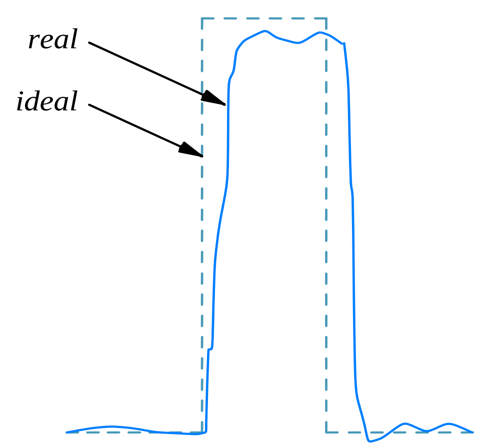
LOCAL ASYNCHRONOUS COMMUNICATION

Limitation of Real Hardware

- Real hardware is imperfect
- Electrical energy vanishes as it travels; usually, it is converted to heat
- Wires have resistance, capacitance, and inductance, which distort signals
- Electrical, or magnetic, interference distorts signals
- Distortion can result in loss or misinterpretation of a signal



The voltage emitted by a real device as it transmits a bit

- Consequences
  - RS-232 hardware must handle minor distortions
    - Takes multiple samples per bit
    - Tolerates less than full voltage

Bandwidth

- Real hardware (devices or cables) can not change voltages/signals instantly
- The fastest continuously oscillating signal that can be sent/received across the hardware is called the "*bandwidth*" of this hardware
- Each hardware has it own bandwidth, a.k.a. *capacity*
- Any attempt to change the signal faster than the hardware bandwidth will fail and lead to transmission errors
- The bandwidth of a system which consists of more than one piece of hardware is the minimum bandwidth of its component (*system bandwidth*)
- Any system in this world has a some sort of limited bandwidth!!!
- Bandwidth is measured in cycle per second or Hertz (Hz)

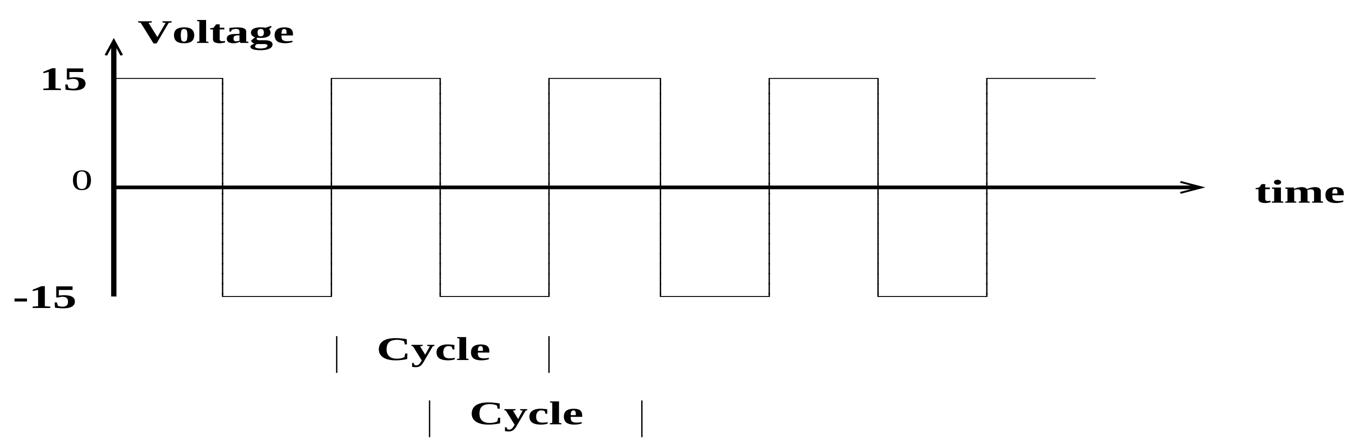


Illustration of a continuously oscillating waveform

Baud Versus Bit-rate

- The time required to transmit a given character depends on
  - The number of changes in the signal per second that the hardware generates, a.k.a. "*baud*"
  - Encoding method
- Baud is a rate; baud rate is a redundant reference to baud
- Baud must be less than or equal to twice the bandwidth
- In general, the maximum bit-rate = 2 × bandwidth × log_2 K
  where K is the maximum possible values of voltage the system can generate
  i.e., the maximum bit-rate = maximum baud × number of encoded bits per change (*Nyquist's Sampling Theorem*, 1920)
- In the binary case, K = 2,
  i.e., the number of encoded bits per change = 1 bit
  hence the maximum bit-rate = 2 × bandwidth × 1 = maximum baud
  i.e., each change carries only one bit
- The higher the value of K, the higher maximum bit-rate is
- Analogy example:
  cars/seat rows rate/passengers rate==> cycles/baud/bit-rate

The Effect of Noise on Communication

- Communication systems, like any other practical system, is subject to noise
- In 1948 Shannon extended Nyquist's work to specify the maximum data rate that could be achieved over a noisy transmission channel
- *Shannon Theorem* stated that the *maximum reliable (practical) bit rate over a channel* = bandwidth $\times\ log_2$(1 + S/N) bits per seconds
  where S is the average signal power and N is the average noise power
- S/N is usually called signal-to-noise ratio
- When engineers refer to the signal-to-noise ratio, they cite the quantity $10 \times log_{10}$(S/N), which is measured in decibels (dB)
- 20dB means S/N = 100
- 30dB means S/N = 1000
- What if N = 0 !!!

LONG-DISTANCE COMMUNICATION

Transmission Deficiency

- If transmission media were perfect, the receiver would receive exactly the same signal that the transmitter sent
- Unfortunately, media are not perfect
  - The received signal is not the same as the transmitted signal
  - The receiver may become not able to detect the signal (signal loss)
- Transmission lines suffer from three major problems
  - Attenuation
  - Delay distortion
  - Noise

Carrier Signal

- DC current is not suitable for long distance communications, it is only suitable for short distance communications
- A continuous oscillating signal propagates farther than other signals
- In long-distance communication systems, a continuously oscillating signal called *carrier* (a.k.a. AC Current) is used, instead of transmitting an electric current that only changes when the value of a bit changes

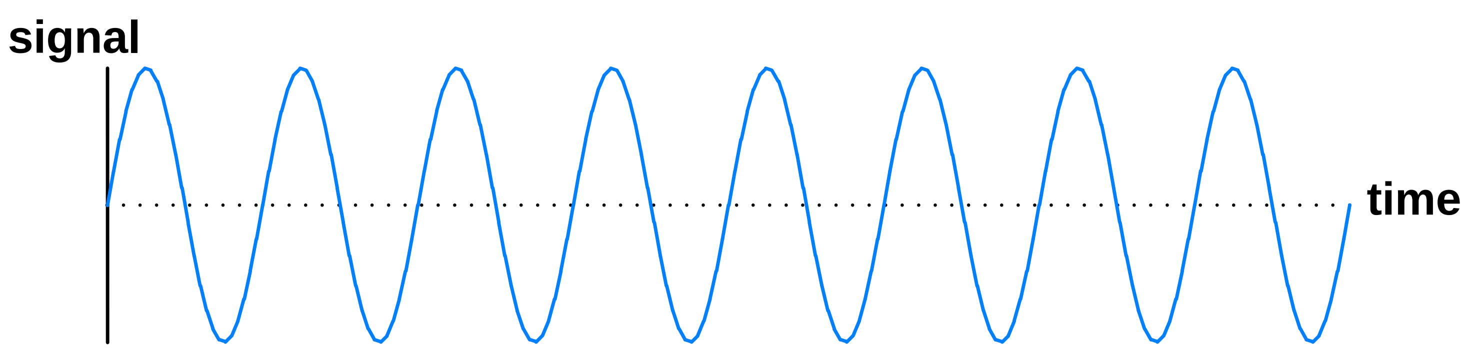
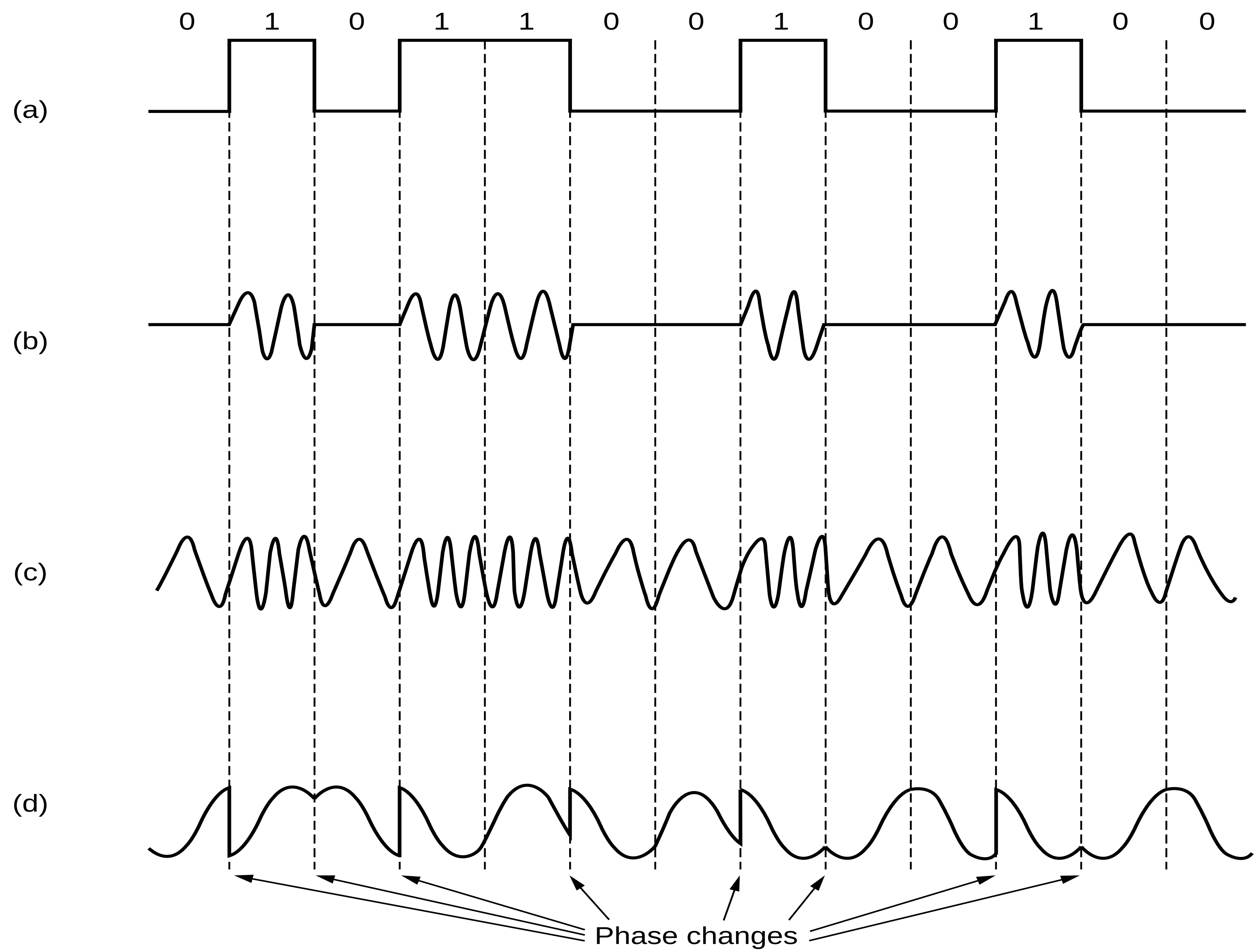


Illustration of a typical waveform carrier

- To send data, the transmitter
  - Generates a continuously oscillating carrier signal
  - Modulates it according to the data being sent
- To receive this data, the receiver
  - Must be configured to recognize the carrier that the sender uses
  - Monitors the incoming carrier
  - Detects modulation
  - Reconstructs the original data
  - Discards the carrier

Modulation

- Amplitude Modulation (AM)
- Frequency Modulation (FM), a.k.a. Frequency shift key
- Phase Shift Modulation, a.k.a. Phase Shift Key
  Note that: A Cosine function is a Sine function phase shifted by 90°
- Sometime, different modulation schemes are combined together, *Why?*



(a) A binary signal; (b) AM; (c) FM; and
(d) Phase modulation 0 = shift of 270°, 1 = shift of 180°

Modem

- Modulator: a hardware circuit that accepts a sequence of data bits and applies modulation to a carrier wave according to these bits
- Demodulator: a hardware circuit that accepts a modulated carrier wave and recreates the sequence of data bits that was used to modulate the carrier
- Modem = modulator + demodulator

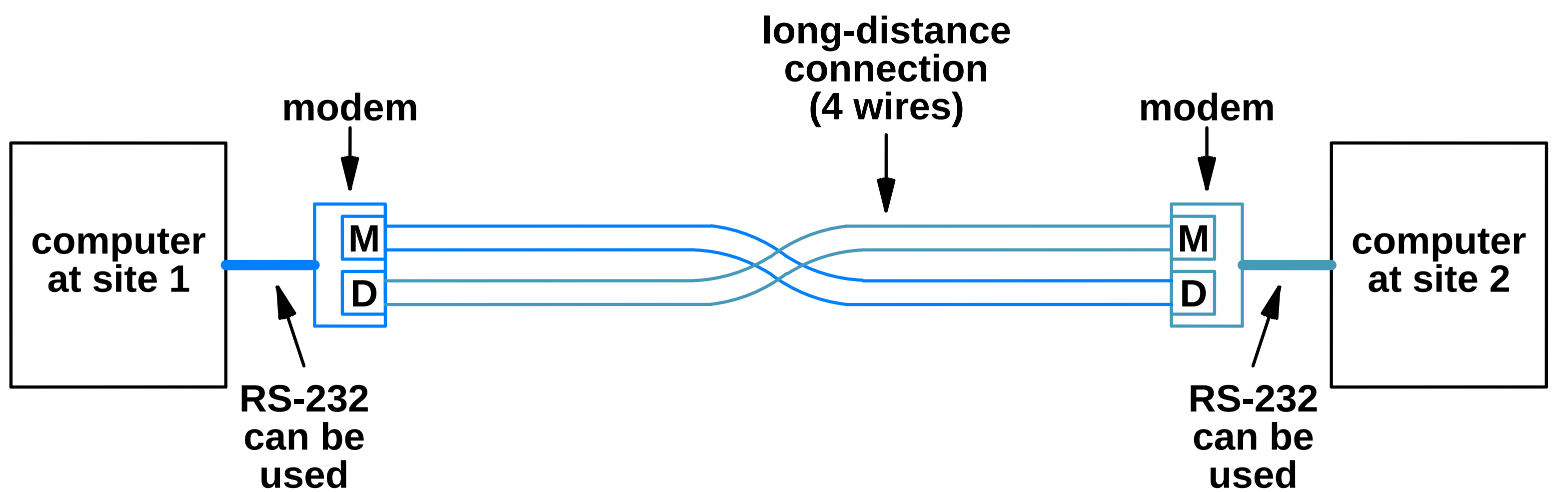


Illustration of two modems used across a 4-wire circuit

- To build such a modem connection, you need to connect a pair of modems through wires, as well as to connect each modem to its neighboring computer

- Many companies use one or more pair of 4-wire modems as a part of their data communication network
- When a circuit connects two locations at a single site, the company can install the necessary wires itself
- Installing and maintaining wires consume time and money
- Moreover, private companies can not install circuits across long distances, or across public property, e.g., across a street, due to governmental regulations; Only utility companies, e.g., telephone company, are allowed to do so
- The good news is, telephone companies allow other companies to lease a circuit between any two locations
  - When a telephone company installs cables, they includes extra wires that can be used in any future expansion, i.e., they already have unused wires running here and there
  - Although it does not sell these wires, they can earn money from leasing these wires for a monthly fee;
  - This fee depends on the distance and bandwidth of the wires
  - These leased lines are dedicated between just two points, i.e., they will not go through the dialup telephone system in any way

Other Types of Modems

- In addition to dedicated wires, modems are also used with other media; these modems include:
  - Radio Frequency modems
  - Optical modems
  - Dialup modems
- Although such modems use entirely different technology than modems that operate over dedicated wires, the principle remain the same
  - At the sending end, a modem transforms data into modulated signal
  - At the receiving end, data is extracted from the modulated signal

RF Modem

- At the sending end, an RF modem
  - Accepts electrical signals from the network or the computer
  - Converts them to data in a digital form
  - Generates an RF transmission equivalent to this digital data
- At the receiving end, an RF modem
  - Receives an RF transmission
  - Converts them to data in a digital form
  - Generates electrical signals, equivalent to this digital data, which go to the network or the computer
- RF modems became attractive due to the increased interest in wireless networking
- For example, a small RF modem attached to a notebook computer makes it possible to move the computer around in a building while maintaining network connectivity in the same way a portable phone can move around
- More powerful RF modems make it possible to establish a wireless communication link over longer distances, e.g., kilometers

Optical Modem

- At the sending end, an optical modem
  - Accepts electrical signals from the network or the computer
  - Converts them to data in a digital form
  - Generates pulses of light, equivalent to this digital data, which travel along the fiber
- At the receiving end, an optical modem
  - Accepts pulses of light from the fiber
  - Converts them to data in a digital form
  - Generates electrical signals, equivalent to this digital data, which go to the network or the computer
- The most common use of fiber modems involve connecting a computer in one building to a LAN in another building, this is due to the fact that a fiber cable has low delay and high bandwidth

Dialup Modem

- One modem must begin the process by waiting for a telephone call at a known telephone number (*answering mode*)
- The other modem begins in a *calling mode*, with the telephone number to dial; this simulates
  - Lifting the handset
  - Listening for a dial tone
  - Dial the number
- When the modem, which is in the answer mode, detects the telephone rings, it answers the call and sends a carrier wave, which initializes the communication
- The calling modem detects the carrier and responds by sending a carrier of its own
- Once the two modems agree on the carriers, data can be sent between them
- At the end of the session, any party can terminate the call

- Dialup modems
  - Use voice telephone systems (a 2-wire connection)
  - Transmit modulated audio tone (the carrier is an audible tone)
  - Can dial and answer the phone
  - Utilize a half-duplex connection to offer a full duplex communication

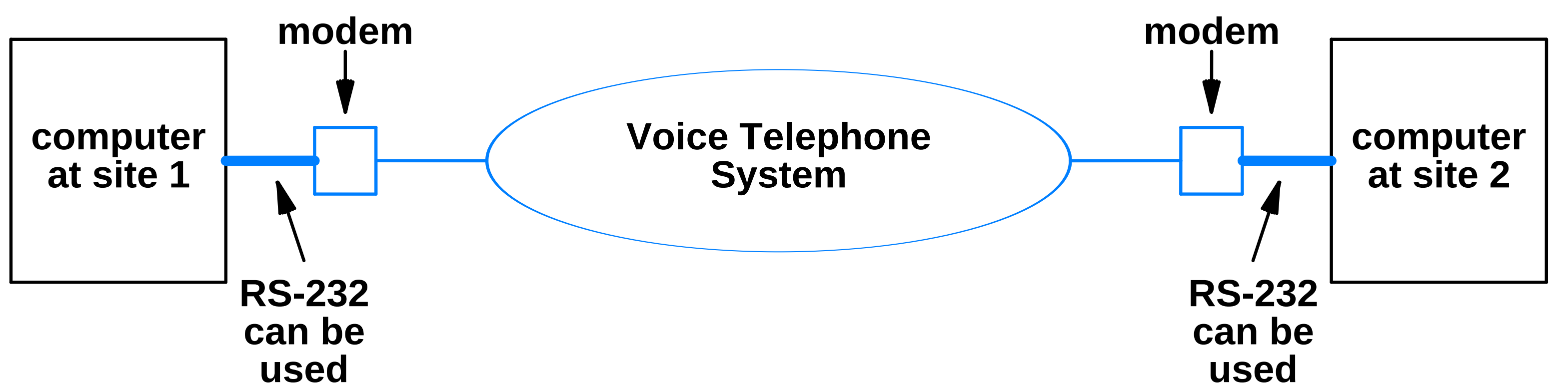


Illustration of two dialup modems that use the voice telephone system (a 2-wire)

Full-duplex Versus Half-duplex Modems

- Both of them provide a bidirectional communication service
- Full-duplex modem
  - Allows simultaneous transmission
  - Uses four wires
- Half-duplex modem
  - Transmits in only one direction at any time
  - Uses two wires

The Limitation of the Conventional Telephone System

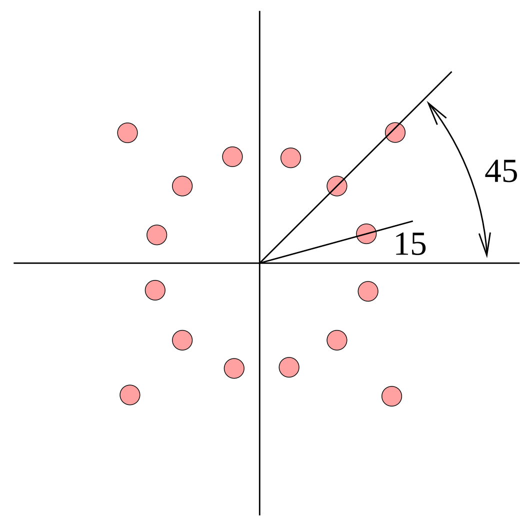
- An ordinary telephone line
  - Is engineered for voice
  - Has a bandwidth of approximately 3000 Hz
  - Has a signal to noise ration of approximately 30dB
  - Its effective capacity is $3000 \times log_2\,(1 + 1000) \approx 30$ Kbps
- Using a modem higher than 28.8 Kbps on an ordinary telephone line is useless

A Question

- What will happen if two 56K modems are connected over a conventional telephone line?
  - Since the effective capacity of an ordinary telephone line is $\approx$ 30 Kbps,
    * Transmission error will occur
    * Re-transmission is required
    * The effective transmission rate will be under 30 Kbps, or so

Some Modem Standards

- V.32
  - Encodes 4 bits per change
  - Uses 2400 bauds to give more time for a signal to be decoded, i.e., to insure lower transmission error
  - $4 \times 2400 = 9600$ bits per second



V32 modulation encoding: 12 different phases with a same amplitude plus another 4 phases with another amplitude

- V.32bis:
  - Encodes 6 bits per change (64 different modulation encoding points)
  - Uses 2400 bauds
  - $6 \times 2400 = 14400$ bits per second
  - "Bis" is the Latin word for "twice" and is used in standards to indicate a significant change or enhancement, i.e., a second revision of a standard
- V.34: Supports connections up to 28800 bits per second
- V.42: An error correction protocol, which checks data as it is transmitted and automatically requests a re-send of corrupted data
- V.42bis: A data compression protocol which includes V.42, reduces the amount of data needed to be transmitted.
- V.42 and V.42bis improve the effective data rate without requiring any changes to the existing software
- V.90: Supports connections up to 56000 bits per second
- Note that: bps means bits per second, it is not bauds per second Sometime, people "incorrectly" use baud-rate to indicate the bit-rate

The Concept of Sharing

- Affording an individual network connection per each pair of computer is not a practical solution:
  - Installing and maintaining wire, or wireless, channels consume time and money
- The practical solution is to share resources
  - Example: private cars versus public buses
- There are some problem might occur when resources are shared
  - Some applications have large transfers
  - Some applications can not wait
- A mechanism is needed to insure fairness when allocating shared resources, for example:
  - Divide data into small units (*packets*)
  - Allow each computer an opportunity to send a packet before re-allowing any computer to send another packet

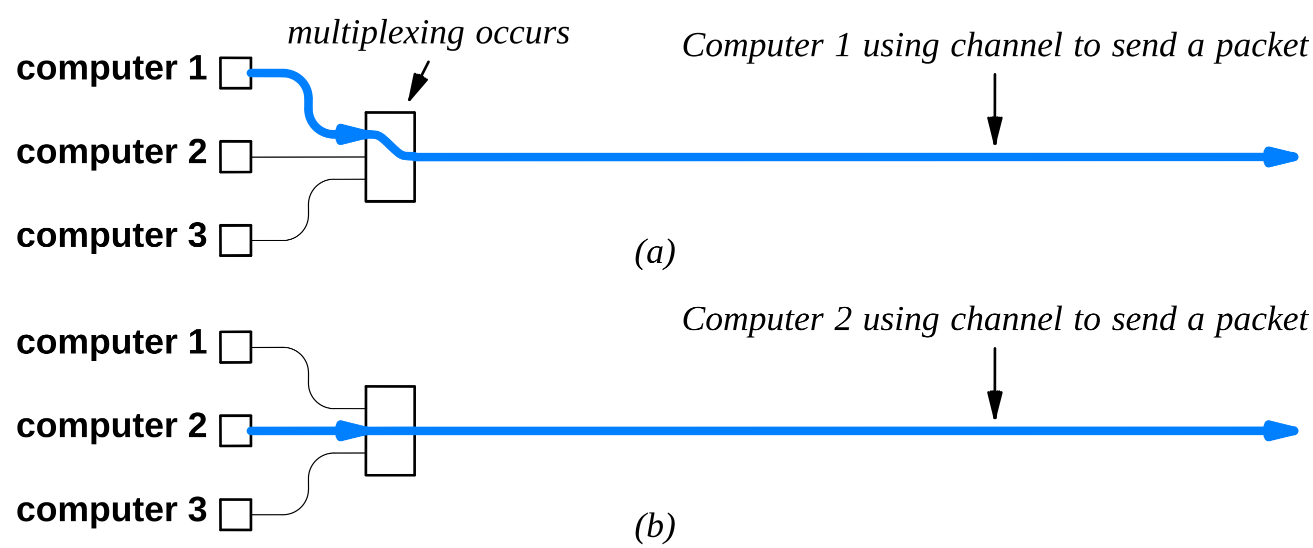
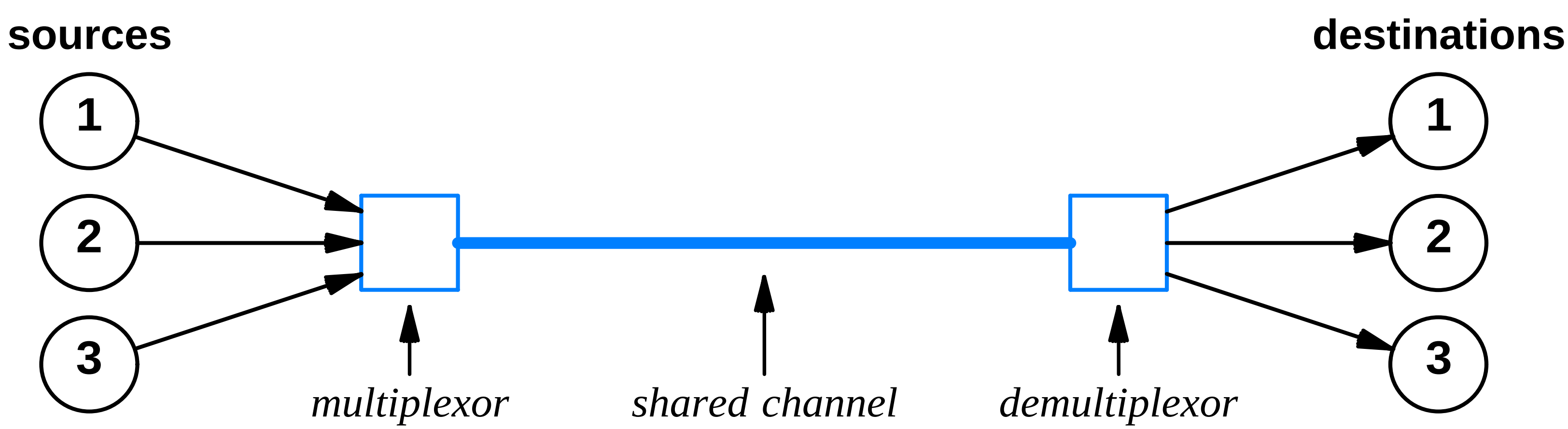


Illustration of multiplexing packets

- A computer
  * Acquires shared medium
  * Sends one packet
  * Allows other computers the opportunity to send before trying to send again
- This approach guarantees a prompt response to a computer with a small amount of data need to be sent, even if there is another computer trying to send a large amount of data

The Concept of Multiplexing

- Data travels across a shared channel
- Each destination receives only the data sent by the corresponding source



The concept of multiplexing

Multiplexing Terminology

- Multiplexor
  - Can be implemented in a software or a hardware form
  - Accepts data from multiple sources
  - Sends data across a shared channel
- Demultiplexor
  - Can be implemented in a software or a hardware form
  - Extracts data from a shared channel
  - Sends data to the correct destination

Basic types of Multiplexing

- Time Division Multiplexing (TDM)
  - Only one item at a time is sent on the shared channel
  - Each item is marked (*by a header*) to identify its source
  - Demultiplexor uses header information to know the destination
  - Analogy: One-way road to be used by only one group of people at a given time, where there is an indicator, or flag, to identify each group
  - Example: Time-sharing
- Frequency Division Multiplexing (FDM)
  - Multiple items are transmitted simultaneously
  - Uses multiple frequency channels (a unique frequency per channel)
  - Is only used on wide-bandwidth transmission systems
  - Analogy: A multi-lanes road
  - Example: Cable TV

Wave Division Multiplexing

- Optical FDM is known as *Wave Division Multiplexing*
- Because human see frequencies of visible light as color, engineers sometimes use the informal term *Color Division Multiplexing* to indicate Wave Division Multiplexing
- Wave Division Multiplexing operates by sending multiple light waves across a single optical fiber
- At the receiving end, an optical prism is used to separate the frequencies
- As in conventional FDM, the carriers can be mixed onto a single medium because light at a given frequency does not interfere with light at another frequency