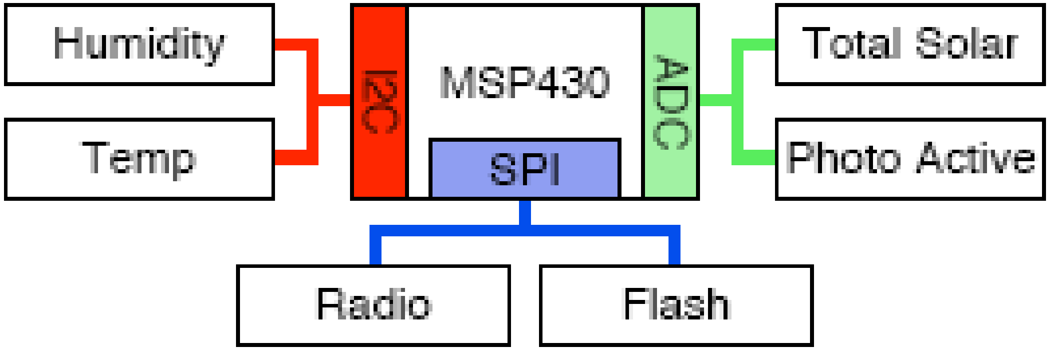
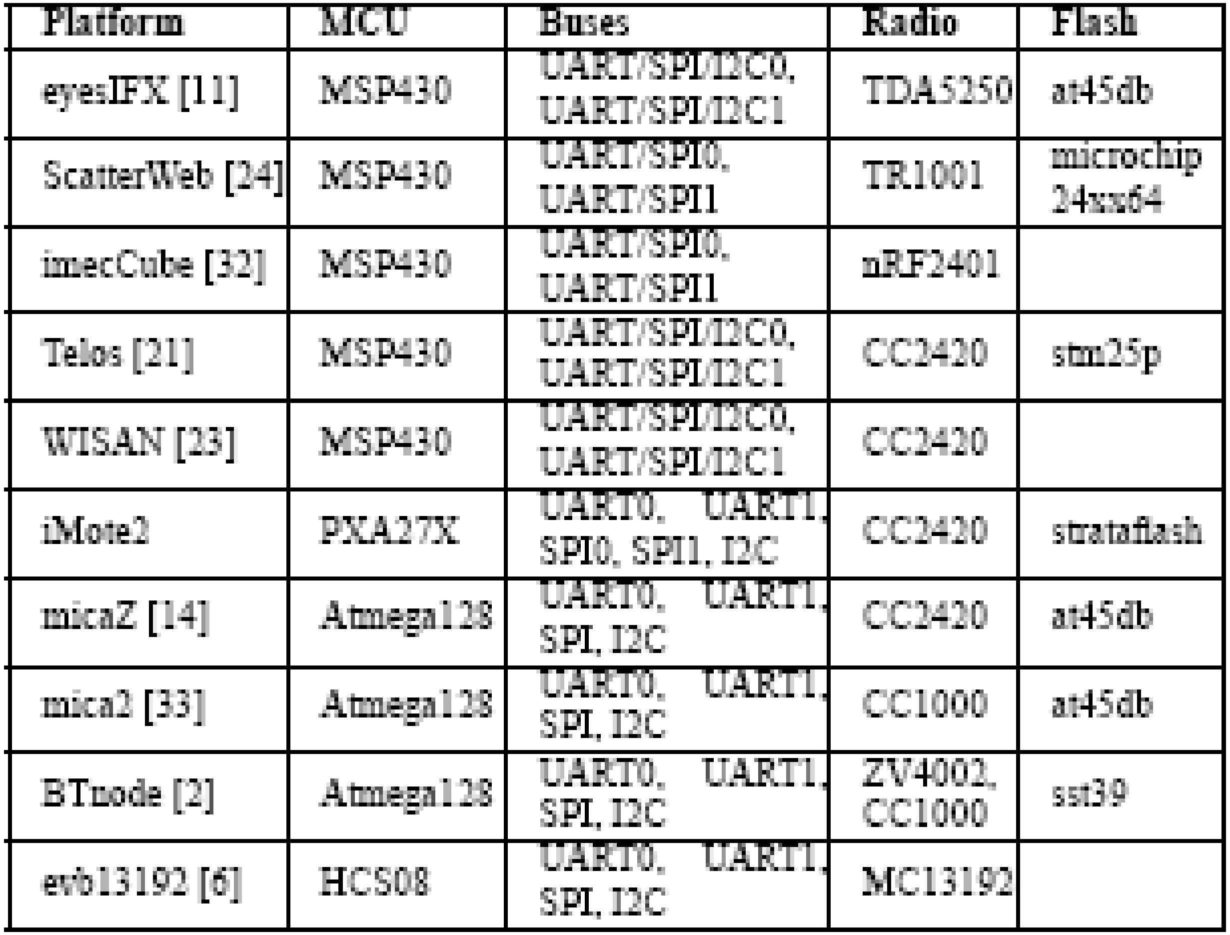


Figure 2: The application uses six peripherals: two SPI devices, two I2C sensors and two ADC sensors. The two I2C sensors are on the same chip (same I2C address), but require separate sensing command sequences.

- [Energy_1]: Figure 2

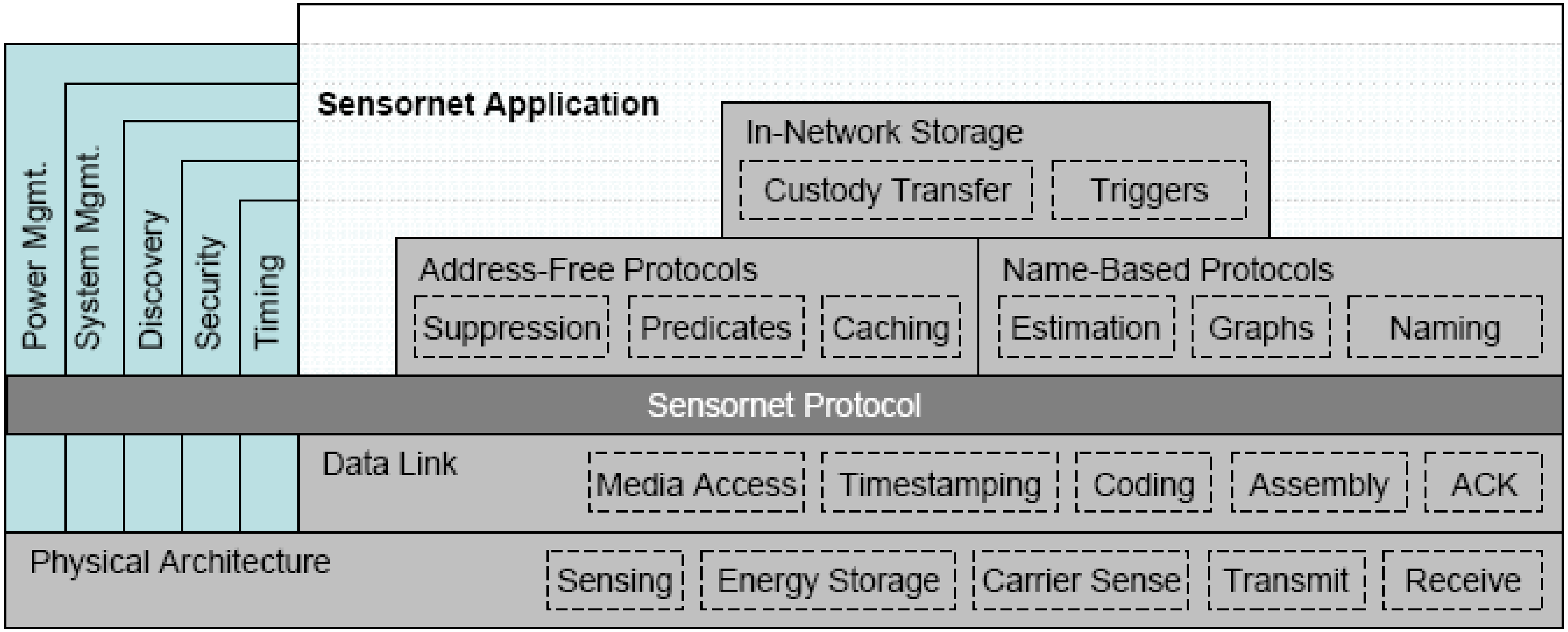
Typical WSN Platforms



Platform	MCU	Buses	Radio	Flash
eyesIFX [11]	MSP430	UART/SPI/I2C0, UART/SPI/I2C1	TDA5250	at45db
ScatterWeb [24]	MSP430	UART/SPI0, UART/SPI1	TR1001	microchip 24xx64
imecCube [32]	MSP430	UART/SPI0, UART/SPI1	nRF2401	
Telos [21]	MSP430	UART/SPI/I2C0, UART/SPI/I2C1	CC2420	stm25p
WISAN [23]	MSP430	UART/SPI/I2C0, UART/SPI/I2C1	CC2420	
iMote2	PXA27X	UART0, UART1, SPI0, SPI1, I2C	CC2420	strataflash
micaZ [14]	Atmega128	UART0, UART1, SPI, I2C	CC2420	at45db
mica2 [33]	Atmega128	UART0, UART1, SPI, I2C	CC1000	at45db
BTnode [2]	Atmega128	UART0, UART1, SPI, I2C	ZV4002, CC1000	sst39
evb13192 [6]	HCS08	UART0, UART1, SPI, I2C	MC13192	

Ref: [TinyOS_1]: Table 1

One Proposed WSN Functional Layer Decomposition



- Ref: Fig. 1.1 of J. Polastre Dissertation: http://www.polastre.com/papers/polastre-thesis-final.pdf

Architecture to Build WSN Applications

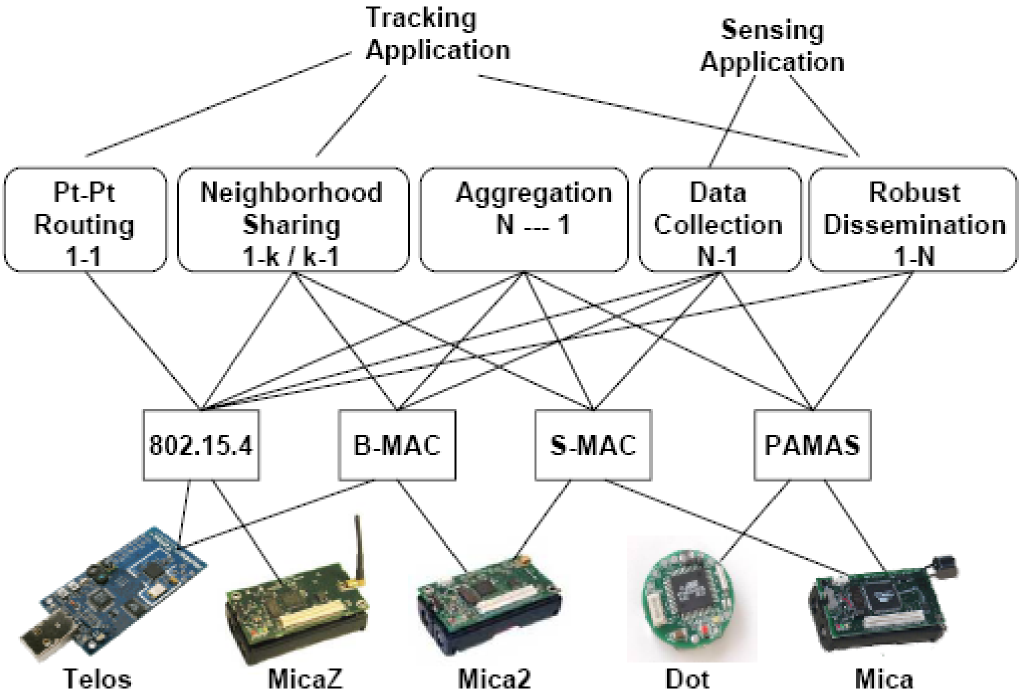


Figure 2.1: Current architecture for building sensornet applications. An application may choose a subset of network services that it requires. Those network protocols specify a set of link protocols that they support, which constrains the platforms available for application developers.

- Ref: Fig. 2.1 of J. Polastre Dissertation: http://www.polastre.com/papers/polastre-thesis-final.pdf