18-345 – Fall 08

Lecture 5
Digital Transmission Fundamentals

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reading: Chapter 3

Outline Physical Layer Lectures

- Digital representation of information
  - Digital representation of analog signals
- Analog versus digital transmission
- Basic properties of dig. transmission
- Fundamental limits of dig. transmission
- Line coding, modulation
  - Amplitude, frequency, and phase modulation
- Properties of transmission media
- Synchronization
- Error detection and error correction

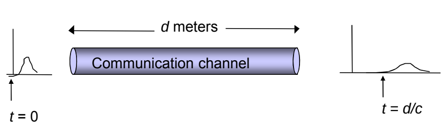
Outline

- Properties of media
- Synchronization

Properties of Media and Digital Transmission Systems

Reading: Section 3.8

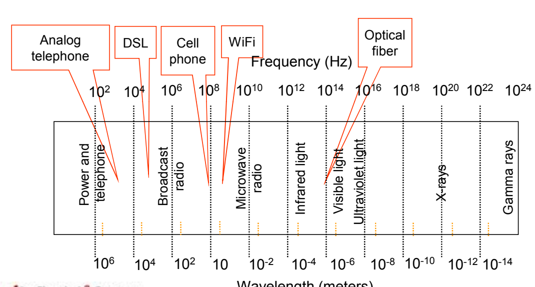
Fundamental Issues in Transmission Media



- Information bearing capacity
  - Amplitude response & bandwidth
    - dependence on distance
  - Susceptibility to noise & interference
    - Error rates & SNRs
- Propagation speed of signal
  - c = 3 x 10^8 meters/second in vacuum
  - $\nu = c/\sqrt{\varepsilon}$, where $\varepsilon > 1$ is the dielectric constant of the medium
  - $\nu = 2.3 \times 10^8$ m/sec in copper wire; $\nu = 2.0 \times 10^8$ m/sec in optical fiber

Communications systems & Electromagnetic Spectrum

- Frequency of communications signals



Wireless & Wired Media

Wireless Media
- Signal energy propagates in space, limited directionality
- Interference possible, so spectrum regulated
- Limited bandwidth
- Simple infrastructure: antennas & transmitters
- No physical connection between network & user
- Users can move

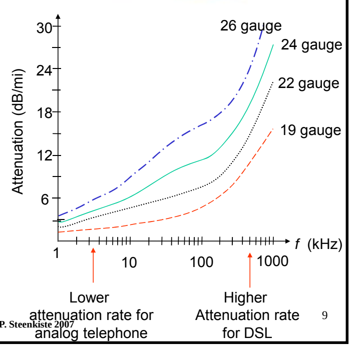
Wired Media
- Signal energy contained & guided within medium
- Spectrum can be re-used in separate media (wires or cables), more scalable
- Extremely high bandwidth
- Complex infrastructure: ducts, conduits, poles, right-of-way

Attenuation

- Attenuation varies with media
  - Dependence on distance is of central importance
- Wired media has exponential dependence
  - Received power at d meters proportional to 10^{-kd}
  - Attenuation in dB = *k d*, where *k* is dB/meter
- Wireless media has power-law dependence
  - Received power at d meters proportional to d^{-n}
  - Attenuation in dB = *n log d*, where *n* is path loss exponent; *n=2* in free space
  - Signal level maintained for much longer distances
  - Space communications possible

Twisted Pair

- Two insulated copper wires arranged in a regular spiral pattern to minimize interference
- Various thicknesses, e.g. 0.016 inch (24 gauge)
- Low cost
- Telephone subscriber loop from customer to CO
- Old trunk plant connecting telephone COs
- Intra-building telephone from wiring closet to desktop



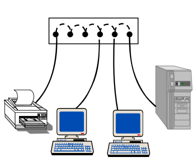
Twisted Pair Bit Rates

Table 3.5 Data rates of 24-gauge twisted pair

Standard	Data Rate	Distance
T-1	1.544 Mbps	18,000 feet, 5.5 km
DS2	6.312 Mbps	12,000 feet, 3.7 km
1/4 STS-1	12.960 Mbps	4500 feet, 1.4 km
1/2 STS-1	25.920 Mbps	3000 feet, 0.9 km
STS-1	51.840 Mbps	1000 feet, 300 m

- Twisted pairs can provide high bit rates at short distances
- Asymmetric Digital Subscriber Loop (ADSL)
  - High-speed Internet Access
  - Lower 3 kHz for voice
  - Upper band for data
  - 64 kbps inbound
  - 640 kbps outbound
- Much higher rates possible at shorter distances
  - Strategy for telephone companies is to bring fiber close to home & then twisted pair
  - Higher-speed access + video

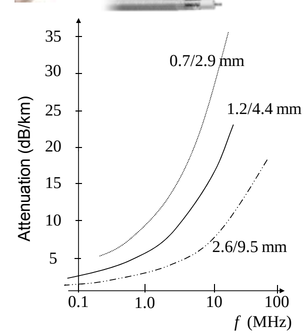
Ethernet LANs



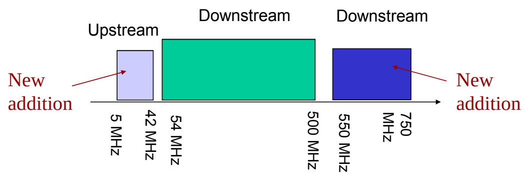
- Category 3 unshielded twisted pair (UTP): ordinary telephone wires
- Category 5 UTP: tighter twisting to improve signal quality
- Shielded twisted pair (STP): to minimize interference; costly
- 10BASE-T Ethernet
  - 10 Mbps, Baseband, Twisted pair
  - Two Cat3 pairs
  - Manchester coding, 100 meters
- 100BASE-T4 *Fast* Ethernet
  - 100 Mbps, Baseband, Twisted pair
  - Four Cat3 pairs
  - Three pairs for one direction at-a-time
  - 100/3 Mbps per pair;
  - 3B6T line code, 100 meters
- Cat5 & STP provide other options

Coaxial Cable

Twisted pair
- Cylindrical braided outer conductor surrounds insulated inner wire conductor
- High interference immunity
- Higher bandwidth than twisted pair
- Hundreds of MHz
- Cable TV distribution
- Long distance telephone transmission
- Original Ethernet LAN medium

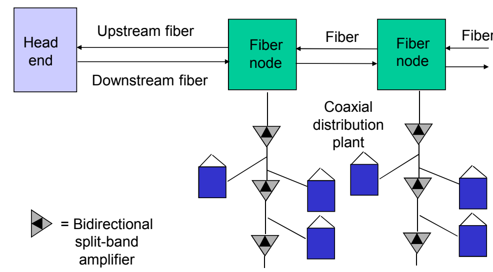


Cable Modem & TV Spectrum

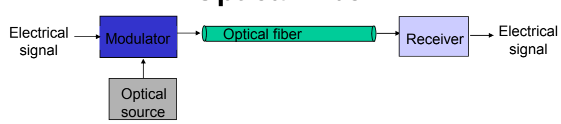


- Cable TV network originally unidirectional
- Cable plant needs upgrade to bidirectional
- 1 analog TV channel is 6 MHz, can support very high data rates
- Cable Modem: *shared* upstream & downstream
  - 5-42 MHz upstream into network; 2 MHz channels; 500 kbps to 4 Mbps
  - >550 MHz downstream from network; 6 MHz channels; 36 Mbps

New Cable Network Topology

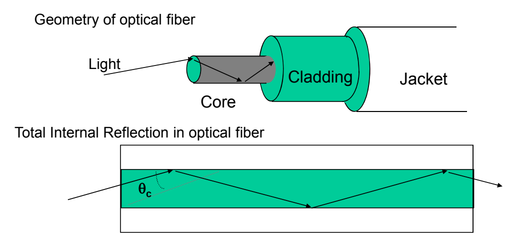


Optical Fiber



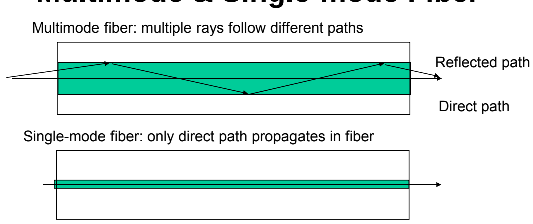
- Light sources (lasers, LEDs) generate pulses of light that are transmitted on optical fiber
  - Very long distances (>1000 km)
  - Very high speeds (>40 Gbps/wavelength)
  - Nearly error-free (BER of 10^{-15})
- Profound influence on network architecture
  - Dominates long distance transmission
  - Distance less of a cost factor in communications
  - Plentiful bandwidth for new services

Transmission in Optical Fiber



- Very fine glass cylindrical core surrounded by concentric layer of glass (cladding)
- Core has higher index of refraction than cladding
- Light rays incident at less than critical angle θ_c is completely reflected back into the core

Multimode & Single-mode Fiber



- Multi Mode: Thicker core, shorter reach
  - Rays on different paths interfere causing dispersion & limiting bit rate
- Single Mode: Very thin core supports only one mode (path)
  - More expensive lasers, but achieves very high speeds

Optical Fiber Properties

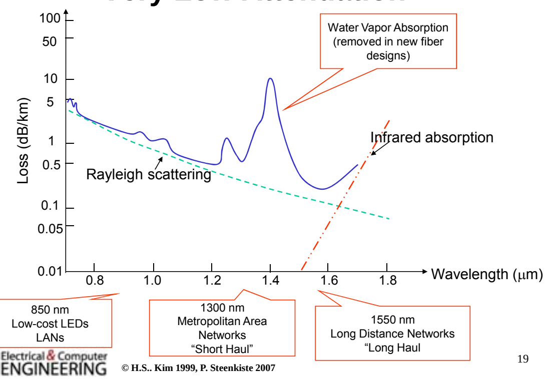
Advantages

- ***Very low attenuation***
- ***Noise immunity***
- ***Extremely high bandwidth***
- Security: Very difficult to tap without breaking
- No corrosion
- More compact & lighter than copper wire

Disadvantages

- New types of optical signal impairments & dispersion
  - Polarization dependence
  - Wavelength dependence
- Limited bend radius
  - If physical arc of cable too high, light lost or won't reflect
  - Will break
- Difficult to splice
- Mechanical vibration becomes signal noise

Very Low Attenuation



Huge Available Bandwidth

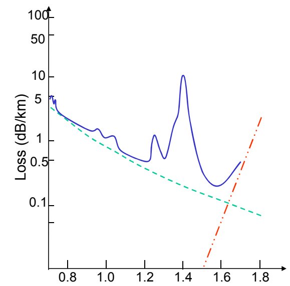
- Optical range from λ_1 to $\lambda_1+\Delta\lambda$ contains bandwidth

$$B = f_1 - f_2 = \frac{v}{\lambda_1} - \frac{v}{\lambda_1 + \Delta\lambda}$$

$$= \frac{v}{\lambda_1}\left\{\frac{\Delta\lambda/\lambda_1}{1+\Delta\lambda/\lambda_1}\right\} \approx \frac{v\Delta\lambda}{\lambda_1^2}$$

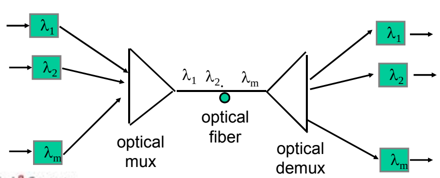
- Example: λ_1 = 1450 nm $\lambda_1+\Delta\lambda$ =1650 nm:

$$B = \frac{2(10^8)\text{m/s } 200\text{nm}}{(1450\text{ nm})^2} \approx 19\text{ THz}$$

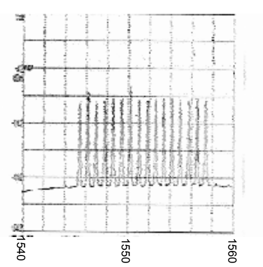


Wavelength-Division Multiplexing

- Different wavelengths carry separate signals
- Multiplex into shared optical fiber
- Each wavelength like a separate circuit
- A single fiber can carry 160 wavelengths, 10 Gbps per wavelength: 1.6 Tbps!



Coarse & Dense WDM



Coarse WDM

- Few wavelengths 4-8 with very wide spacing
- Low-cost, simple

Dense WDM

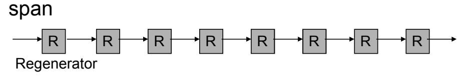
- Many tightly-packed wavelengths
- ITU Grid: 0.8 nm separation for 10Gbps signals
- 0.4 nm for 2.5 Gbps

Regenerators & Optical Amplifiers

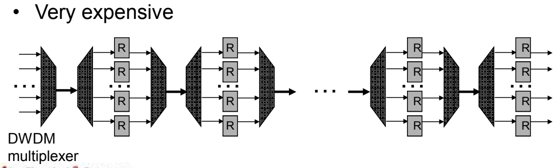
- The maximum span (distance) of an optical signal is determined by the available power & the attenuation:
  - Ex. If 30 dB power available,
  - then at 1550 nm, optical signal attenuates at 0.25 dB/km,
  - so max span = 30 dB/0.25 km/dB = 120 km
- Optical amplifiers amplify optical signal (no equalization, no regeneration)
- Impairments in optical amplification limit maximum number of optical amplifiers in a path
- Optical signal must be regenerated when this limit is reached
  - Requires optical-to-electrical (O-to-E) signal conversion, equalization, detection and retransmission (E-to-O)
  - Expensive
- Severe problem with WDM systems

DWDM & Regeneration

- Single signal per fiber requires 1 regenerator per span

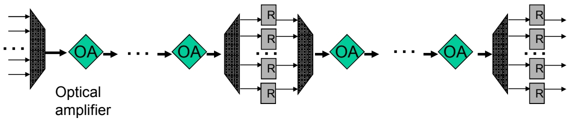


- DWDM system carries many signals in one fiber
- At each span, a separate regenerator required per signal
- Very expensive



Optical Amplifiers

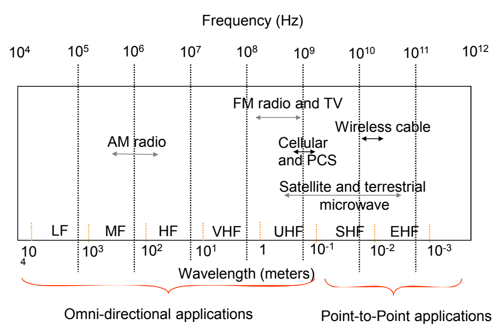
- Optical amplifiers can amplify the composite DWDM signal without demuxing or O-to-E conversion
- Erbium Doped Fiber Amplifiers (EDFAs) boost DWDM signals within 1530 nm to 1620 nm range
  - Spans between regeneration points >1000 km
  - Number of regenerators can be reduced dramatically
- Dramatic reduction in cost of long-distance communications



Radio Transmission

- Radio signals: antenna transmits sinusoidal signal (“carrier”) that radiates in air/space
- Information embedded in carrier signal using modulation, e.g. QAM
- Communications without tethering
  - Cellular phones, satellite transmissions, Wireless LANs, Radio/TV broadcast
- Multipath propagation causes fading
- Interference from other users
- Spectrum regulated by national & international regulatory organizations

Radio Spectrum



Examples

Cellular Phone
- Allocated spectrum
- First generation:
  - 800, 900 MHz
  - Initially analog voice
- Second generation:
  - 1800-1900 MHz
  - Digital voice, messaging

Wireless LAN
- Unlicensed ISM spectrum
  - Industrial, Scientific, Medical
  - 902-928 MHz, 2.400-2.4835 GHz, 5.725-5.850 GHz
- IEEE 802.11 LAN standard
  - 11-54 Mbps

Point-to-Multipoint Systems
- Directional antennas at microwave frequencies
- High-speed digital communications between sites
- High-speed Internet Access Radio backbone links for rural areas

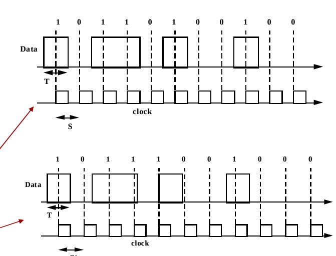
Satellite Communications
- Geostationary satellite @ 36000 km above equator
- Relays microwave signals from uplink to downlink
- Long distance telephone
- Satellite TV broadcast

Synchronous and Asynchronous Data Transmission

Reading: Appendix 3A

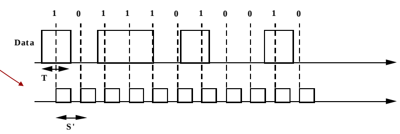
Synchronization

- Synchronization of clocks in transmitters and receivers.
  - clock drift causes a loss of synchronization
- Example: assume ‘1’ and ‘0’ are represented by V volts and 0 volts respectively
  - Correct reception
  - Incorrect reception due to slow clock at the receiver



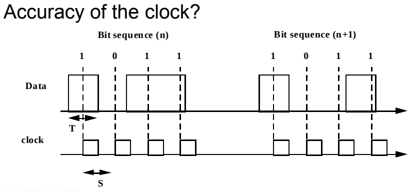
Synchronization (cont')

- Incorrect reception due to faster clock
- How to avoid a loss of synchronization?
  - Asynchronous transmission
  - Synchronous transmission



Asynchronous Transmission

- Avoids synchronization loss by
  - specifying a short maximum length for the bit sequences (so that clock doesn't drift much within sequence)
  - and resetting the clock in the beginning of each bit sequence (by using a 'start bit')
- Accuracy of the clock?



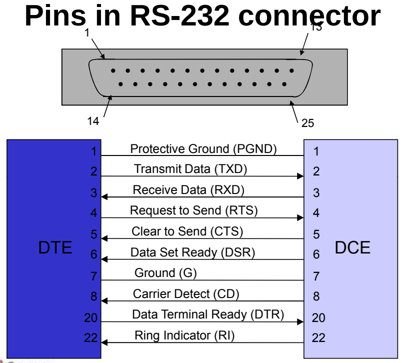
Asynchronous transmission: ASCII code

- ASCII (American National Standard Code for Information Interchange) code
  - 7 bits to represent 128 letters, symbols, and control characters. (i.e. A='1000001', CR(Carriage Return)='0001101')
  - Asynchronous transmission sends sequences of 8 bits=one start bit + 7 ASCII bits.
  - some systems add one parity bit to make number of '1' to be even number
  - i.e. '11001011'1 or '10100110'0

Recommended Standard (RS) 232

- for short distance (less than 15 meters) at up to 38,400 bps.
  - uses bipolar modulation ('0' = voltage between +3V and +25 V and '1'=voltage between -3V and -25V)
- Serial line interface between computer and modem or similar device
- Data Terminal Equipment (DTE): computer
- Data Communications Equipment (DCE): modem
- Mechanical and Electrical specification

Pins in RS-232 connector

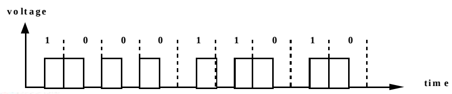


RS-232-C

- DTE to DCE
  - DTE sends data on TXD if DSR=0.
  - DCE can stop DTE's transmission by setting DSR=1
  - if CTS is connected, DTE can transmit only when CTS=0.
- DCE to DTE:
  - DCE sends data on RXD if DTR=0.
  - if RTS is connected, DCE can transmit only when RTS=0.

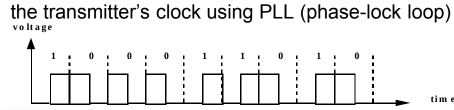
Synchronous Transmission

- Overcomes the inefficiency of the asynchronous transmission.
- Improves efficiency by transmitting longer sequences of bits, called packets (variable length).
- Requires extra information to indicate the end of the packet.



Synchronous Transmission

- Synchronization problem due to long packets
- Packet contains clock information in addition to the data
  - i.e. Manchester encoding, self-synchronizing codes
  - R transitions per second for R bits per second transmission
  - R transitions/sec contains a sine wave with R Hz.
  - R Hz sine wave is used to synch receiver clock to the transmitter's clock using PLL (phase-lock loop)



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