

**EECS, University of Ottawa**

**CEG3185 –Winter 2021**

**Introduction to Data Communication & Networking**

**Physical Layer**

**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 been given written permission by the instructor. Sale or distribution of the materials to others is STRICTLY PROHIBITED.

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

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**Elements of Physical Layer**

```

graph LR
    Source[DTE] --> Transmitter[DCE]
    Transmitter --> Medium[Transmission]
    Medium --> Receiver[DCE]
    Receiver --> Destination[DTE]
  
```

**Source      Transmitter      Receiver      Destination**

**DTE      DCE      Transmission      DCE      DTE**

**Medium**

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

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## Continuous signal vs discrete signal

amplitude

time

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

amplitude

time

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

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### 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 :  $\phi$

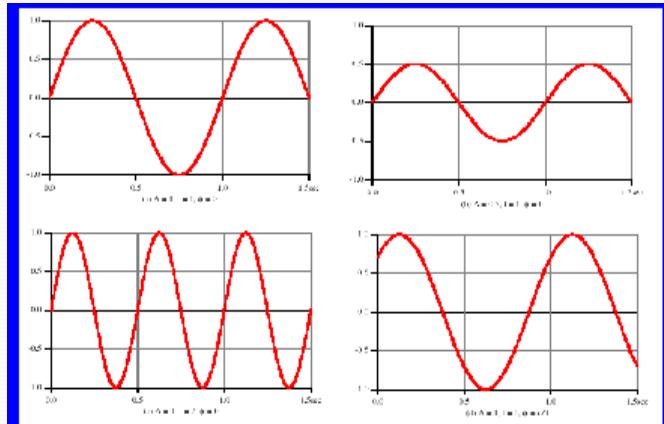
Signal strength

time

$t_0, t_1 = 1 \times T_1$

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## Varying the sine wave parameters

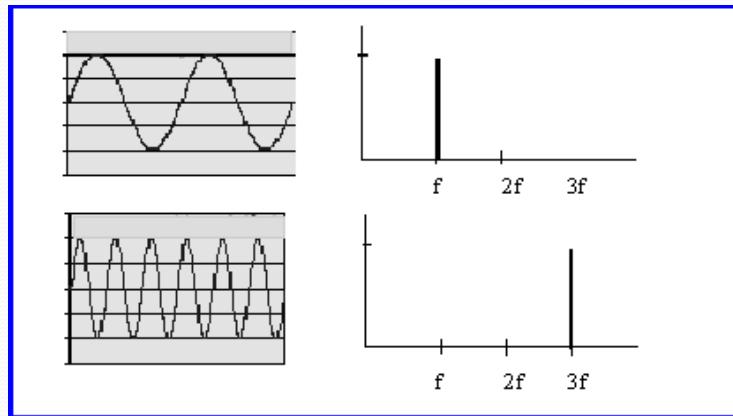


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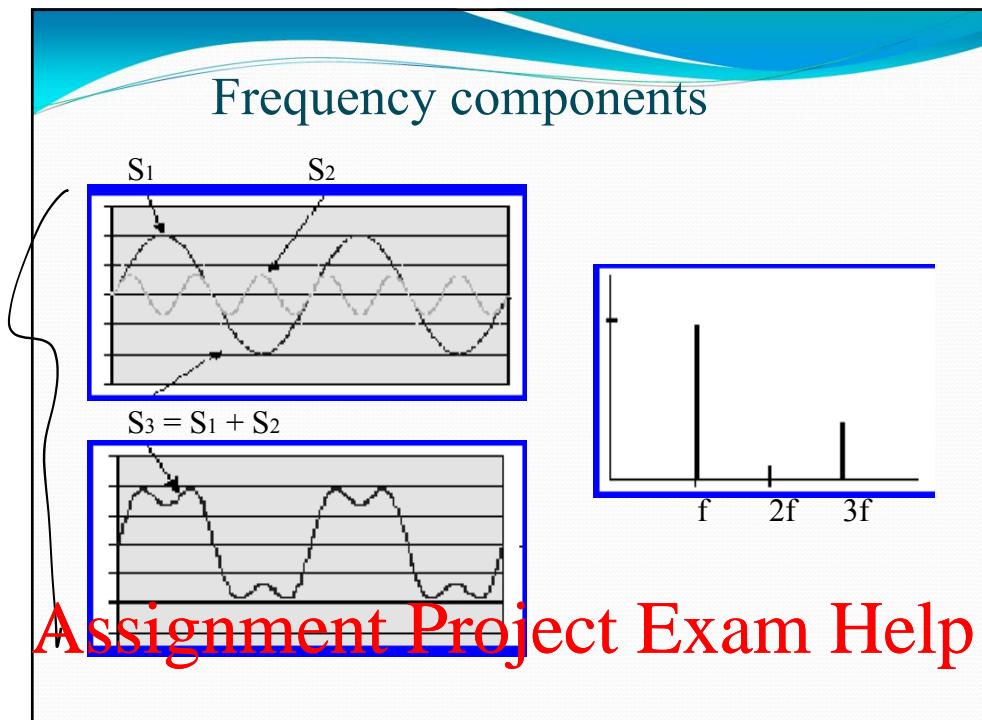
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Time domain vs frequency domain

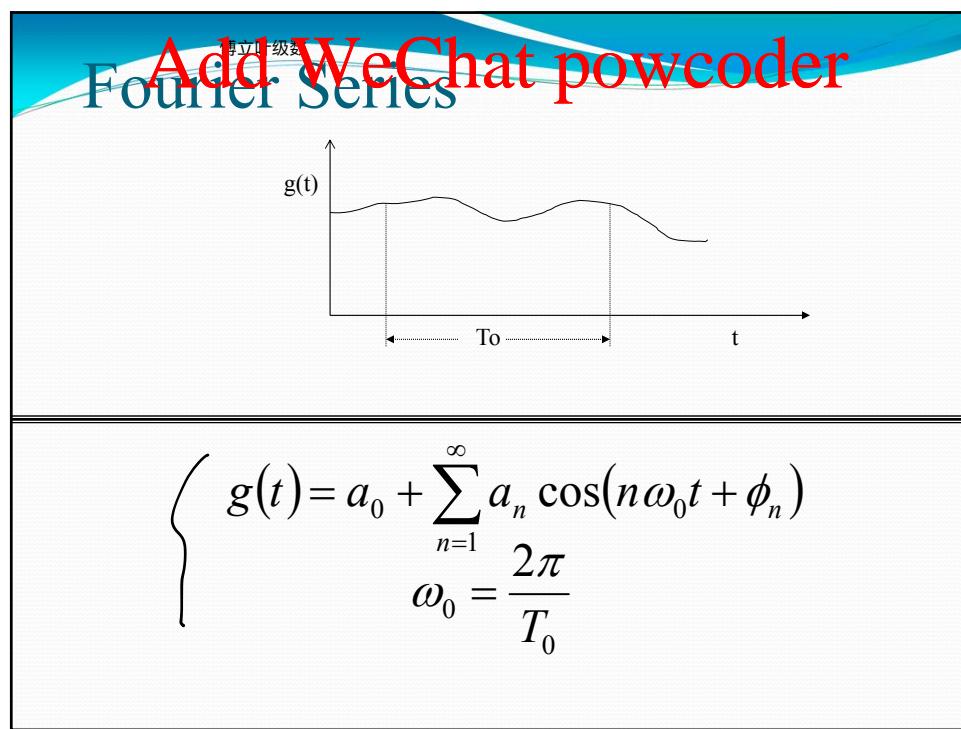


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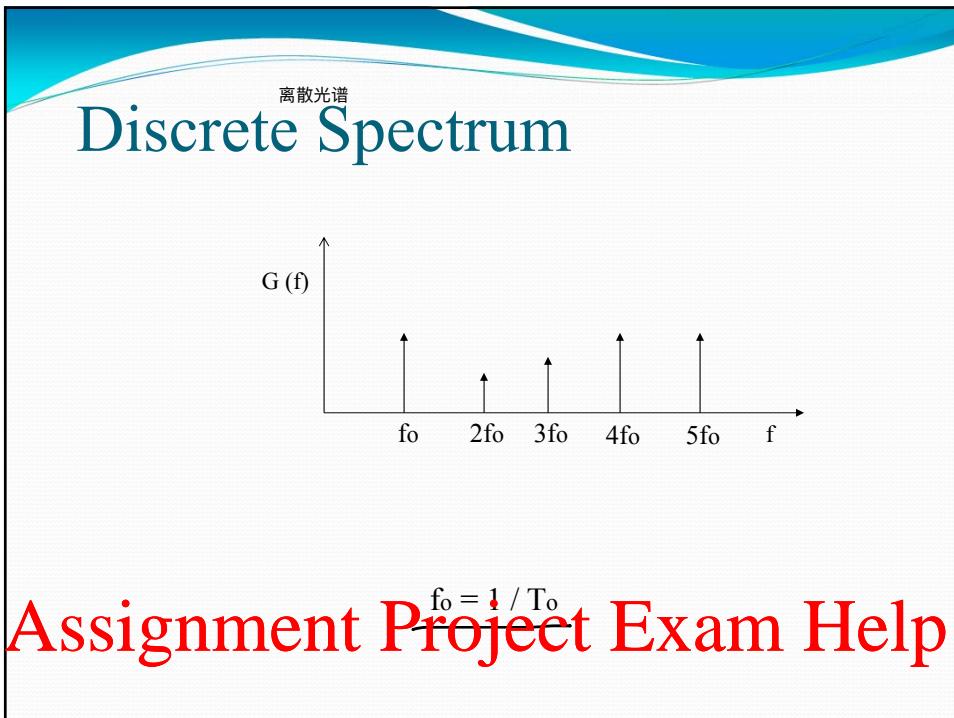


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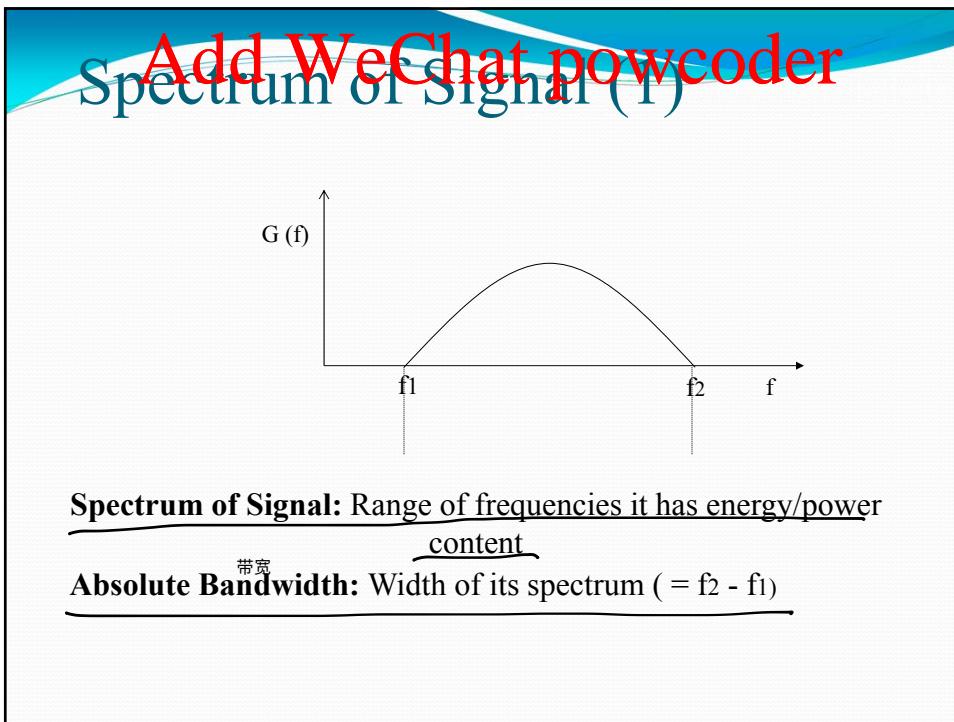
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## Spectrum of Signal (2)

- **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

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通道容量  
Channel capacity (without noise)

Nyquist Formula

$$C = 2W \log_2 M$$

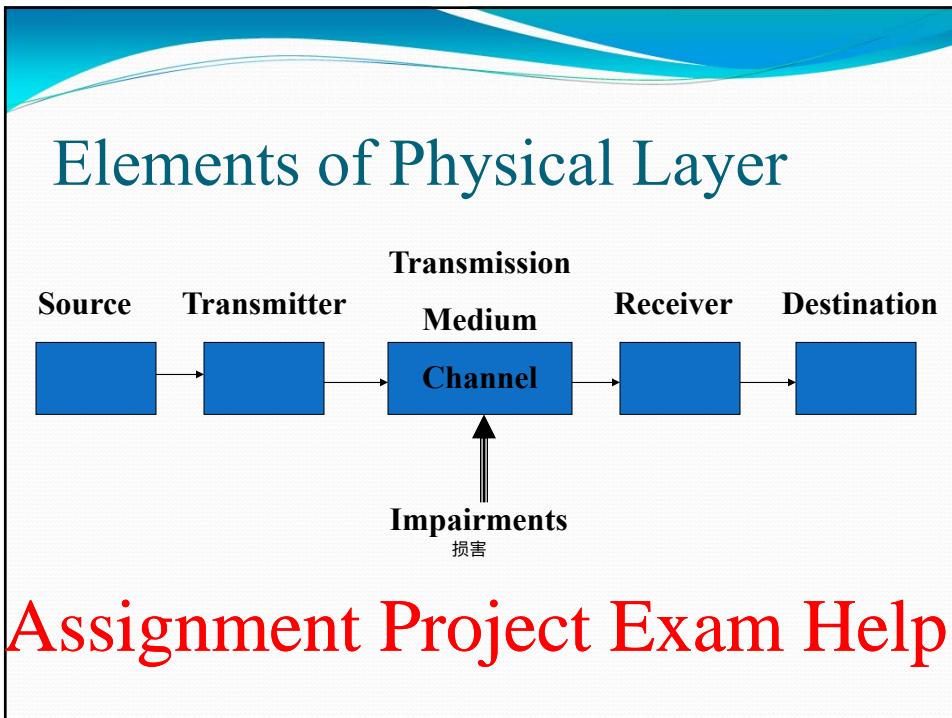
where

W = bandwidth in hertz

M = number of discrete signal levels

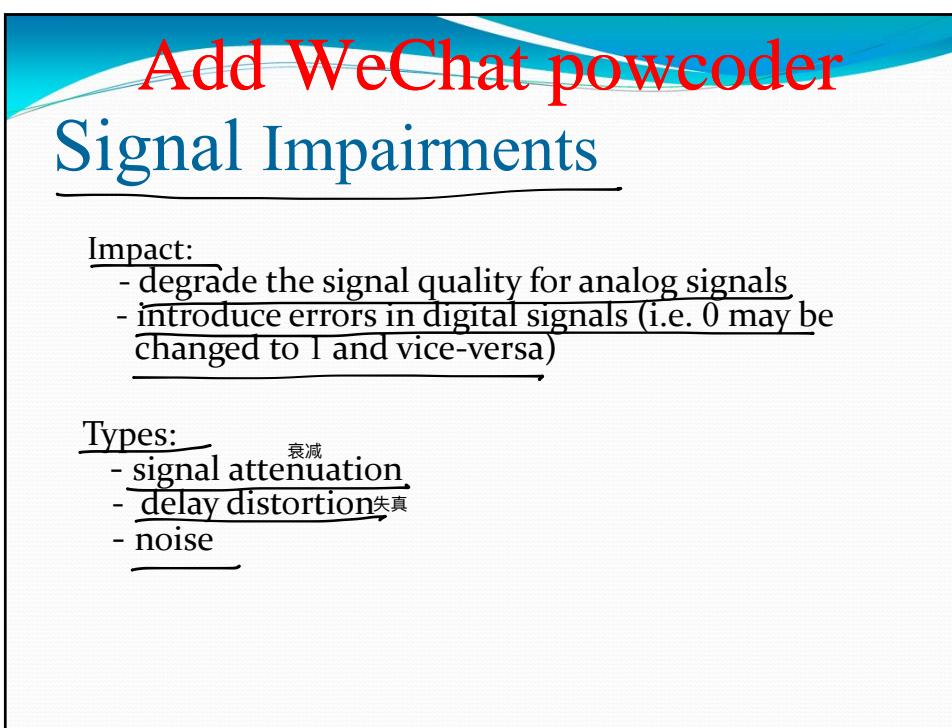
C = theoretical maximum capacity in bits per second

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**衰減**

## Attenuation

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

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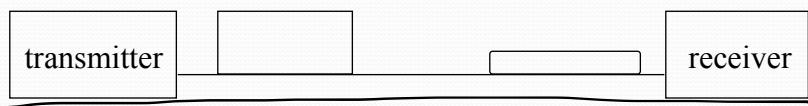
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### Signal impairments

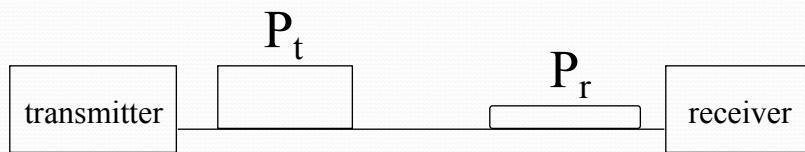
- Fact:
  - As a signal propagates along a transmission path there is loss, attenuation of signal strength.



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

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## Signal impairments



Attenuation is measured in dB

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Decibel (1)

- 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)

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## 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.

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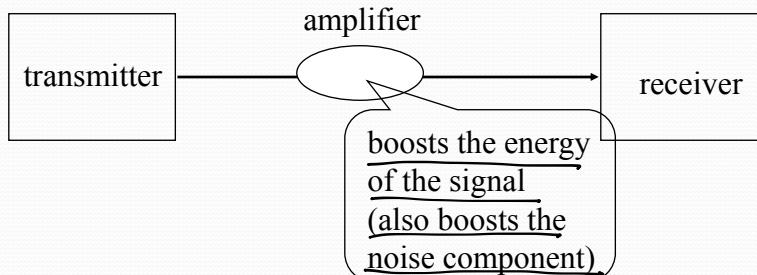
## Add WeChat powcoder Amplifiers and Repeaters

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

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## Amplifiers

- Can be used with Analog and Digital Communication Systems



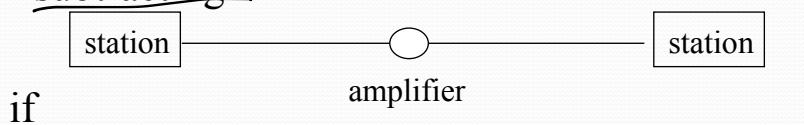
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- Useful to determine overall gain or loss in a system. This is done simply by adding or subtracting

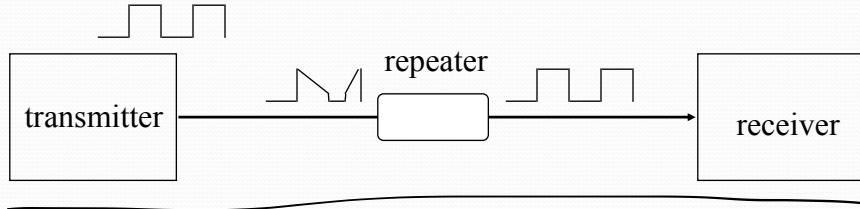


- { - loss on first portion of line is 13 dB  
   - gain of the amplifier is 30 dB  
   - loss of second portion of line is 40 dB  
   - the overall loss is 23 dB (i.e.  $-13 + 30 - 40 = -23$  dB)

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## Repeaters

- Can be used with Digital Communication Systems

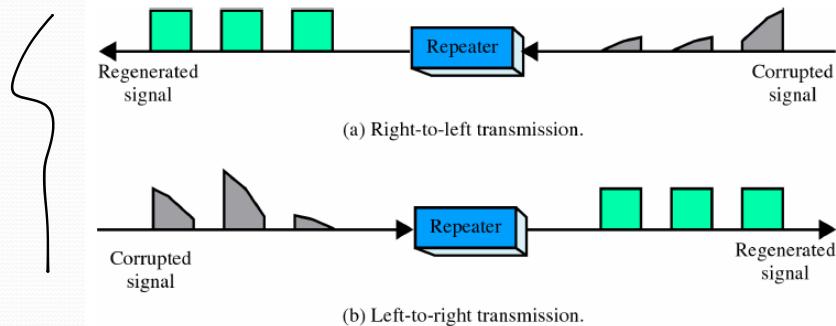


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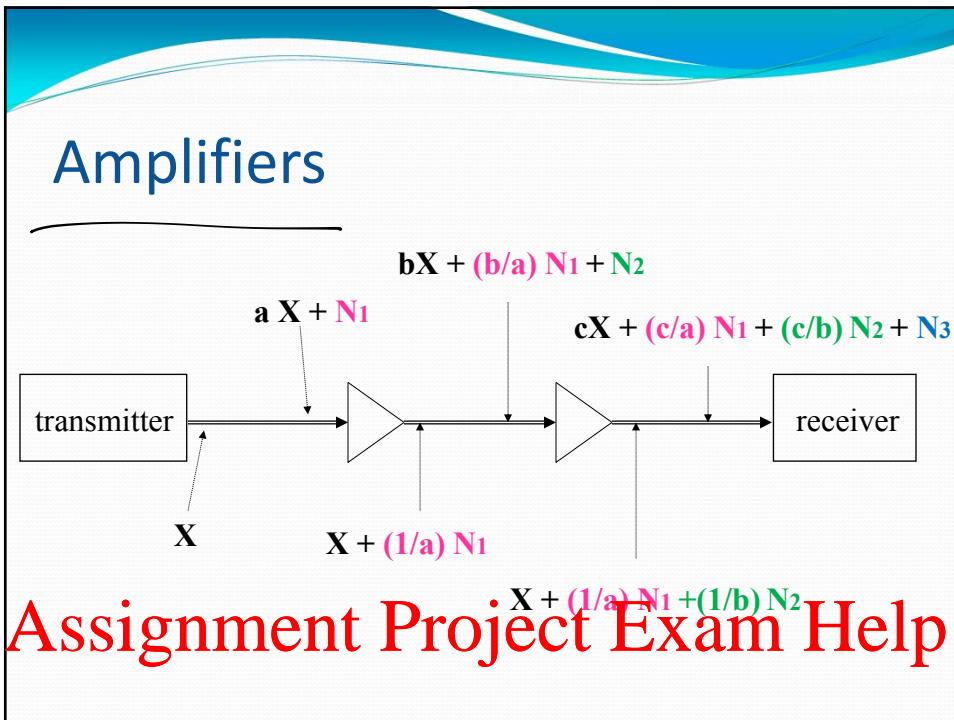
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## Add WeChat powcoder Function of Repeater

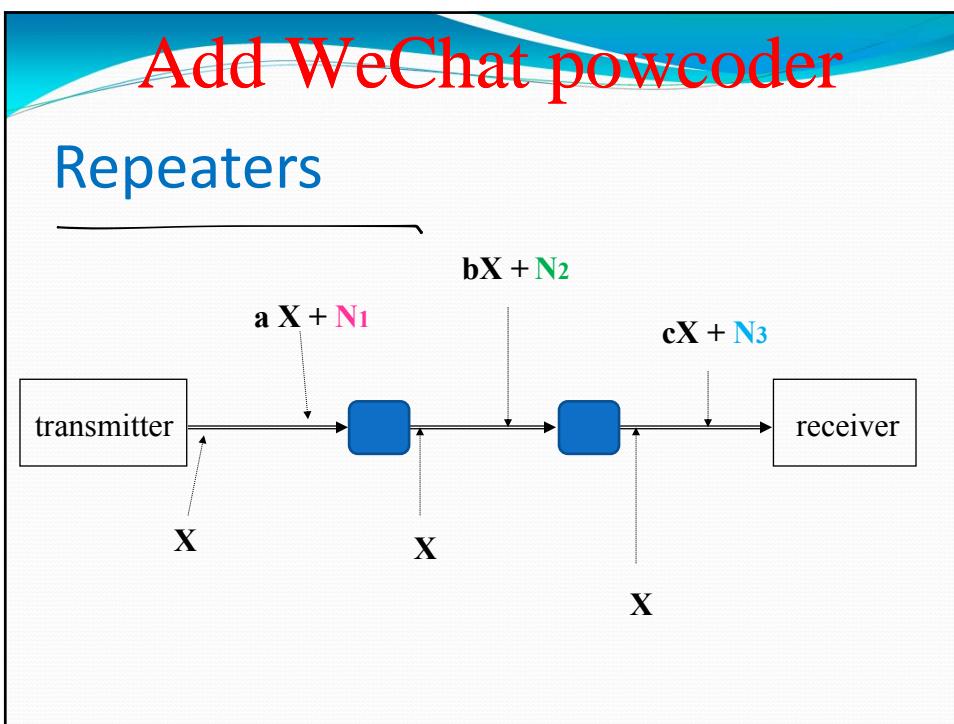


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# Noise

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

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## Thermal NOISE

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- Due to the thermal agitation 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:

$$N_0 = \frac{kT}{\text{搅动}}$$

where:

- $N_0$  = noise power density
- $k$  = Boltzmann's constant =  $1.3803 \times 10^{-23} \text{ J/K}$
- $T$  = temperature ( $\text{^{\circ}K}$ )

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## 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.

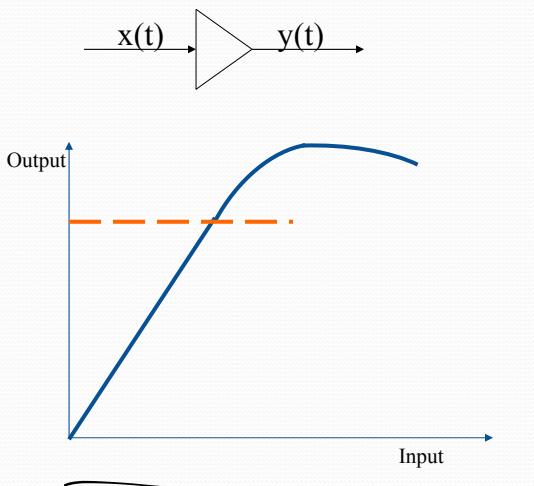
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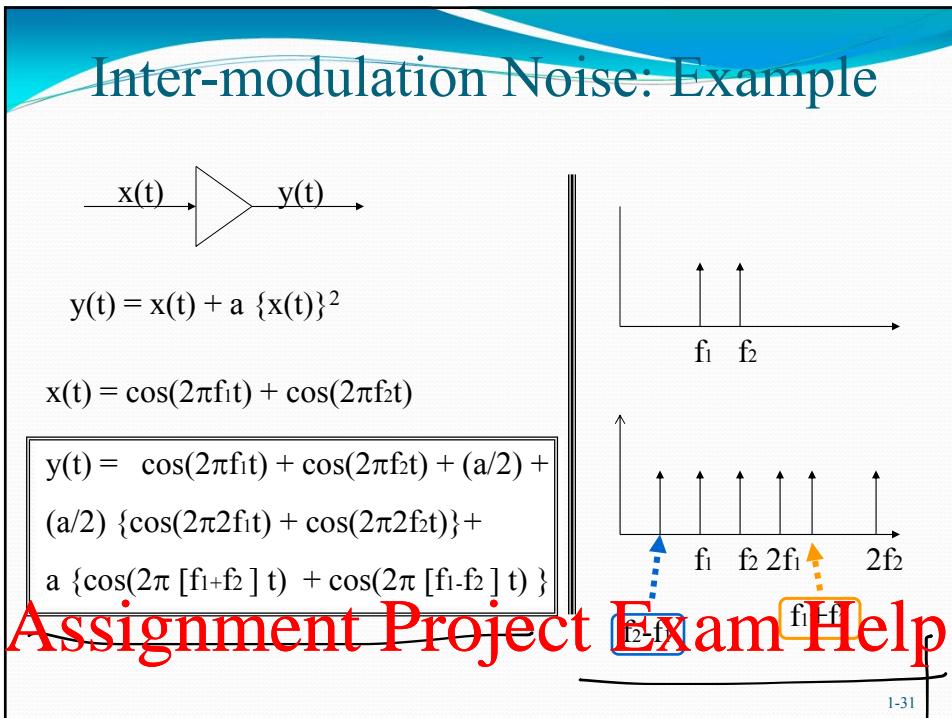
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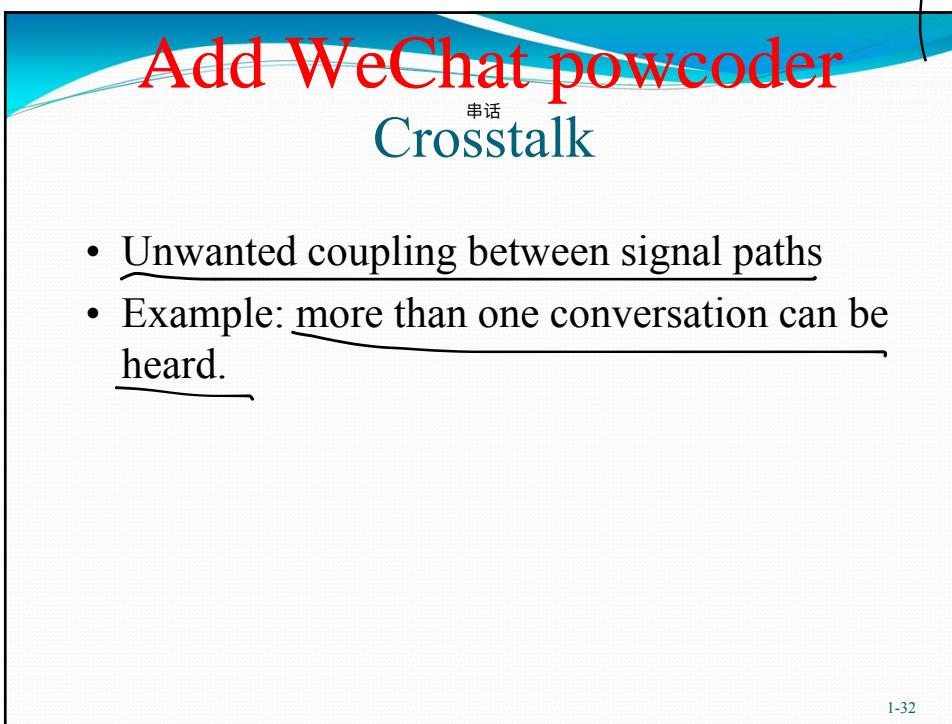
1-30

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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:**

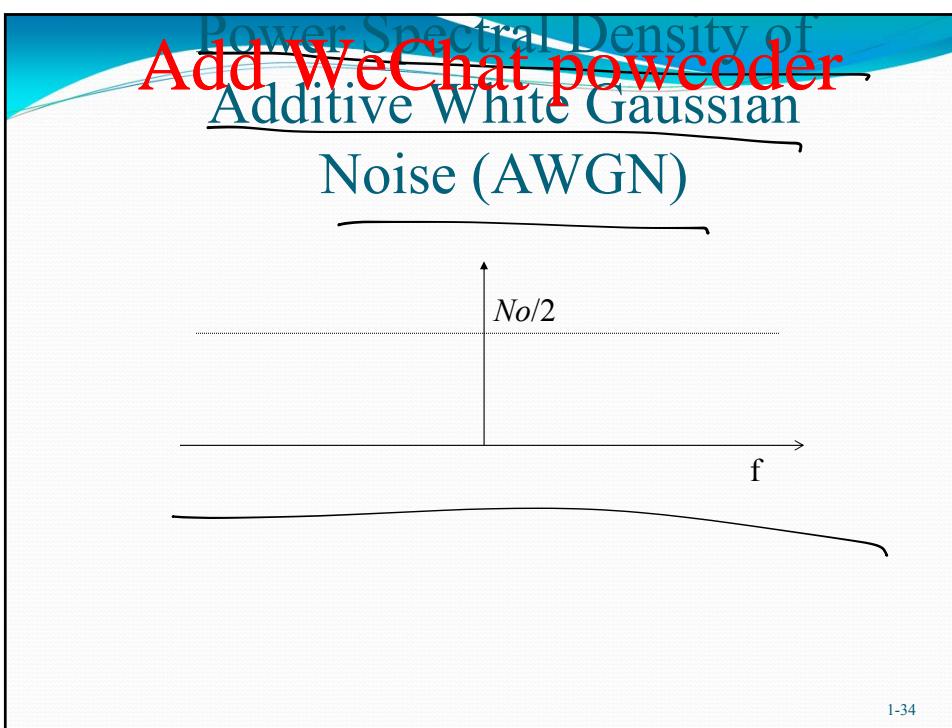
- external electromagnetic disturbances and faults in the communication system

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## 失真 Delay distortion

- The speed of propagation of a sinusoidal 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) => incorrect interpretation of the received signal

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## 大气吸收 Atmospheric absorption

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

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## Intersymbol Interference (1)

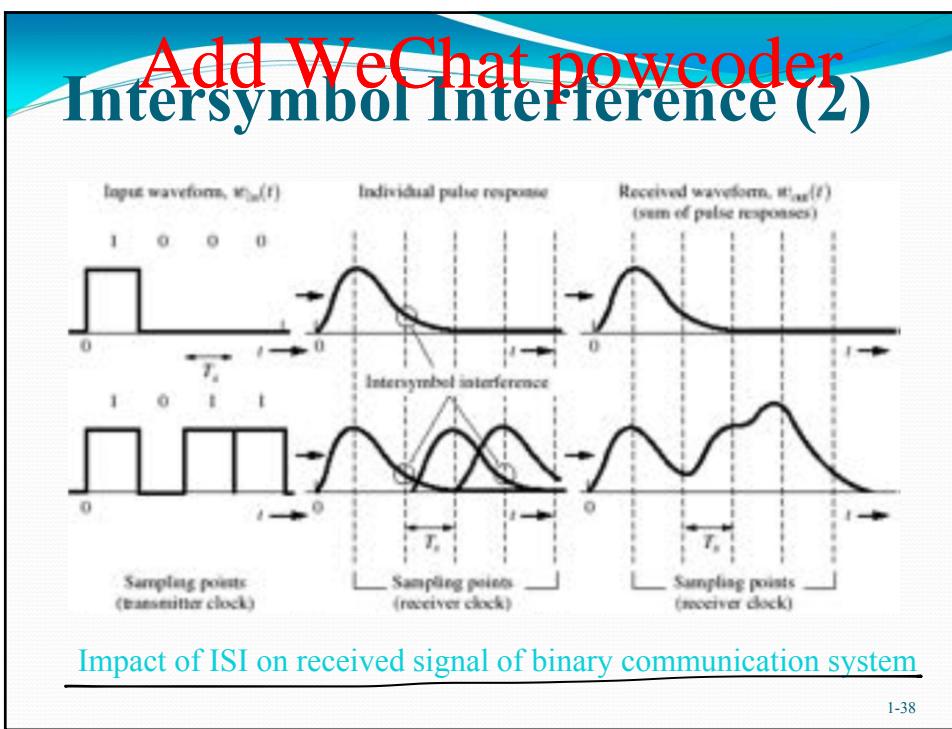
- Intersymbol interference (ISI) occurs when a pulse spreads out in such a way that it interferes with adjacent at the sample instant.
- Example: assume polar NRZ line code. The channel outputs are shown as “smeared” (width  $T_b$  becomes  $2T_b$ ) pulses (spreading due to bandlimited channel)

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## Causes of Impairments

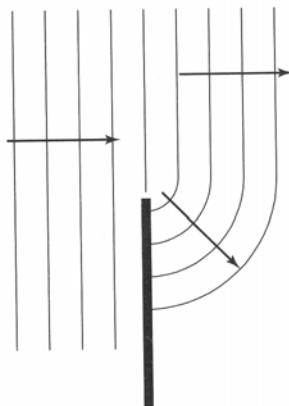
- **Reflection** - occurs when signal encounters a surface that is large relative to the wavelength of the signal.
- **Diffraction** - occurs at the edge of an impenetrable body that is large compared to wavelength of radio wave.
- **Scattering** – occurs when incoming signal hits an object whose size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

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Illustration of knife-edge diffraction



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# 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.

Building reflection  
Rooftop diffraction  
Line of sight path  
Ground reflection

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# Add WeChat powcoder ISI due to Multipath

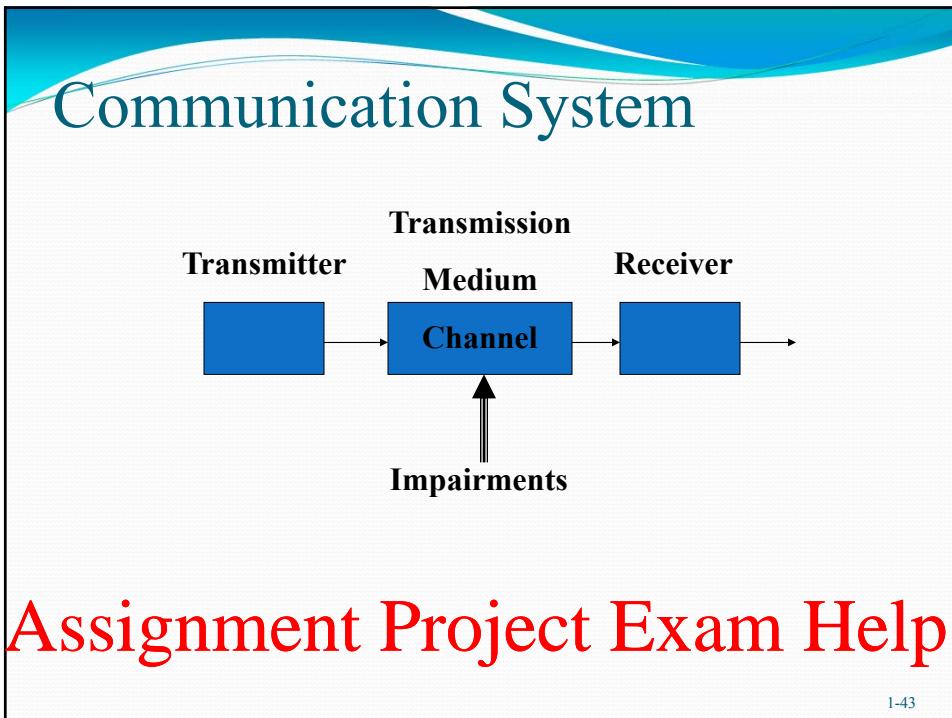
Transmitted pulse      Transmitted pulse

Received LOS pulse      Received multipath pulses      Received LOS pulse      Received multipath pulses

Time

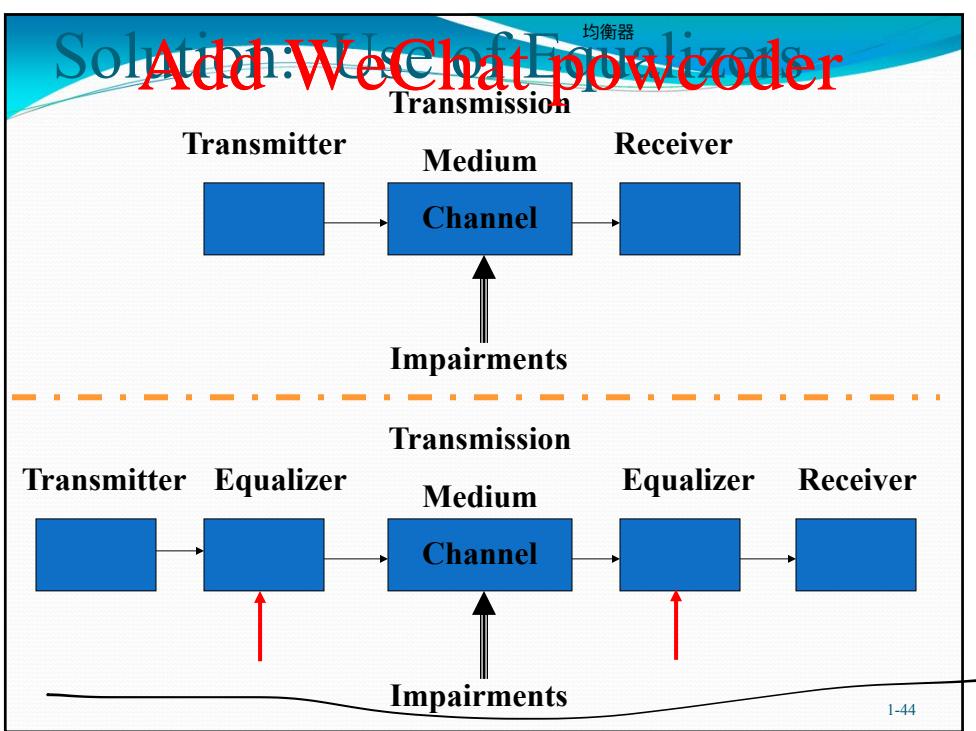
1-42

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## 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

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### Nyquist Formula

$$C = 2W \log_2 M$$

where

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

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## Channel capacity with noise

- Shannon-Hartley formula

$$\text{--- } C = W \log_2(1+S/N)$$

where

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

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## Add WeChat powcoder Digital vs. Analog Transmission (1)

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

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## Digital vs. Analog Transmission (2)

- Capacity utilization  
– links can be shared (multiplexed) effectively
- Security and privacy  
– encryption techniques can be applied easily to digital data

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## Add WeChat powcoder Bit rate and baud rate

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

$$\text{bit rate} = \text{baud rate} * n$$

where

$$n = \text{number of bits per change}$$

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Transmission media

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## Transmission media

引导的  
Guided Transmission media

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

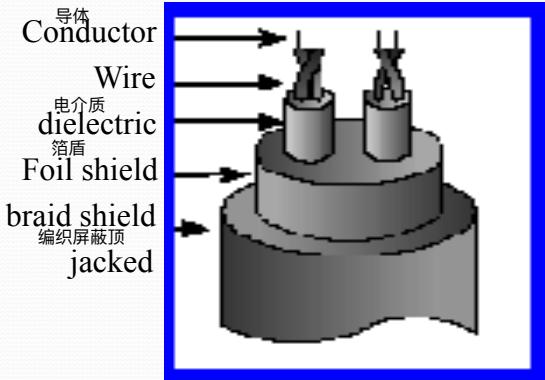
Wireless transmission

- { • microwave  
    微波
- radio  
    无线电
- infrared and millimeter waves  
    红外线 and 毫米波
- light-wave transmission  
    光波传输

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## Twisted pair (1)



The diagram illustrates a cross-section of a twisted pair cable. It shows two conductors (wires) twisted together, surrounded by a dielectric insulation layer. This central assembly is protected by a foil shield and a braid shield. The entire cable is terminated with a jacked connector.

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

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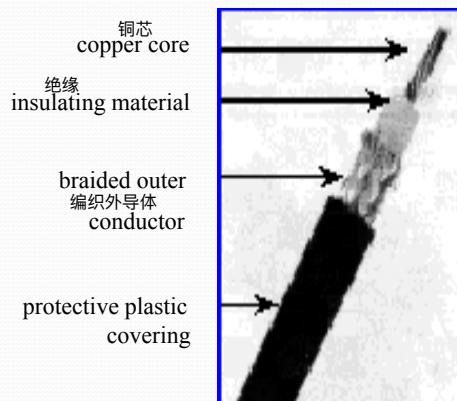
### Twisted pair (2)

- 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

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## Coaxial cable (1)



铜芯 copper core  
绝缘 material  
braided outer 编织外导体 conductor  
protective plastic covering

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

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### 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

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## Optical Fiber

- Physical Description
  - an optical fiber is a thin (2 to 125  $\mu\text{m}$ ), 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 cladding and the jacket.

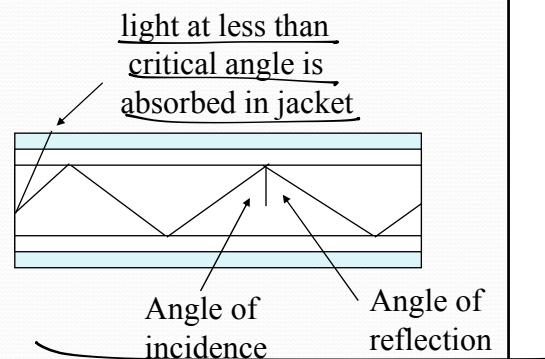
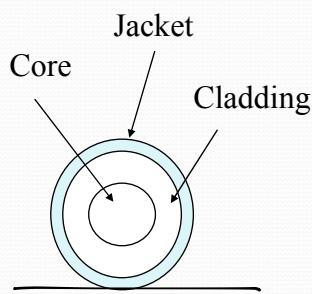
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## Add WeChat powcoder Optical Fibers (cont'd)



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

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## 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)

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### 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

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## Optical Fiber (cont'd)

- Applications

- Long-haul trunks
  - average length 900 miles
  - 20,000 to 60,000 voice channels
- Metropolitan networks
  - average length 7.8 miles
  - 100,000 voice channels
- Rural-exchange trunks
  - 25 to 100 miles
  - less than 5,000 voice channels

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## Add WeChat powcoder Optical Fiber (cont'd)

- Applications (cont'd)

- Subscriber loop

- 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,...

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## Optical Fiber (cont'd)

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

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**UNITED STATES FREQUENCY ALLOCATIONS**

**THE RADIO SPECTRUM**

**Spectrum is valuable commodity; needs to be shared**

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**Spectrum Allocation**

Band name	Abbreviation	ITU band number	Frequency and Wavelength	Example Uses
Extremely low frequency	ELF	1	3–30 Hz 100,000–10,000 km	Communication with submarines
Super low frequency	SLF	2	30–300 Hz 10,000–1,000 km	Communication with submarines
Ultra low frequency	ULF	3	300–3,000 Hz 1,000–100 km	Submarine communication, communication within mines
Very low frequency	VLF	4	3–30 kHz 100–10 km	Navigation, time signals, submarine communication, wireless heart rate monitors, geophysics
Low frequency	LF	5	30–300 kHz 10–1 km	Navigation, time signals, AM longwave broadcasting (Europe and parts of Asia), RFID, amateur radio
Medium frequency	MF	6	300–3,000 kHz 1,000–100 m	AM (medium-wave) broadcasts, amateur radio, avalanche beacons
High frequency	HF	7	3–30 MHz 100–10 m	Shortwave broadcasts, citizens band radio, amateur radio and over-the-horizon aviation communications, RFID, over-the-horizon radar, automatic link establishment (ALE) / near-vertical incidence skywave (NVIS) radio communications, marine and mobile radio telephony
Very high frequency	VHF	8	30–300 MHz 10–1 m	FM, television broadcasts, line-of-sight ground-to-aircraft and aircraft-to-aircraft communications, land mobile and maritime mobile communications, amateur radio, weather radio
Ultra high frequency	UHF	9	300–3,000 MHz 1–0.1 m	Television broadcasts, microwave oven, microwave devices/communications, 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			1–0.1 GHz 10–1 mm	Radio astronomy, high frequency ground-to-space radio relay, microwave relay, millimeter wave communications, millimeter wave radars, weather radars, millimeter wave scanner, telecommunication (BSR, TDR)
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 -65

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**Spectrum Allocation**

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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

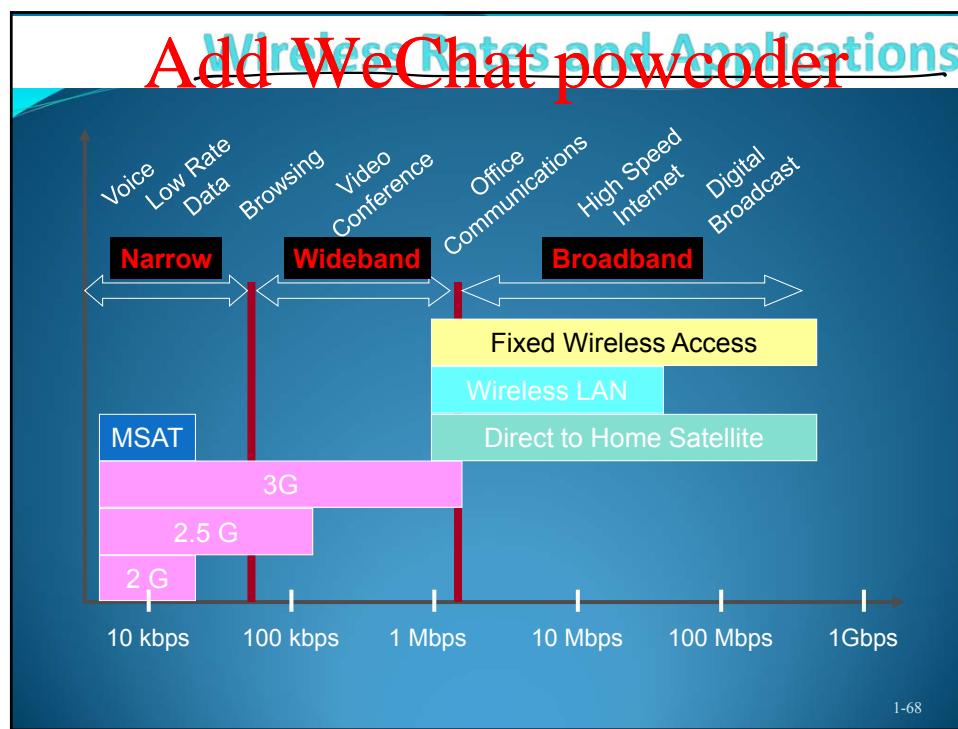
Microwave frequencies: range between  $10^9$  Hz (1 GHz) to  $3 \times 10^{11}$  Hz (300 GHz). Specific wavelength: 30 cm to 0.1 cm.

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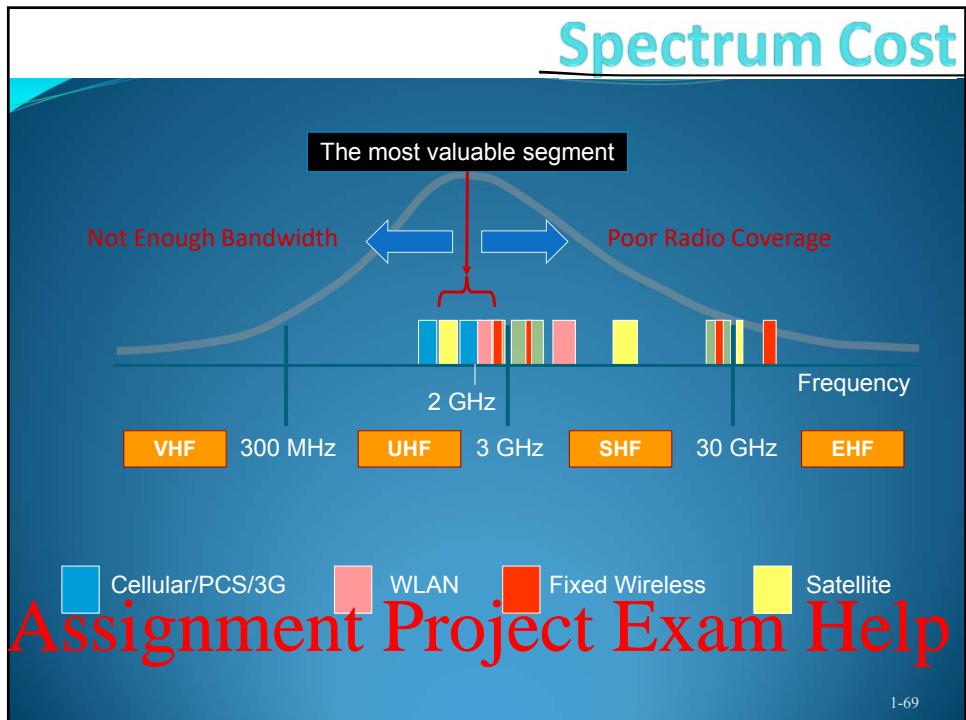
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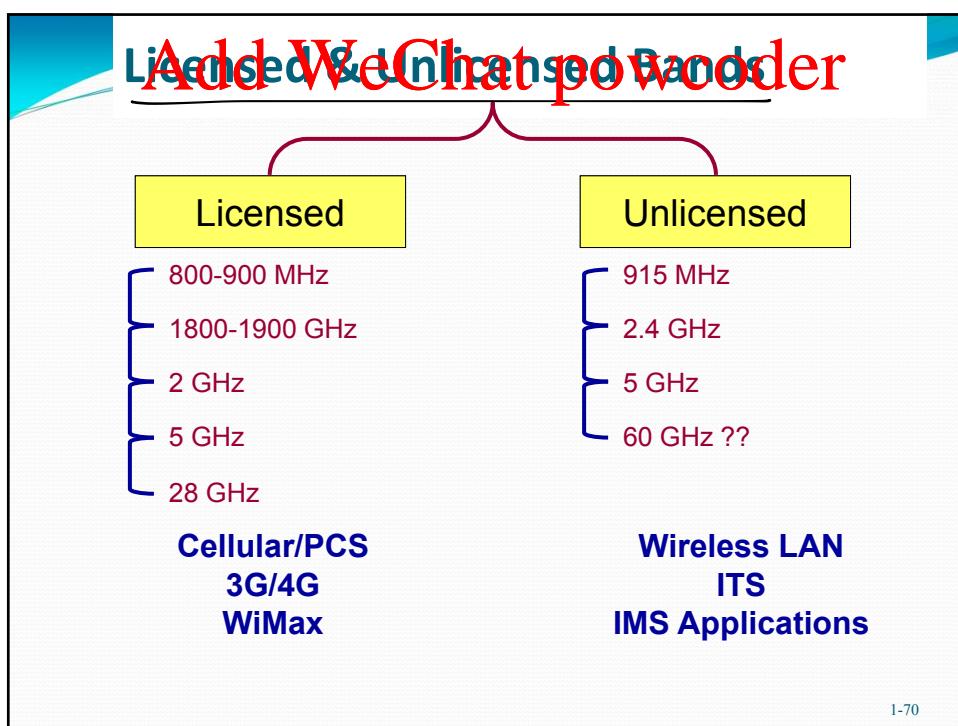


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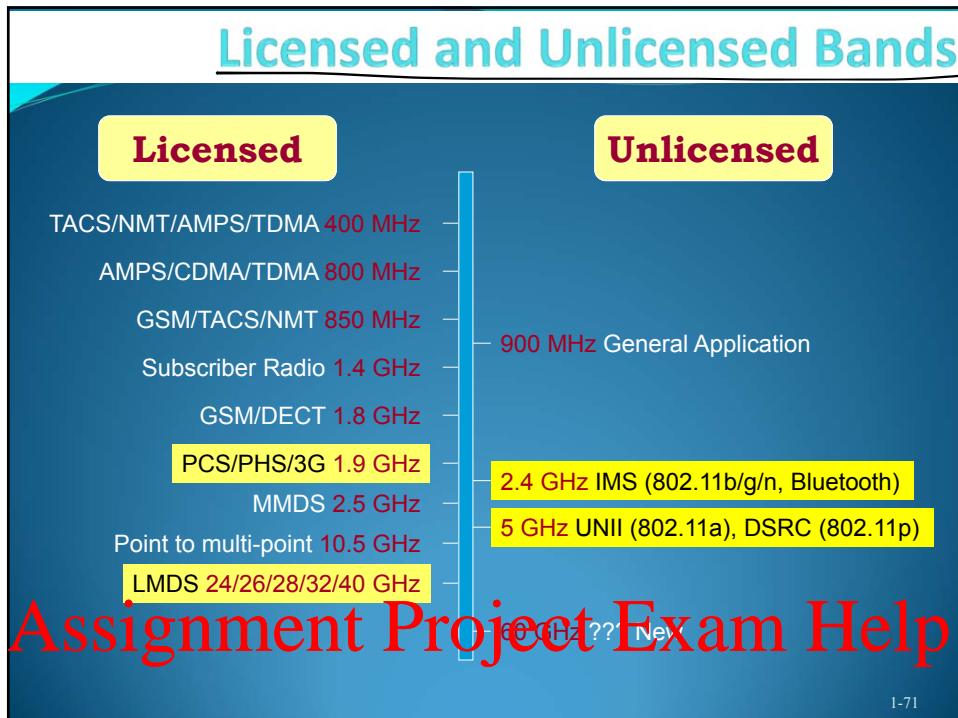


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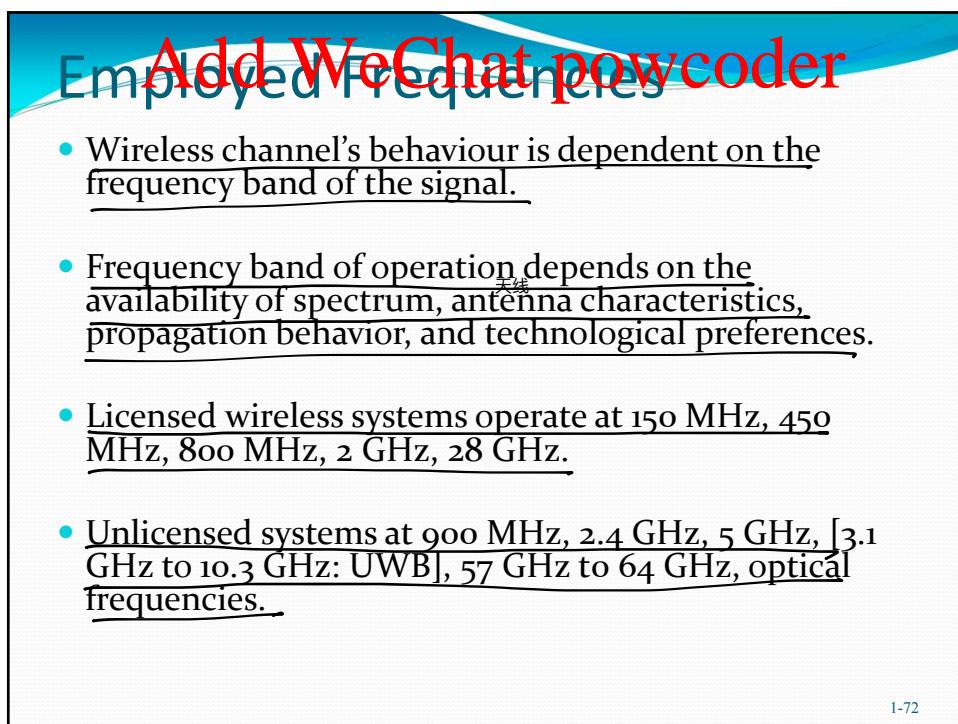


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无线电

## Radio transmission

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

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## Radio transmission

- Radio waves

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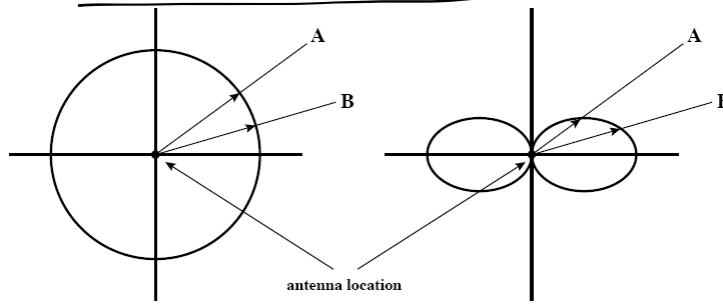
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## Wireless transmission patterns

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- directional -
  - the transmitting antenna puts out a focused electromagnetic beam
  - example: terrestrial microwave, satellite
- omnidirectional
  - the transmitted signal spreads out in all directions



(a) Omnidirectional

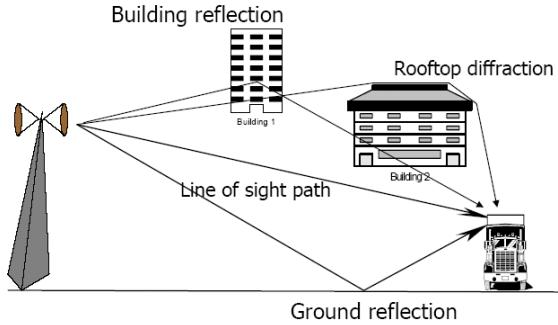
(b) Directional

1-74

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## 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  $\lambda$ , which is a few centimeters for the frequencies used) the signal amplitude can very greatly. Also produces ISI.

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## Add WeChat powcoder Microwave transmission

- 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 penetrate deep into buildings
- Multipath fading effect can occur

1-76

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## Terrestrial Microwave

- Physical Description
  - parabolic dish 抛物面
  - ~ 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)

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## Terrestrial Microwave (cont'd)

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

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## 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  $\lambda$  is the wavelength, expressed in the same units.

IMPORTANT:

~~loss varies as the square of the distance~~

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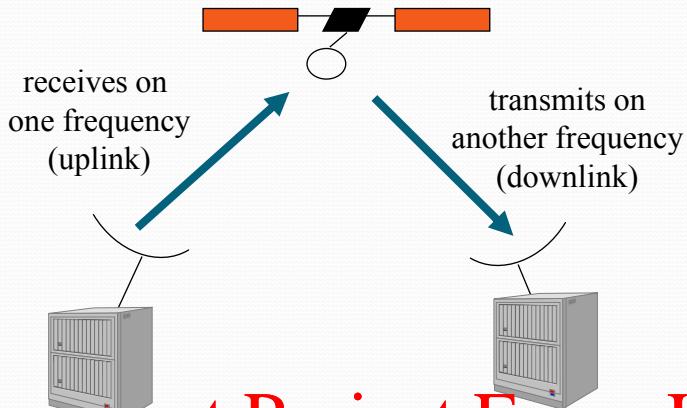
## Add WeChat powcoder Satellite Microwave

- Physical Description
  - a satellite is a microwave relay station used to link 2 or more ground-based microwave transmitters/receivers.
  - a single orbiting satellite will operate on a number of frequency bands, called **transponder** channels.
  - 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

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## Satellite Microwave (cont'd)



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## Satellite Microwave (cont'd)

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

1-82

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## 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)

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## Infrared, Optical and millimeter waves

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- 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 ....

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### 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 emit a bit. For a data rate R, the bit duration,  $t_B$ , is  $1/R$ .

1-86

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## Data Rate vs. Modulation Rate

- data rate:

$$\overbrace{\quad\quad\quad}^R = \overbrace{1/t_B}$$

where  $t_B$  is the bit duration

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

$$2 R$$

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Data Encoding

1-88

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**基带**  
Data Encoding - Baseband Transmission

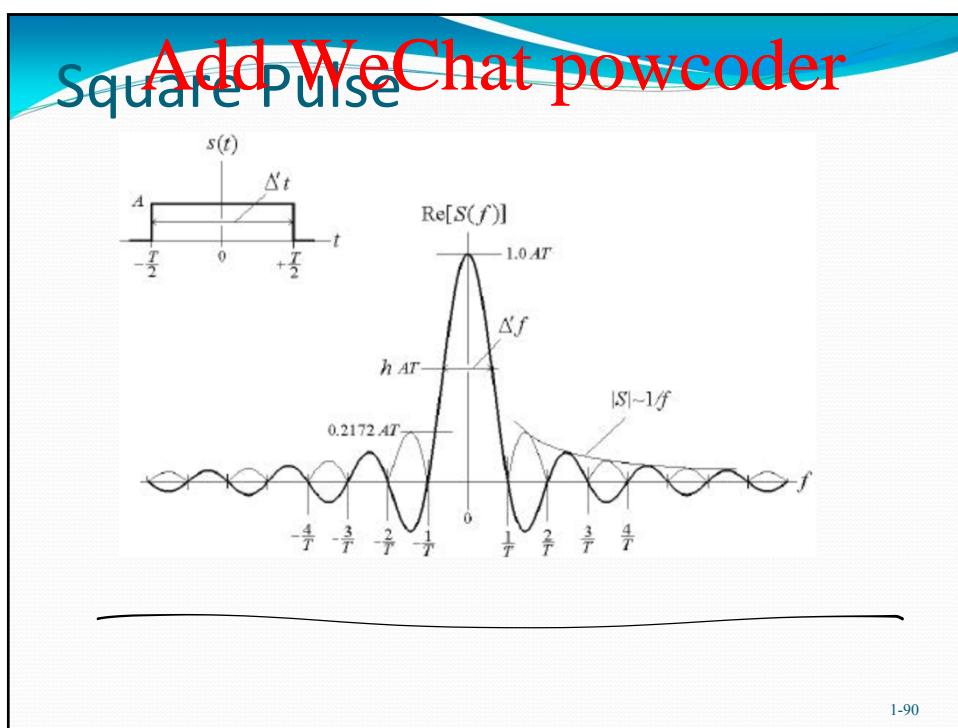
- Encoding onto a digital signal located at baseband

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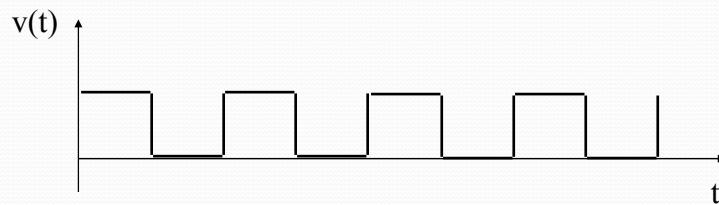


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## Digital Data/Digital Signals

- Definition

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



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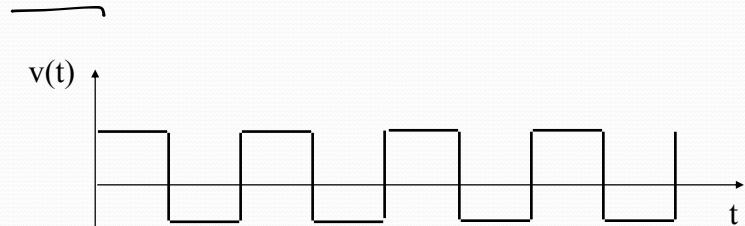
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## Add WeChat powcoder Digital Data/Digital Signals

- Definition

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



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## 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

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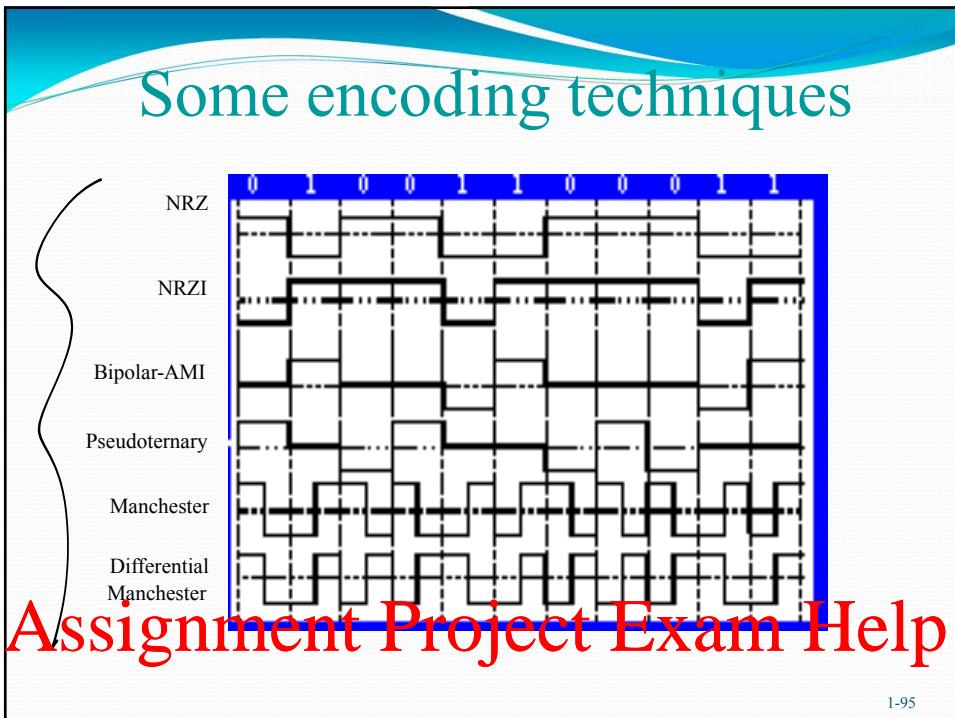
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## Add WeChat powcoder Digital Signal Encoding Schemes

- 3) error detection
  - useful to be able to detect errors at the physical level
- 4) signal interference and noise immunity
- 5) cost and complexity

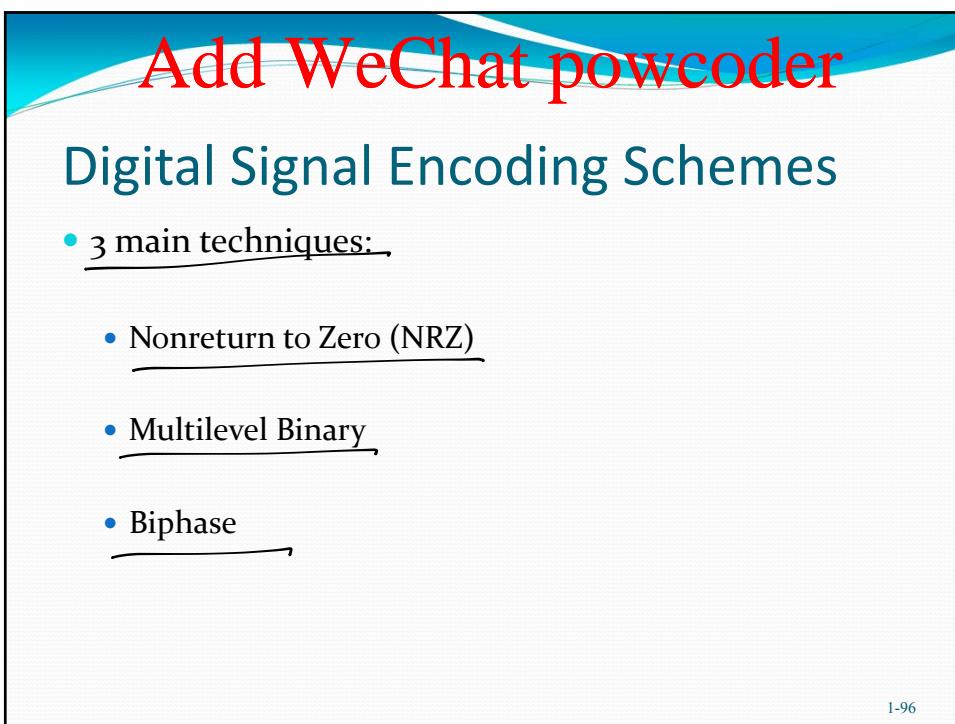
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## Digital Signal Encoding Schemes

- 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

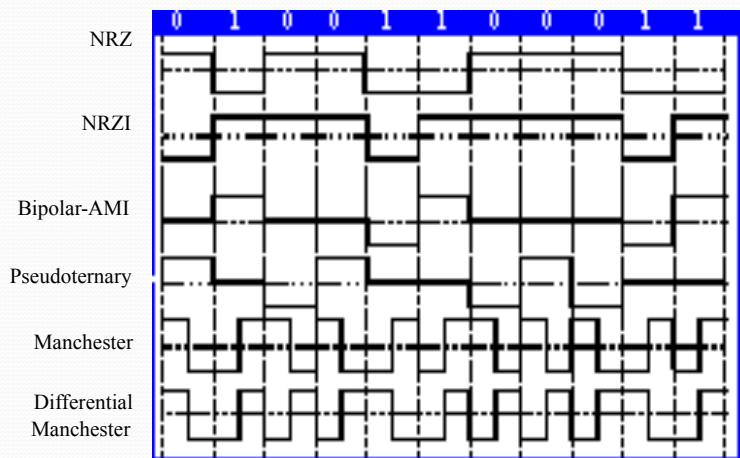
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Some encoding techniques



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## 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)

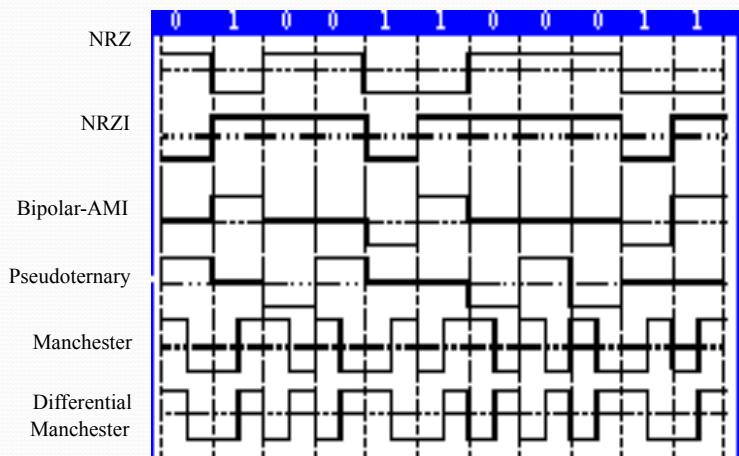
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Some encoding techniques



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## Digital Signal Encoding Schemes

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

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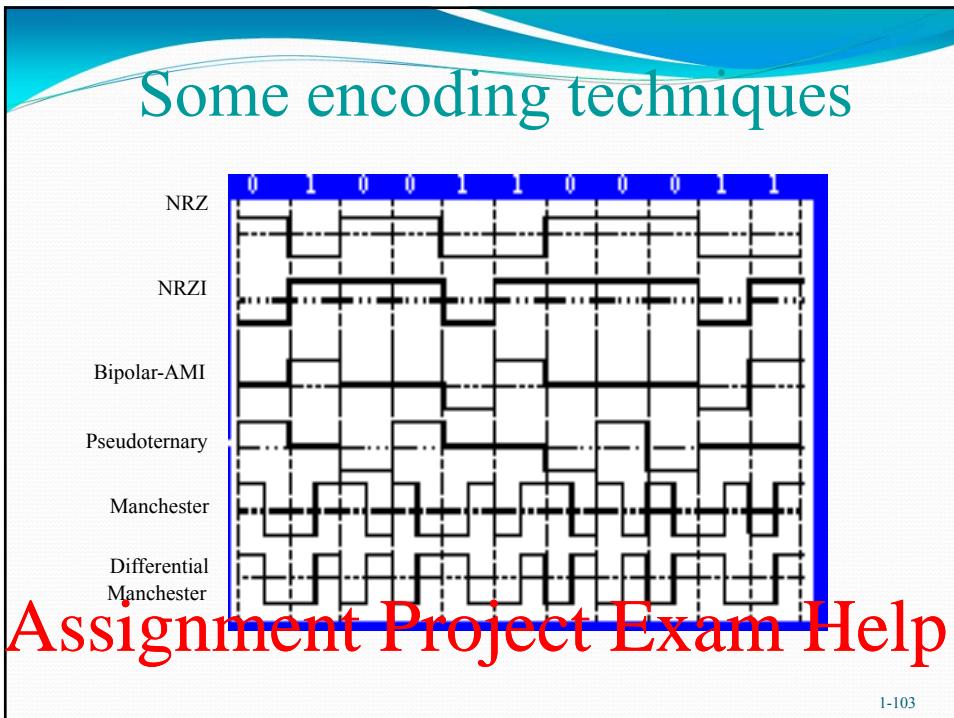
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### Digital Signal Encoding Schemes

- 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

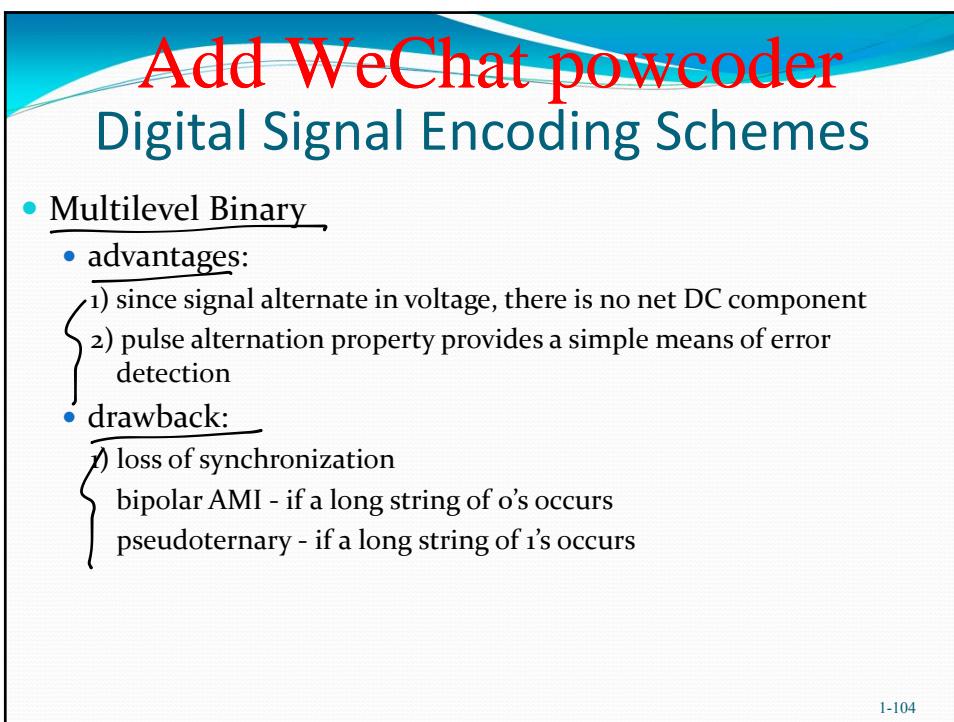
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## Digital Signal Encoding Schemes

- 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

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## Add WeChat powcoder Some encoding techniques

	0	1	0	0	1	1	0	0	0	1	1
NRZ	1	0	1	0	1	0	1	0	1	0	1
NRZI	0	1	0	1	0	1	0	1	0	1	0
Bipolar-AMI	-1	1	-1	1	-1	1	-1	1	-1	1	-1
Pseudoternary	-1	0	-1	0	-1	0	-1	0	-1	0	-1
Manchester	0	1	0	1	0	1	0	1	0	1	0
Differential Manchester	0	1	0	1	0	1	0	1	0	1	0

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## 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 调制
    - a) higher modulation rate than NRZ => higher BW

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### Digital Signal Encoding Schemes

Normalized Signal Transition Rate of Various Digital Signal Encoding Schemes

	Minimum	101010...	Maximum
NRZ-L	0 (all 0'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 0's or 1's)
Differential Manchester	1.0 (all 1's)	1.5	2.0 (all 0's)

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## Evaluation

- NRZ

- lack of synchronization capability; widely used for digital magnetic recording but not for signal transmission

- Multilevel binary

- long string of Os (Bipolar-AMI) and 1s (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)

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## Data Encoding

- Modulation onto an analog signal

$m(t)$   
digital  
or  
analog

Modulator

$s(t)$

Demodulator

$m(t)$

$f_c$

$S(f)$

$f$

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### 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  $s(t)$

Signal strength

time

$s(t) = A\sin(2\pi ft + \phi)$

Parameters:

Amplitude:  $A$

Frequency:  $f$

Phase :  $\phi$

$T_1 = 1/f$

1-111

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## Modulation Techniques

- Amplitude modulation

- $S(t) = [1+n_a X(t)] \cos 2\pi f_c t$ , 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

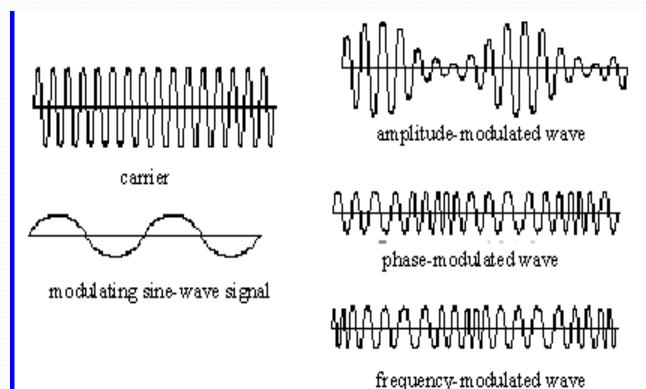
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Modulation of a sine-wave carrier by a sine-wave signal



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## Modulation of digital signal

Amplitude-shift keying

Frequency-shift keying

Phase-shift keying

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## Add WeChat powcoder Multilevel modulation

<p>Quadrature phase-shift keying (R=2*D)</p> <p>Quadrature amplitude modulation (R=4*D)</p>	<p>Quadrature amplitude modulation (R=4*D)</p>
---	--

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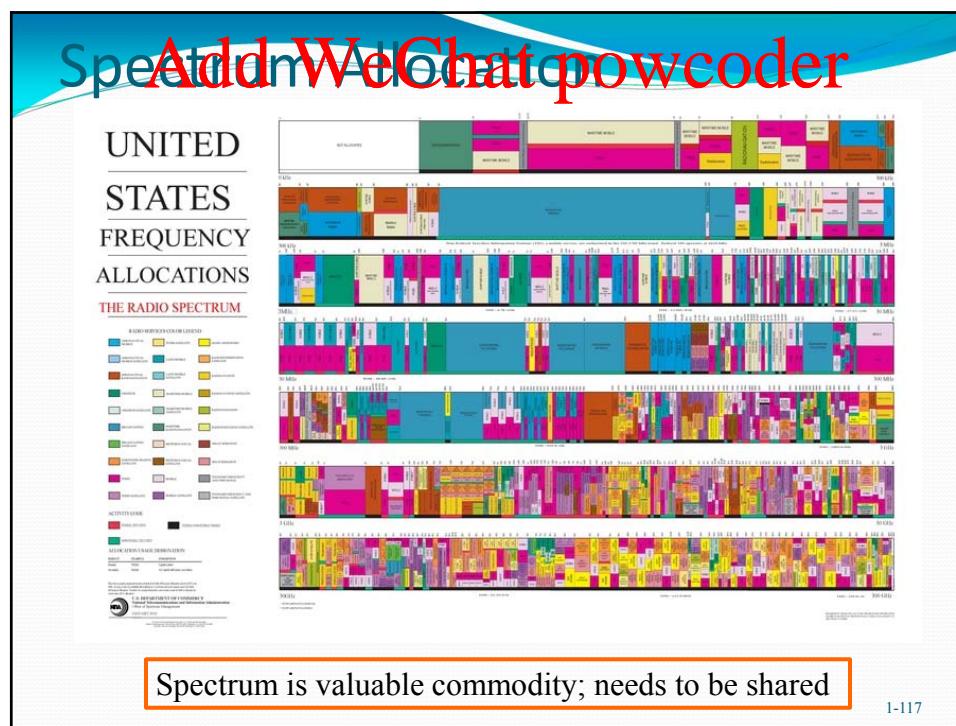
## Multiplexing

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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)

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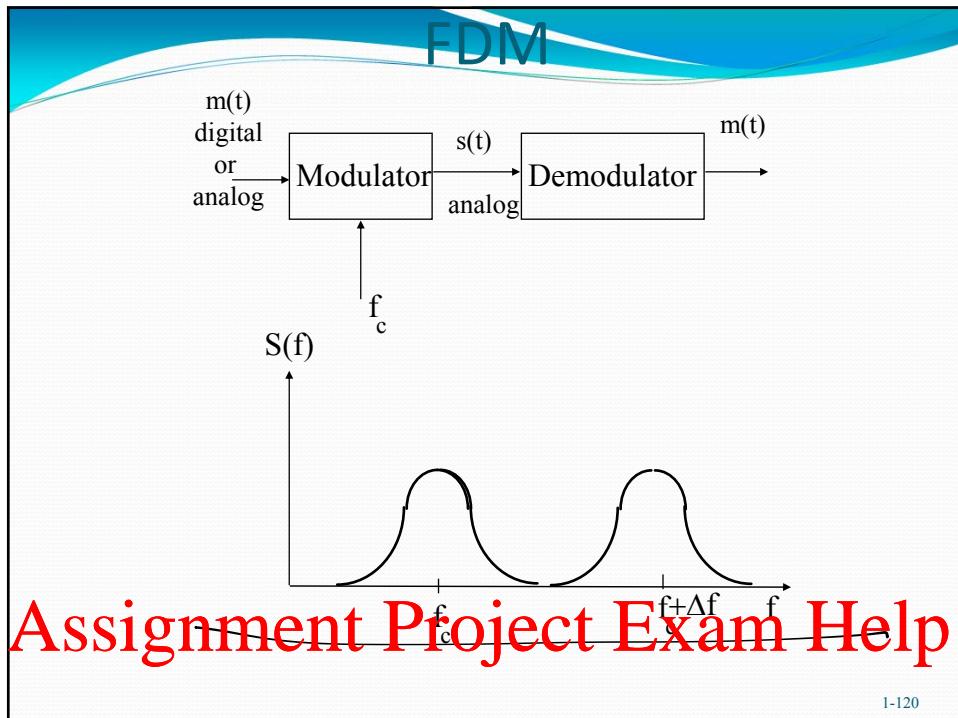
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Frequency-division multiplexing

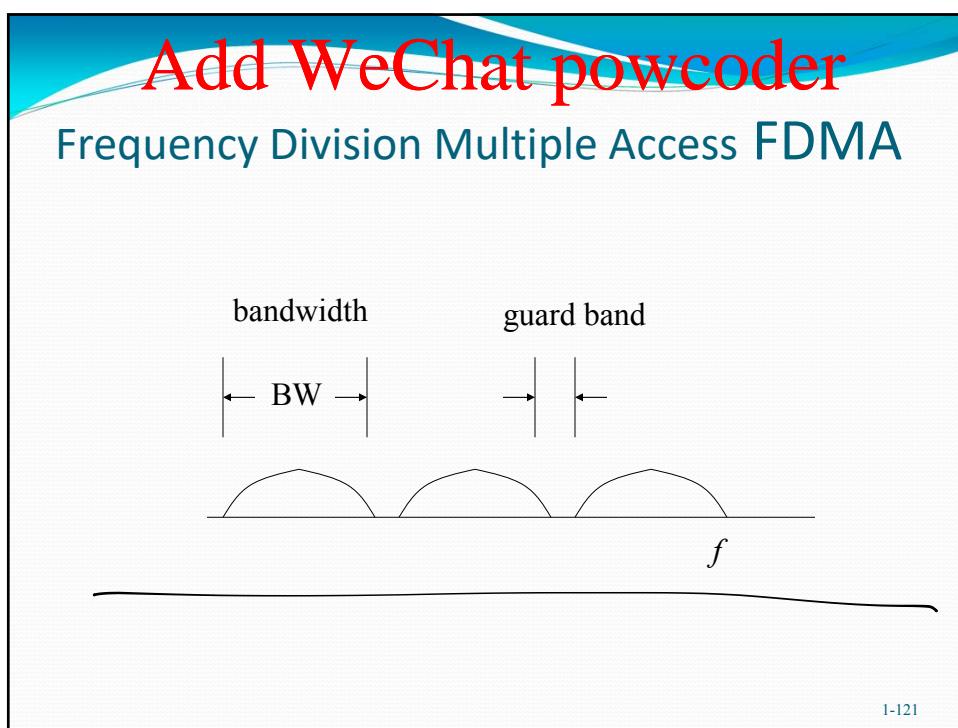
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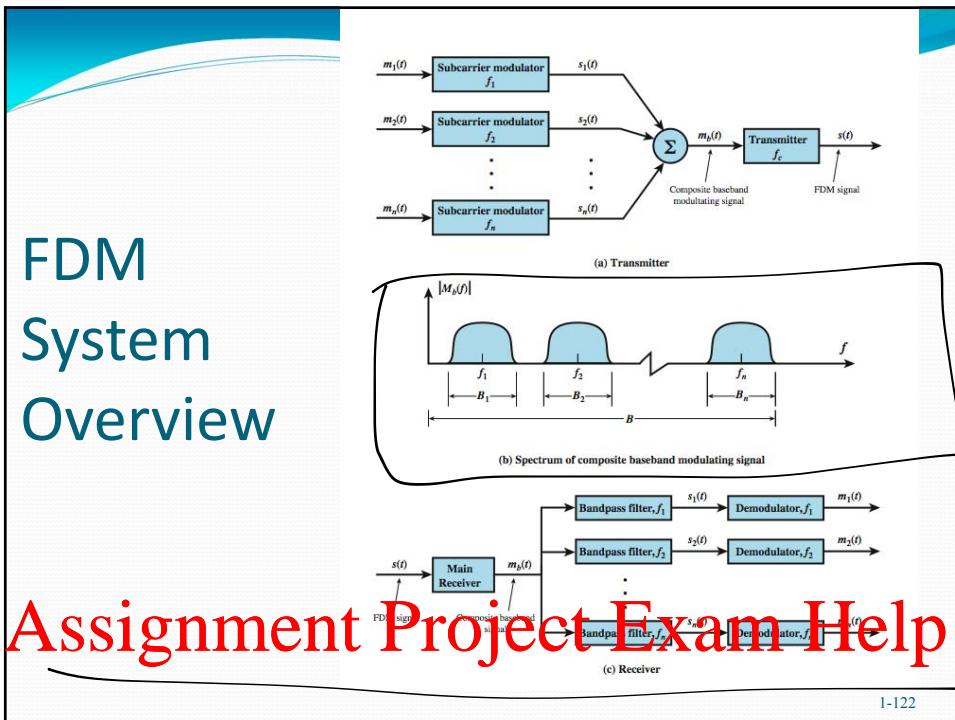


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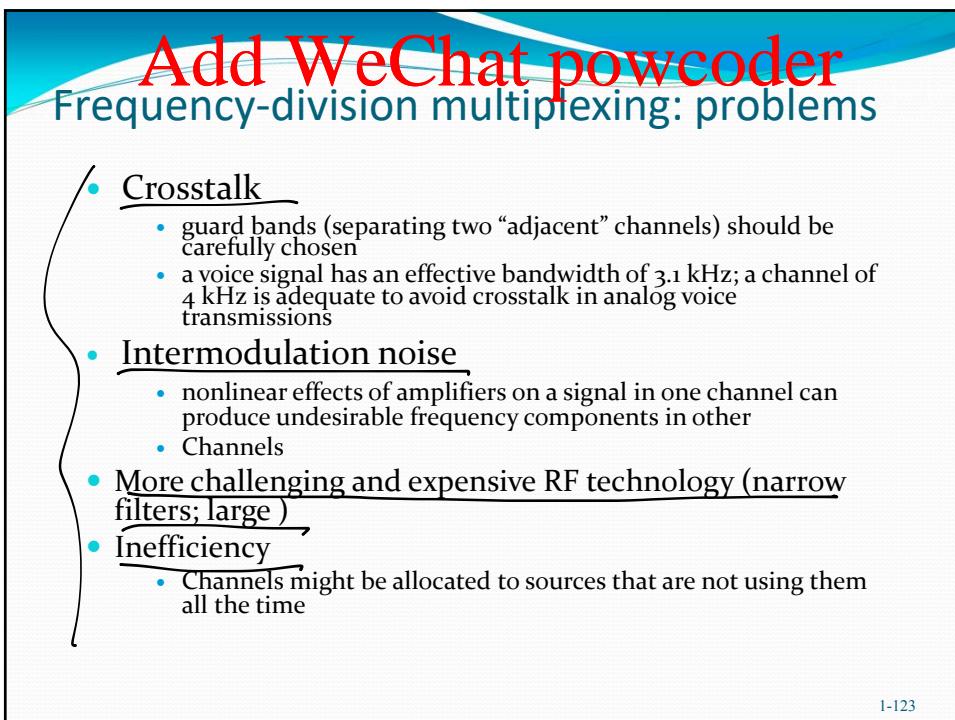


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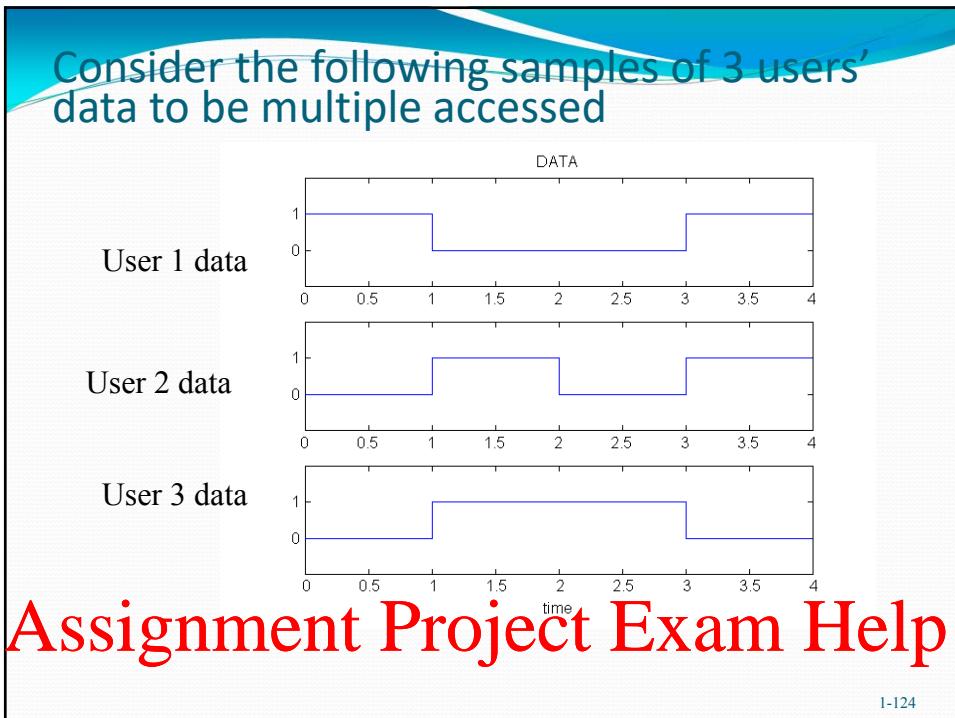
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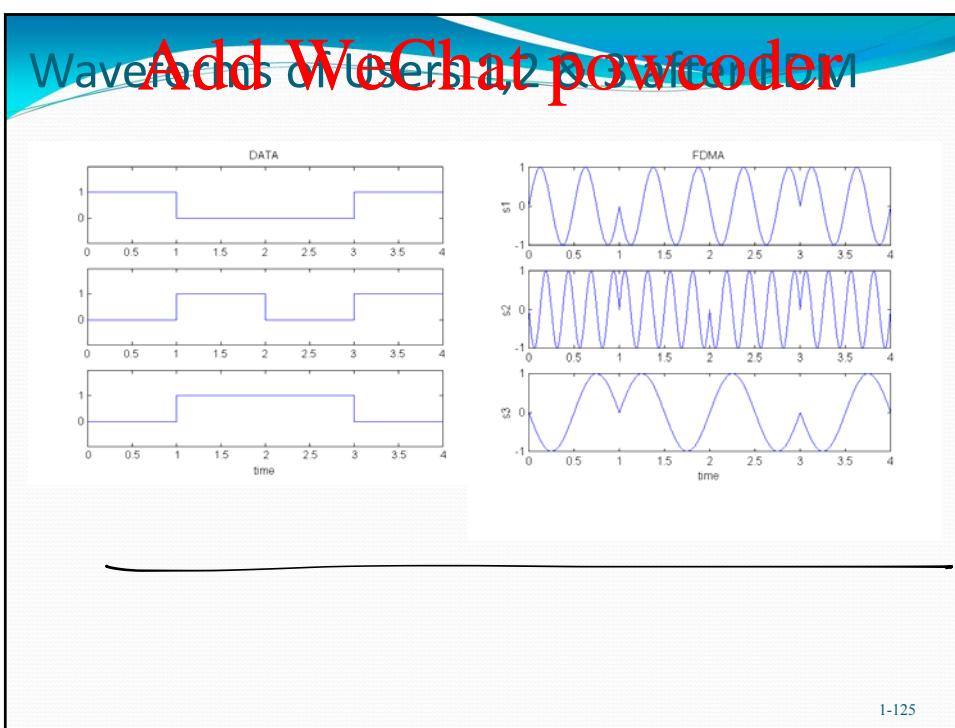
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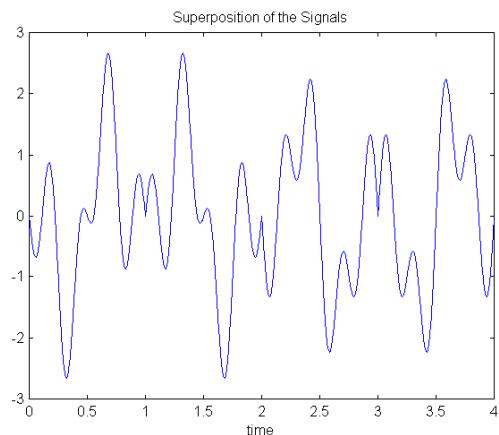
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Input to the amplifier after 3 FDM signals are added



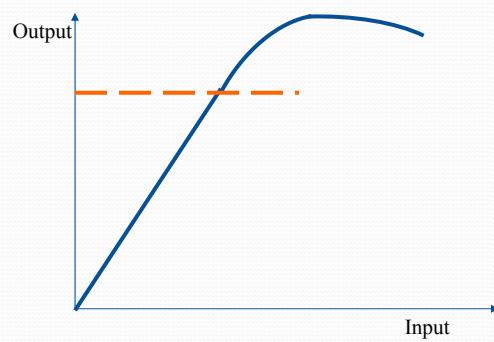
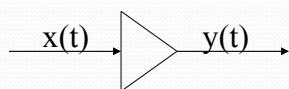
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## Nonlinear Effects in FDM

- 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.

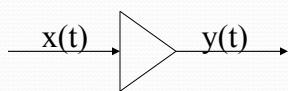
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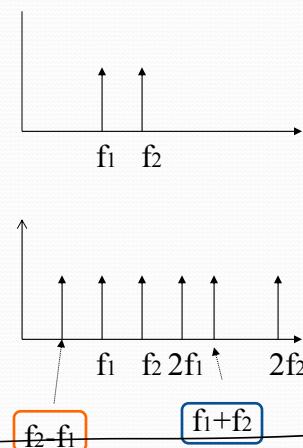
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Inter-modulation Noise



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

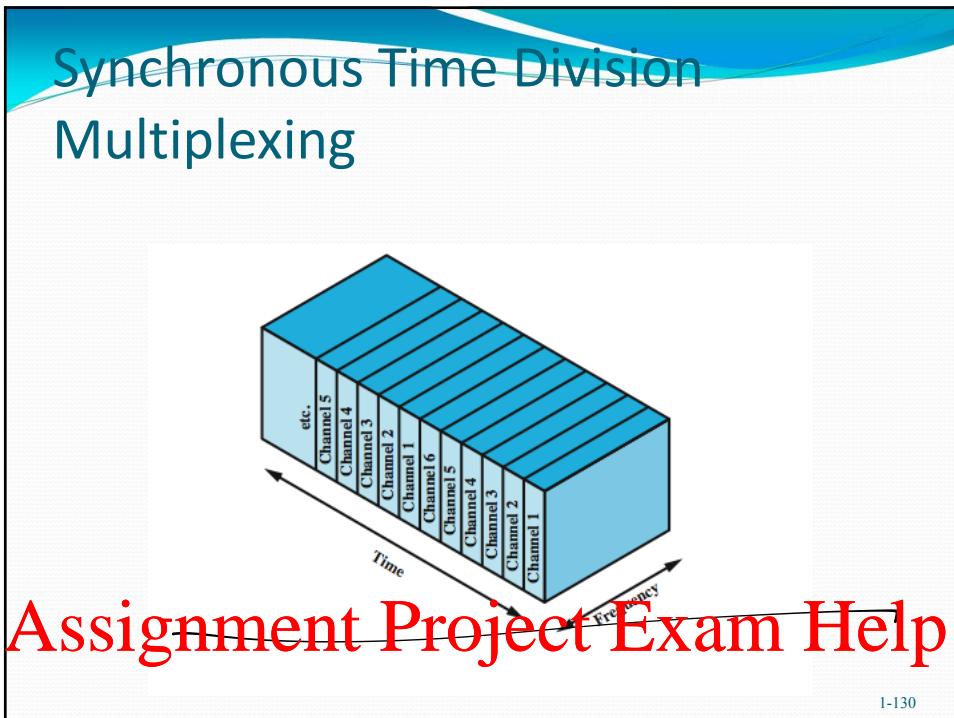
$$x(t) = \cos(2\pi f_1 t) + \cos(2\pi f_2 t)$$

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



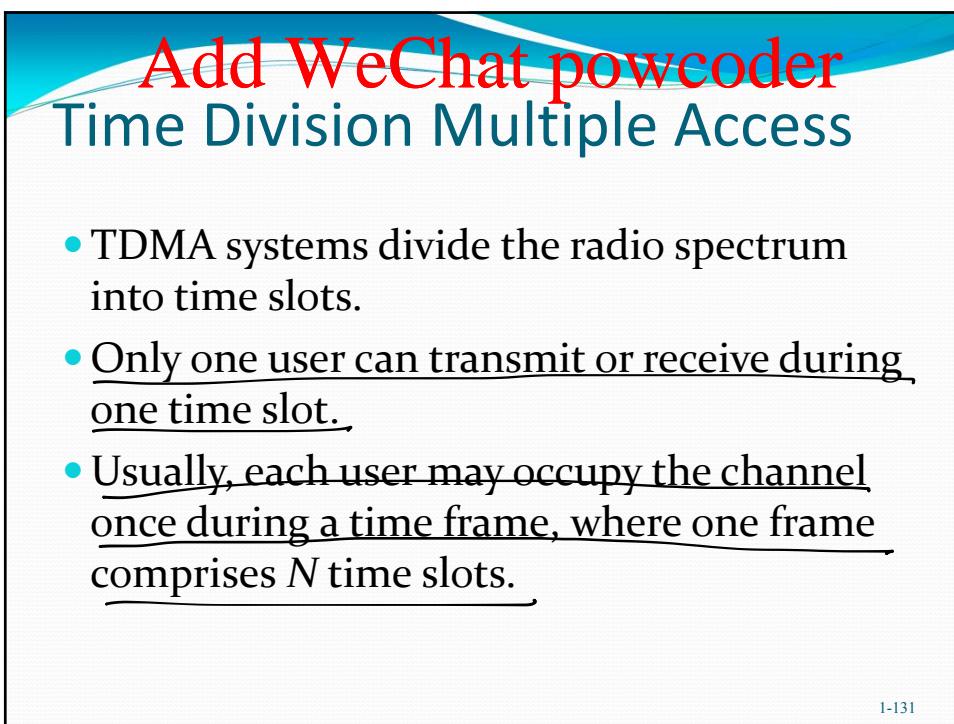
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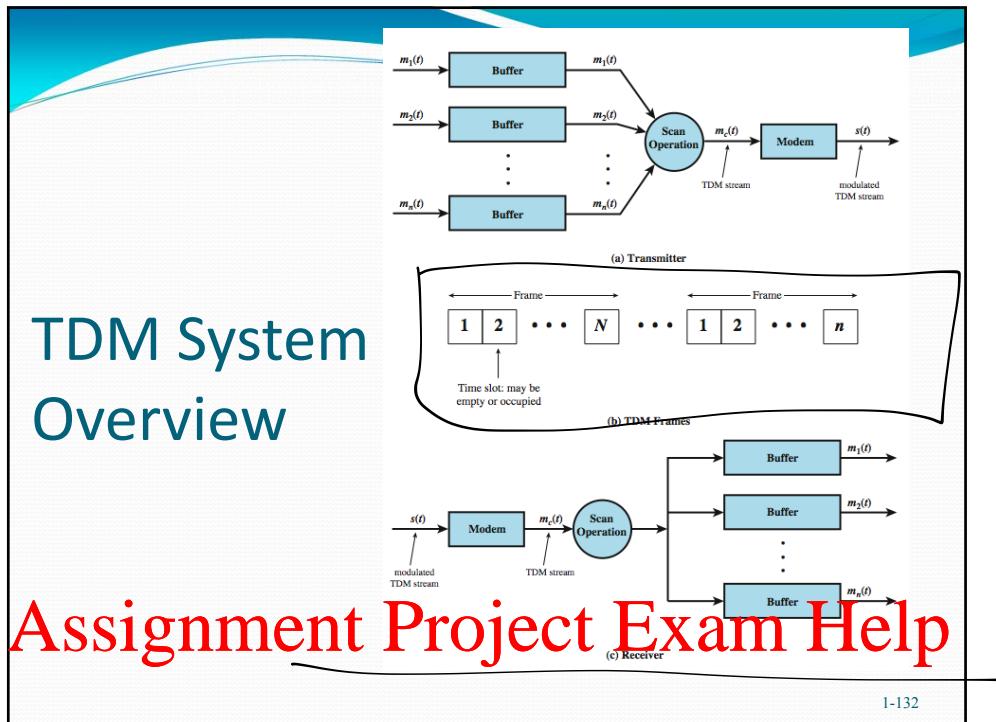


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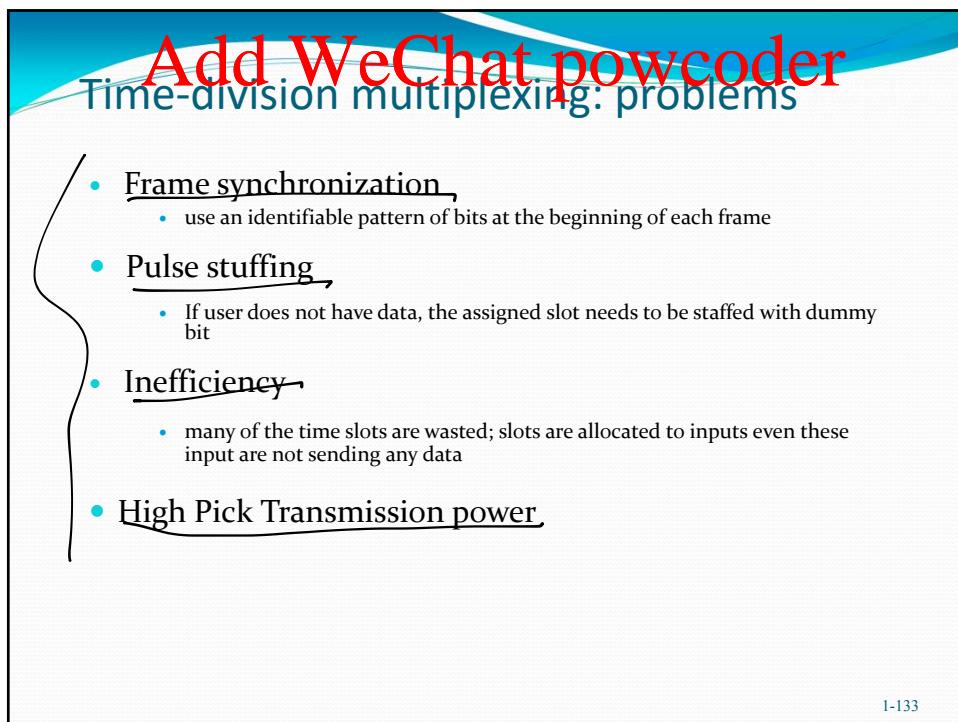


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## Statistical TDM

- 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

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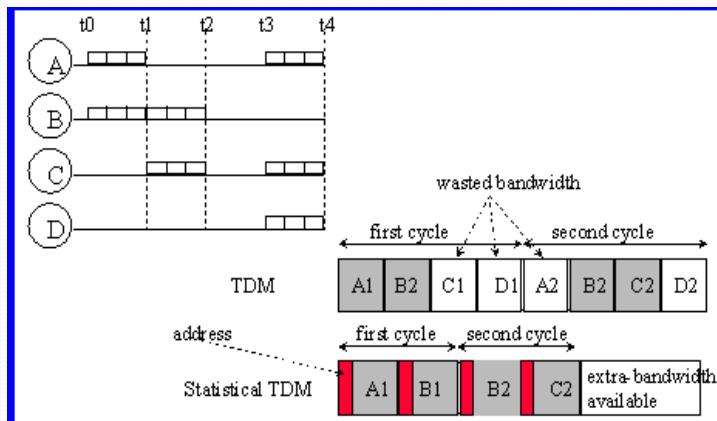
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Statistical time-division multiplexing



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## 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.

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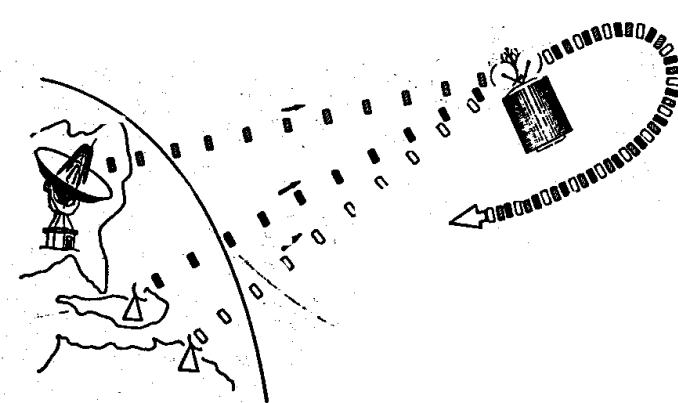
1-136

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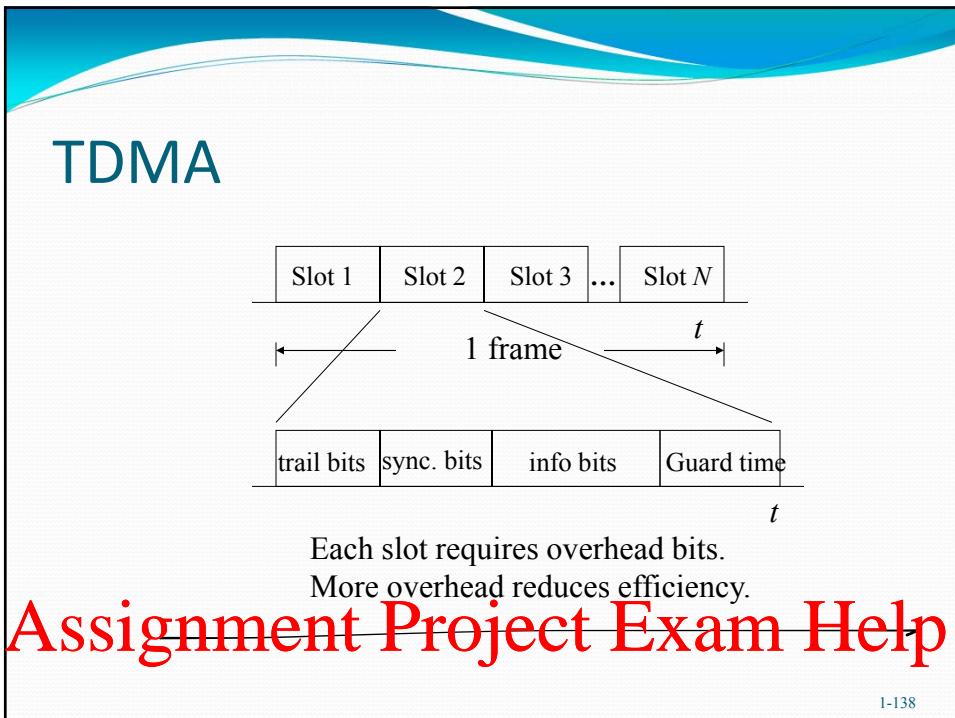
TDMA

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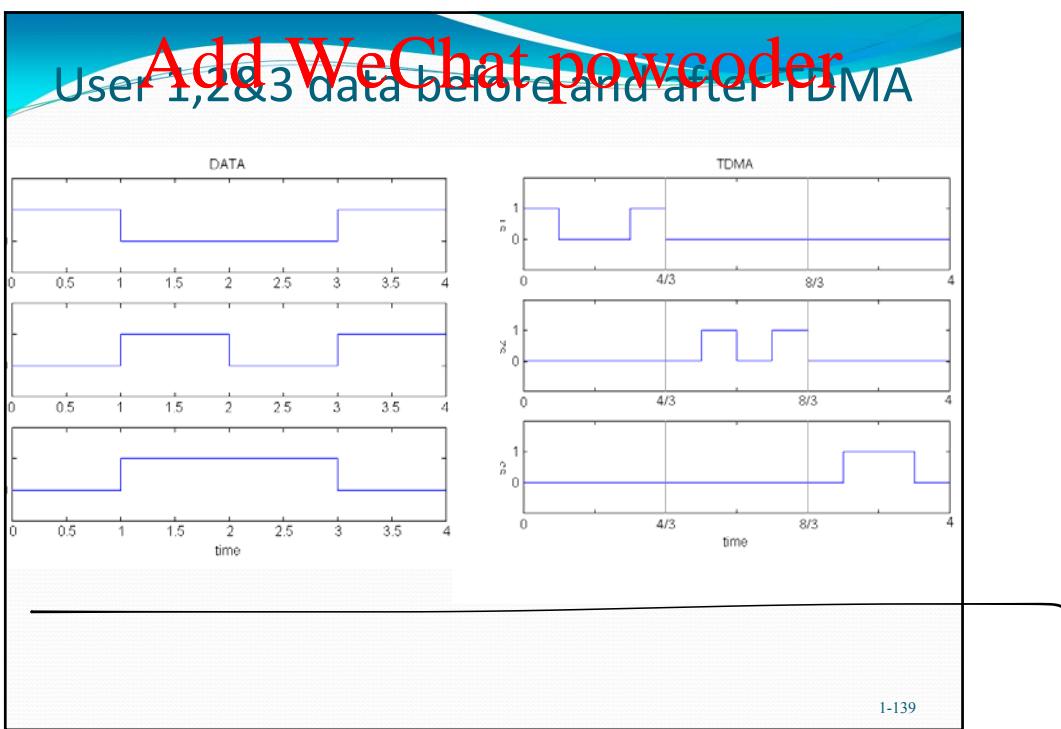
1-137

137



138

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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.

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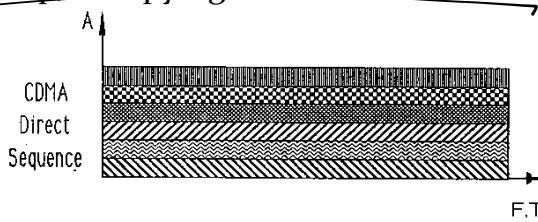
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## Spread Spectrum Add WeChat powcoder

- 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.

1-141

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)

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1-142

142

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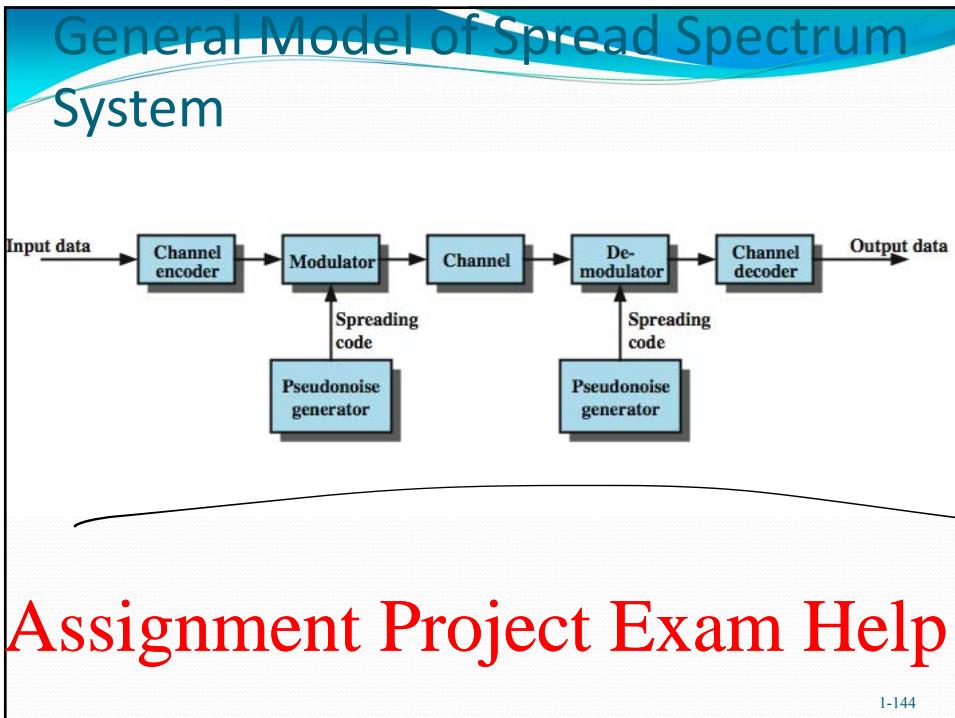
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### Spread Spectrum: Advantages/Disadvantages

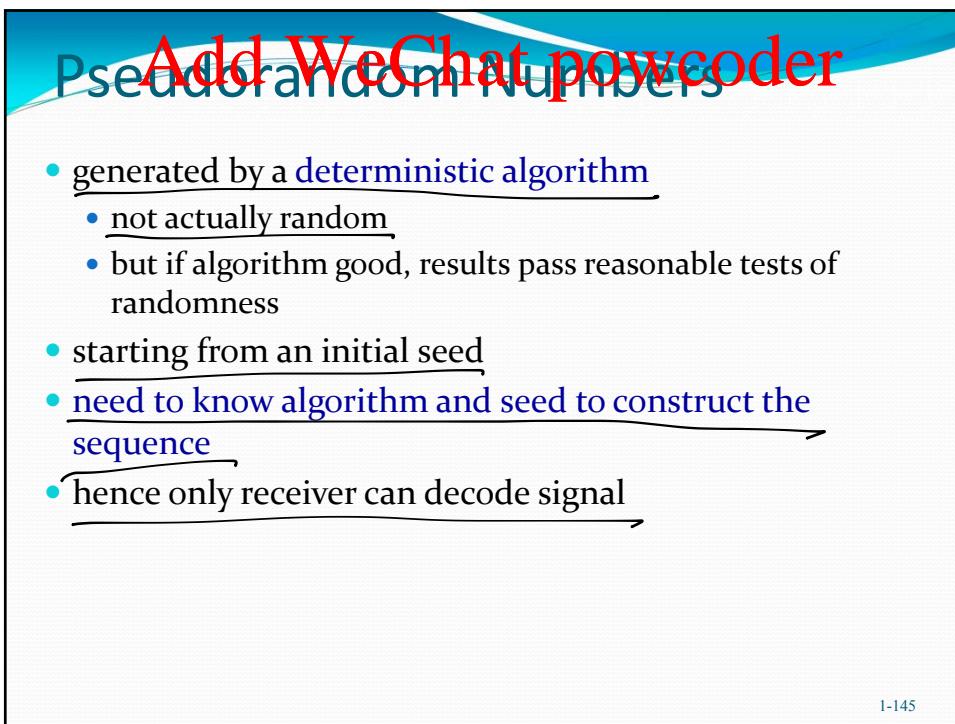
- Resistive to interference, multipath fading
- Easy Encryption
- Easy traffic multiplexing of discontinuous sources
- Allows “soft” hand-offs
- Synchronization imposes a challenge

1-143

143



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## 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

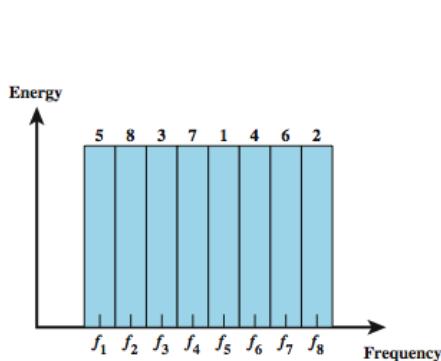
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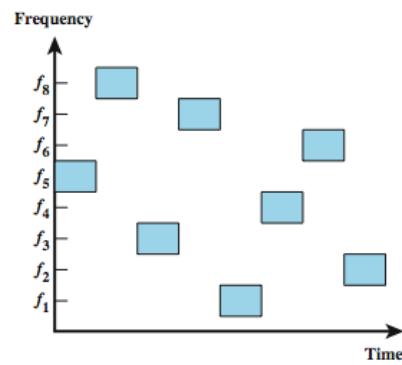
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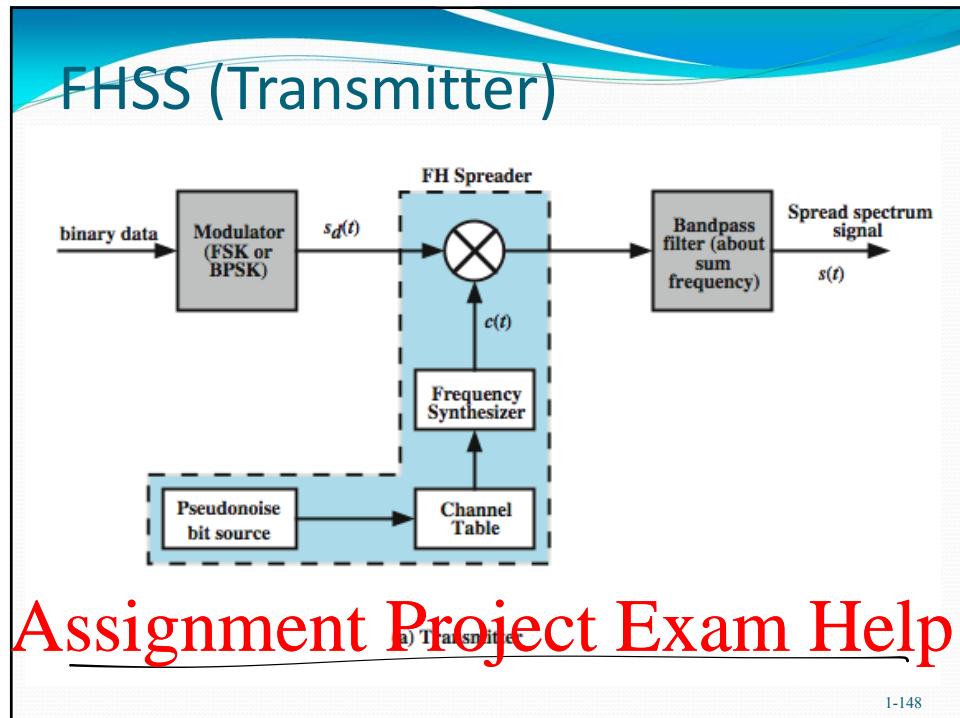
(a) Channel assignment



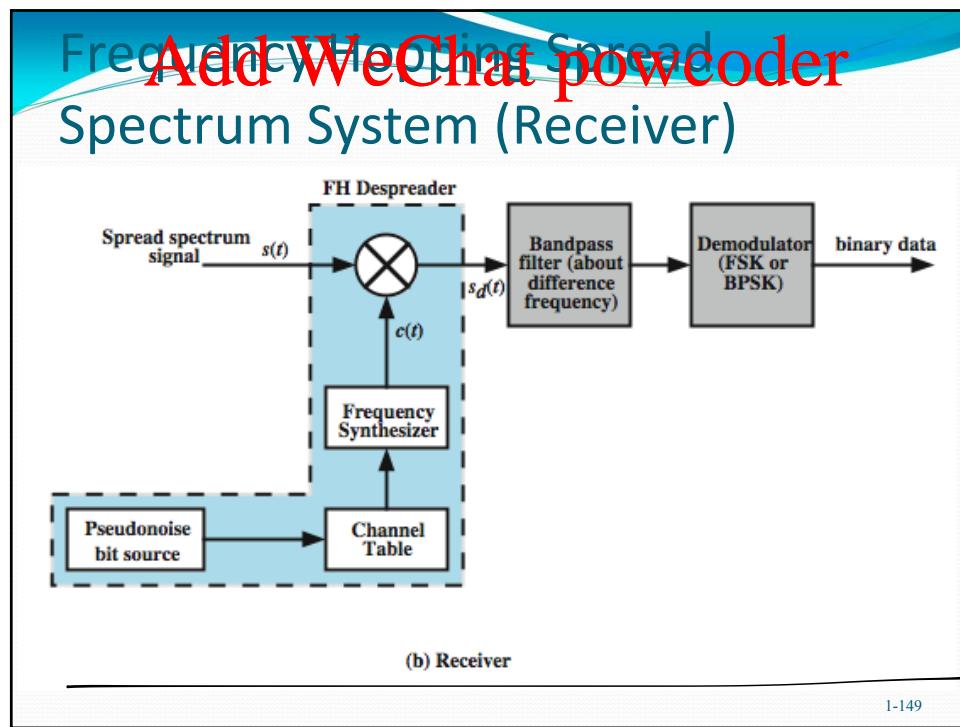
(b) Channel use

1-147

147



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## 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

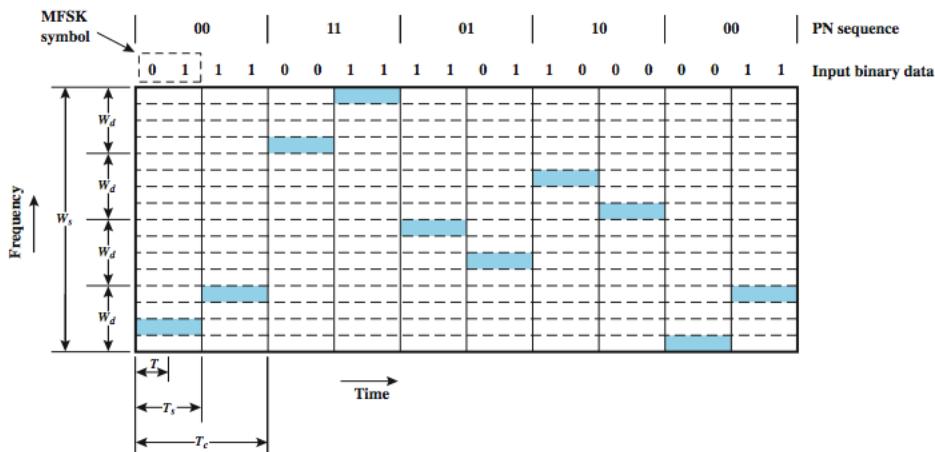
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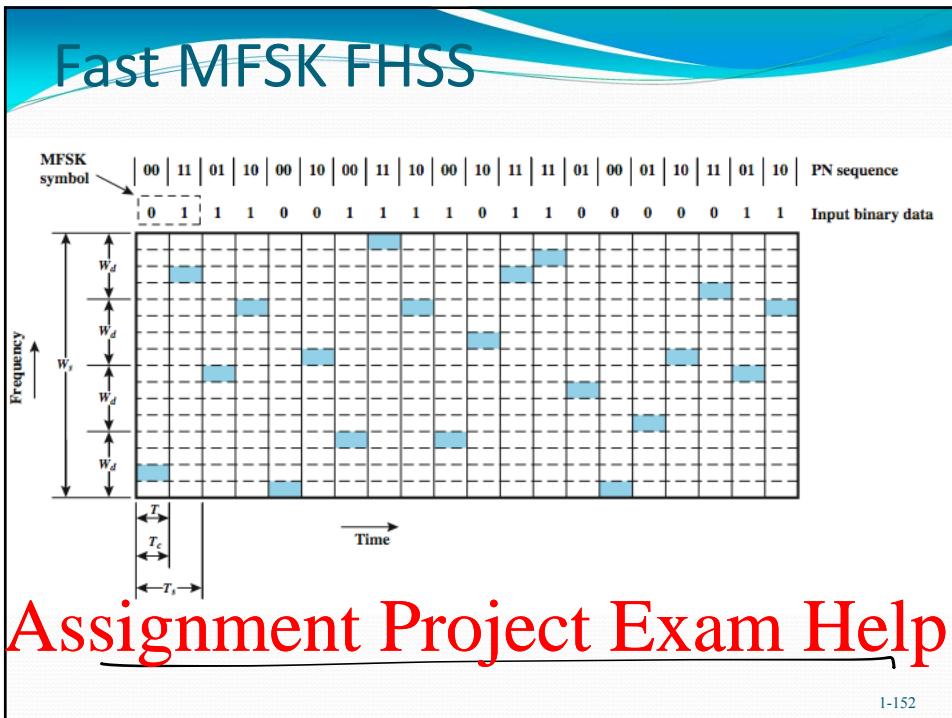
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Slow MFSK FHSS



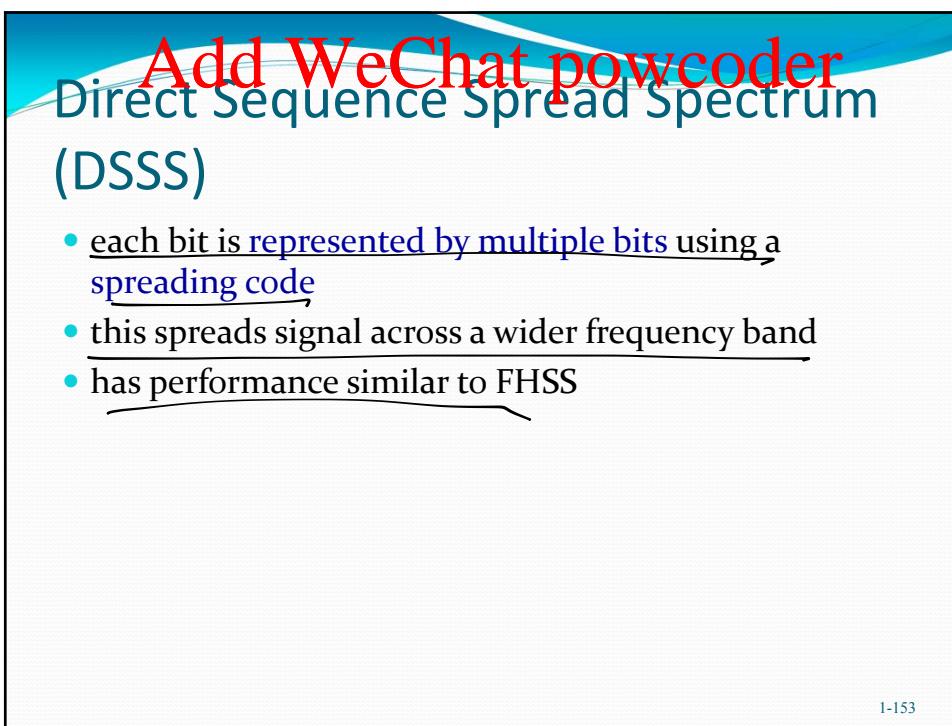
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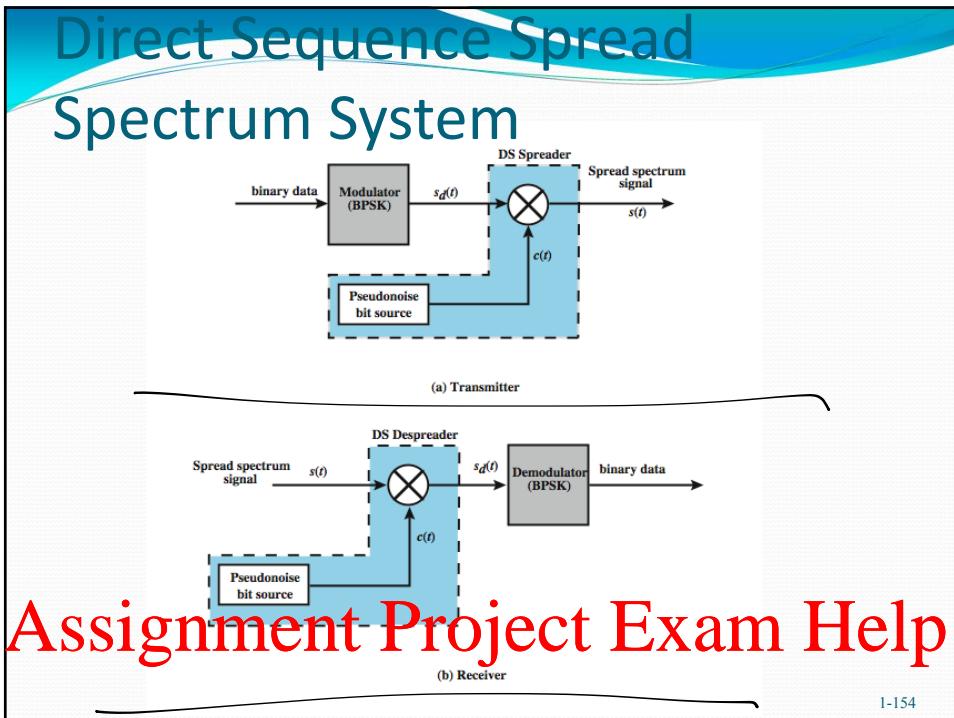


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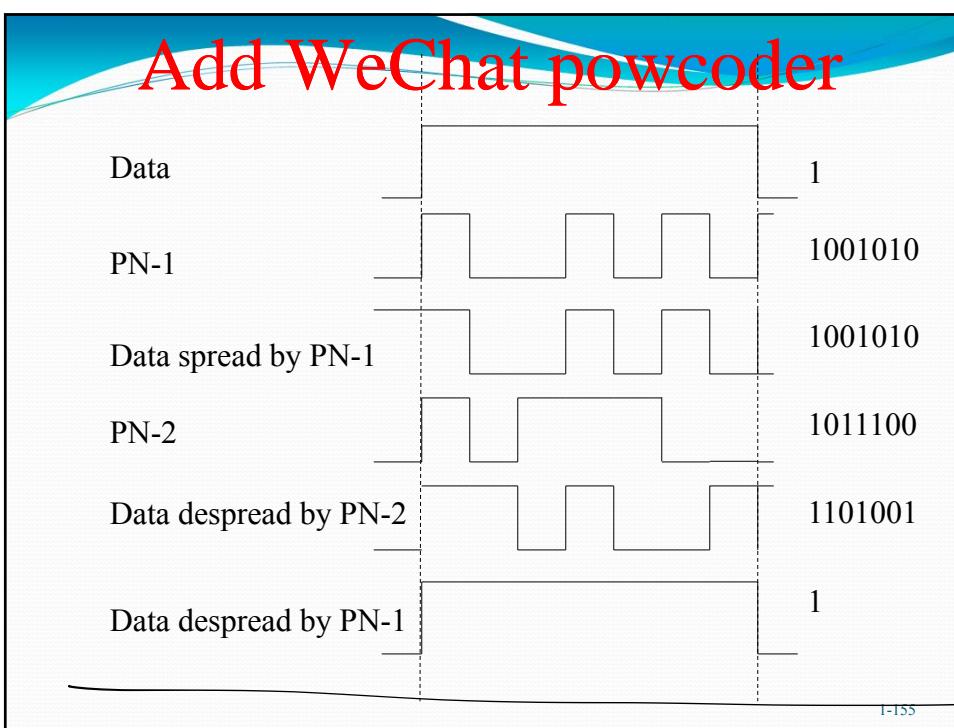


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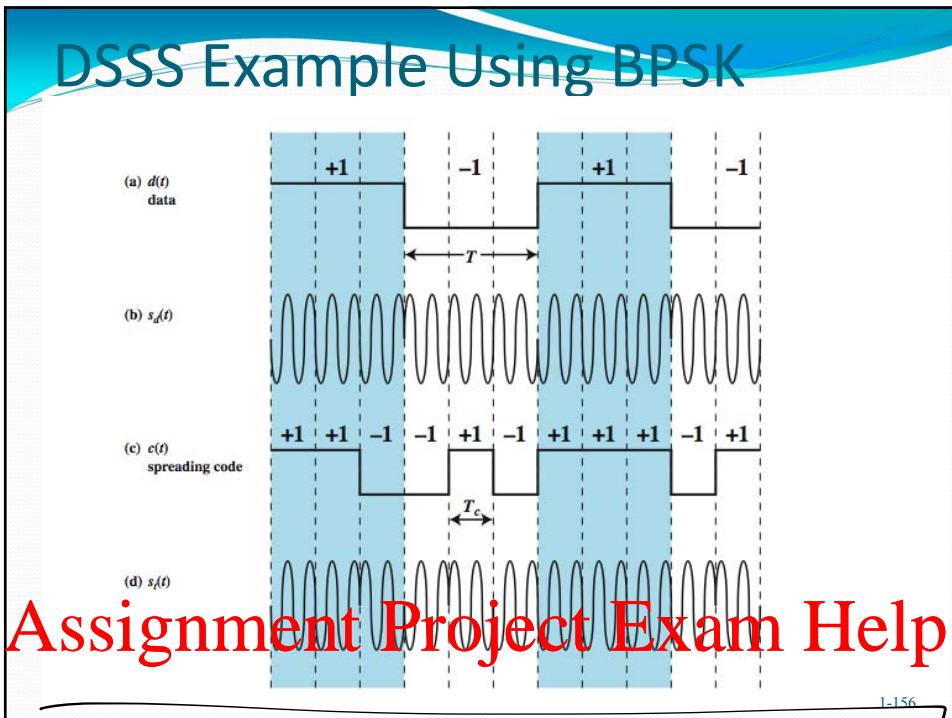


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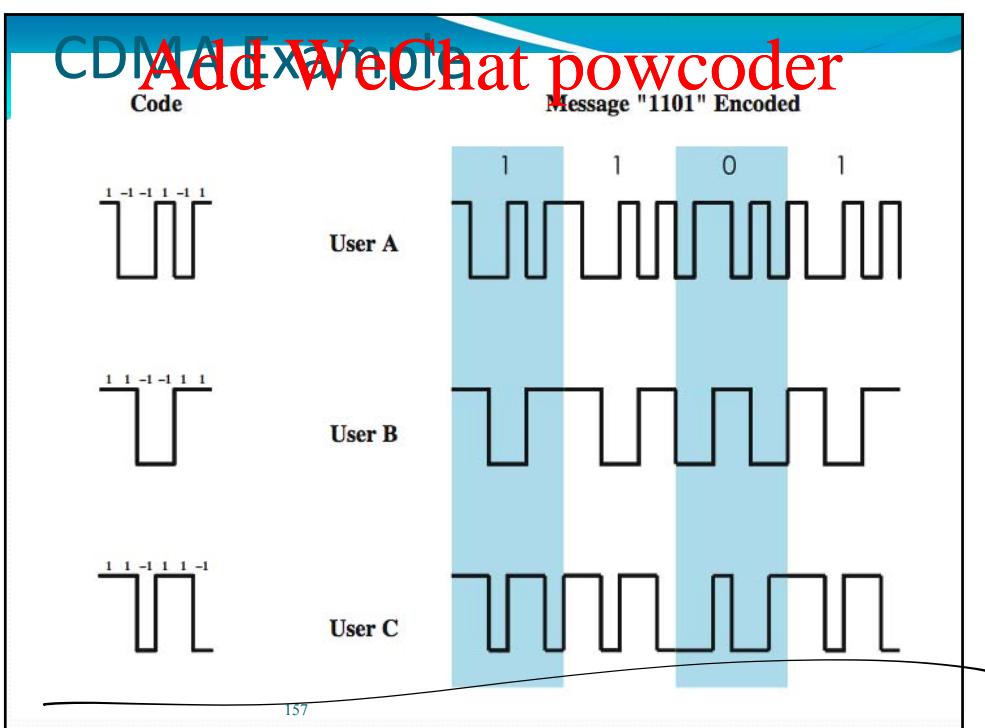


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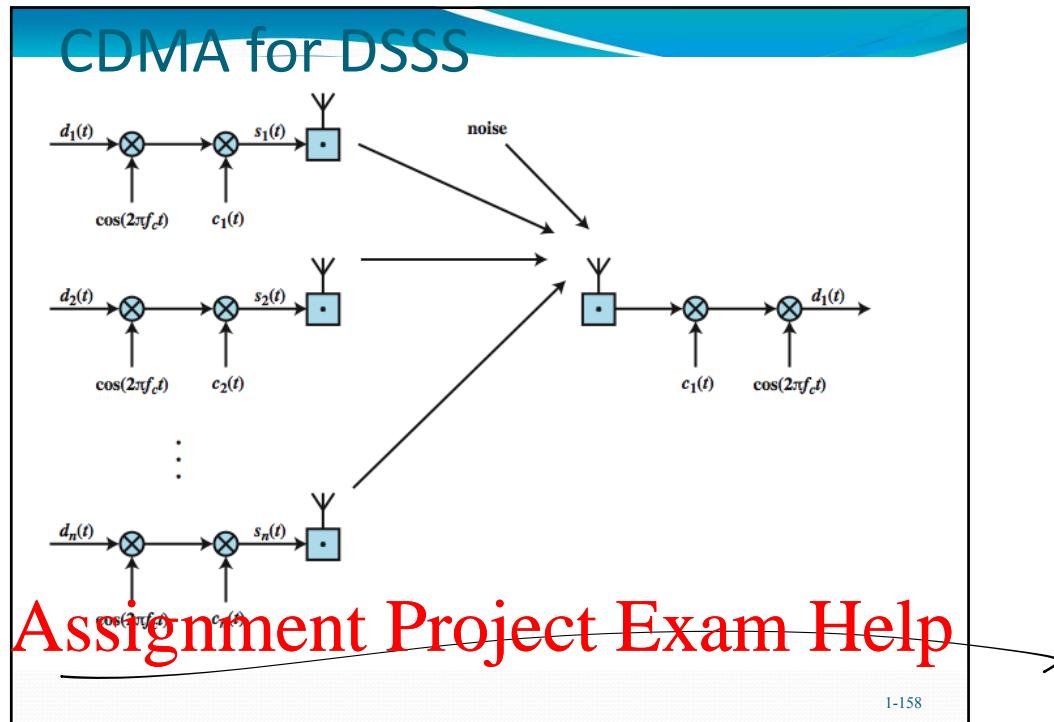


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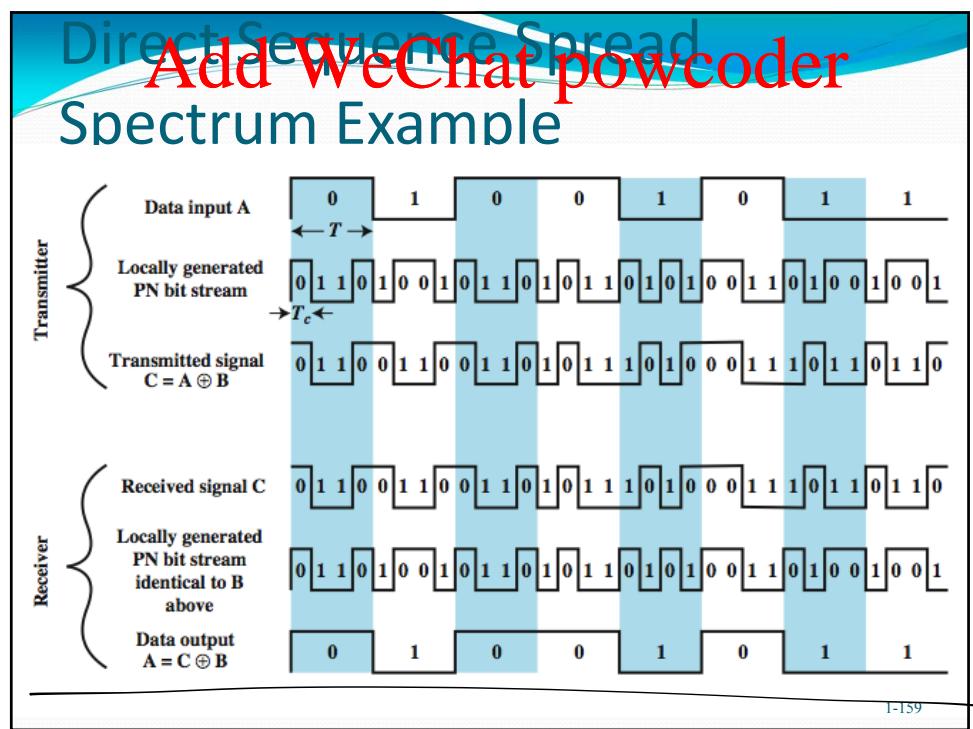


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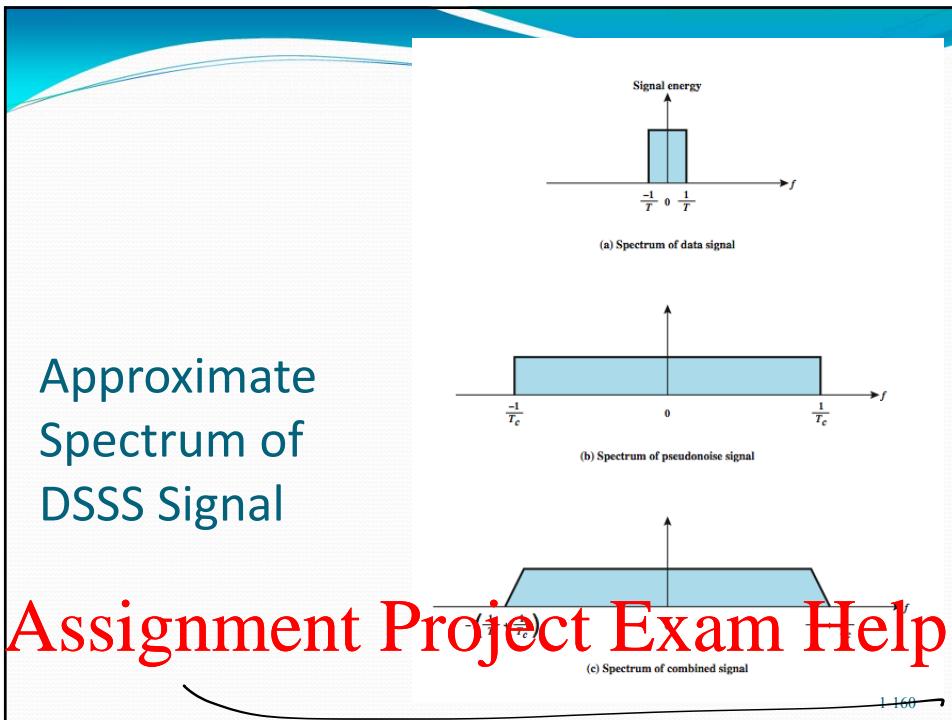


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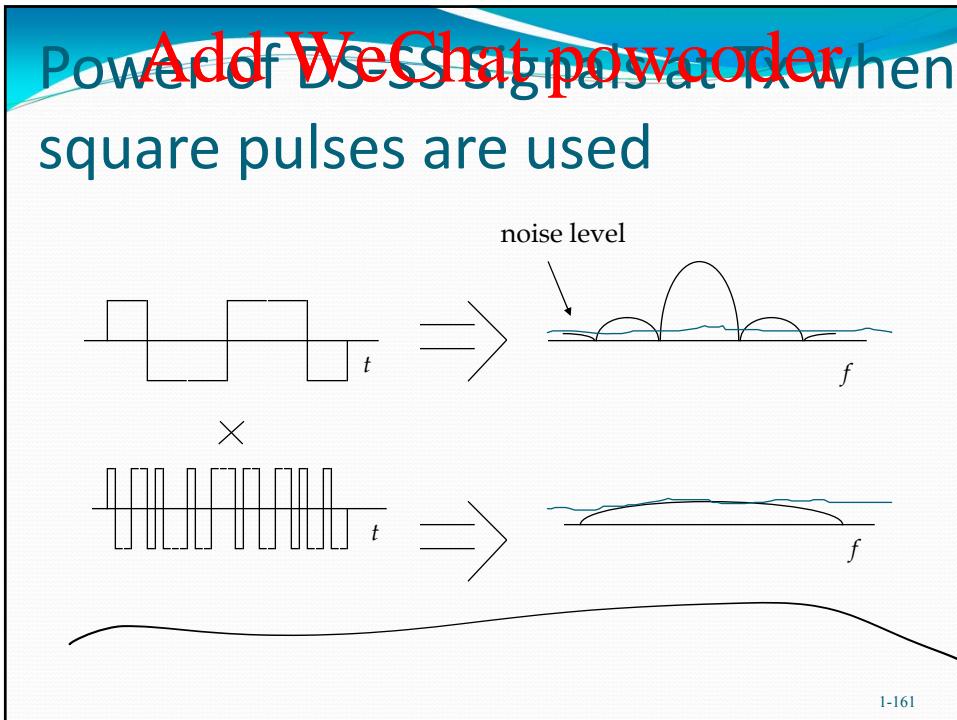
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161

Do all systems fall into only one of 3 categories?

Answer: In practice NO.

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Examples of their use in wireless mobile communications systems

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- FDM/FDMA
  - 1<sup>st</sup> generation: analog cellular, AMPS (each channel was occupying 60 KHz bandwidth)
  - 2<sup>nd</sup> generation North American digital cellular radio; IS-41
  - 2<sup>nd</sup> generation North American digital cellular radio (improved); IS-136.
    - Hybrid architecture. TDMA multiplexing 4 users in each 60 KHz AMPS channel.
- TDM/TDMA
  - 2<sup>nd</sup> and 2.5 generation European cellular radio, GSM/GPRS/EDGE
- CDMA
  - 2<sup>nd</sup> generation: IS-95 based North American cellular radio (DS-SS).
  - 3<sup>rd</sup> 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

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EECS, University of Ottawa

**CEG3185 –Winter 2021**

**Introduction to Data Communication & Networking**

**Digital Data Communication Techniques**

**Assignment Project Exam Help**

**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 been given written permission by the instructor. Use of the material by others is STRICTLY PROHIBITED.

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

1

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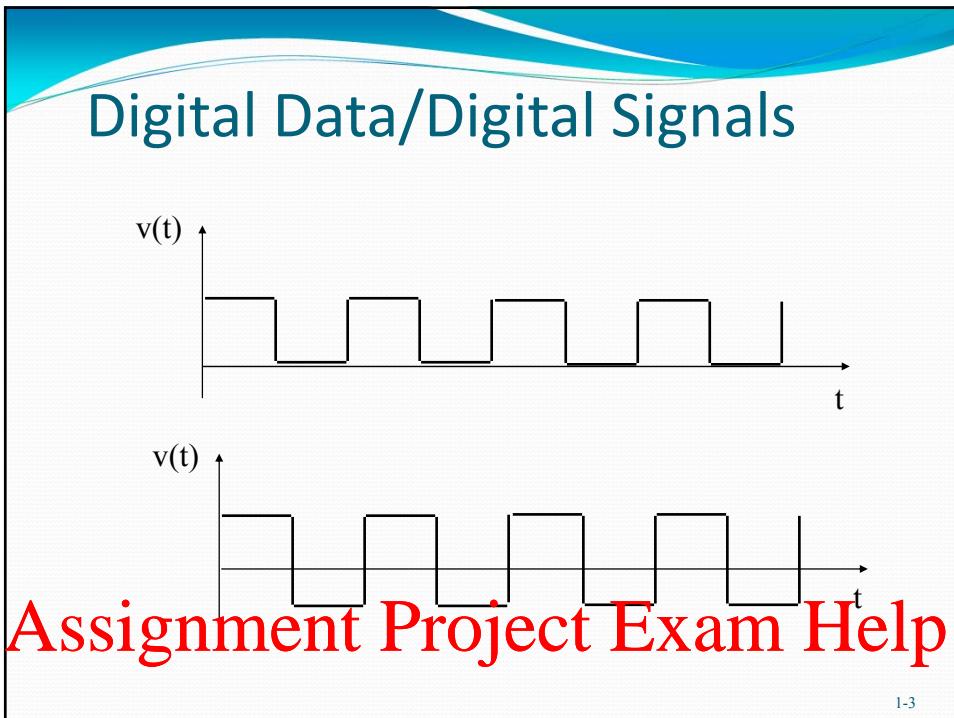
**Outline**

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

1-2

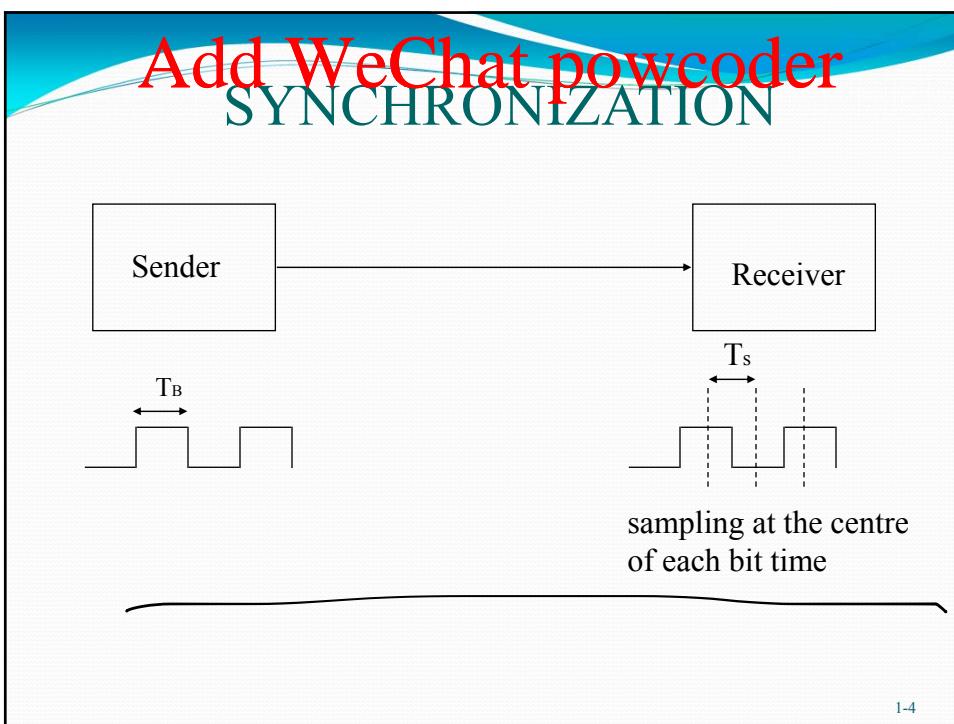
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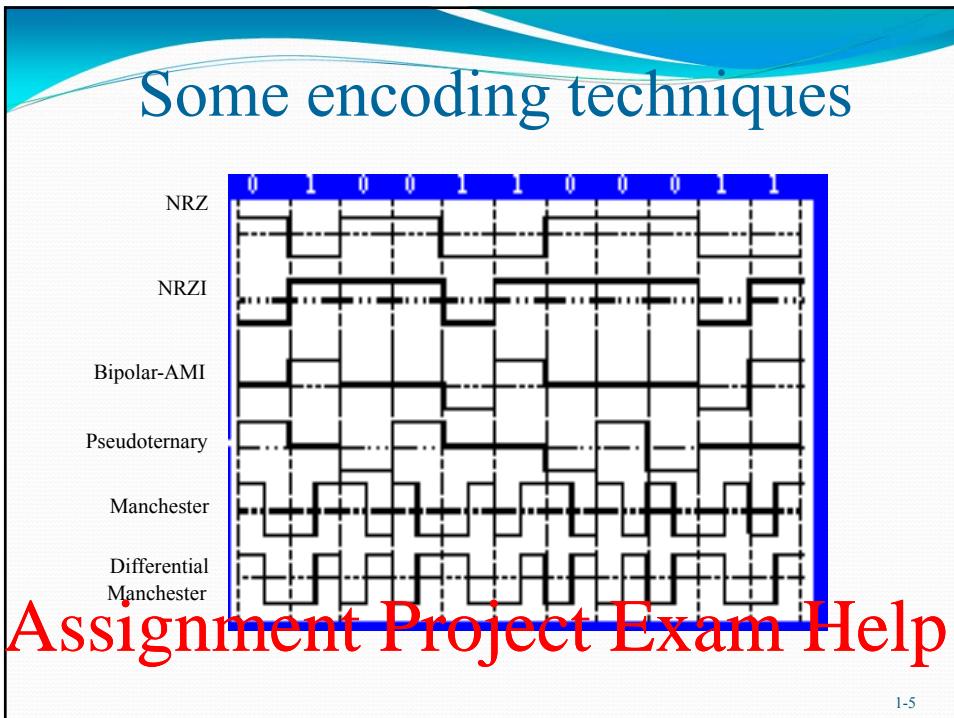


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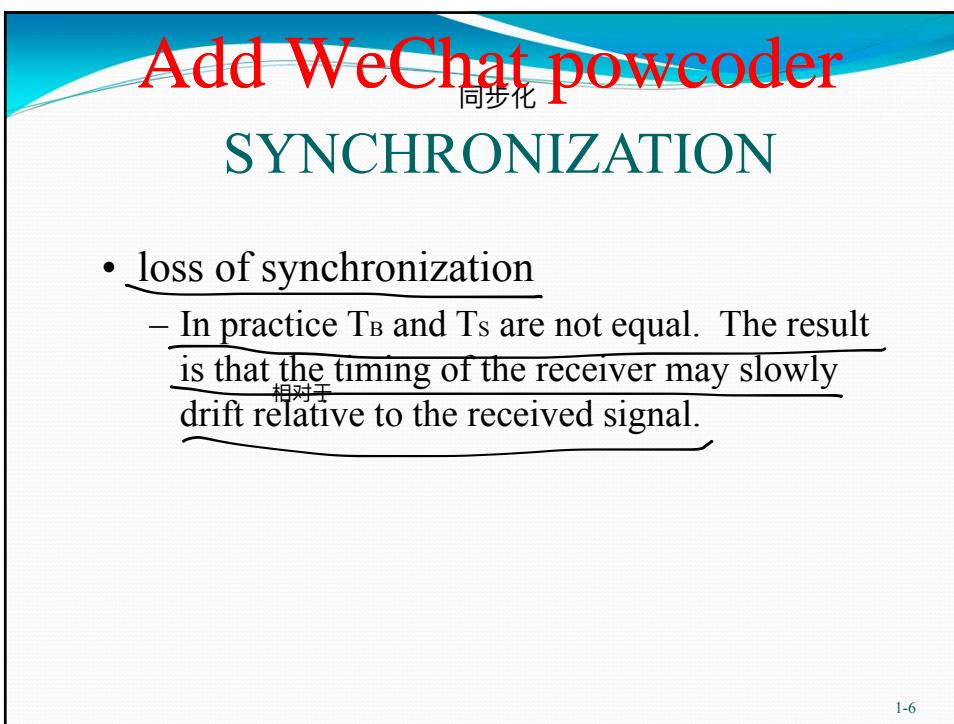


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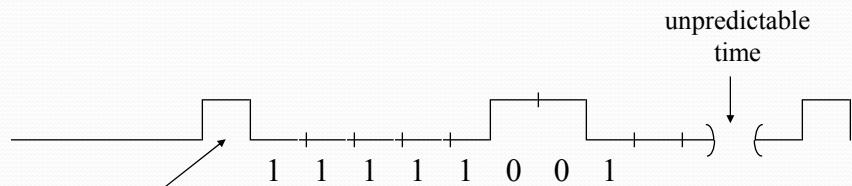
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6

## SYNCHRONIZATION



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1-7

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### SYNCHRONIZATION

- 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

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### SYNCHRONIZATION

- 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

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

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1-11

11 <https://powcoder.com>

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## SYNCHRONOUS TRANSMISSION

- In this mode, blocks of characters or bits are transmitted. Each block begins with a preamble <sup>前言</sup> and ends with a postamble <sup>后同步码</sup>

- 2 types:
  - character-oriented
  - bit-oriented

1-12

12

## SYNCHRONOUS TRANSMISSION

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

The diagram shows a horizontal sequence of rectangular boxes representing a frame. On the left, two boxes are labeled 'SYN'. To their right is a box containing three small vertical lines. Following this is a box with three dots ('...'), which is followed by a sequence of five empty boxes. Below the first two boxes is the text 'one or more SYN characters'. Below the third box is the text 'control characters'. Below the fourth box is the text 'data characters'. Below the fifth box is the text 'control characters'. Arrows point from each of these descriptive labels to its corresponding box in the sequence.

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

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1-13

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### SYNCHRONOUS TRANSMISSION

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

The diagram shows a horizontal sequence of rectangular boxes representing a frame. On the left, two boxes are labeled 'SYN'. To their right is a box containing three small vertical lines. Following this is a box with three dots ('...'), which is followed by a sequence of five empty boxes. Below the first two boxes is the text 'PREAMBLE'. Below the last five boxes is the text 'POSTAMBLE'.

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

The diagram shows a horizontal sequence of rectangular boxes representing a frame. On the left, three boxes are labeled 'SYN', 'SYN', and 'LEN'. To their right is a box containing three small vertical lines. Following this is a box with three dots ('...'), which is followed by a sequence of five empty boxes. A bracket below the first three boxes covers them and extends to the right, ending under the 'LEN' box. An arrow points from the right end of this bracket to the right, with the text 'starts to look for next preamble' written below it.

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

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1-15

15

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### 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:  $\text{BER} = 10^{-6}$  and length of frame=[100obytes\*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 =  $8,000 * \text{receiving a frame correctly} = 10^{-6} * [1-10^{-6}]^{7,999} * {8,000} = 0.007873$   
Probability of having more than error  $= 1 - 0.992 = 0.007873 = 0.000127$

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1-17

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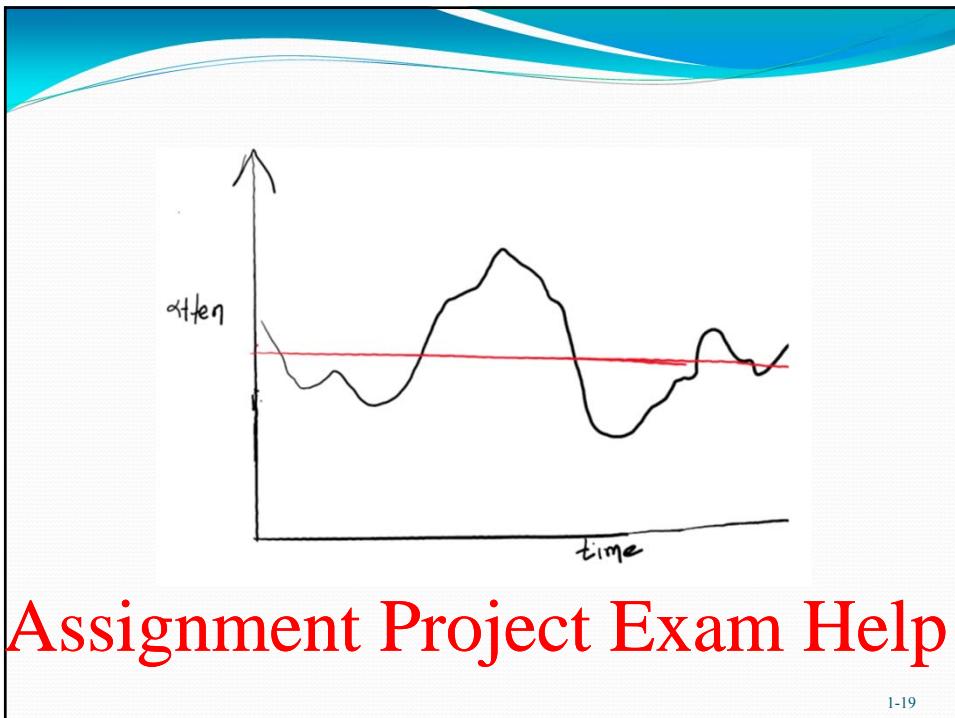
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### Burst Errors

- 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 of errored bits closely located in the sequence) form
- Some channel related impairments 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

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## 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

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1-20

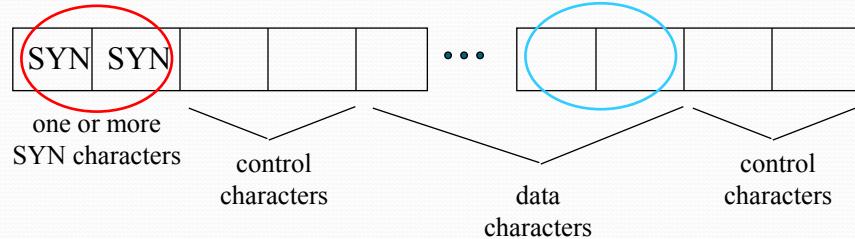
20

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### Impact of error location

The frame consists of a sequence of characters



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

1-21

21

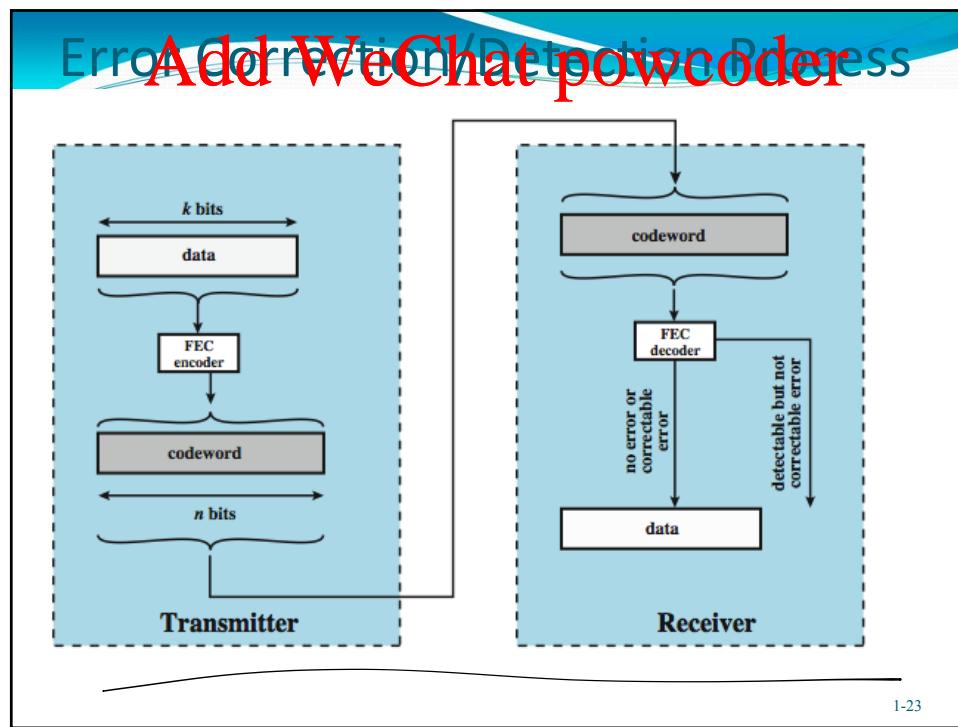
## Error Detection

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1-22

22

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23

## How Error Correction & Detection Works

- Adds redundancy to transmitted message 冗余
- Can deduce original despite some errors 尽管
- 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<sub>2</sub> arithmetic - is a case of it)

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1-24

24

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### Code rate & minimum distance

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  $\mu$  errors if  $d_{\min} \geq 2\mu + 1$

$\Rightarrow$  if  $d_{\min}=3$ , then  $\mu=1$ . 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  $\lambda$  errors in the  $n$ -bits codeword, the existence of errors is detected with certainty if  $\lambda < d_{\min}$ .

However, even when  $\lambda \geq d_{\min}$ , 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 combinations.

Above statement applies when no error correction is used.

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1-26

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## A simple block code (7,4) Hamming Code Add WeChat powcoder

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 Hamming 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 Hamming distance? **3**
- Error Correction capability? **1**
- Error detection w/o error correction? **3**
- Error detection with error correction? **0**

1-28

28

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### Add WeChat powcoder “Popular” Error Detection Techniques

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

1-29

29

## Simple Error Detection Scheme

- 奇偶性 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

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1-30

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## Parity Checks Add WeChat powcoder

1	0	1	1	1	0	1	0	←
1	2	3	4	5	6	7	8	9

Odd Parity

1	0	1	1	1	0	1	0	0	0	0	1	1	0	1	0	0
1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8

N

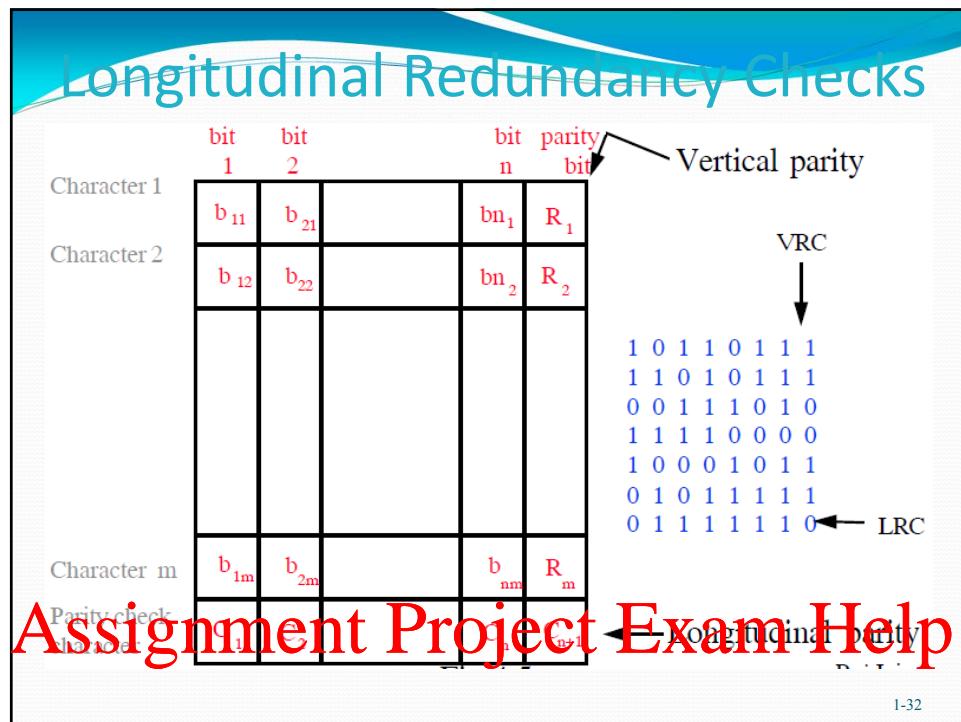
1-bit error

Even Parity

1	0	1	1	1	0	1	1	0
1	2	3	4	5	6	7	8	9

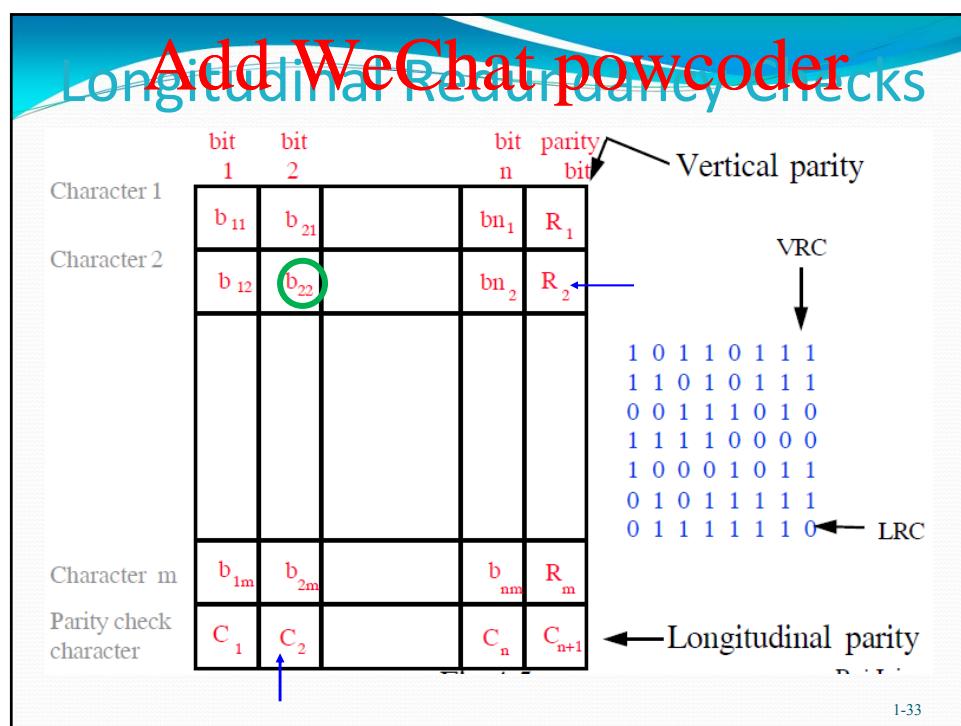
1-31

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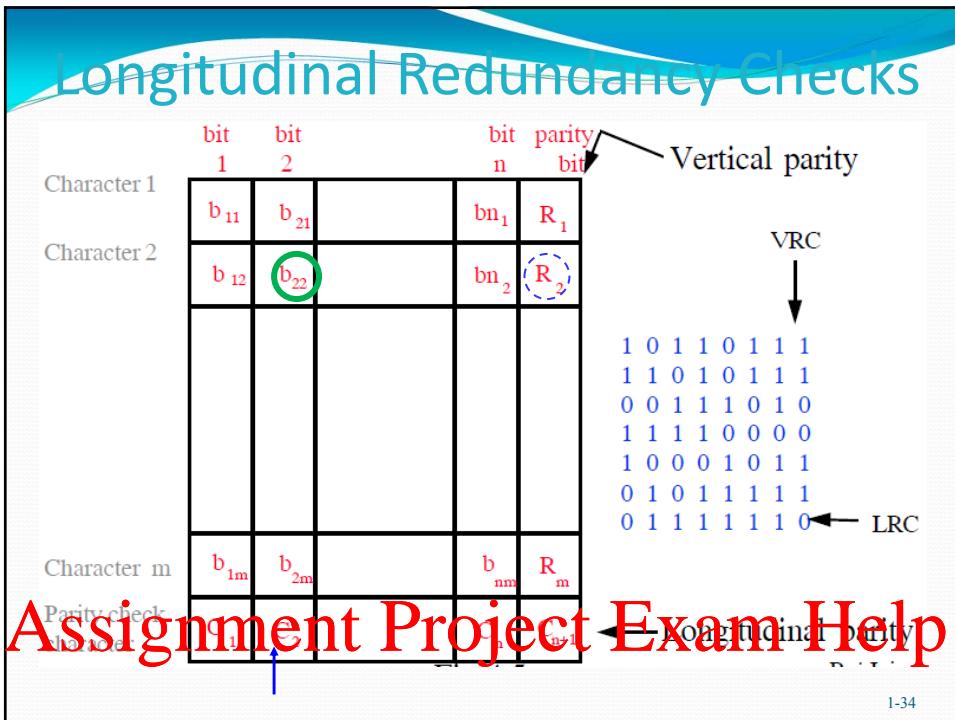


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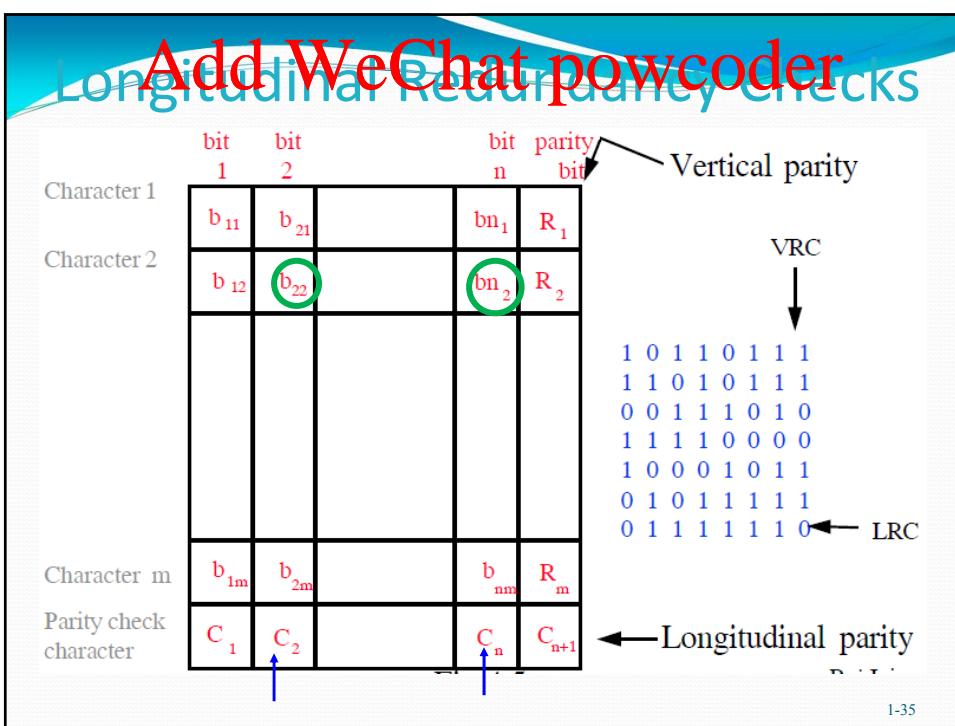


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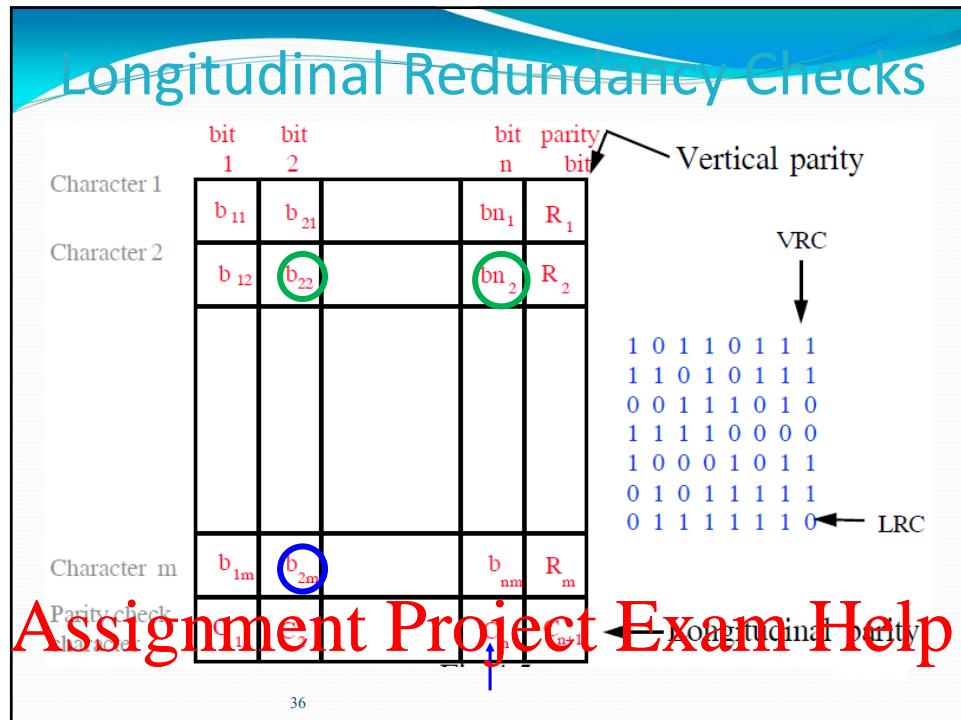


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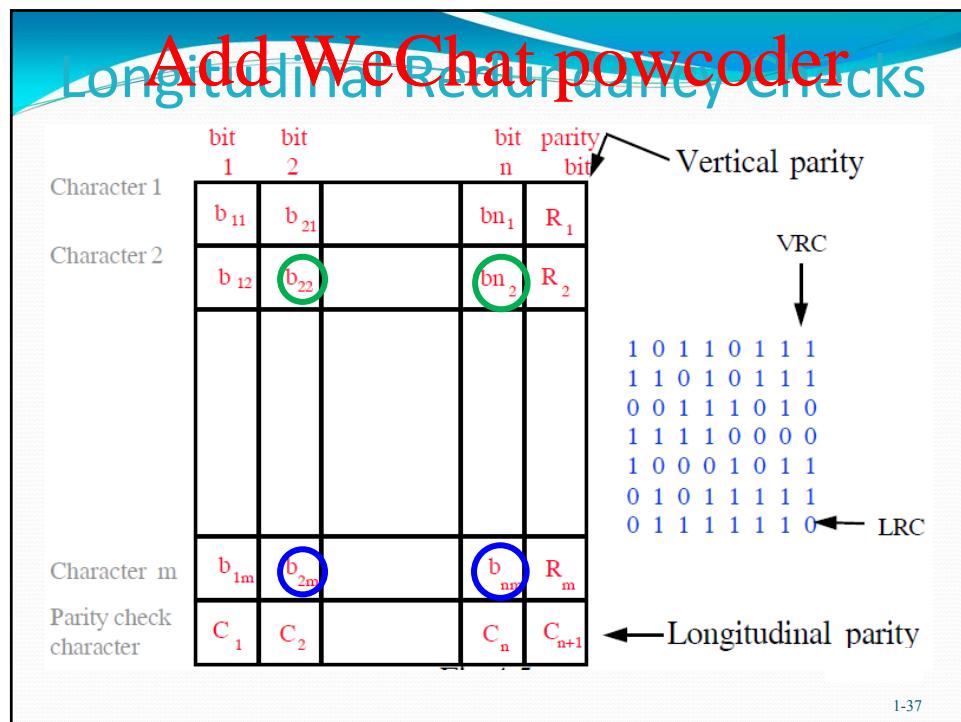
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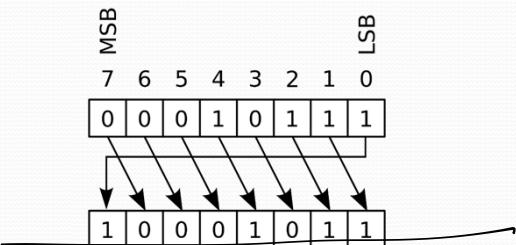
36 <https://powcoder.com>



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## 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

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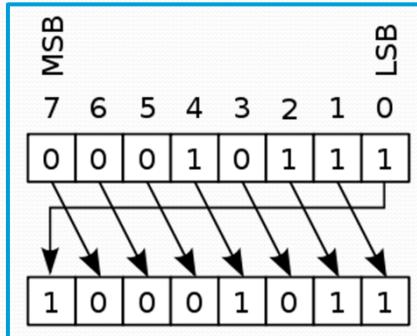
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## Cyclic Codes

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- “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”.



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## Fundamentals of CRC coding

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

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

- ♦ 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

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### Addition/Subtraction

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

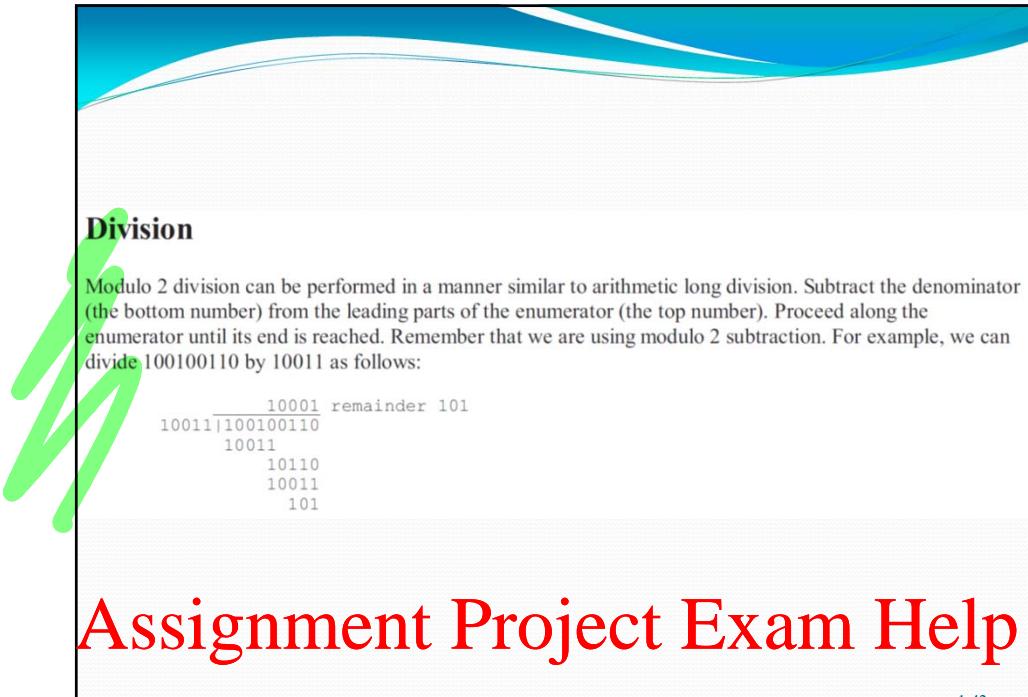
$$\underline{0 \pm 0 = 0; \quad 0 \pm 1 = 1; \quad 1 \pm 0 = 1; \quad 1 \pm 1 = 0}$$

### Multiplication

$$\begin{array}{r}
 1011 \\
 \times 0101 \\
 \hline
 1011 \\
 0000 \\
 1011 \\
 0000 \\
 \hline
 0100111
 \end{array}$$

1-41

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## 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 numerator (the top number). Proceed along the numerator until its end is reached. Remember that we are using modulo 2 subtraction. For example, we can divide 100100110 by 10011 as follows:

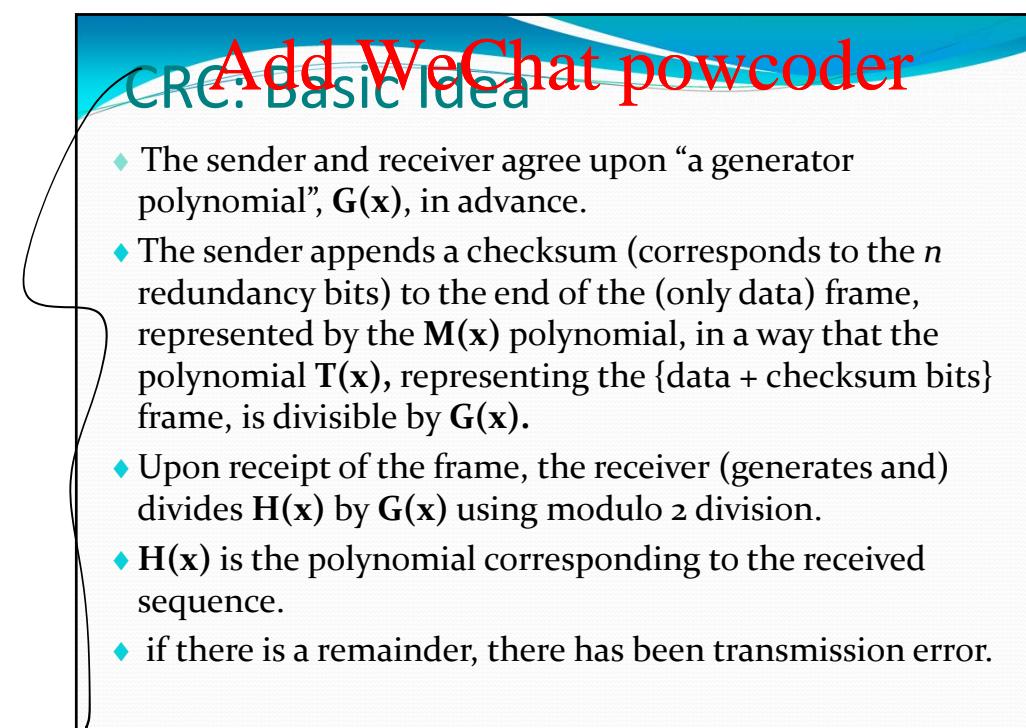
$$\begin{array}{r}
 & 10001 \text{ remainder } 101 \\
 10011 | & 100100110 \\
 & 10011 \\
 & \quad 10110 \\
 & \quad 10011 \\
 & \quad \quad 101
 \end{array}$$

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1-42

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## CRC: Basic Idea

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- ◆ 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.

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## 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  $X^n M(x)$ .

$11001\textcolor{red}{000} \xrightarrow{n=3} 1 * X^7 + 1 * X^6 + 0 * X^5 + 0 * X^4 + 1 * X^3 + 0 * X^2 + 0 * X^1 + 0 * X^0 = X^7 + X^6 + X^3 = X^3 * M(X)$

- 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

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

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## How to compute the checksum

### Add WeChat powcoder

- Subtract the remainder from  $X^n M(x)$  using modulo 2 subtraction/addition.
- The result is the checksummed frame's polynomial,  $T(x)$ .

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

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

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

$$\Leftrightarrow T(X) = D(X) \otimes G(X) \oplus \textcolor{red}{O} \Leftrightarrow \boxed{\frac{T(X)}{G(X)} = D(X) \text{ perfectly } T(X) \text{ (remainder } O\text{)}}$$

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## CRC: an Example

- Frame: 1101011011
- Generator: 10011

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## Add WeChat powcoder CRC Error Detection

- ◆ Let us assume that some transmission errors occur
- ◆ Instead of receiving  $T(x)$ , the receiver will receive  $H(x) = T(x) \oplus E(x)$
- ◆ If there are  $k$  “1” bits in  $E(x)$ , (it is most probable that)  $k$  bit errors have occurred
- ◆ the receiver computes  $(T(x) \oplus E(x))/G(x) = E(x)/G(x)$
- ◆ 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  $0 < m \leq n + k$

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## 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 ( $0 < m \leq n+k$ ; 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.

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## Add WeChat powcoder

### Shift register circuit

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

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组态

# Line Configuration

拓扑结构

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

```

graph TD
    LC[Line Configuration] --> P2P[Point-to-point]
    LC --> MP[Multipoint]
  
```

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## 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)

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## 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

The diagram illustrates a point-to-point topology. A central computer, labeled "Computer (primary)", is connected to four separate terminals, labeled "terminals (secondaries)". Each connection is represented by a red line originating from the computer and ending at a terminal. A bracket on the right side groups the four terminals together.

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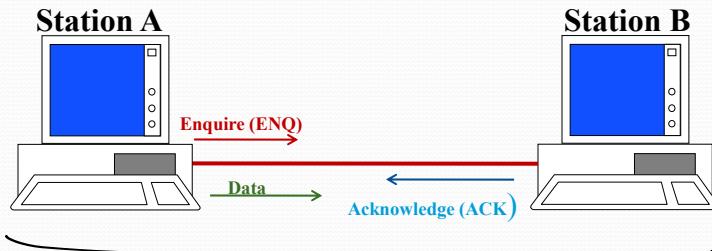
### Examples of Point-to-point topology

The diagram shows three examples of point-to-point topology:

- Workstation - Workstation:** Two workstations are connected by a horizontal line labeled "Link". Above the line, a callout bubble says "Link". To the right, two options are shown: "Null modem" and "RS 232".
- Mainframe - Workstation:** A mainframe computer is connected to a workstation by a horizontal line labeled "Link". Above the line, a callout bubble says "Link".
- Workstation - Satellite - Workstation:** A workstation is connected to a satellite dish, which is then connected to another workstation. This represents a point-to-point link between the two workstations through a satellite medium.

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## Line Discipline: Point-to-Point

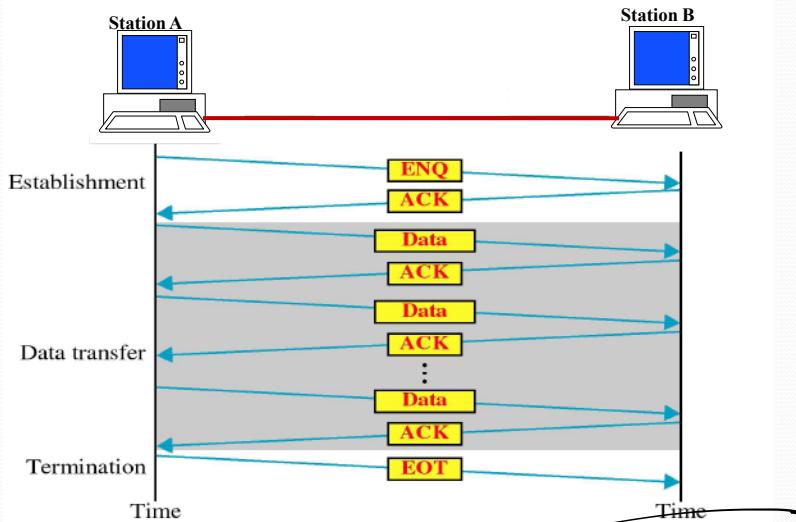


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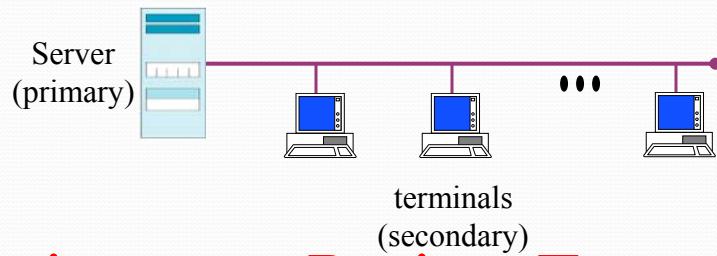
## Line Discipline: Point-to-Point



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

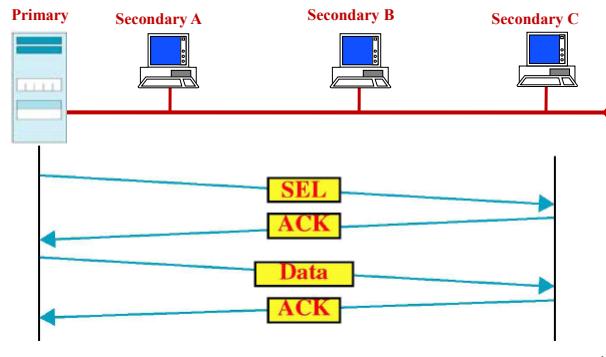


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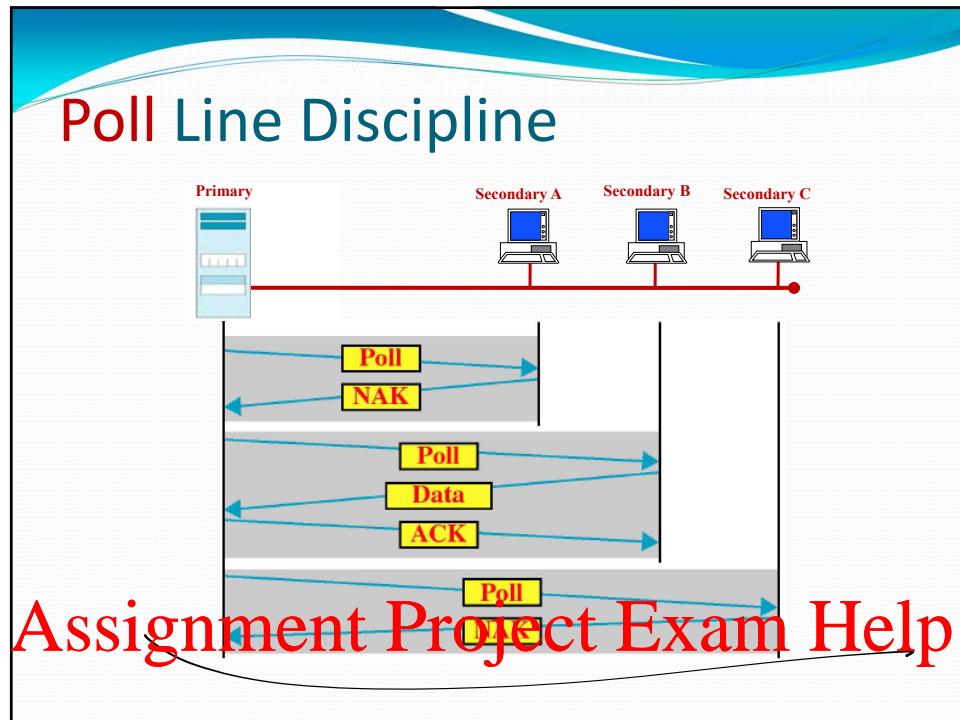
56

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Add WeChat powcoder  
Select Line Discipline

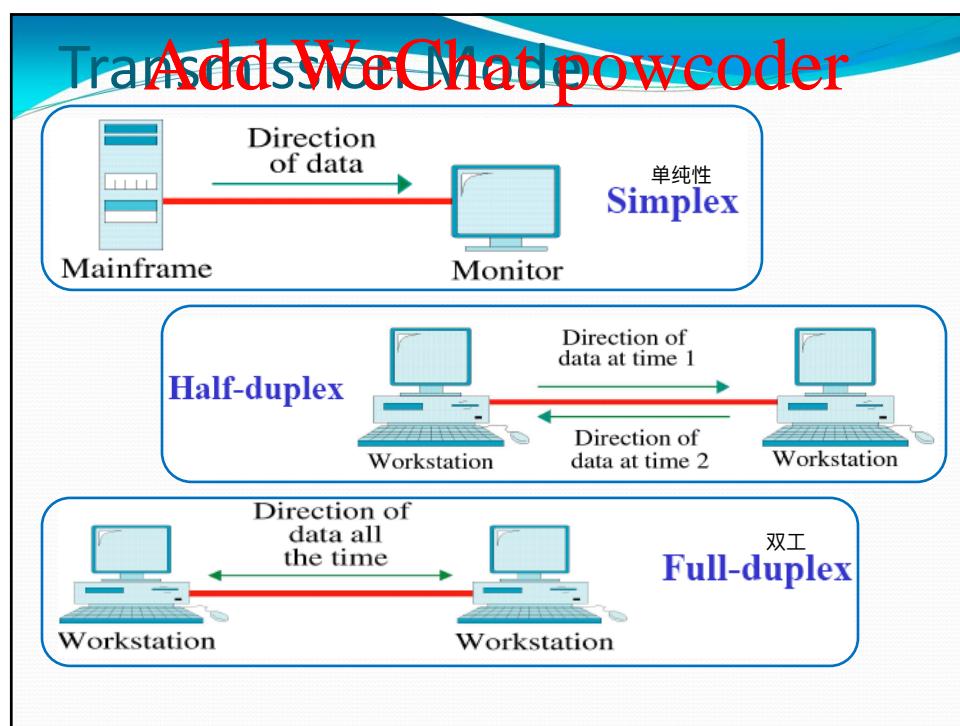


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## Line Configuration - Duplex

- 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

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**END**

1-61

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EECS, University of Ottawa

**CEG3185 –Winter 2021**

**Introduction to Data Communication & Networking**

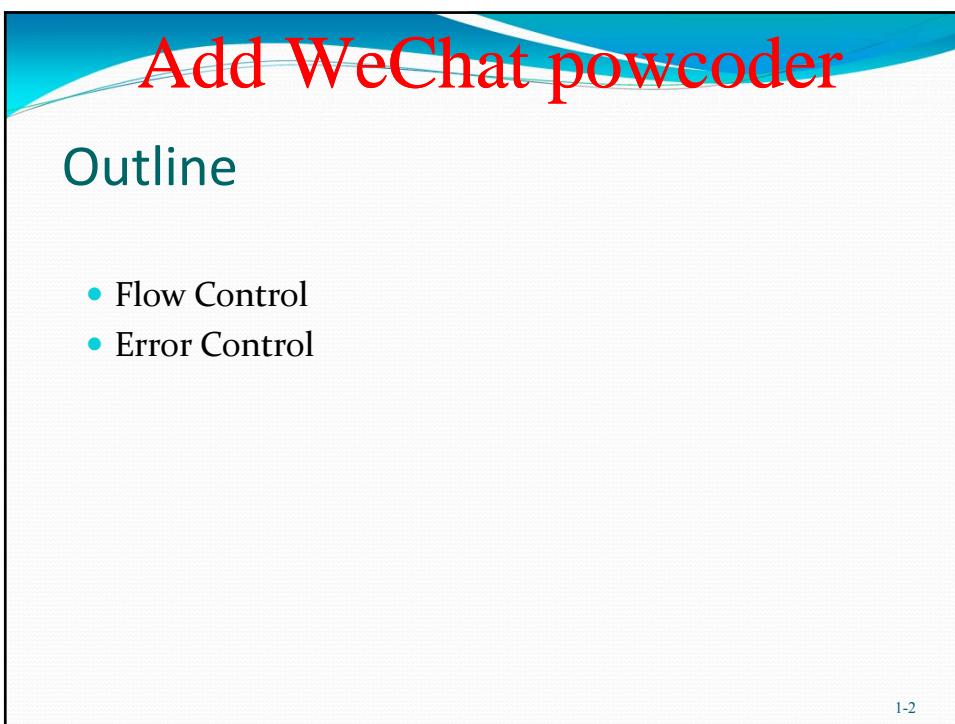
**Data Link Control**

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

1

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Outline

- Flow Control
- Error Control

1-2

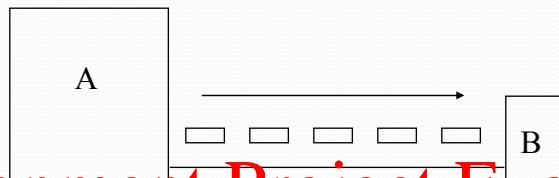
2

1

## Flow Control/1

- Definition:

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



3

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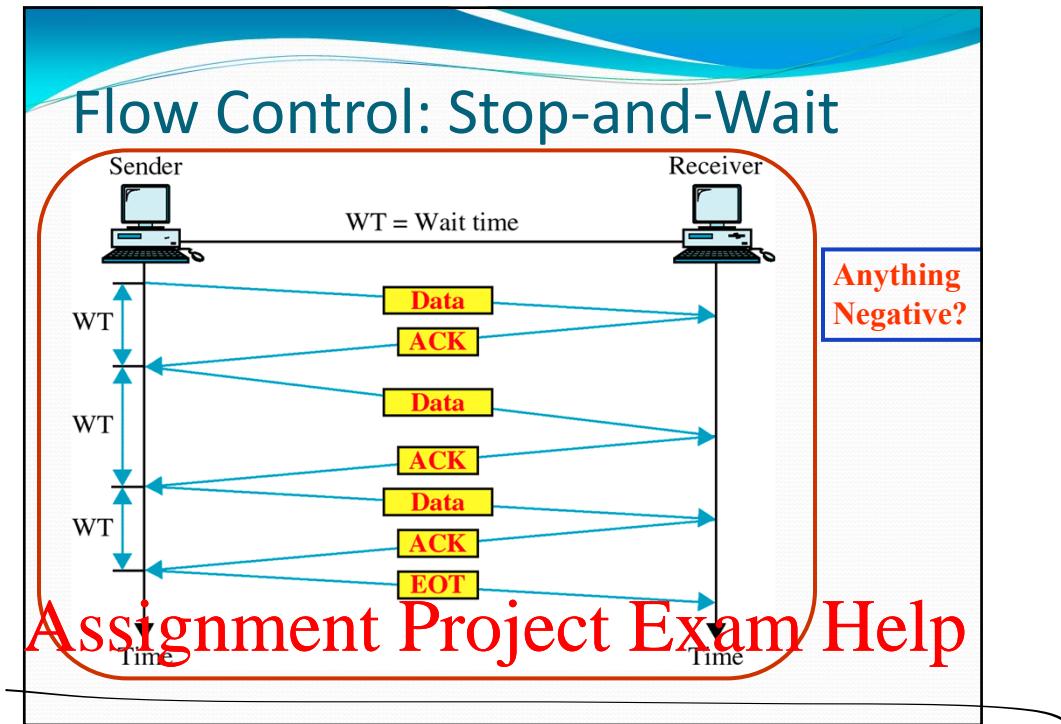
## Flow Control/2

- two flow control mechanisms

- stop-and-wait
    - also referred as “alternating bit” or “send and wait”
  - sliding window

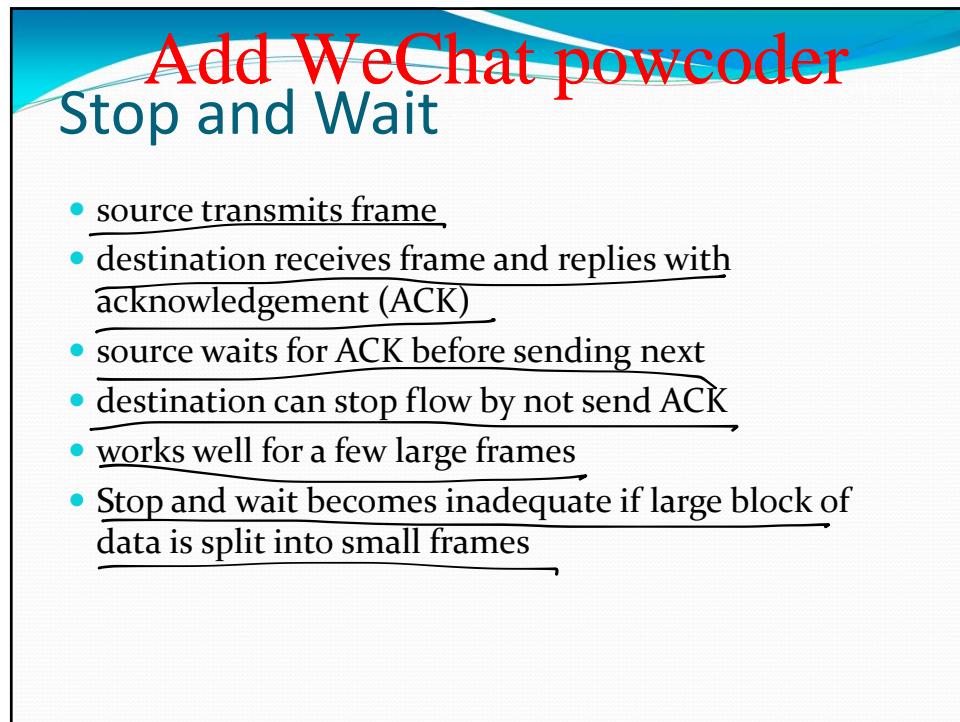
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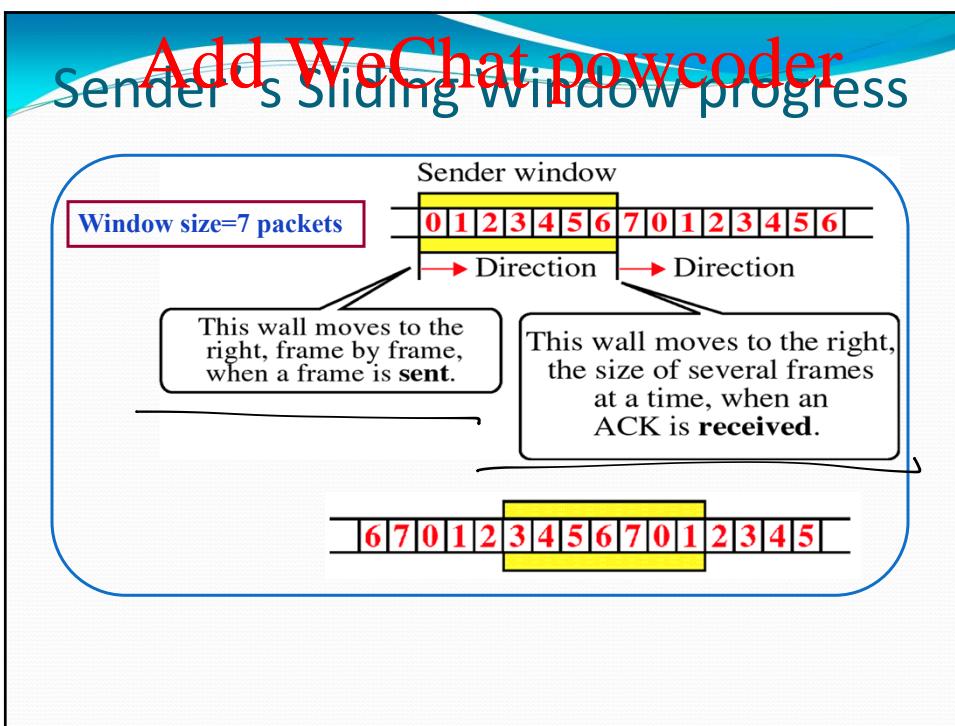
## Flow Control: Sliding Window

- 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

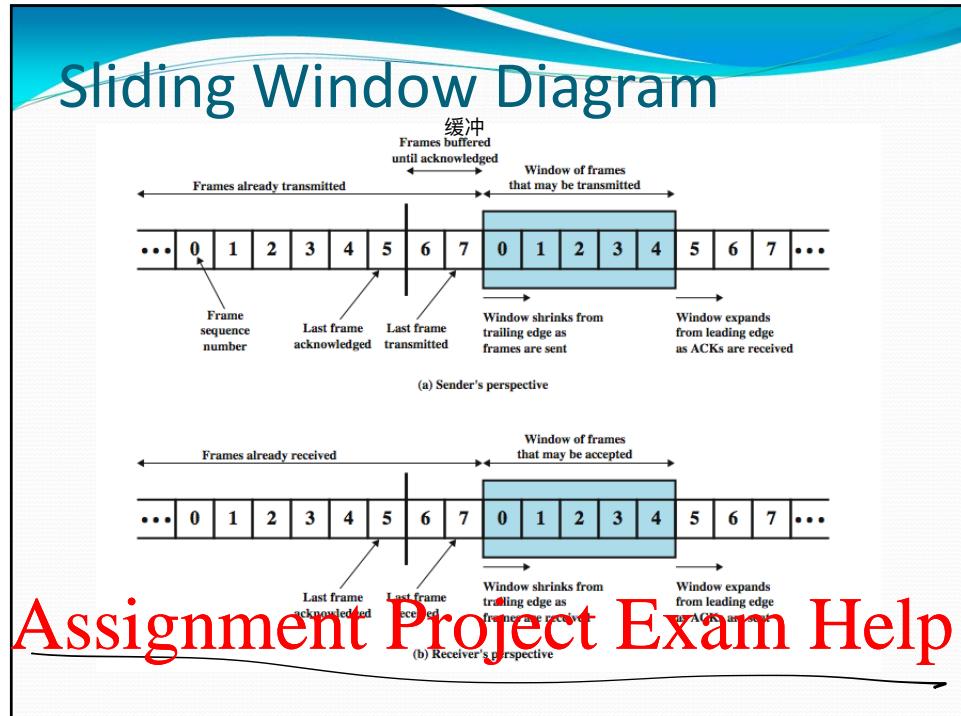
~~Assignment Project Exam Help~~  
~~I have full-duplex link (piggyback ACK)~~

7

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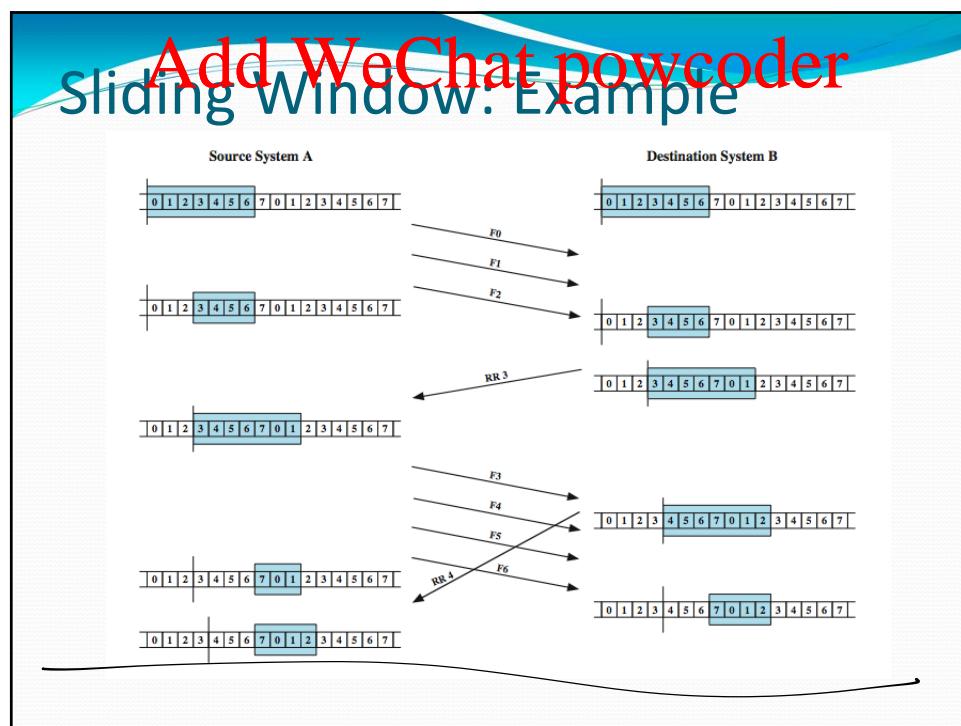


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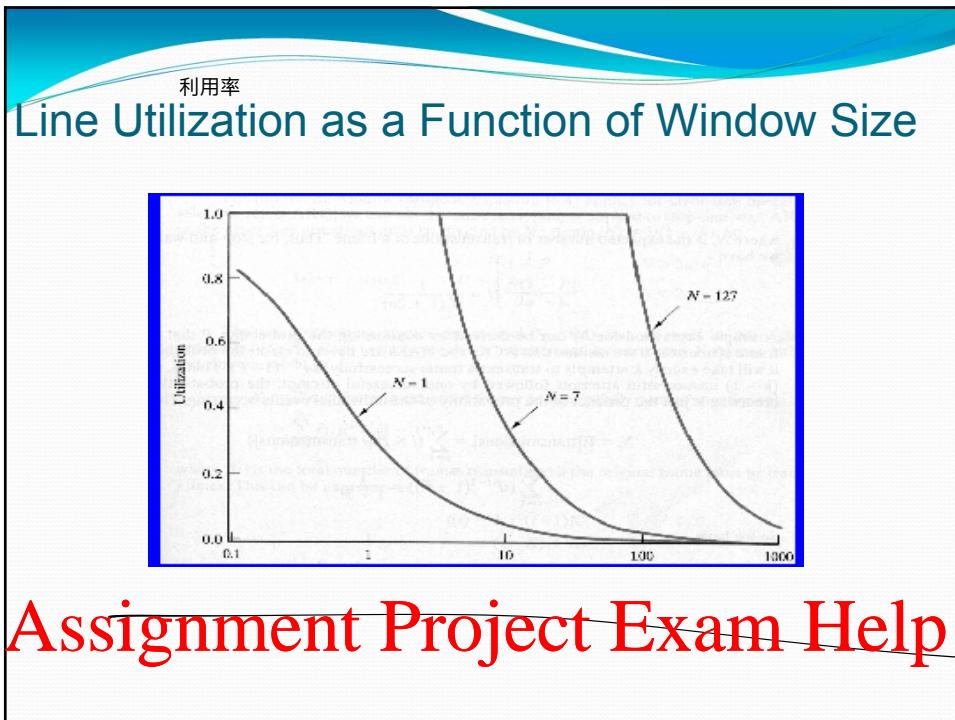


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10



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## Error Control

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### 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

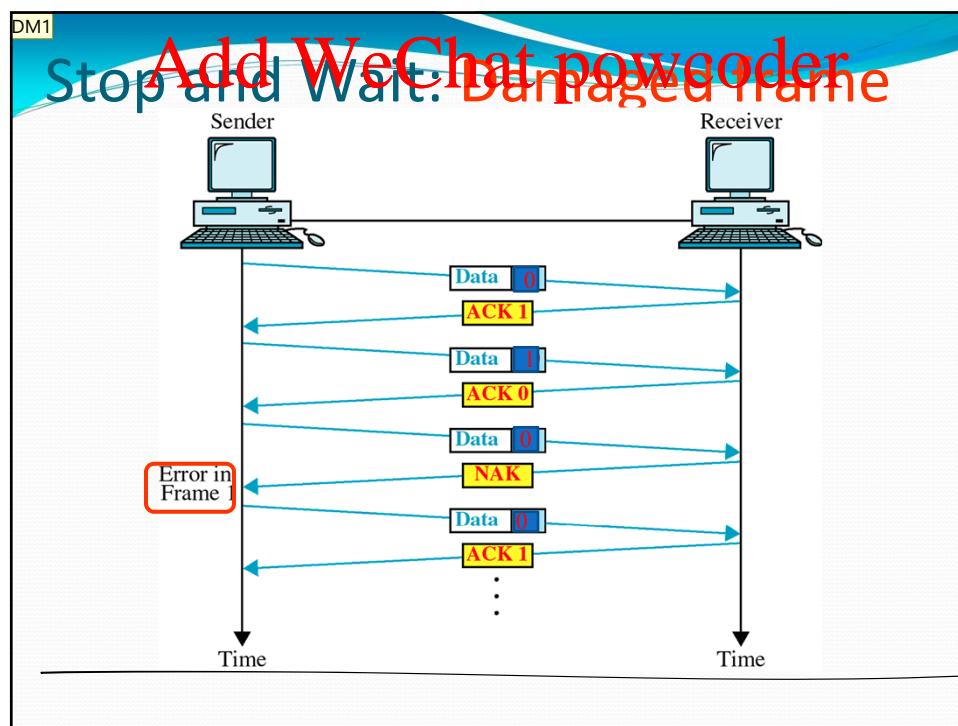
## Stop and Wait

- 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 ACK<sub>0</sub> / ACK<sub>1</sub>

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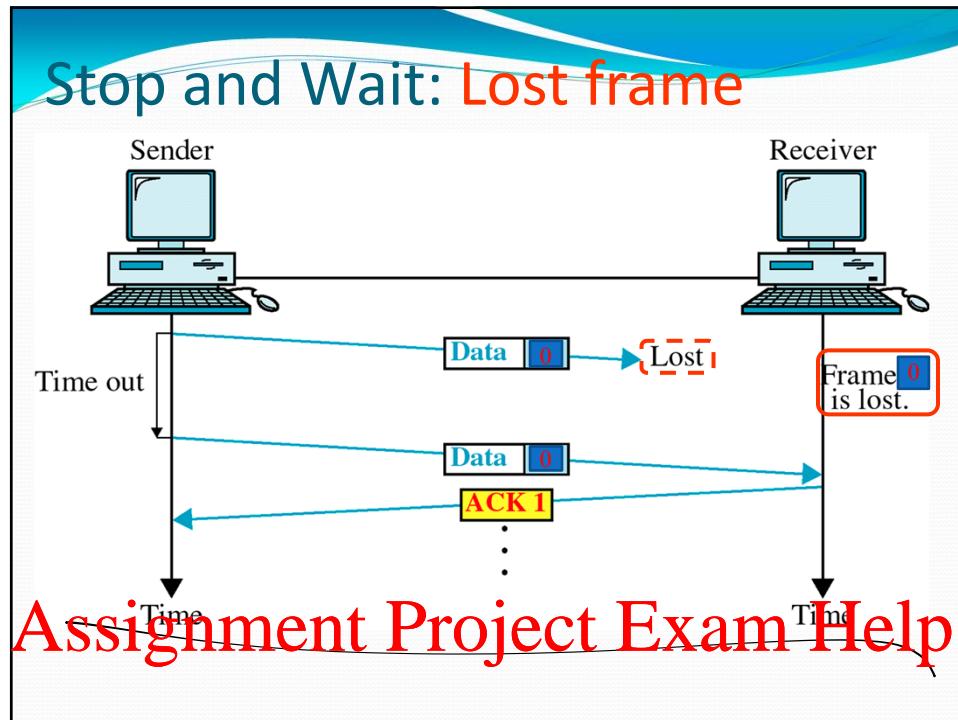


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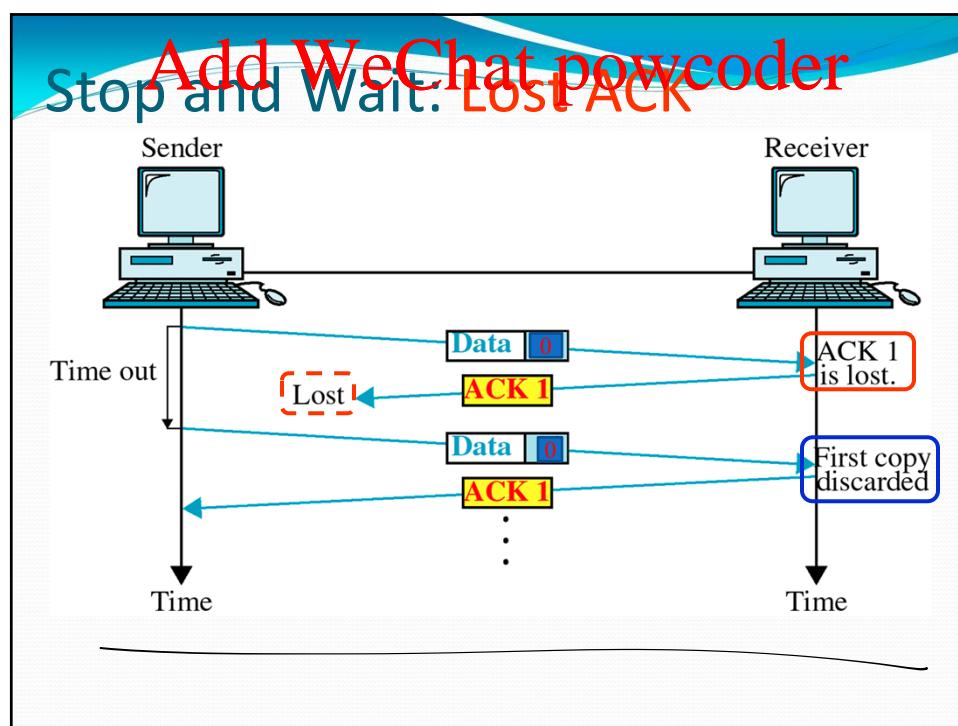
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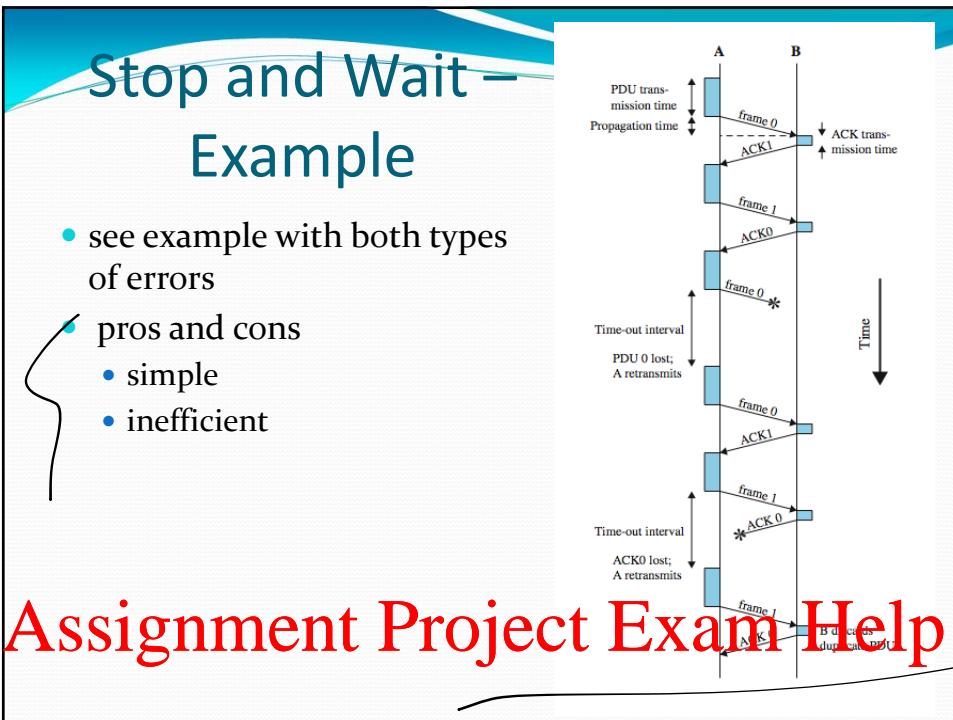


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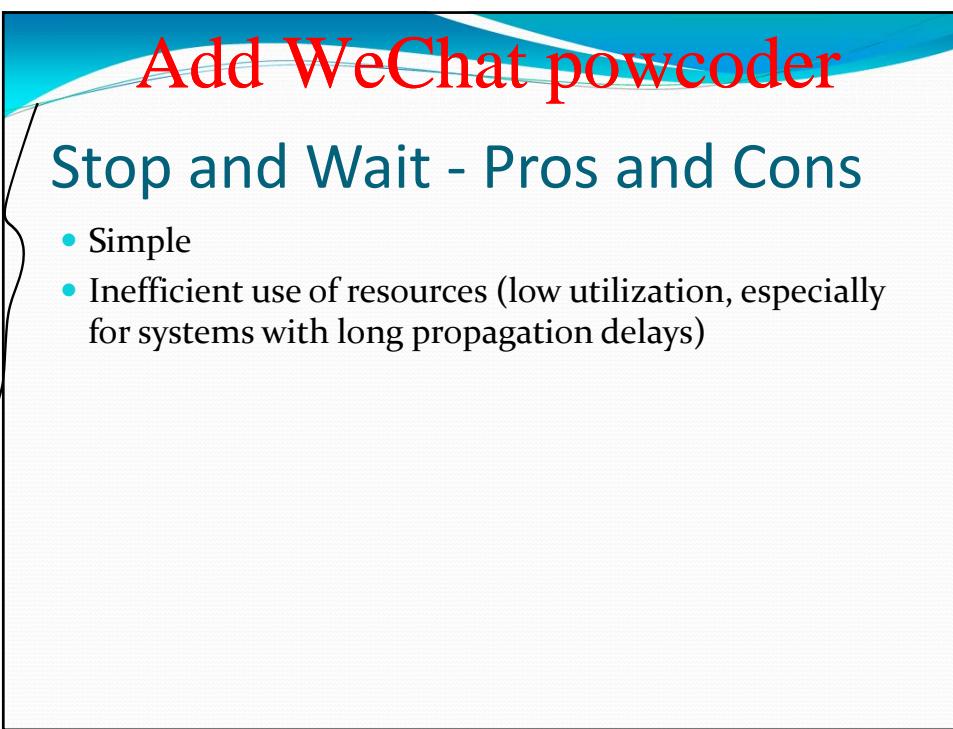


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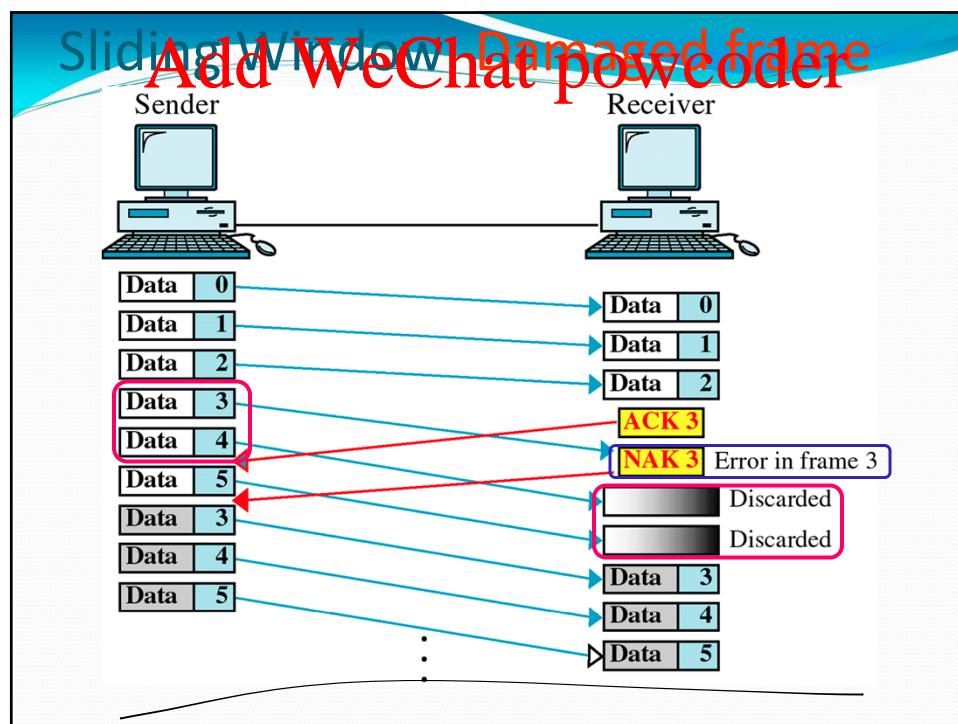
## Go Back N

- 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

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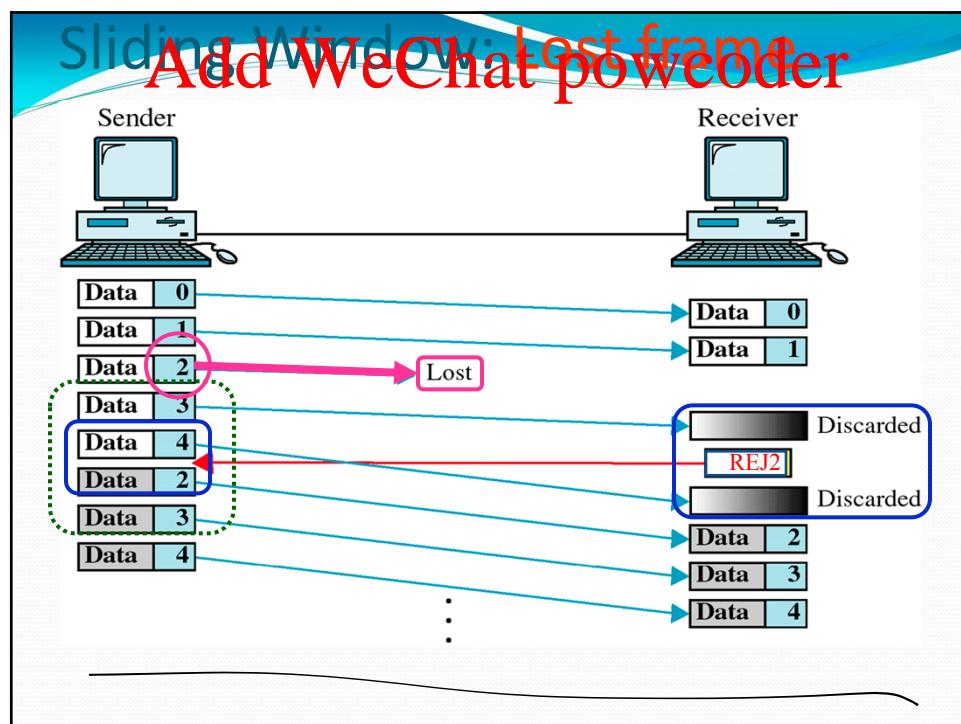
## Go Back N - Damaged Frame

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

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## Go Back N - Lost Frame (1)

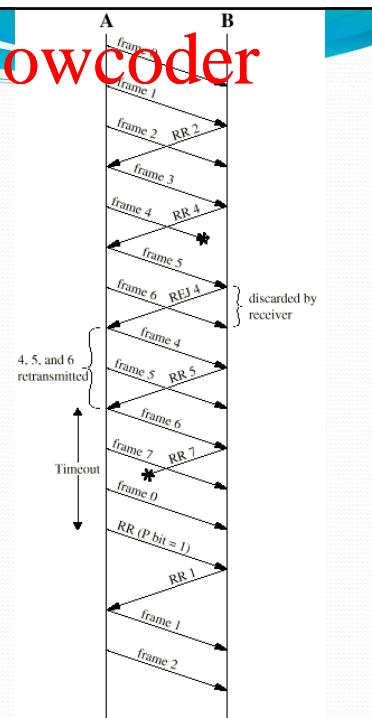
- Frame  $i$  lost
- Transmitter sends  $i+1$
- Receiver gets frame  $i+1$  out of sequence
- Receiver send rejection  $i$  (RR*i*)
- Transmitter goes back to frame  $i$  and retransmits frame  $i$  and all subsequent frames

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Go Back N -  
Example



25

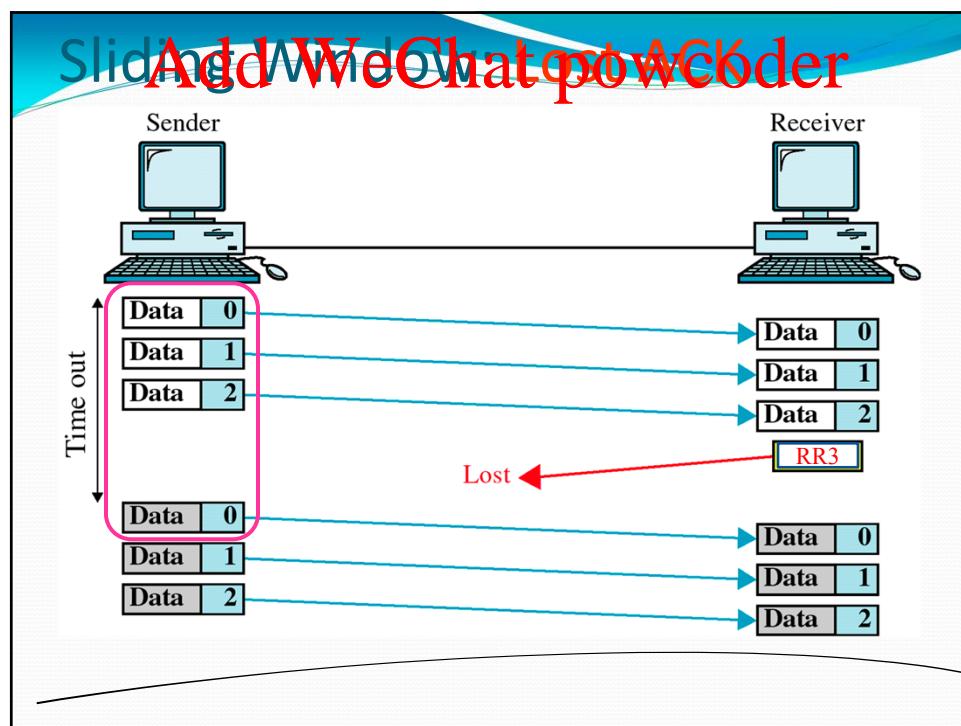
## Go Back N - Lost Frame (2)

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

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## Go Back N – Damaged or Lost Acknowledgement

- Receiver gets frame  $i$  and sends acknowledgement ( $i+1$ ) which is lost
- Acknowledgements are cumulative, 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 from the receiver to be able to "add" it

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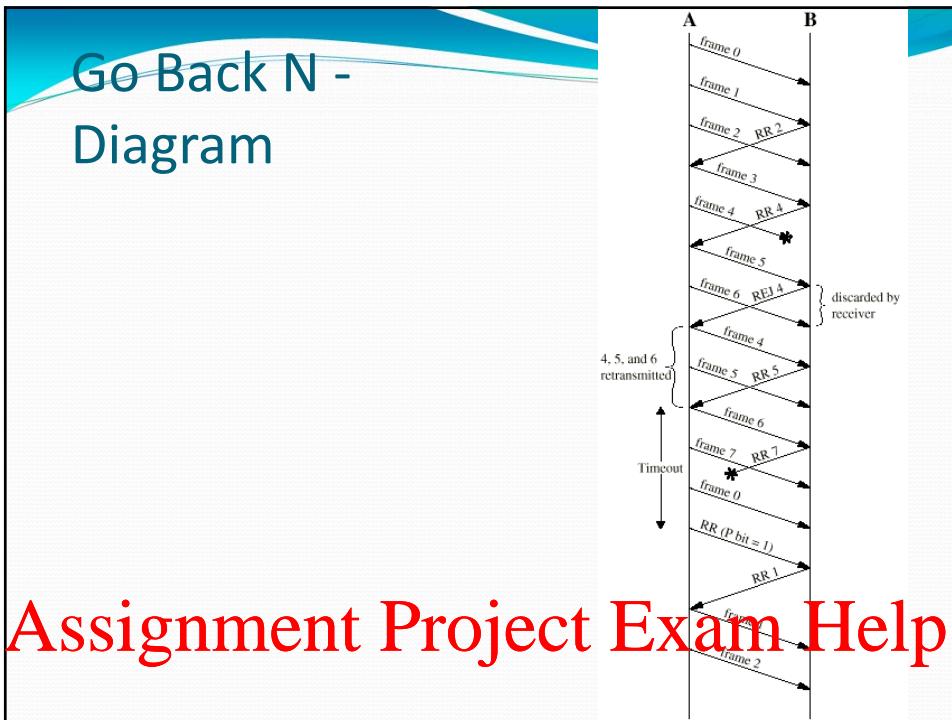
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## Add WeChat powcoder Go Back N - Damaged Rejection

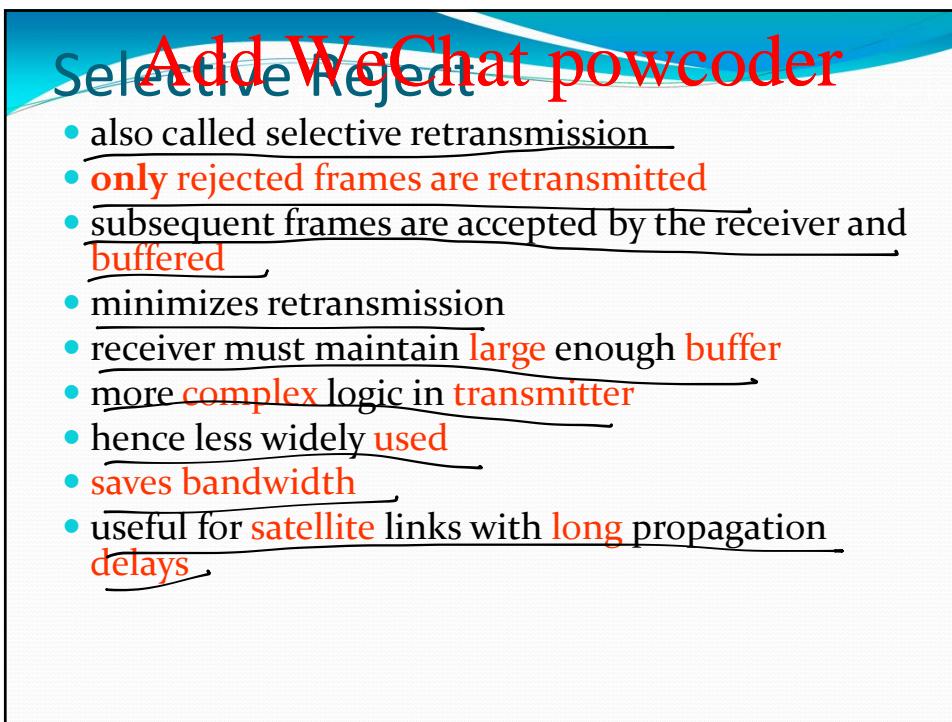
- As for lost frame

29

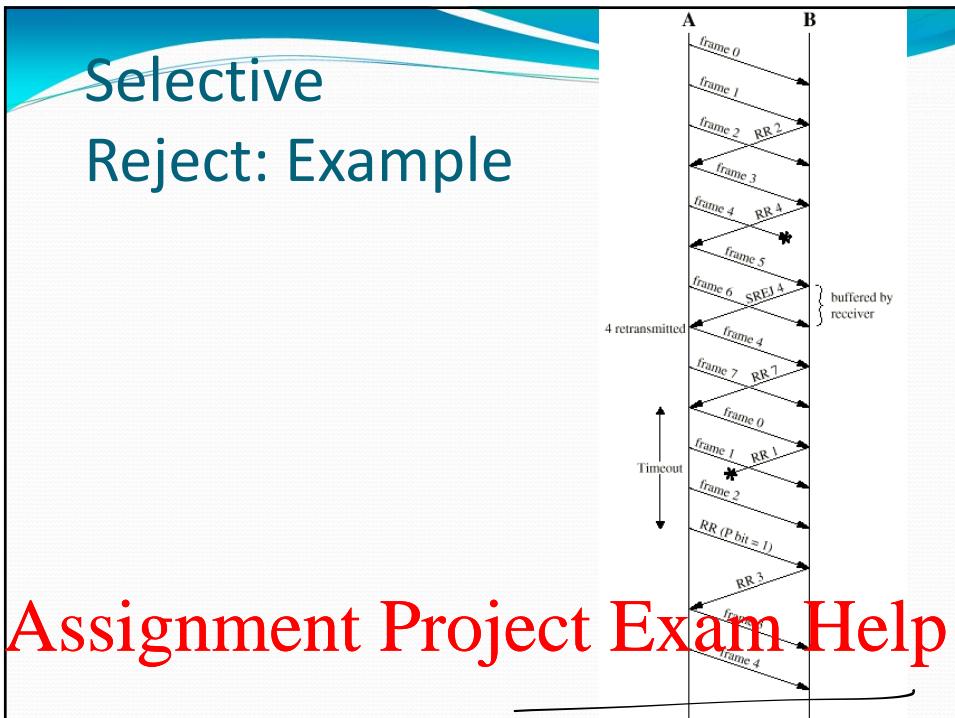


30

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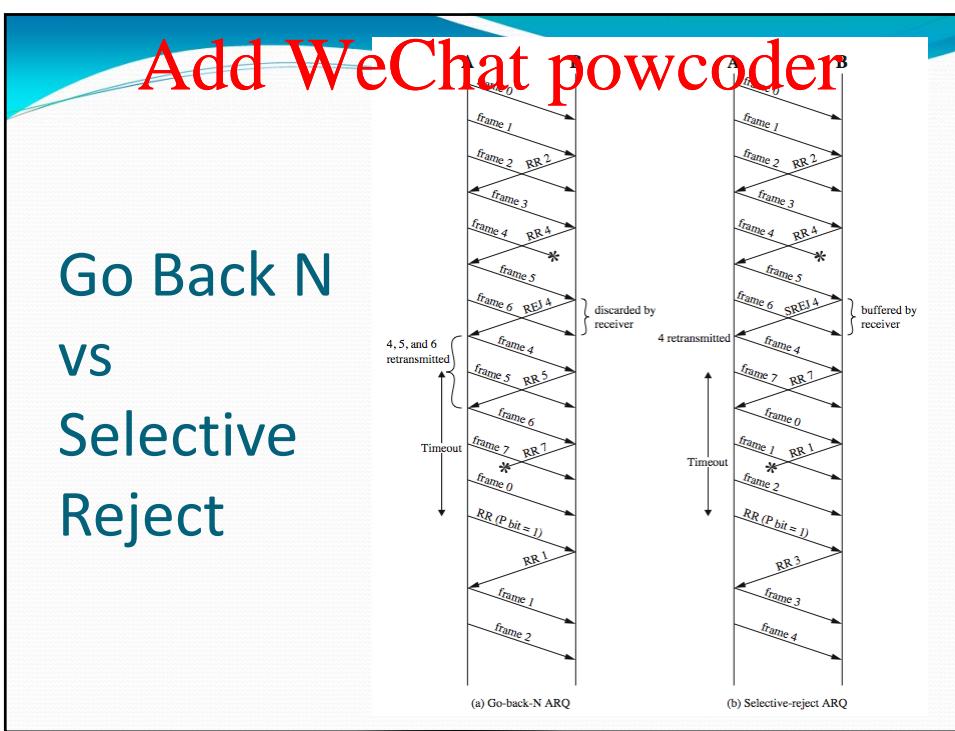


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**EECS, University of Ottawa**

**CEG3185 –Winter 2021**

**Introduction to Data Communication & Networking**

**Basics**

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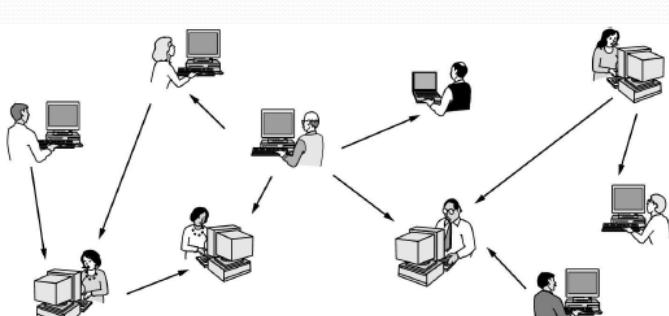
Note: some material in the slides has been taken from various other sources

1

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**Add WeChat powcoder**

Why we need computer networks?



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)

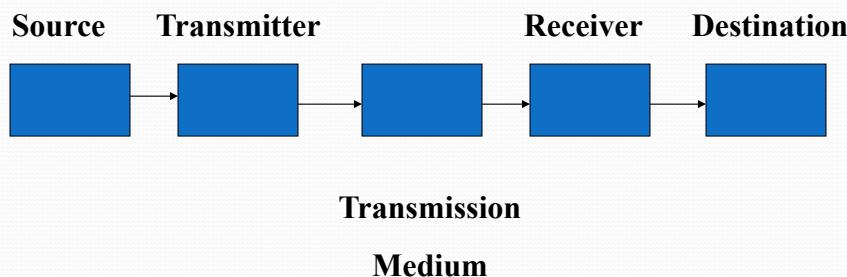
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## Add WeChat powcoder Communications System Model



1-4

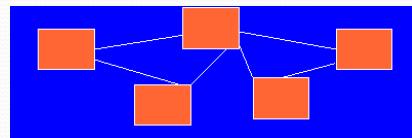
4

## Structure of Transmission System

Two communicating nodes



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



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1-5

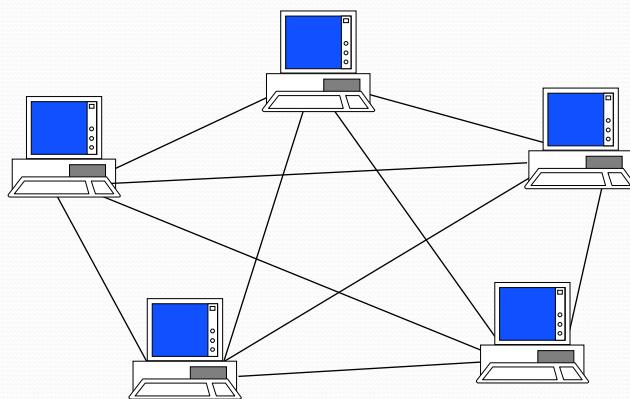
5

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## Add WeChat powcoder Computer Networks. Why?

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.

```

graph TD
    S1(( )) --- C1[Computer]
    S1 --- C2[Computer]
    S1 --- C3[Computer]
    S1 --- C4[Computer]
    S1 --- C5[Computer]
    C1 --- C2
    C2 --- C3
    C3 --- C4
    C4 --- C5
  
```

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1-7

7

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Is “Computer Communication” important?

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- 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	

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## Add WeChat powcoder

### Communication Tasks (2)

- 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

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1-11

11

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### Communication Tasks (4)

- 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

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1-13

13

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## Communication Tasks (6)

- 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

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## Types of Communication Networks

Classification according to the way the “information flows” are transported to the users

- Switching Networks
- Broadcast Networks

1-16

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## Switching Networks

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

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Broadcast Network

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

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## 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

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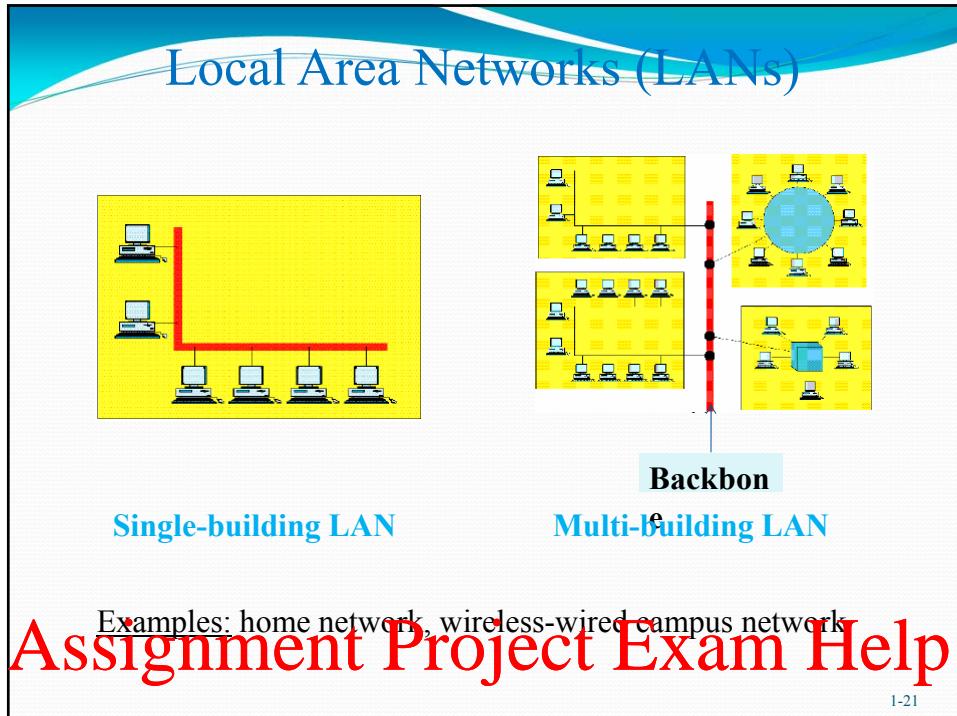
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## Add WeChat powcoder Local Area Networks (LANs)

- 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????)

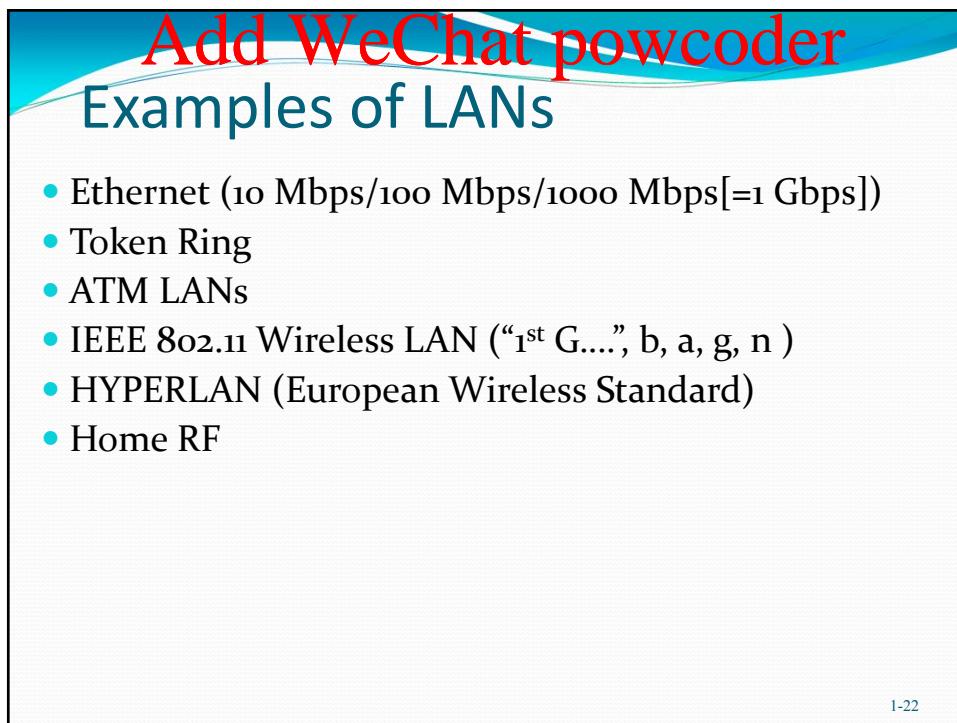
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## Metropolitan Area Networks (MAN)

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

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## Wide Area Networks (WAN)

Example: Canadian Network for the Advancement of Research, Industry and Education (CANARIE)

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## Wide Area Networks (WAN)

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

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## Add WeChat powcoder Internetworking

- ◆ Internetworking: interconnecting **multiple** networks of **different** 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 ***Internet*** or ***Internet***

1-26

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## 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

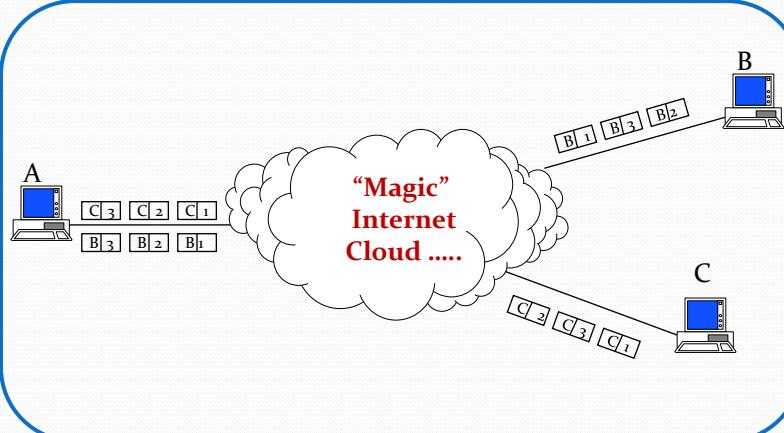
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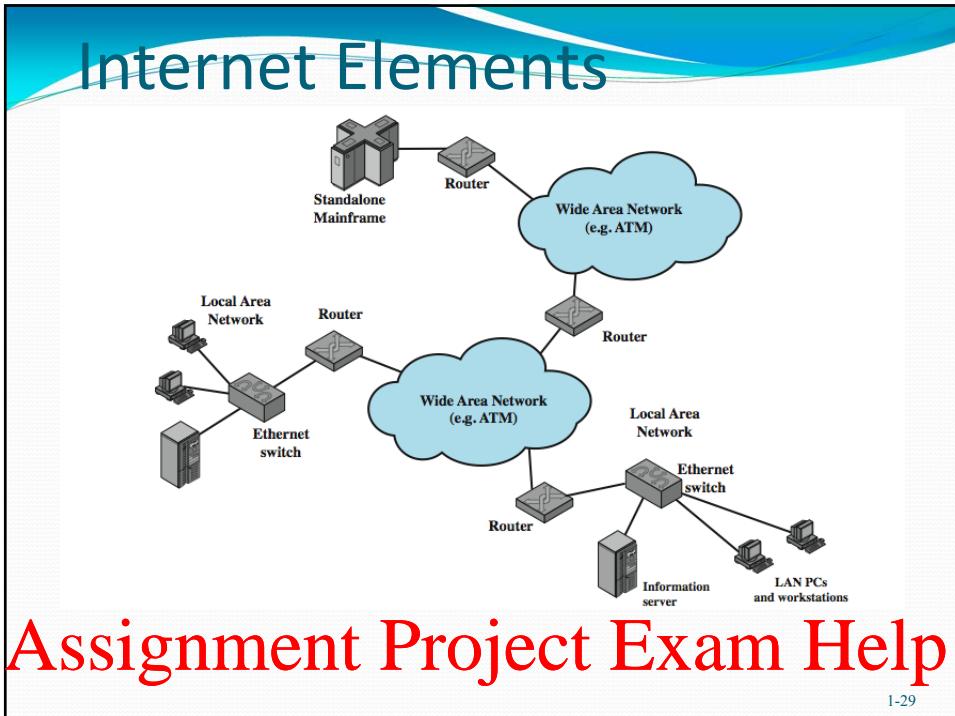
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User' s view of Internet



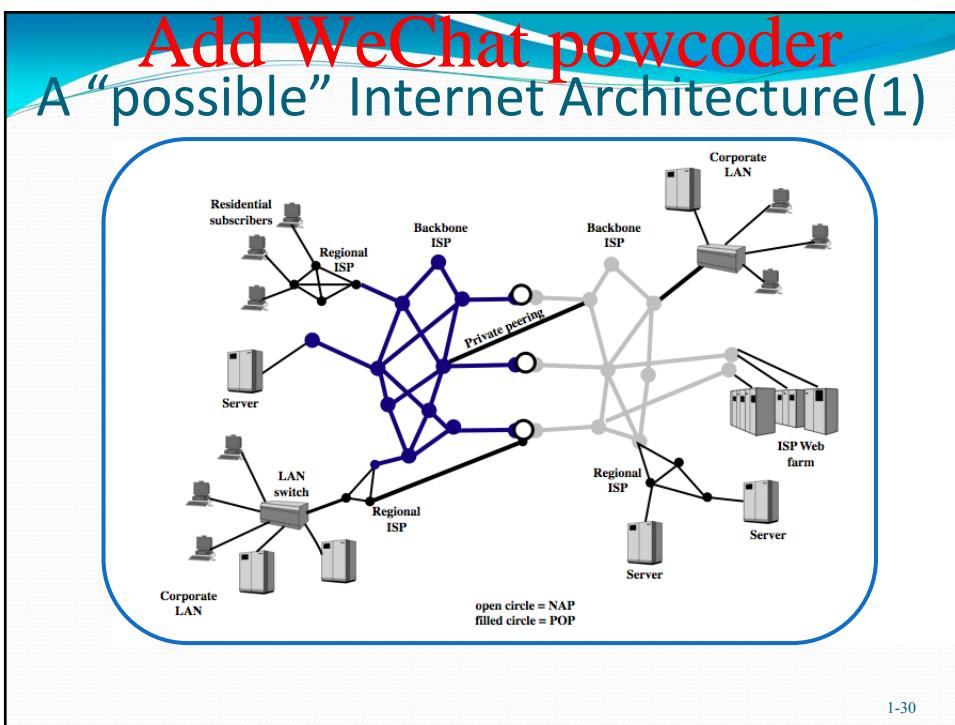
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## Autonomous System (AS)

- 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.

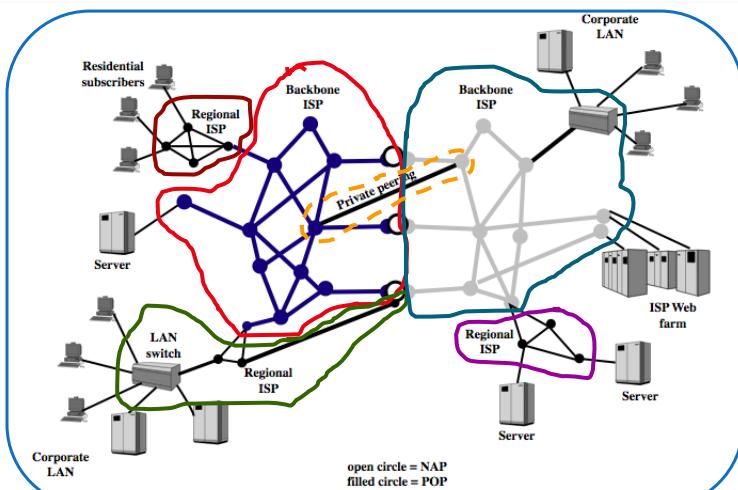
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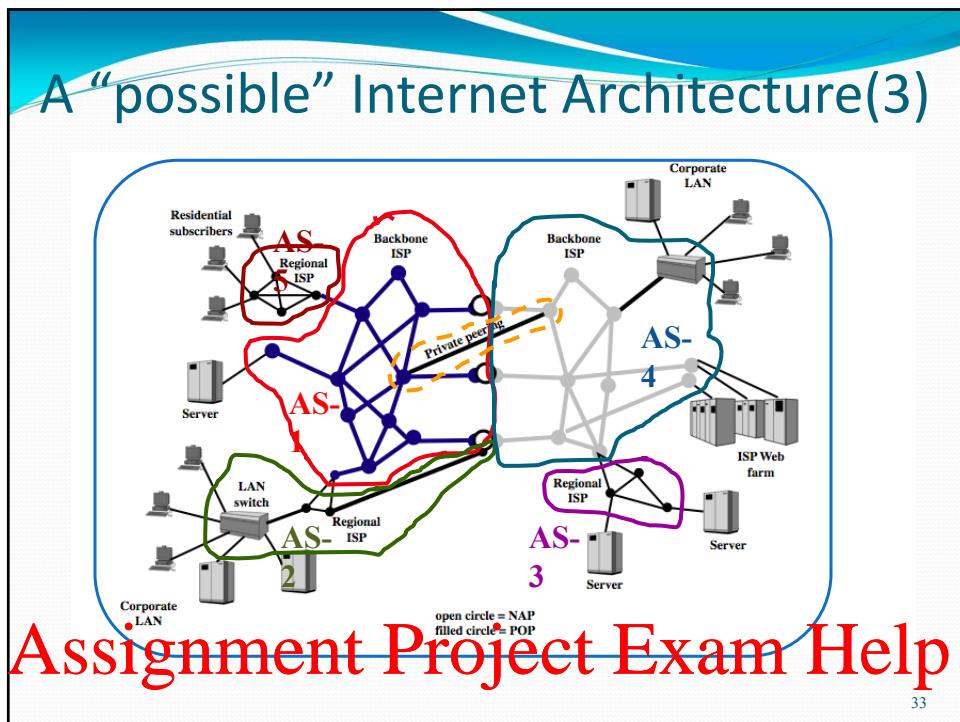
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## Add WeChat powcoder A “possible” Internet Architecture(2)



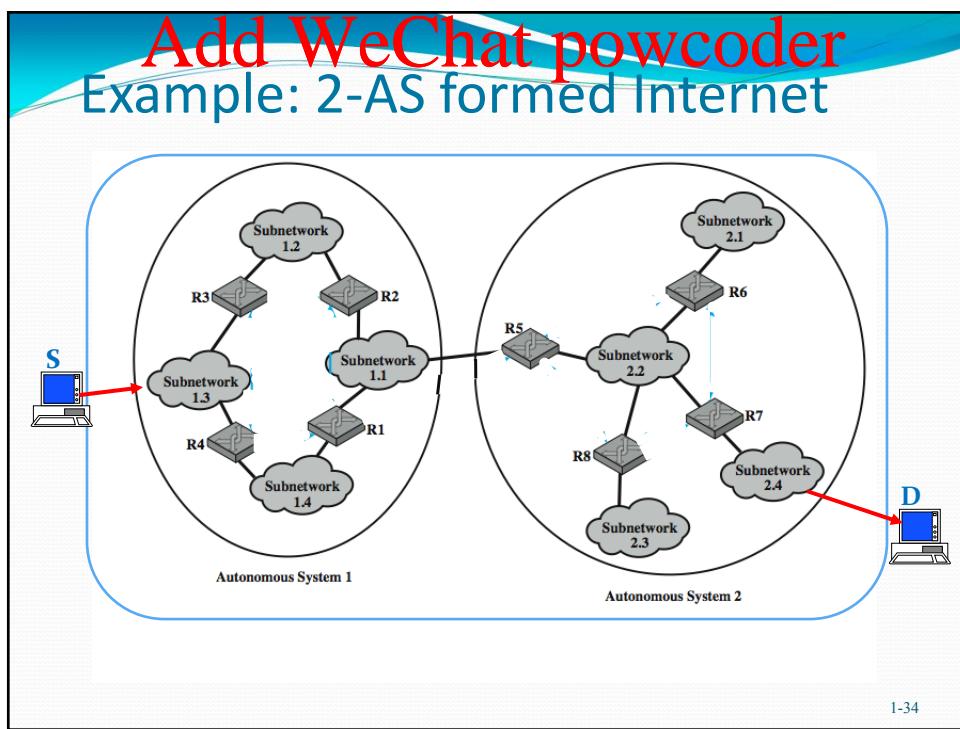
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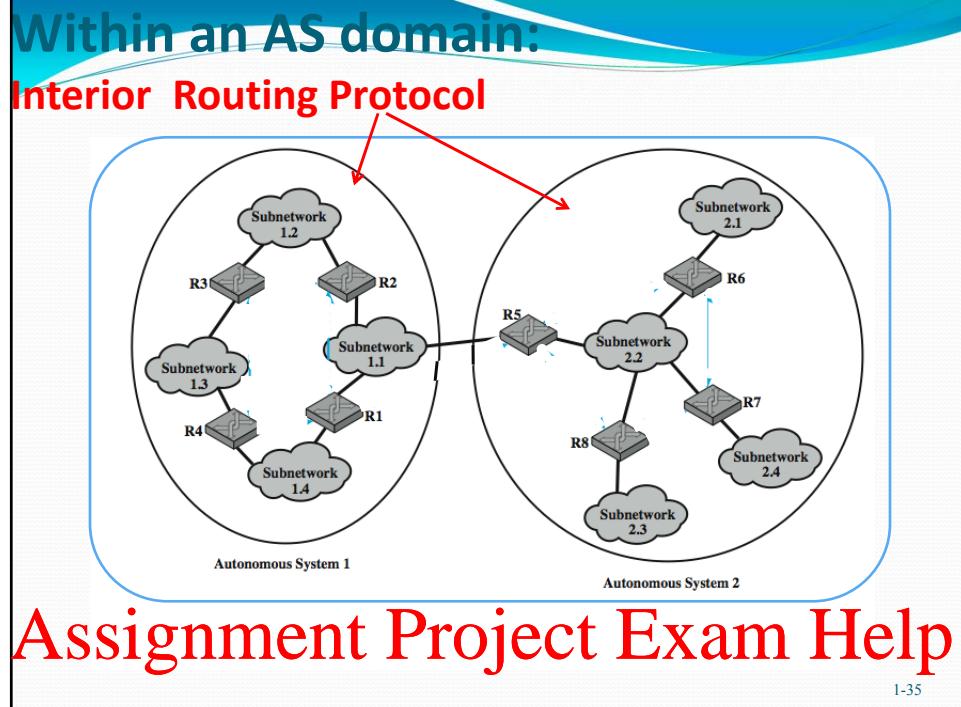


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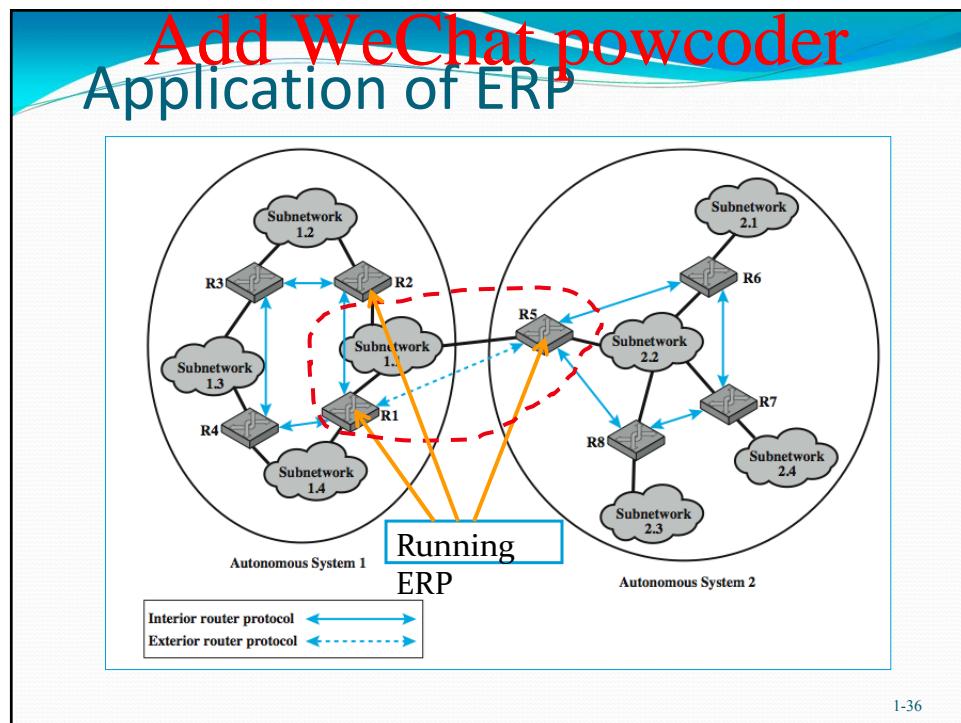


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## Protocols (1)

- 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**.

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## 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.

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## 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

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## 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

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## 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**

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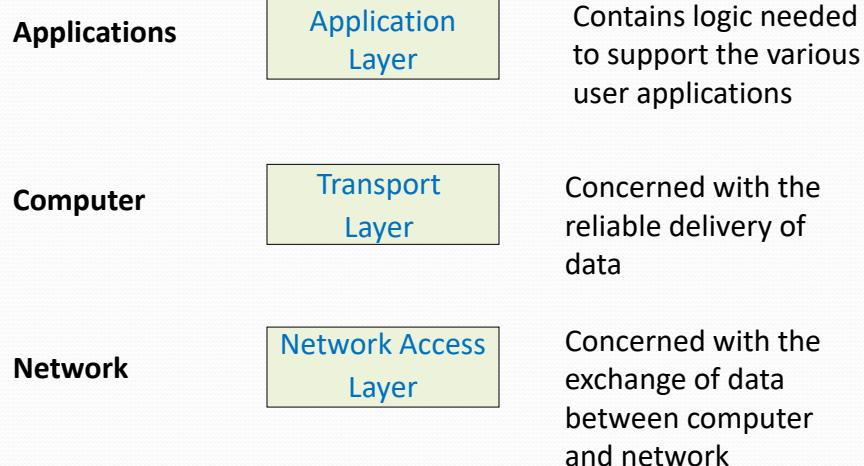
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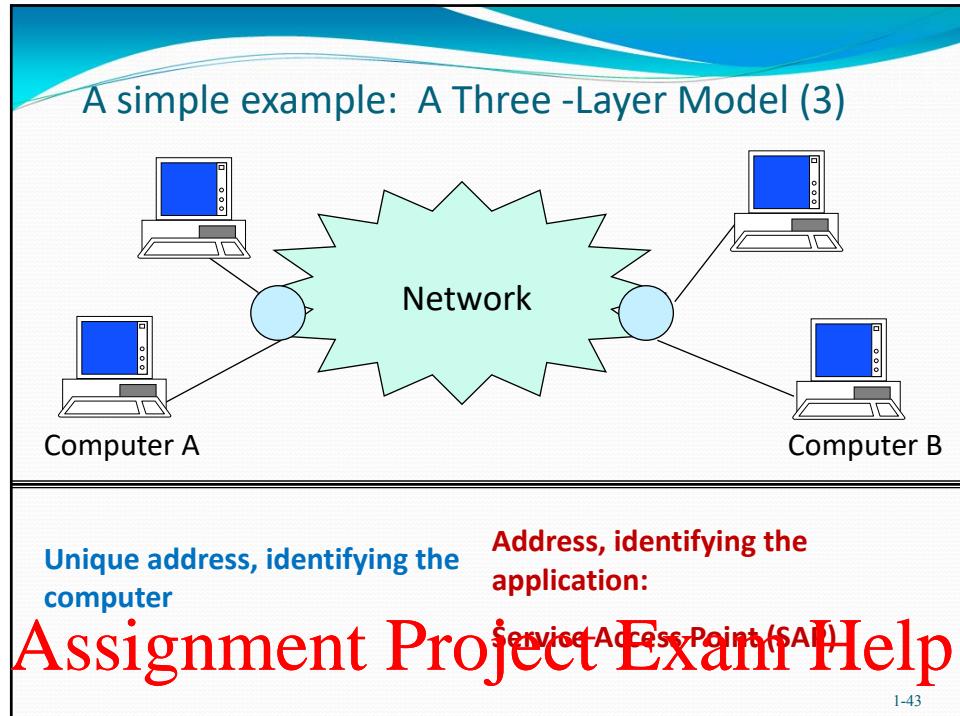
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### A simple example: A Three -Layer Model (2)



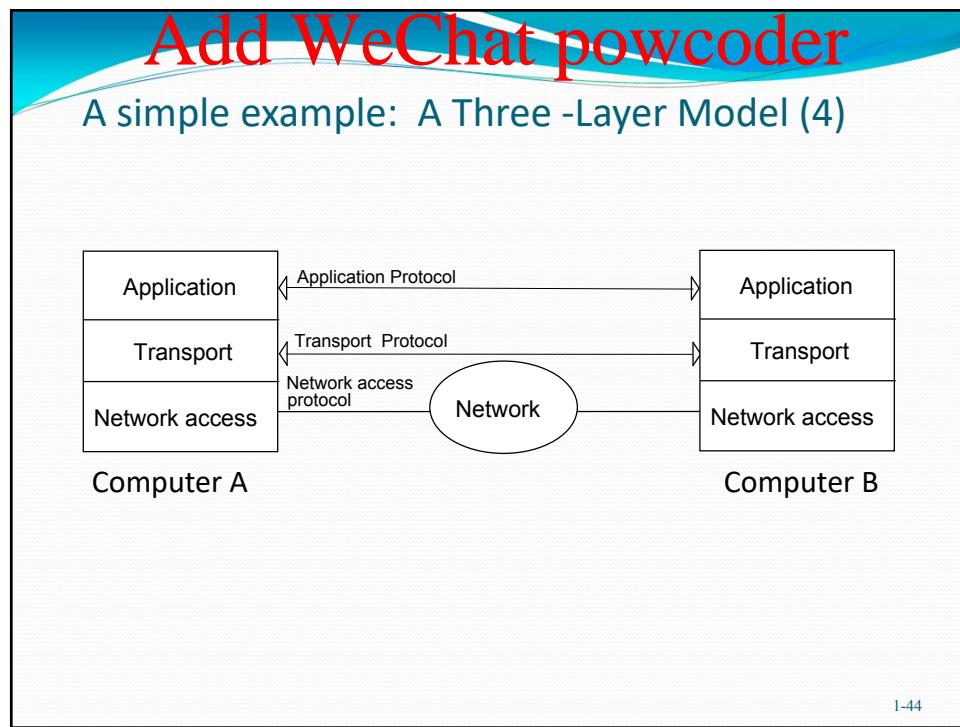
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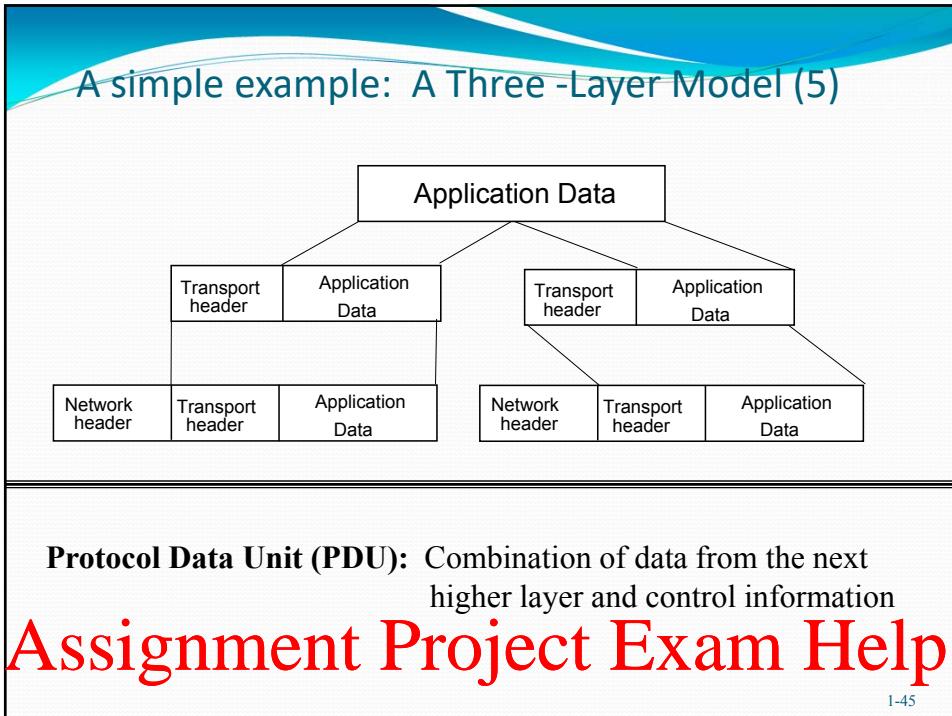


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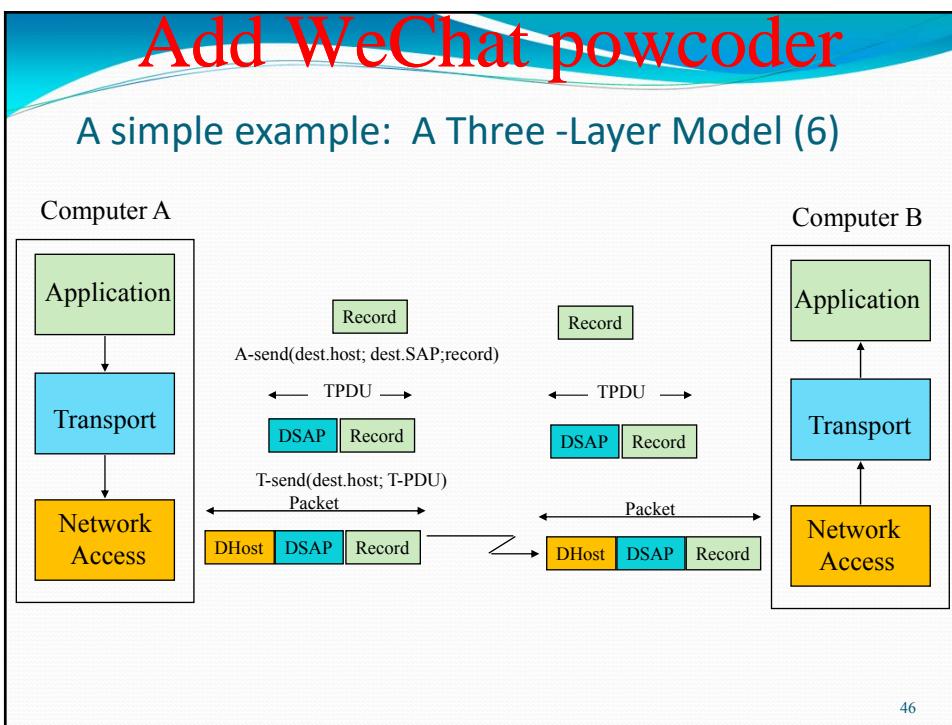


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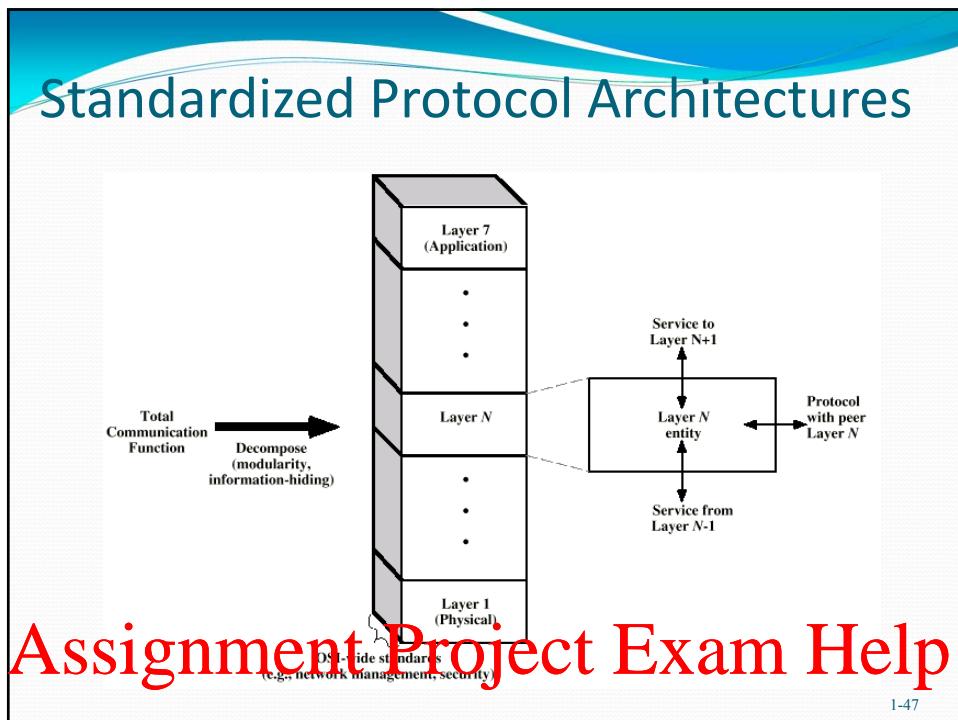


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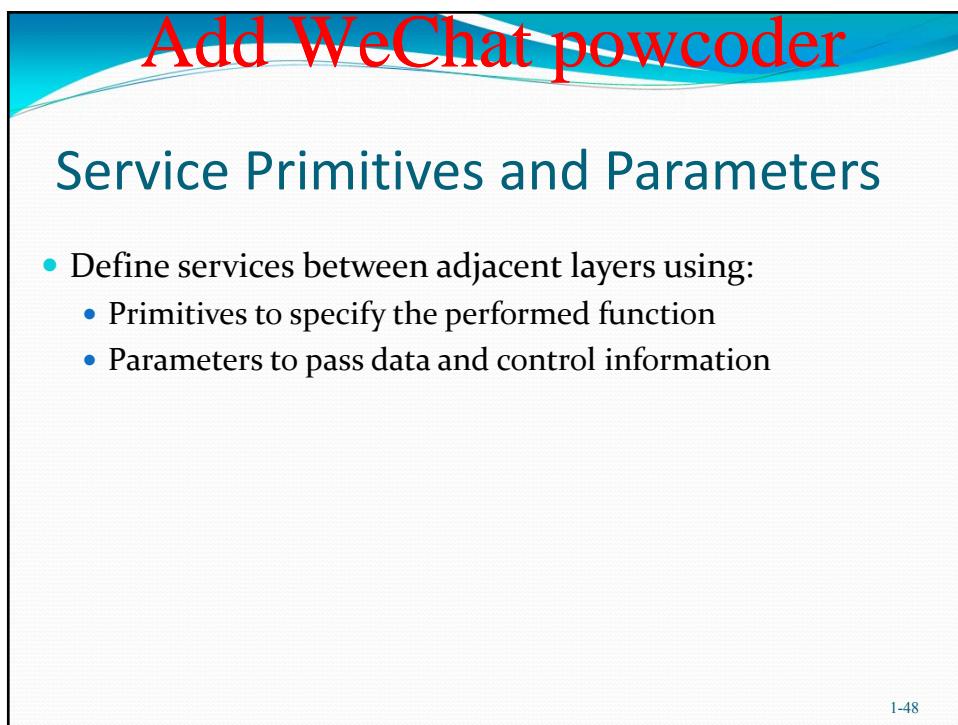


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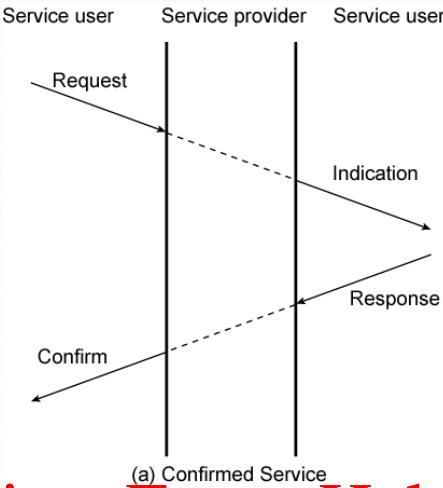
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## Service Primitives and Parameters

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.



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### Generic Protocol Issues

- **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

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**Relevant Standards Bodies**

- **ISO: International Organization for Standardization** ([www.iso.org](http://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 «ἴσος» (read as “isos”), meaning equal.
- **ITU: International Telecommunications Union** ([www.itu.int](http://www.itu.int))
  - UN treaty agency that sets telecommunications standards.
  - ITU-T (Telecommunications section)
- **ANSI: American National Standards Institute** ([www.ansi.org](http://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](http://www.ieee.org))
  - US based international professional organization.
  - Among other things, develops standards.
- **IETF / IRTF**
  - Internet Engineering Task Force ([www.ietf.org](http://www.ietf.org)) / Internet Research Task Force ([www.irtf.org](http://www.irtf.org))
  - IEC Electrotechnical Expertise Alliance ([www.iec.org](http://www.iec.org))
    - e.g., standards for wiring and interconnection

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## Protocol Architectures

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

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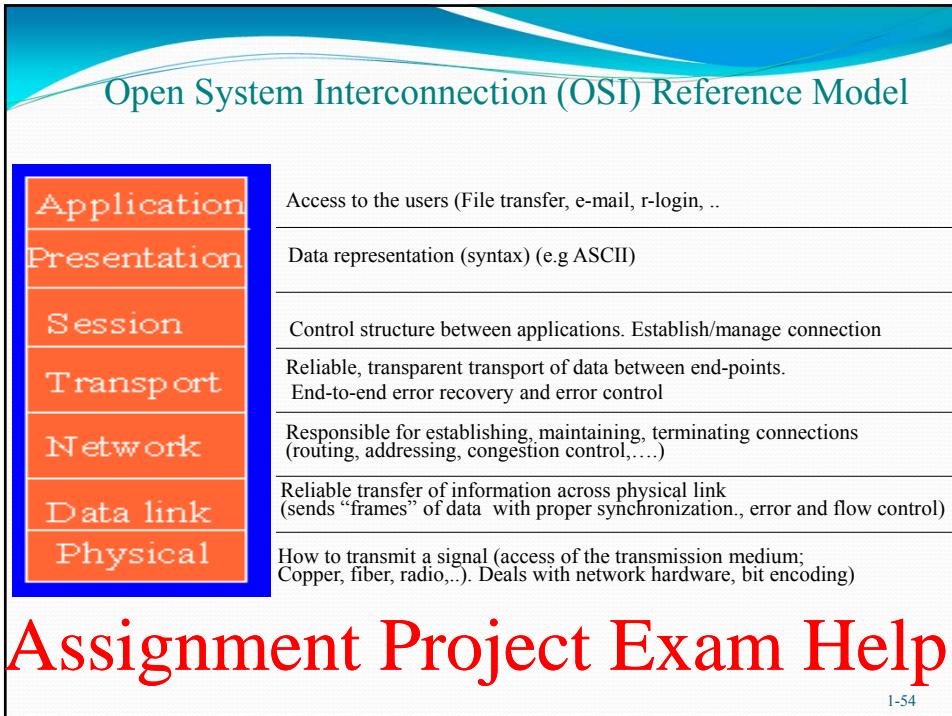
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### Open System Interconnection (OSI) Reference Model

- 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”

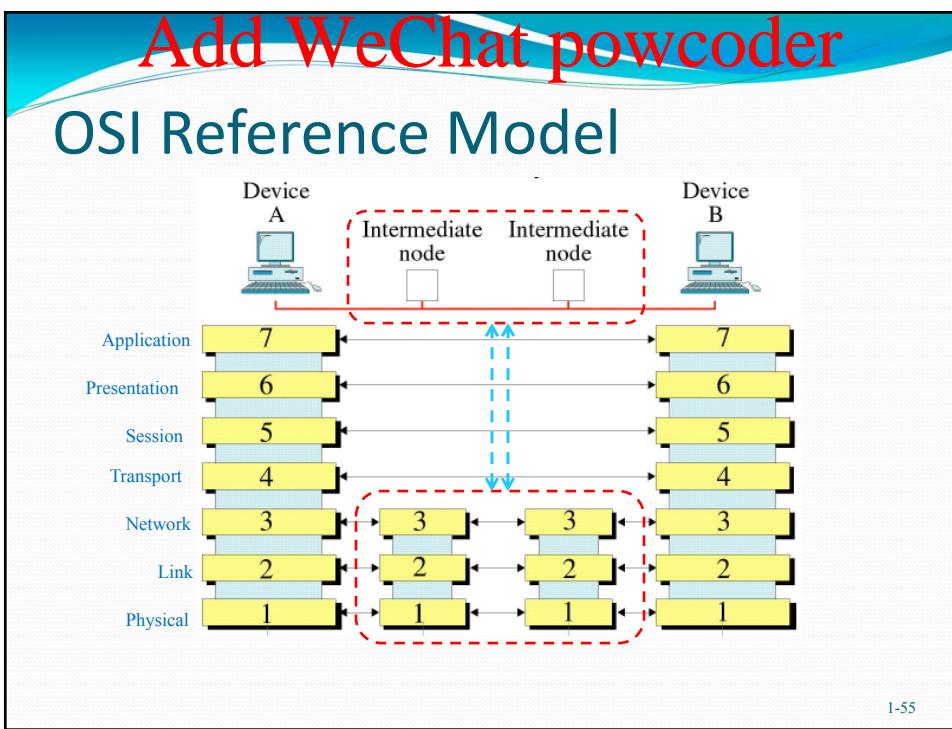
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## TCP/IP Protocol Architecture

- 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.

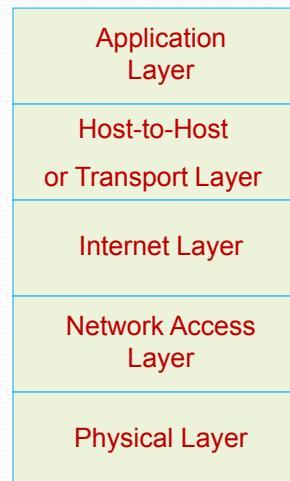
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## Add WeChat powcoder TCP/IP Protocol Architecture (2)



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## 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

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## 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

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## 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

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## Host-to-host / Transport Layer

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

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## Application Layer

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

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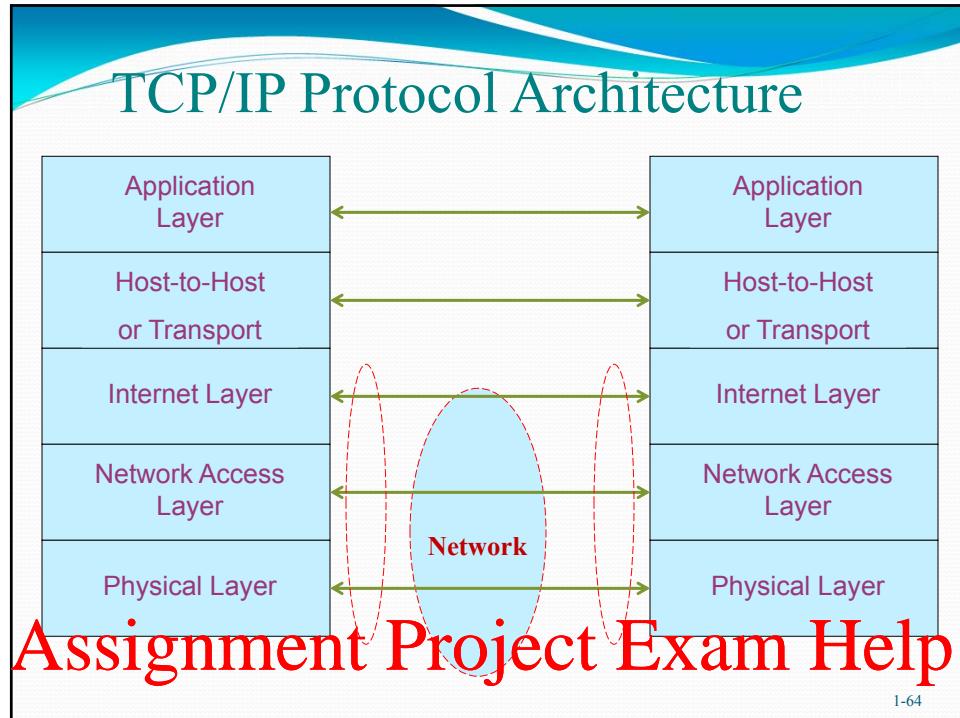
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## Add WeChat powcoder TCP/IP Protocol Architecture

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 <u>end-systems</u> 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..)

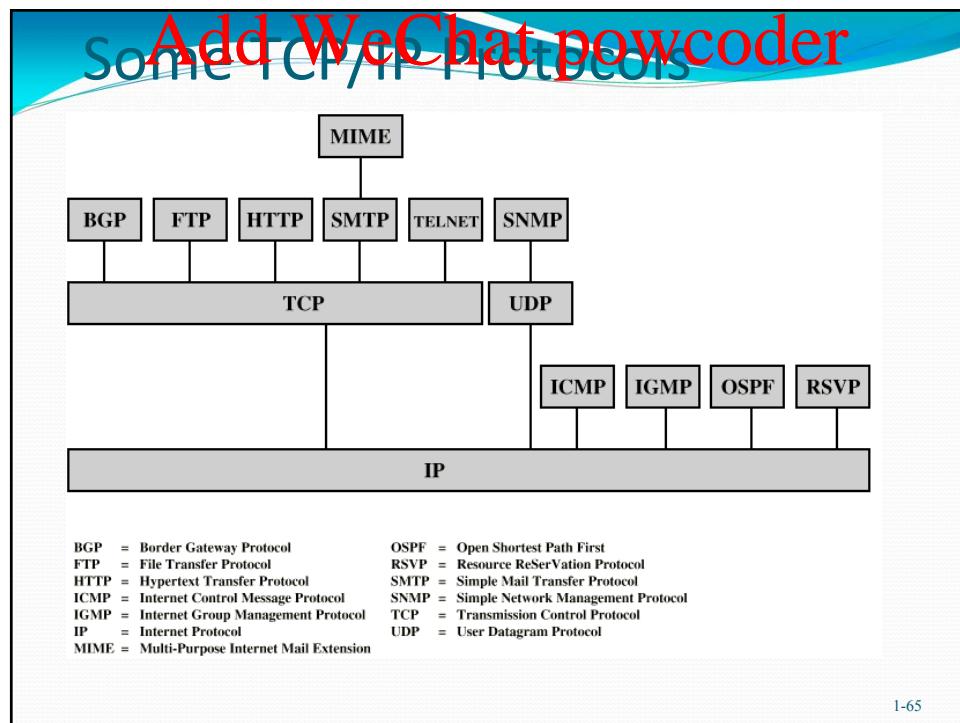
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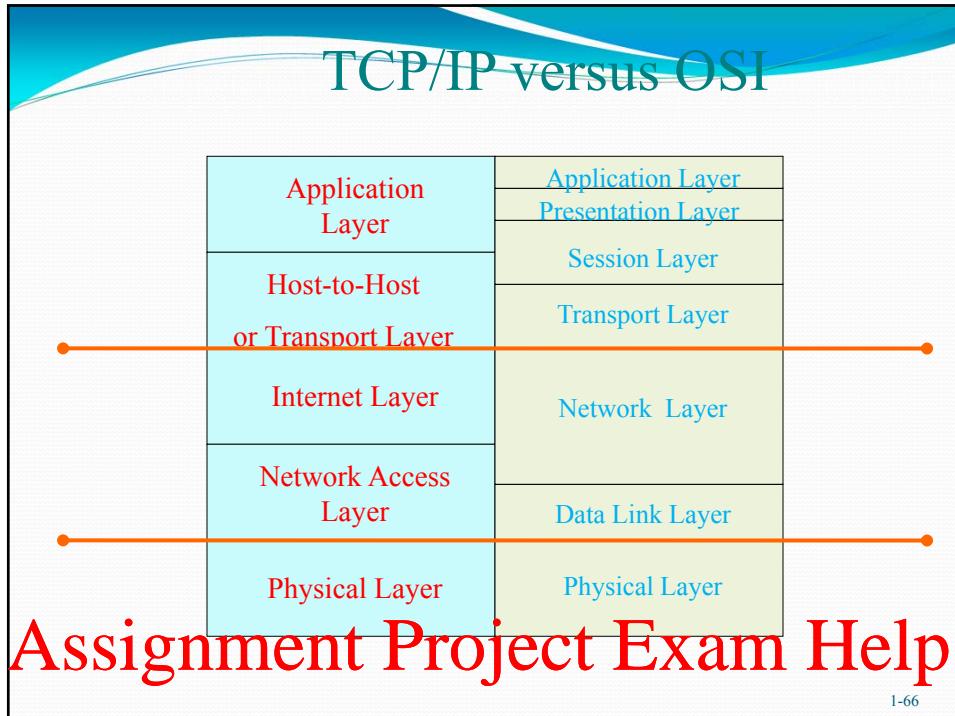


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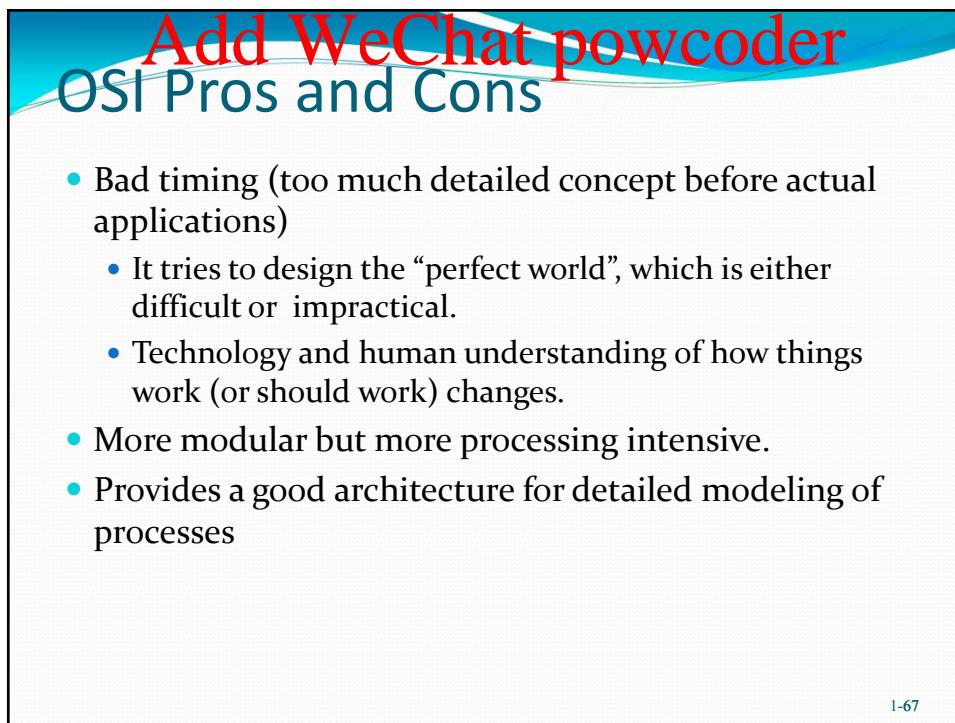


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# IPv4

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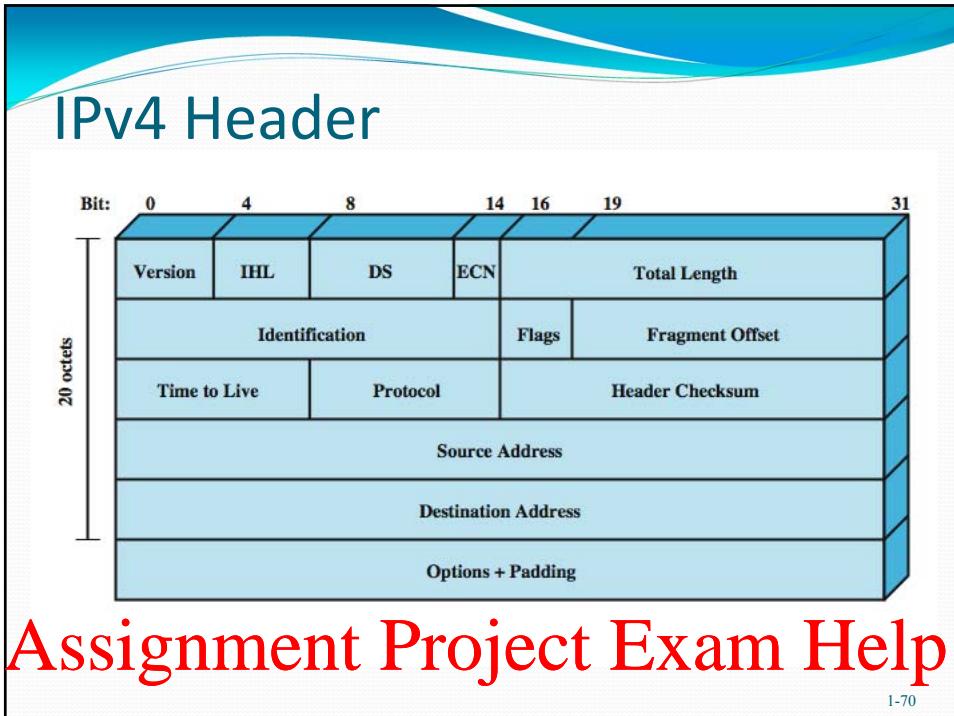
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## Add WeChat powcoder Internet Protocol (IP) v4

- 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

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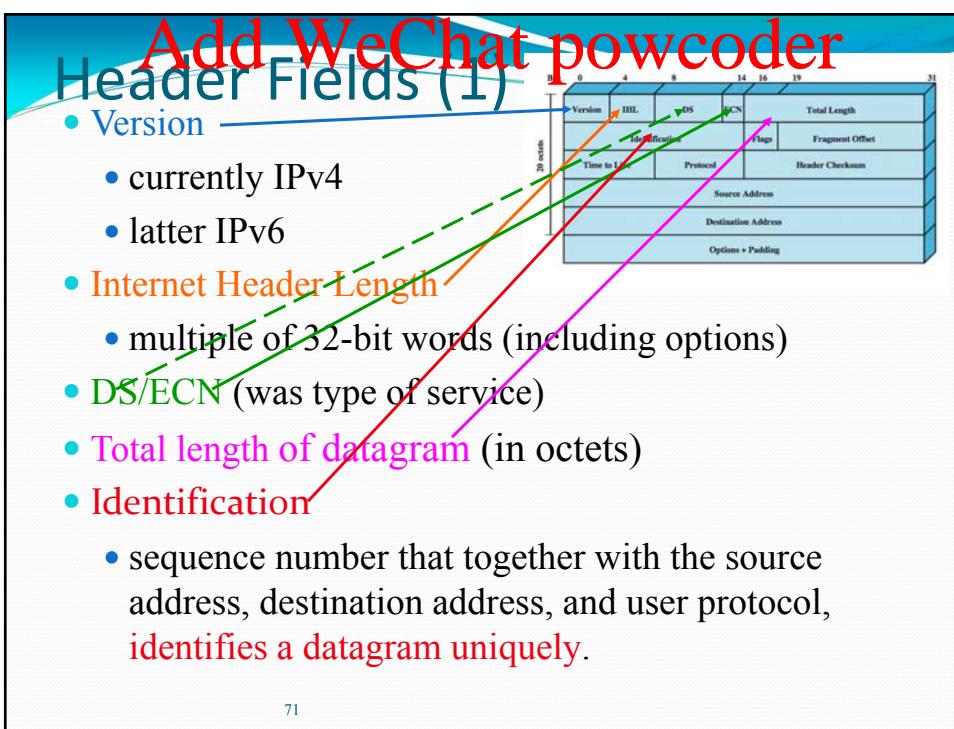


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## Header Fields (2)

- 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
- 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)

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1-72

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## Add WeChat powcoder 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

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## IPv6

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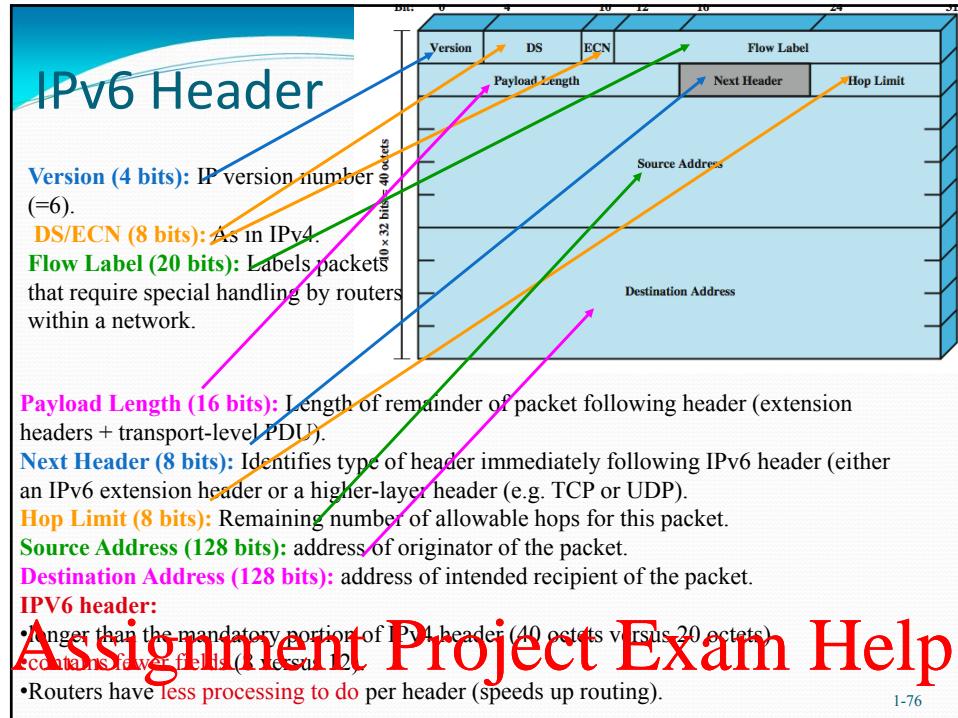
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### Why Change IP?

- 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

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**EECS, University of Ottawa**

**CEG3185 –Winter 2021**

**Introduction to Data Communication & Networking**

**Local Area Networks (LANs)**

**Assignment Project Exam Help**

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 Department. Students of the University of Ottawa are REMINDED THAT IT IS ILLEGAL TO COPY MATERIALS FROM THIS COURSE FOR USE IN OTHER COURSES.

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

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**Local Area Networks**

- 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)

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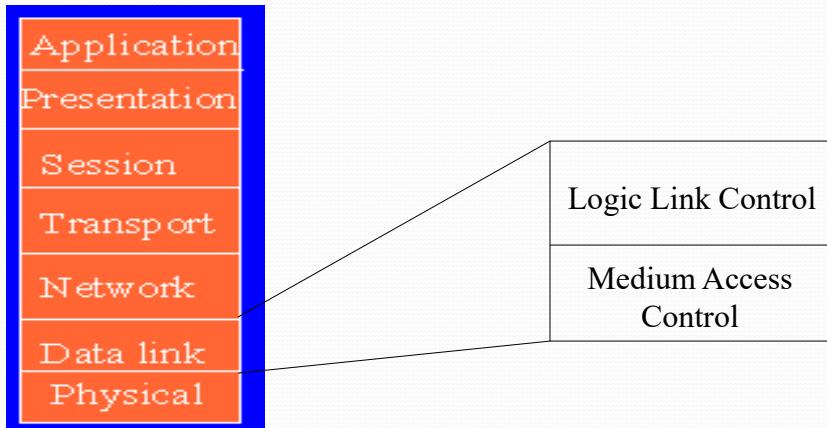
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Open System Interconnection (OSI) Reference Model



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## Functions Performed by Physical Layer

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

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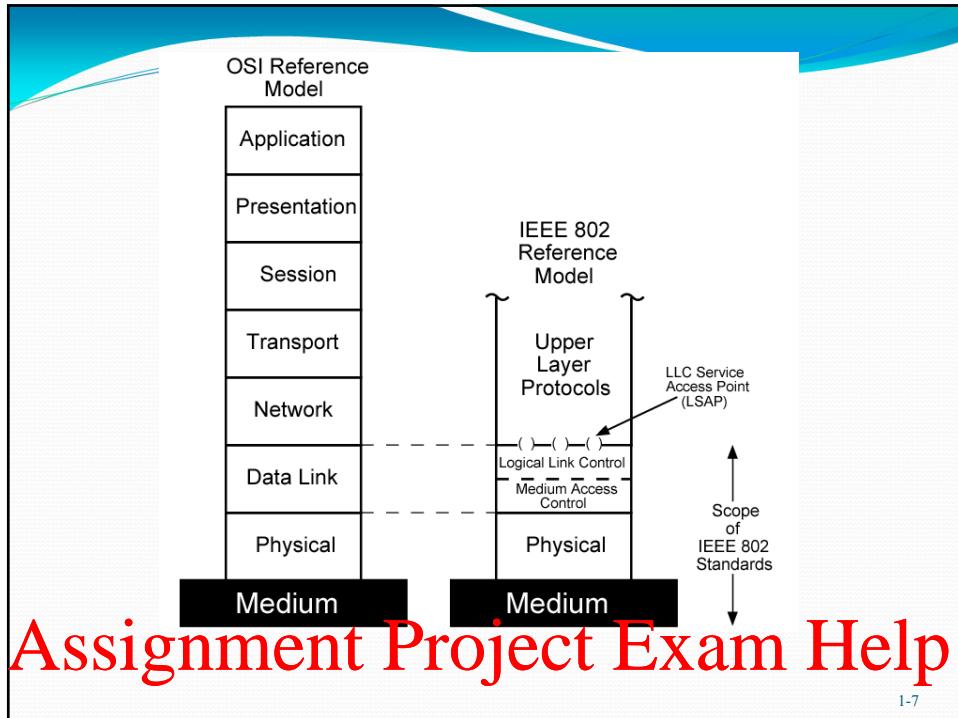
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## Add WeChat powcoder Functions Performed at Data Link Layer

- |   |                       |
|---|-----------------------|
| <ul style="list-style-type: none"> <li>• Provide an interface to higher layers</li> <li>• Perform flow and error control</li> </ul>   | <p>LLC</p> <p>MAC</p> |
| <ul style="list-style-type: none"> <li>• Assemble data into frame with address and error-detection fields</li> <li>• Assemble/de-assemble frame, perform address recognition and error detection</li> <li>• Govern Access to the LAN transmission medium</li> </ul> |                       |

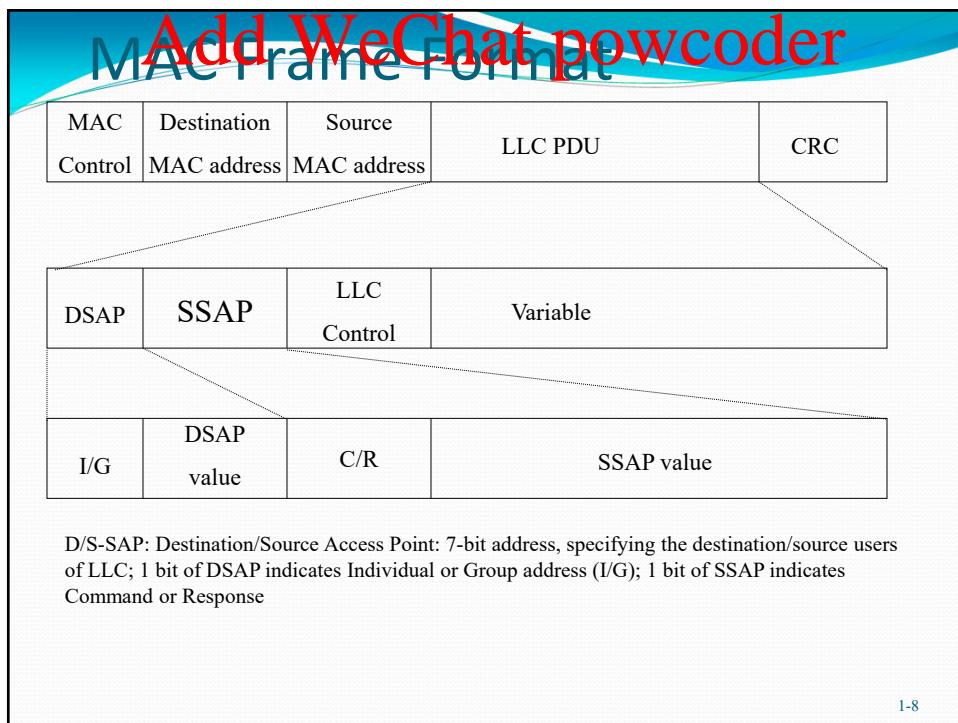
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## Topologies

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

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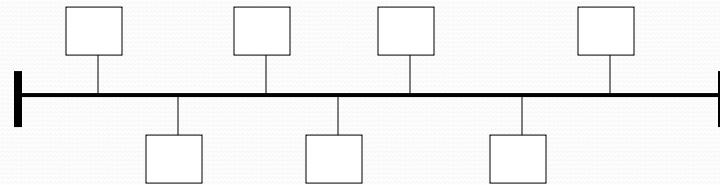
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## Bus Topology



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# Tree Topology

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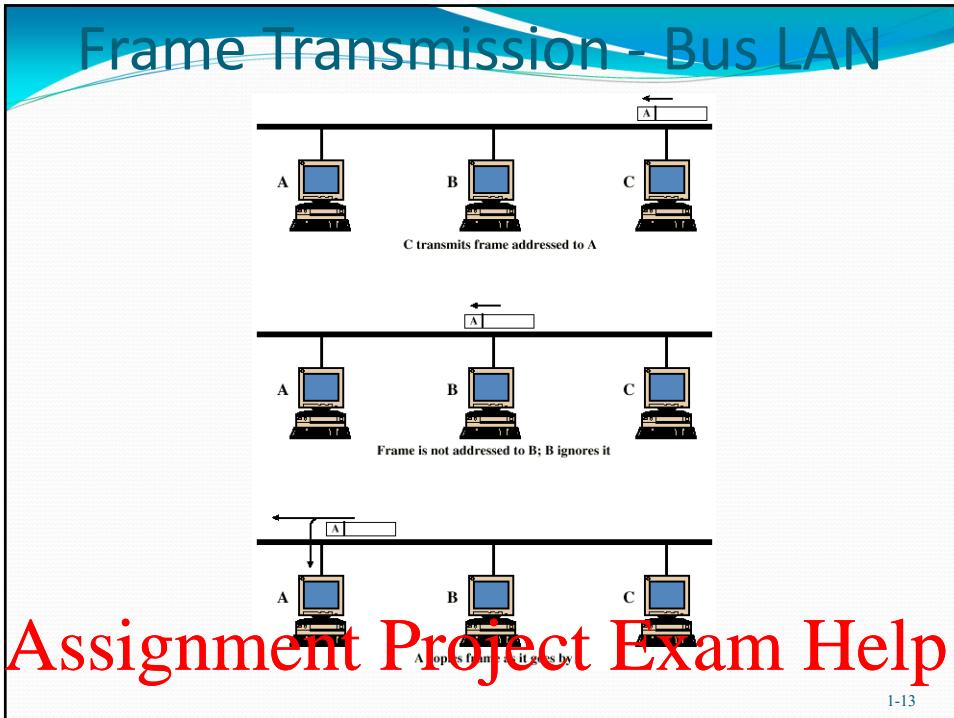
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### Bus and Tree

- 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

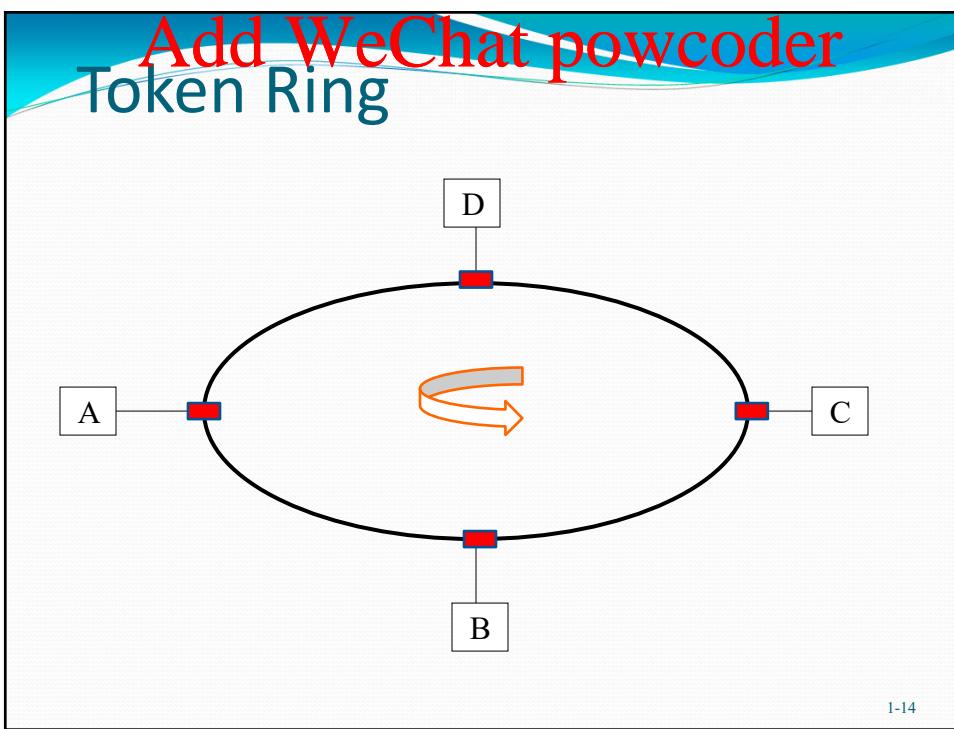
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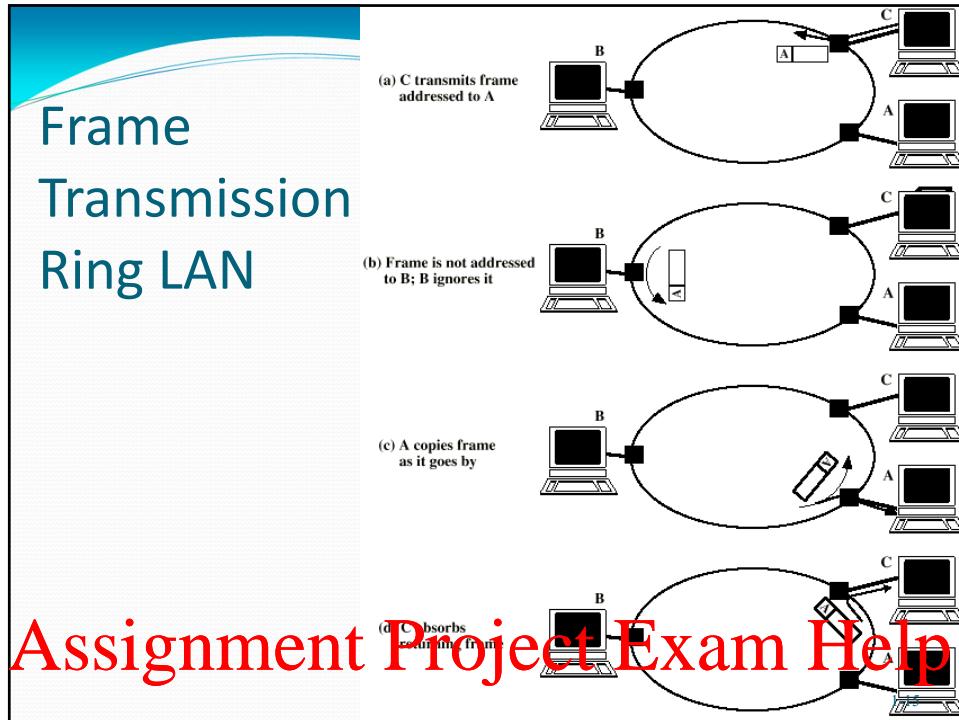


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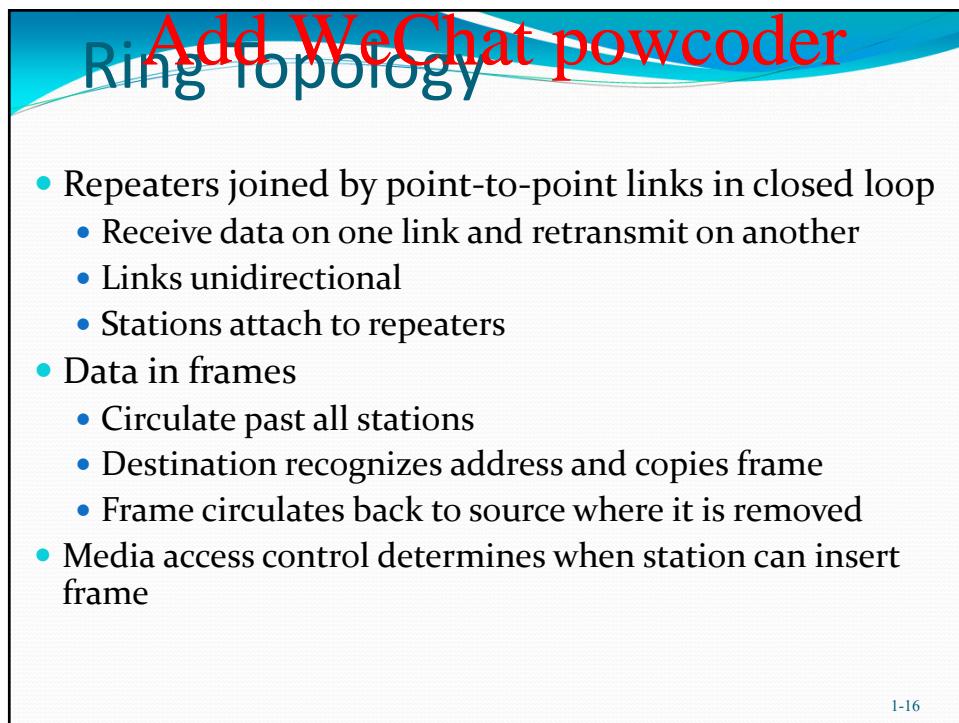


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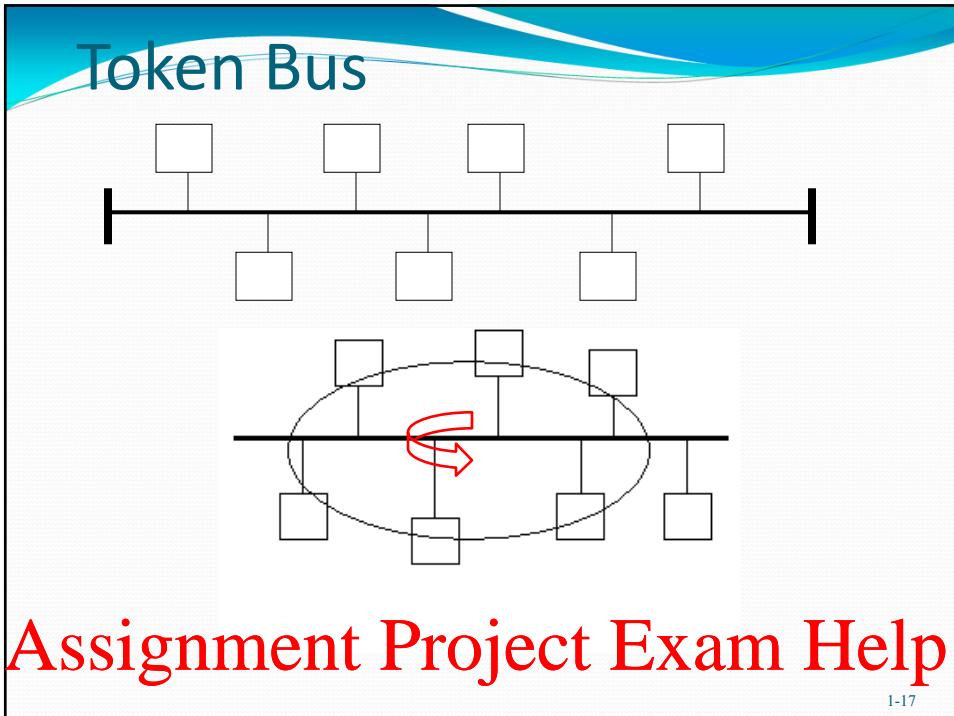


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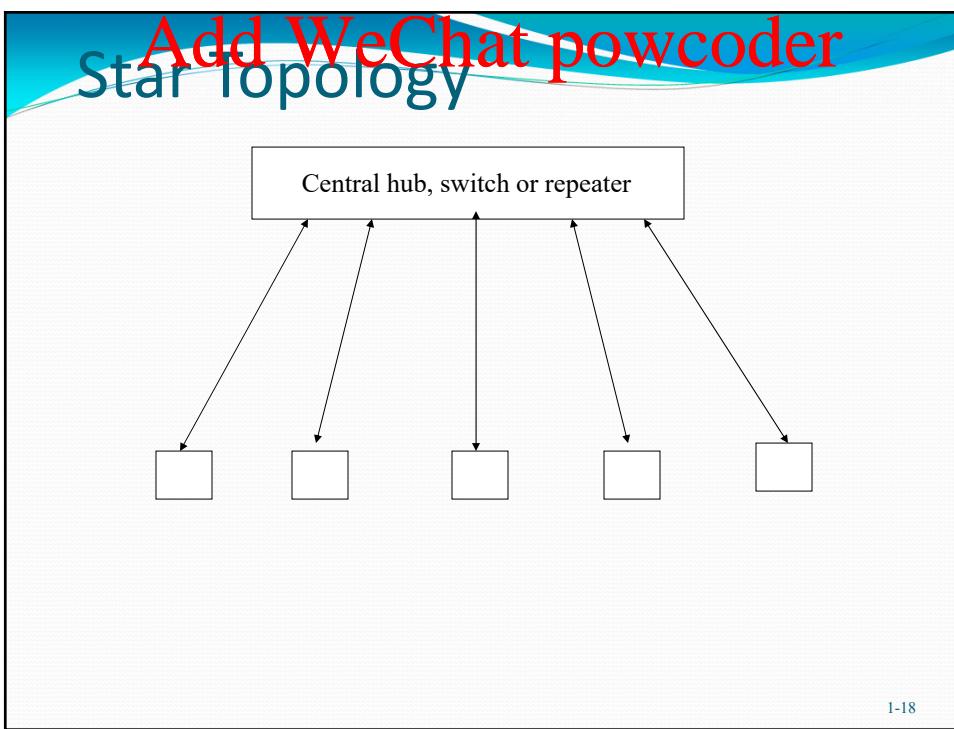


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18

## 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

## Assignment Project Exam Help

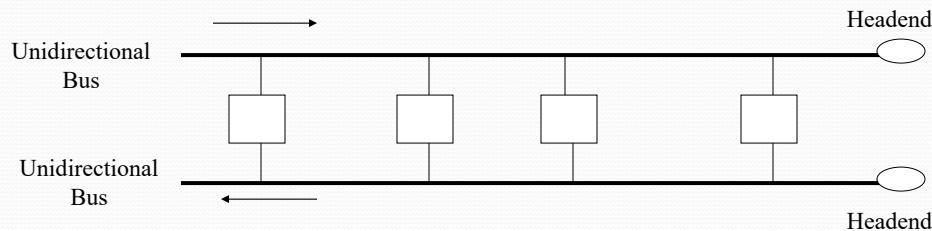
1-19

19

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## Add WeChat powcoder Distributed Queue Dual Bus (DQDB)

Used with Fiber Links



1-20

20

## LAN/MAN MAC Standards

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

## Assignment Project Exam Help

1-21

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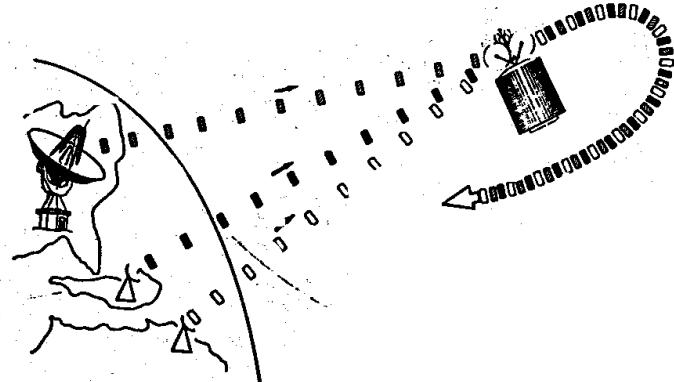
## Add WeChat powcoder IEEE802.3 Medium Access Control

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

1-22

22

## Random Access Packet Radio-Satellite Communication Net



**Assignment Project Exam Help**

1-23

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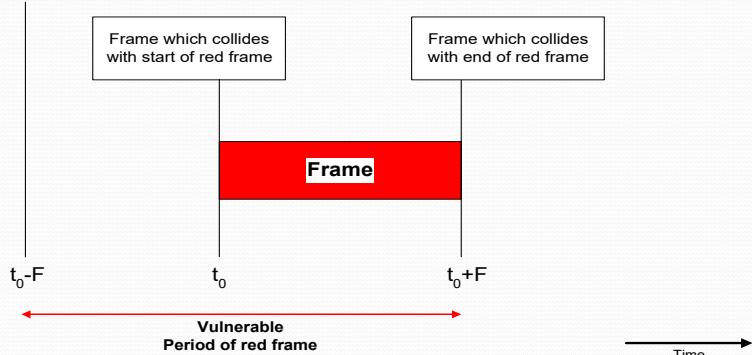
## ALOHA Add WeChat powcoder

- 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

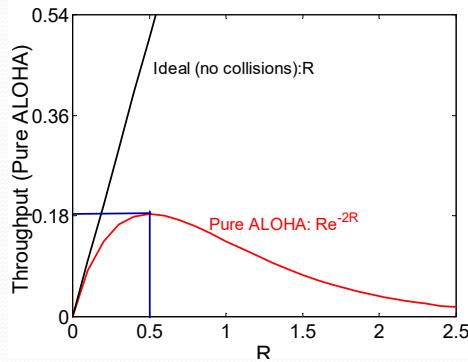
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1-25

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- 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%

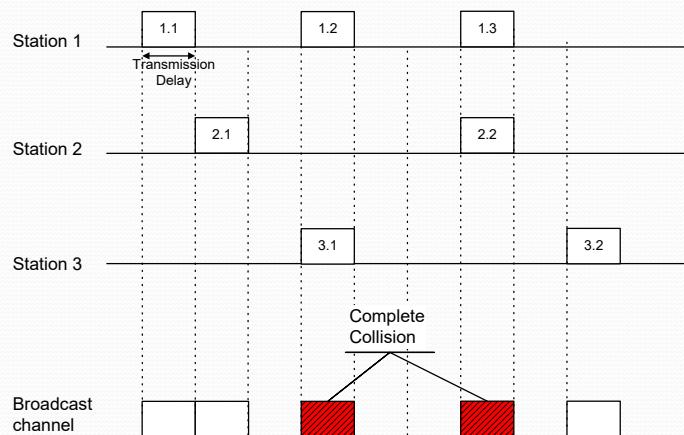
**Assignment Project Exam Help**

1-27

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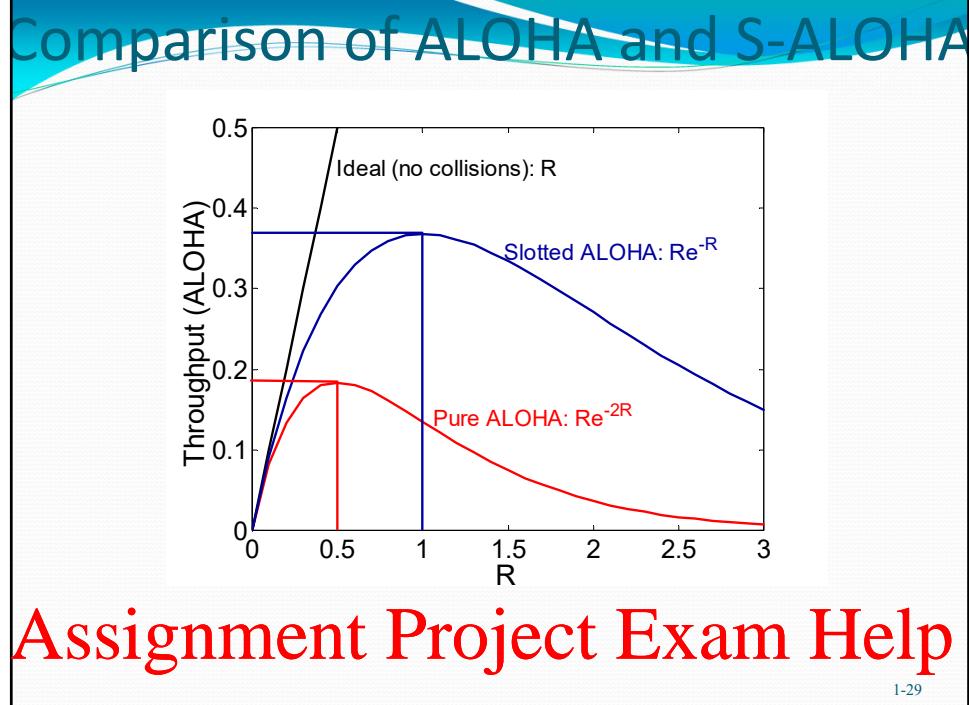
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## Add WeChat powcoder



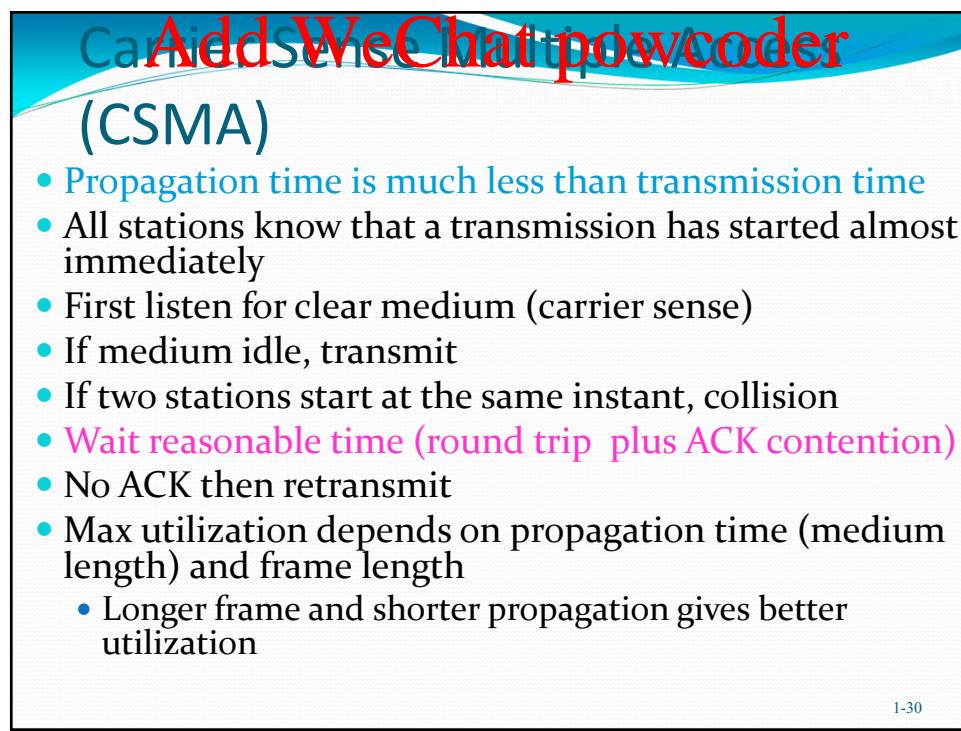
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30

## 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.

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1-31

31

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## Add WeChat powcoder Carrier Sensing Multiple 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

```

graph TD
    Start(( )) --> Listen[listen]
    Listen --> Idle{idle?}
    Idle -- no --> Listen
    Idle -- yes --> Transmit[transmit]
    Transmit --> Collision{collision?}
    Collision -- no --> Listen
    Collision -- yes --> Jamming[jamming signal]
    Jamming --> Wait[wait random time]
    Wait --> Listen
  
```

The flowchart illustrates the CSMA/CD algorithm. It begins with a start node, followed by a 'listen' block. A decision diamond 'idle?' follows. If 'no', it loops back to 'listen'. If 'yes', it proceeds to a 'transmit' block. After transmission, a second decision diamond 'collision?' is reached. If 'no', it loops back to 'listen'. If 'yes', it leads to a 'jamming signal' block, which then leads to a 'wait random time' block, before returning to 'listen'.

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1-33

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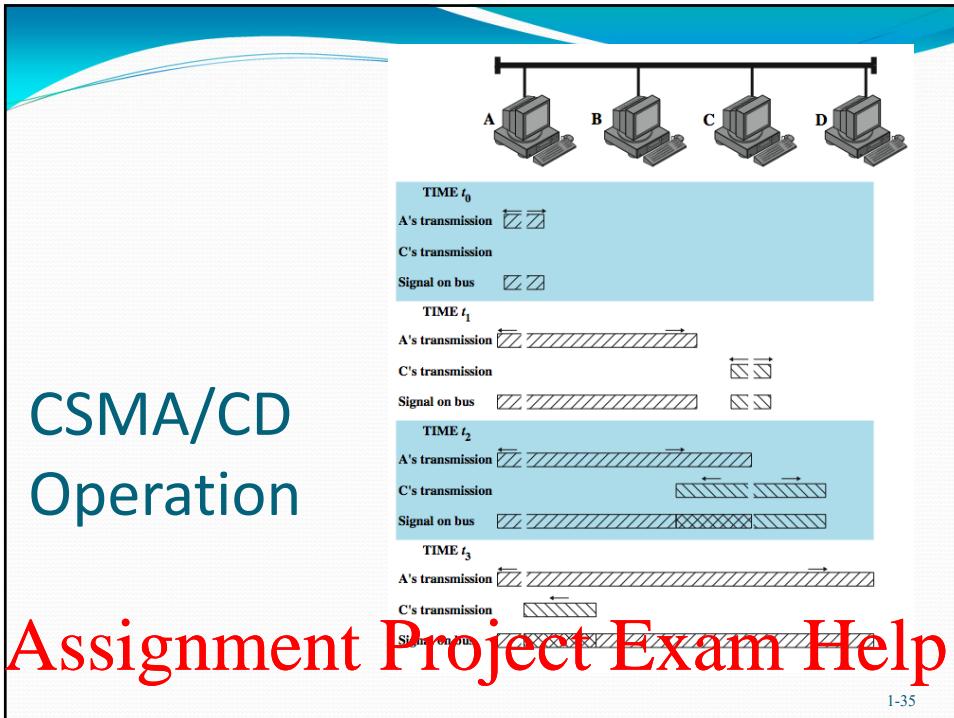
## CSMA with Collision Detection (CSMA/CD)

### Add WeChat powcoder

- 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

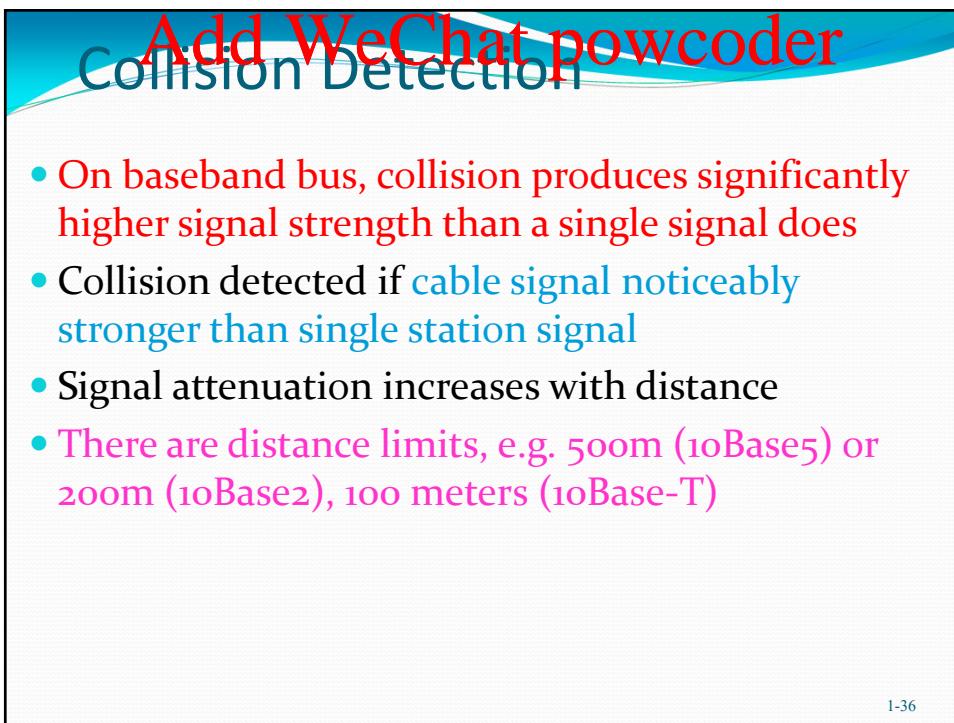
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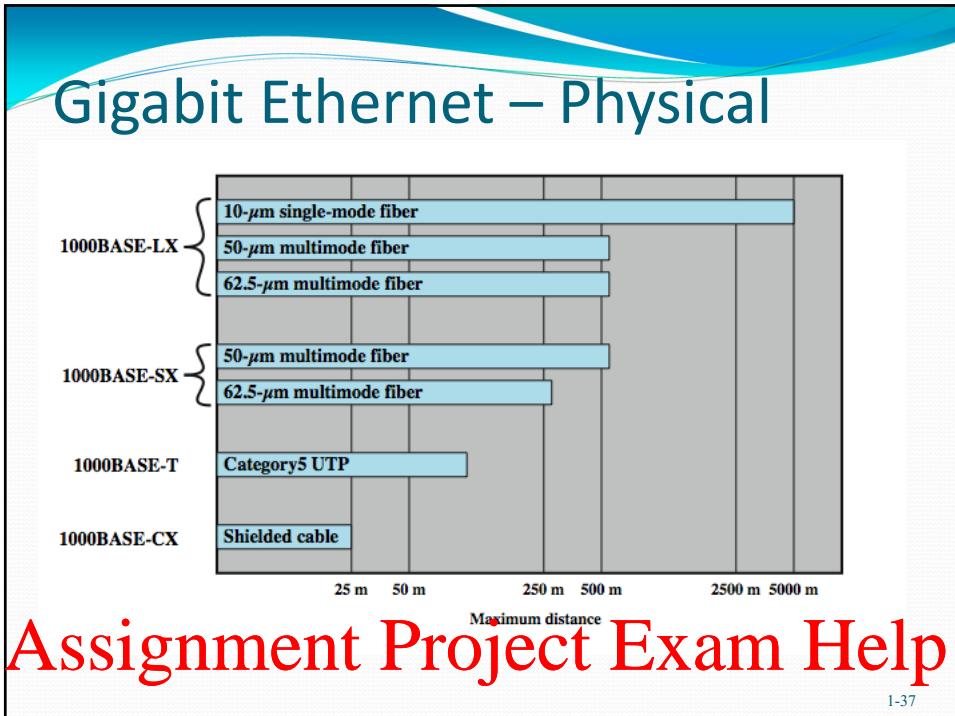


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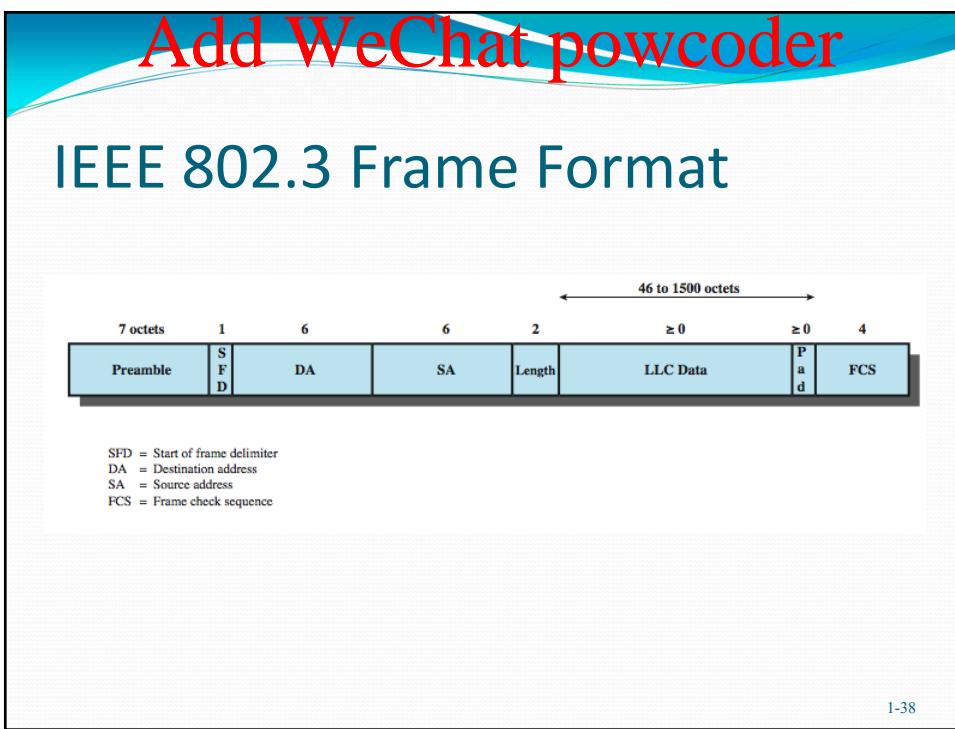


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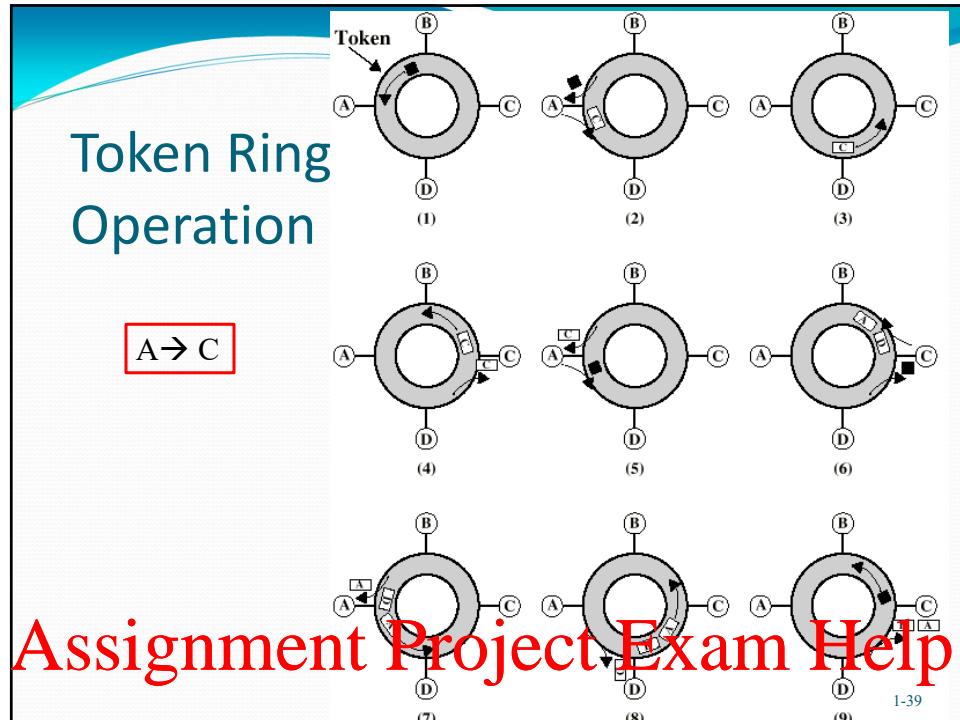


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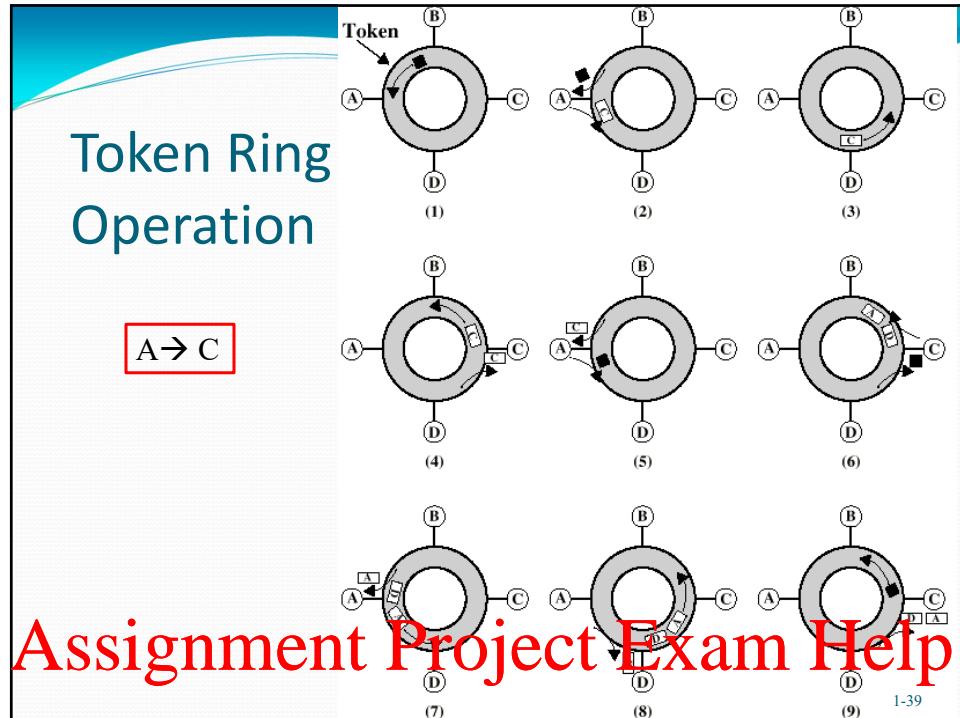
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### Token Ring (802.5)

- 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

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## Add WeChat powcoder

### Token Ring (802.5)

- MAC protocol
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  - Under light loads, some inefficiency
  - Under heavy loads, round robin

1-40

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## FDDI:

### Fiber Distributed Data Interface

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

## Assignment Project Exam Help

1-41

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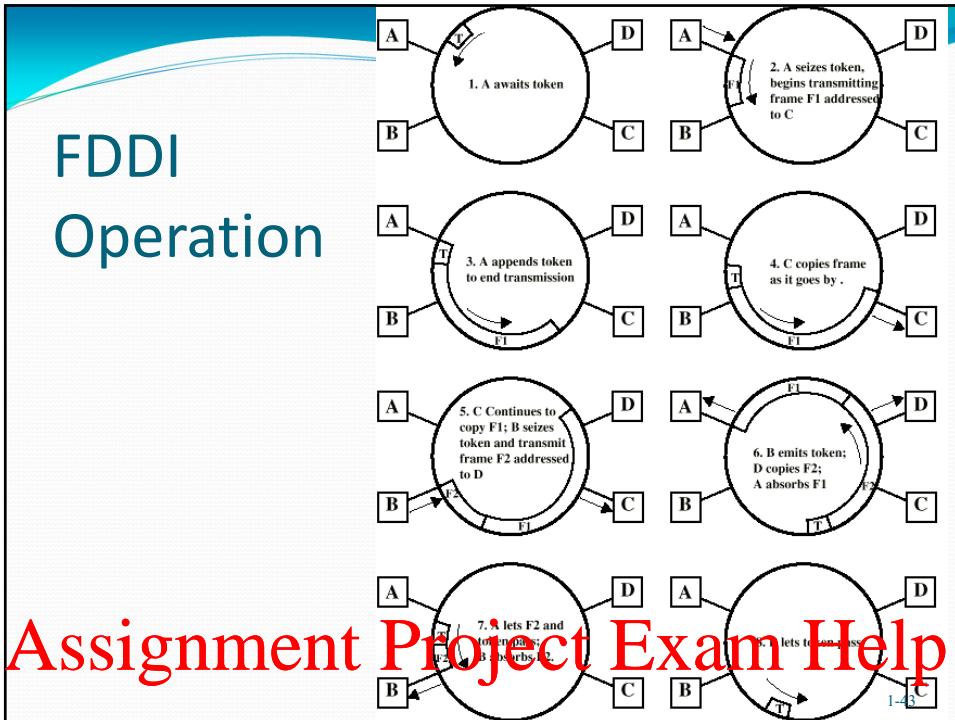
## Add WeChat powcoder FDDI MAC Protocol

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



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## Wireless LANs & PANs

- 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

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1-45

45

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## 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

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

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1-47

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### The hidden node problem

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

The diagram shows two laptop icons representing stations. One station is connected to a base station icon (a blue box with two antennae) by a straight line. Another station is shown below and to the left, with a diagonal line extending from it towards the base station, indicating that the base station cannot see this station directly due to a hidden terminal.

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1-49

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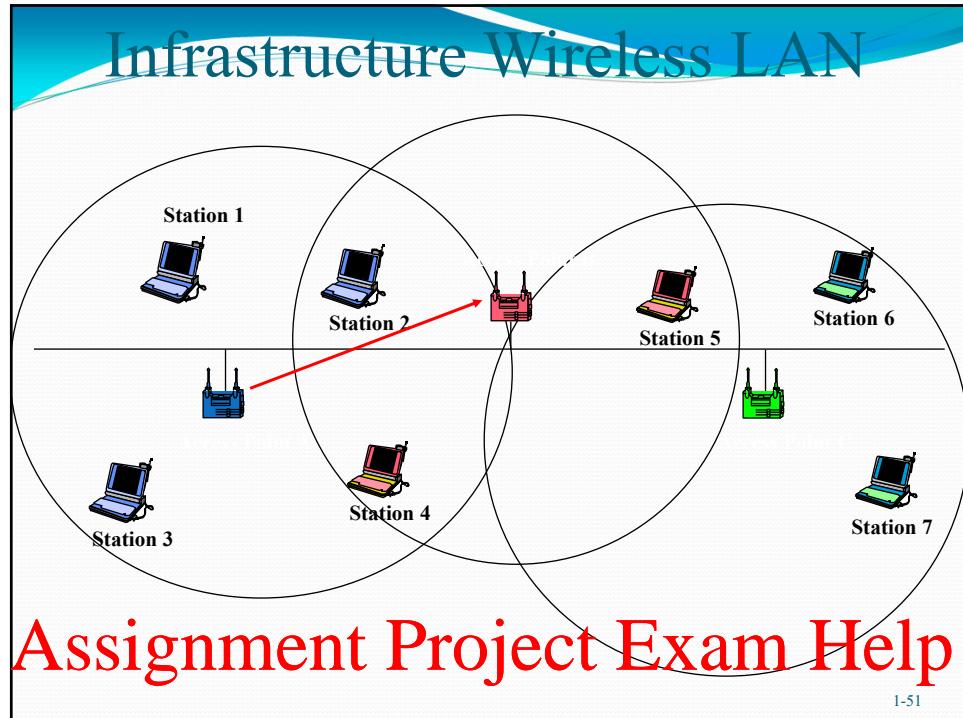
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## Add WeChat powcoder

### Ad Hoc Wireless LAN

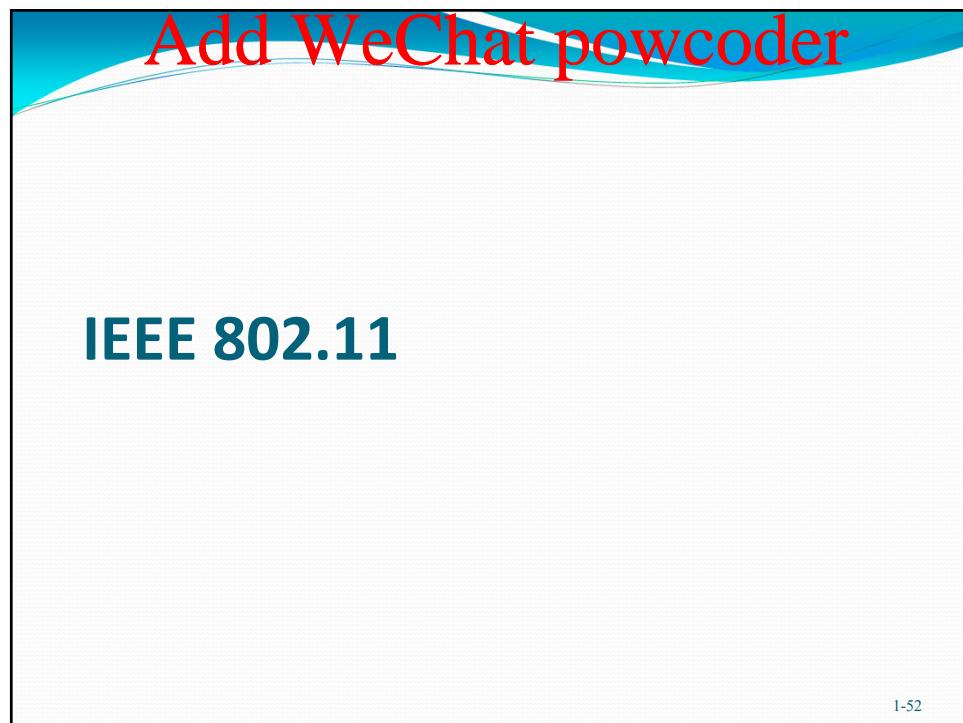
The diagram shows four laptop icons labeled Station 1, Station 2, Station 3, and Station 4, all enclosed within a single large oval boundary. A red line connects Station 1 and Station 2, and another red line connects Station 3 and Station 4, representing direct links between these pairs of stations.

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## 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

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## 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 Mbps	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

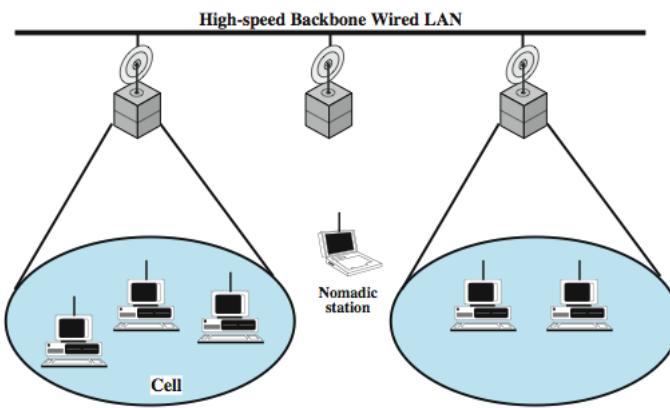
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## Add WeChat powcoder Infrastructure Wireless LAN

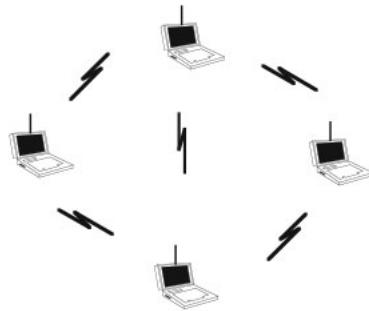


1-56

56

# Ad Hoc Networking

- peer-to-peer network



## Assignment Project Exam Help

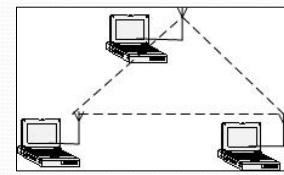
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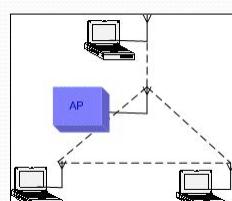
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## Add WeChat powcoder Architectures summary

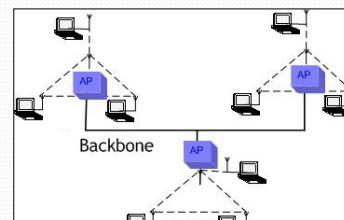
- There are different topologies for an IEEE 802.11 WLAN
- A basic service set (BSS) is a set of terminals that communicate locally, either directly or through multiple hops, but no wired segments



Independent BSS  
(Ad-hoc, MANETs)



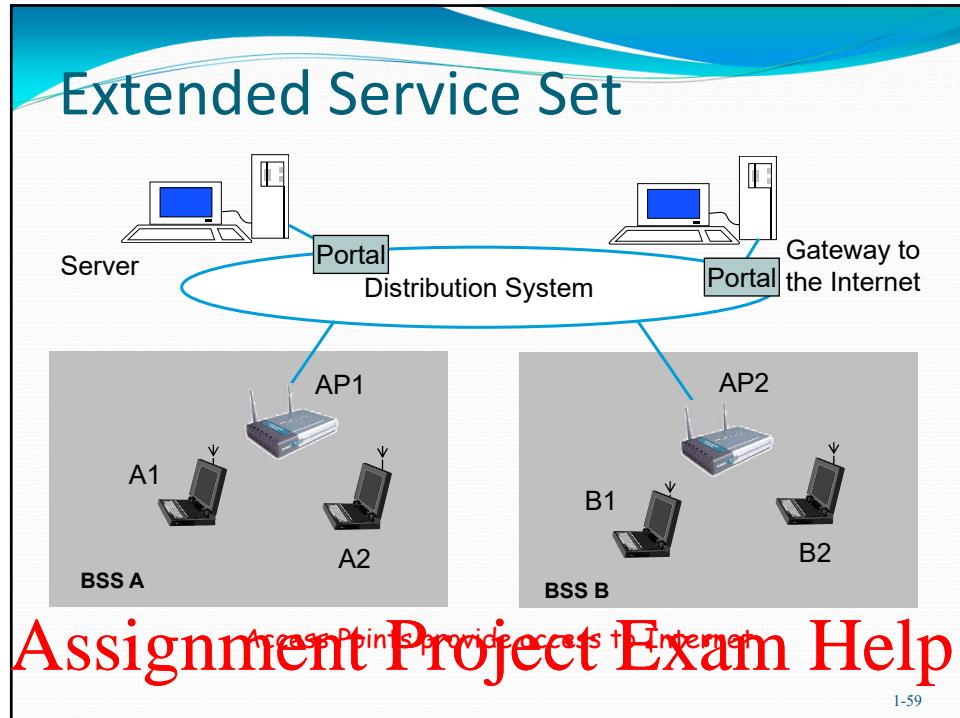
Infrastructure BSS



Extended SS

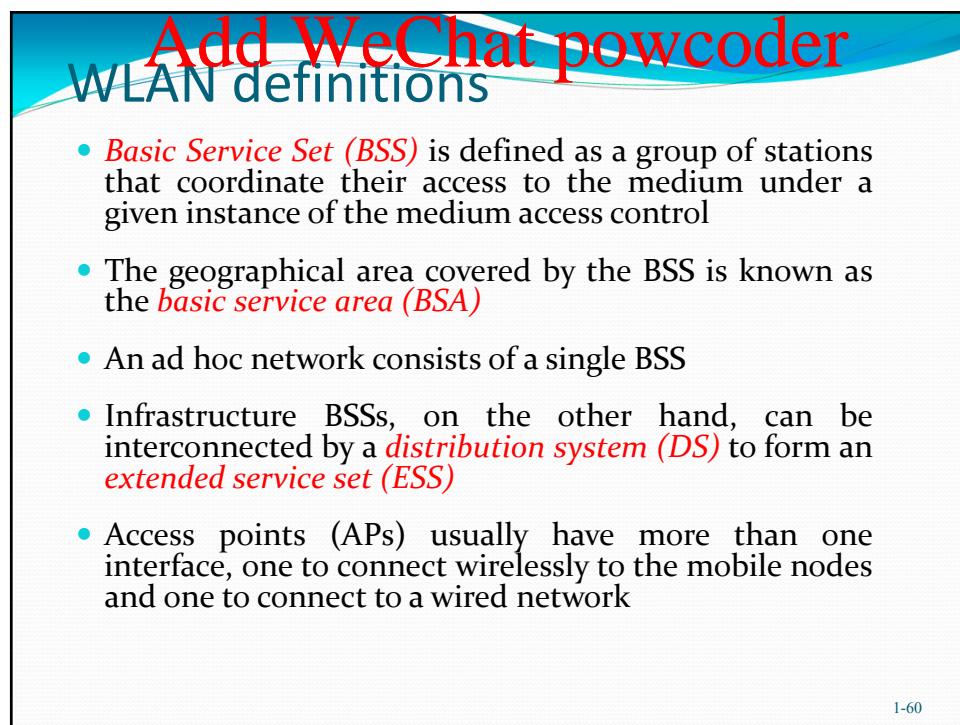
1-58

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## 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.

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1-61

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## Add WeChat powcoder

### Establishing Connectivity: Scanning

- 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.

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1-63

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## Add WeChat powcoder 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.

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1-65

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## 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

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## Add WeChat powcoder MAC & PHY Layer Operation

- 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

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1-68

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## Add WeChat powcoder 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

1-69

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## 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

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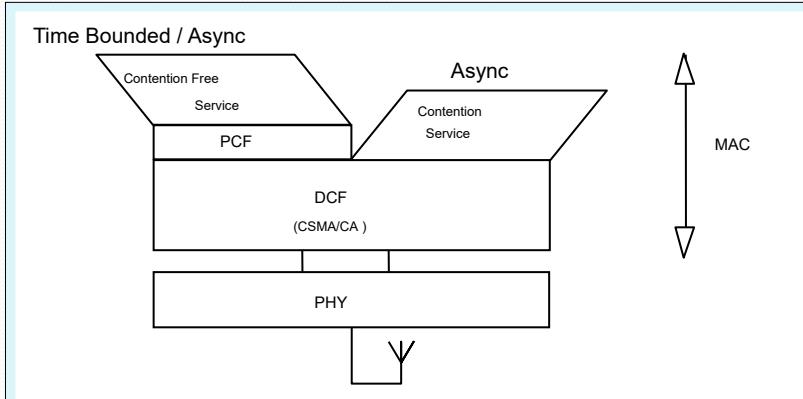
## Add WeChat powcoder CSMA/CA: Interframe spaces

- 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)

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## Optional Point Coordination Function



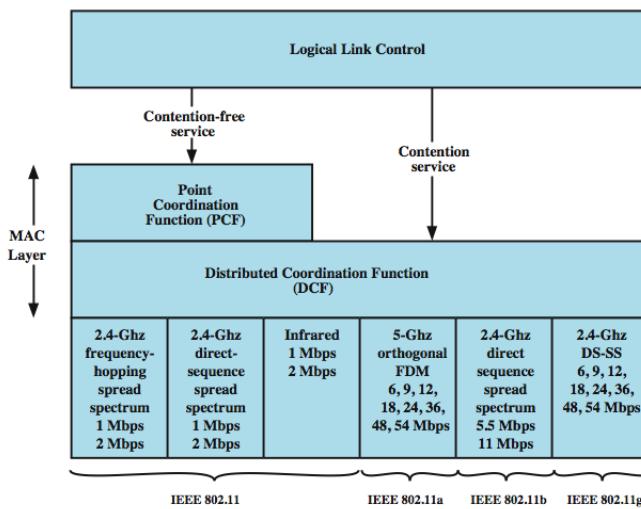
- Async Data, Voice, Video or mixed implementations
- Coexistence between Contention and Contention free

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## Add WeChat powcoder Media Access Control



1-73

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## Distributed Coordination Function (DCF)

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1-74

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## Add WeChat powcoder CSMA/CA: Interframe spaces

- Time, the stations have to wait after completion of a packet transmission
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1-75

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## Network Allocation Vector

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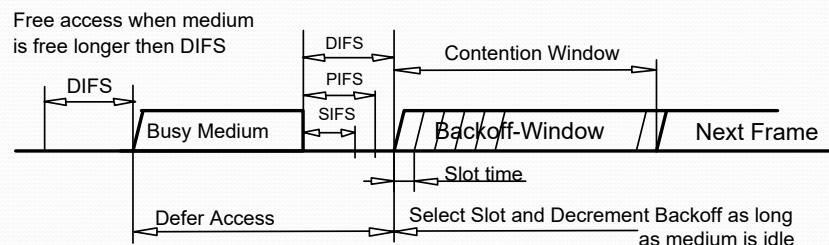
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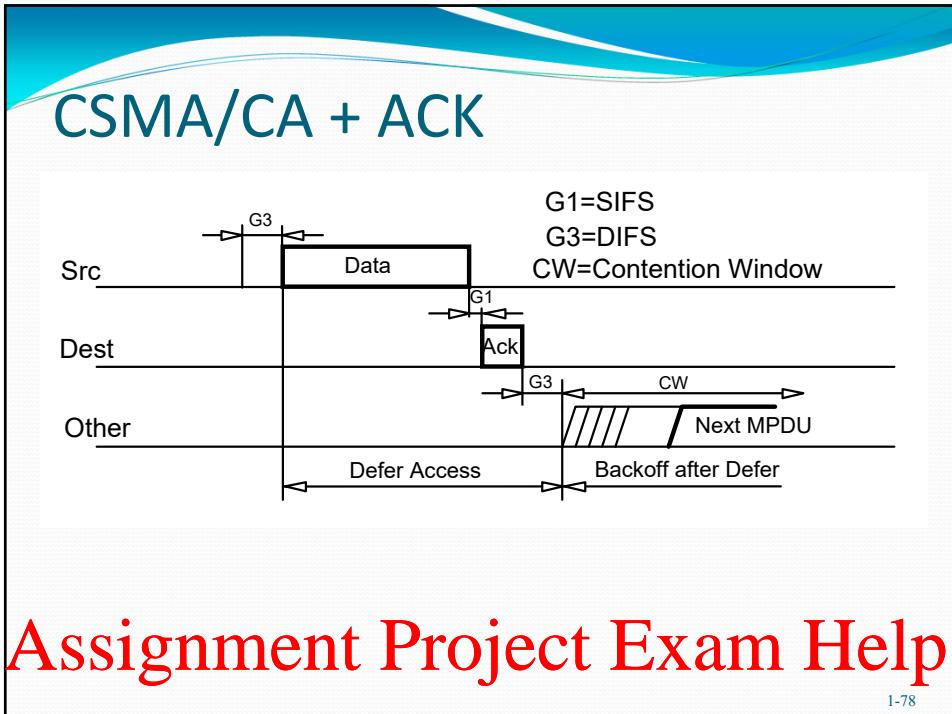
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## Add WeChat powcoder CSMA/CA



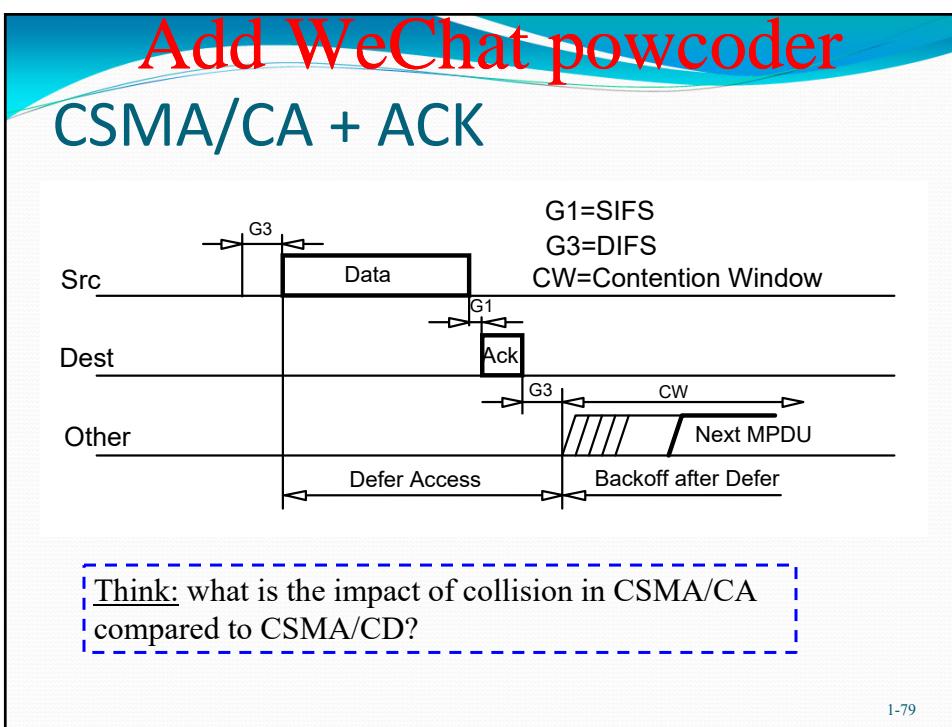
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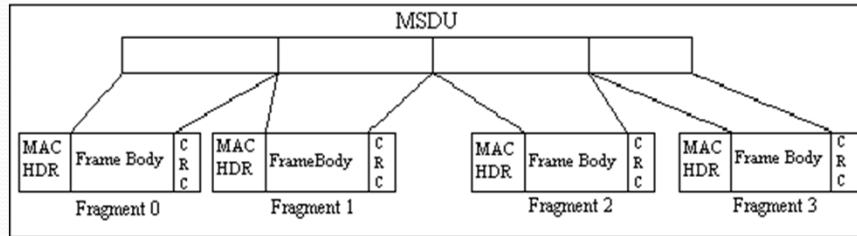
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## Fragmentation (1)



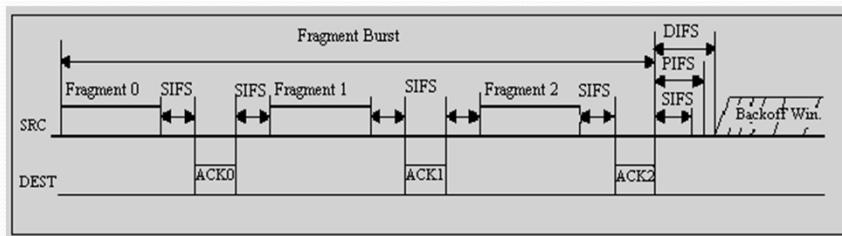
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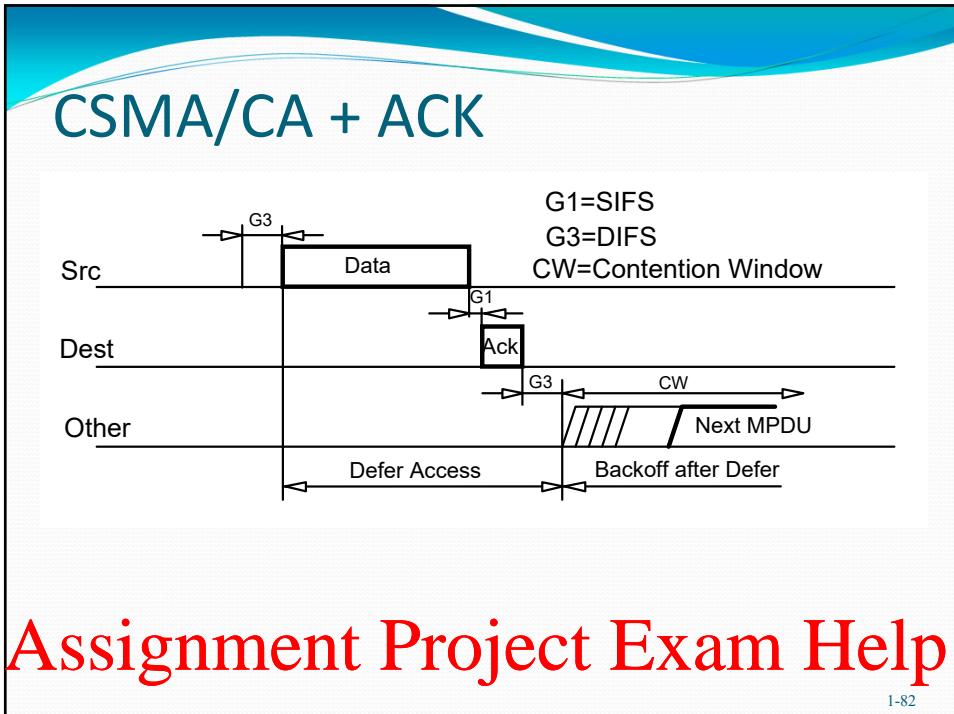
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## Fragmentation (2)



1-81

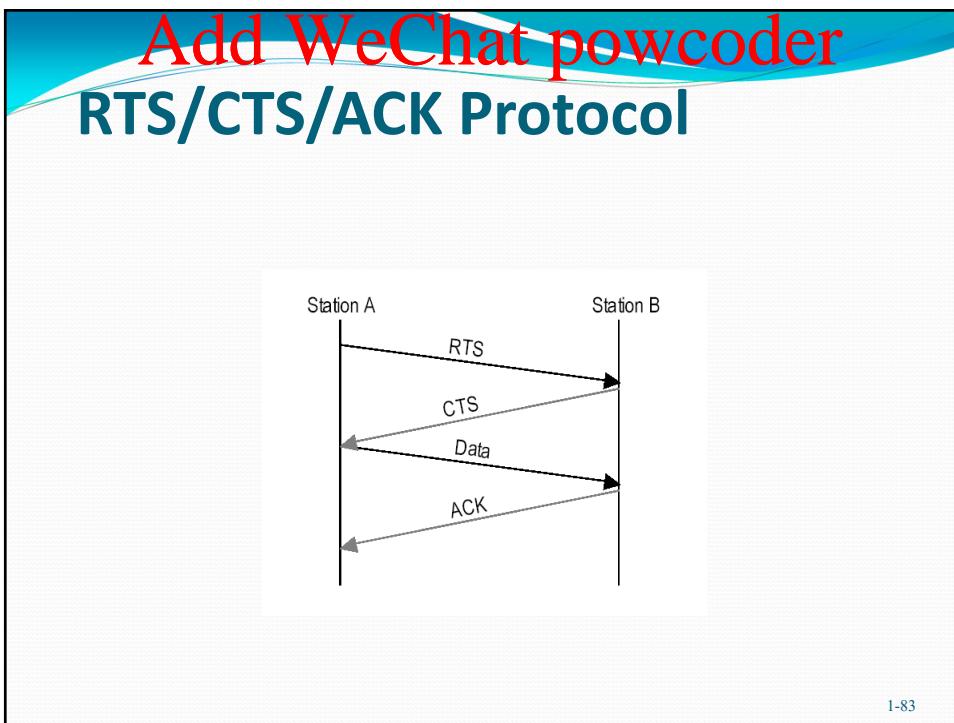
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## RTS/CTS Process Functioning

- Example:

The diagram illustrates the RTS/CTS process functioning. It shows the sequence of frames between a Transmitter and a Receiver over time. The Transmitter sends an RTS frame, followed by a Frame, and then an ACK frame. The Receiver responds with a CTS frame and then an ACK frame. The NAV (Network Allocation Vector) is updated at each step. The diagram includes SIFS (Short Inter Frame Space), DIFS (Distributed Inter Frame Space), and a Contention window.

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## Add WeChat powcoder 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

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1-85

**RTS/CTS improves performance in the presence of hidden terminals**

The diagram shows two nodes (laptops) connected by a straight line, and another node (laptop) located below and to the right, represented by a zigzag line, indicating it is a hidden terminal. To the right, two overlapping circles represent the 'Área accesible para nodo 1' (Node 1's accessible area) and 'Área accesible para nodo 2' (Node 2's accessible area). Inside these areas are three nodes labeled 1, 2, and 3. Node 1 is in the intersection of both areas, while nodes 2 and 3 are only in the area of Node 2.

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1-86

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## Fragmentation using RTS/CTS

The timing diagram illustrates the sequence of frames and interframe spaces (IFS) during a fragmented transmission. The timeline is divided into several intervals:

- NAV (RTS)
- NAV (CTS)
- NAV (Fragment0)
- NAV (ACK0)
- NAV (Fragment1)
- NAV (ACK1)
- DIFS
- PIFS
- SIFS
- Backoff

Below the timeline, the sequence of frames is shown between the Source (SRC) and Destination (DEST).

Frame Type	Sequence	Interframe Space
RTS	1	SIFS
CTS	2	SIFS
Fragment0	3	SIFS
ACK0	4	SIFS
Fragment1	5	SIFS
ACK1	6	SIFS
ACK2	7	Backoff

1-87

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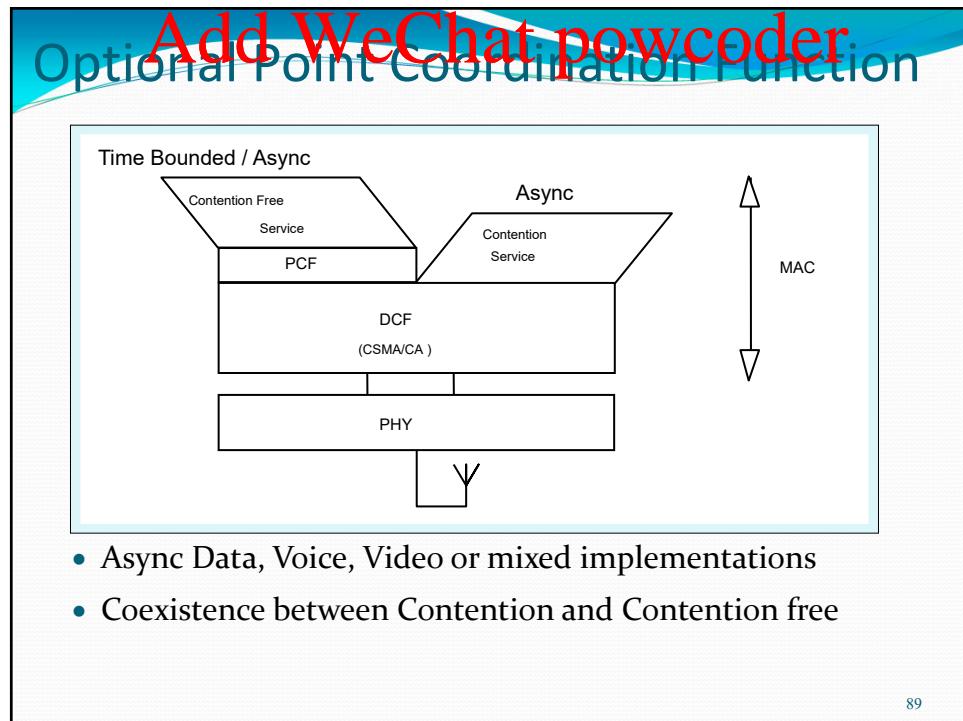
## Point Coordination Function (PCF)

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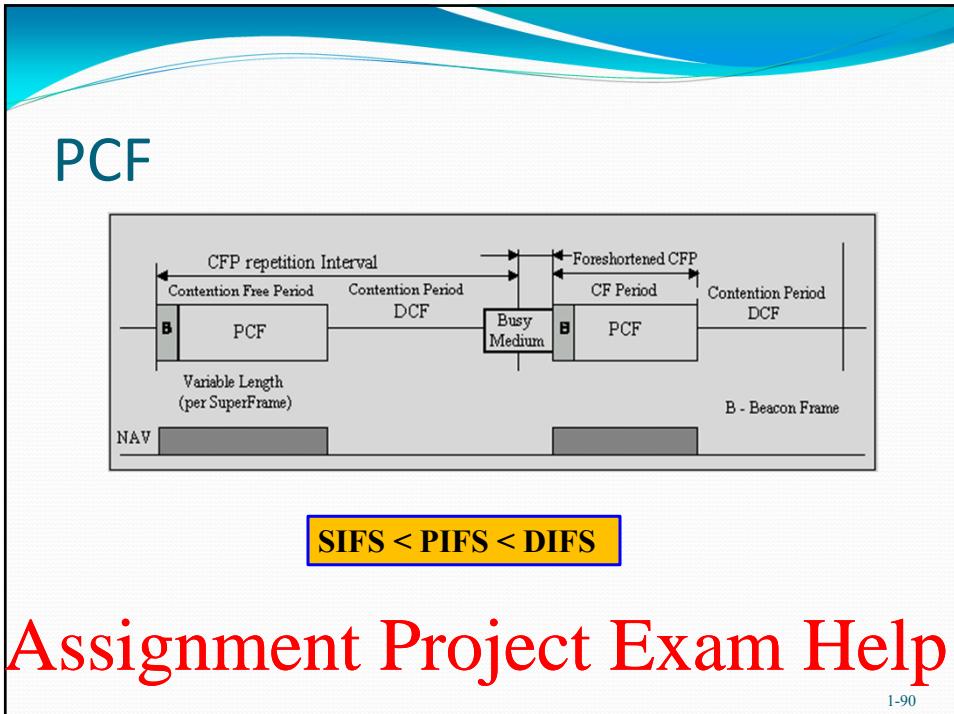
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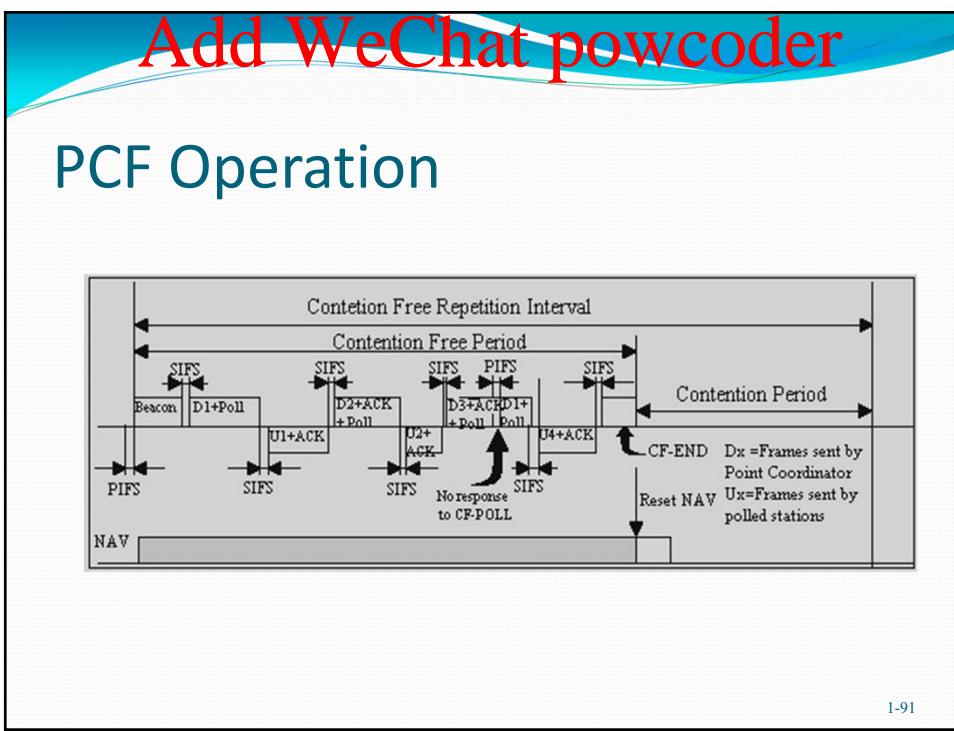


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## PCF Limitations

- 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.

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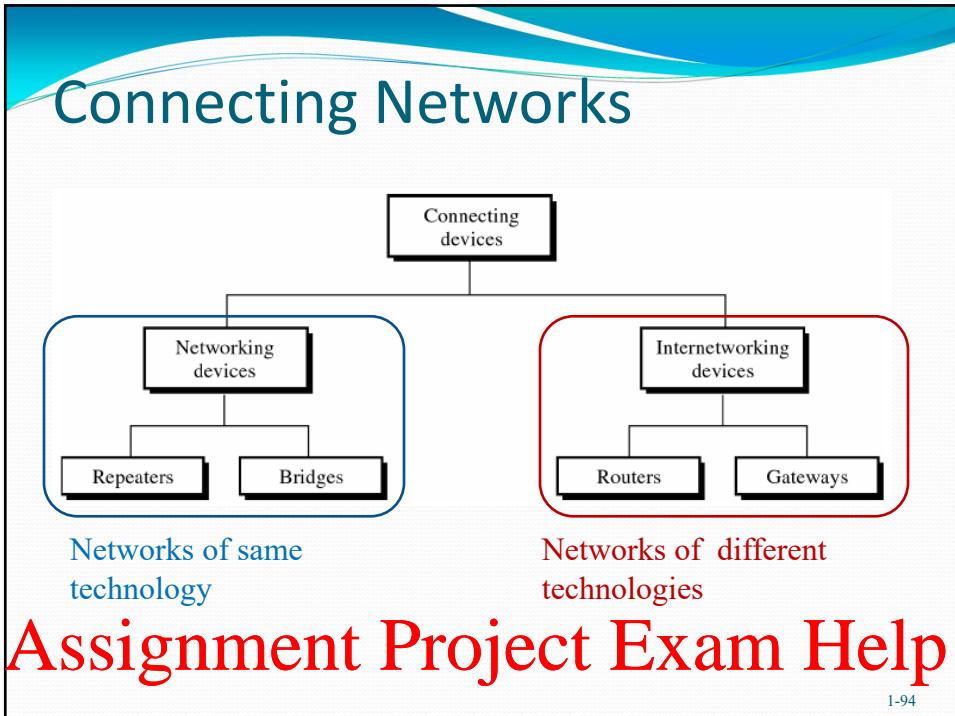
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### IEEE 802.11e standard (QoS MAC)

- 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.

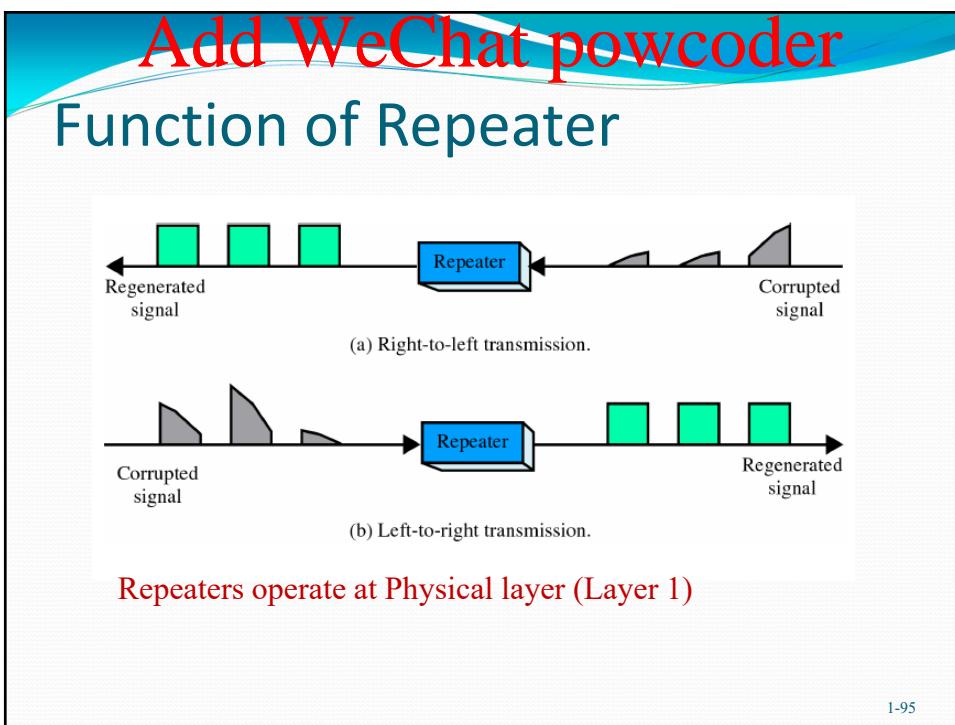
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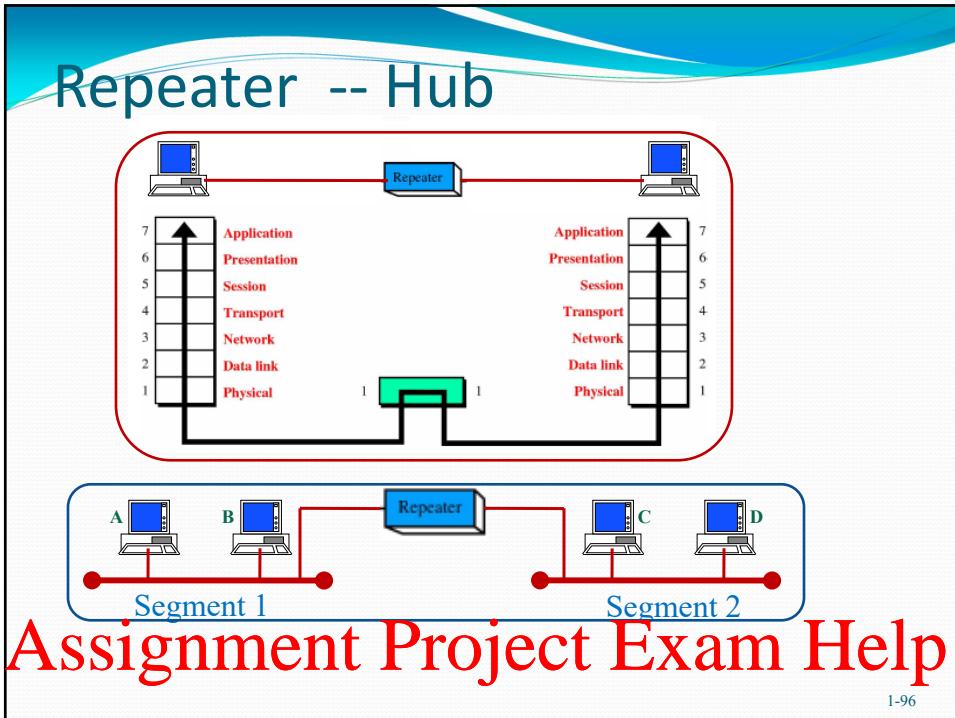


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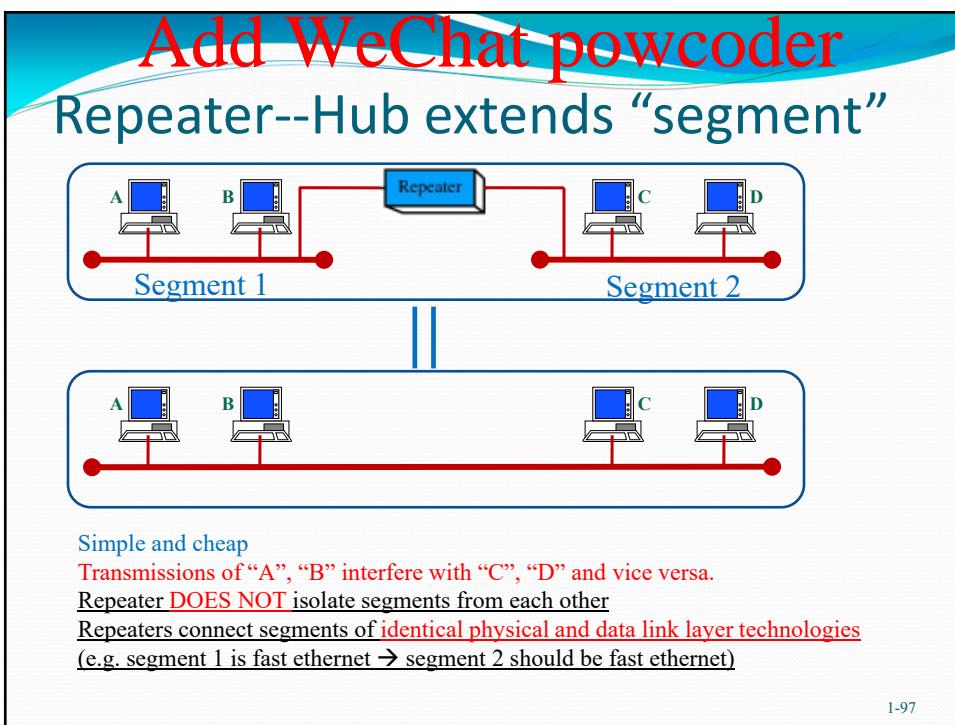


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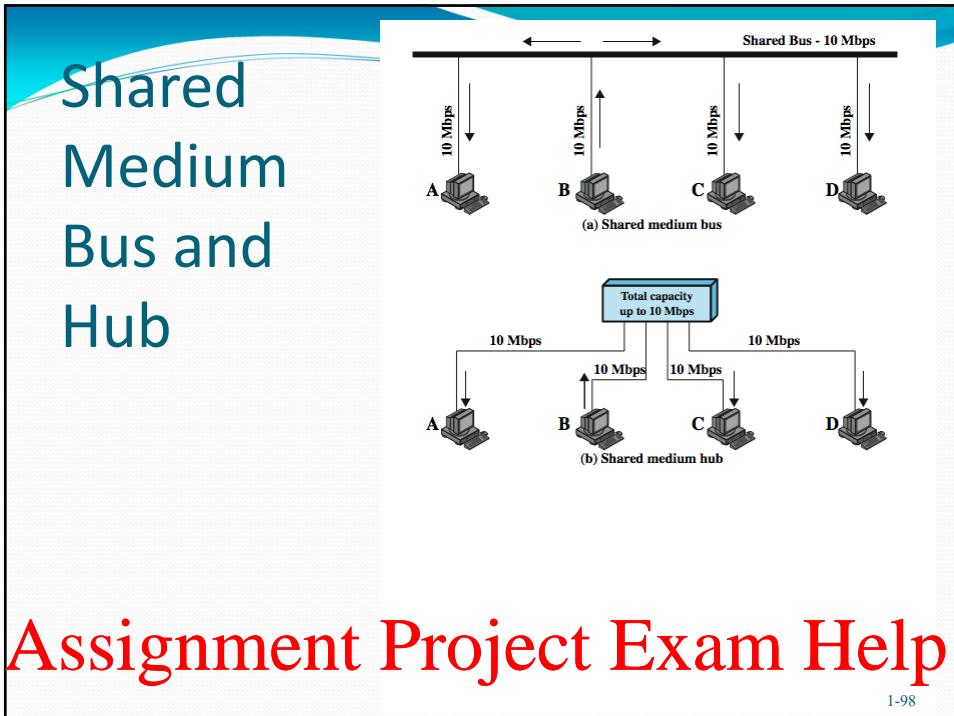


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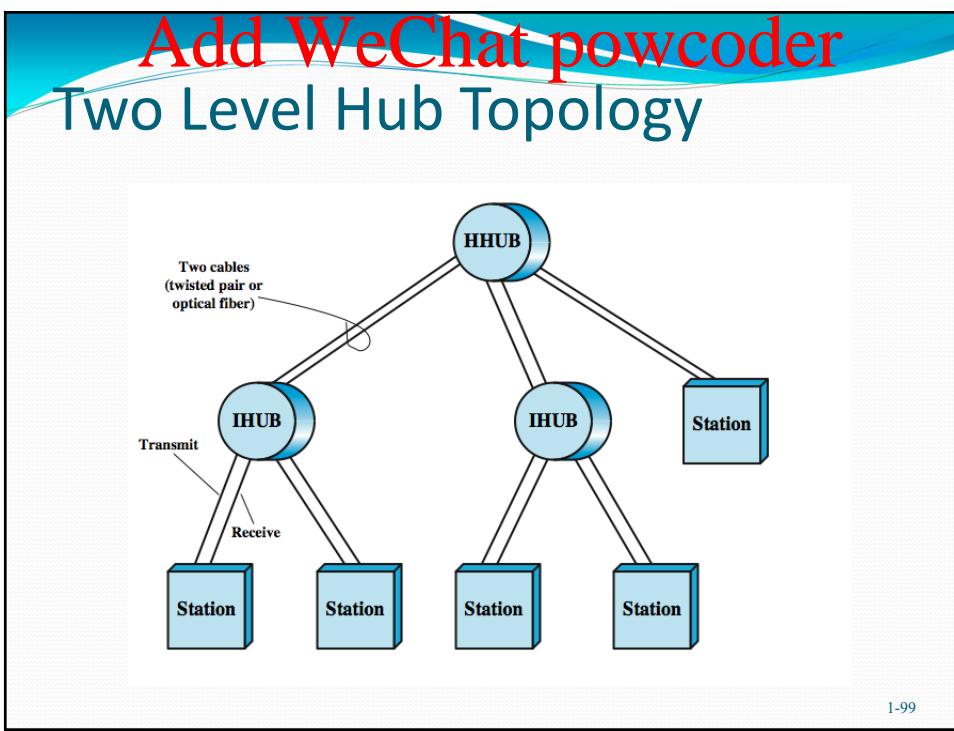


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1-99

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## Bridge

Bridges operate at Data Link layer (Layer 2)  
 They physically separate the PHY layers of different segments  
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1-100

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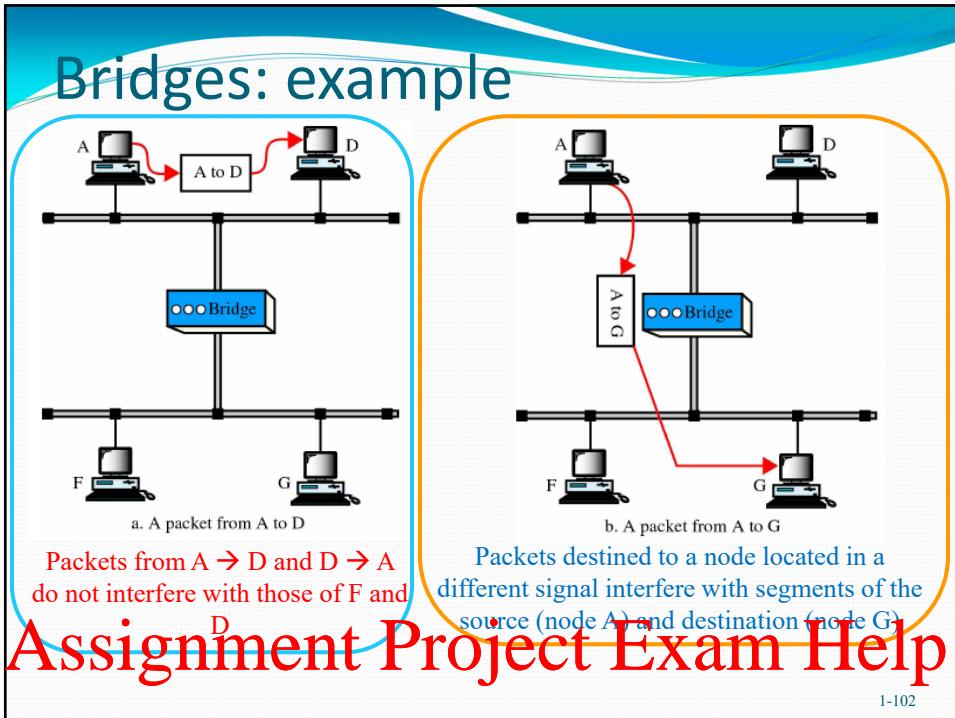
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### Interconnecting LANs - Hubs

- 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

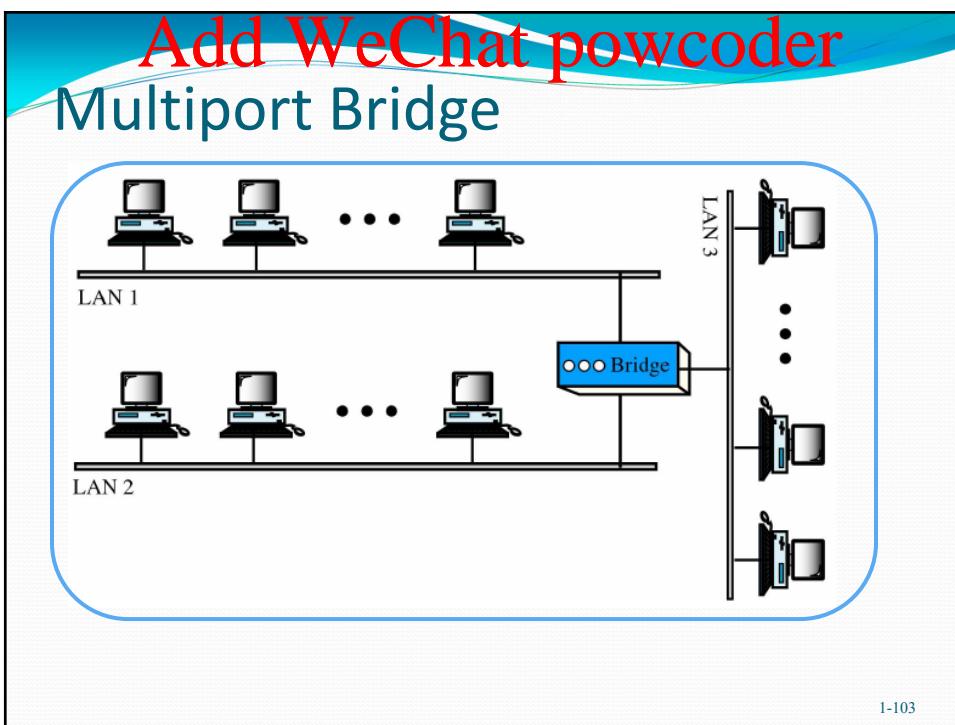
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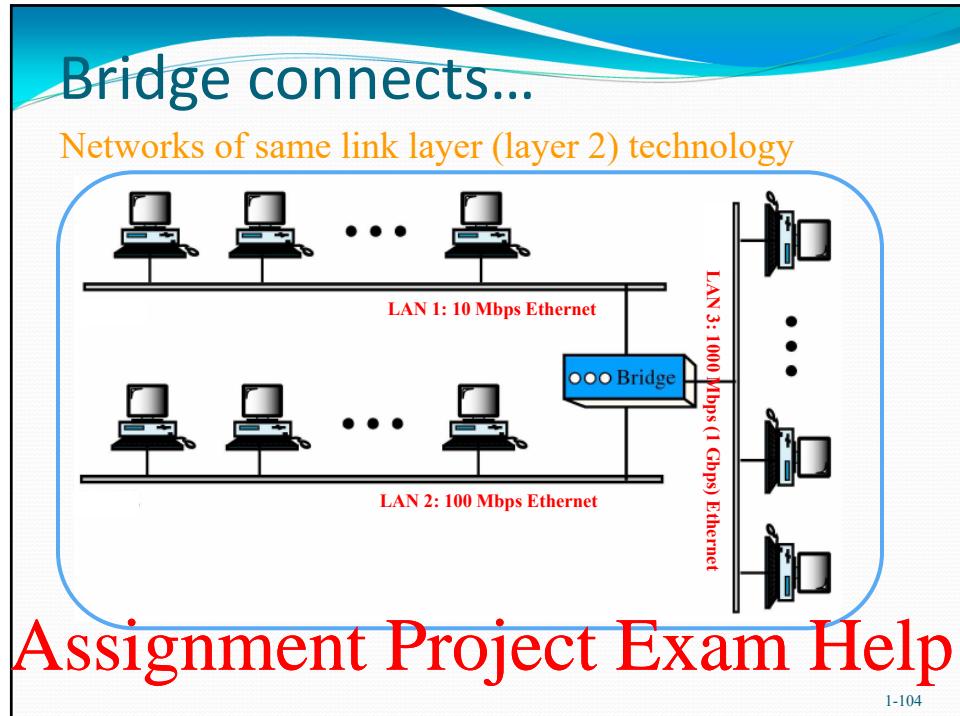


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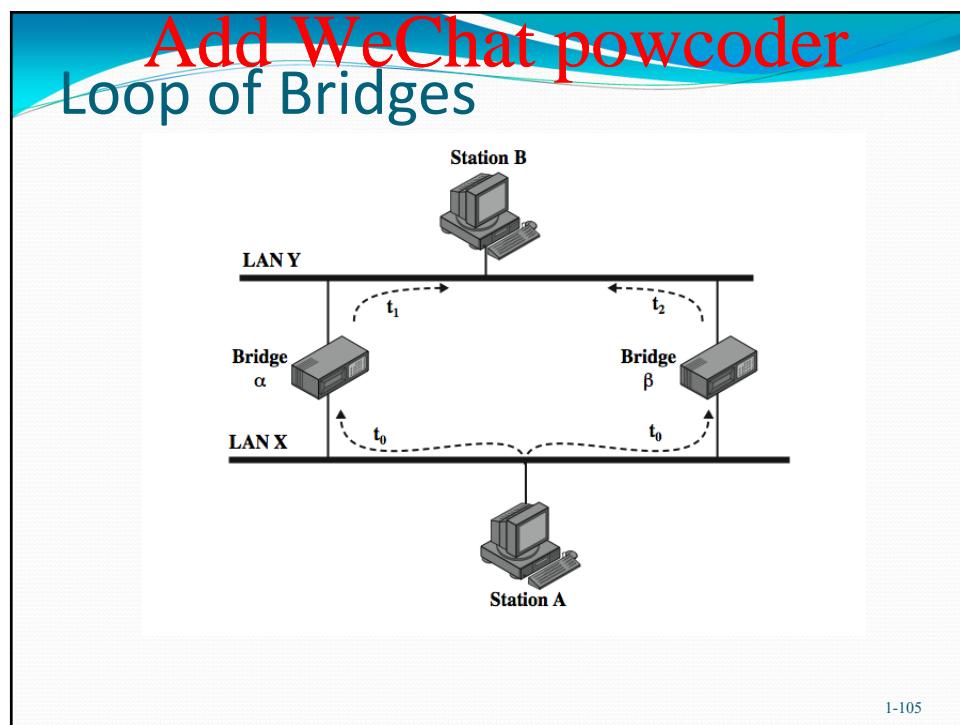


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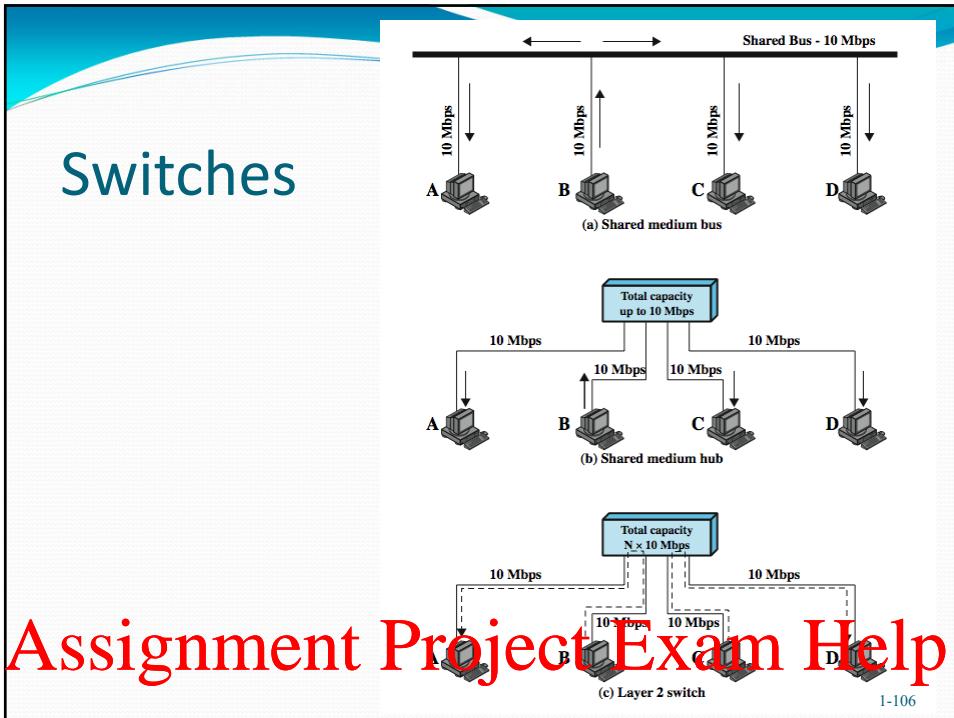


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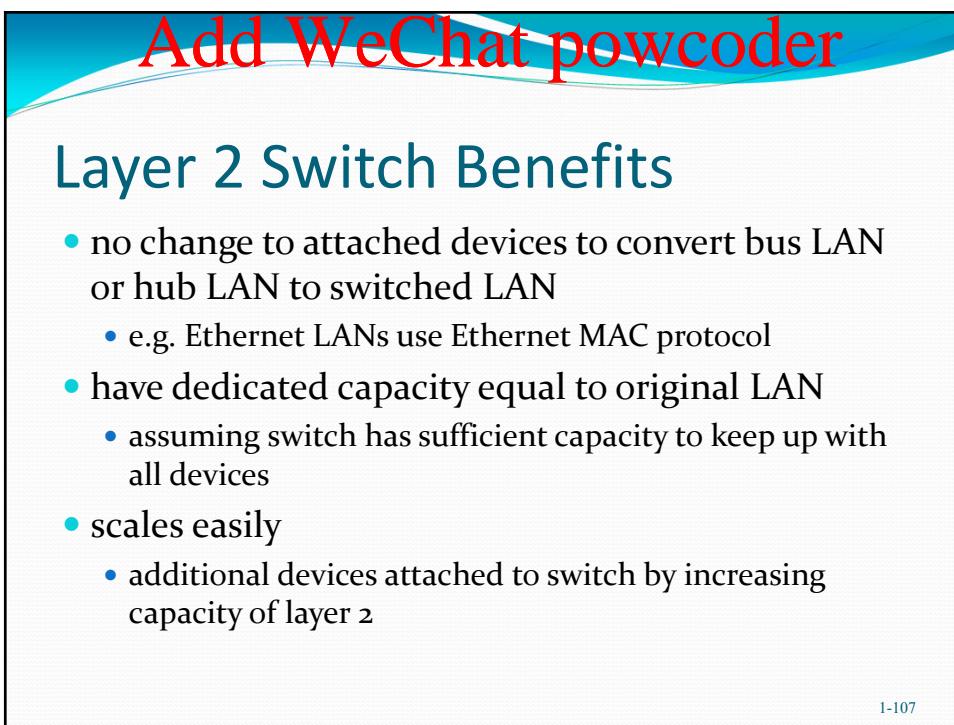


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1-107

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## 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

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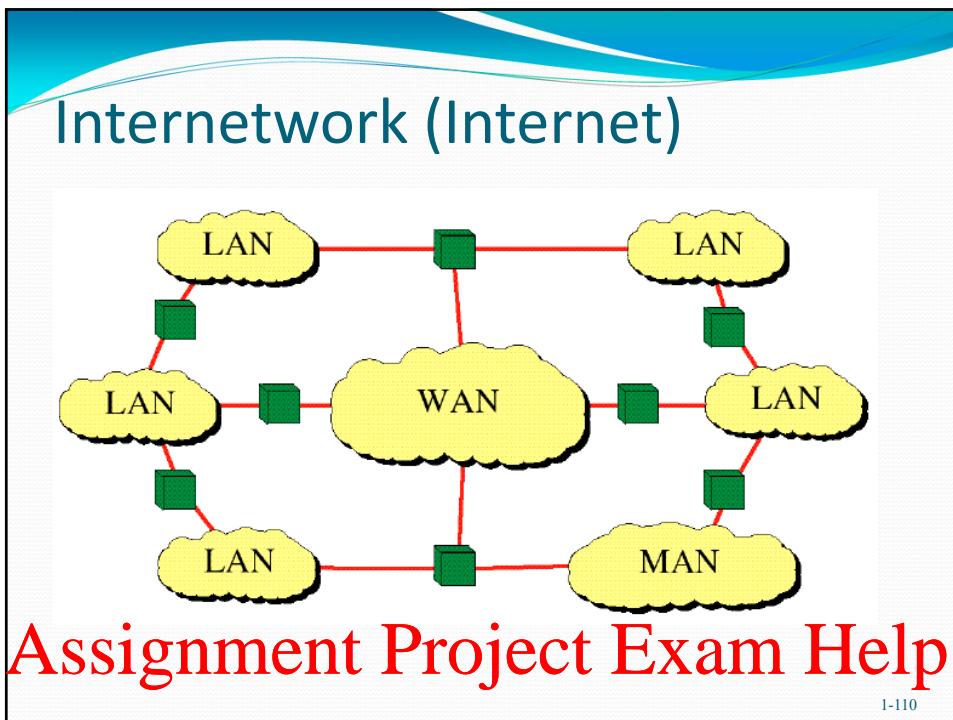
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## Add WeChat powcoder Layer 2 Switch Problems

- 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

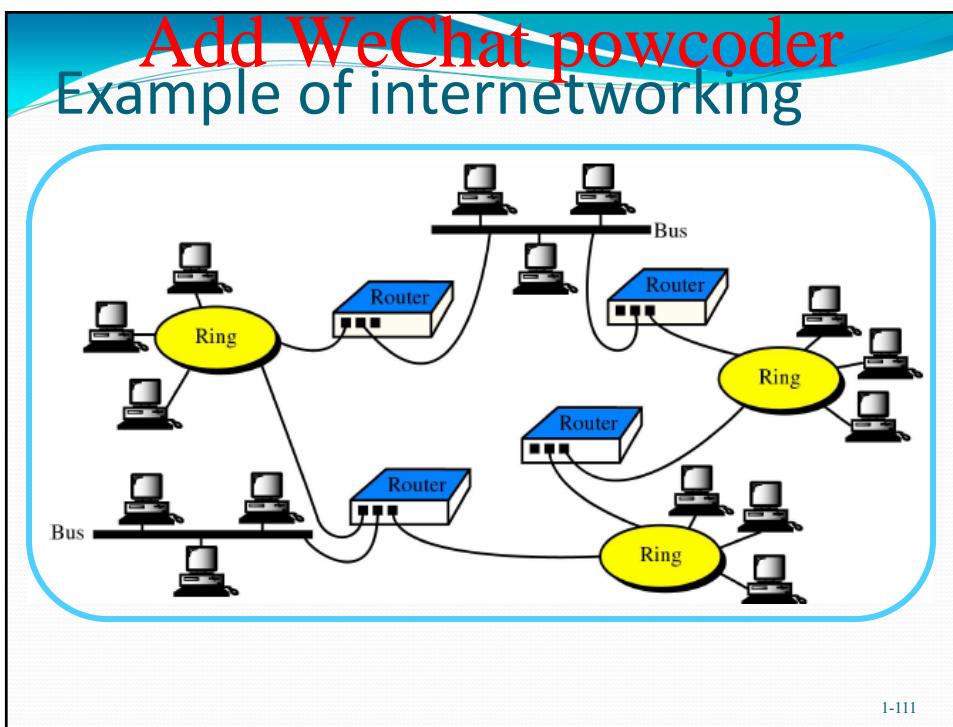
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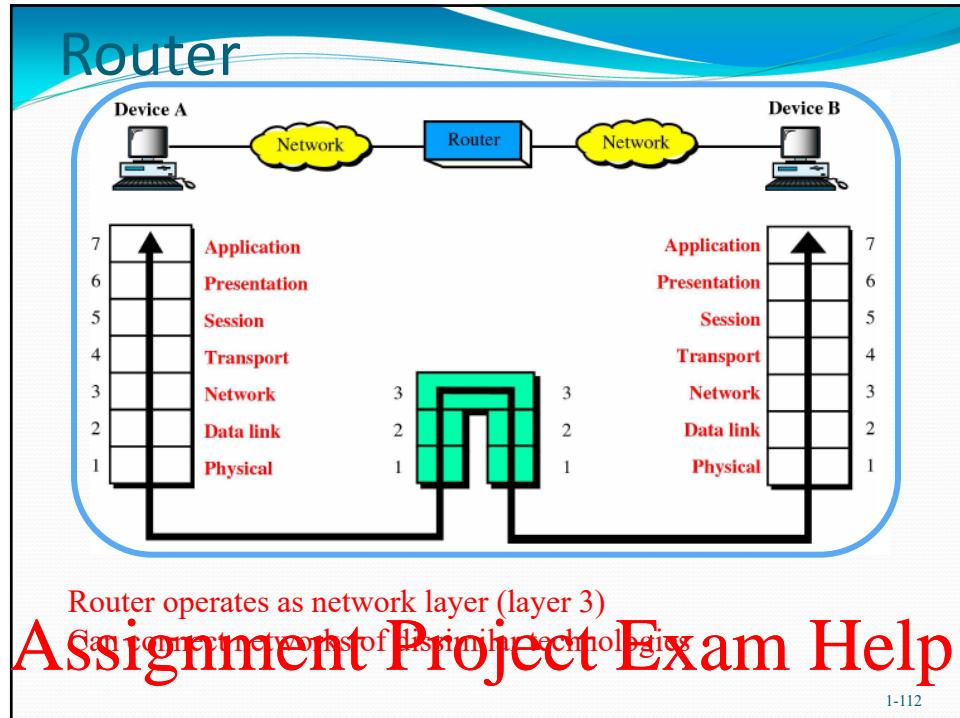


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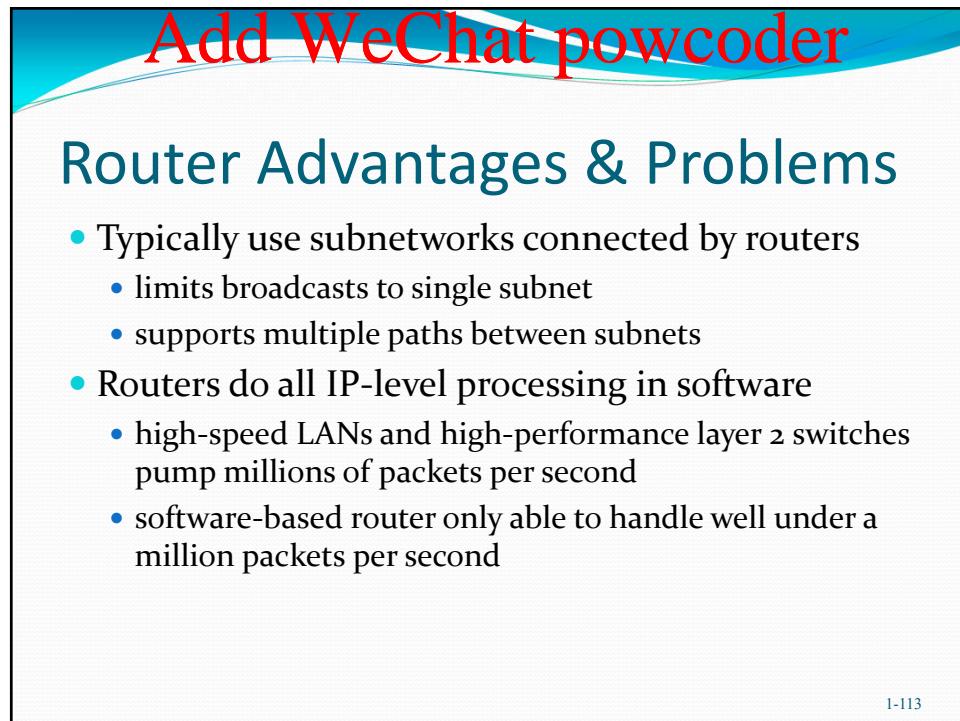


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## Use of Layer 3 Switches

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

1-114

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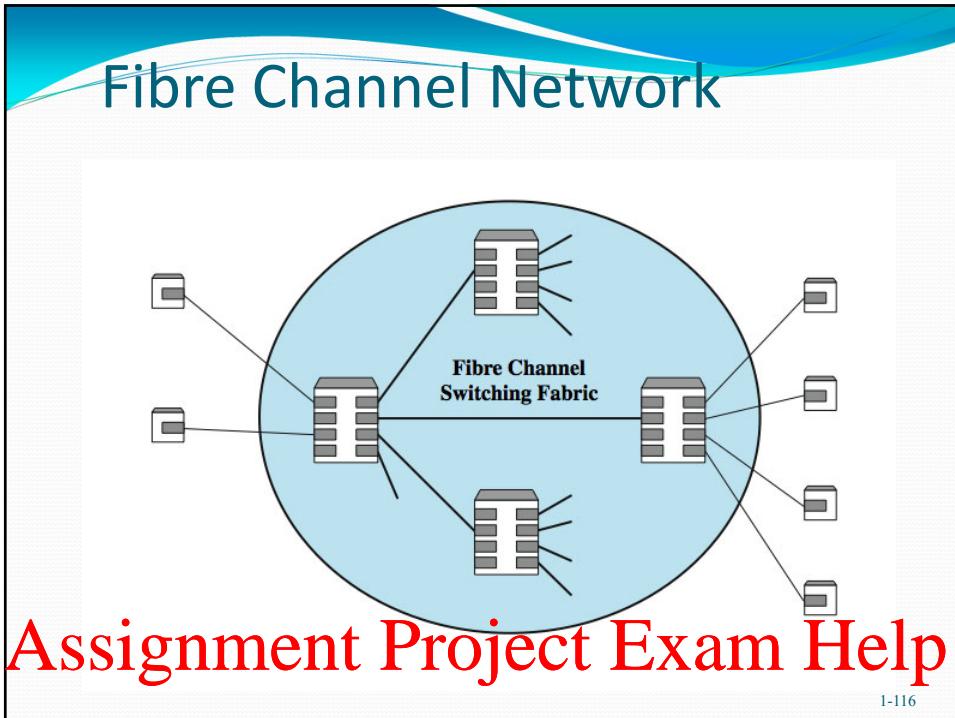
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## Add WeChat powcoder Packet by Packet or Flow Based

- 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

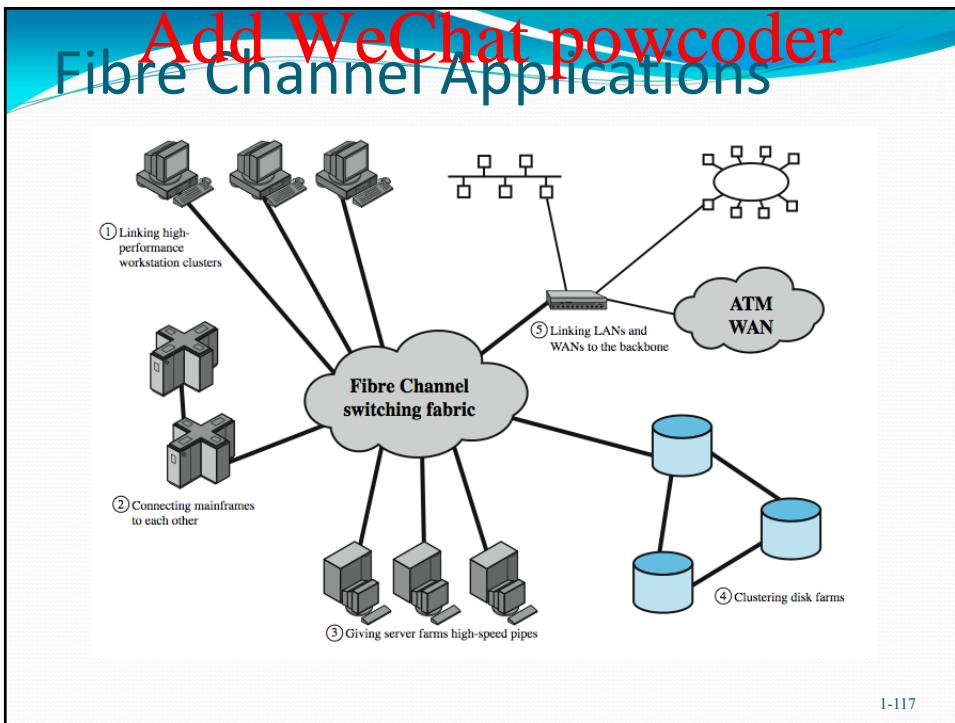
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## Fibre Channel - Background

- 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

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1-118

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## Add WeChat powcoder 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

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## 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

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1-120

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## 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

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# END

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**EECS, University of Ottawa**

**CEG3185 –Winter 2021**

**Introduction to Data Communication & Networking**

**Circuit & Packet Switching**

**Assignment Project Exam Help**

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. Students of the material for others is RESTRICTED.

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

1

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**Computer Networks. Why?**

Computing & communication devices need to exchange information

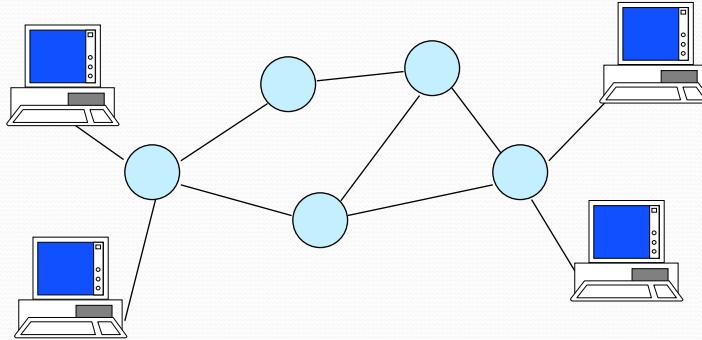
# of links required:  
unidirectional links:  
 $n(n-1)$   
bidirectional links:  
 $n(n-1)/2$   
**n: # of devices**

1-2

2

# Computer Networks

We need switching nodes.



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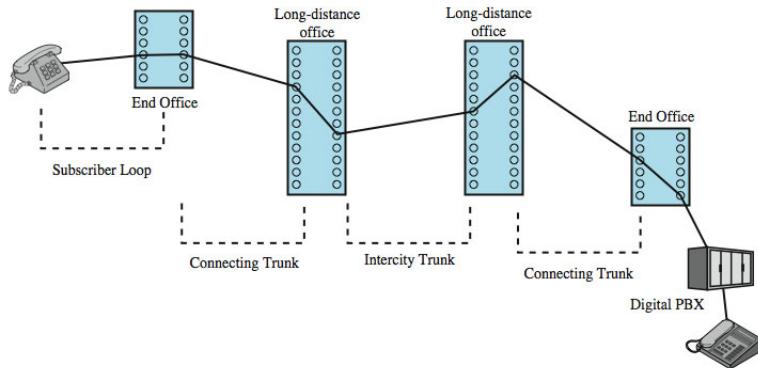
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Switching Technologies

- Circuit Switching
- Packet Switching
  - Datagram
  - Virtual Circuit

4

# Circuit Switching Network

Example: Public Service Telephone Network (PSTN)

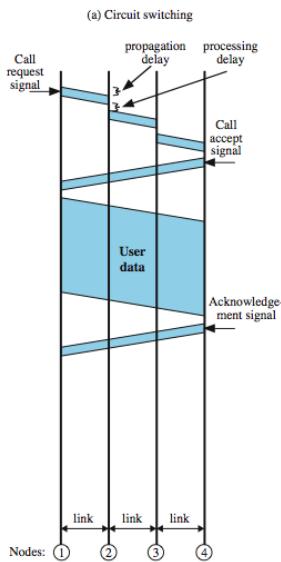


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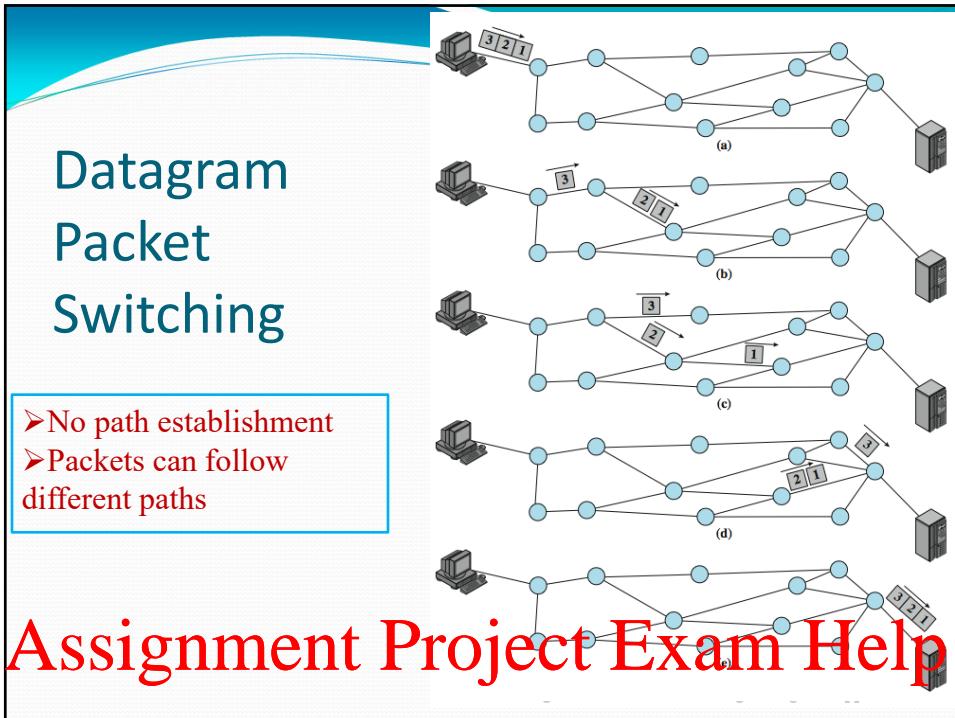
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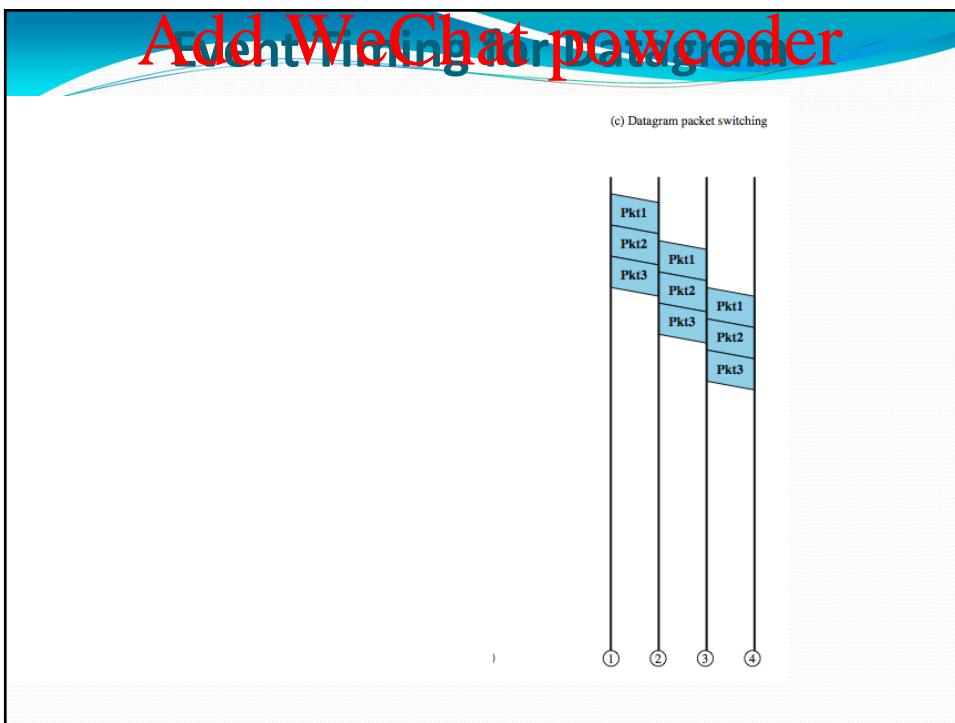


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## Circuit Switching

- 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

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## Add WeChat powcoder 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.

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## 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)

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## Add WeChat powcoder Virtual Circuits versus Datagram

- 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)

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## 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

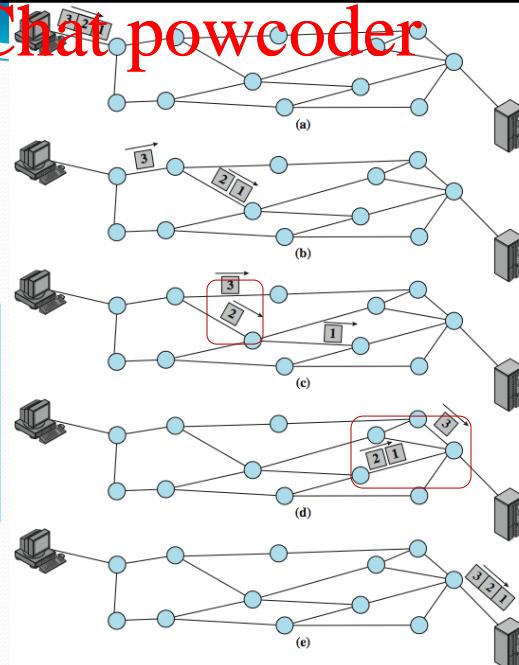
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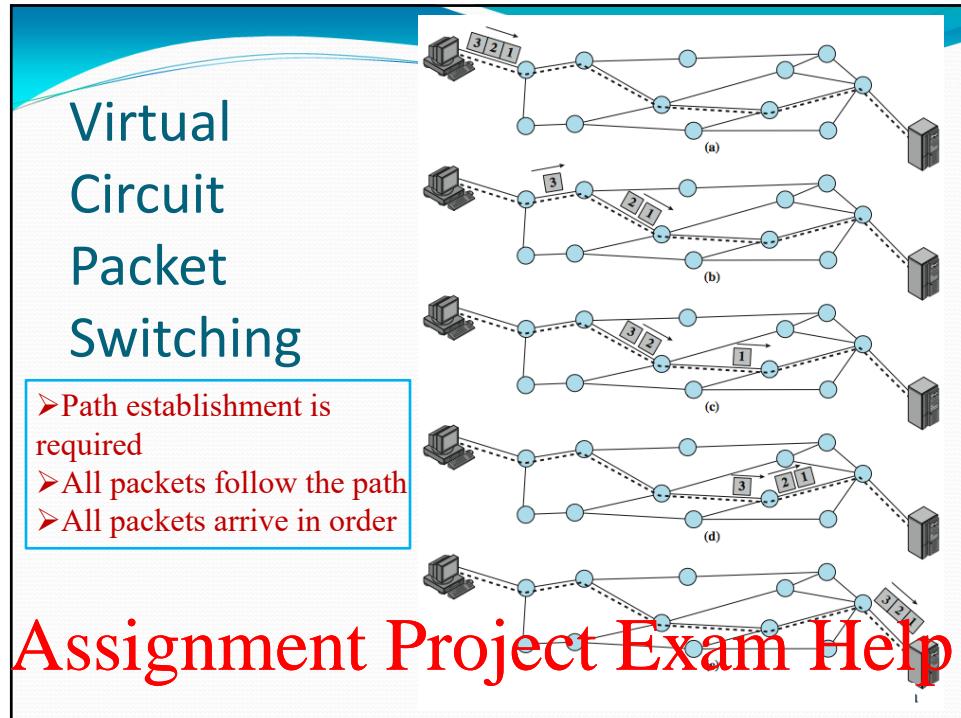
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### Datagram Diagram

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

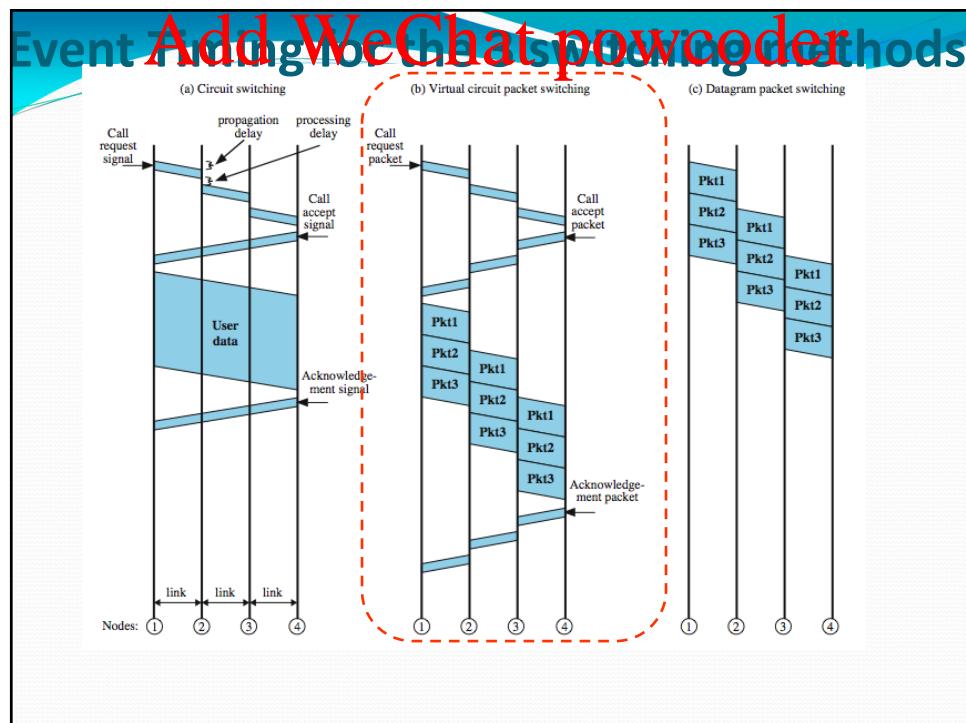


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## Virtual Packet Switching Networks

- 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) choice

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## Add WeChat powcoder 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”.

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## 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

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## Add WeChat powcoder

- 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.

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## 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

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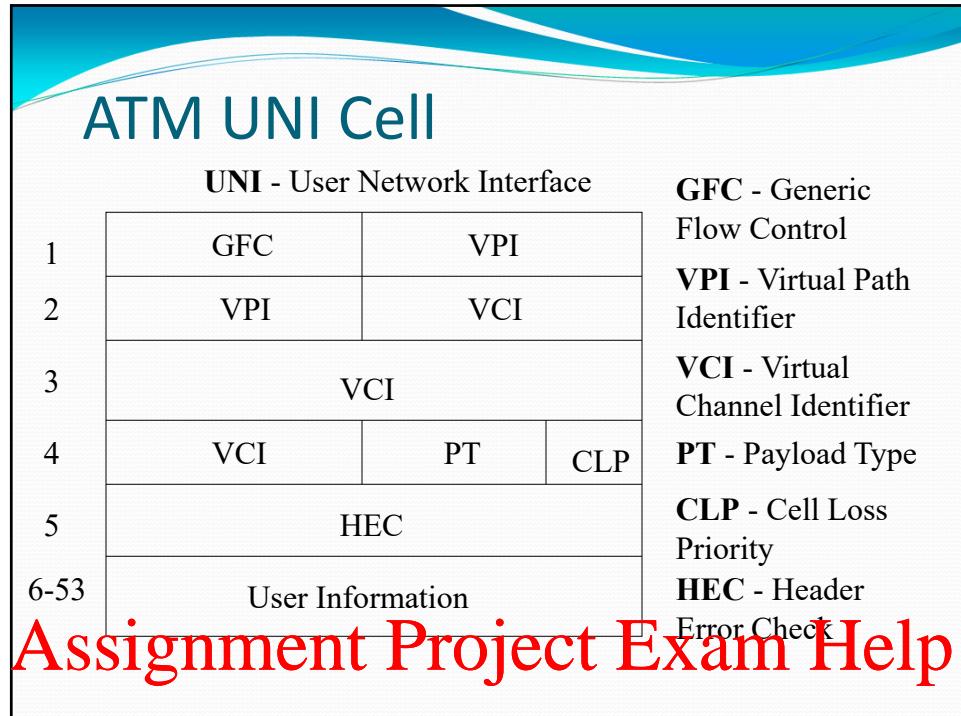
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## ATM Cell Header

- 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)

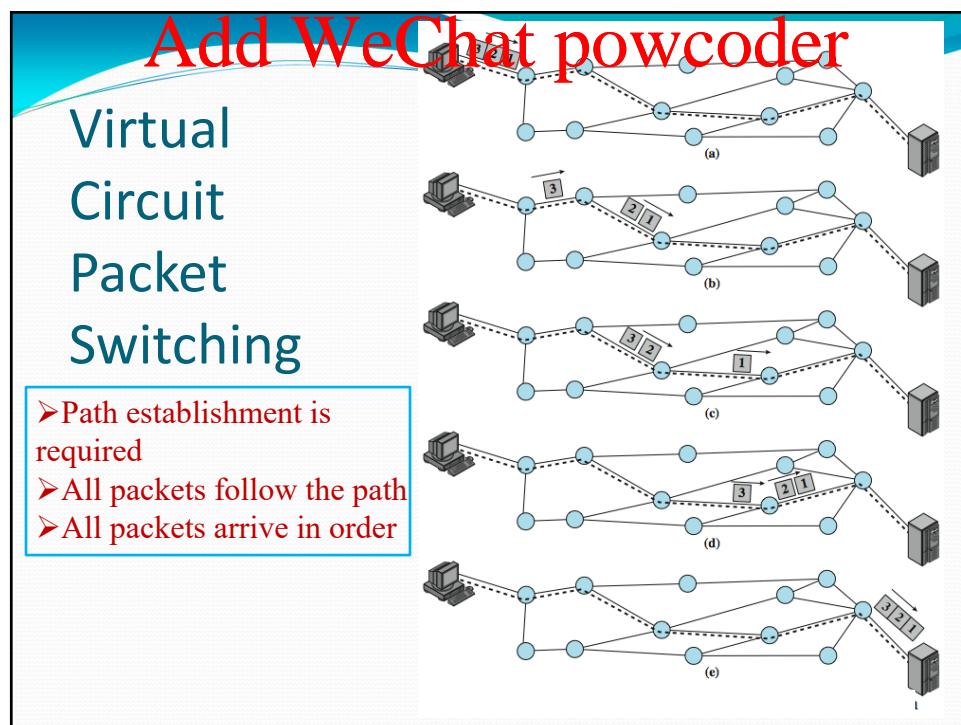
4 bytes	H E C	48 bytes of user information
---------	-------------	------------------------------

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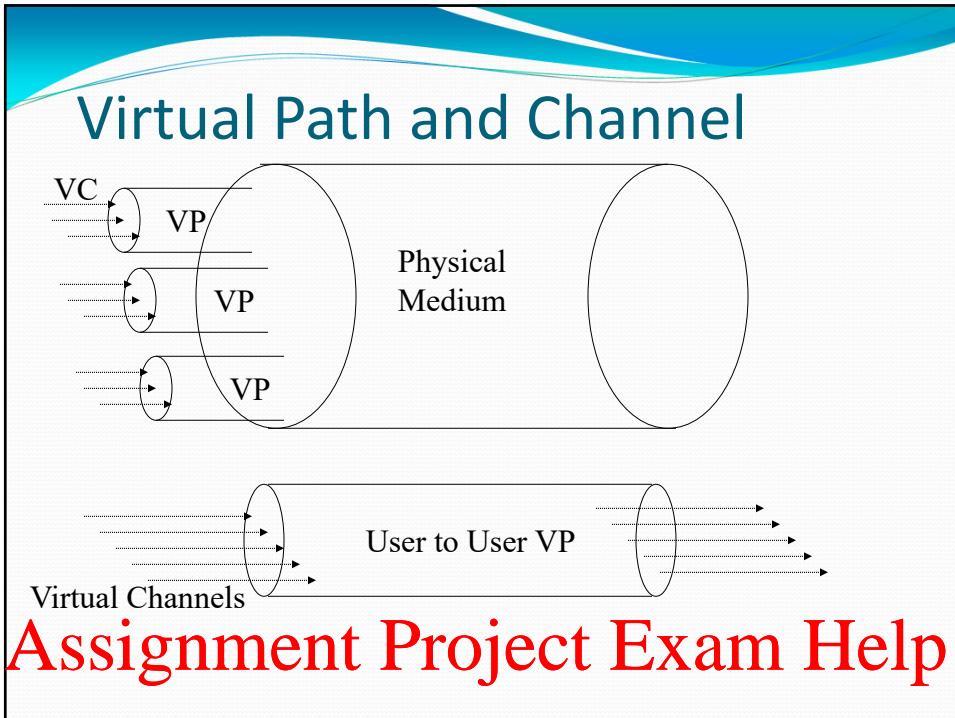


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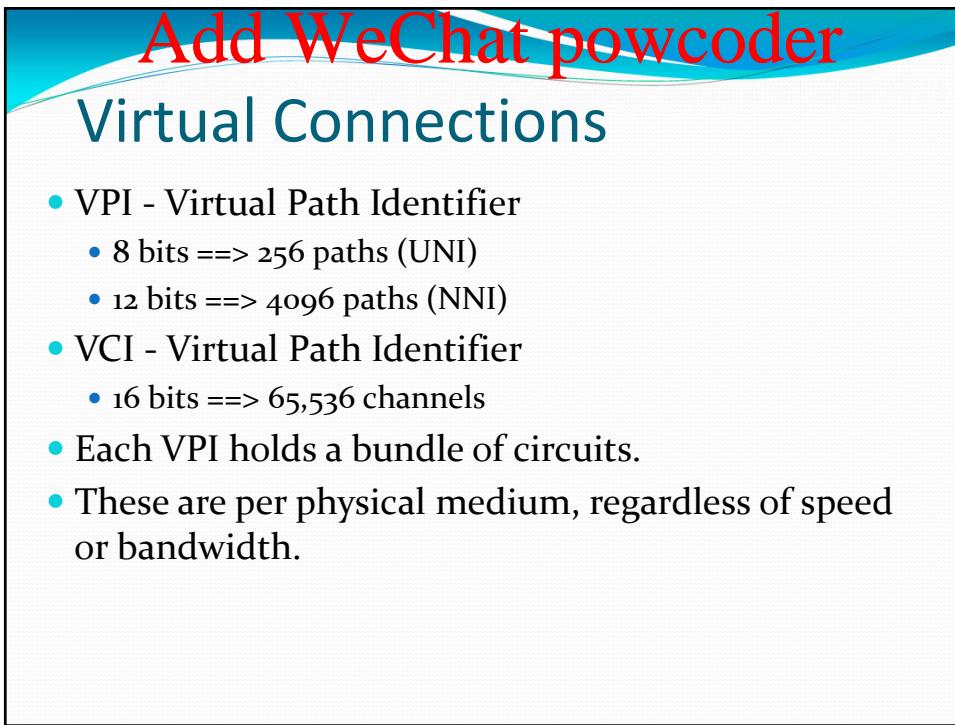


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## Payload Type Identifier

- 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

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## Add WeChat powcoder 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

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## Virtual Connections

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

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## Add WeChat powcoder 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

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## 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)

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1-31

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## Add WeChat powcoder 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

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## ATM Bit Rate Services

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1-33

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## Add WeChat powcoder

### 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

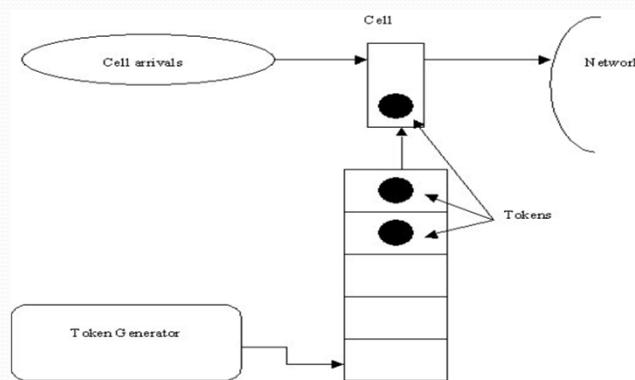
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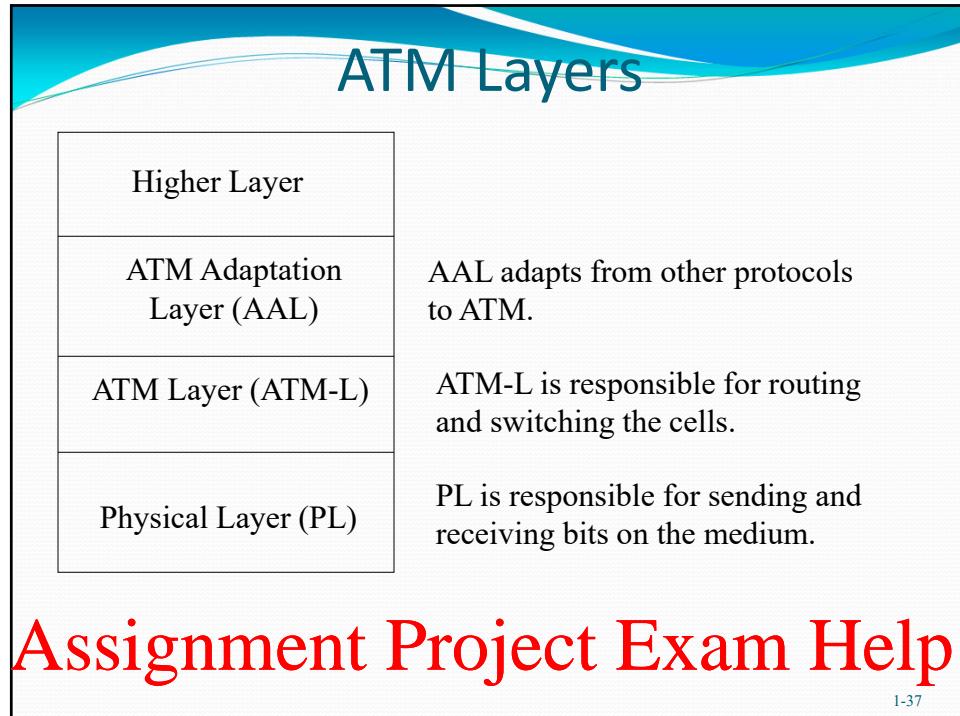
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## Add WeChat powcoder Leaky Bucket



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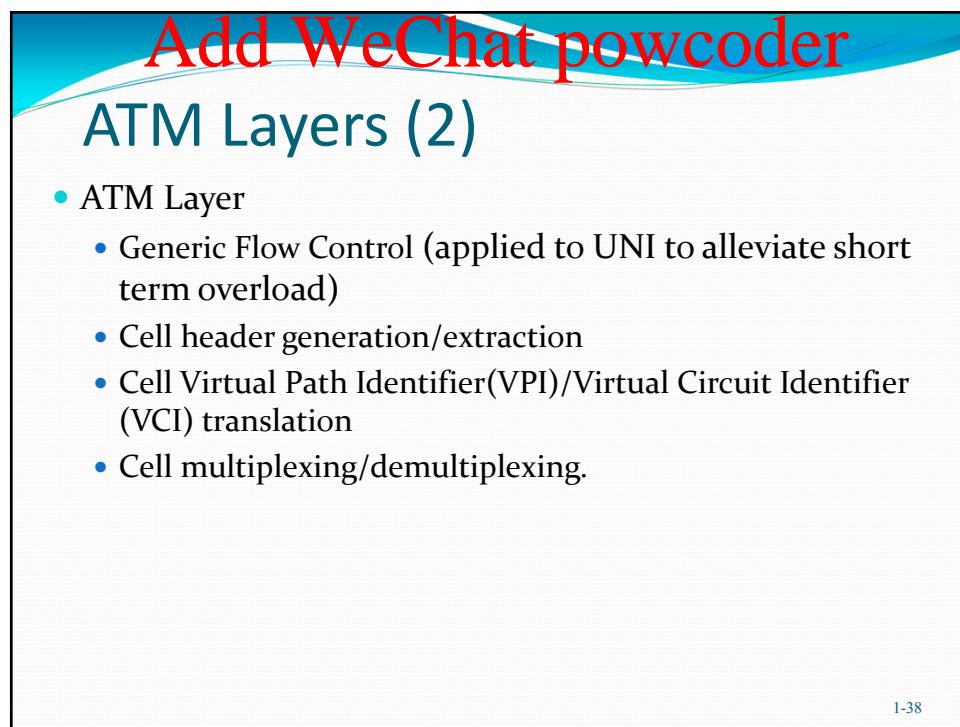


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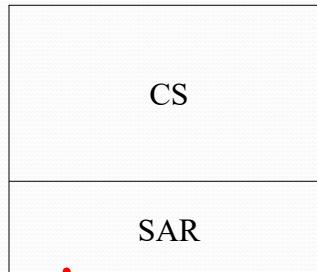


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## ATM Layers (3)

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



CS - interfaces with the upper layer protocol information - provides padding and CRC checking.

SAR - generates the ATM payload.

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## Add WeChat powcoder 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

1-40

40

## 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

**Assignment Project Exam Help**

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**END**

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