EECS, University of Ottawa

CEG3185 –Winter 2021

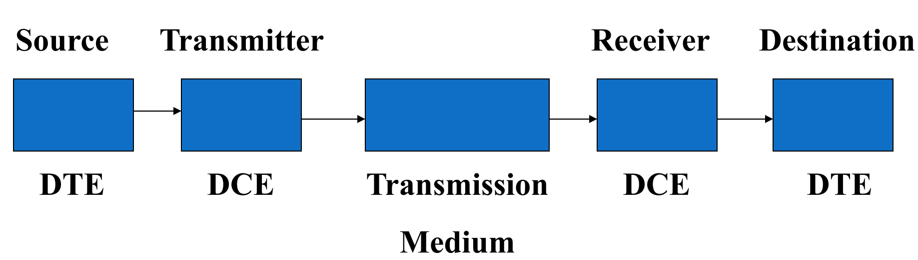
Introduction to Data Communication & Networking

Physical Layer

Note: some material in the slides has been taken from various other sources

1

Elements of Physical Layer



- **Data Terminating Equipment (DTE)**
- **Data Circuit Terminating Equipment (DCE)**

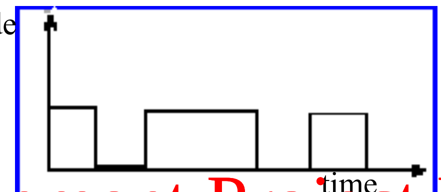
2

Continuous signal vs discrete signal

amplitude

Continuous signal (e.g. speech) => 类比 Analog signal

amplitude

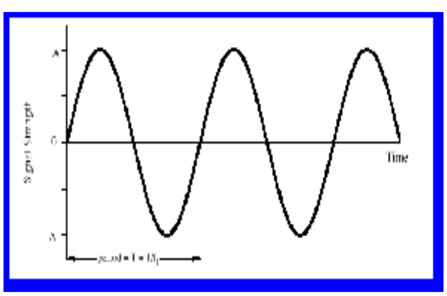


Discrete signal (e.g. binary 1s and 0s) => Digital signal

3

Periodic signal

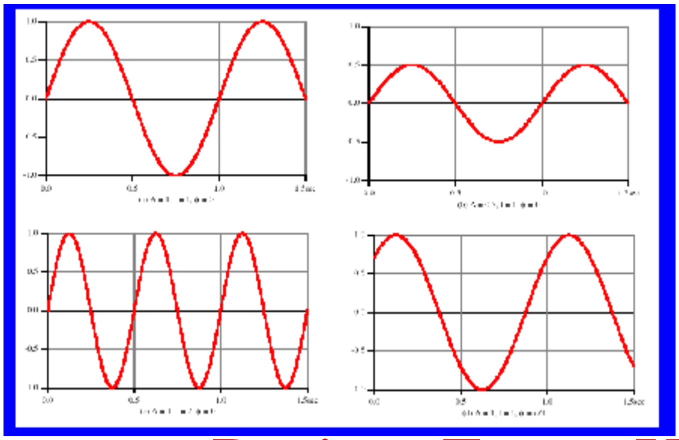
- A signal s(t) is periodic if and only if s(t+T)=s(t) for all t where T is the period of the signal
- Example: sine wave s(t)



- $s(t) = A\sin(2\pi ft + \phi)$
- Parameters:
  - Amplitude: A
  - Frequency: f
  - Phase : ϕ

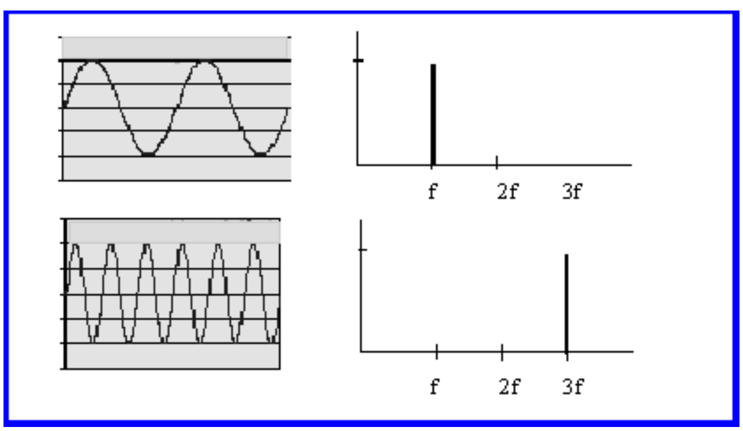
4

Varying the sine wave parameters



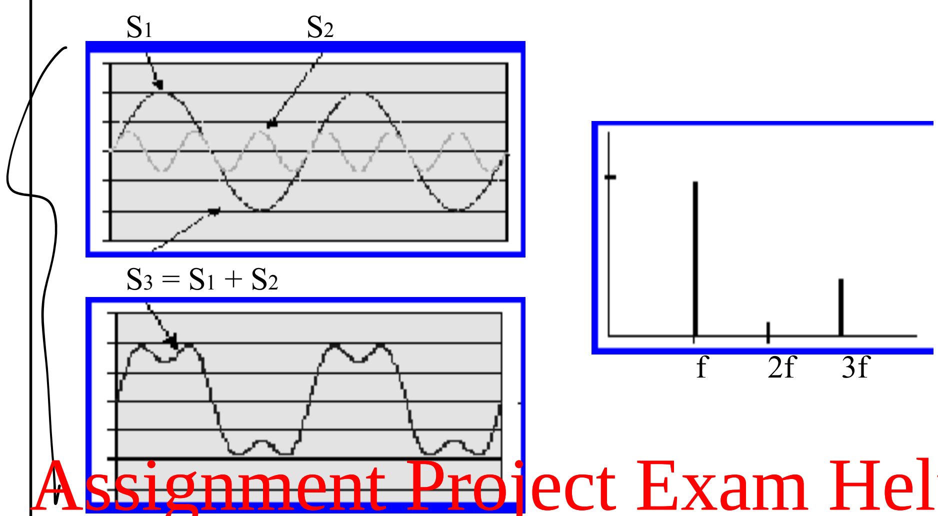
5

Time domain vs frequenc



6

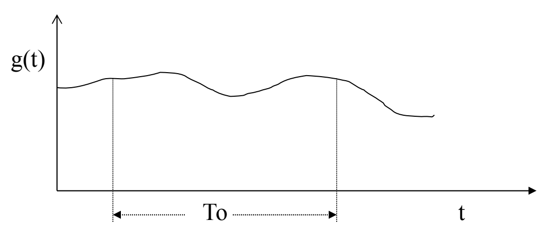
Frequency components



7

傅立叶级数

Fourier Series



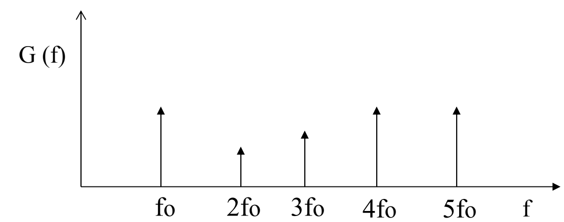
$$g(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos(n\omega_0 t + \phi_n)$$

$$\omega_0 = \frac{2\pi}{T_0}$$

8

离散光谱

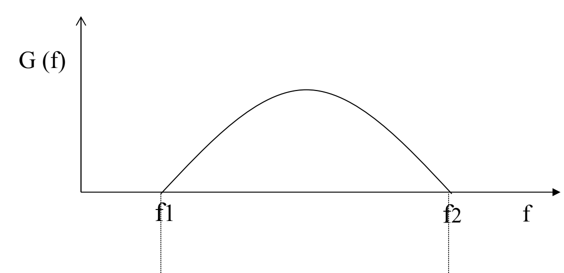
Discrete Spectrum



$f_o = 1 / T_o$

9

Spectrum of Sign



Spectrum of Signal: Range of frequencies it has energy/power content

带宽

Absolute Bandwidth: Width of its spectrum ($= f_2 - f_1$)

10

Spectrum of Signal (2)

- **Band-limited Signal**: A signal with finite Absolute Bandwidth
- All band-limited signals expand from - infinity to + infinity in time domain --> No real signal can be band-limited
- **Effective Bandwidth:** Area of spectrum where MOST of the signal bandwidth is contained

11

Channel capacity (通道容量 se)

Nyquist Formula

$C = 2W\log_2 M$

where

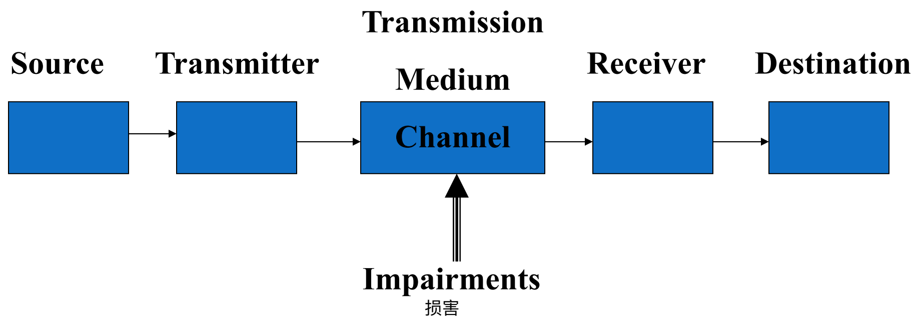
W = bandwidth in hertz

M = number of discrete signal levels

C = theoretical maximum capacity in bits per second

12

Elements of Physical Layer



13

Signal Impairments

Impact:

- degrade the signal quality for analog signals
- introduce errors in digital signals (i.e. 0 may be changed to 1 and vice-versa)

Types:

- signal attenuation 衰减
- delay distortion 失真
- noise

14

Attenuation

衰减

振幅

The amplitude of signal decreases with distance over any transmission medium

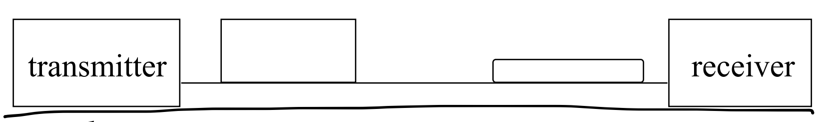
- repeaters and amplifiers are used to restore the signal to its original level

Attenuation is an increasing function of frequency

15

Signal impairme

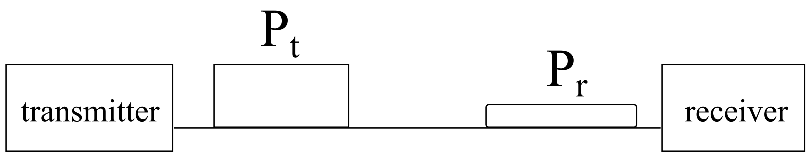
- Fact:
  - 传播
  - As a signal propagates along a transmission path there is loss, attenuation of signal strength.



- Solution:
  - 补偿
  - To compensate the attenuation, we can use devices inserted at various points to "boost" signal's strength (amplifiers).

16

Signal impairments



Attenuation is measured in dB

17

Decibel

- Gains and losses are expressed in decibels (dB)
- Definition:

$$N_{dB} = 10 \log_{10} \frac{P_r}{P_t}$$

where:
N_{dB} = number of decibels
P_r = power at destination
P_t = power at source
$\log_{10}$ = logarithm base 10 (also noted log)

18

Decibel (2)

- Important: the decibel is a measure of relative, not absolute difference.
- For example:
  - a loss from 1000 W to 500 W is a loss of 3 dB.
  - a loss from 10 mW to 5 mW is also a loss of 3 dB.
- In other words, a loss of 3 dB halves the strength; similarly, a gain of 3 dB doubles the strength.

19

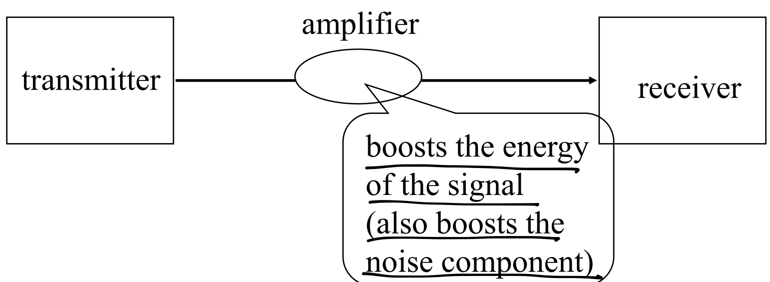
Amplifiers and R

- **Amplifiers**: 放大 Amplify the received signals (this includes useful signal plus noise).
- **Repeaters:** Recover the digital information, and retransmit it.

20

Amplifiers

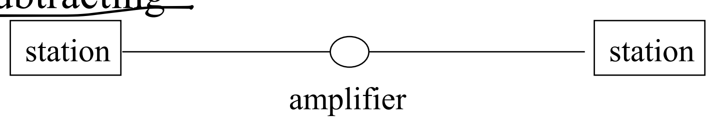
- Can be used with Analog and Digital Communication Systems



21

Decibel

- Useful to determine overall gain or loss in a system. This is done simply by adding or subtracting



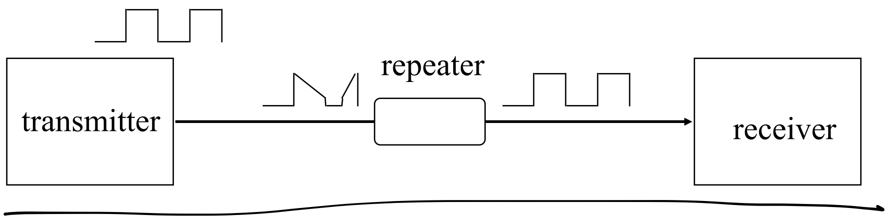
if

- loss on first portion of line is 13 dB
- gain of the amplifier is 30 dB
- loss of second portion of line is 40 dB
- the overall loss is 23 dB (i.e. -13 + 30 - 40 = -23 dB)

22

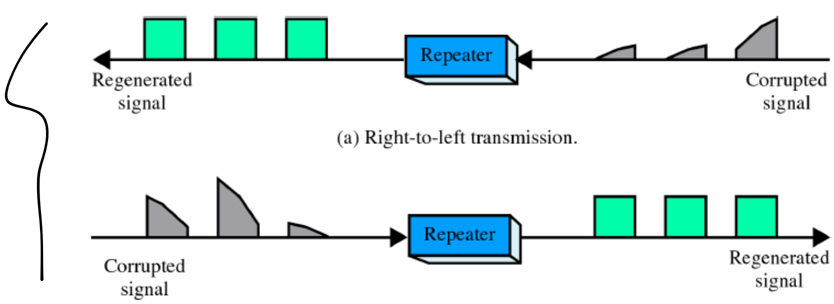
Repeaters

- Can be used with Digital Communication Systems



23

Function of Repea

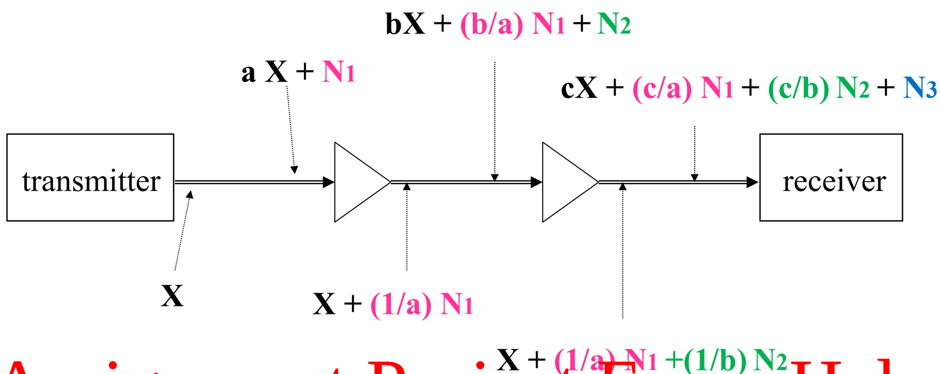


(a) Right-to-left transmission.

(b) Left-to-right transmission.

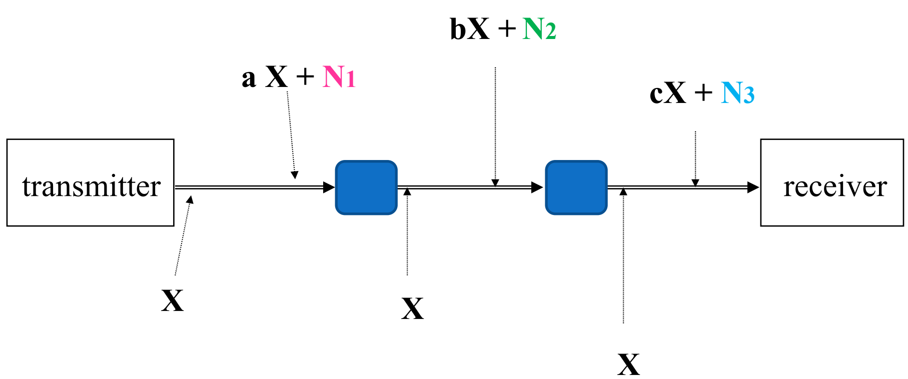
24

Amplifiers



25

Repeaters



26

Noise

- 4 categories
  - thermal noise
  - intermodulation noise
  - crosstalk
  - impulsive noise

1-27

27

Thermal

- Due to the thermal agitation (搅动) of electrons in a conductor (uniformly distributed across the frequency spectrum)
- The amount of thermal noise power in a BW of 1 Hz is given by:

$$N_0 = kT$$

where:
  - N_0 = noise power density
  - k = Boltzmann' s constant = 1.3803 x E-23 J/ºK
  - T = temperature (ºK)

1-28

28

互调
Inter-modulation Noise (1)

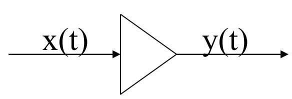
- It is produced when different frequencies are passed through the same non-linear device (e.g. non-linear amplifier)

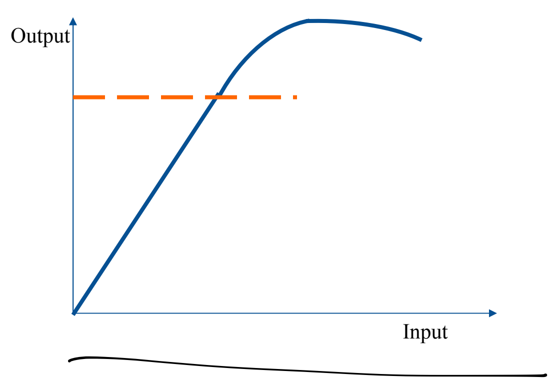
Effect:

produces signals at frequencies that are the multiple, sum or difference of the frequencies the original signal contains.

1-29

29

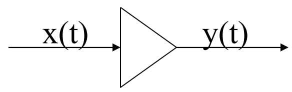




1-30

30

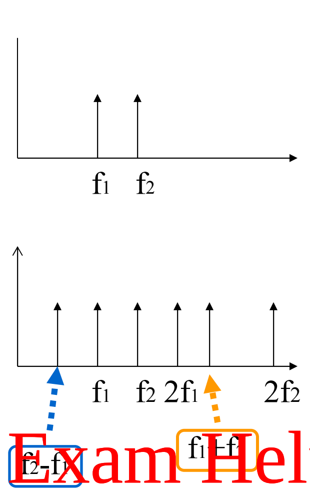
Inter-modulation Noise: Example



$$y(t) = x(t) + a\,\{x(t)\}^2$$

$$x(t) = \cos(2\pi f_1 t) + \cos(2\pi f_2 t)$$

$$\boxed{\begin{aligned} y(t) = {} & \cos(2\pi f_1 t) + \cos(2\pi f_2 t) + (a/2) + \\ & (a/2)\,\{\cos(2\pi 2 f_1 t) + \cos(2\pi 2 f_2 t)\} + \\ & a\,\{\cos(2\pi\,[f_1+f_2]\,t) + \cos(2\pi\,[f_1-f_2]\,t)\} \end{aligned}}$$



1-31

31

串话

Crosstalk

- Unwanted coupling between signal paths
- Example: more than one conversation can be heard.

1-32

32

浮躁
Impulsive Noise

- Non-continuous noise consisting of irregular pulses or noise spikes of short duration and of relatively high amplitude. 振幅

Causes:

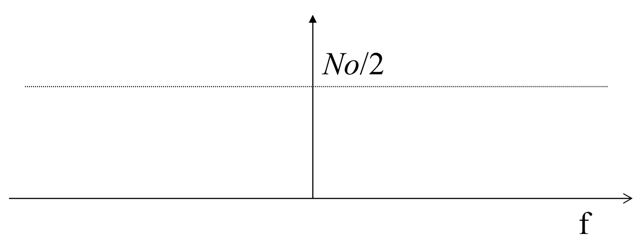
- external electromagnetic disturbances 骚乱 and faults in the communication system

1-33

33

Power Spectra

Additive Whit
Noise (AWGN)



1-34

34

Delay distortion 失真

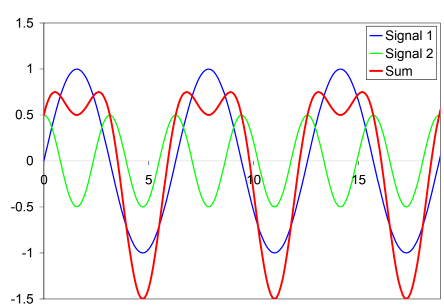
- The speed of propagation 传播 of a sinusoidal 正弦曲线 signal along a transmission line varies with the frequency
  - For a signal composed of more than one frequencies, the signal frequency components arrive at the receiver with different delays from each other
- This distorts the signal
- The effect of delay distortion tends to increase with the size of the signal bandwidth (=> it increases with an increase in transmission rate)
  - the pulses become distorted, spread in time and can spill over to neighboring pulses, making their detection difficult
  - (Intersymbol Interference 符号间干扰) => incorrect interpretation 翻译 of the received signal

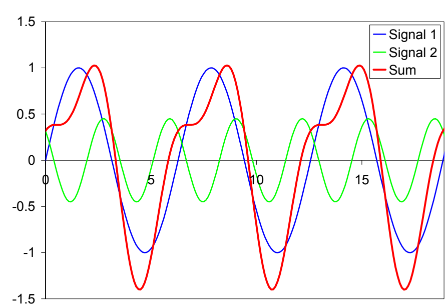
1-35

35

Atmospheric 大气 abso 吸收

- Strength of signal falls off because the atmosphere absorbs some of its energy
- Attenuation 衰减 and delay are greater at higher frequencies, causing distortion



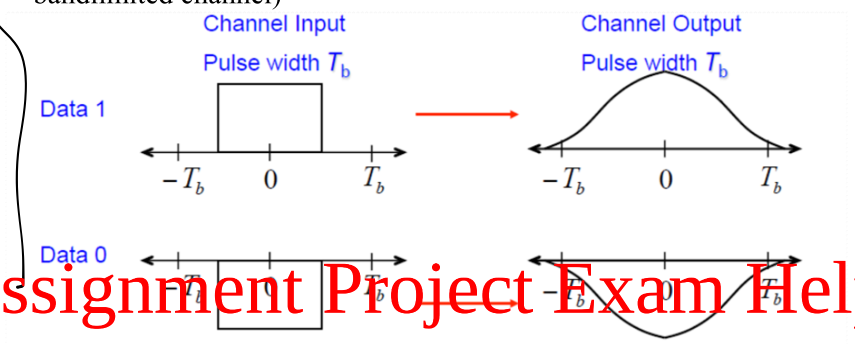


1-36

36

Intersymbol Interference (1)

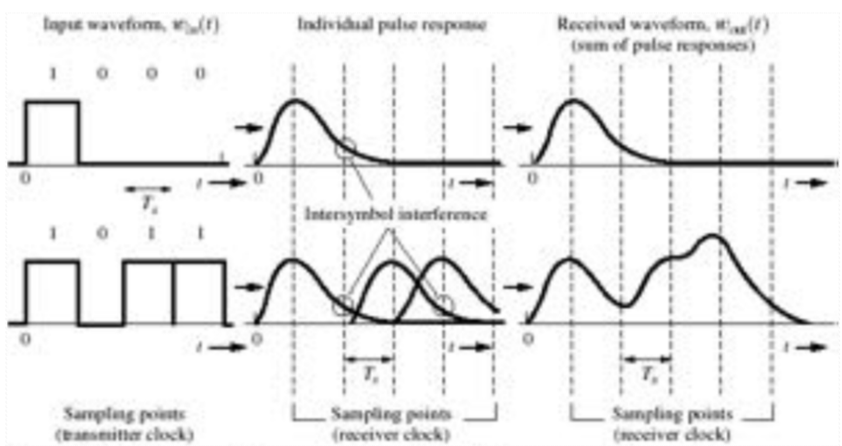
- **Intersymbol interference (ISI)** occurs when a pulse spreads out in such a way that it interferes with adjacent at the sample instant.
- Example: assume polar NRZ line code. The channel outputs are shown as "smeared" (width T_b becomes $2T_b$) pulses (spreading due to bandlimited channel)



1-37

37

Intersymbol Inter



Impact of ISI on received signal of binary communication system

1-38

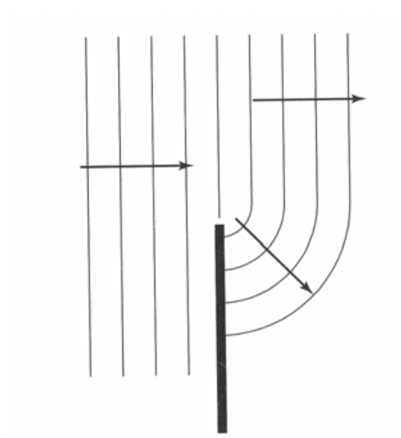
38

Causes of Impairments

- **Reflection** - occurs when signal encounters a surface that is large relative to the wavelength of the signal.
- 衍射 坚不可摧
  Diffraction - occurs at the edge of an impenetrable body that is large compared to wavelength of radio wave.
- 散射
  Scattering – occurs when incoming signal hits an object whose size is in the order of the wavelength of the signal or less.

39

Illustration of knife-ed

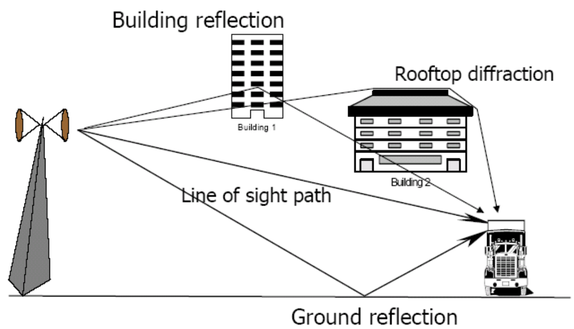


1-40

40

Multipath Propagation

- 障碍 Obstacles reflect signals so that multiple copies of a signal may arrive at the receiver at different times, and therefore with different phases.

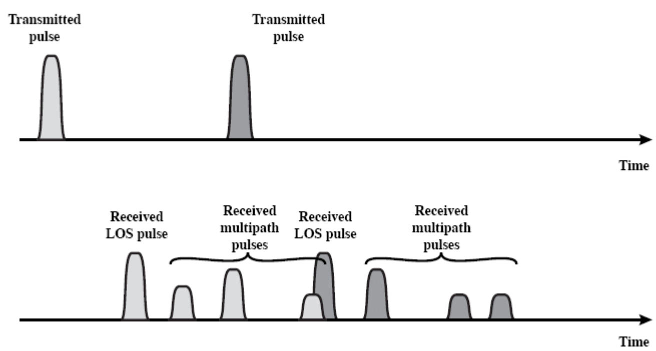


- If phases add 破坏性的 destructively the signal level declines, and vice versa.
- When the transmitter or the receiver moves even short distances (of the order of λ, which is a few 厘米 centimeters for the frequencies used) the signal amplitude can vary greatly.
- Also produces ISI.

1-41

41

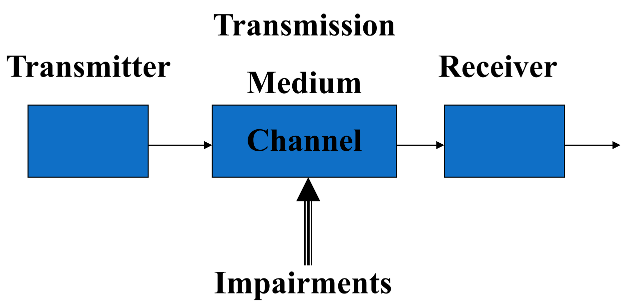
ISI due to Multip



1-42

42

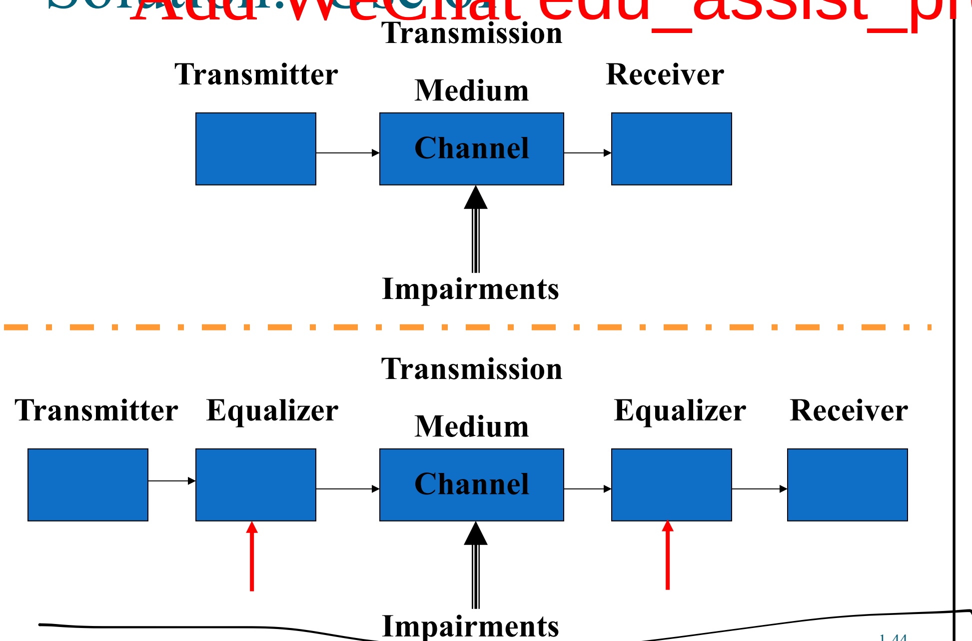
Communication System



1-43

43

Solution: Use of



1-44

44

Adaptive Equalization

- Used to compensate the distortion introduced by the channel
- It basically tries to reverse the unequal response of the channel, both in amplitude and phase, to the frequency components of the transmitted signal
- It is commonly adaptive in the sense that the channel response is periodically estimated and the equalizer adapts accordingly
- It is useful to combat intersymbol interference
- It involves sophisticated digital signal processing algorithms

补偿

战斗

复杂的

1-45

45

Channel capacity W

- Nyquist Formula
  - $C = 2W\log_2 M$

  where
  - W = bandwidth in hertz
  - M = number of discrete signal levels
  - C = capacity in bits per second

1-46

46

Channel capacity with noise

- Shannon-Hartley formula
  - $C = W \log_2(1+S/N)$

  where

  - W = bandwidth in hertz
  - S/N = signal-to-noise ratio
  - C = maximum theoretical capacity in bits per second

1-47

47

类比

Digital vs. Analog n (1)

- Digital technology
  - VLSI product became "low cost"
- Data integrity
  - Example: the use of repeaters guarantees the integrity of the data being transmitted

1-48

48

Digital vs. Analog Transmission (2)

- Capacity utilization 利用率
  - links can be shared (multiplexed)effectively 多路复用
- Security and privacy
  - encryption techniques can be applied easily to digital data

1-49

49

Bit rate and baud ra

- Bit rate:
  - number of bits transmitted per second
- Baud rate:
  - number of signal changes per second
- Relation

bit rate = baud rate * n

where

n = number of bits per change

1-50

50

Transmission media

Transmission me

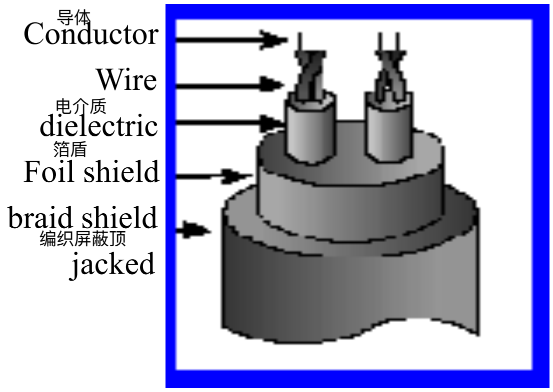
引导的
Guided Transmission media

- 双绞线 twisted pair
- 同轴电缆 coaxial Cable
- 光纤 optical Fiber

Wireless transmission

- microwave
- radio
- 红外线 infrared and millimeter waves
- light-wave transmission

Twisted pair (1)



- Widely used in the telephone network
- Used for either analog and digital transmission

1-53

53

Twisted pair (2)

- Attenuation very strong with frequency
  - analog: amplifiers every 5-6 km
  - digital: repeaters every 2-3 km
- Low noise immunity
  - crosstalk is a problem
  - poor channel characteristics
- Easy to install, repair, ..
- Low cost

1-54

54

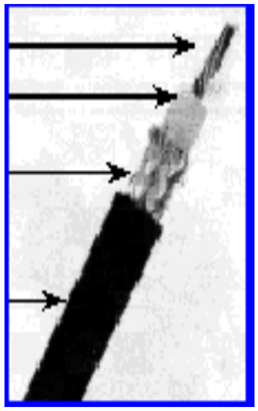
Coaxial cable (1)

铜芯
copper core

绝缘
insulating material

braided outer
编织外导体
conductor

protective plastic
covering



- 基带同轴电缆 Baseband coaxial cable commonly used for digital transmission
- one channel
- 宽频 Broadband coaxial cable commonly used for analog transmission
- multiple channels, e.g. analog 模拟电视 TV, CD-quality audio
- two types:
  - 双 dual cable system
  - single cable system

1-55

55

Coaxial cable (2)

- Attenuation linear with frequency
- Better noise immunity
- Error rate:
  - baseband: 10^{-7}
  - broadband: 10^{-9}
- ~ 1 Km Baseband Cable =?-2 Gbps
- ~100 km Broadband cable => 300-450 MHz
- Moderate cost

1-56

56

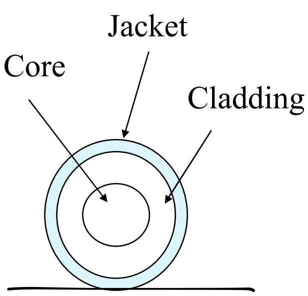
Optical Fiber

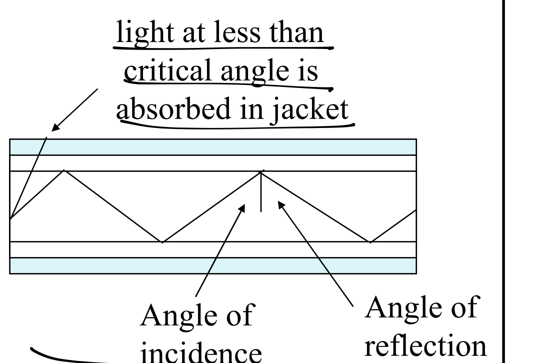
- Physical Description
  - an optical fiber is a thin (2 to 125 µm), flexible medium capable of conducting an optical ray
  - an optical fiber cable has a cylindrical shape and consists of three concentric sections: the core, the 覆层 cladding and the jacket.

1-57

57

Optical Fibers (co





- Idea: refraction principle
- Utilization: light 被困 trapped by total internal reflection when…

1-58

58

Fiber optics (2)

Three components:

- light source (LED or laser diode) 激光二极管
- transmission medium (fiber)
- detector (photodiode) 光电二极管

Two major types of fiber

- multimode fiber (largely used)
- single mode fiber (expensive but can be used for long distances)

1-59

59

Fiber optics(3)

- Attenuation very low
- High noise immunity
- Error rate: 10^{-15}
- ~100 km of fiber => ~2 Gbps
- Unfamiliar technology: high skills required
- Lightweight
- Expensive

1-60

60

Optical Fiber (cont'd)

- Applications
  - Long-Haul trunks 长途
    - average length 900 miles
    - 20,000 to 60,000 voice channels
  - Metropolitan networks 大都市
    - average length 7.8 miles
    - 100,000 voice channels
  - Rural-exchange trunks 农村交流干线
    - 25 to 100 miles
    - less than 5,000 voice channels

Optical Fiber (con

- Applications (cont'd)
  - Subscriber loop 订户
    - fibers running from the central exchange to the subscriber
  - Local Area Networks
    - networks linking 100's and even 1000's of workstations
    - Ethernet, ATM-LAN,...

Optical Fiber (cont'd)

波分复用

- Wavelength Division Multiplexing (WDM)
  - Send more than one wavelengths through the same fiber
  - Allows re-use of fiber

1-63

63

Spectrum Allocation

有价值 商品

Spectrum is valuable commodity; needs to be shared

1-64

64

Spectrum
Allocation

1-65

65

Spectrum Allocation

1-66

66

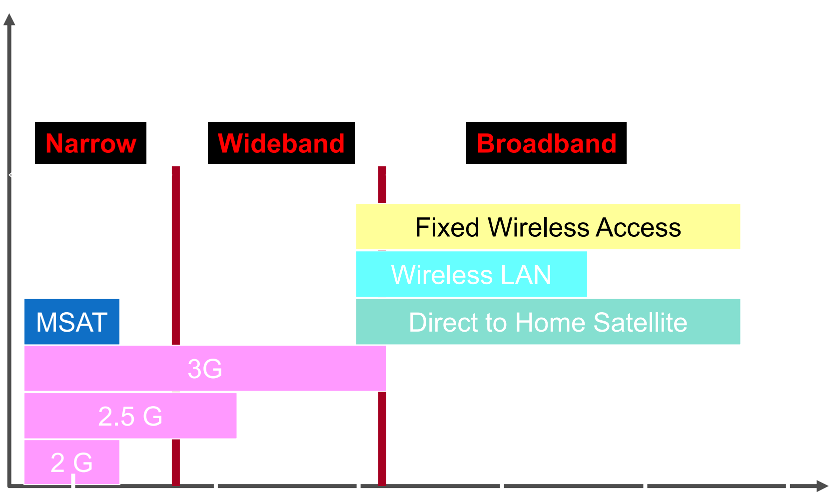
Spectrum Allocation

Band name	Abbreviation	ITU band number	Frequency and Wavelength	Example Uses
Ultra high frequency	UHF	9	300–3,000 MHz 1–0.1 m	Television broadcasts, microwave oven, microwave devices/communications, radio astronomy, mobile phones, wireless LAN, Bluetooth, ZigBee, GPS and two-way radios such as land mobile, FRS and GMRS radios, amateur radio, satellite radio, Remote control Systems, ADSB
Super high frequency	SHF	10	3–30 GHz 100–10 mm	Radio astronomy, microwave devices/communications, wireless LAN, DSRC, most modern radars, communications satellites, cable and satellite television broadcasting, DBS, amateur radio, satellite radio
Extremely high frequency	EHF	11	30–300 GHz 10–1 mm	Radio astronomy, high-frequency microwave radio relay, microwave remote sensing, amateur radio, directed-energy weapon, millimeter wave scanner, wireless LAN (802.11ad)
Terahertz or Tremendously high frequency	THz or THF	12	300–3,000 GHz 1–0.1 mm	Experimental medical imaging to replace X-rays, ultrafast molecular dynamics, condensed-matter physics, terahertz time-domain spectroscopy, terahertz computing/communications, remote sensing

Microwave frequencies: range between 10^9 Hz (1 GHz) to 1000 GHz. Respective wavelengths: 30cm to 0.03 cm.

1-67

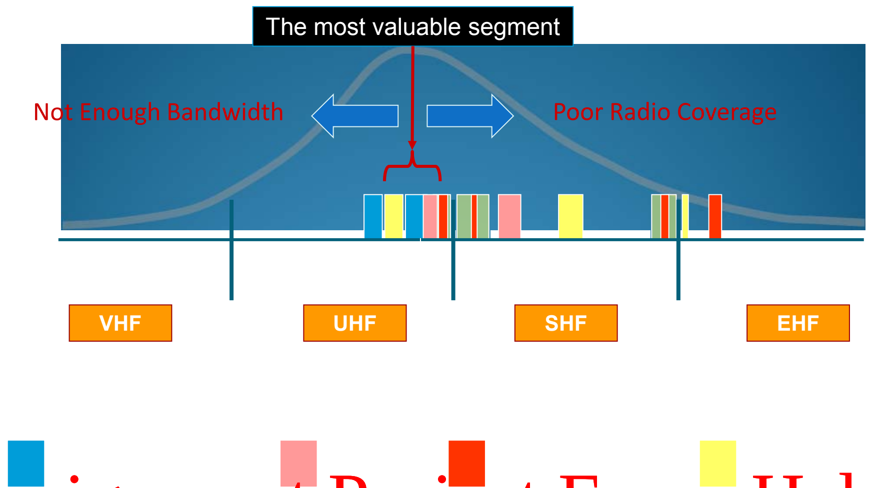
67



1-68

68

Spectrum Cost



1-69

69

Licensed & Unlicensed

Licensed	Unlicensed
800-900 MHz	915 MHz
1800-1900 GHz	2.4 GHz
2 GHz	5 GHz
5 GHz	60 GHz ??
28 GHz	
Cellular/PCS **3G/4G** **WiMax**	**Wireless LAN** **ITS** **IMS Applications**

1-70

70

Licensed and Unlicensed Bands

Licensed

400 MHz
800 MHz
850 MHz
1.4 GHz
1.8 GHz
PCS/PHS/3G 1.9 GHz
2.5 GHz
10.5 GHz
LMDS 24/26/28/32/40 GHz

Unlicensed

900 MHz
2.4 GHz IMS (802.11b/g/n, Bluetooth)
5 GHz UNII (802.11a), DSRC (802.11p)
60 GHz

1-71

71

Employed Freque

- Wireless channel’s behaviour is dependent on the frequency band of the signal.
- Frequency band of operation depends on the availability of spectrum, 天线 antenna characteristics, propagation behavior, and technological preferences.
- Licensed wireless systems operate at 150 MHz, 450 MHz, 800 MHz, 2 GHz, 28 GHz.
- Unlicensed systems at 900 MHz, 2.4 GHz, 5 GHz, [3.1 GHz to 10.3 GHz: UWB], 57 GHz to 64 GHz, optical frequencies.

1-72

72

无线电

Radio transmission

- Radio waves
  - easy to generate, can travel long distances, penetrate buildings at lower part of spectrum, omnidirectional (all directions from the source)

    穿透 全向的
  - widely used for indoor and outdoor communication
- Low noise immunity
  - interference from electrical equipment
  - multipath interference
  - Co/adjacent-channel interference
- Attenuation increases with distance "fast"

1-73

73

Radio transmission

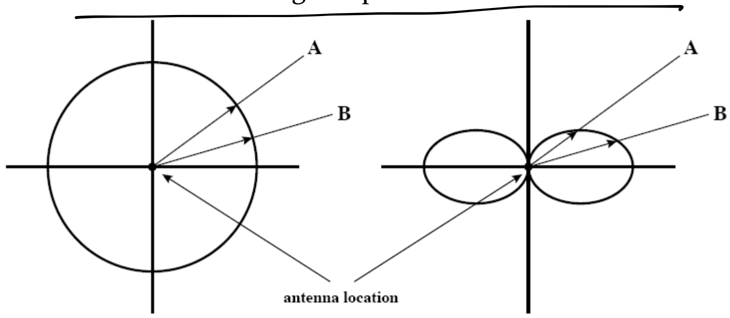
- Radio waves
  - easy to generate, can travel long distances, penetrate buildings at lower part of spectrum, omnidirectional (all directions from the source)
  - widely used for indoor and outdoor communication
- Low noise immunity
  - interference from electrical equipment
  - multipath interference
  - Co/adjacent-channel interference
- Attenuation increases with distance "fast"

1-73

73

Wireless transmis s

- directional -
  - the transmitting antenna 天线 puts out a focused electromagnetic beam 光束
    example: terrestrial microwave 地面微波, satellite
- omnidirectional 全向的
  - the transmitted signal spreads out in all directions



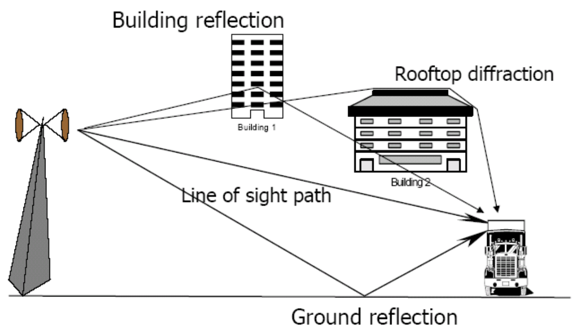
(a) Omnidirectional (b) Directional

1-74

74

Multipath Propagation

- Obstacles reflect signals so that multiple copies of a signal may arrive at the receiver at different times, and therefore with different phases.



- If phases add destructively the signal level declines, and vice versa.
- When the transmitter or the receiver moves even short distances (of the order of λ, which is a few centimeters for the frequencies used) the signal amplitude can vary greatly.
- Also produces ISI.

1-75

75

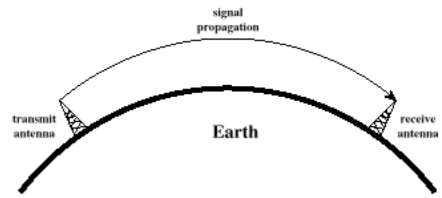
Microwave transmissi

- Microwave transmission is widely used
  - long-distance communication, cellular phones, TV distribution, etc.
- Microwave transmissions can be made easier directional
  - repeaters are needed (for 100-m high towers, repeaters can be spaced 80 km apart)
- Higher signal to noise ratio
- They do not 穿透 penetrate deep into buildings
- Multipath 衰退 fading effect can occur

1-76

76

Terrestrial Microwave



- Physical Description
  - 抛物面
  - parabolic dish
  - ~ 10 feet in diameter
  - 视线
  - line-of-sight transmission
  - maximum distance between 2 antennas (in km):

$$d = 3.57\left(\sqrt{Kh_1} + \sqrt{Kh_2}\right)$$

where
  - h_1 = height of antenna one
  - h_2 = height of antenna two
  - K = 4/3 (adjustment factor)

1-77

77

Terrestrial Microwave (cont'd)

- Applications
  - long-haul communications
  - TV and voice communications
  - transmission in small regions (radius < 10 km)

1-78

78

Terrestrial Microwave (cont'd)

- Transmission Characteristics
  - attenuation is the major source of loss

$$L = 10\log\left(\frac{4\pi d}{\lambda}\right)^2 dB$$

  - where d is the distance and λ is the wavelength, expressed in the same units.

IMPORTANT:

loss varies as the square of the distance

1-79

79

Satellite Microw

- Physical Description
  - a satellite is a **microwave relay station** used to link 2 or more ground-based microwave transmitters/receivers.

中继

  - a single orbiting satellite will operate on a number of frequency bands, called **transponder** channels.

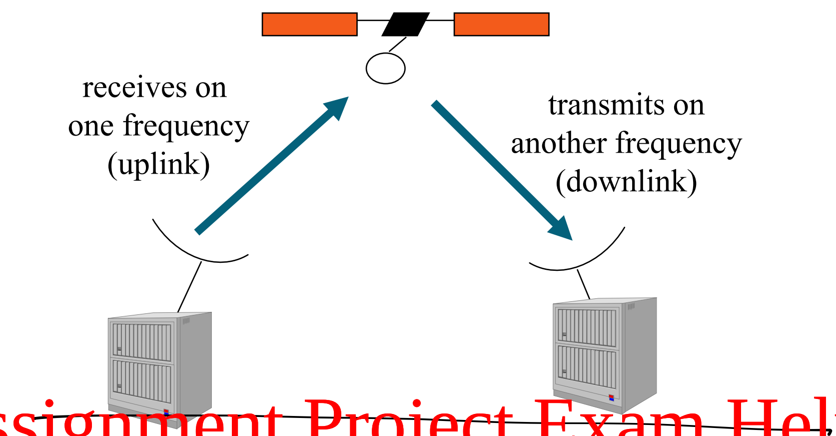
绕轨道的

  - **Geostationary** - a satellite is required to remain stationary with respect to its position over the earth. This match occurs at ~36,000 km
  - Low Earth Orbit (LEO), Medium Earth Orbit (MEO) systems (satellite phones)

1-80

80

Satellite Microwave (cont'd)



1-81

81

Satellite Microwave (cont'd)

- Applications:
  - television distribution (broadcast)
  - long-distance telephone
  - private business networks (VSAT/USAT networks)

1-82

82

Satellite Microwave (cont'd)

- Transmission characteristics
  - 4GHz / 6GHz , 12 GHz / 14 GHz, 15 GHz / 17 GHz
    - below 1 GHz there is significant noise from natural sources, including galactic solar and atmospheric noise.
  - 20 GHz to 30 GHz
    - Personal Satellite Communication Systems
    - High-Definition TV (around 23 GHz)

1-83

83

Infrared, Optical an waves

- They are widely used for short-range communication
  - remote control on TV, VCRs, etc.
  - indoor wireless LANs
- Characteristics
  - relatively directional, cheap, easy to build
  - do not pass-through solid object (e.g. wall)
  - mmWave and Visual Optical proposed for use in 5G Access networks

1-84

84

Free Space Lightwave transmission

- An application: connect two LANs in two buildings via lasers
  - high bandwidth, very low cost and easy to install

- Characteristics
  - laser beams cannot penetrate rain or thick fog
  - laser beams work well on sunny days, but ….

1-85

85

Digital Data/Digital Signals

- Modulation rate is the rate at which signal level is changed (rate at which signal elements are generated)
- Digital signaling rate or just data rate of a signal is the rate, in bits per seconds, that data are transmitted.
- Duration of length of a bit is the amount of time it takes for the transmitter to 发出 emit a bit. For a data date R, the bit duration, t_B, is 1/R.

1-86

86

Data Rate vs. Modulation Rate

- data rate:

$R = 1/t_B$

where t_B is the bit duration

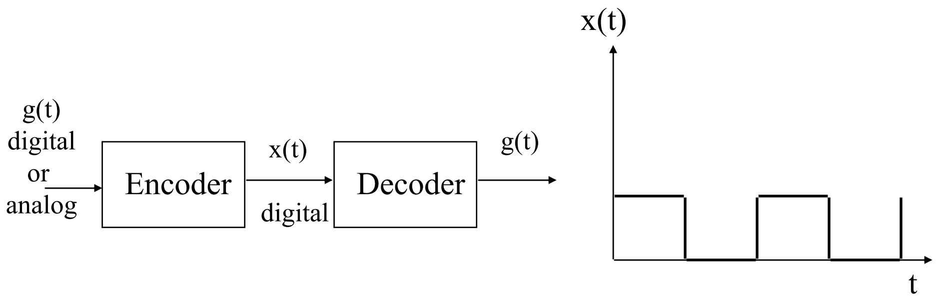
example: In the case of code Manchester, the maximum modulation rate, D_{max}, is 2 R

Data Encoding

Data Encoding - Baseband Transmission

基带

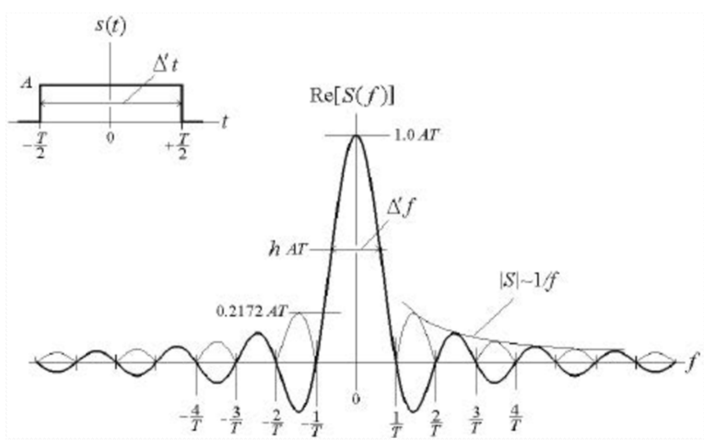
- Encoding onto a digital signal located at baseband



1-89

89

Square Pulse

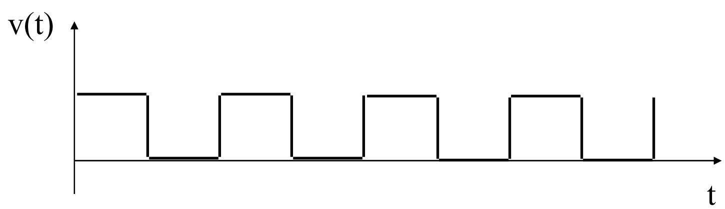


1-90

90

Digital Data/Digital Signals

- Definition
  - 单极
    Unipolar signal: all the signal elements have the same algebraic sign, all positive or all negative

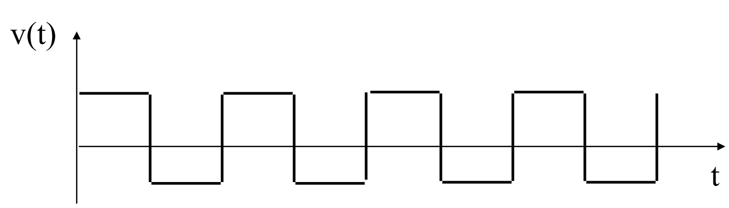


1-91

91

Digital Data/Digi

- Definition
  - Bipolar signalling: one logic state is represented by a positive voltage level an the other by a negative voltage level



1-92

92

Digital Signal Encoding Schemes

- Five evaluation factors:

1) signal spectrum
   - lack of high-frequency components means that less bandwidth is required for transmission

2) clocking
   - every bit being received needs to be identified

1-93

93

Digital Signal Encod

3) error detection
   - useful to be able to detect errors at the physical level

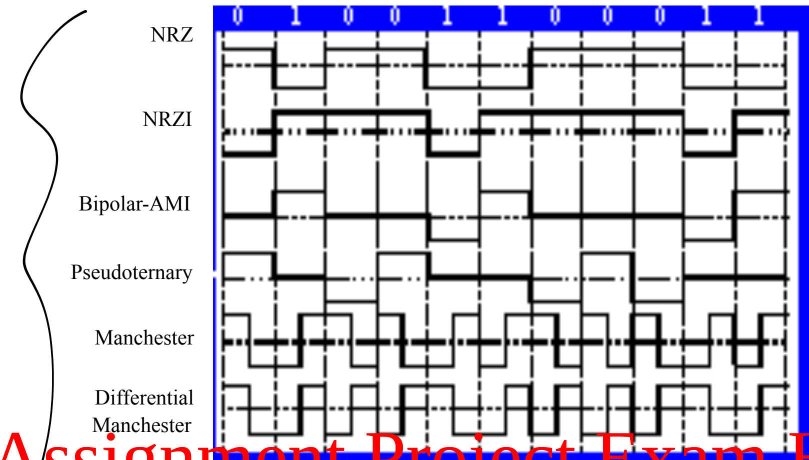
4) signal interference and noise immunity

5) cost and complexity

1-94

94

Some encoding techniques



1-95

95

Digital Signal Encoding Schemes

- 3 main techniques:
  - Nonreturn to Zero (NRZ)
  - Multilevel Binary
  - Biphase

1-96

96

Digital Signal Encoding Schemes

- Non-return to zero (NRZ)
  - maintains a constant value for the duration of a bit time.

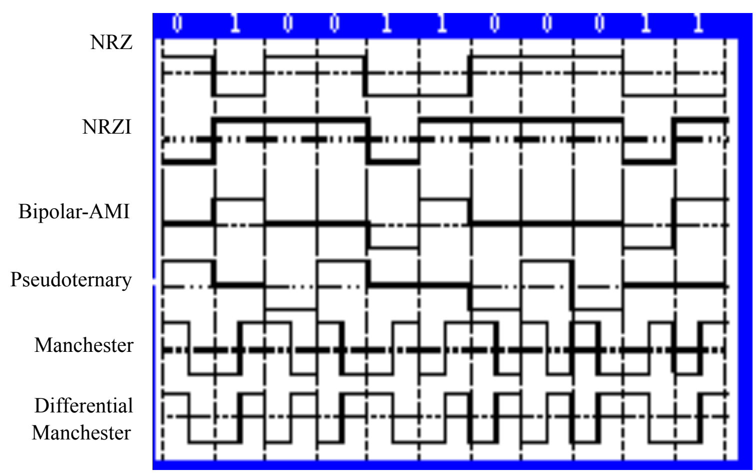
example 1: NRZ-L (nonreturn-to-zero-level)

- during a bit interval there is no transition
- two different levels for the two binary digits
  - binary 0 - negative voltage
  - binary 1 - positive voltage

1-97

97

Some encodin



1-98

98

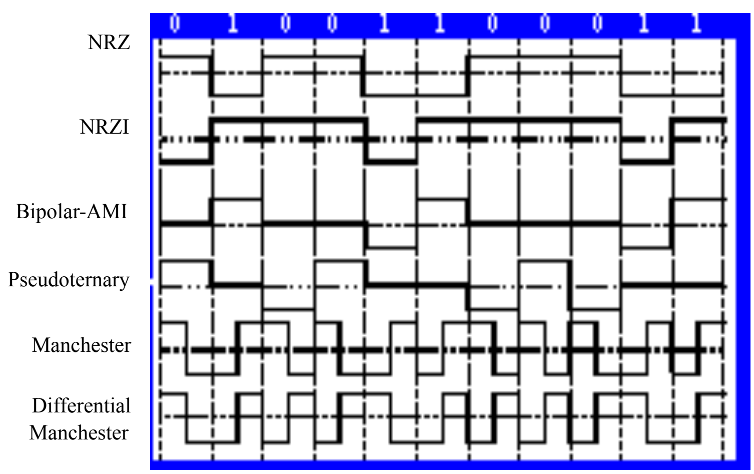
Digital Signal Encoding Schemes

- Non-return to zero (NRZ)
  - example 2: NRZI (non-return to zero, invert on ones)
    - the data is encoded as the presence or absence of a signal transition at the beginning of the bit time.
    - this type is called differential encoding (the signal is decoded by comparing the polarity of adjacent signal elements)

1-99

99

Some encodin



1-100

100

Digital Signal Encoding Schemes

- Non-return to zero (NRZ)
  - Advantage:
    - make efficient use of bandwidth
  - Drawback:
    - presence of a 直流电 dc component and lack of 同步化 synchronization (used in digital magnetic recording)

1-101

101

Digital Signal Encoding Schemes

- Multilevel Binary
  - uses more than 2 signal levels

example 1:

bipolar AMI - the binary 1 pulses alternate in polarity

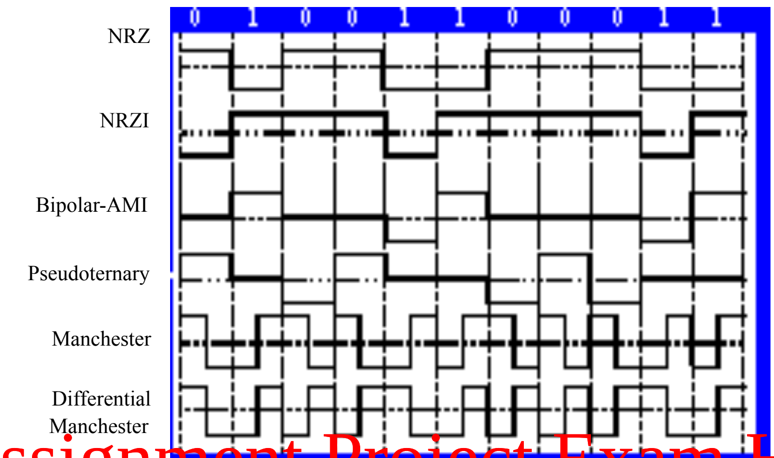
example 2:

Pseudo-ternary - the binary 0 pulses alternate in polarity

1-102

102

Some encoding techniques



1-103

103

Digital Signal Encoding Schemes

- Multilevel Binary
  - advantages:

    1) since signal alternate in voltage, there is no net DC component

    2) pulse alternation property provides a simple means of error detection
  - drawback:

    1) loss of synchronization

    bipolar AMI - if a long string of 0's occurs

    pseudoternary - if a long string of 1's occurs

1-104

104

Digital Signal Encoding Schemes

- 双相
  Biphase:
  - there is a transition at the middle of each bit period

  Example 1:

  Manchester - the mid-bit transition serves as a clocking mechanism and also for transporting data.

- Biphase:

  example 2:

  Differential Manchester - mid-bit transition provides clocking

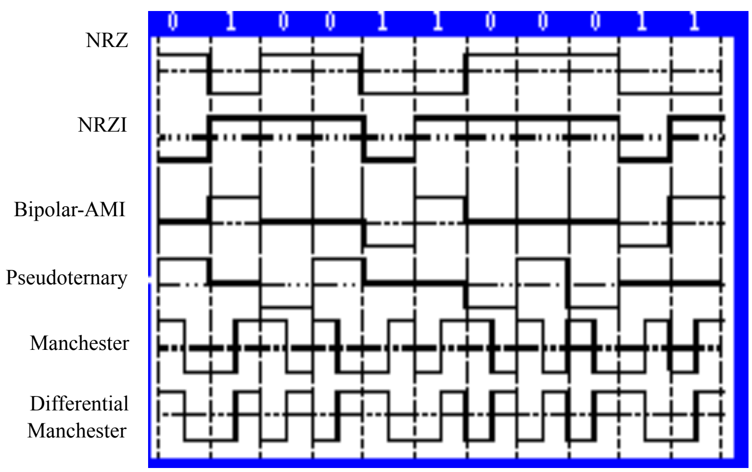
  binary 0 - transition at the beginning of a bit

  binary 1 - no transition at the beginning of a bit

1-105

105

Some encodin



1-106

106

Digital Signal Encoding Scheme

- Biphase
  - advantages:
    - a) synchronization - predictable transition permit to the receiver to resynchronize.
    - b) absence of expected transition can be used to detect errors
    - c) no DC component
  - drawback
    - a) higher modulation rate than NRZ => higher BW

    调制

1-107

107

Digital Signal Encod

Normalized Signal Transition Rate of Various Digital Signal Encoding Schemes

	Minimum	101010...	Maximum
NRZ-L	0 (all o's or 1's)	1.0	1.0
NRZI	0 (all 0's)	0.5	1.0 (all 1's)
Binary-AMI	0 (all 0's)	1.0	1.0
Pseudoternary	0 (all 1's)	1.0	1.0
Manchester	1.0 (1010...)	1.0	2.0 (all o's or 1's)
Differential Manchester	1.0 (all 1's)	1.5	2.0 (all 0's)

1-108

108

Evaluation

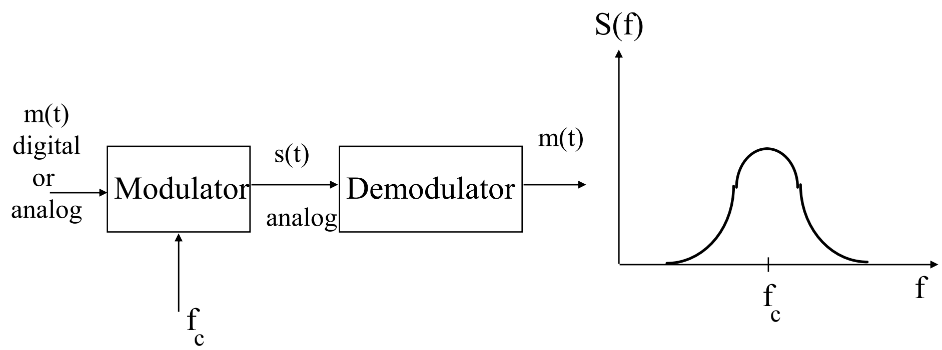
- NRZ
  - lack of synchronization capability; widely used for digital magnetic recording but not for signal transmission
- Multilevel binary
  - long string of **0**s (Bipolar-AMI) and **1**s (pseudoternary) cause synchronization problems (scrambling techniques are used to address this deficiency);
  - it is easy to detect isolated errors; it is not as efficient as NRZ (three signal levels are used instead of 2 levels used in NRZ)
- Biphase
  - no synchronization problems; good error detection; more bandwidth is needed (as many as two transitions per bit time)

1-109

109

Data Encoding

- Modulation onto an analog signal

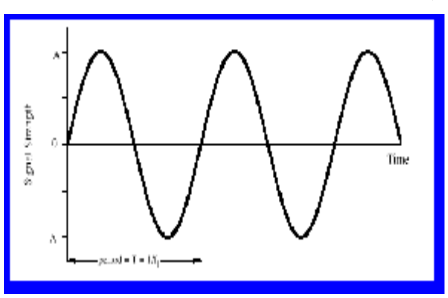


1-110

110

Periodic signal

- A signal s(t) is periodic if and only if s(t+T)=s(t) for all t where T is the period of the signal
- Example: sine wave s(t)



- $s(t) = A\sin(2\pi ft + \phi)$
- Parameters:
  Amplitude: A
  Frequency: f
  Phase : ϕ

1-111

111

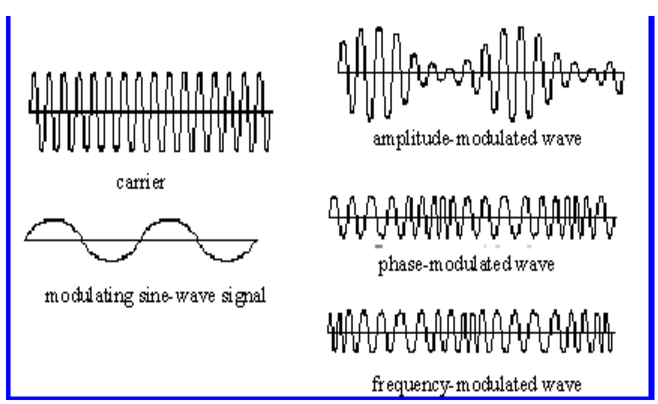
Modulation Techniques

- Amplitude modulation
  - $S(t)=[1+n_aX(t)]\cos 2\pi f_c t$, where $\cos 2\pi f_c t$ is the carrier and $x(t)$ is the input signal, n_a is the modulation index (ratio of the amplitude of $x(t)$ to the carrier)
  - simplest form of modulation
- Angle modulation
  - $S(t)=A\cos[2\pi f_c t + \phi(t)]$
  - phase modulation : $\phi(t)=n_p m(t)$ where n_p is the phase modulation index
  - frequency modulation: $d\phi(t)/dt=n_f m(t)$ where n_f is the frequency modulation index

1-112

112

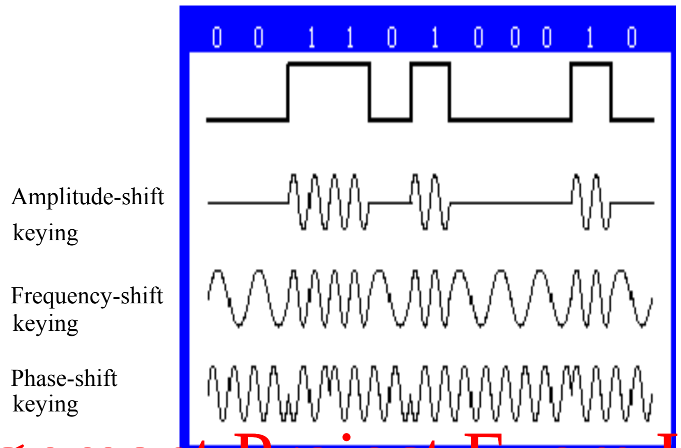
Modulation of a sine-wave signal



1-113

113

Modulation of digital signal



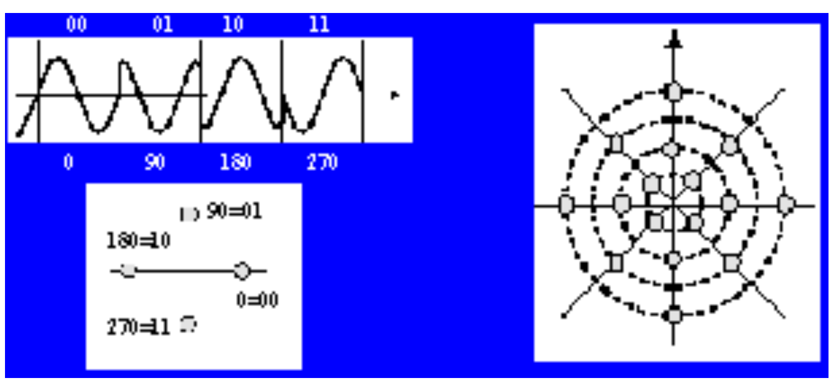
1-114

114

Multilevel modu

Quadrature phase-shift keying (R=2*D)

Quadrature amplitude modulation (R=4*D)



1-115

115

Multiplexing

1-116

116

Spectrum Allocati

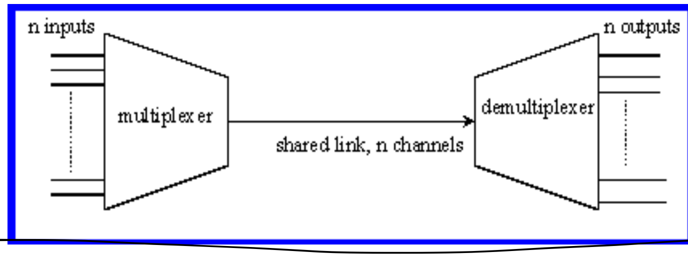
Spectrum is valuable commodity; needs to be shared

1-117

117

多路复用

Multiplexing

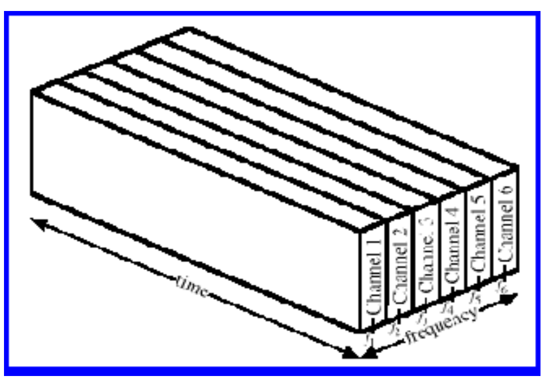


- Objective: share a link between several users (i.e., telephone companies transmit many conversations over a single physical trunk)
- Two basic techniques: FDM (Frequency Division Multiplexing) and TDM (Time Division Multiplexing)

1-118

118

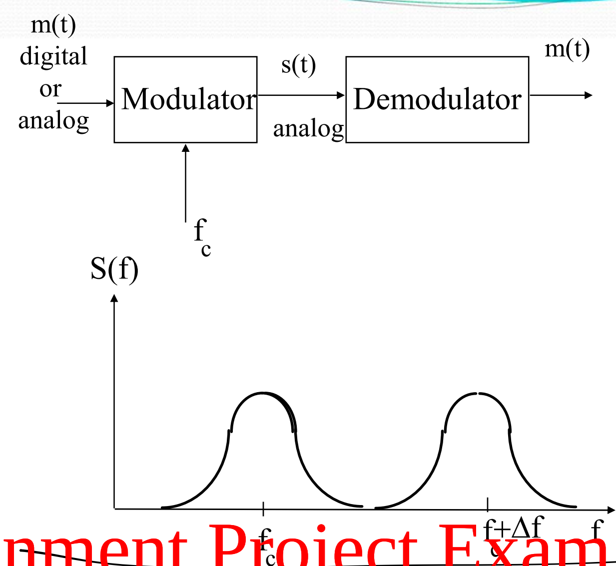
Frequency-division mult



1-119

119

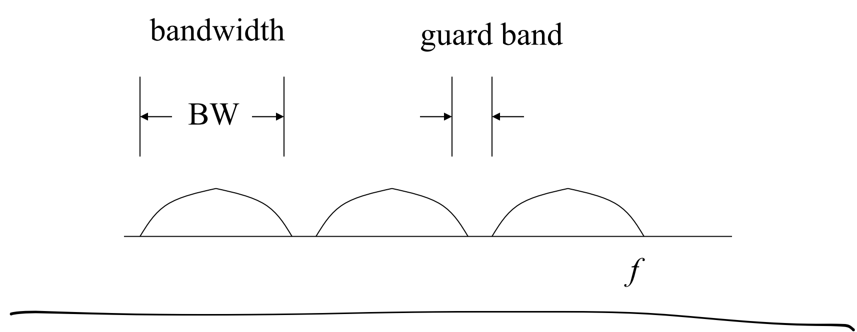
FDM



1-120

120

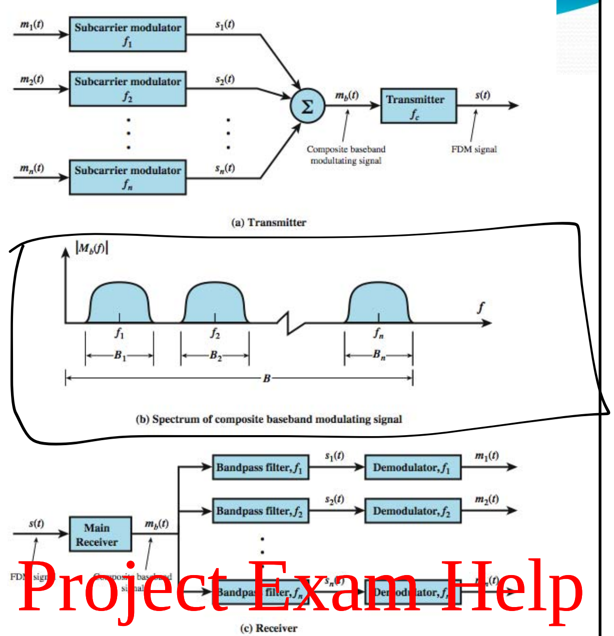
Frequency Division Multiple Access FDMA



1-121

121

FDM System Overview



1-122

122

Frequency-division multi s

- Crosstalk
  - guard bands (separating two “adjacent” channels) should be carefully chosen
  - a voice signal has an effective bandwidth of 3.1 kHz; a channel of 4 kHz is adequate to avoid crosstalk in analog voice transmissions
- Intermodulation noise
  - nonlinear effects of amplifiers on a signal in one channel can produce undesirable frequency components in other
  - Channels
- More challenging and expensive RF technology (narrow filters; large)
- Inefficiency
  - Channels might be allocated to sources that are not using them all the time

1-123

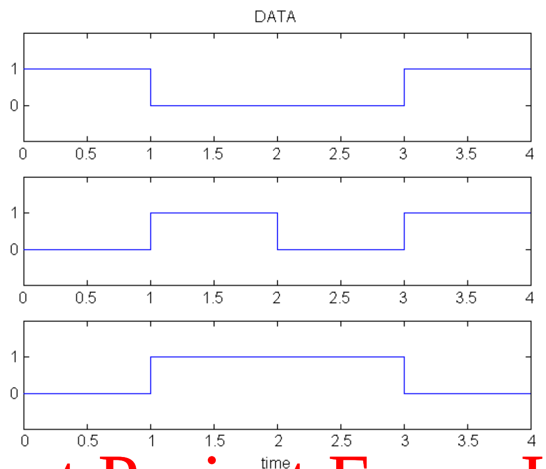
123

Consider the following samples of 3 users' data to be multiple accessed

User 1 data

User 2 data

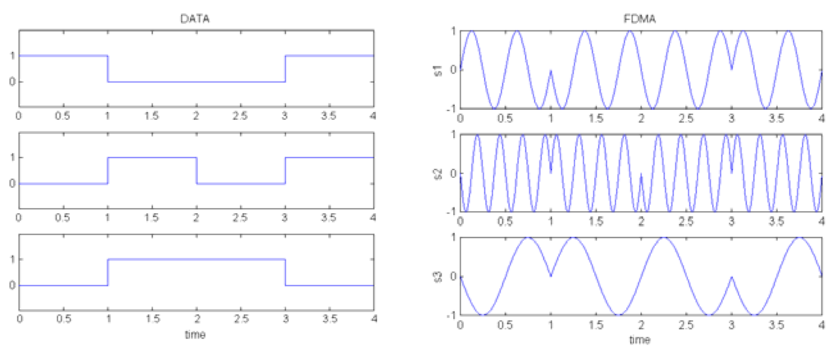
User 3 data



1-124

124

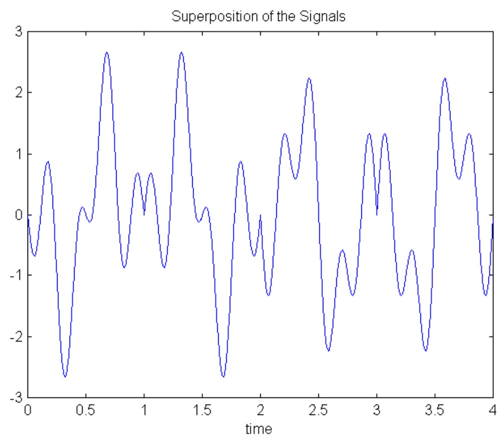
Waveforms of Users 1,2



1-125

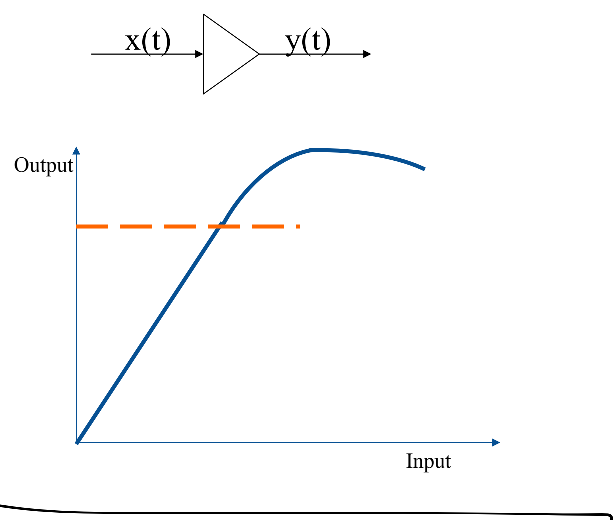
125

Input to the amplifier after 3 FDM signals are added



1-126

126



1-127

127

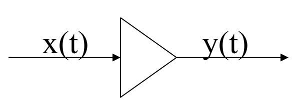
Nonlinear Effects in FDM

- Received signal is sum of multiple carriers.
- Receiver power amplifiers are operated nonlinearly (near saturation) for maximum efficiency.
- The nonlinearities cause intermodulation (IM) frequencies to appear in the amplifier output.
- IM components can interfere with other channels in the FDMA system.

1-128

128

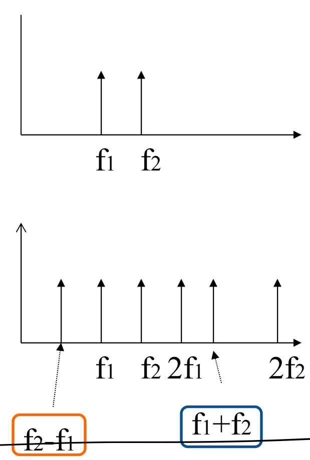
Inter-modulat



$$y(t) = x(t) + a\,\{x(t)\}^2$$

$$x(t) = \cos(2\pi f_1 t) + \cos(2\pi f_2 t)$$

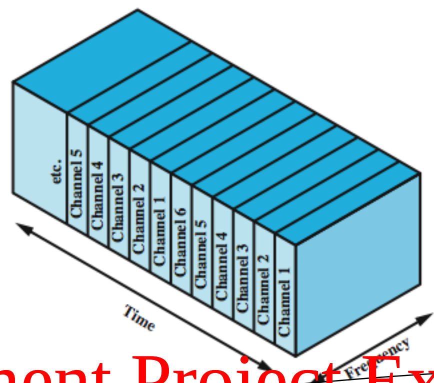
$$\boxed{\begin{aligned} y(t) = {} & \cos(2\pi f_1 t) + \cos(2\pi f_2 t) \\ & a + (a/2)\,\{\cos(2\pi 2 f_1 t) + \cos(2\pi 2 f_2 t) + \\ & a\,\{\cos(2\pi\,[f_1+f_2]\,t) + \cos(2\pi\,[f_1-f_2]\,t) \end{aligned}}$$



1-129

129

Synchronous Time Division Multiplexing



1-130

130

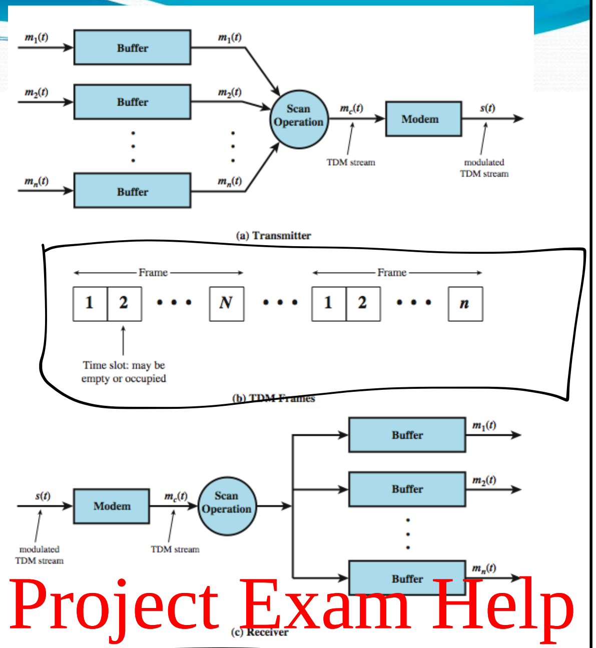
Time Division Mul

- TDMA systems divide the radio spectrum into time slots.
- Only one user can transmit or receive during one time slot.
- Usually, each user may occupy the channel once during a time frame, where one frame comprises *N* time slots.

1-131

131

TDM System Overview



1-132

132

Time-division multiplexi

- Frame synchronization
  - use an identifiable pattern of bits at the beginning of each frame
- Pulse stuffing
  - If user does not have data, the assigned slot needs to be staffed with dummy bit
- Inefficiency
  - many of the time slots are wasted; slots are allocated to inputs even these input are not sending any data
- High Pick Transmission power

1-133

133

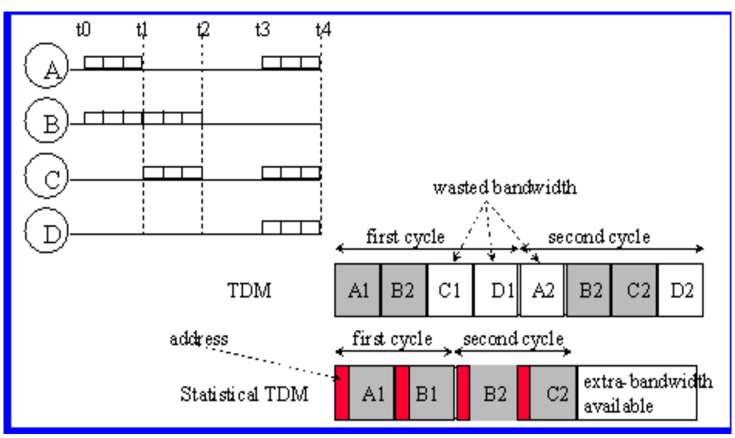
Statistical TDM

- in Synch TDM many slots are wasted
- Statistical TDM allocates time slots dynamically based on demand
- multiplexer scans input lines and collects data until frame full
- line data rate lower than aggregate input line rates
- may have problems during peak periods
  - must buffer inputs

1-134

134

Statistical time-division



1-135

135

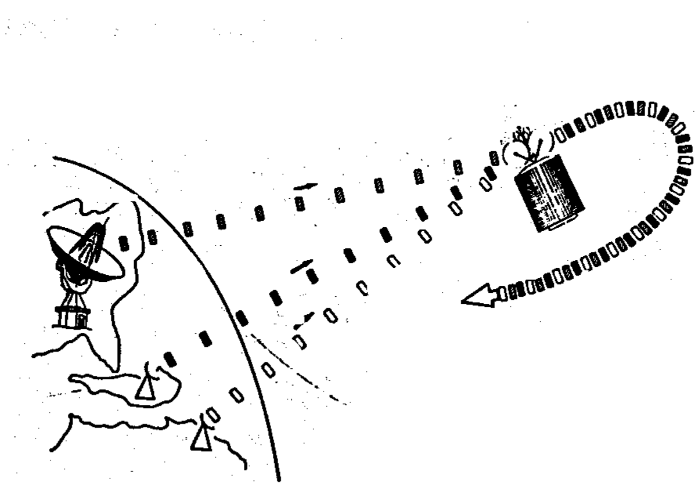
TDMA Systems

- TDMA systems transmit data in a buffer and burst method.
- The transmission is non-continuous.
- Unlike FDMA systems which can transmit analog signals, TDMA must transmit data and digital modulation must be used.

1-136

136

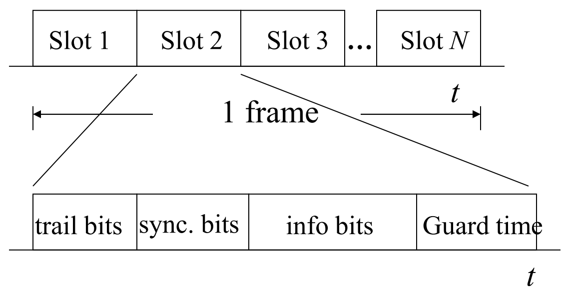
TDMA



1-137

137

TDMA

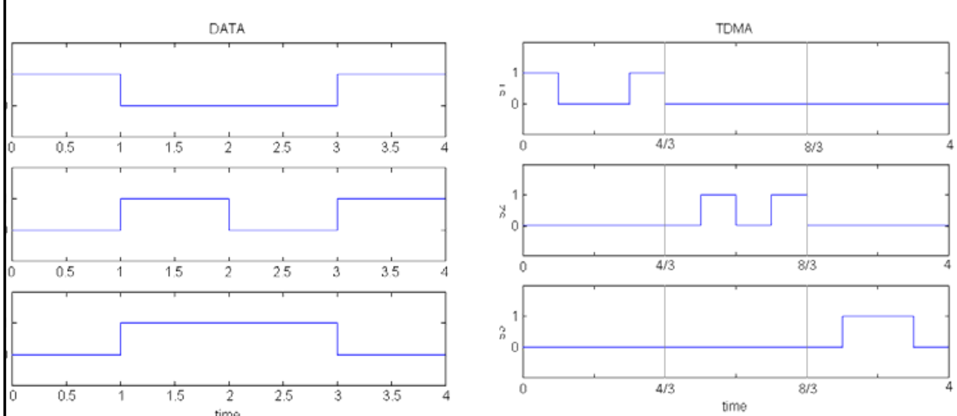


Each slot requires overhead bits.
More overhead reduces efficiency.

1-138

138

User 1,2&3 data befor A



1-139

139

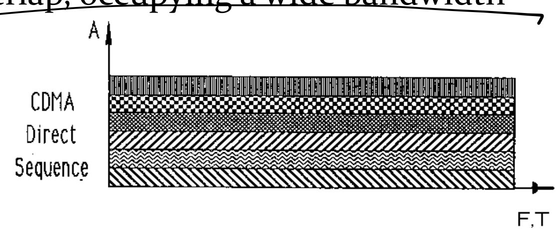
TDMA Features

- Only one carrier. No intermodulation.
- Number of time slots per frame depends on bandwidth, desired date rate, modulation technique.
- Receiver must synchronize to each time slot, thus more synchronization bits are required in TDMA compared to FDMA.
- It is possible to allocate more than one time slot per frame – bandwidth on demand.

140

Spread Spectrum

- Also known as Code Division Multiple Access (CDMA)
- Important encoding method for wireless communications
- Can be used with analog & digital signal formats
- Users share both time & frequency domains; their signals overlap, occupying a wide bandwidth



- The separation is achieved by assigning different codes to each user.

141

Spread Spectrum

- Makes jamming and interception harder
- Initially used for military communications
- Two approaches, both in use:
  - Frequency Hopping (FH)
  - Direct Sequence (DS-SS)
- Cellular radio (IS-95, CDMA2000,WCDMA)
- Wireless LANs (IEEE 802.11 b, g)

1-142

142

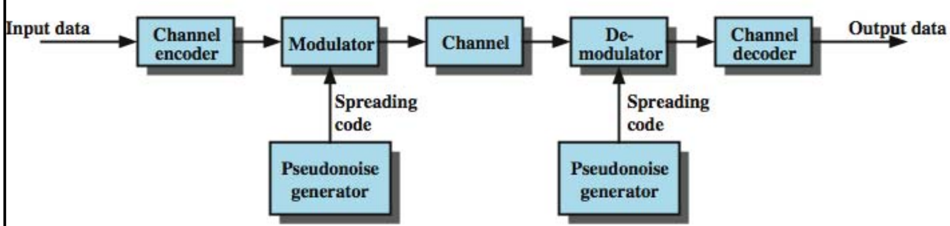
Spread Spectrum: Advantages/Disadvantages

- Resistive to interference, multipath fading
- Easy Encryption
- Easy traffic multiplexing of discontinuous sources
- Allows "soft" hand-offs
- Synchronization imposes a challenge

1-143

143

General Model of Spread Spectrum System



1-144

144

Pseudorandom N

- generated by a deterministic algorithm
  - not actually random
  - but if algorithm good, results pass reasonable tests of randomness
- starting from an initial seed
- need to know algorithm and seed to construct the sequence
- hence only receiver can decode signal

1-145

145

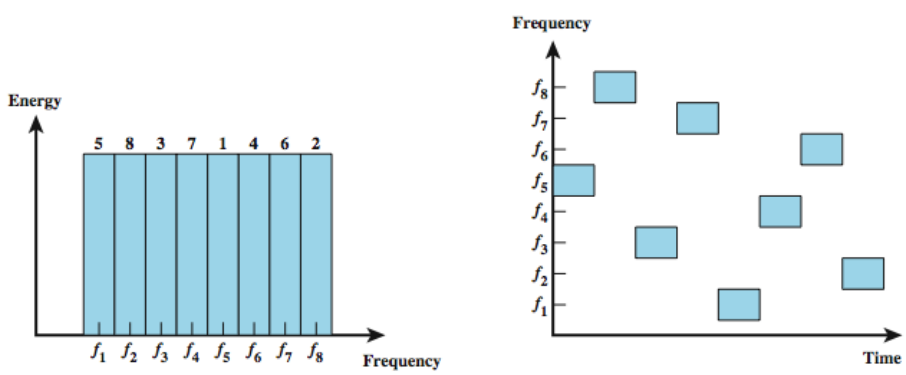
Frequency Hopping Spread Spectrum (FHSS)

- signal is broadcast over seemingly random series of frequencies
- receiver hops between frequencies in sync with transmitter
- 窃听者
  eavesdroppers hear unintelligible blips
- jamming on one frequency affects only a few bits

1-146

146

Frequency Hopping

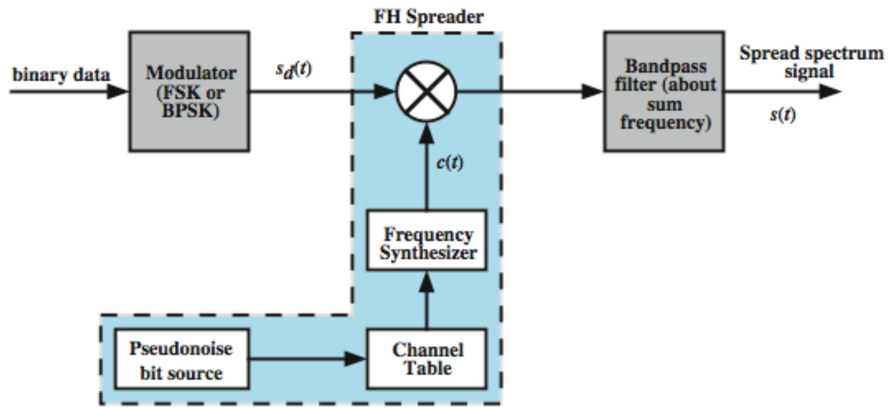


(a) Channel assignment (b) Channel use

1-147

147

FHSS (Transmitter)

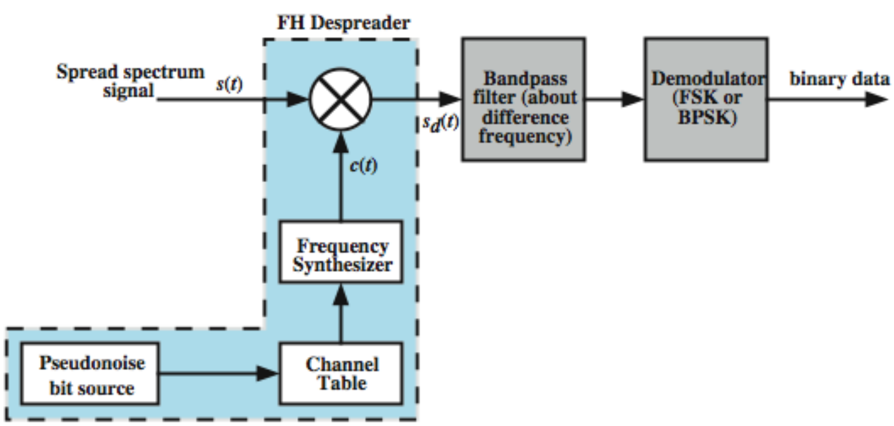


(a) Transmitter

1-148

148

Frequency Hopping Spectrum System (R



(b) Receiver

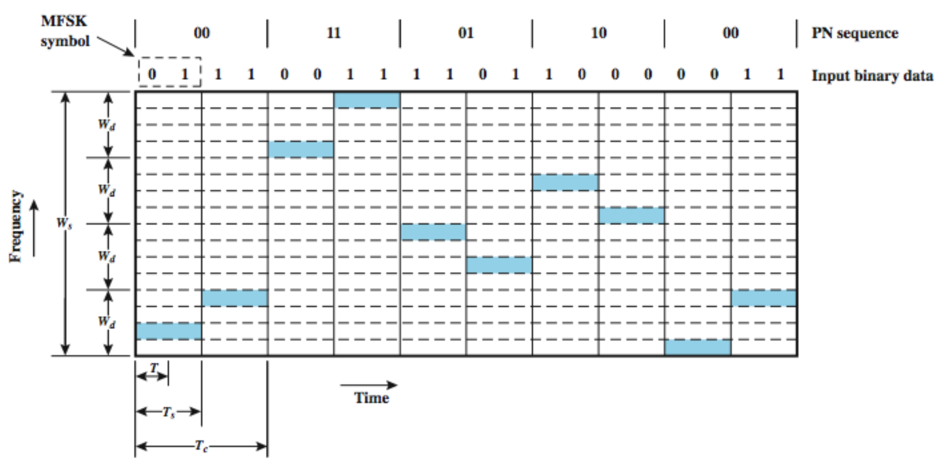
1-149

149

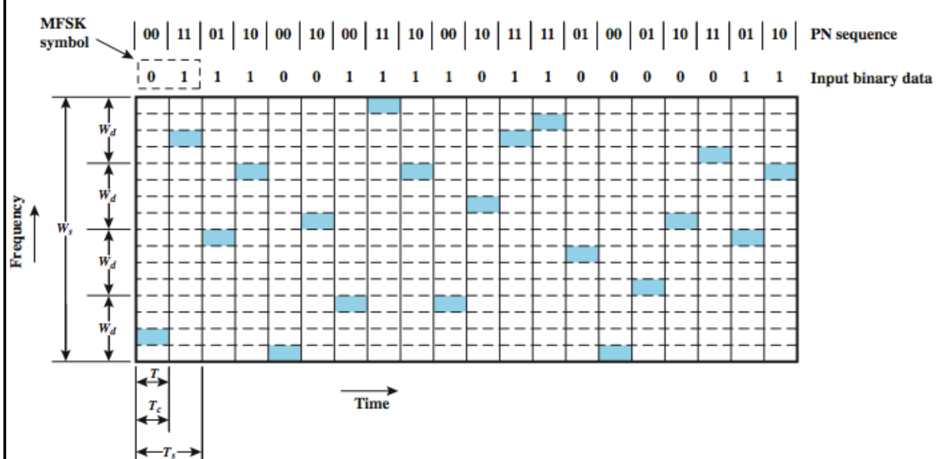
Slow and Fast FHSS

- commonly use multiple FSK (MFSK)
- have frequency shifted every T_c seconds
- duration of signal element is T_s seconds
- Slow FHSS has $T_c \geq T_s$
- Fast FHSS has $T_c < T_s$
- FHSS quite resistant to noise or jamming
  - fast FHSS is giving better performance

Slow MFSK FHSS



Fast MFSK FHSS



1-152

152

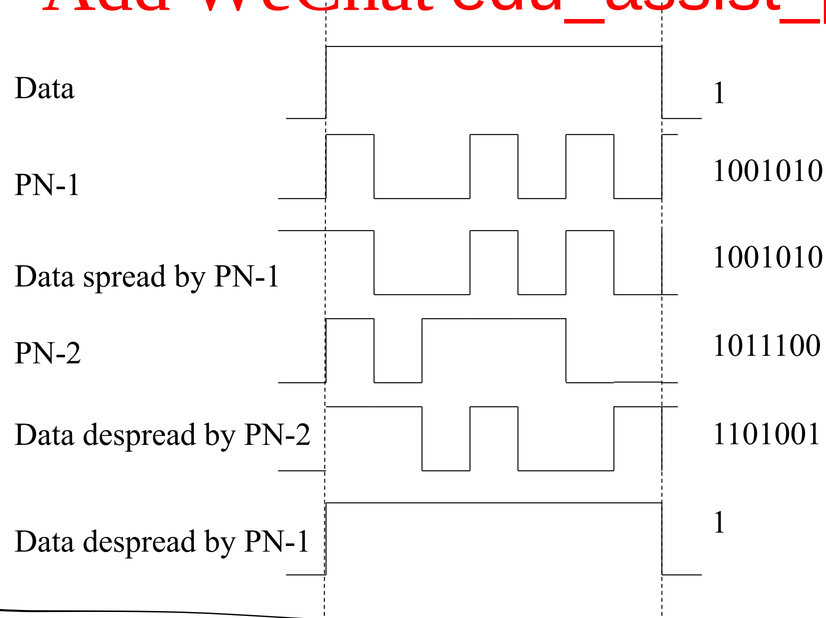
Direct Sequence Spr (DSSS)

- each bit is represented by multiple bits using a spreading code
- this spreads signal across a wider frequency band
- has performance similar to FHSS

1-153

153

Direct Sequence Spread Spectrum System



DSSS Example Using BPSK

1-156

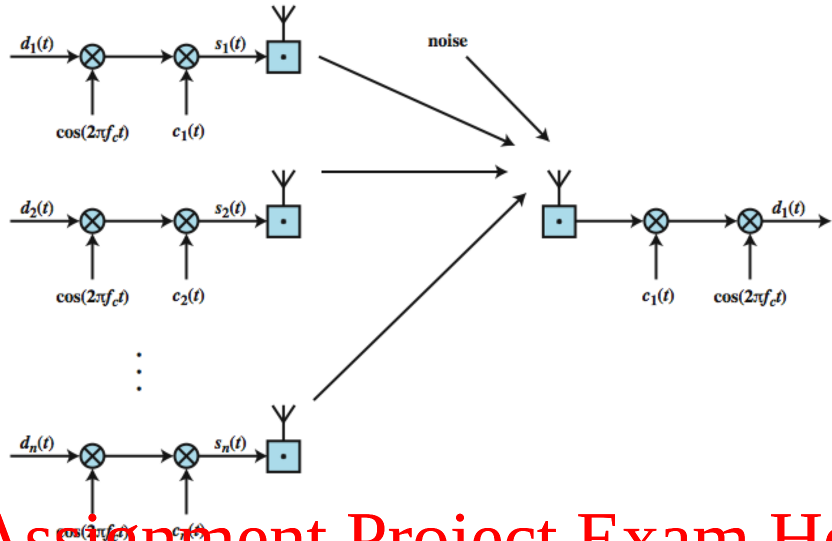
156

CDMA Example

157

157

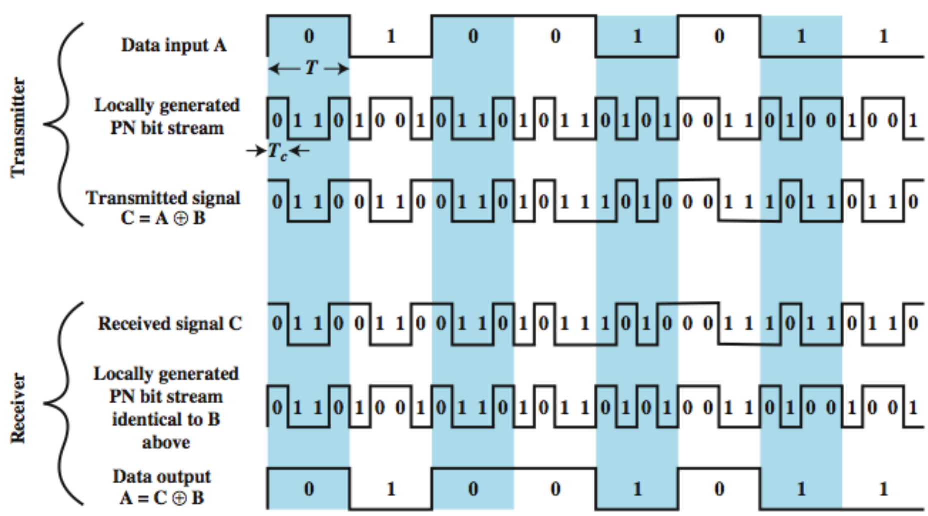
CDMA for DSSS



1-158

158

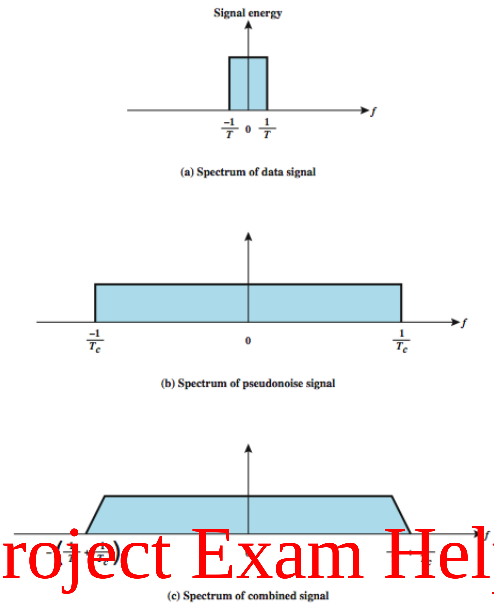
Direct Sequence Spectrum Exampl



1-159

159

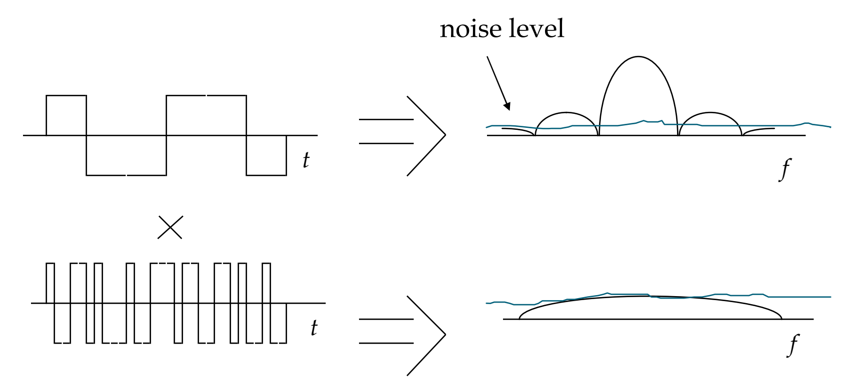
Approximate Spectrum of DSSS Signal



1-160

160

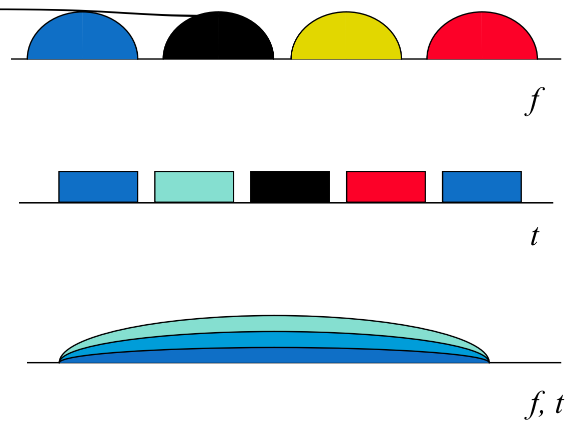
Power of DS-SS signal when square pulses are used



1-161

161

Do all systems fall into only one of 3 categories?



Answer: In practice NO.

162

Examples of their use in w mobile communications s

- **FDM/FDMA**
  - 1st generation: analog cellular, AMPS (each channel was occupying 60 KHz bandwidth)
  - 2nd generation North American digital cellular radio; IS-41
  - 2nd generation North American digital cellular radio (improved); IS-136.
    - Hybrid architecture. TDMA multiplexing 4 users in each 60 KHz AMPS channel.
- **TDM/TDMA**
  - 2nd and 2.5 generation European cellular radio, GSM/GPRS/EDGE
- **CDMA**
  - 2nd generation: IS-95 based North American cellular radio (DS-SS).
  - 3rd generation CDMA2000 and WCDMA (DS-SS)
  - IEEE 802.11 WLAN (FH & DS-SS)
  - Bluetooth (FH-SS), ZigBee (DS-SS), Home RF (FH & DS-SS)

1-163

163

1

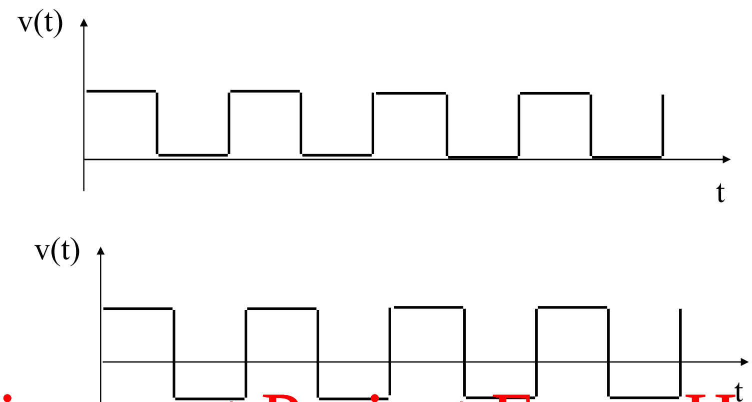
Outline

- Synchronization
- Asynchronous and synchronous transmission
- Error detection/correction techniques
- Line Configuration

1-2

2

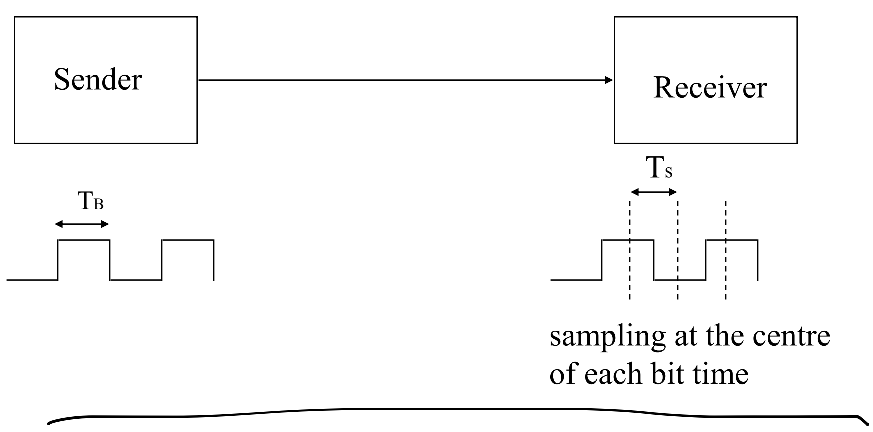
Digital Data/Digital Signals



1-3

3

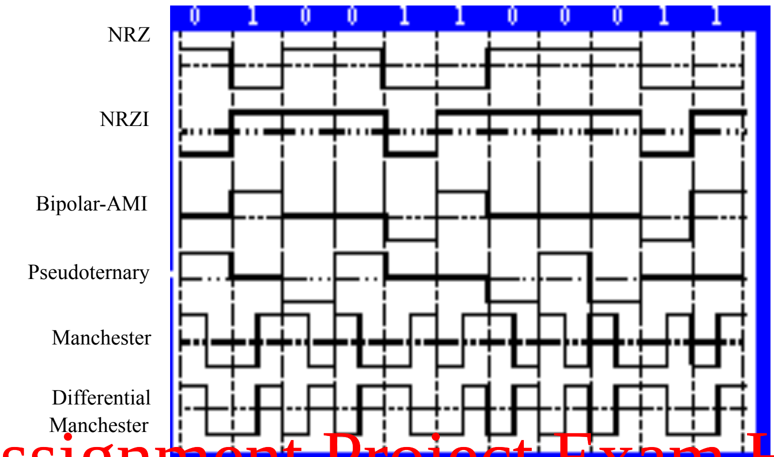
SYNCHRON



1-4

4

Some encoding techniques



1-5

5

同步化

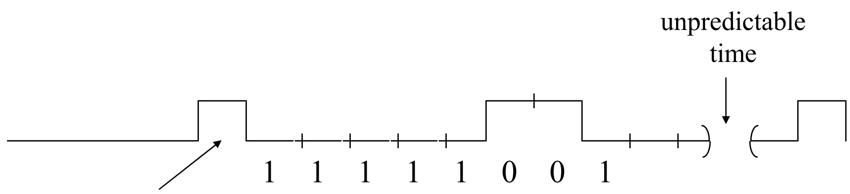
SYNCHRONIZATION

- loss of synchronization
  - In practice T_B and T_S are not equal. The result is that the timing of the receiver may slowly drift 相对于 relative to the received signal.

1-6

6

SYNCHRONIZATION



1-7

7

SYNCHRONI

- loss of synchronization
  - Solution:
    - data is sent in bit sequences called frames
    - the receiving clock is started at the beginning of each bit sequence
  - Question:

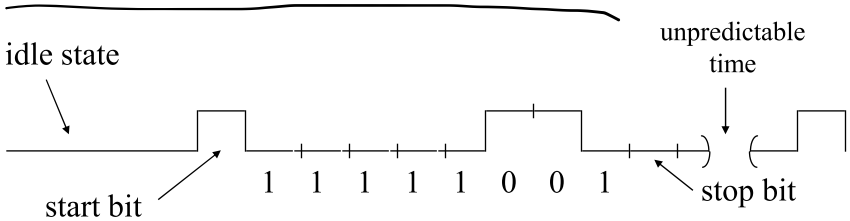
    Since synchronization needs to be kept only for the duration of the frame, what is the length of the frame that will allow us to avoid loss of synchronization?

1-8

8

ASYNCHRONOUS TRANSMISSION

- Timing or synchronization must only be maintained within each character; the receiver has the opportunity to resynchronize at the beginning of each new character.



1-9

9

SYNCHRON

- loss of synchronization

example:

- a frame consists of 11 bits
- assume that the synchronization at the start of the first bit is late at most 10% of T_B

We must fulfill the following 2 conditions:

$$(10+\frac{1}{2})\times T_S + 0.1\times T_B < 11\times T_B \quad \text{and} \quad (10+\frac{1}{2})\times T_S > 10\times T_B$$

These are satisfied if: $\left|\frac{T_s - T_B}{T_B}\right| < 3.8\%$

1-10

10

ASYNCHRONOUS TRANSMISSION

- Timing requirements are modest. Sender and receiver are synchronized at the beginning of every character (8 bits if ASCII)
  - high overhead

$$overhead = \frac{control\_bits}{total\_bits}$$

1-11

11

SYNCHRONOUS TRANSMISSION

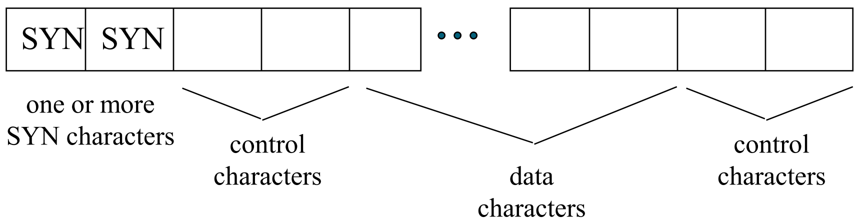
- In this mode, blocks of characters or bits are transmitted. Each block begins with a preamble 前言 and ends with a postamble 后同步码
  - 2 types:
    - character-oriented
    - bit-oriented

1-12

12

SYNCHRONOUS TRANSMISSION

- Character-oriented
  - the frame consists of a sequence of characters



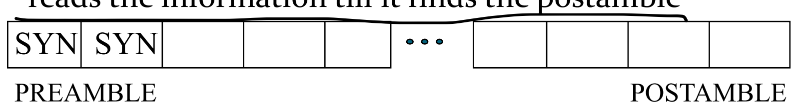
SYN is a unique bit pattern that signals the receiver the beginning of a block

1-13

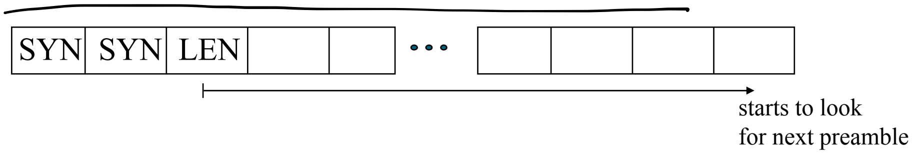
13

SYNCHRONOUS TR

- character-oriented - 2 approaches
  - the receiver having detected the beginning of the block reads the information till it finds the postamble



the receiver having received the preamble, looks for extra information regarding the length of the frame



1-14

14

SYNCHRONOUS TRANSMISSION

- Bit oriented
  - In this mode, the frame is treated as a sequence of bits. Neither data nor control information is interpreted in units of x-bit characters
  - a special bit pattern indicates the beginning of a frame
  - the receiver looks for the occurrence of the flag

FLAG			• • •			FLAG

control fields   control fields

1-15

15

Dealing with presence of errors

- Detect presence of errors (error detection)
- Try to correct them (error correction)
- If no correction have the mechanism to request retransmission (use of Automatic Repeat Request)

1-16

16

Random Errors

- An error occurs when a bit is altered between transmission and reception
- Random, statistically uniformly spread errors
  - occurrence of an error does not increase the probability that other bits, close to the one in error, while be in error
  - white noise is producing such errors
- For low BER and frames of "reasonable" length, most framers would experience no error or 1 error at most.
  - example: BER = 10^{-6} and length of frame=[1000bytes*8=] 8,000 bits
  - probability of receiving a frame correctly = [1-10^{-6}]^{8,000}>0.992
  - probability of a frame having a single error=8,000*receiving a frame correctly = 10^{-6}*[1-10^{-6}]^{7,999}* {8,000}=0.007873
  - Probability of having more than 1 error =[1-0.992-0.007873=]0.000127

1-17

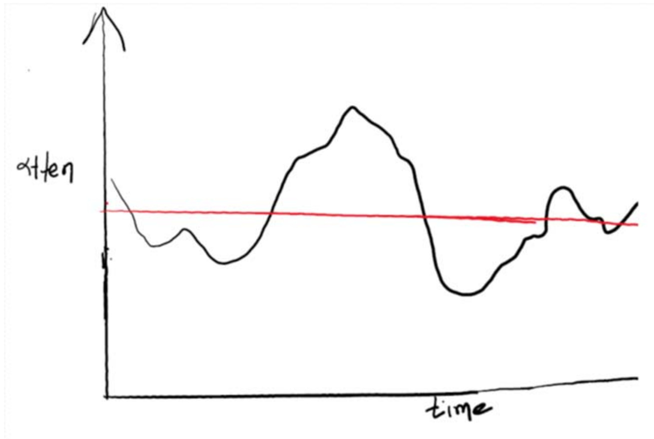
17

Burst Errors

- Occurrence of an error having occurred in the sequence, means bits preceding/following the one in error have higher probability than the average bit error probability to be in error
- Error strings (clusters 簇 of errored bits closely located in the sequence) form
- Some channel related impairments 减损 producing error bursts
  - impulsive noise
  - "slow" fading/shadowing in wireless (relevance of bit rate to average time/distribution channel attenuation remains below certain level)
  - effect greater at higher data rates

1-18

18



1-19

19

Error detection and control

Objective

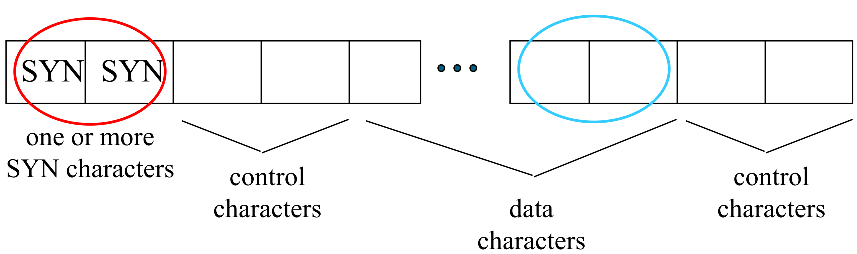
- detect and correct errors that occur in the transmission of frames

Types of errors

- lost frame: a frame that the receiver does not receive (e.g., because starting of frame/clock extraction is not achieved due to excessive signal attenuation, increased levels of noise...)
- damaged frame: a frame that the receiver receives, but some of its bits are in error

Impact of error loc

The frame consists of a sequence of characters



SYN is a unique bit pattern that signals the receiver the beginning of a block

Error Detection

1-22

22

Error Correction/De ss

1-23

23

How Error Correction & Detection Works

冗余

- Adds redundancy to transmitted message

尽管

- Can deduce original despite some errors
- Example: block error correction code
  - map *k* bit input onto an *n* bit codeword
  - each distinctly different
  - if get error assume codeword sent was closest to that received
- means have reduced effective data rate
- most of work concerning error correction & detection is making use of Galois field algebra (Boolean algebra - mod_2 arithmetic – is a case of it)

1-24

24

Code rate & mini e

$$\text{Code rate } r = \frac{\#\text{ of information bits in a block}}{\#\text{ of total bits in a block}} = \frac{k}{n}$$

The bandwidth expansion is $1/r = n/k$

The energy per channel bit (E_c) is related to energy per information bit (E_b) through $E_c = rE_b$

Minimum distance $(d_{\min})$: Minimum number of positions in which any 2 codewords differ.

1-25

25

Correctable and detectable errors

- A block code can correct at least μ errors if $d_{min} >= 2\mu + 1$
- => if dmin=3, then μ=1. If there is only one error in the block, it can be corrected.
- A block code can detect any error pattern if the received n bits do not correspond to a codeword.
- If there are λ errors in the n-bits codeword, the existence of errors is detected with certainly if $\lambda < d_{min}$.
- However, even when $\lambda >= d_{min}$, many of the corrupted blocks can still be detected.
- Out of the 2^n possible n-bit combinations, only 2^k codewords can be generated, thus, there are $2^n - 2^k = 2^k(2^{(n-k)}-1)$ prohibited 禁止 combinations.
- Above statement applies when no error correction is used.

1-26

26

A simple block code: (7,4)

Message	Codeword
0000	000 0000
1000	110 1000
0100	011 0100
1100	101 1100
0010	111 0010
1010	001 1010
0110	100 0110
1110	010 1110
0001	101 0001
1001	011 1001
0101	110 0101
1101	000 1101
0011	010 0011
1011	100 1011
0111	001 0111
1111	111 1111

- Minimum Humming distance?
- Error Correction capability?
- Error detection w/o error correction?
- Error detection with error correction?

27

27

A simple block code: (7,4) Hamming Code

Message	Codeword
0000	000 0000
1000	110 1000
0100	011 0100
1100	101 1100
0010	111 0010
1010	001 1010
0110	100 0110
1110	010 1110
0001	101 0001
1001	011 1001
0101	110 0101
1101	000 1101
0011	010 0011
1011	100 1011
0111	001 0111
1111	111 1111

•Minimum Humming distance?
3

•Error Correction capability?
1

•Error detection w/o error correction? **3**

•Error detection with error correction? **0**

1-28

28

"Popular" Error Detec

- Parity Checks
- Longitudinal redundancy checks (LRC)
- Cyclic redundancy checks (CRC)

1-29

29

Simple Error Detection Scheme

- 奇偶性 Parity check
  - Value of parity bit is such that character has even (even parity) or odd (odd parity) number of ones
  - Even number of bit errors goes undetected

1-30

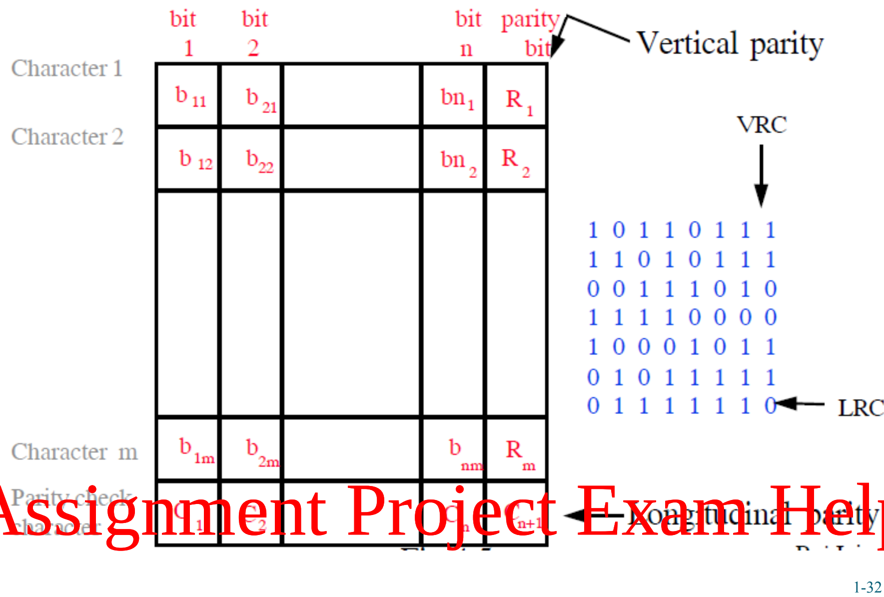
30

Parity Checks

1-31

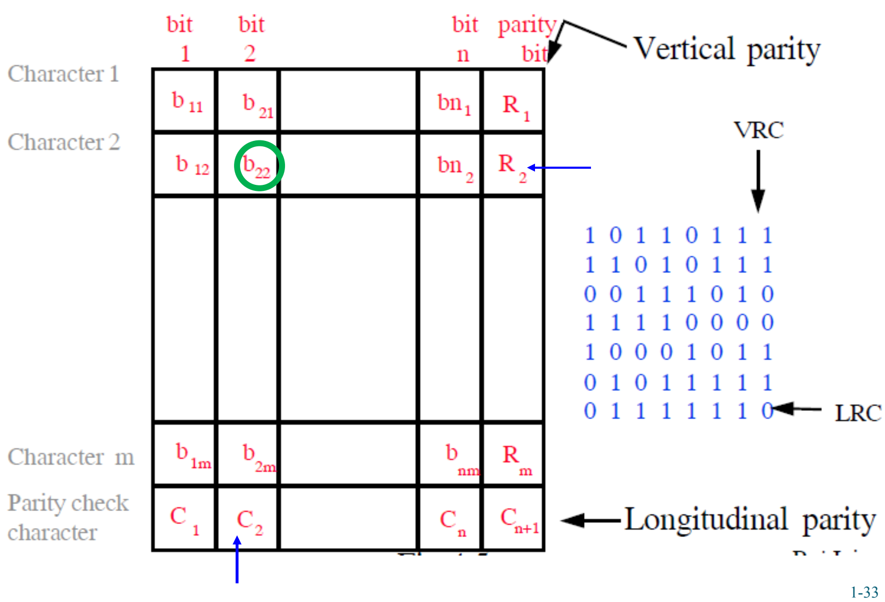
31

Longitudinal Redundancy Checks



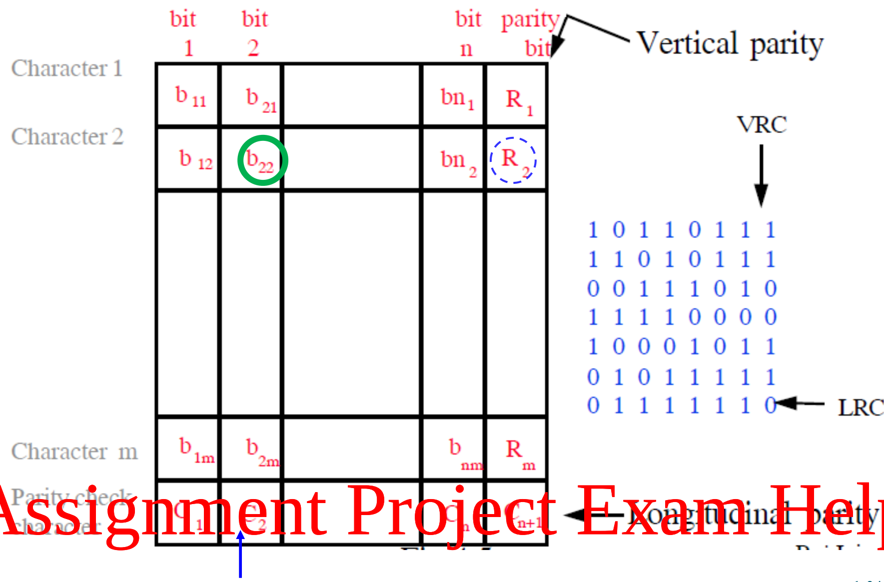
32

Longitudinal Redu ks



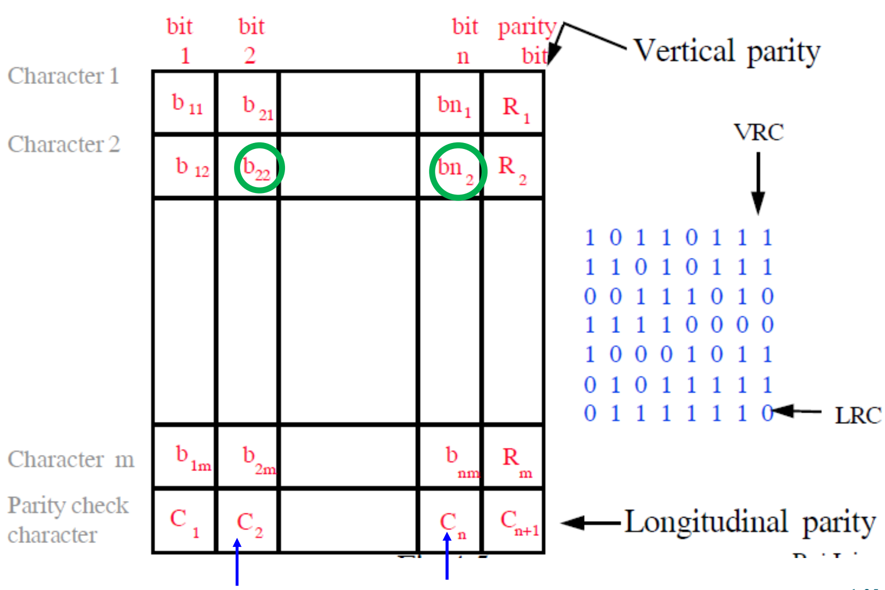
33

Longitudinal Redundancy Checks

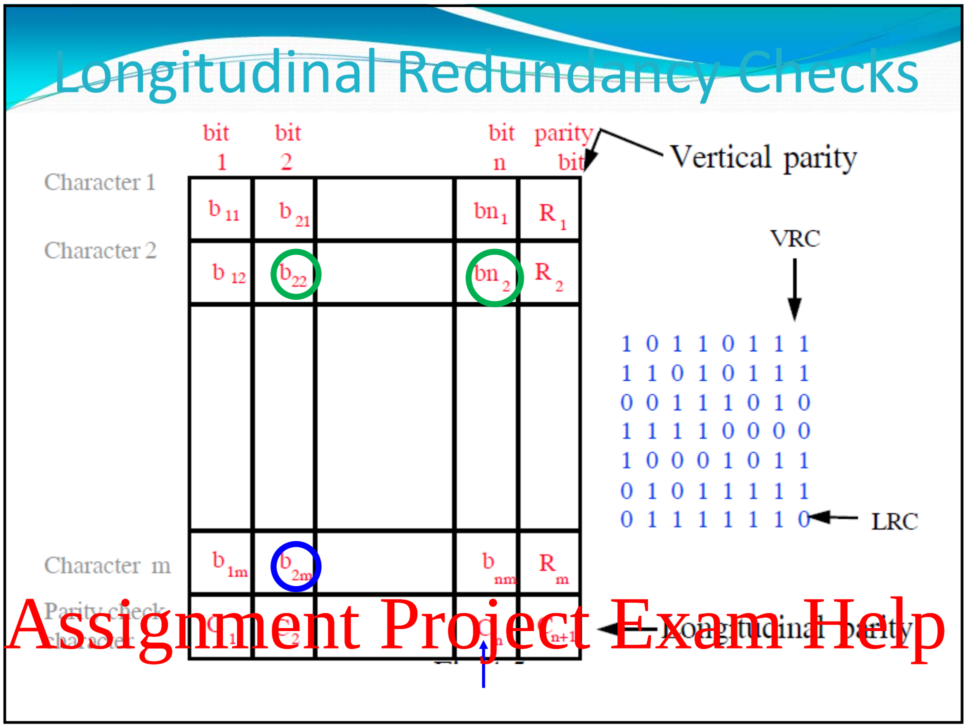


34

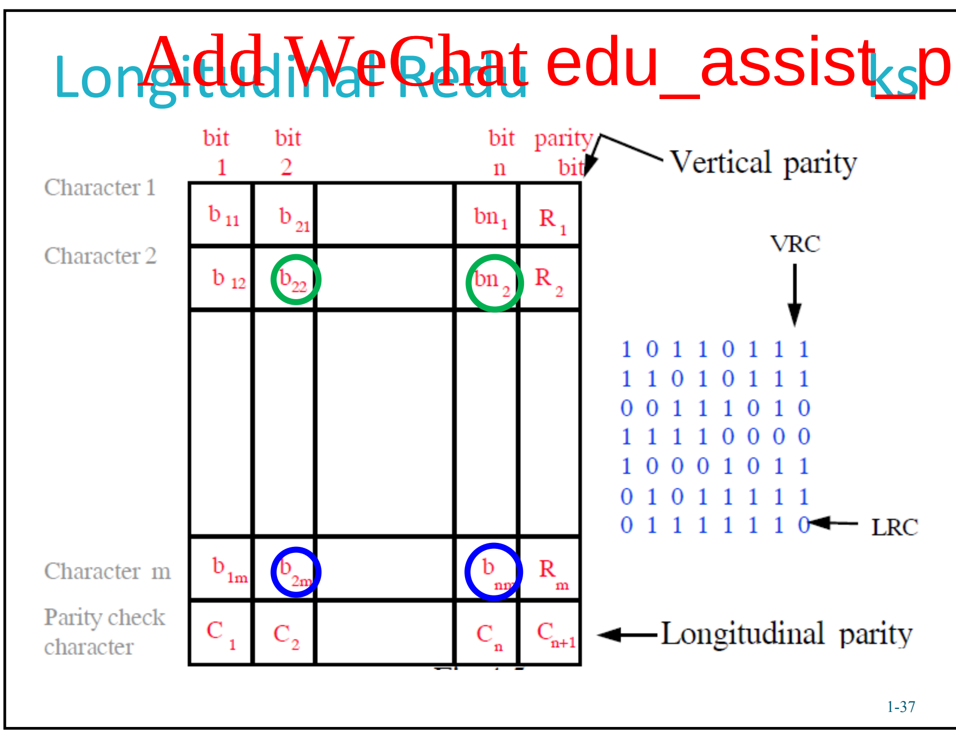
Longitudinal Redu ks



35


Longitudinal Redundancy Checks
bit 1
bit 2
bit n
parity bit
Vertical parity
Character 1
Character 2
Character m
b 11
b 21
bn 1
R 1
b 12
b 22
bn 2
R 2
b 1m
b 2m
b nm
R m
VRC
1 0 1 1 0 1 1 1
1 1 0 1 0 1 1 1
0 0 1 1 1 0 1 0
1 1 1 1 0 0 0 0
1 0 0 0 1 0 1 1
0 1 0 1 1 1 1 1
0 1 1 1 1 1 1 0
LRC

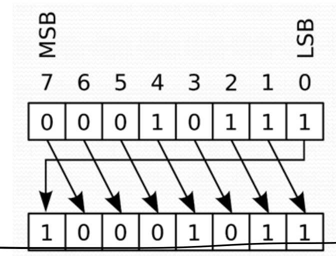
36


Longitudinal Redu
ks
bit 1
bit 2
bit n
parity bit
Vertical parity
Character 1
Character 2
Character m
Parity check character
b 11
b 21
bn 1
R 1
b 12
b 22
bn 2
R 2
b 1m
b 2m
b nm
R m
C 1
C 2
C n
C n+1
Longitudinal parity
VRC
1 0 1 1 0 1 1 1
1 1 0 1 0 1 1 1
0 0 1 1 1 0 1 0
1 1 1 1 0 0 0 0
1 0 0 0 1 0 1 1
0 1 0 1 1 1 1 1
0 1 1 1 1 1 1 0
LRC
1-37

37

Cyclic Redundancy Check

- Based on cyclic error-correcting codes

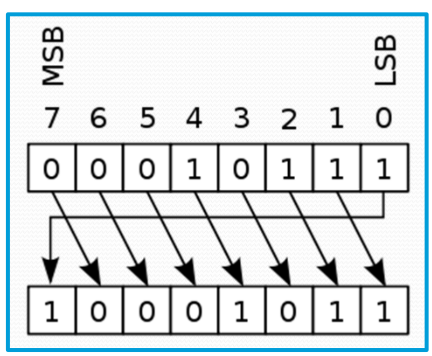


- For a block of *k* bits the transmitter generates *n* bit sequence
- *n* insert redundancy in the codeword
- Transmitter transmits the *k*+*n* bits
- Receiver uses error detection process to decide if there were errors in the received sequence or otherwise

38

Cyclic Codes

- "**Cyclic code** is a block code, where the circular shifts of each codeword gives another codeword that belongs to the code".
- "They are error-correcting codes having algebraic properties that are convenient for efficient error correction & detection".



39

Fundamentals of CRC coding

- CRC codes treat bit strings as representations of polynomials with coefficients of 0 and 1 only (modulo 2 arithmetic)

$$11001 \leftrightarrow 1*X^4+1*X^3+0*X^2+0*X^1+1*X^0 = X^4+X^3+1$$

- Polynomial arithmetic is done modulo 2
  - subtraction and addition are similar to EXCLUSIVE OR
  - division is similar to the one in decimal except the subtraction is done modulo 2
- Make sure you are familiar with mod2 arithmetic/algebra

40

Addition/Subtraction

Modulo 2 addition/subtraction is performed using an exclusive OR (xor) operation on the corresponding binary digits of each operand.

$0 \pm 0 = 0;\quad 0 \pm 1 = 1;\quad 1 \pm 0 = 1;\quad 1 \pm 1 = 0$

Multiplication

```
   1011
 x 0101
 ------
   1011
  0000
 1011
0000
-------
0100111
```

1-41

41

Division

Modulo 2 division can be performed in a manner similar to arithmetic long division. Subtract the denominator (the bottom number) from the leading parts of the enumerator (the top number). Proceed along the enumerator until its end is reached. Remember that we are using modulo 2 subtraction. For example, we can divide 100100110 by 10011 as follows:

```
           10001 remainder 101
     10011|100100110
           10011
               10110
               10011
                 101
```


1-42

42

CRC: Basic Idea

- The sender and receiver agree upon "a generator polynomial", **G(x)**, in advance.
- The sender appends a checksum (corresponds to the *n* redundancy bits) to the end of the (only data) frame, represented by the **M(x)** polynomial, in a way that the polynomial **T(x),** representing the {data + checksum bits} frame, is divisible by **G(x).**
- Upon receipt of the frame, the receiver (generates and) divides **H(x)** by **G(x)** using modulo 2 division.
- **H(x)** is the polynomial corresponding to the received sequence.
- if there is a remainder, there has been transmission error.

43

How to compute the checksum

$11001 \leftrightarrow 1*X^4+1*X^3+0*X^2+0*X^1+1*X^0 =$
$X^4+X^3+1 = M(X)$

- If *n-1* is the degree of G(x), then append *n* zero to the low order end of the frame; the resulting frame corresponds to the polynomial $X^n M(x)$.

$11001000 \overset{n=3}{\longleftrightarrow} 1*X^7+1*X^6+0*X^5+0*X^4+1*X^3+$
$0*X^2+0*X^1+0*X^0 = X^7+X^6+X^3 = X^3*M(X)$

- Divide G(x) into $X^n M(x)$ using modulo 2 division.

$$\frac{X^n M(X)}{G(X)} \rightarrow D(X); R(X)$$

- *D(X)*: divisor; *R(X)*: remainder

$$X^n M(X) = G(X) \otimes D(X) \oplus R(X)$$

44

How to compute th

- Subtract the remainder from modulo 2 subtraction/addition.
- The result is the checksumed frame's polynomial , T(x).

$$T(x) = X^n M(X) \oplus R(X)$$

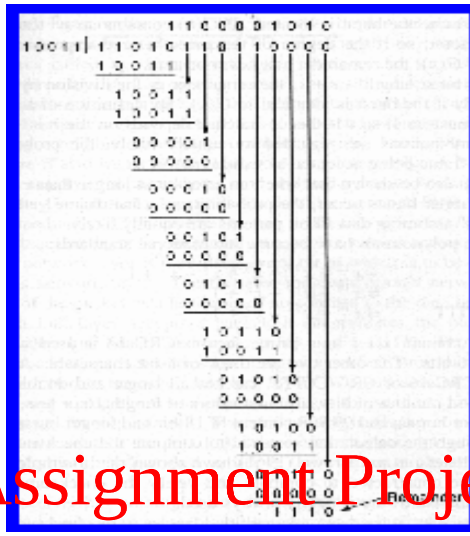
- The frame corresponding to ***T(x)*** is transmitted.

$$T(X) = X^n M(X) \oplus R(x) = [D(X) \otimes G(X) \oplus \boxed{R(x)] \oplus R(X)} \Leftrightarrow$$
$$\Leftrightarrow T(X) = D(X) \otimes G(X) \oplus O \Leftrightarrow \frac{T(X)}{G(X)} = D(X)$$

G(X) divides perfectly T(X) (remainder = *O*)

45

CRC: an Example



- Frame: 1101011011
- Generator: 10011

46

CRC Error Detectio

- Let us assume that some transmission errors occur
- Instead of receiving **T(x)**, the receiver will receive **H(x)=T(x)⊕E(x)**
- If there are k "1" bits in E(x), (it is most probable that) k bit errors have occurred
- the receiver computes (T(x) ⊕ E(x))/G(x)=E(x)/G(x)
- If G(x) contains two or more terms, (i.e. n>1) all single errors will be detected.
- single-bit error means $E(X) = X^{m-1}$, where $0 < m \leq n + k$

47

Single error and $G(x)=X^n$

- $H(X)=T(X)\oplus E(X)$ where
- $E(X)=O$ if no bit errors occur
- $E(X)=X^{m-1}$ if only the m-th bit of the *[k+n]*-bit long frame is reversed ($0<m\le n+k$; the larger the value of m is, the more significant the location of the bit within the frame is)
- $E(X)=L(X)\otimes G(X)\oplus F(X)$
- $H(X)=T(X)\oplus E(X)=T(X)\oplus L(X)\otimes G(X)\oplus F(X)$
- $\frac{H(X)}{G(X)}=D(X)\oplus L(X)\oplus\frac{F(X)}{G(X)}$

Error will be detected if $\frac{F(X)}{G(X)}\neq O$

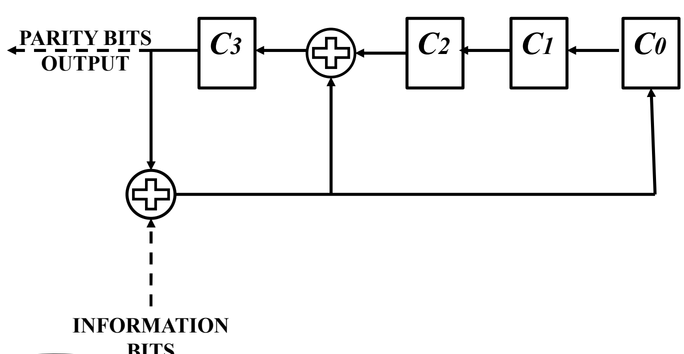
For *m-1>=n*, $L(X)=X^{m-n-1}$ and $\frac{F(X)}{G(X)}=O$. Error is not detected.

For *m-1<n*, *L(x)=O* and $\frac{F(X)}{G(X)}\neq O$. Error is detected.

48

Shift register circui

$11001 \leftrightarrow 1*X^4+1*X^3+0*X^2+0*X^1+1*X^0=$
X^4+X^3+1=*G(X)*



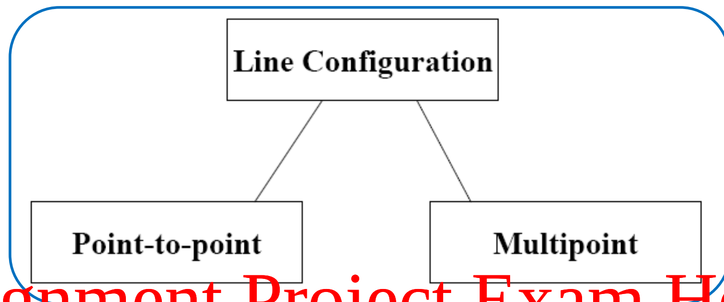
1-49

49

Line Configuration

组态

- Topology 拓扑结构
  - refers to physical arrangement of stations on the medium
  - two topologies are commonly used
    - point-to-point
    - multipoint



50

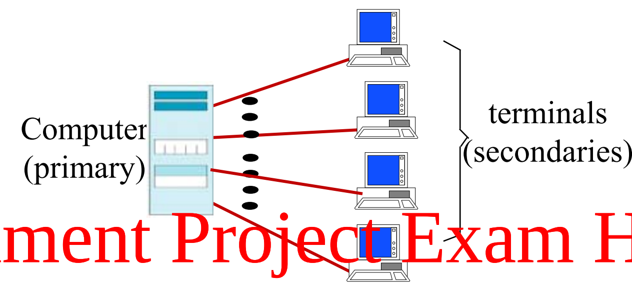
Line Configuration - Topology

- point to point - two stations
  - traditionally mainframe computer and terminals
  - between two routers / computers
- multi point - multiple stations
  - typically, a local area network (LAN)

51

Point-to-point topology

- a separate transmission line from the computer to each terminal
- the computer must have an I/O port for each terminal

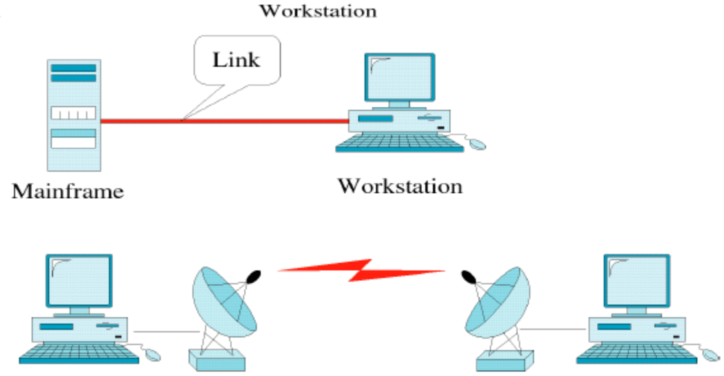


52

Examples of Point-to[illegible]gy

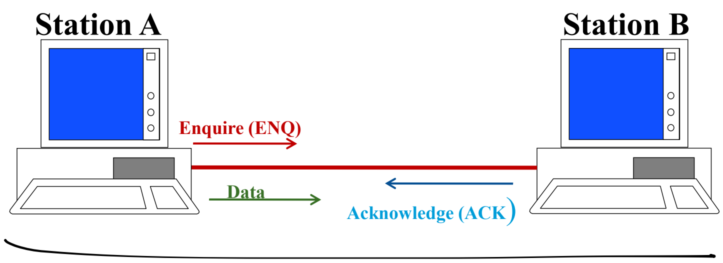
Null modem

RS 232



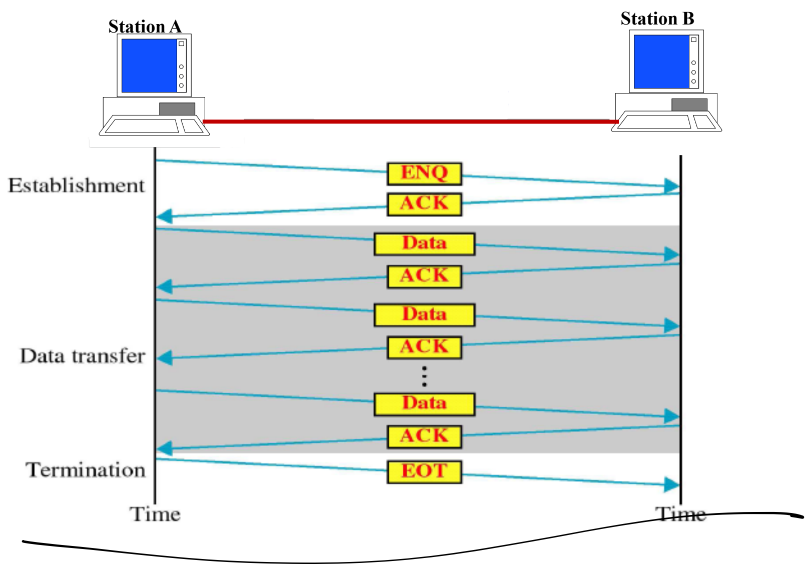
53

Line Discipline: Point-to-Point



54

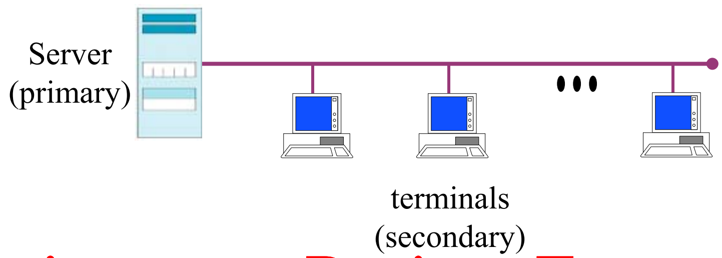
Line Discipline: P



55

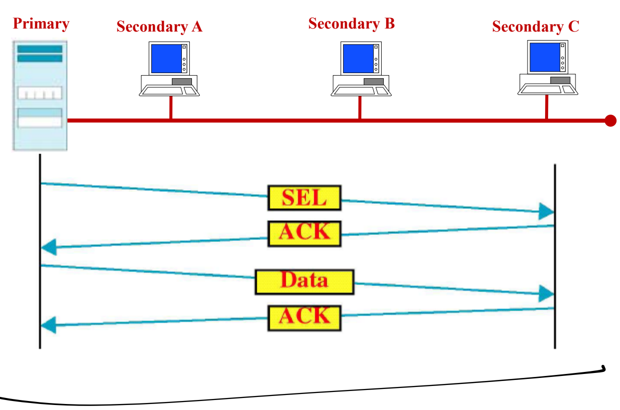
Point to Multipoint topology

- A single "line" is needed
- The computer needs only a single I/O port
  - e.g. Ethernet, Token Ring, WiFi



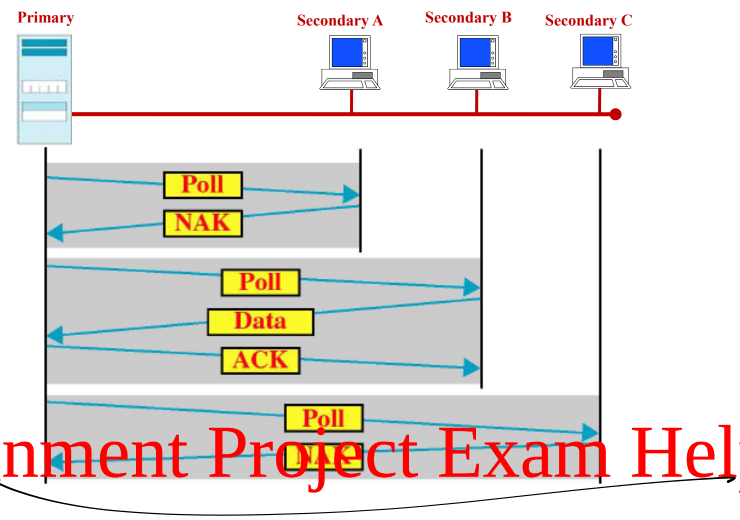
56

Select Line Discipli



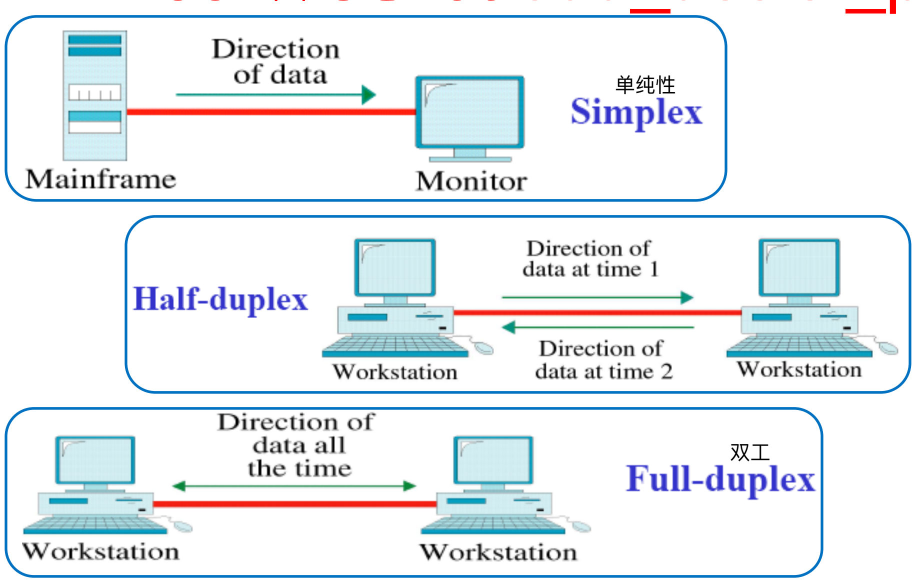
57

Poll Line Discipline



58

Transmission Mode



59

Line Configuration - Duplex

- classify data exchange as half or full duplex
- half duplex (two-way alternate)
  - only one station may transmit at a time
  - requires one data path
- full duplex (two-way simultaneous)
  - simultaneous transmission and reception between two stations
  - requires two data paths
    - separate media or frequencies used for each direction
  - or echo canceling

60

END

1-61

61

EECS, University of Ottawa

CEG3185 –Winter 2021

Introduction to Data Communication & Networking

Data Link Control

IMPORTANT: All components of the course including notes, delivered lectures, tutorials, laboratory material, are available ONLY to those registered in the course during the indicated semester, or those having received written permission by the instructor. Sharing of the material with others is STRICTLY PROHIBITED

Note: some material in the slides has been taken from various other sources 1-1

1

Outline

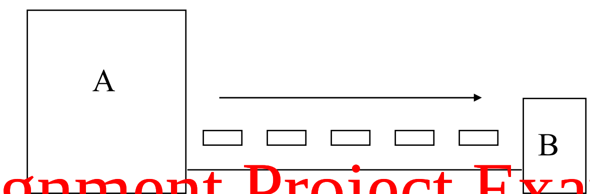
- Flow Control
- Error Control

1-2

2

Flow Control/1

- Definition:
  - flow control is a technique for assuring that a transmitting station does not overwhelm 压倒 a receiving station with data



3

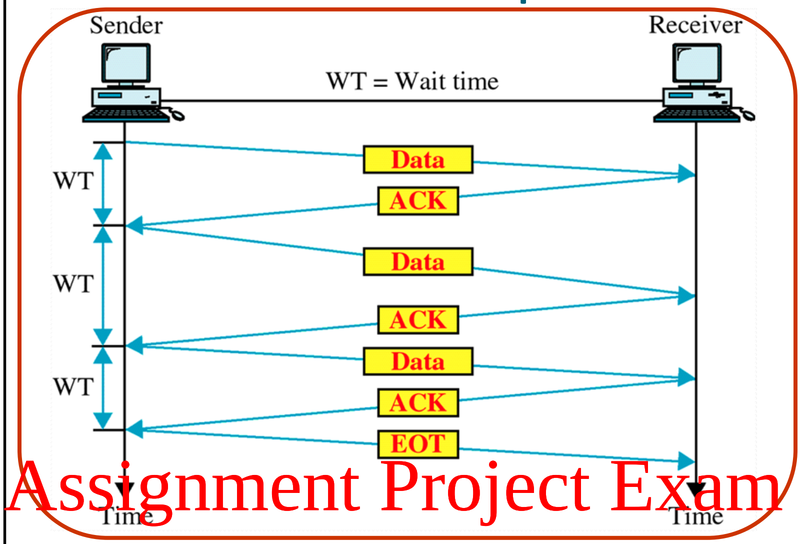
3

Flow Control/2

- two flow control mechanisms
  - stop-and-wait
    - also referred as "alternating bit" or "send and wait"
  - sliding window

4

Flow Control: Stop-and-Wait



Anything Negative?

5

Stop and Wait

- source transmits frame
- destination receives frame and replies with acknowledgement (ACK)
- source waits for ACK before sending next
- destination can stop flow by not send ACK
- works well for a few large frames
- Stop and wait becomes inadequate if large block of data is split into small frames

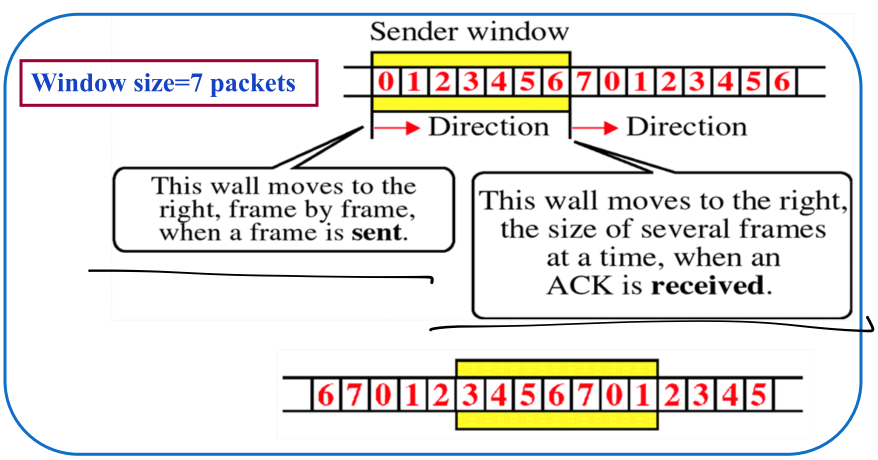
6

Flow Control: Sliding Window

- allows multiple numbered frames to be in transit
- receiver has buffer W long
- transmitter sends up to W frames without ACK
- ACK includes number of next frame expected
- sequence number is bounded by size of field (k)
  - frames are numbered modulo 2^k
  - giving max window size of up to $2^k - 1$
- receiver can ack frames without permitting further transmission (Receive Not Ready)
- must send a normal acknowledge to resume
- If have full-duplex link, can piggyback ACKs

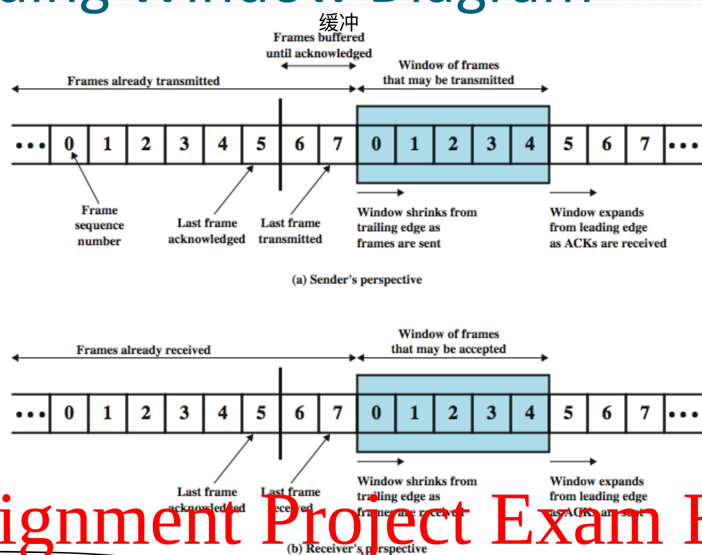
7

Sender's Sliding Wi ss



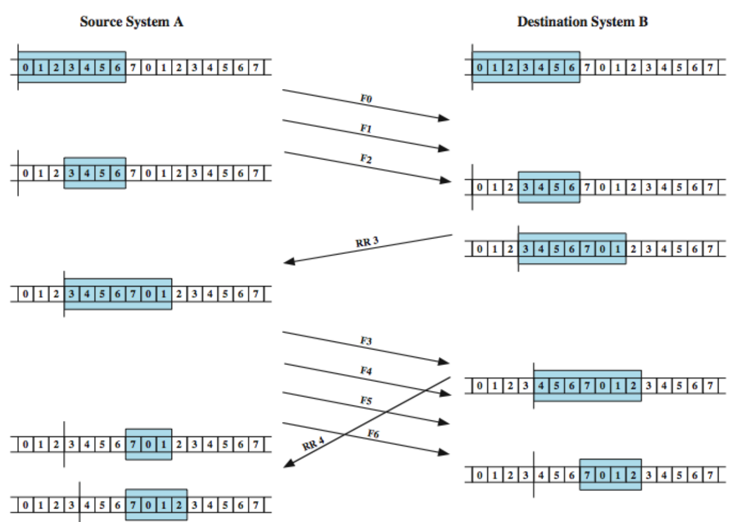
8

Sliding Window Diagram



9

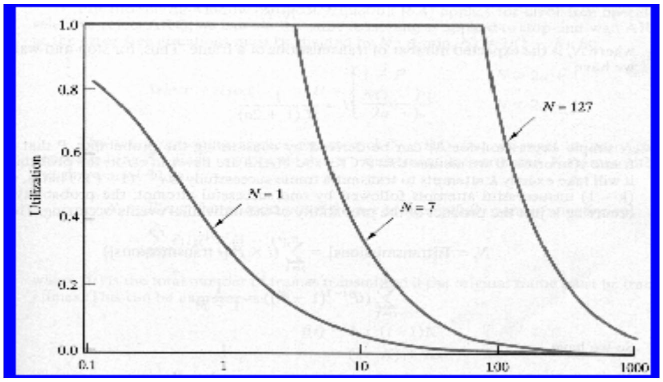
Sliding Window: E



10

利用率

Line Utilization as a Function of Window Size



11

Error Control

12

Error Control

- Error control techniques use some or all of these mechanisms

Automatic repeat request (ARQ)	error detection positive acknowledgment retransmission after timeout negative acknowledgment and retransmission

- Some versions of ARQ
  - Stop-and-Wait ARQ
  - Go-back-N ARQ
  - Selective-reject ARQ

13

Stop and Wait

- Source transmits single frame
- Wait for ACK
- If received frame damaged, discard it
  - Transmitter has timed-out
  - If no ACK within timeout, retransmit
- If ACK damaged, transmitter will not recognize it
  - Transmitter will retransmit
  - Receiver gets two copies of frame
  - use alternate numbering and ACK0 / ACK1

14

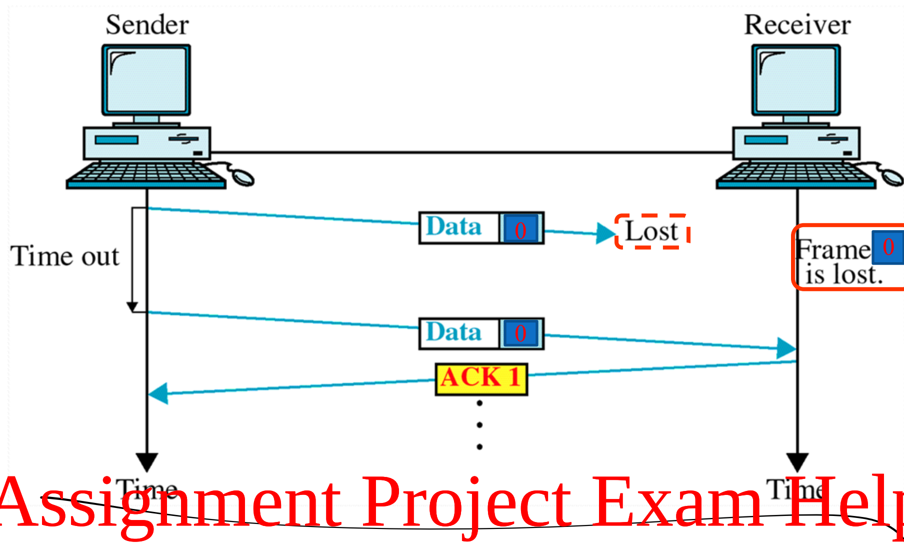
DM1

Stop and Wait: Da

15

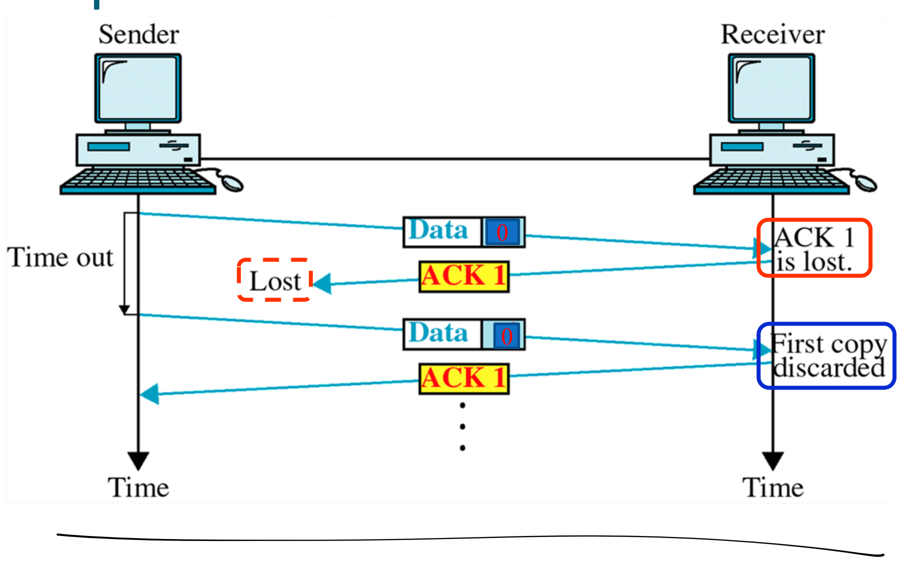
DM1 Dimitrios Makrakis, 2021-02-04

Stop and Wait: Lost frame



16

Stop and Wait: Los



17

Stop and Wait – Example

- see example with both types of errors
- pros and cons
  - simple
  - inefficient

18

Stop and Wait - Pros and Cons

- Simple
- Inefficient use of resources (low utilization, especially for systems with long propagation delays)

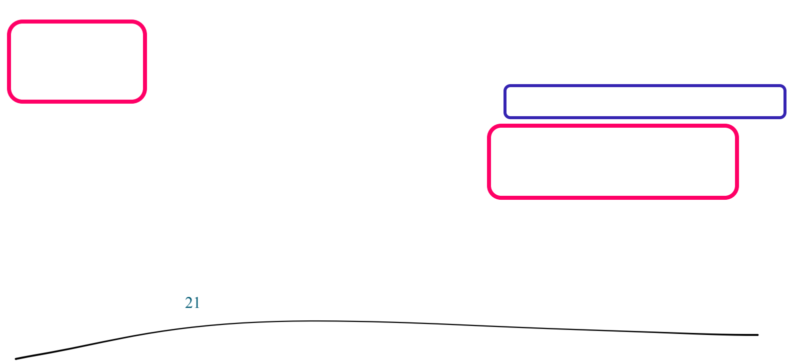
19

Go Back N

- Based on sliding window
- If no error, ACK as usual, indicating next frame expected
- Use window to control number of outstanding frames
- If error, reply with rejection
  - discard that frame and all future frames until error frame received correctly
  - transmitter must go back and retransmit that frame and all subsequent frames

20

Sliding Window Da



21

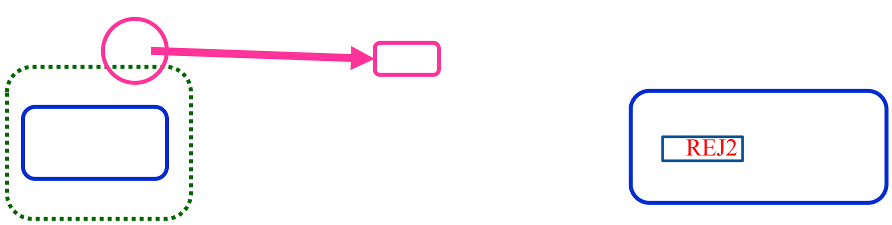
21

Go Back N - Damaged Frame

- Receiver detects error in frame *i*
- Receiver sends rejection-*i (RRi)*
- Transmitter gets rejection-*i*
- Transmitter retransmits frame *i* and all subsequent frames

22

Sliding Window:



23

Go Back N - Lost Frame (1)

- Frame *i* lost
- Transmitter sends *i+1*
- Receiver gets frame *i+1* out of sequence
- Receiver send rejection *i (RRi)*
- Transmitter goes back to frame *i* and retransmits frame *i* and all subsequent frames

24

Go Back N - Example

25

Go Back N - Lost Frame (2)

- Frame *i* lost and no additional frame sent
- Receiver gets nothing and returns neither acknowledgement nor rejection
- 确认
  Transmitter times out and sends acknowledgement frame with P bit set to 1
- Receiver interprets this as command which it acknowledges with the number of the next frame it expects (frame *i*)
- Transmitter then retransmits frame *i*

26

Sliding Window: 1

27

Go Back N – Damaged or Lost Acknowledgement

- Receiver gets frame *i* and sends acknowledgement (*i*+1) which is lost
- Acknowledgements are cu累积的mulative, so next acknowledgement (*i*+*n*) may arrive before transmitter times out on frame *i*
- If transmitter times out, it sends acknowledgement with P bit set as before
- This can be repeated a number of times before a reset procedure is initiated
- NOTE: either damaged or lost, for sender is the same since it can't reconstruct the Acknowledgement frame to be able to "read" it.

28

Go Back N - Dama n

- As for lost frame

29

Go Back N - Diagram

30

Selective Reject

- also called selective retransmission
- **only** rejected frames are retransmitted
- subsequent frames are accepted by the receiver and buffered
- minimizes retransmission
- receiver must maintain large enough buffer
- more complex logic in transmitter
- hence less widely used
- saves bandwidth
- useful for satellite links with long propagation delays

31

Selective Reject: Example

32

Go Back N vs Selective Reject

33

EECS, University of Ottawa

CEG3185 –Winter 2021

Introduction to Data Communication & Networking

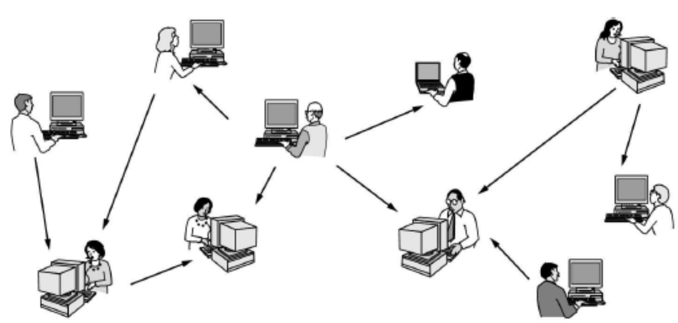
Basics

IMPORTANT: All components of the course including notes, delivered lectures, tutorials, laboratory material, are available ONLY to those registered in the course during the indicated semester, or those having received written permission by the instructor. Sharing of the material with others is STRICTLY PROHIBITED.

Note: some material in the slides has been taken from various other sources 1-1

1

Why we need comp[illegible]s?



Application Type	Example
Business-to-consumer	Ordering books on-line
Business-to-business	Car manufacturer ordering tires from supplier
Government-to-consumer	Government distributing tax forms electronically
Consumer-to-consumer	Auctioning second-hand products on-line
Peer-to-peer	File sharing

1-2

2

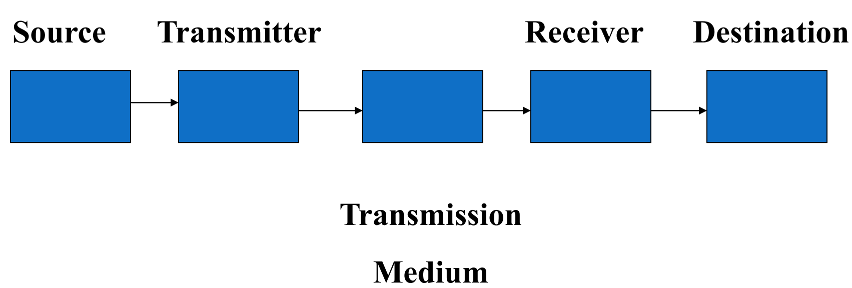
Fundamental Problem of Communication

- Reproduce at one point - either exactly or approximately - a message produced at another point
- Father of Communication Theory: Claude Shannon (MIT Professor)

1-3

3

Communications System Model



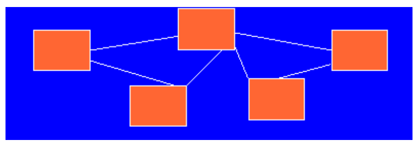
1-4

4

Structure of Transmission System

Two communicating nodes

Two or more nodes (routing issues, ..); ***Computer Network***



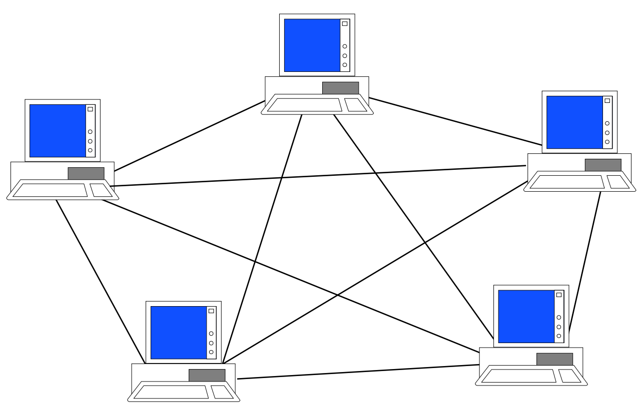
1-5

5

Computer Networ

Computing & communication devices need to exchange information

# of links required:
unidirectional links:
n (n-1)
bidirectional links:
n (n-1)/2
n: # of devices

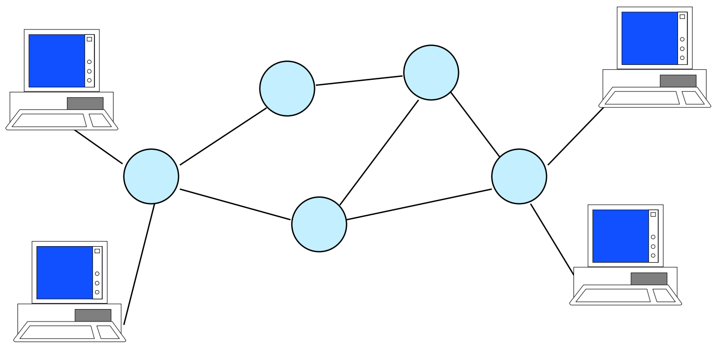


1-6

6

Computer Networks

We need switching nodes.



1-7

7

Is “Computer Communication” Important?

- History
  - 1960’s “time-sharing” computers
  - 1970’s several computers interconnected via wide area networks (WANs)
  - 1980’s local area networks (LANs)
  - 1990’s Integrated Services Digital Network (ISDN)
  - Late 1990’s wireless LANs (WLANs)
  - 2000 Pervasive Computing, Broadband Wireless Access, Optical Networks, Home networks, Personal Access Networks
  - 2004+ Vehicular networks, sensor-nets, PANs, BANs….

1-8

8

Communication Tasks (1)

Transmission system utilization	Addressing
Interfacing	Routing
Signal generation	Recovery
Synchronization	Message formatting
Exchange management	Security
Error detection and correction	Network management
Flow control	

9

9

Communicatio

- Transmission System Utilization
  - to make efficient use of transmission facilities
- Interface
  - compatible physical and electrical characteristics

1-10

10

Communication Tasks (3)

- Signal generation
  - generate signals capable of propagating through the transmission medium
- Synchronization
  - receiver should be able to determine when a signal begins to arrive and when it ends

1-11

11

Communicatio

- Exchange Management
  - establishment of a connection, communication types, amount of data to be sent at one time
- Error Detection and Correction
  - procedures to make the communication reliable

1-12

12

Communication Tasks (5)

- Flow Control
  - mechanisms required to assure that the source does not overwhelm the destination
- Addressing
  - each computer must be identified

1-13

13

Communicatio

- Routing
  - mechanisms to determine the route to use when transferring data from one point to another
- Recovery
  - mechanisms to recover from fatal errors

1-14

14

Communication Tasks (7)

- Message Formatting
  - form of the data to be exchanged or transmitted
- Security
  - Protect the confidentiality of the transferred information
- Network Management
  - Oversee the operation of the network

1-15

15

Types of Communication Networks

Classification according to the way the "information flows" are transported to the users

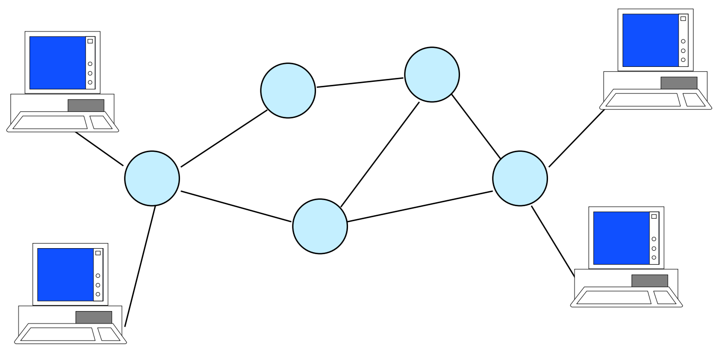
- Switching Networks
- Broadcast Networks

1-16

16

Switching Networks

Data are transferred from source to destination through a series of intermediate nodes

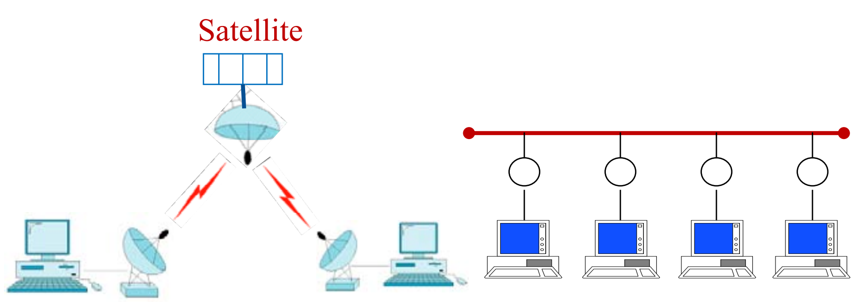


1-17

17

Broadcast Ne

- There are no intermediate switching nodes
- All users are connected on the same medium



1-18

18

Classification According to Coverage Area

- Local Area Networks (0-2 Km; campus)
  - Ethernet (10/100/1000 Mbps), Token ring (4, 16 Mbps), IEEE 802.11(b, g, a, n)
- Metropolitan Area Networks (2-50 km; corporate offices, city)
  - DQDB (Distributed Queue Dual Bus), WiMAX (IEEE 802.16.a/b/e), 4G/LTE
- Wide Area Networks (country, continent)
  - transmission lines, switching elements
- Personal Access Networks (PANs)
  - Bluetooth/IEEE 802.15.3
- Sensor Networks (Sensor-Nets)
  - ZigBee/IEEE 802.15.4
- Body Area Networks (BANs)

1-19

19

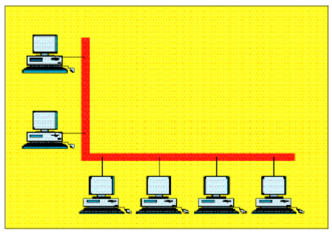
Local Area Netw

- It expands over small geographic areas (within a building or close-by buildings)
- It is usually owned by the same organization
- The internal data rates are typically much greater than those of WANs
- Typically, they make use of broadcast rather than switching (Why????)

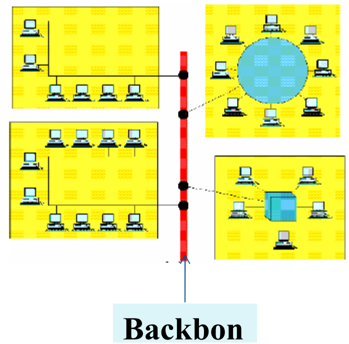
1-20

20

Local Area Networks (LANs)



Single-building LAN



Multi-building LAN

Examples: home network, wireless-wired campus network

1-21

21

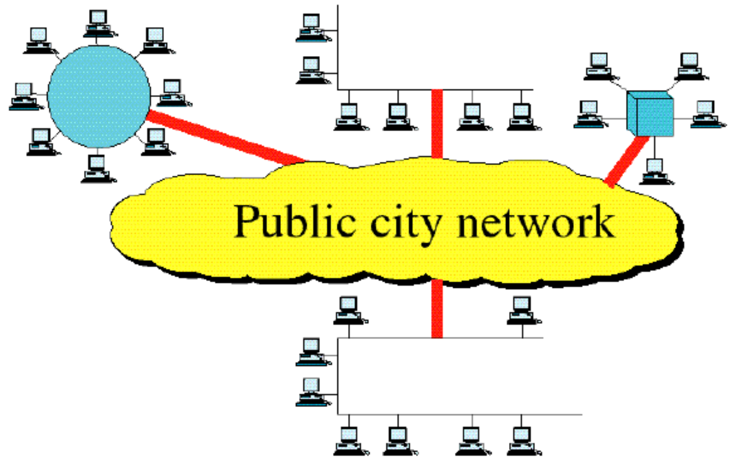
Examples of LAN

- Ethernet (10 Mbps/100 Mbps/1000 Mbps[=1 Gbps])
- Token Ring
- ATM LANs
- IEEE 802.11 Wireless LAN (“1st G….”, b, a, g, n)
- HYPERLAN (European Wireless Standard)
- Home RF

1-22

22

Metropolitan Area Networks (MAN)

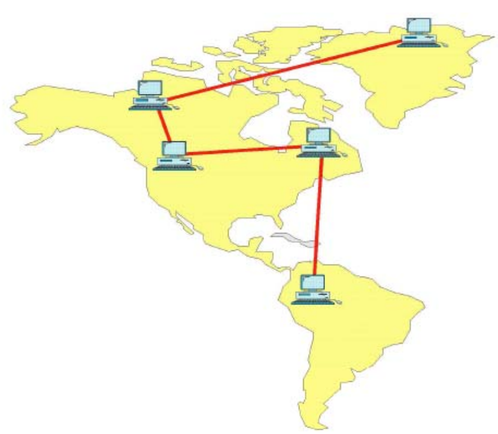


Examples: Ottawa-Carleton Research Institute (OCRI) MAN
National Capital Institute in Telecommunications (NCIT) MAN

1-23

23

Wide Area Networks (WAN)



Example: **Ca**nadian **N**etwork for the **A**dvancement of **R**esearch, **I**ndustry and **E**ducation (**CANARIE**)

1-24

24

Wide Area Networks (WAN)

- Traditionally, WANs have been implemented using one of two technologies
- Circuit Switching
- Packet Switching
  - Datagram
  - Virtual Circuit

1-25

25

Internetworking

- Internetworking: interconnecting **multiple** networks of **<u>different</u>** technologies in a **seamless** manner

- Uses both hardware and software
  - Extra hardware positioned between networks
  - Software on each attached computer

- System of interconnected networks is called an ***Internetwork*** or ***Internet***

1-26

26

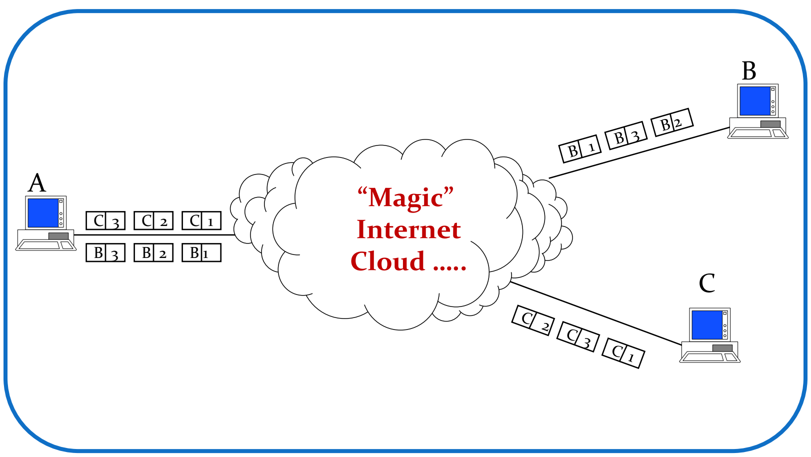
The Internet

- Internet evolved from ARPANET
  - first operational packet network
  - applied to tactical radio & satellite nets as well
  - had a need for interoperability
  - needed to be highly survivable (i.e. tolerate losses of network nodes)
  - lead to standardized TCP/IP protocols

1-27

27

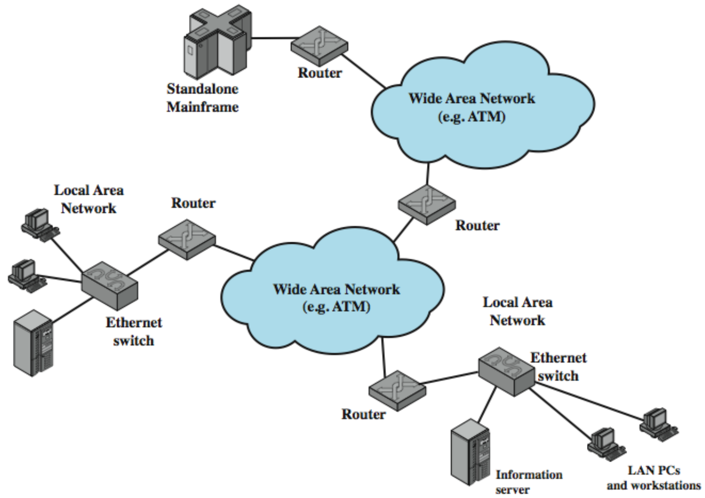
User’ s view of Internet



1-28

28

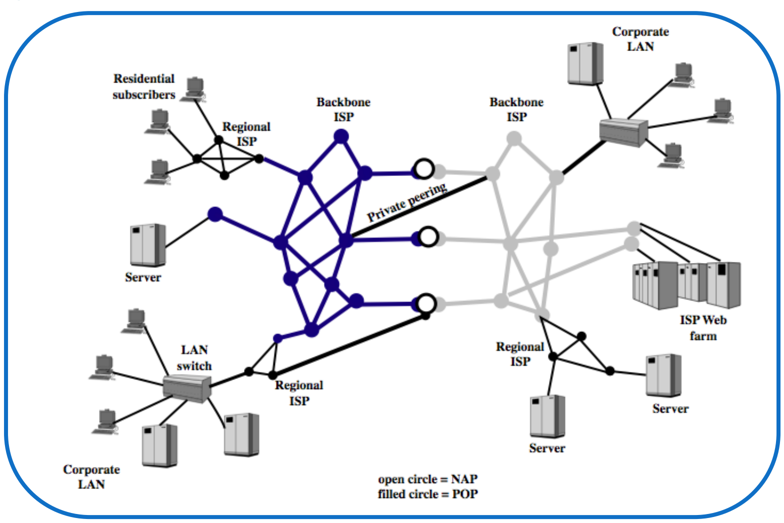
Internet Elements



1-29

29

A “possible” Internet (1)



1-30

30

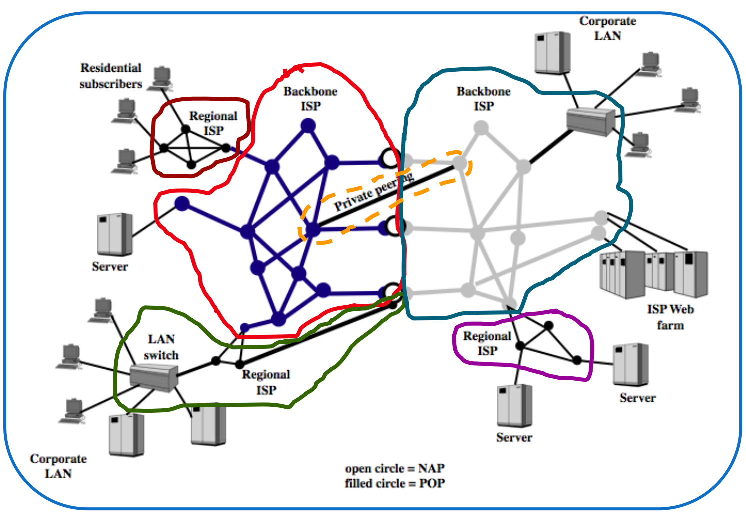
Autonomous System (AS)

- AS is a set of routers and networks managed by a single organization.
- AS consists of a group of routers exchanging information via a common routing protocol.
- Claiming that an AS is "connected", means that (excluding times of failures) there is always a "path" between any pair of nodes.

1-31

31

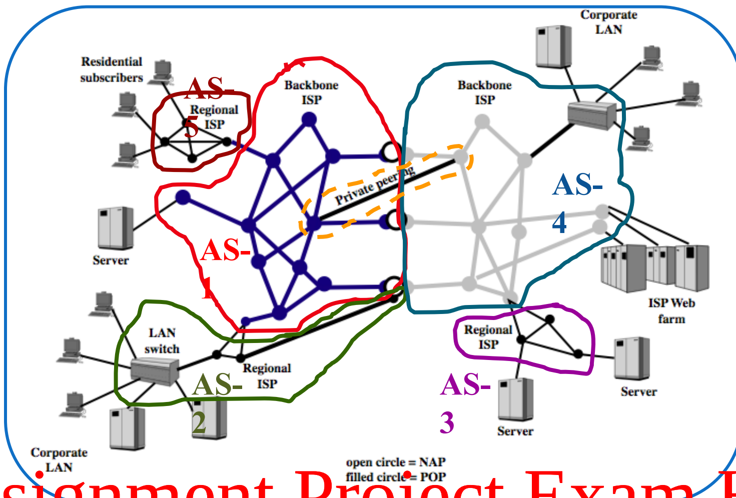
A "possible" Internet (2)



1-32

32

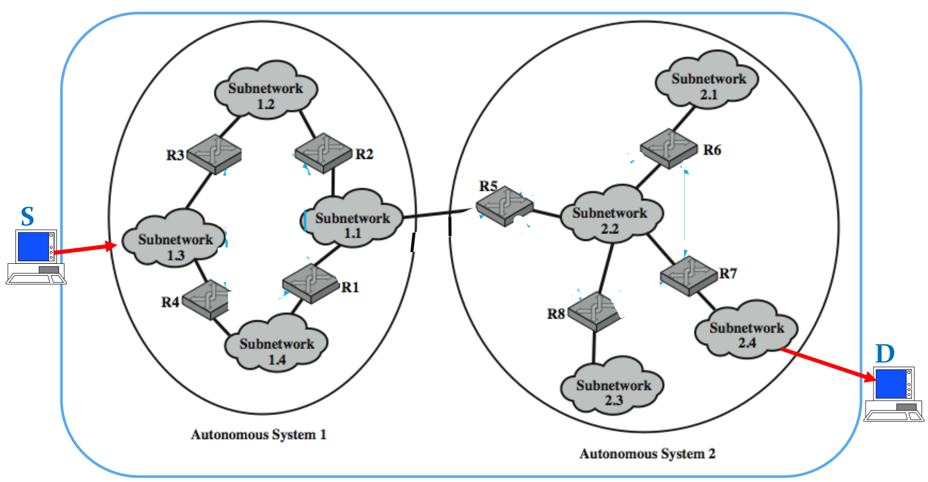
A "possible" Internet Architecture(3)



33

33

Example: 2-AS form

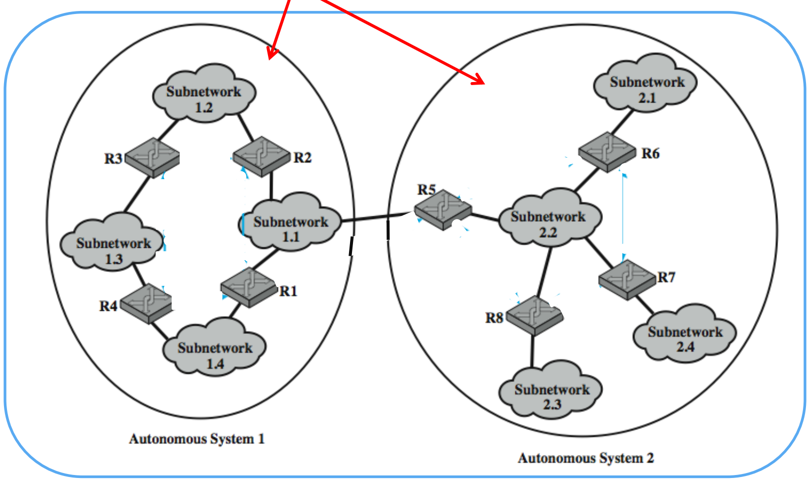


1-34

34

Within an AS domain:

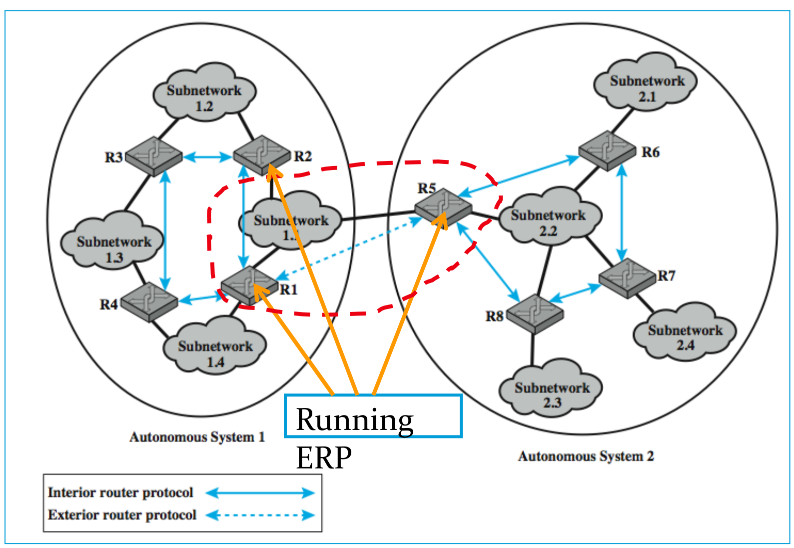
Interior Routing Protocol



1-35

35

Application of ER



1-36

36

Protocols (1)

- Computer Networks pass useful information between (two or more) entities.
- The information is produced by "applications" (e.g. file transfer, e-mail, video-conferencing etc.)
- In order for the end-systems and networks to pass the information intelligibly, definition of a set of rules governing the exchange of data between two "entities" is needed.
- These rules constitute the protocols.

1-37

37

Protocols (2)

- Protocols
  - set of mutually acceptable conventions between the communicating entities.

  - 3 key elements
    - **syntax**: data formats and signals levels (format, fields, order, …).
    - **semantics**: control information for coordination and error handling (meaning of things).
    - **timing**: speed matching and sequencing.

1-38

38

Protocol Architecture(1)

- Definition
  - A structured set of modules that implements the communication function
- Objective
  - Provide a flexible, modular structure, developed such that a change in one of the elements within the communications system will require minimal changes in the other elements

1-39

39

Protocol Architecture(2)

- How do we accomplish our objective?
  - By developing a layered architecture
  - the upper layer performs some tasks of its own, exchanges data and requests some service from the lower layer
  - the formatting of the data is independent of the actual implementation, and is not concerned how the lower layer is performing its part

1-40

40

A simple example: A Three -Layer Model (1)

- In general terms, communications involve three agents:
  - **applications** (e.g. file transfers, e-mail, www) more than one application may be running simultaneously on the same computer
  - **computers**
  - **networks**

1-41

41

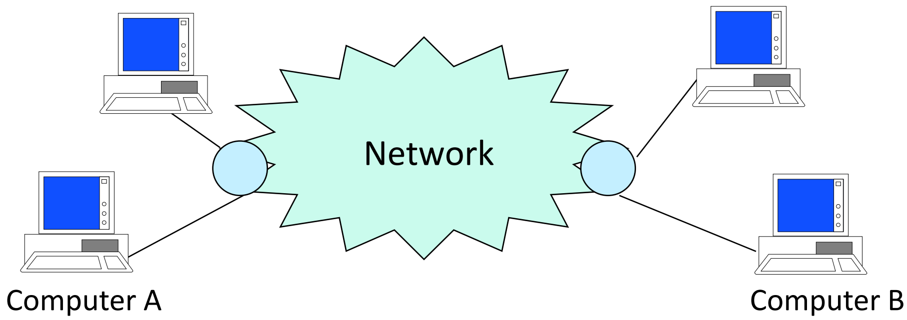
A simple example: A Three

Applications	Application Layer	Contains logic needed to support the various user applications
Computer	Transport Layer	Concerned with the reliable delivery of data
Network	Network Access Layer	Concerned with the exchange of data between computer and network

1-42

42

A simple example: A Three -Layer Model (3)



Unique address, identifying the computer

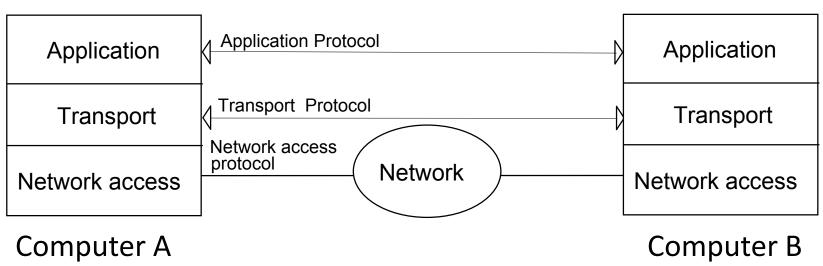
Address, identifying the application:

Service Access Point (SAP)

1-43

43

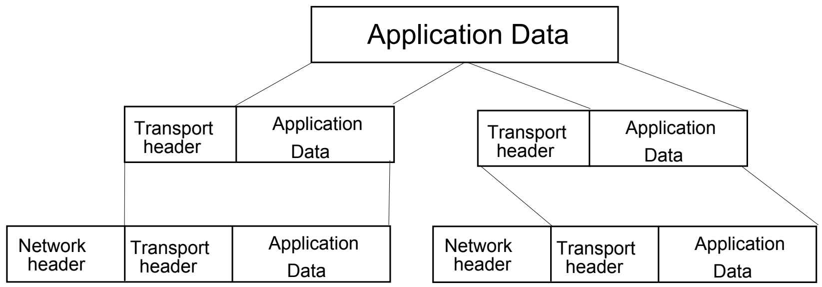
A simple example: A Three -Layer Model (4)



1-44

44

A simple example: A Three -Layer Model (5)

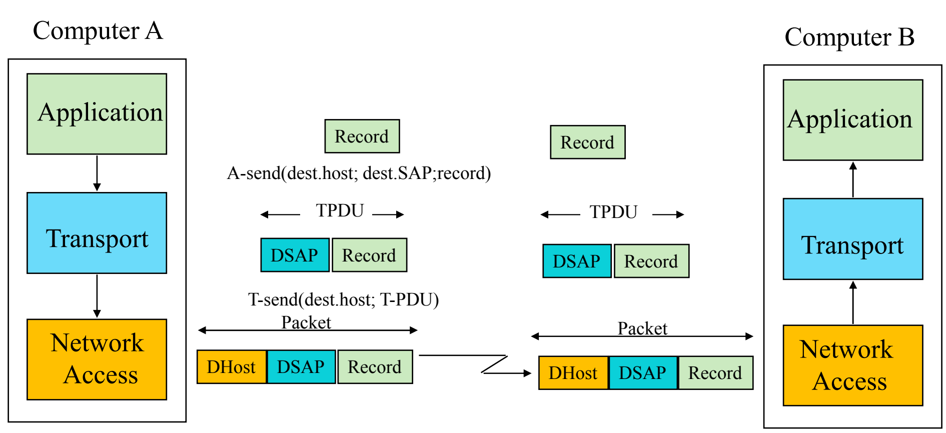


Protocol Data Unit (PDU): Combination of data from the next higher layer and control information

1-45

45

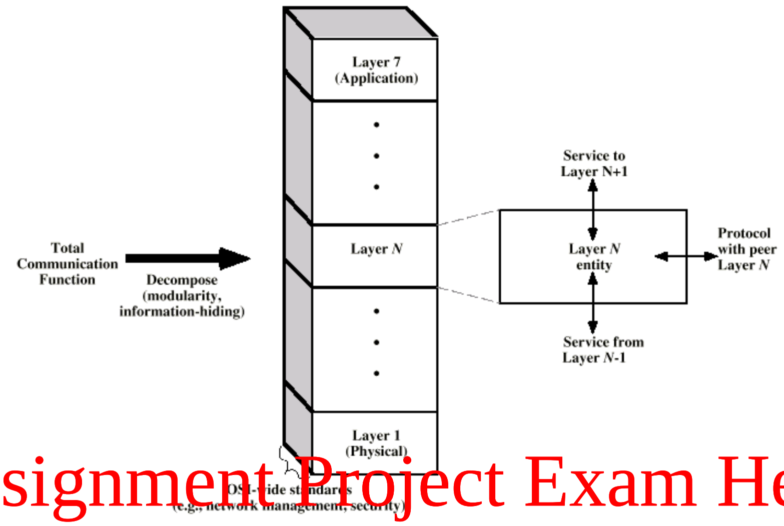
A simple example: A Three -Layer Model (6)



46

46

Standardized Protocol Architectures



1-47

47

Service Primitives and Parameters

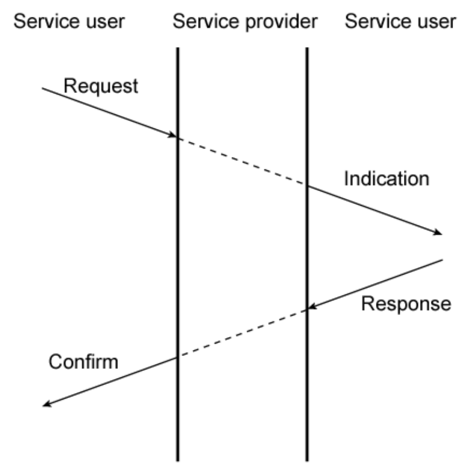
- Define services between adjacent layers using:
  - Primitives to specify the performed function
  - Parameters to pass data and control information

1-48

48

Service Primitives and Parameters

1. Source (N) entity invokes its (N –1) entity with a ***request*** primitive **including needed parameters**, such as the **data to be transmitted and the destination address.**
2. The source (N –1) entity prepares an **(N –1) PDU** to be sent to its peer (N –1) entity.
3. The destination (N –1) entity delivers the data to the appropriate destination (N) entity via an ***indication*** primitive, which includes the data and source address as parameters.
4. If an ack needed, destination (N) entity issues a ***response*** primitive to its (N –1) entity.
5. The (N –1) entity conveys the acknowledgment in an **(N –1) PDU**.
6. The acknowledgment is delivered to the (N) entity as a ***confirm*** primitive.



(a) Confirmed Service

1-49

49

Generic Protocol Iss

- Error control: making a channel more reliable, and handling lost or out of sequence messages.
- Flow control: avoid flooding a slower peer entity.
- Resource allocation: mediating contention for physical (e.g. buffers) or logical (e.g. data structures) resources
- Fragmentation (Segmentation): dividing chunks of data into smaller pieces, and subsequent reassembly
- Multiplexing: combining several higher layer sessions
- Connection setup: initiating logical communication with peer entity
- Addressing / naming: managing identifiers
- Compression: reducing data rate
- Encryption: provide data security
- Timer management: bookkeeping and error recovery

1-50

50

Relevant Standards Bodies

- ISO: International Organization for Standardization (www.iso.org)
  - An agency of the United Nations.
  - Collaborative standards development for information technology.
  - ISO is not an acronym but a word, derived from the Greek «ίσος» (read as "isos"), meaning equal.
- ITU: International Telecommunications Union (www.itu.int)
  - UN treaty agency that sets telecommunications standards.
  - ITU-T (Telecommunications section)
- ANSI: American National Standards Institute (www.ansi.org)
  - The US national standards body.
  - Coordinates and accredits standards development across the US.
- IEEE; Institute of Electrical & Electronics Engineers (www.ieee.org)
  - US based international professional organization.
  - Among other things, develops standards.
- IETF / IRTF
  - Internet Engineering Task Force (www.ietf.org) / Internet Research Task Force (www.irtf.org)
- EIA: Electronic Industries Alliance (www.eia.org)
  - e.g., standards for wiring and interconnection.

51

51

Protocol Architectures

- ISO OSI (Open System Interconnection)
- IBM SNA (System Network Architecture)
- Internet Architecture (TCP/IP Protocol Suite)

1-52

52

Open System Interconnection (odel

- Developed by the International Organization for Standardization (ISO).
- Has become the standard model for classifying communication functions.
- Has seven layers.
- It is a "theoretical" system delivered too late!
- It has NOT dominated. TCP/IP is the de facto standard.
- Several reasons:
  - TCP/IP appeared earlier
  - Internet "won" the game
  - OSI has a "complex" structure that could result in "heavy processing"

1-53

53

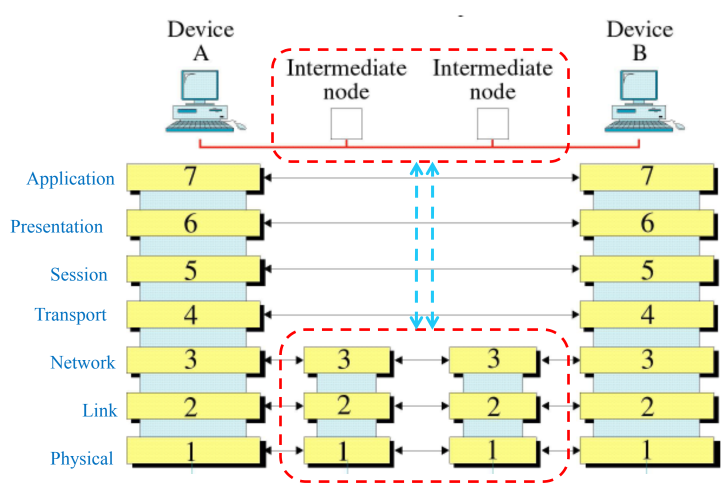
Open System Interconnection (OSI) Reference Model

Application	Access to the users (File transfer, e-mail, r-login, ..
Presentation	Data representation (syntax) (e.g ASCII)
Session	Control structure between applications. Establish/manage connection
Transport	Reliable, transparent transport of data between end-points. End-to-end error recovery and error control
Network	Responsible for establishing, maintaining, terminating connections (routing, addressing, congestion control,….)
Data link	Reliable transfer of information across physical link (sends "frames" of data with proper synchronization., error and flow control)
Physical	How to transmit a signal (access of the transmission medium; Copper, fiber, radio,..). Deals with network hardware, bit encoding)

1-54

54

OSI Reference Model



1-55

55

TCP/IP Protocol Architecture

- ***No official*** model but a working one.
- Has 5 layers (OSI has 7 layers)
- Funded by DARPA (USA).
- Initially developed as a US military research effort funded by the Department of Defense
- It has dominated.
- It is the "heart" of Internet.

1-56

56

TCP/IP Protocol 2)

Application Layer
Host-to-Host or Transport Layer
Internet Layer
Network Access Layer
Physical Layer

1-57

57

Physical Layer

- concerned with physical interface between computer and network
- concerned with issues like:
  - characteristics of transmission medium
  - signal levels
  - data rates
  - other related matters

58

58

Network Access Layer

- exchange of data between an end system and attached network
- concerned with issues like :
  - destination address provision
  - invoking specific services like priority
  - access to & routing data across a network link between two attached systems
- allows layers above to ignore link specifics

59

59

Internet Layer (IP)

- routing functions across multiple networks
- for systems attached to different networks
- using IP protocol
- implemented in end systems and routers
- routers connect two networks and relay data between them

60

60

Host-to-host / Transport Layer

- common layer shared by all applications
- provides reliable delivery of data
- in same order as sent
- commonly uses TCP

61

61

Application Layer

- Provides support for user applications
- Needs a separate module for each type of application

62

62

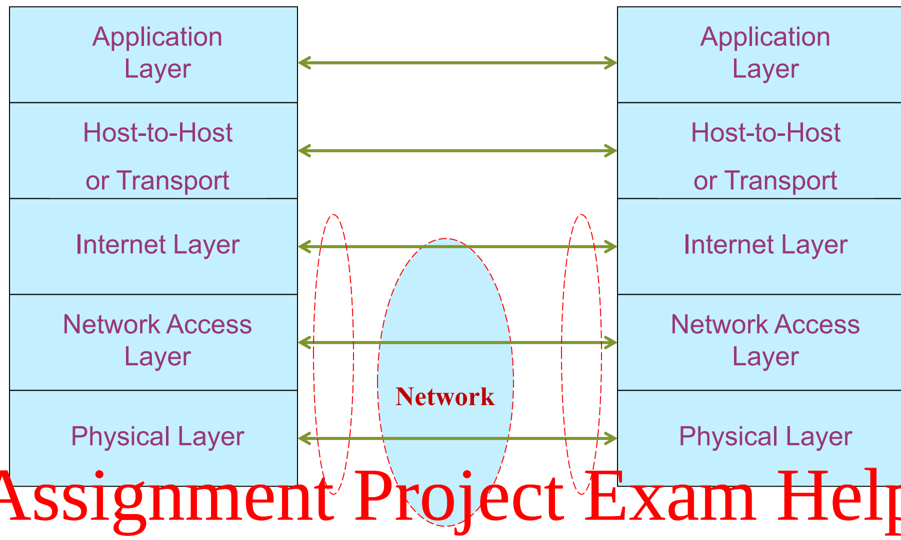
TCP/IP Protocol

Application Layer	Contains the logic needed to support user applications (ftp, telnet, http etc.) Each application requires different module.
Host-to-Host or Transport	Concerned with the reliability of transmission/reception (error control, sequencing, flow control)
Internet Layer	Provides routing functions across multiple networks. It is implemented in end-systems and routers
Network Access Layer	Concerned with the exchange of data between communicating entities. Depends on network type.
Physical Layer	Covers the physical interface between device (computer and transmission medium or network - medium, signals, data rates..)

1-63

63

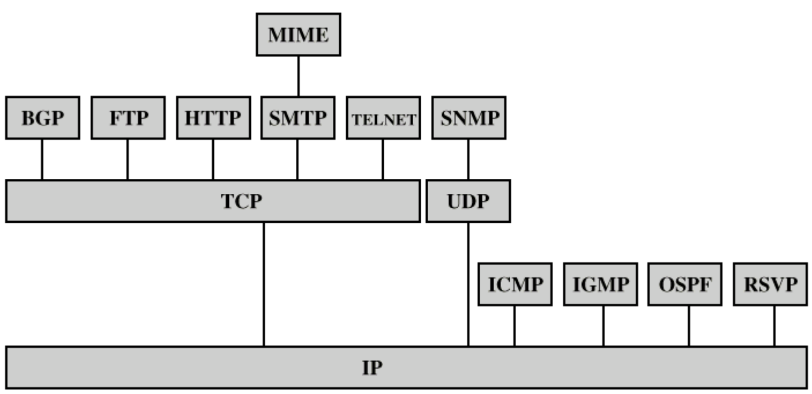
TCP/IP Protocol Architecture



1-64

64

Some TCP/IP Prot

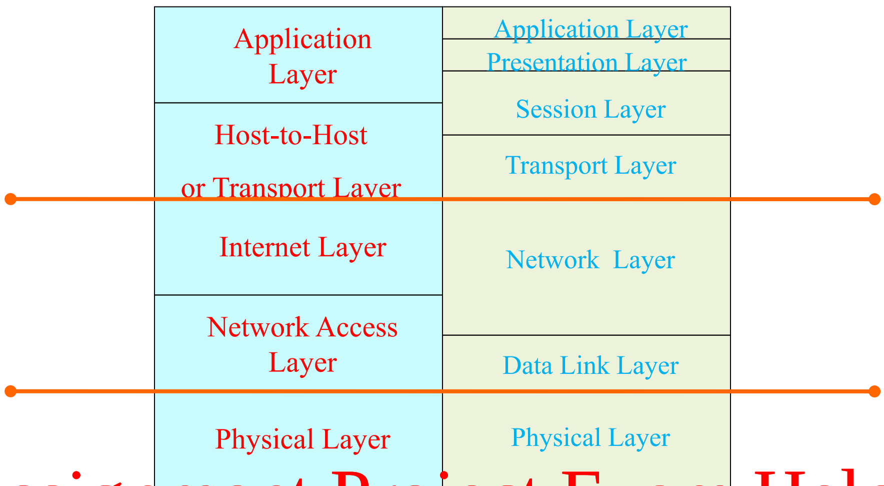


BGP = Border Gateway Protocol
FTP = File Transfer Protocol
HTTP = Hypertext Transfer Protocol
ICMP = Internet Control Message Protocol
IGMP = Internet Group Management Protocol
IP = Internet Protocol
MIME = Multi-Purpose Internet Mail Extension
OSPF = Open Shortest Path First
RSVP = Resource ReSerVation Protocol
SMTP = Simple Mail Transfer Protocol
SNMP = Simple Network Management Protocol
TCP = Transmission Control Protocol
UDP = User Datagram Protocol

1-65

65

TCP/IP versus OSI



1-66

66

OSI Pros and Cons

- Bad timing (too much detailed concept before actual applications)
  - It tries to design the "perfect world", which is either difficult or impractical.
  - Technology and human understanding of how things work (or should work) changes.
- More modular but more processing intensive.
- Provides a good architecture for detailed modeling of processes

1-67

67

IPv4

68

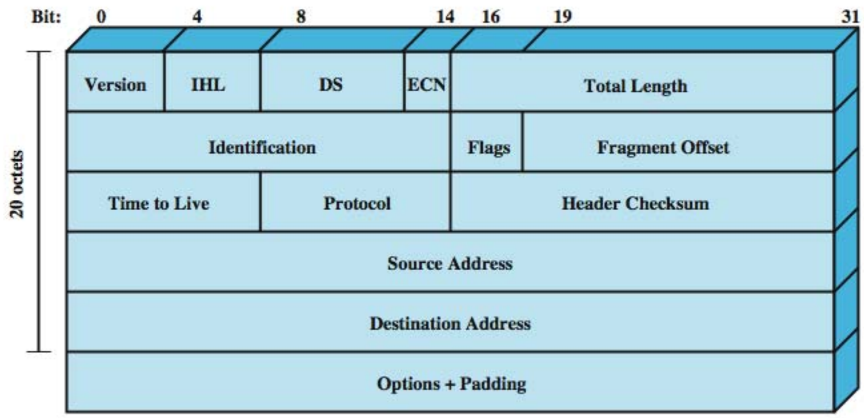
Internet Protocol (IP) v4

- defined in RFC 791
- part of TCP/IP suite
- two parts
  - specification of interface with a higher layer (e.g. TCP)
  - specification of actual protocol format and mechanisms
- is gradually replaced by IPv6

1-69

69

IPv4 Header



1-70

70

Header Fields (1)

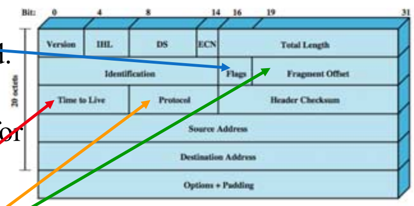
- Version
  - currently IPv4
  - latter IPv6
- Internet Header Length
  - multiple of 32-bit words (including options)
- DS/ECN (was type of service)
- Total length of datagram (in octets)
- Identification
  - sequence number that together with the source address, destination address, and user protocol, identifies a datagram uniquely.

71

71

Header Fields (2)

- Flags
  - Only 2 of the bits are currently defined.
  - "More" bit indicates there are more segments of the packet coming (used for fragmentation and reassembly
  - "Don't fragment" bit prohibits packet fragmentation when set.



- Fragmentation offset
  - Indicates where in the original datagram this fragment belongs.
- Time to live
  - Specifies how long a datagram is allowed to remain in the internet.
- Protocol
  - Next higher layer to receive data field at destination (e.g. TCP)

1-72

72

Header Fields (3)

- Header checksum
  - re-verified and recomputed at each router
  - 16 bit ones complement sum of all 16 bit words in header
- Source address
- Destination address
- Options
  - Encodes the options requested by the sending user
- Padding
  - to fill to multiple of 32 bits

1-73

73

IPv6

1-74

74

Why Change IP?

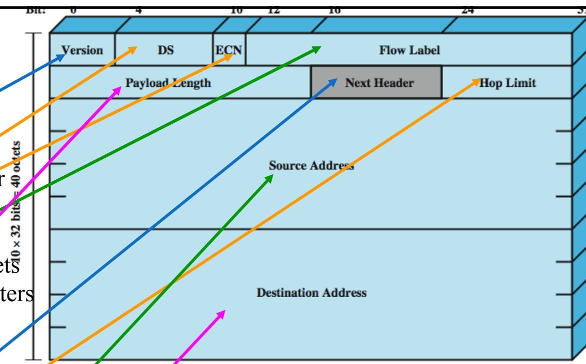
- Address space exhaustion
  - two-level addressing (network and host) wastes space
  - network addresses used even if not connected
  - you have to wait for a while, to get more info, in order to understand these two statements
  - growth of networks and the Internet
  - extended use of TCP/IP
  - single address per host
- requirements for new types of service

1-75

75

IPv6 Header

Version (4 bits): IP version number (=6).
DS/ECN (8 bits): As in IPv4.
Flow Label (20 bits): Labels packets that require special handling by routers within a network.



Payload Length (16 bits): Length of remainder of packet following header (extension headers + transport-level PDU).
Next Header (8 bits): Identifies type of header immediately following IPv6 header (either an IPv6 extension header or a higher-layer header (e.g. TCP or UDP).
Hop Limit (8 bits): Remaining number of allowable hops for this packet.
Source Address (128 bits): address of originator of the packet.
Destination Address (128 bits): address of intended recipient of the packet.

IPV6 header:

- longer than the mandatory portion of IPv4 header (40 octets versus 20 octets).
- contains fewer fields (8 versus 12).
- Routers have less processing to do per header (speeds up routing).

1-76

76

EECS, University of Ottawa

CEG3185 –Winter 2021

Introduction to Data Communication & Networking

Local Area Networks (LANs)

Note: some material in the slides has been taken from various other sources 1-1

1

Local Area Netw

- It expands over small geographic areas (within a building or close-by buildings)
- It is usually owned by the same organization
- The internal data rates are typically much greater than those of WANs
- Typically, they make use of broadcast approach than switching approach

1-2

2

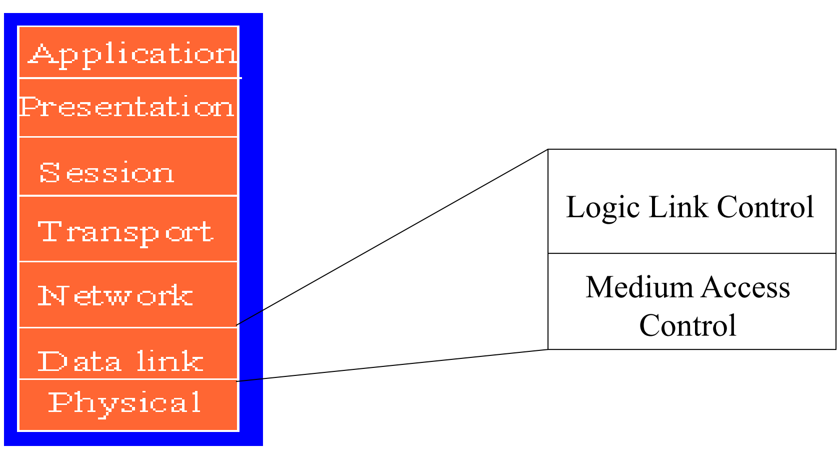
Examples of LANs

- Ethernet (10 Mbps)
- Fast Ethernet (100 Mbps)
- Gigabit Ethernet (1,000 Mbps)
- Token Ring
- ATM LANs
- IEEE 802.11 Wireless LAN
- HYPERLAN (European Wireless Standard)

1-3

3

Open System Interconnection odel



1-4

4

Functions Performed by Physical Layer

- Encoding/decoding of signals
- Preamble generation / removal (for synchronization)
- Bit Transmission / Reception

1-5

5

Functions Performed a er

- Provide an interface to higher layers
- Perform flow and error control

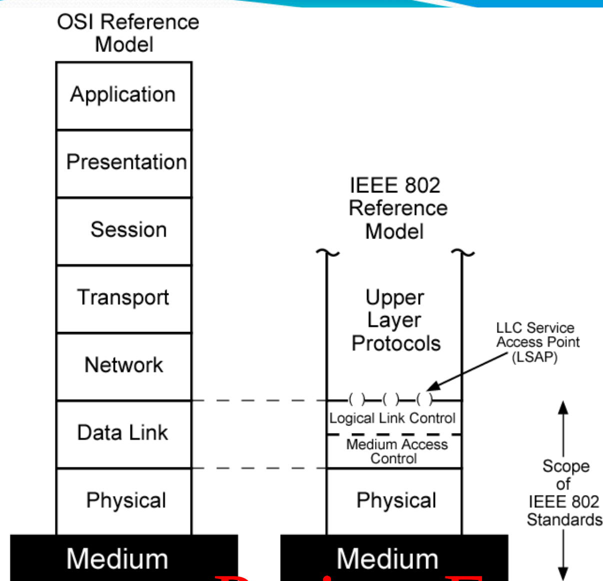
LLC

- Assemble data into frame with address and error-detection fields
- Assemble/de-assemble frame, perform address recognition and error detection
- Govern Access to the LAN transmission medium

MAC

1-6

6



1-7

7

MAC Frame For

MAC Control	Destination MAC address	Source MAC address	LLC PDU	CRC

DSAP	SSAP	LLC Control	Variable

I/G	DSAP value	C/R	SSAP value

D/S-SAP: Destination/Source Access Point: 7-bit address, specifying the destination/source users of LLC; 1 bit of DSAP indicates Individual or Group address (I/G); 1 bit of SSAP indicates Command or Response

1-8

8

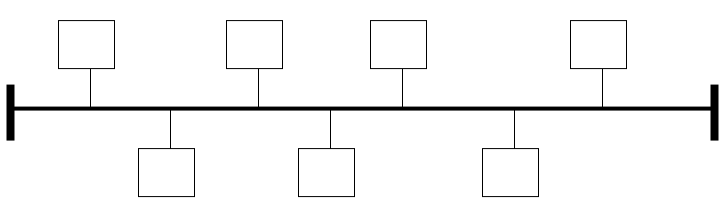
Topologies

- Tree
- Bus
  - Special case of tree
    - One trunk, no branches
- Ring
- Star

1-9

9

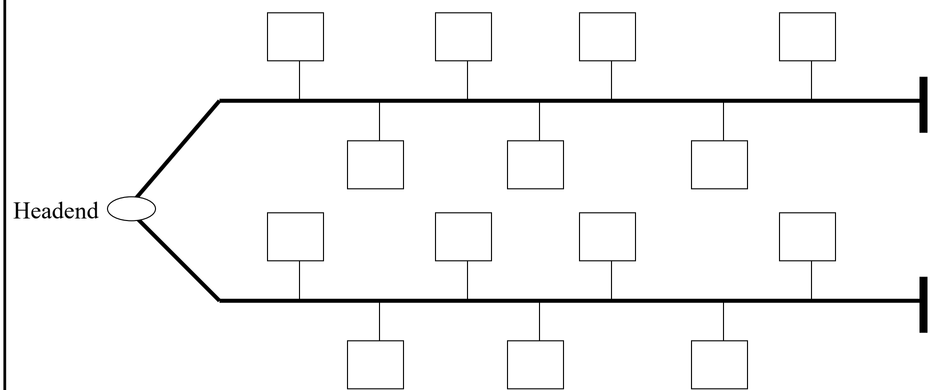
Bus Topology



1-10

10

Tree Topology



1-11

11

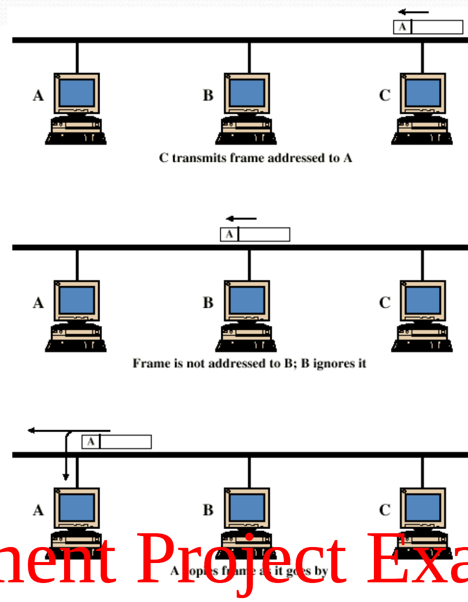
Bus and Tree

- Multipoint medium
- Signal propagates throughout medium
- Heard by all stations
  - Need to identify target station
    - Each station has unique address
- "Full duplex" connection between station and tap
  - Allows for transmission and reception
- Need to regulate transmission
  - To avoid collision and hogging Data in small blocks - frames
- Terminator absorbs frames at end of medium

1-12

12

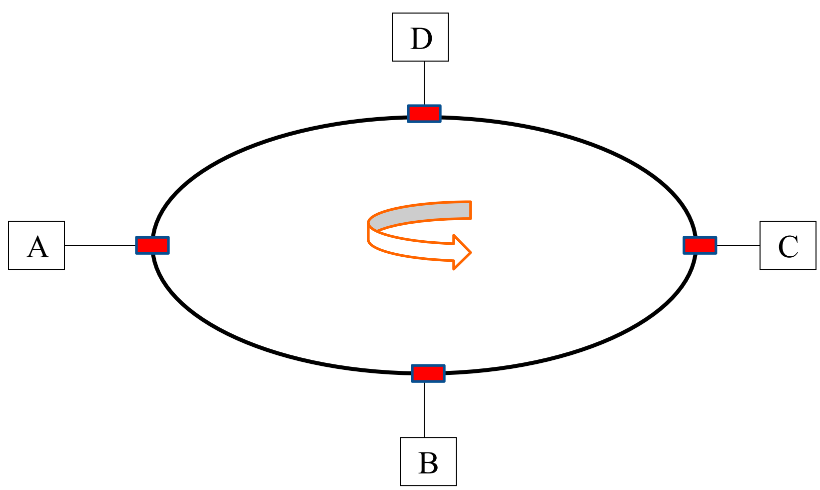
Frame Transmission - Bus LAN



1-13

13

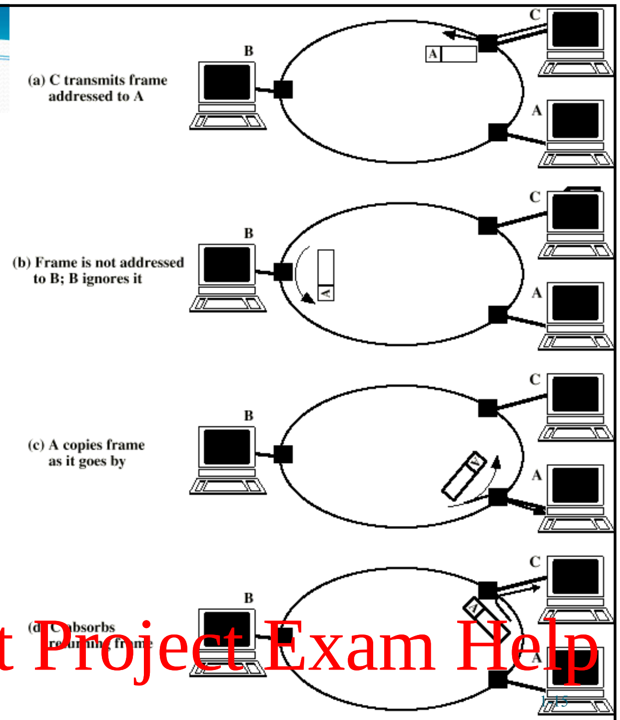
Token Ring



1-14

14

Frame Transmission Ring LAN



15

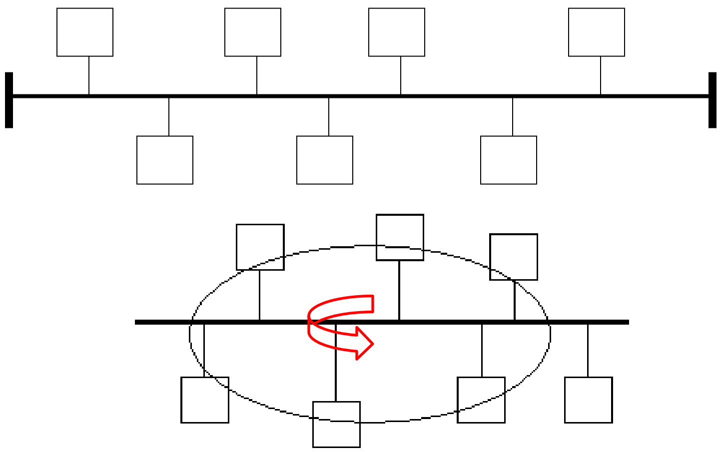
Ring Topology

- Repeaters joined by point-to-point links in closed loop
  - Receive data on one link and retransmit on another
  - Links unidirectional
  - Stations attach to repeaters
- Data in frames
  - Circulate past all stations
  - Destination recognizes address and copies frame
  - Frame circulates back to source where it is removed
- Media access control determines when station can insert frame

1-16

16

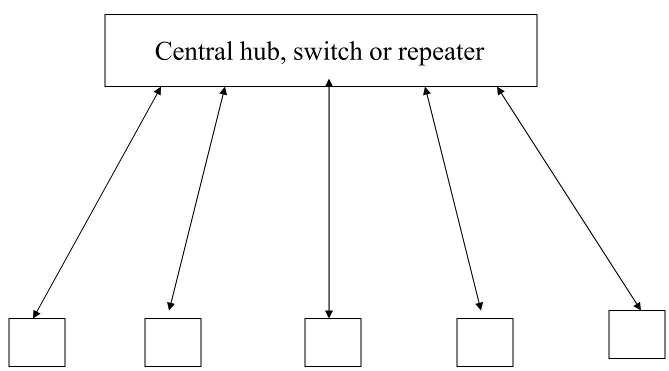
Token Bus



1-17

17

Star Topology



1-18

18

Star Topology

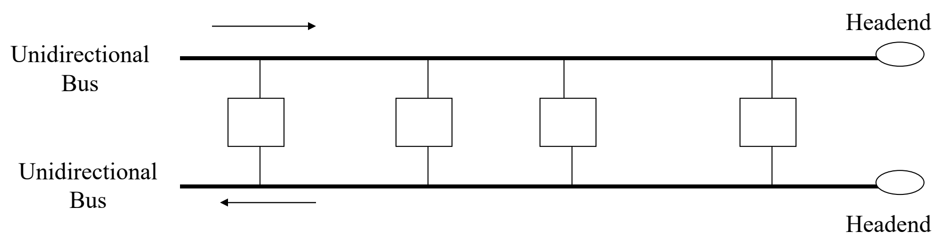
- Each station connected directly to central node
  - Usually via two point to point links
- Central node can broadcast
  - Physical star, logical bus
  - Only one station can transmit at a time
- Central node can act as frame switch

1-19

19

Distributed Que s (DQDB)

Used with Fiber Links



1-20

20

LAN/MAN MAC Standards

- CSMA/CD
- Token Bus
- Round Robin
- Token Ring
- DQDB
- CSMA/CA

1-21

21

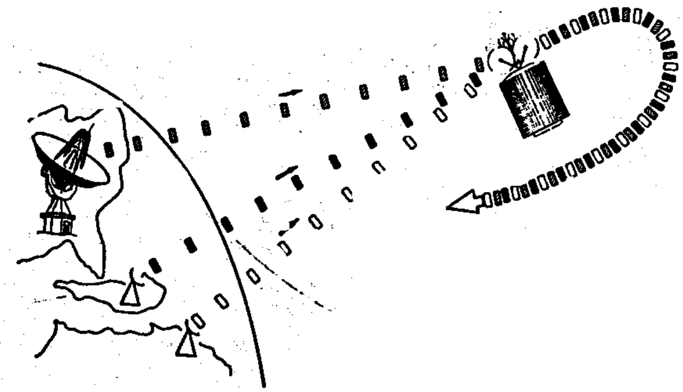
IEEE802.3 Medium Access Control

- Random Access
  - Stations access medium randomly
- Contention
  - Stations content for time on medium

1-22

22

Random Access Packet Radio-Satellite Communication Net



1-23

23

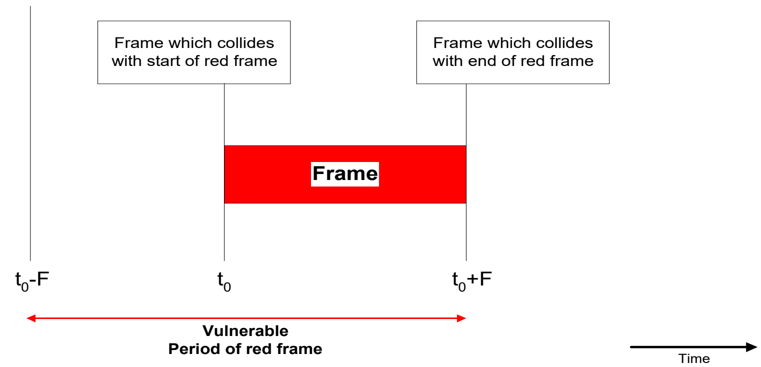
ALOHA

- Packet Radio
- When station has frame, it sends
- Station listens (for max round trip time) plus small increment
- If ACK, fine. If not, retransmit
- If no ACK after repeated transmissions, give up
- Frame check sequence (as in HDLC)
- If frame OK and address matches receiver, send ACK
- Frame may be damaged by noise or by another station transmitting at the same time (collision)
- Any overlap of frames causes collision
- Max utilization 18%

1-24

24

Collisions and Vulnerable Period

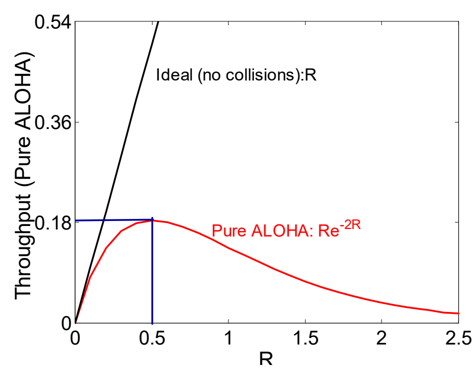


- A frame (red frame) will be in a collision if and only if another transmission begins in the vulnerable period of the frame
- Vulnerable period has the length of 2 frame times

1-25

25

Performance of A



- Maximum throughput approximately 18% of the capacity
- Can do better with improved control
- **However, ALOHA is still used for its simplicity**

1-26

26

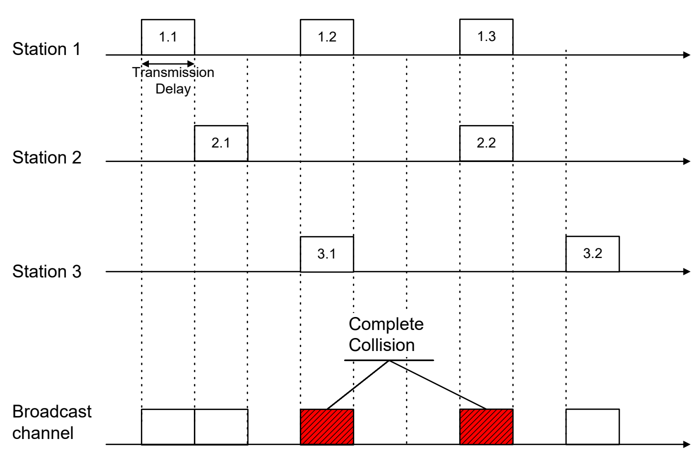
Slotted ALOHA

- Time in uniform slots equal to frame transmission time
- Need central clock (or other sync mechanism)
- Transmission begins at slot boundary
- Frames either miss or overlap totally
- Max utilization 37%

1-27

27

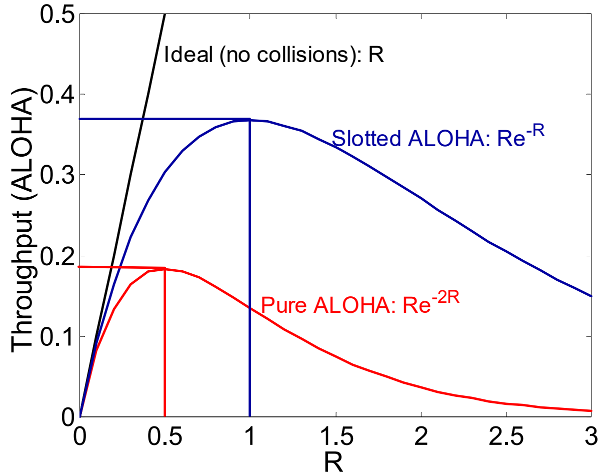
Collisions in S-AL



1-28

28

Comparison of ALOHA and S-ALOHA



1-29

29

Carrier Sense Multiple Access (CSMA)

- Propagation time is much less than transmission time
- All stations know that a transmission has started almost immediately
- First listen for clear medium (carrier sense)
- If medium idle, transmit
- If two stations start at the same instant, collision
- Wait reasonable time (round trip plus ACK contention)
- No ACK then retransmit
- Max utilization depends on propagation time (medium length) and frame length
  - Longer frame and shorter propagation gives better utilization

1-30

30

If Busy?

- If medium is idle, transmit.
- If busy, listen for idle; then transmit immediately 1-persistent.
- If two or more stations are waiting, collision.
- Probability for collision higher when waiting in busy channel because during waiting time for transmission to complete, another or more stations might have produced frames for transmission.
- Use p-persistent: after channel idle, transmit with probity p (0<p<1). If you decide not to transmit wait for next "slot" and repeat process.

1-31

31

Carrier Sensing Access / Collision Detection (CSMA/CD)

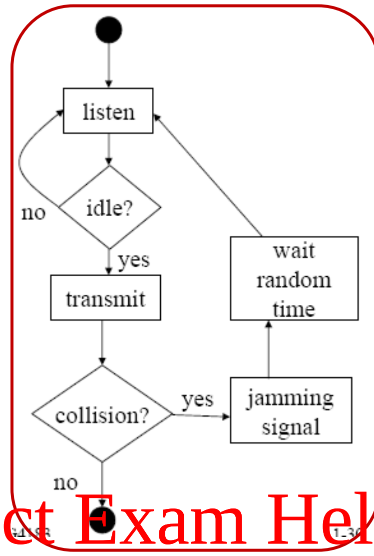
- Used in Ethernet
- Usually applied with Bus and Tree topologies

1-32

32

Carrier Sensing Multiple Access / Collision Detection (CSMA/CD)

- IEEE 802.3 standard
- Useful when propagation time much shorter to frame’s duration
- Used in Ethernet (the most widely used type of LAN)
- Usually applied with Bus and Tree topologies



1-33

33

CSMA with Collisio

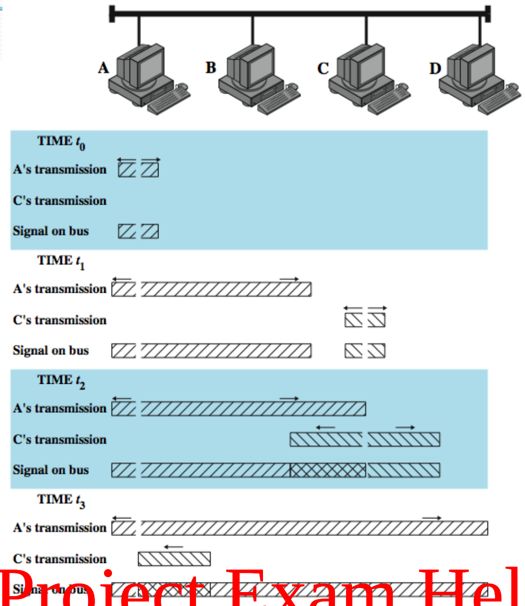
(CSMA/CD)

- With CSMA, collision occupies medium for duration of transmission
- Stations listen while transmitting
- If medium idle, transmit
- If busy, listen for idle, then transmit
- If collision detected, jam then cease transmission
- After jam, wait random time then start again
  - Binary exponential back off

1-34

34

CSMA/CD Operation



1-35

35

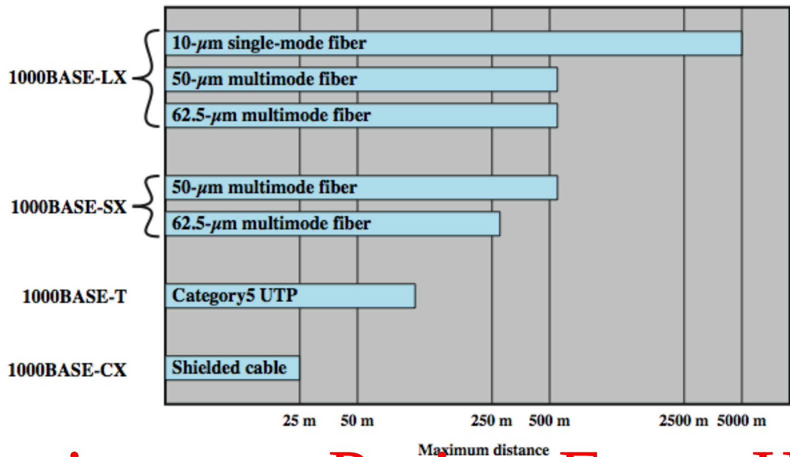
Collision Detecti

- On baseband bus, collision produces significantly higher signal strength than a single signal does
- Collision detected if cable signal noticeably stronger than single station signal
- Signal attenuation increases with distance
- There are distance limits, e.g. 500m (10Base5) or 200m (10Base2), 100 meters (10Base-T)

1-36

36

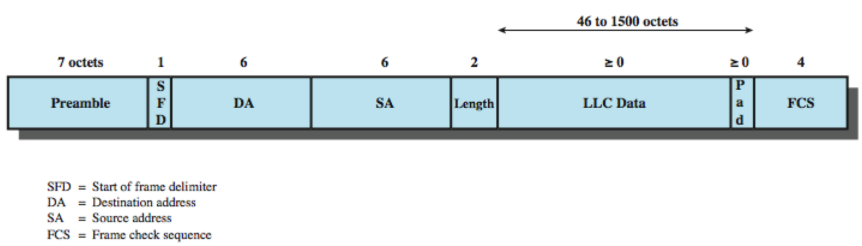
Gigabit Ethernet – Physical



1-37

37

IEEE 802.3 Frame Format

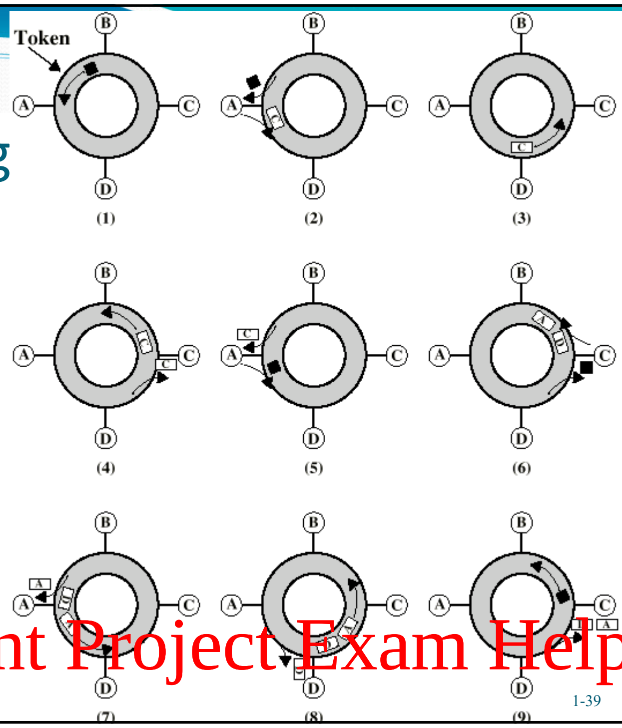


1-38

38

Token Ring Operation

A→ C



1-39

39

Token Ring (802.

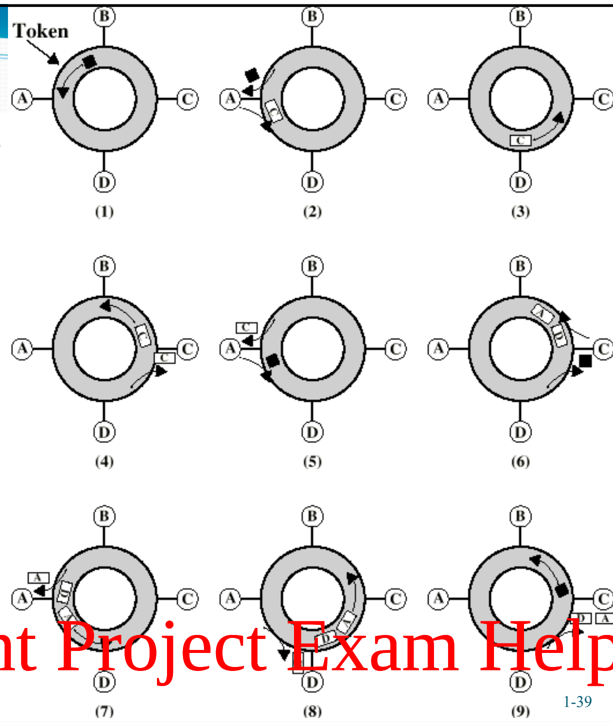
- MAC protocol
  - Small frame (token) circulates when idle
  - Station waits for token
  - Changes one bit in token to make it SOF for data frame
  - Append rest of data frame
  - Frame makes round trip and is absorbed by transmitting station
  - Station then inserts new token when transmission has finished and leading edge of returning frame arrives
  - Under light loads, some inefficiency
  - Under heavy loads, round robin

1-40

40

Token Ring Operation

A→ C



1-39

39

Token Ring (802.

- MAC protocol
  - Small frame (token) circulates when idle
  - Station waits for token
  - Changes one bit in token to make it SOF for data frame
  - Append rest of data frame
  - Frame makes round trip and is absorbed by transmitting station
  - Station then inserts new token when transmission has finished and leading edge of returning frame arrives
  - Under light loads, some inefficiency
  - Under heavy loads, round robin

1-40

40

FDDI: Fiber Distributed Data Interface

- 100Mbps
- LAN and MAN applications
- Based on Token Ring

1-41

41

FDDI MAC Protoc

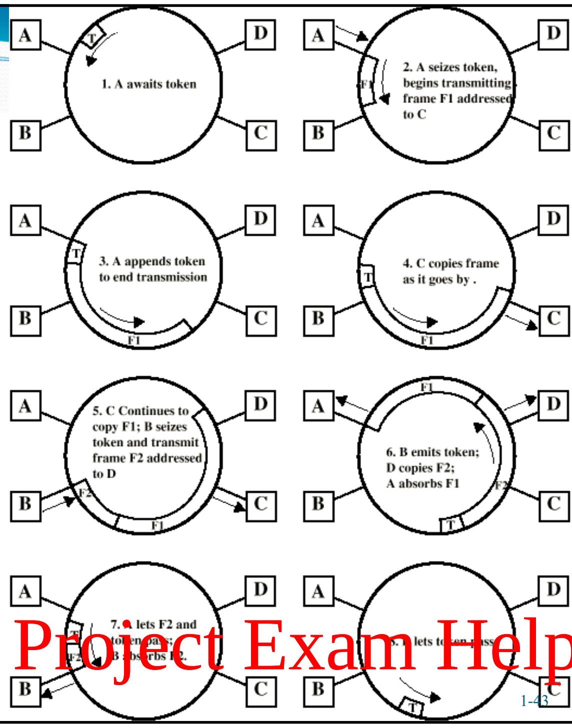
As for 802.5 except:

- Station seizes token by aborting (failing to repeat) token transmission
- Once token captured, one or more data frames transmitted
- New token released as soon as transmission finished (early token release in 802.5)

1-42

42

FDDI Operation



43

Wireless LANs

- Physical layer can use:
  - Infrared (IR)
  - Code Division Multiple Access (CDMA)
  - Frequency Hopping Spread Spectrum (FH/SS)
  - Orthogonal Frequency Multiplexing (OFM)
  - Multiple Input Multiple Output (MIMO)
- Standards:
  - IEEE 802.11
  - HIPERLAN
  - Bluetooth
  - Home RF
- Several important differences with wired environment

1-44

44

Wireless LAN Standards

- European standard : ETSI- HIPERLAN
  + 5.15- 5.30, 17.1 -17.2 GHz transmission band
  + Data rates up to 23.529 Mbps
  + FEC for error correction
- American Standard : IEEE 802.11 WLAN
  + 2.4 ISM/5 GHz UNII Bands (first generation products used 900 MHz)
  + data rates up to 2 Mbps (today we have 1.7Gbps products)
  + Stop and Wait ARQ

1-45

45

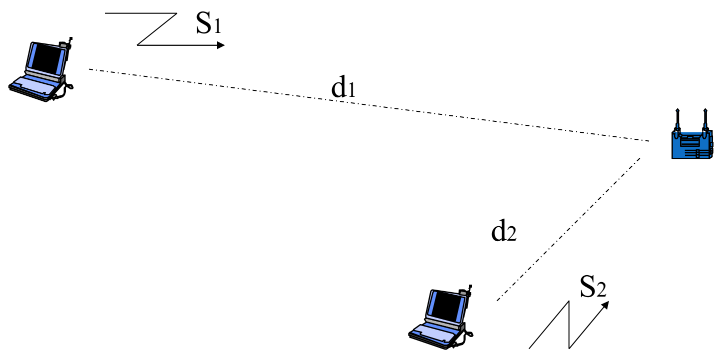
Wireless LAN Design Challenges

- Reliability, noise, fading, interference.
- Hidden Terminal issue.
- Fairness of access (capture effect).
- Handoff and roaming.
- The ability of having carrier sense.
- Battery power consumption.

1-46

46

Capture Effect



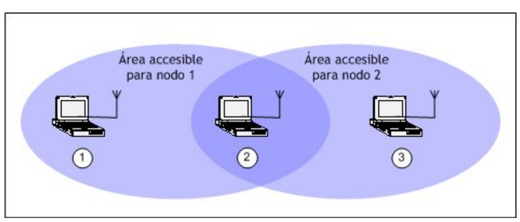
$d_1 \gg d_2 \rightarrow \{(S_1)^2/(S_2)^2\} \ll 1$

1-47

47

The hidden node

This problem comes from the fact that not every station can hear everybody else's transmissions. For instance, in the figure node 2 can hear both stations 1 and 3, but these two stations cannot hear each other.

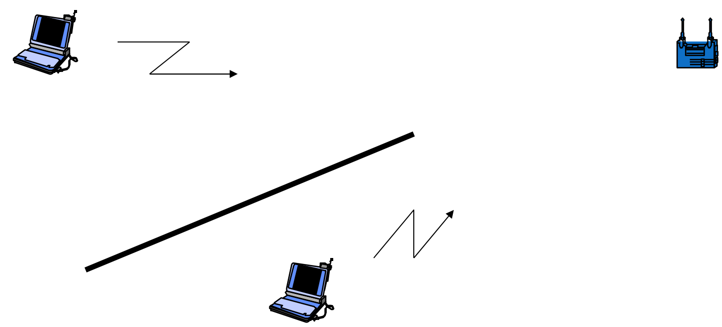


Node 1 and 3 are hidden from each other

1-48

48

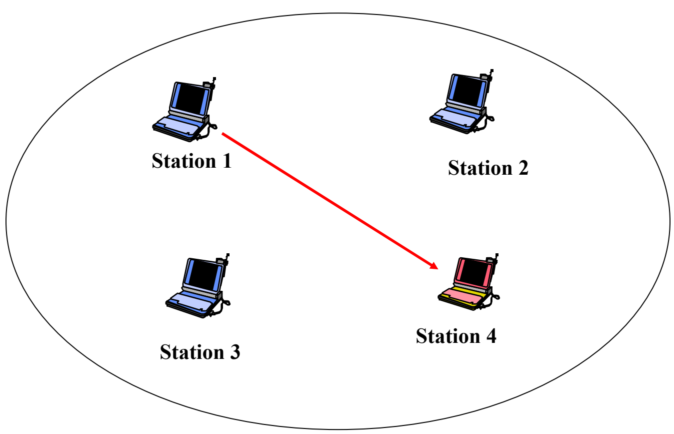
Hidden Terminal



1-49

49

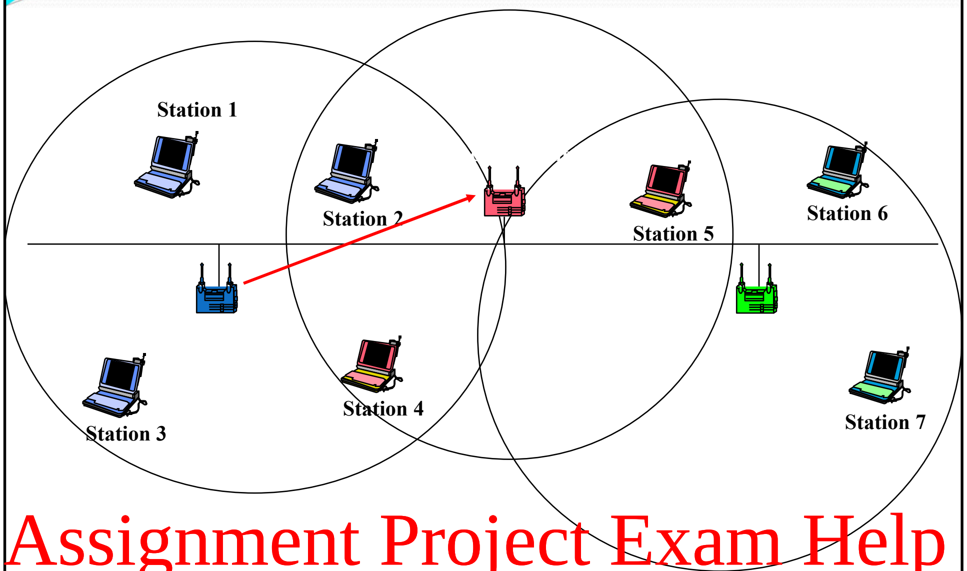
Ad Hoc Wireless LAN



1-50

50

Infrastructure Wireless LAN



1-51

51

IEEE 802.11

1-52

52

What is IEEE 802.11?

- IEEE standard addressing the 2.4 & 5 GHz WLAN market
- Spec is steered by the IEEE committee
  - Specifies "over the air" interface between a wireless client & a base station (or access point) or wireless clients
  - Conceived in 1990, final draft approved in June 1997
  - Like the IEEE 802.3 Ethernet & 802.5 Token Ring Standards.
  - Wide range: 152 m indoors/457 m outdoors for 802.11b

1-53

53

Modern WiFi Systems

Frequency	Theoretical	Speed Real-World Speed
2.4 **GHz** (802.11g)	54 Mbps	10 -29 Mbps
2.4 **GHz** (802.11n)	300 Mpbs	150 Mbps
5 **GHz** (802.11a)	6-54 Mbps	3 - 32 Mbps
5 **GHz** (802.11ac)	433 Mbps-1.7 Gbps	210 Mbps - 1 G

1-54

54

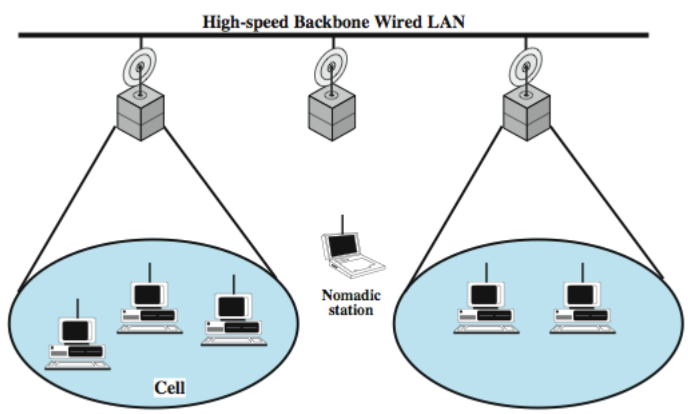
IEEE 802.11 WLAN Standard Requirements

- Provide reliable, efficient wireless data networking
- Define MAC & PHY layer specifications
- Provide a single MAC layer to work with multiple PHYs
- Be robust against interference
- Provide mechanism to handle hidden nodes
- Support peer-to-peer & infrastructure configurations
- Support time sensitive applications

1-55

55

Infrastructure Wir

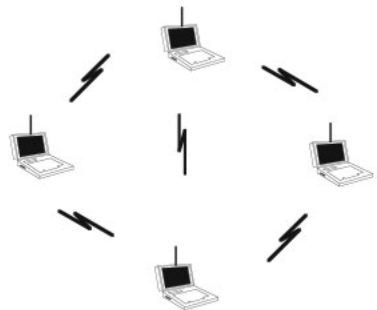


1-56

56

Ad Hoc Networking

- peer-to-peer network

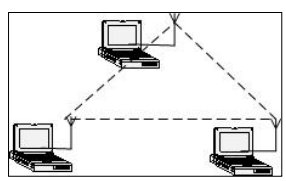


1-57

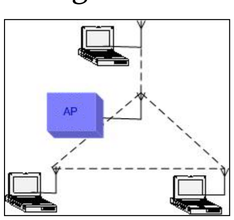
57

Architectures sum

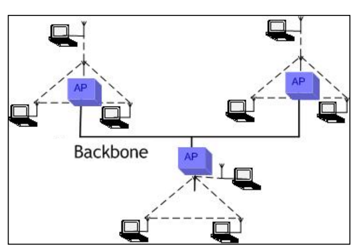
- There are different topologies for an IEEE 802.11 WLAN
- A basic service set (BSS) is a set of terminals that communicate locally, either directly or through multiple hops, but no wired segments



Independent BSS (Ad-hoc, MANETs)



Infrastructure BSS

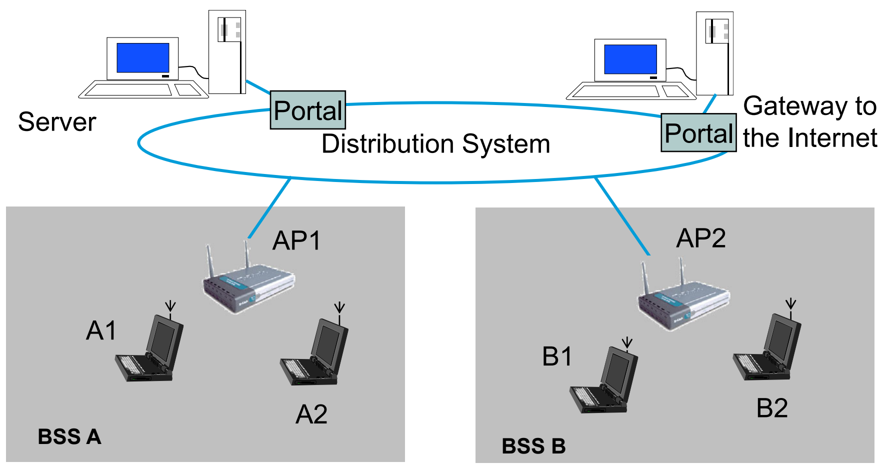


Extended SS

1-58

58

Extended Service Set



Access Points provide access to Internet

1-59

59

WLAN definitions

- *Basic Service Set (BSS)* is defined as a group of stations that coordinate their access to the medium under a given instance of the medium access control
- The geographical area covered by the BSS is known as the *basic service area (BSA)*
- An ad hoc network consists of a single BSS
- Infrastructure BSSs, on the other hand, can be interconnected by a *distribution system (DS)* to form an *extended service set (ESS)*
- Access points (APs) usually have more than one interface, one to connect wirelessly to the mobile nodes and one to connect to a wired network

1-60

60

Establishing Connectivity: Scanning

- When a station is activated it listens for a device with which it can associate (scanning).
- Scanning can be either passive or active.

1-61

61

Establishing Connectivity

- Passive scanning
  - Nodes listen for **beacon** frames transmitted by AP (infrastructure mode) or peer stations (ad hoc).
  - Station attempts to join network (authentication and association steps) on reception of beacon frame containing SSID (Service Set ID) of network it wants to join.
  - Passive scanning is a continuous process as stations can associate or disassociate with APs as signal strength varies.

1-62

62

Establishing Connectivity: Scanning

- Active scanning
  - Instead of waiting for a beacon, a **probe request** is sent by a station wishing to join a network.
  - APs hearing the request issue a **probe response.**
  - The station can choose one of the APs that responded based on the received power level, or other network characteristics.
  - Authentication and association steps are then completed.

1-63

63

Authentication

- WLAN authentication occurs at layer 2 (authenticates device, not user)
  - Station sends authentication request frame to AP
  - AP sends authentication response frame (accept or reject)
  - AP may be configured to delegate authentication to an authentication server which does more thorough checking

1-64

64

Association

- Association, which is performed after authentication, is the state that permits a station to use the AP's services to transfer data.

1-65

65

IEEE 802.11 Draft Standard Description

- Mandatory support for asynchronous data transfer is specified
  - Asynchronous data transfer refers to traffic that is insensitive to time delay
- Optional support for distributed time-bounded services (DTBS)
  - Time-bounded traffic is bounded by specific time delays in order to achieve an acceptable QoS, e.g. packetized voice and video
- Support for 2 fundamentally different MAC schemes to transport asynchronous & time-bounded services
  - **Distributed Coordination Function (DCF)**
  - **Point Coordination Function (PCF)**

1-66

66

MAC & PHY Layer

- MAC layer operates together with the PHY layer by sampling the energy over the medium transmitting data.
- PHY layer uses a clear channel assessment (CCA) algorithm to determine if the channel is clear.
  - This is accomplished by measuring the RF energy at the antenna and determining the strength of the received signal.
  - If the received signal strength is below a specified threshold the channel is declared clear and the MAC layer is given the clear channel status for data transmission.
  - If the RF energy is above the threshold, data transmissions are deferred in accordance with the protocol rules.

1-67

67

The MAC Sub-layer

- Mac specification for 802.11 has similarities to 802.3 (which is the Ethernet wired line standard)
- CSMA/CA protocol used for 802.11
  - Uses carrier-sense, multiple access, collision avoidance
  - Avoids collisions instead of detecting a collision like the algorithm in IEEE 802.3 (CSMA/CD)
  - Collision avoidance is used because it is difficult to detect collisions in an RF transmission network

Network Allocati

- The NAV is a countdown timer maintained by each STA
  - A STA is not permitted to attempt accessing the medium until its NAV has reached zero
- NAV acts as a virtual carrier sense mechanism
  - When a STA checks for an idle medium, both the physical and virtual carrier sense mechanisms must show the medium to be clear

Physical and virtual sensing

- Physical sensing
  - Performed by the physical layer and indicated to the MAC sub-layer
- Virtual sensing
  - Most frames carry a field indicating the duration of the atomic frame exchange that they precede; it is interpreted as a channel reservation
  - The time that the channel has been reserved is known as network allocation vector (NAV)
  - If the NAV is greater than zero, the virtual sensing indicates that the channel is busy
  - All stations must read the header of all received frames, either addressed for them or not, to update their NAV
- The medium is considered free only when both, the physical and the virtual sensing, indicate so

1-70

70

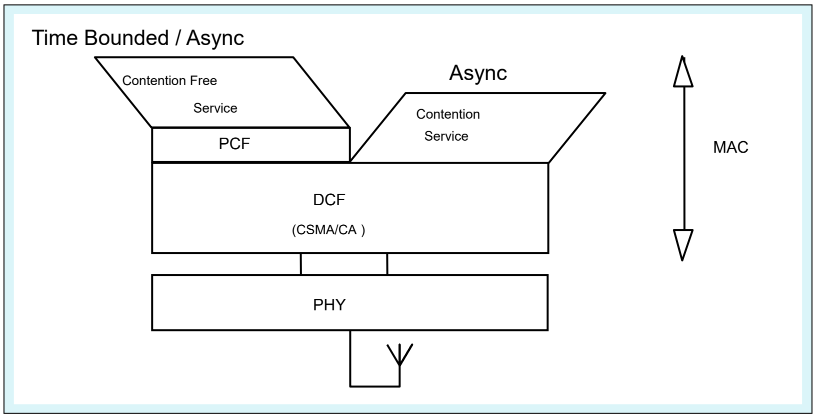
CSMA/CA: Interf s

- Time, the stations have to wait after completion of a packet transmission
- Used to reduce collision probability between multiple stations accessing a medium (time when medium becomes free after a busy period)
- Used to provide some form of priority / service differentiation
  - Short Inter-frame Space (SIFS)
  - PCF Inter-frame Space (PIFS)
  - DCF Inter-frame Space (DIFS)
  - Extended Inter-frame Space (EIFS)

1-71

71

Optional Point Coordination Function

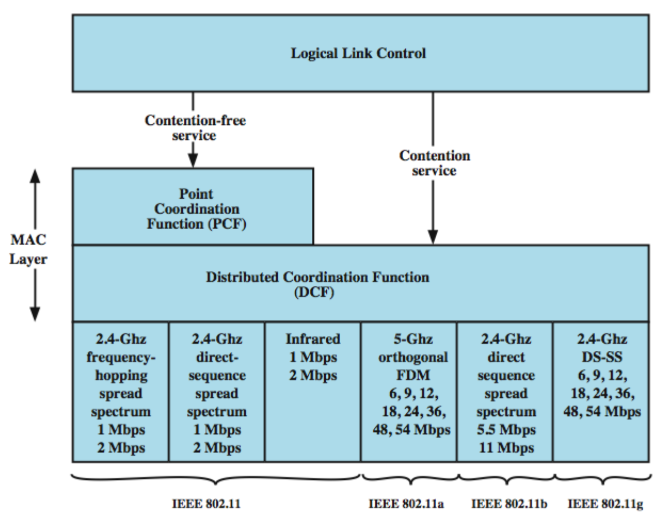


- Async Data, Voice, Video or mixed implementations
- Coexistence between Contention and Contention free

72

72

Media Access Con



1-73

73

Distributed Coordination Function (DCF)

1-74

74

CSMA/CA: Interf

- Time, the stations have to wait after completion of a packet transmission
- Used to reduce collision probability between multiple stations accessing a medium (time when medium becomes free after a busy period)
- Used to provide some form of priority / service differentiation
  - Short Inter-frame Space (SIFS)
  - PCF Inter-frame Space (PIFS)
  - DCF Inter-frame Space (DIFS)
  - Extended Inter-frame Space (EIFS)

1-75

75

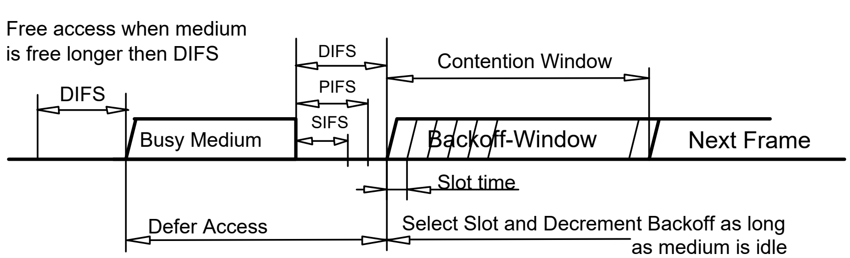
Network Allocation Vector

- The NAV is a countdown timer maintained by each STA
  - A STA is not permitted to attempt accessing the medium until its NAV has reached zero
- NAV acts as a virtual carrier sense mechanism
  - When a STA checks for an idle medium, both the physical and virtual carrier sense mechanisms must show the medium to be clear

1-76

76

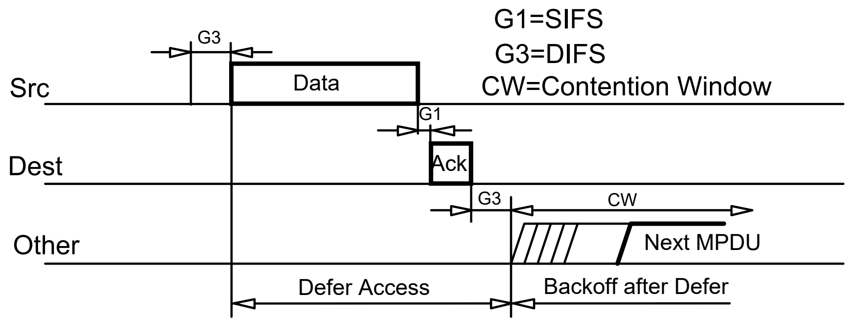
CSMA/CA



1-77

77

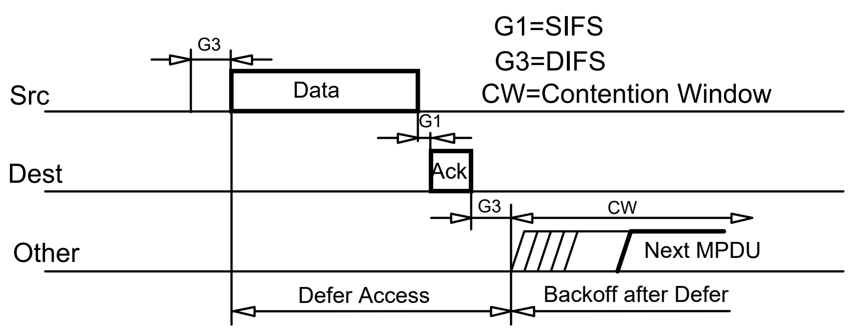
CSMA/CA + ACK



1-78

78

CSMA/CA + ACK

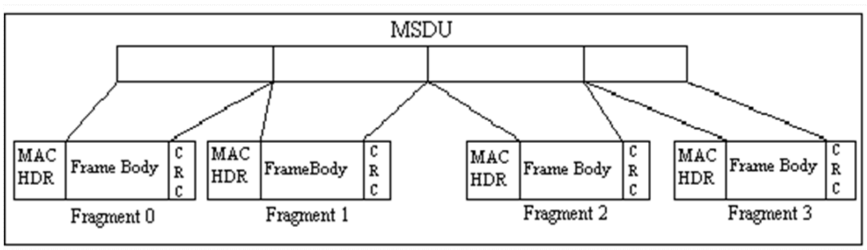


Think: what is the impact of collision in CSMA/CA compared to CSMA/CD?

1-79

79

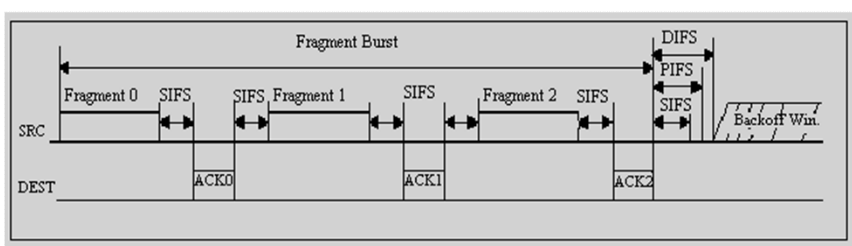
Fragmentation (1)



1-80

80

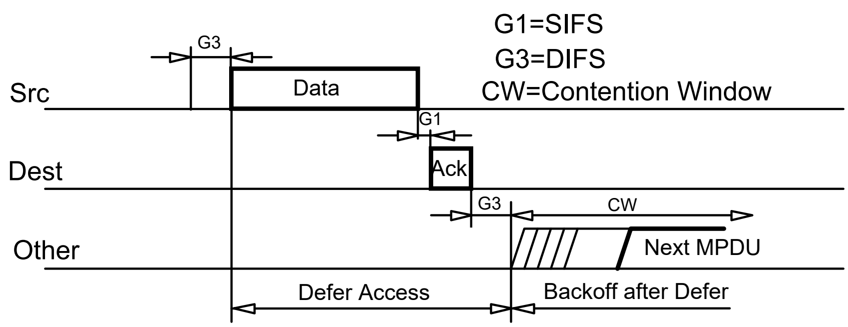
Fragmentation (2)



1-81

81

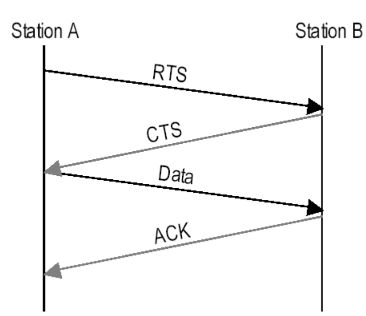
CSMA/CA + ACK



1-82

82

RTS/CTS/ACK Protocol

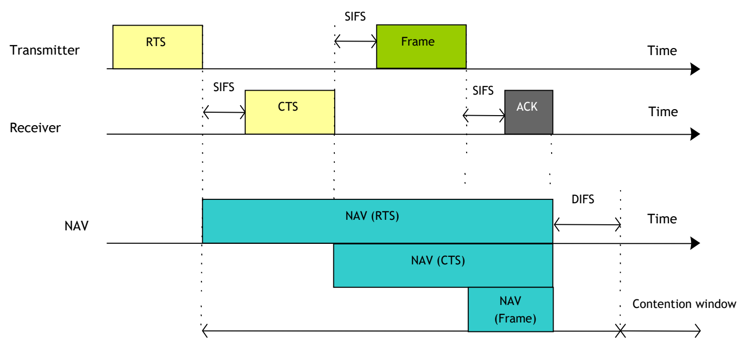


1-83

83

RTS/CTS Process Functioning

- Example:



1-84

84

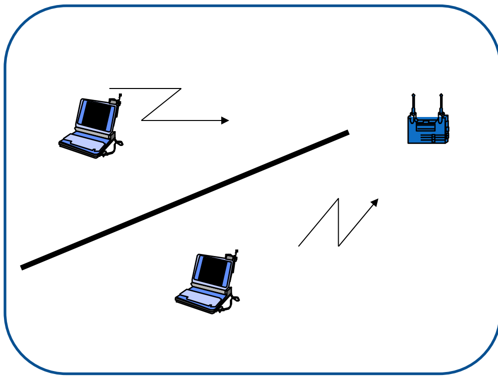
RTS/CTS Process

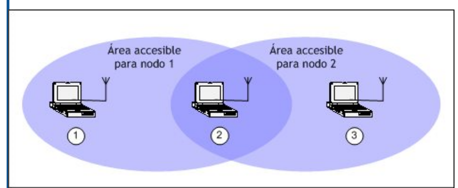
- Transmitting station sends an RTS message, specifying length of data and destination station
- The receiving station issues a CTS frame which echoes the sender address and the NAV
- If the CTS frame is not received, it is assumed that a collision occurred and the RTS process starts over
- After the data frame is received, an ACK frame is sent back verifying a successful data transmission

1-85

85

RTS/CTS improves performance in the presence of hidden terminals

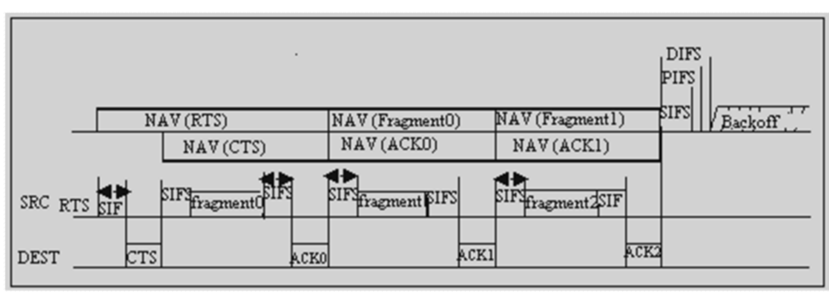




1-86

86

Fragmentation using RTS/CTS



1-87

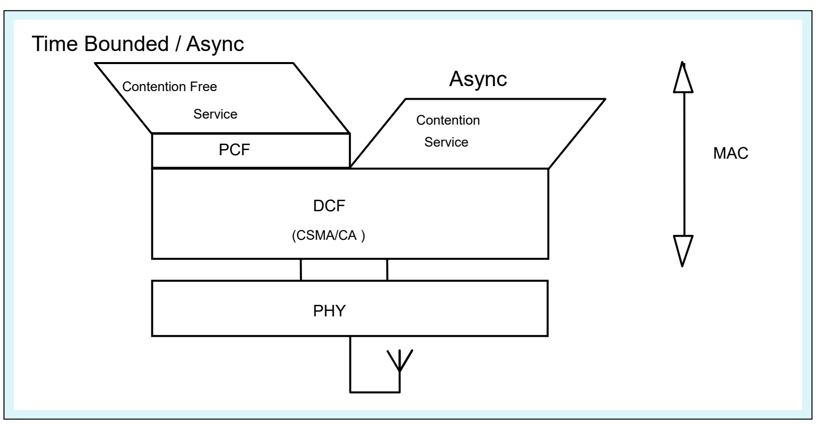
87

Point Coordination Function (PCF)

1-88

88

Optional Point Coordi[illegible]on

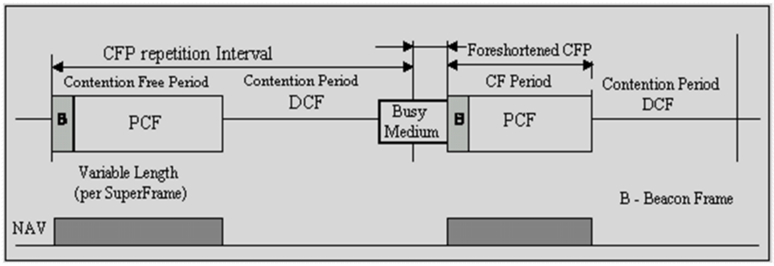


- Async Data, Voice, Video or mixed implementations
- Coexistence between Contention and Contention free

89

89

PCF

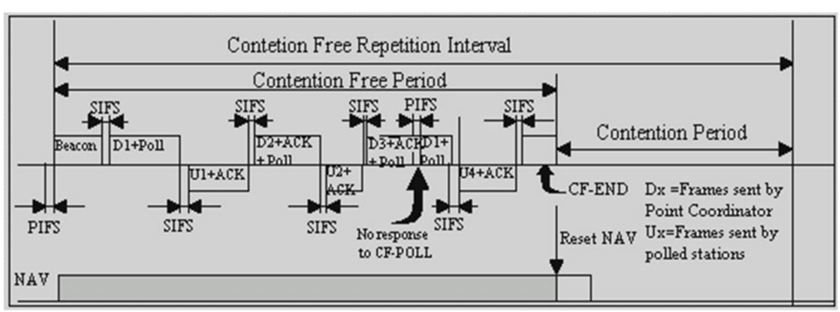


SIFS < PIFS < DIFS

1-90

90

PCF Operation



1-91

91

PCF Limitations

- PCF doesn't support multiple overlapping PCFs.
- More complexity & bandwidth consumption& cost.
- PCF means longer delay with less variance.
- Not suitable for non-periodic time bounded data.
- Provides only two levels of QoS.

1-92

92

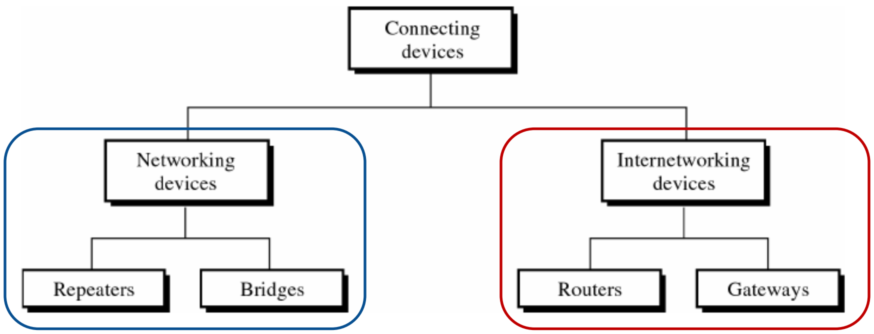
IEEE 802.11e standard (QoS MAC)

- The MAC protocol of the original IEEE 802.11 standard cannot satisfy quality-of-service (QoS) requirements of multimedia applications
- Study group E was created to define an extension to the existing MAC protocol to make it QoS capable
- The protocol IEEE 802.11e became a standard in late 2005
- This new standard includes features for establishing priorities among stations, for connection admission negotiation, for resource reservation, for the direct communication among mobile stations without going through the AP, for new ways to handle ACKs, etc.
- A new and unique coordination function is defined, known as *Hybrid Coordination Function* (HCF), which combines and improves the characteristics of DCF and PCF.

1-93

93

Connecting Networks



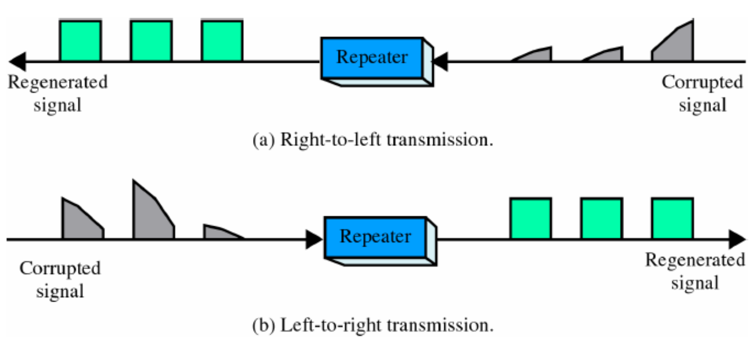
Networks of same technology

Networks of different technologies

1-94

94

Function of Repeater

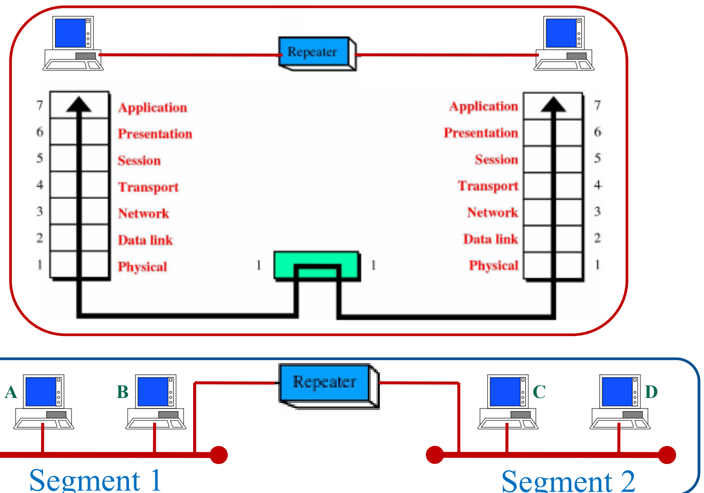


Repeaters operate at Physical layer (Layer 1)

1-95

95

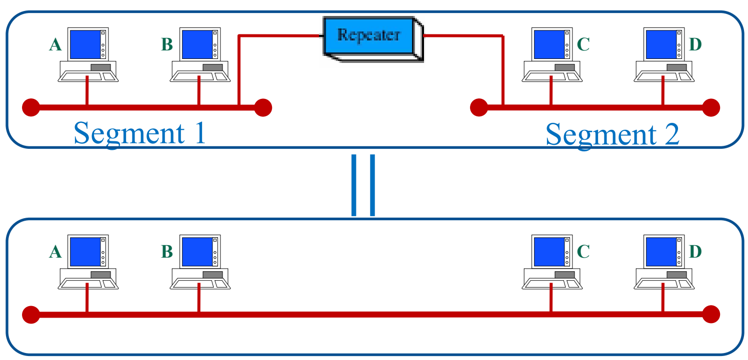
Repeater -- Hub



1-96

96

Repeater--Hub extends "segment"

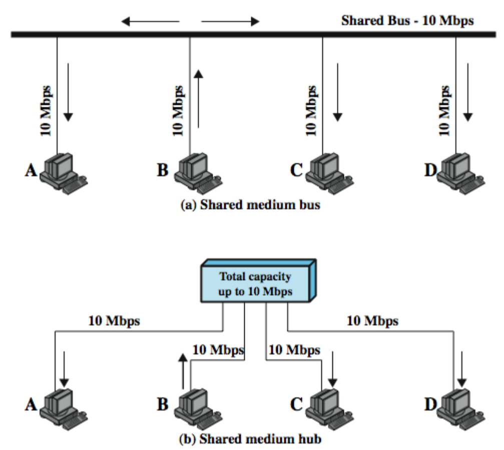


Simple and cheap
Transmissions of "A", "B" interfere with "C", "D" and vice versa.
Repeater DOES NOT isolate segments from each other
Repeaters connect segments of identical physical and data link layer technologies
(e.g. segment 1 is fast ethernet → segment 2 should be fast ethernet)

1-97

97

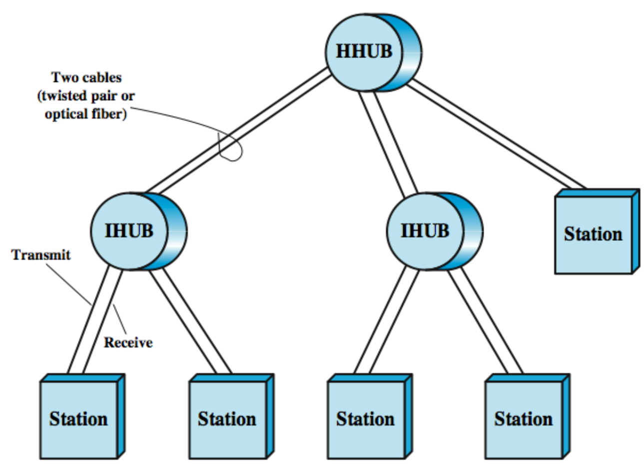
Shared Medium Bus and Hub



1-98

98

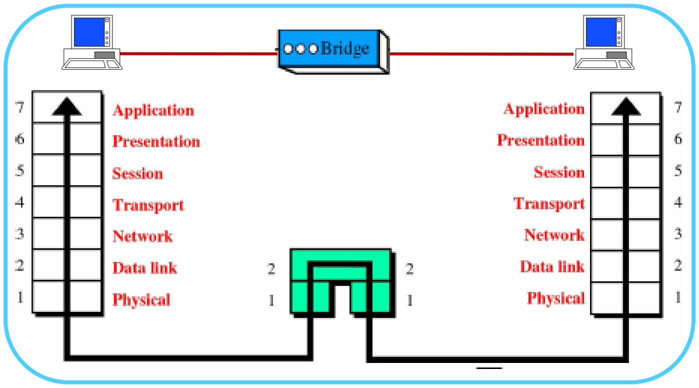
Two Level Hub Top



1-99

99

Bridge



Bridges operate at Data Link layer (Layer 2)
They physically separate the PHY layers of different segments
They connect networks of same layer 2 technology

1-100

100

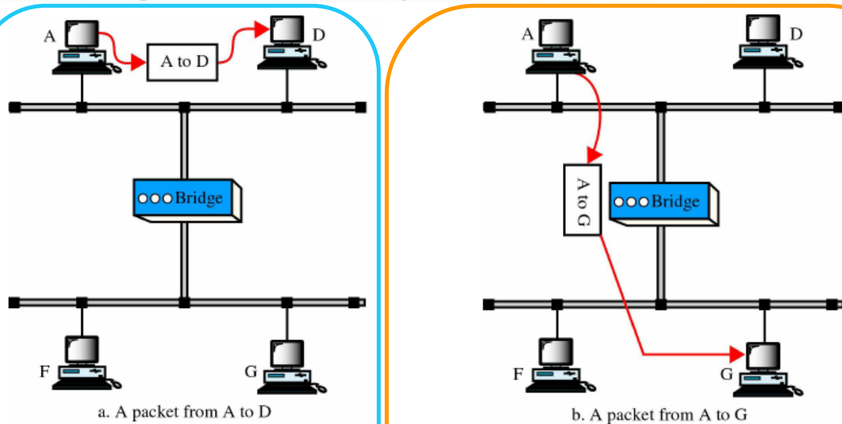
Interconnecting LANs - Hubs

- active central element of star layout
- each station is connected to hub by two UTP lines
- hub acts as a repeater
- limited to about 100 m by UTP properties
- optical fiber may be used out to 500m
- physically star, logically bus
- transmission from a station seen by all others
- if two stations transmit at the same time have a collision

1-101

101

Bridges: example



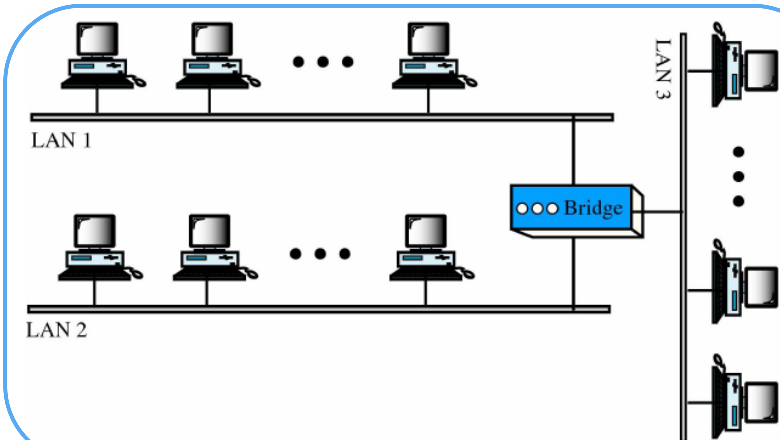
Packets from A → D and D → A do not interfere with those of F and D

Packets destined to a node located in a different signal interfere with segments of the source (node A) and destination (node G)

1-102

102

Multiport Bridge

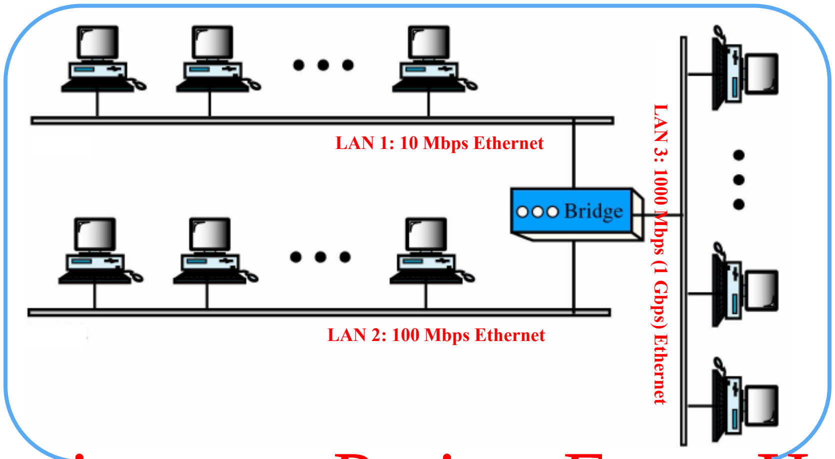


1-103

103

Bridge connects…

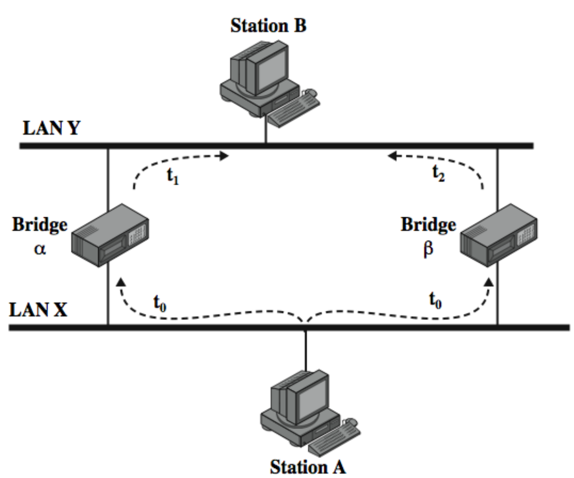
Networks of same link layer (layer 2) technology



1-104

104

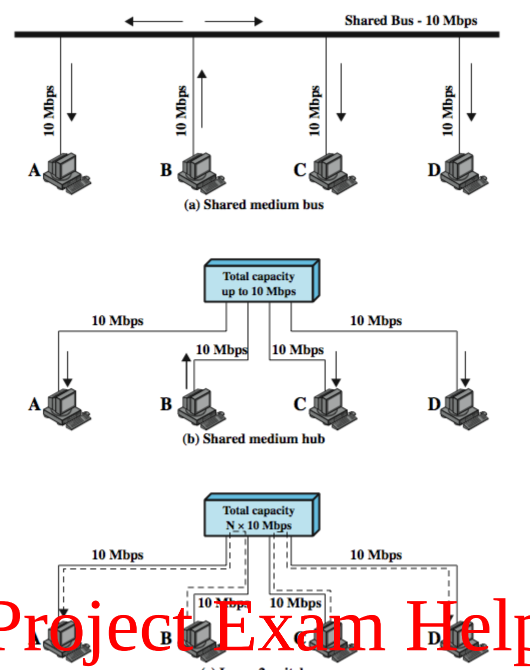
Loop of Bridges



1-105

105

Switches



(a) Shared medium bus

(b) Shared medium hub

(c) Layer 2 switch

1-106

106

Layer 2 Switch Benefits

- no change to attached devices to convert bus LAN or hub LAN to switched LAN
  - e.g. Ethernet LANs use Ethernet MAC protocol
- have dedicated capacity equal to original LAN
  - assuming switch has sufficient capacity to keep up with all devices
- scales easily
  - additional devices attached to switch by increasing capacity of layer 2

1-107

107

Layer 2 Switch vs Bridge

- Layer 2 switch can be viewed as full-duplex hub
- incorporates logic to function as multiport bridge
- differences between switches & bridges:
  - bridge frame handling done in software
  - switch performs frame forwarding in hardware
  - bridge analyzes and forwards one frame at a time
  - switch can handle multiple frames at a time
  - bridge uses store-and-forward operation
  - switch can have cut-through operation
- hence bridge have suffered commercially

1-108

108

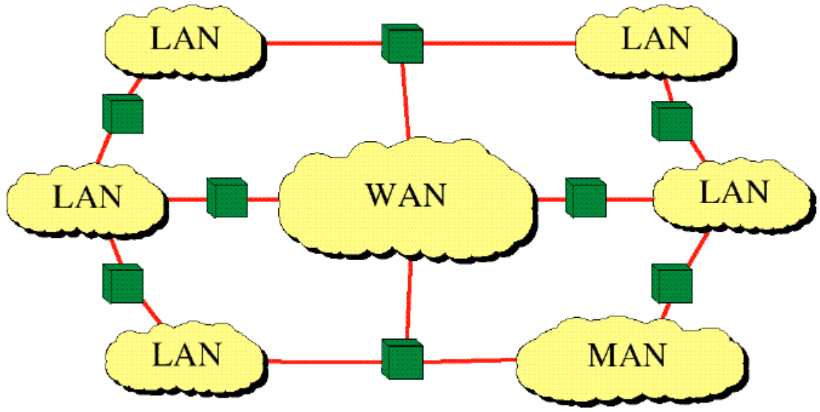
Layer 2 Switch Pro

- broadcast overload
  - users share common MAC broadcast address
  - broadcast frames are delivered to all devices connected by layer 2 switches and/or bridges
  - broadcast frames can create big overhead
  - broadcast storm from malfunctioning devices
- lack of multiple links
  - limits performance & reliability

1-109

109

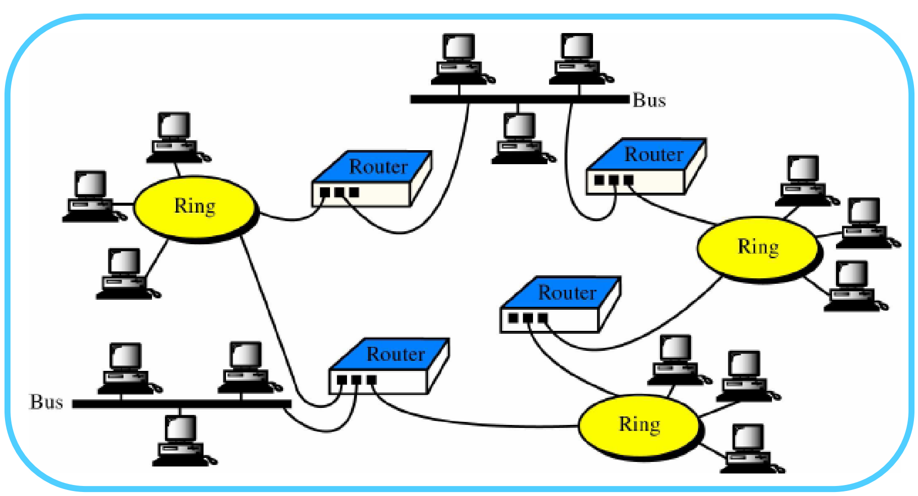
Internetwork (Internet)



1-110

110

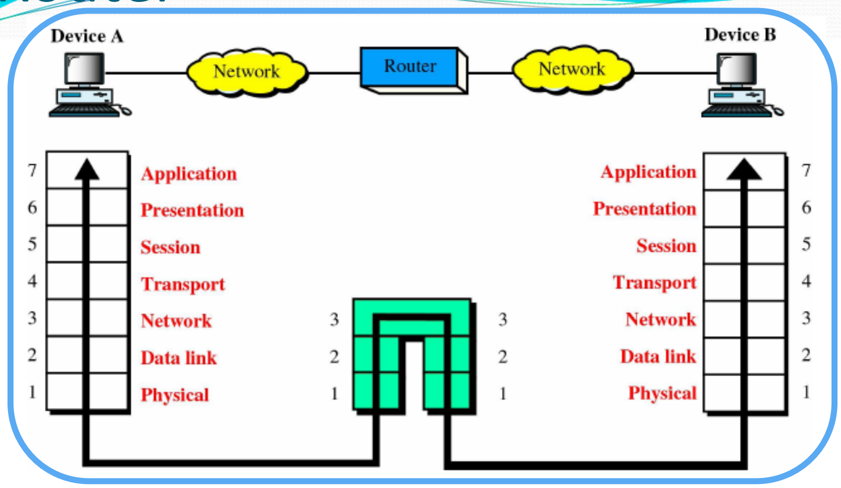
Example of intern



1-111

111

Router



Router operates as network layer (layer 3)
Can connect networks of dissimilar technologies

1-112

112

Router Advantages & Problems

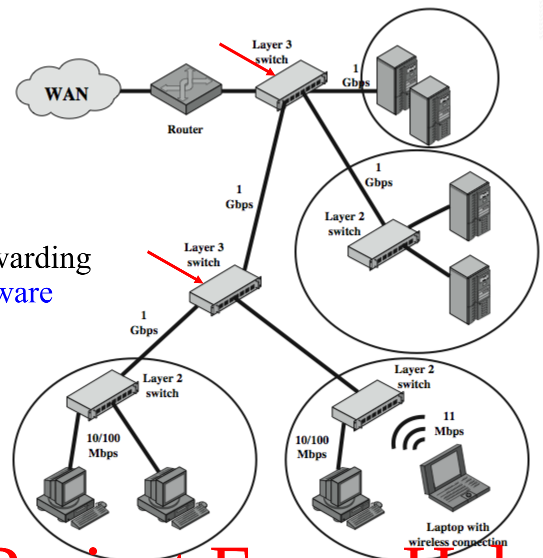
- Typically use subnetworks connected by routers
  - limits broadcasts to single subnet
  - supports multiple paths between subnets
- Routers do all IP-level processing in software
  - high-speed LANs and high-performance layer 2 switches pump millions of packets per second
  - software-based router only able to handle well under a million packets per second

1-113

113

Use of Layer 3 Switches

- Layer 3 switches
  - implement packet-forwarding logic of router in hardware
- Two categories
  - packet by packet
  - flow based



1-114

114

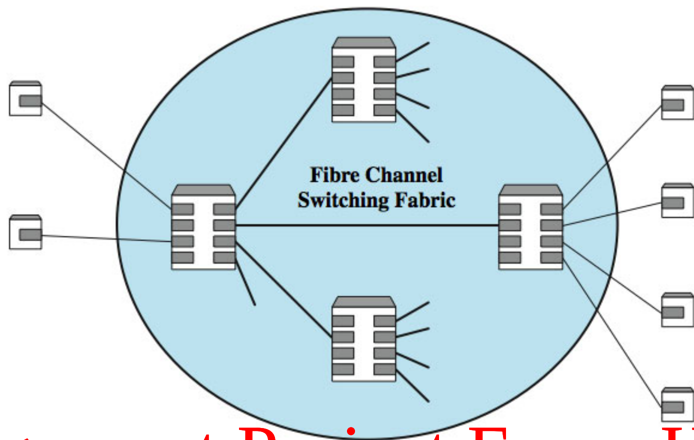
Packet by Packet or

- Packet by packet
  - operates like a traditional router
  - order of magnitude increase in performance compared to software-based router
- Flow-based switch
  - enhances performance by identifying flows of IP packets with same source and destination
  - by observing ongoing traffic or using a special flow label in packet header (IPv6)
  - a predefined route is used for identified flows

1-115

115

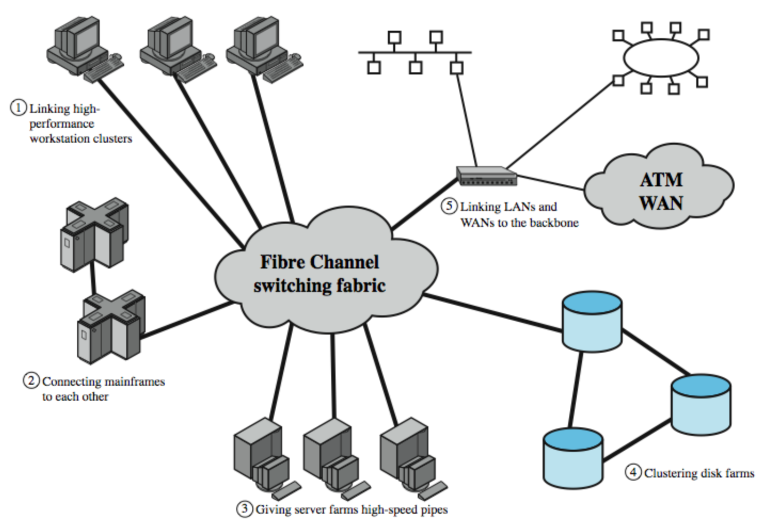
Fibre Channel Network



1-116

116

Fibre Channel App



1-117

117

Fibre Channel - Background

- I/O channel
  - direct point to point or multipoint comms link
  - hardware based, high speed, very short distances
- network connection
  - based on interconnected access points
  - software based protocol with flow control, error detection & recovery
  - for end systems connections

1-118

118

Fibre Channel

- combines best of both technologies
- channel oriented
  - data type qualifiers for routing frame payload
  - link level constructs associated with I/O ops
  - protocol interface specifications to support existing I/O architectures
- network oriented
  - full multiplexing between multiple destinations
  - peer to peer connectivity
  - internetworking to other connection technologies

1-119

119

Fibre Channel Requirements

- full duplex links with two fibers per link
- 100 Mbps to 800 Mbps on single line
- support distances up to 10 km
- small connectors
- high-capacity utilization, distance insensitivity
- greater connectivity than existing multidrop channels
- broad availability
- multiple cost/performance levels
- carry multiple existing interface command sets for existing channel and network protocols

1-120

120

Fibre Channel Fabric

- most general supported topology is fabric or switched topology
  - arbitrary topology with at least one switch to interconnect number of end systems
  - may also consist of switched network
- routing transparent to nodes
  - when data transmitted into fabric, edge switch uses destination port address to determine location
  - either deliver frame to node attached to same switch or transfers frame to adjacent switch

1-121

121

END

1-122

122

EECS, University of Ottawa

CEG3185 –Winter 2021

Introduction to Data Communication & Networking

Circuit & Packet Switching

Note: some material in the slides has been taken from various other sources

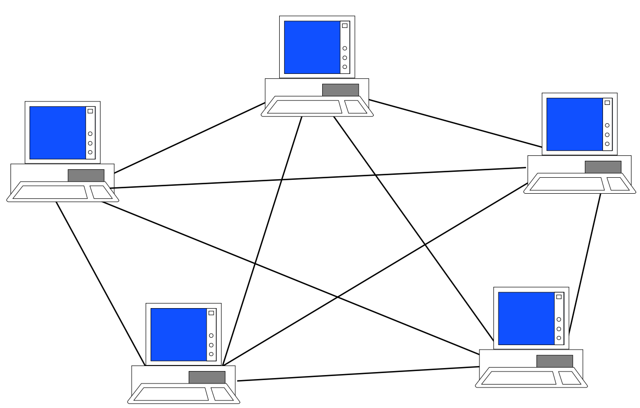
1-1

1

Computer Networ

Computing & communication devices need to exchange information

# of links required:
unidirectional links:
n (n-1)
bidirectional links:
n (n-1)/2
n: # of devices

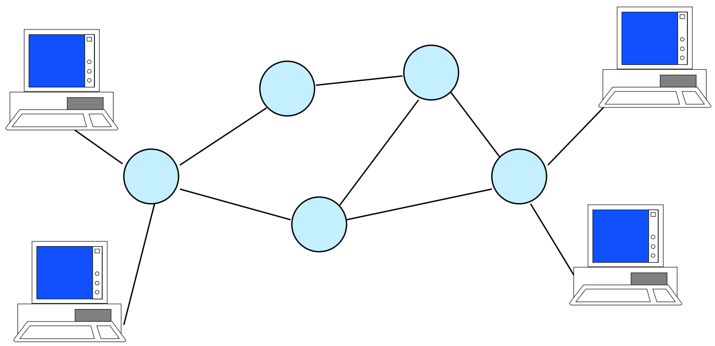


1-2

2

Computer Networks

We need switching nodes.



1-3

3

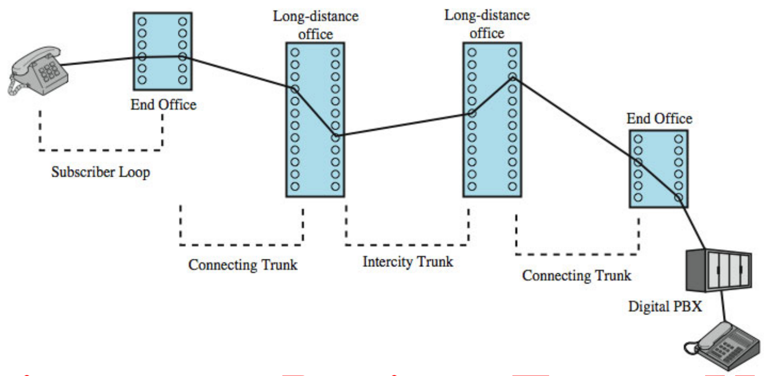
Switching Techn

- Circuit Switching
- Packet Switching
  - Datagram
  - Virtual Circuit

4

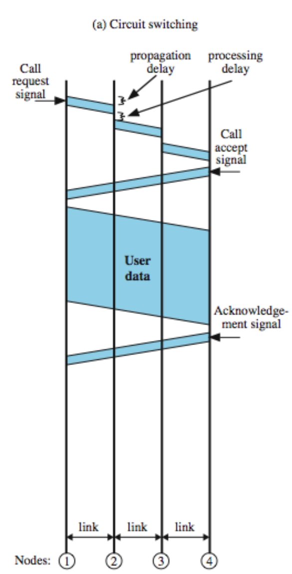
Circuit Switching Network

Example: Public Service Telephone Network (PSTN)



5

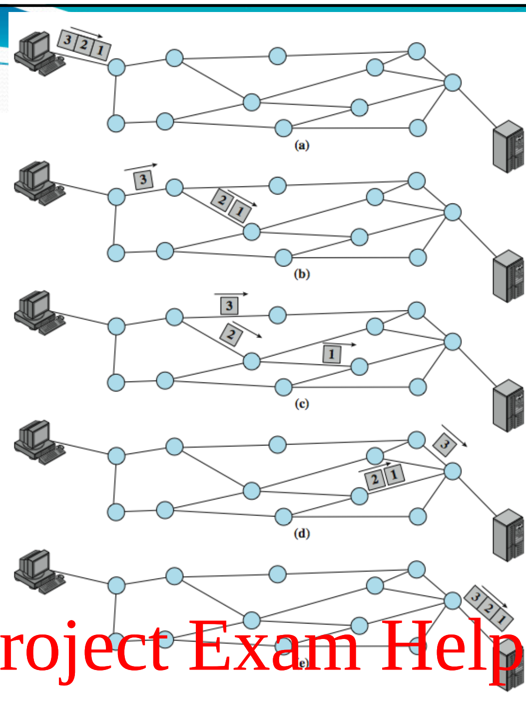
Event Timing for Cir g



6

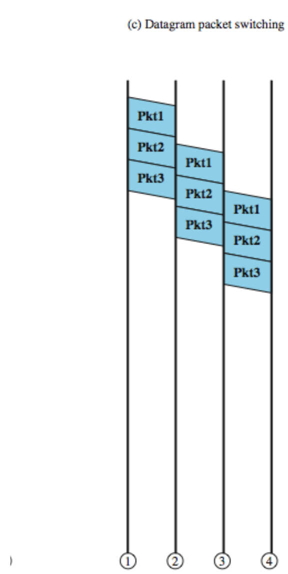
Datagram Packet Switching

- No path establishment
- Packets can follow different paths



7

Event Timing for



8

Circuit Switching

- Uses a dedicated path between two stations
- Process consists of three phases
  - establish
  - transfer
  - disconnect
- Bandwidth inefficient
  - channel capacity dedicated for duration of connection
  - if no data, capacity wasted
- Set up (connection) takes time
- Once connected, transfer is transparent
- Can provide deterministic performance guarantees

9

Packet Switching

- Source breaks long message into “information transporting segments” (packets).
- Packets are sent one at a time to the network.
- Packets contain user data and control/signaling information.
  - user data may be part of a larger message
  - control information includes routing/addressing information
- Packets are received, stored “briefly” (buffered) and are passed onto the next node.

10

Characteristics

- Line efficiency
  - single link shared by many packets over time
  - packets queued and transmitted as fast as possible
- Data rate conversion
  - stations connect to local nodes at their own speed
  - nodes buffer data if required to equalize rates
- Packets are accepted even when the “line” is busy
- Priorities can be used to support users’ needs, instead of dedicating resources regardless if they are used or not (becoming wasted if they are not)

11

Virtual Circuits ve m

- Virtual circuits
  - network can provide sequencing
  - traffic engineering can be applied, enabling more practical provision of quality of service (QoS) support
  - less reliable in cases of switching node failures
- Datagram
  - no call setup phase
  - more flexible
  - more reliable in cases of switching node failures
  - difficult to control network’s state and provide quality of service (QoS)

12

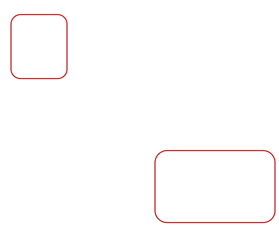
Circuit versus Packet Switching: Comparison

- **Circuit Switching**
  - Dedicated channels/resources
  - Constant delay
  - Blocking
  - Continuous flow
  - Point-to-Point
- **Packet Switching**
  - Shared channels
  - Variable delay
  - Store-and-forward point-to-point & multipoint

13

Datagram Diagram

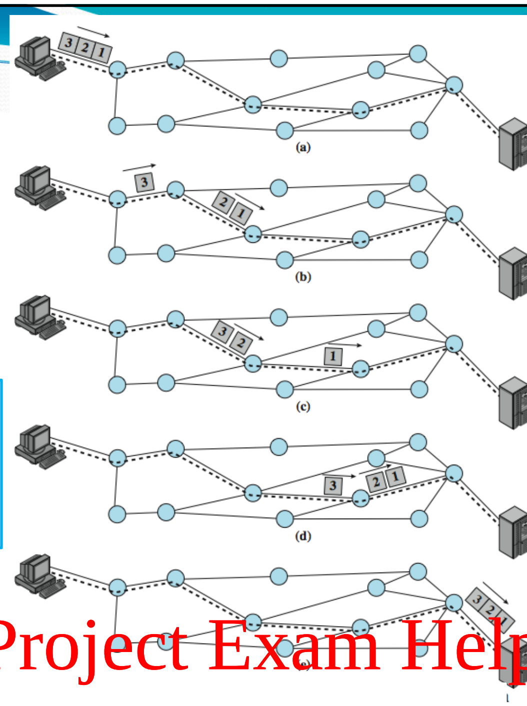
➢No path establishment
➢Packets can follow different paths
➢**Packets may arrive out of order**



14

Virtual Circuit Packet Switching

- Path establishment is required
- All packets follow the path
- All packets arrive in order



15

Event Timing for the 3 s[illegible]hods

16

Virtual Packet Switching Networks

- Integrated Services Digital Network (ISDN)
- Narrowband ISDN: X25 & Frame Relay
- X-25:
  - ITU-T standard for interface between host and packet switched network.
  - almost universal on packet switched networks and packet switching in ISDN.
- Frame Relay
  - designed to eliminate most X.25 overhead, improves efficiency
  - requires high level of network reliability.
- Broadband ISDN: Asynchronous Transfer Mode (ATM)
  - based on the use of fixed size packets (53 bytes, called ATM cells).
  - first Broadband ISDN (B-ISDN) .
  - offered quality of service (QoS) choices.

17

What is ATM?

- ATM was born out of B-ISDN in mid 1980s.
- It was a new multiplexing and switching technique.
- First broadband, QoS capable switching technology.
- It is based on fixed-length packets, called "cells".
- Cell structure facilitated silicon implementation of switch fabric for fast packet switching.
- Supports high performance cell switching or "cell relay".

18

Why all the Interest in ATM?

- Need for world-wide standard to allow interoperability of information.
- Historically there were separate methods used to transmit information among the following users:
  - Local Area Networks
  - Wide Area Networks
- It was thought that ATM will provide a network for efficient traffic integration and a solution for application to both; LAN and WAN environments.
- ATM allowed to consolidate networks; instead of using separate networks for different applications (e.g. integrate voice, video, data).
- ATM can support communications at all speeds; from Megabits to Terabits.

19

Basic Principles o

- ATM is based on fixed length cells
  - information field
  - header used for addressing
  - cell sequence integrity is preserved
- ATM is connection oriented
  - Header values are assigned to each section of a connection.
  - Signaling and user information are carried on separate virtual channels.
- The information field is carried transparently through the network
  - no processing like error control is performed by the network.
  - ATM does not guarantee that cells arrive.
  - for efficient operation, a highly reliable physical layer is required (bit error rates in the order of 10^{-9} to 10^{-12}).
- All services (voice, video, even connectionless data) can be supported via ATM.
  - to accommodate various services, an adaptation function is provided.

20

ATM Cell Format

5 bytes header	48 bytes of information

- Small cells reduce queuing delay for high priority cells
- Small cells can be switched more efficiently
- Easier to implement switching of small cells in hardware

21

ATM Cell Header

- 5 bytes in length
- Contains a Header Error Check (HEC) to find cell boundaries
- Receiver locks on 5 bytes that satisfy the HEC algorithm (on first 4 bytes)

4 bytes	HEC	48 bytes of user information

22

ATM UNI Cell

UNI - User Network Interface

Byte			
1	GFC	VPI	
2	VPI	VCI	
3	VCI		
4	VCI	PT	CLP
5	HEC		
6-53	User Information		

GFC - Generic Flow Control

VPI - Virtual Path Identifier

VCI - Virtual Channel Identifier

PT - Payload Type

CLP - Cell Loss Priority

HEC - Header Error Check

23

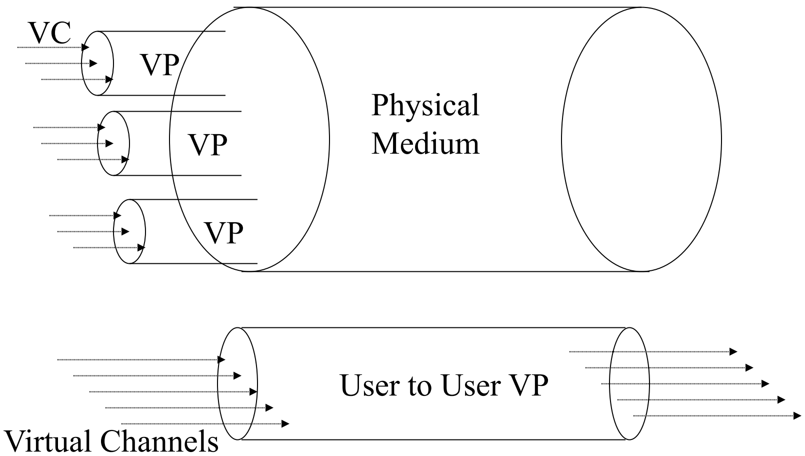
Virtual Circuit Packet Switching

- Path establishment is required
- All packets follow the path
- All packets arrive in order

4

24

Virtual Path and Channel



25

Virtual Connections

- VPI - Virtual Path Identifier
  - 8 bits ==> 256 paths (UNI)
  - 12 bits ==> 4096 paths (NNI)
- VCI - Virtual Path Identifier
  - 16 bits ==> 65,536 channels
- Each VPI holds a bundle of circuits.
- These are per physical medium, regardless of speed or bandwidth.

26

Payload Type Identifier

- Used to identify the following cells:
- Network generated cells
  - used for maintenance & control of network
  - used for call set-up, loopbacks and keep alives
- Customer generated cells
  - user information

27

Cell Loss Priority

- CLP in the header
  - CLP = 0: High priority, last likely to be discarded
  - CLP =1: Low priority, maybe discarded during congested intervals
- CLP can be set:
  - by the terminal
  - by the ATM switch
- CLP determines the class of service or service contract

28

Virtual Connections

- Permanent Virtual Circuits (PVC)
  - network operator connects endpoints
- Switched Virtual Circuits (SVC)
  - can be switched like PSTN
  - Call set-up routine

1-29

29

Service Categories (1)

- Quality of Service (QoS) are parameters that are set for end-to-end network performance
  - Cell Transfer Delay (CTD): delay between start & finish of cell
  - Peak to Peak Cell Delay Variation (CDV): difference between maximum CTD and minimum CTD
  - Cell Loss Ratio (CLR): % of cells lost
  - Sustained Cell Rate (SCR): average rate of transmitted cells
  - Bust Tolerance (BT): maximum burst size at PCR
  - Maximum Burst Size (MBS): maximum No. of cells sent at PCR
  - Minimum Cell Rate (MCR)

1-30

30

Service Categories (2)

- ATM is divided into (5 + 1=) 6 service categories
  - Constant Bit Rate (CBR).
    - CTD & CDV are tightly constrained, low CLR
  - Real - Time Variable Bit Rate (rt - VBR)
    - CTD & CDV are tightly constrained
  - Non-Real - Time Variable Bit Rate (nrt - VBR)
    - CTV is tightly constrained
  - Available Bit Rate (ABR)
    - Minimize CTD, CDV and CLR
  - Unspecified Bit Rate (UBR)
    - No CTD, CVD or CLR constraints
  - Guaranteed Frame Rate (guarantees delivery of “x”% of frames to user)

1-31

31

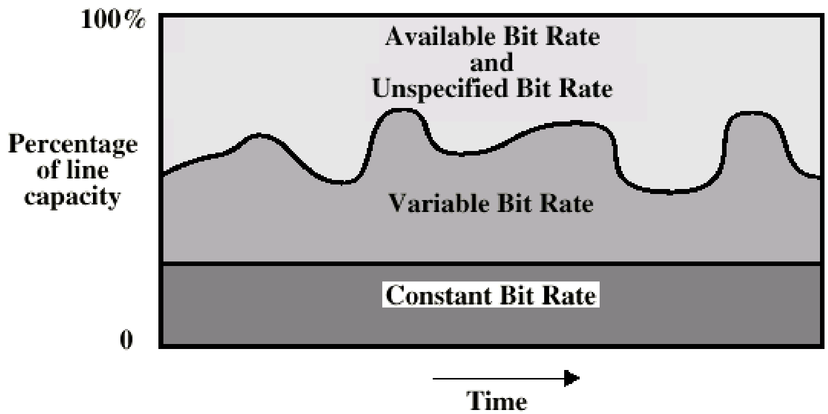
Available Bit Rate (ABR)

- It guarantees to the sources a minimum rate. It is based on adaptation of the source rate to use resources when available and reduce transmission rate when resource are scarce, in order to avoid congestion.
- Its primary use was to carry Internet traffic
- Two main categories
  - Rate Based Control
  - Credit Based Control

1-32

32

ATM Bit Rate Services



1-33

33

Traffic Shaping(1)

- Traffic shaping is forcing your traffic to conform to certain specified behaviour
- Each service has a contract
- If the contract is violated, the network has the right to discard the cells
- The ATM switch monitors the traffic flow
- The shaping and policing is based on the Generic Cell Rate Algorithm (Leaky Bucket)

1-34

34

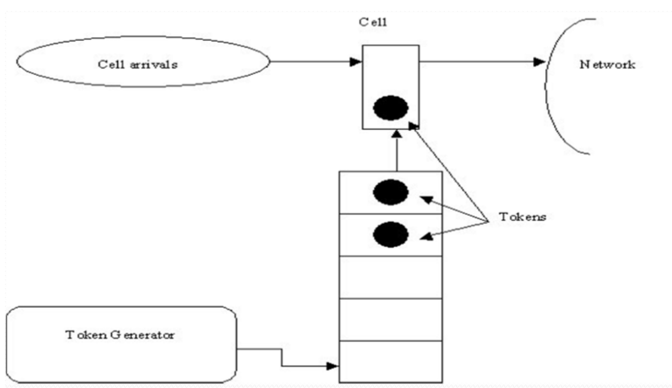
Traffic Shaping(2)

- Traffic parameters
  - Mean Cell Rate (Sustained Rate)
  - Peak Cell Rate
  - Burst Frequency
  - Burst Length
  - Cell-loss Priority
  - Cell-loss Rate

1-35

35

Leaky Bucket



1-36

36

ATM Layers

Higher Layer	
ATM Adaptation Layer (AAL)	AAL adapts from other protocols to ATM.
ATM Layer (ATM-L)	ATM-L is responsible for routing and switching the cells.
Physical Layer (PL)	PL is responsible for sending and receiving bits on the medium.

1-37

37

ATM Layers (2)

- ATM Layer
  - Generic Flow Control (applied to UNI to alleviate short term overload)
  - Cell header generation/extraction
  - Cell Virtual Path Identifier(VPI)/Virtual Circuit Identifier (VCI) translation
  - Cell multiplexing/demultiplexing.

1-38

38

ATM Layers (3)

- ATM Adaptation Layer is subdivided into:
  - Segmentation And Reassembly (SAR)
  - Convergence Service Specific (CS)

CS	CS - interfaces with the upper layer protocol information - provides padding and CRC checking.
SAR	SAR - generates the ATM payload.

ATM Adaptation Layers

- Standardized ATM Adaptation Layers
  - AAL1 - provides connection oriented Constant Bit Rate services that have timing and delay requirements
  - AAL2 - provides connection oriented Variable Bit Rate services that have timing and delay requirements
  - AAL3/4 - provides connection-oriented Variable Bit Rate services with no timing requirements (e.g., frame relay)
  - AAL5 - provides connectionless Variable Bit Rate services with no timing requirements

ATM Interfaces

- User to Network Interface (UNI)
  - specifies how cells come to a public network
- Broadband Inter-Carrier Interface (B-ICI)
  - specifies how two carriers interact their services
  - defines the traffic contract between two carriers
- ATM Data Exchange Interface (DXI)
  - protocol between router and CSU/DSU
- Network to Network Interface (NNI)
  - connection between switches

1-41

41

END

1-42

42