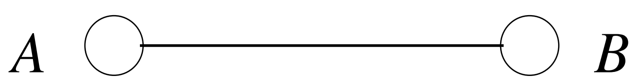
Fundamentals of information transmission

→ applies to both wired and wireless networks

→ additional features unique to wireless discussed later

Bits, information, and signals

Motivation: hosts A and B are connected by point-to-point link

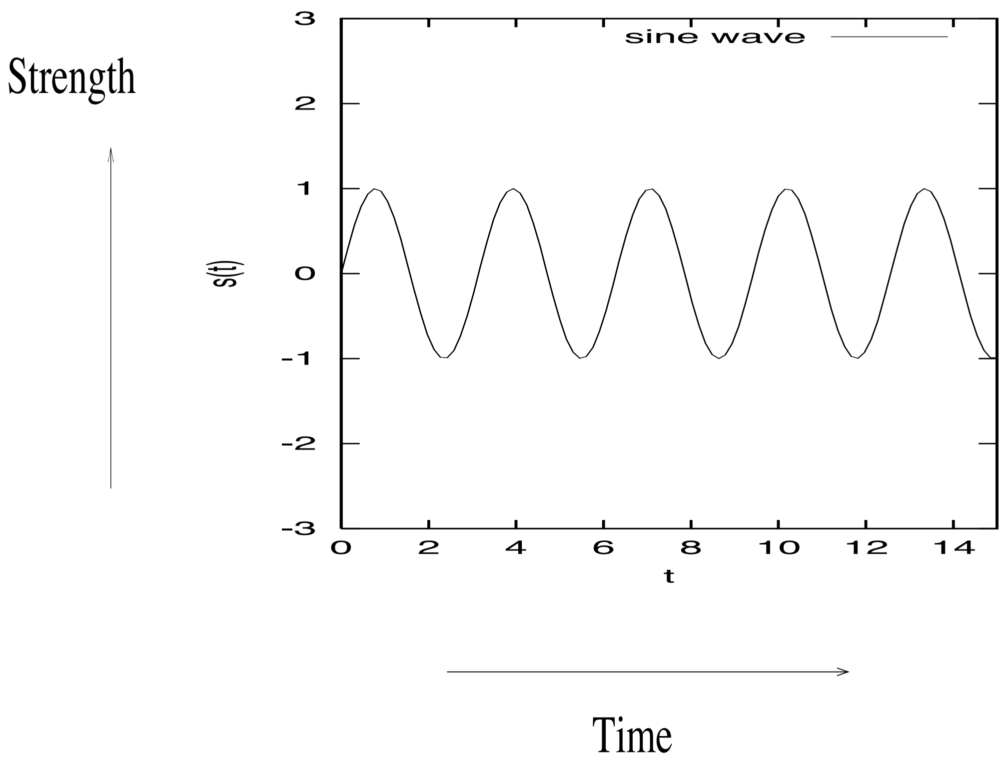


A wants to send bits 011001 to B

Physical medium: wired (fiber/copper) or wireless (space)

→ signals: electromagnetic waves

Electromagnetic wave: oscillating sine curve

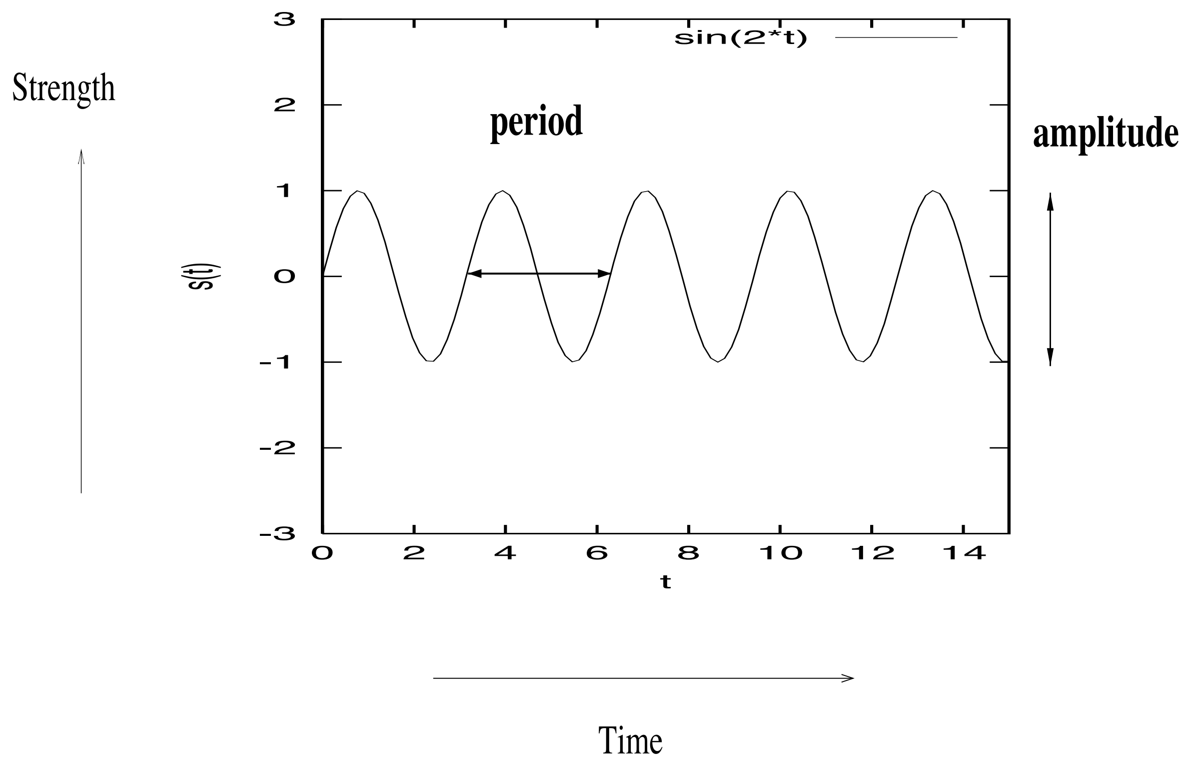


Direction of vibration: perpendicular to direction of travel

$\rightarrow$ called transverse wave

$\rightarrow$ sound wave: longitudinal — vibration in same direction as travel

Electromagnetic wave: two key features



$\rightarrow$ period: T

$\rightarrow$ amplitude (or magnitude)

$\rightarrow$ third key feature?

Frequency f: how much vibration—i.e., how many periods—occur within a 1-second time window

→ f: $1/T$

→ unit: Hz

Ex.: 1 GHz sine wave has period 1 nanosecond

Travel speed of EM waves

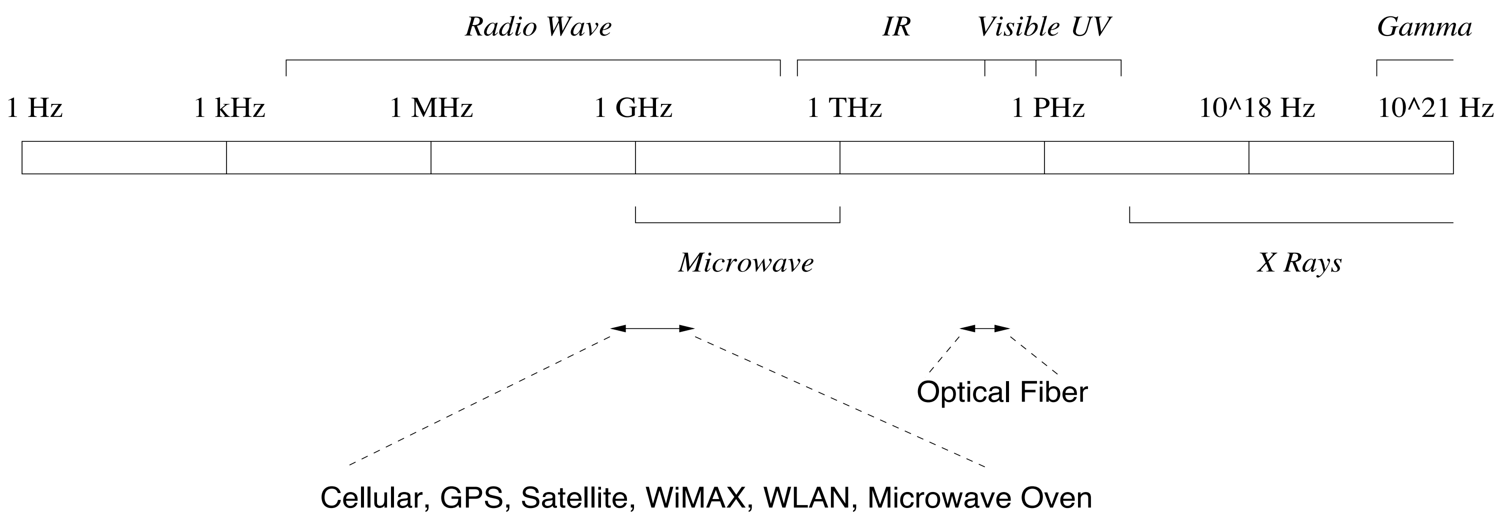
→ speed of light (in vacuum)

→ slower in copper, optical fiber, atmosphere

Electromagnetic spectrum:

→ some of its use today

→ logarithmic scale

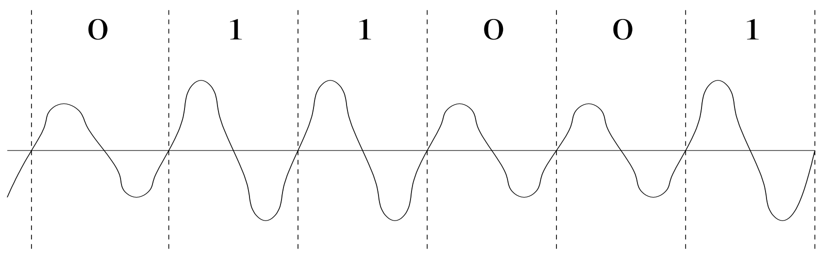


→ crowded near the 1 GHz neighborhood

Back to original problem: A wants to send B six bits 011001

$\rightarrow$ how do sine waves help?

Utilize amplitude (signal strength) to encode 1's and 0's



$\rightarrow$ large amplitude: 1

$\rightarrow$ small amplitude: 0

Called amplitude modulation (AM)

$\rightarrow$ same concept as AM radio

Throughput (bps):

$\rightarrow$ if frequency is 1 Hz then 1 bps

$\rightarrow$ if frequency is 1 MHz then 1 Mbps

$\rightarrow$ if frequency is 1 GHz then 1 Gbps

$\rightarrow$ if frequency is 1 THz then 1 Tbps

Networking problem solved!

(or not ...)

Issues with just increasing frequency:

Increasing frequency requires increase in processing speed

$\rightarrow$ cost

Wireless: above 10 GHz requires line-of-sight (LOS)

For a given frequency band (say 2.4–2.5 GHz) want to pack as many bits as possible

$\rightarrow$ utilize the band as much as possible

$\rightarrow$ also called "bandwidth"

$\rightarrow$ multiple lanes, i.e., broadband

$\rightarrow$ if one lane per user: multi-user communication

Issues with just increasing frequency (cont.):

Wireless: simultaneous uplink (to base station) transmission by multiple clients (from mobiles)

$\rightarrow$ problem of multi-user communication

$\rightarrow$ also referred to as multiplexing

Simple solution to multi-user communication:

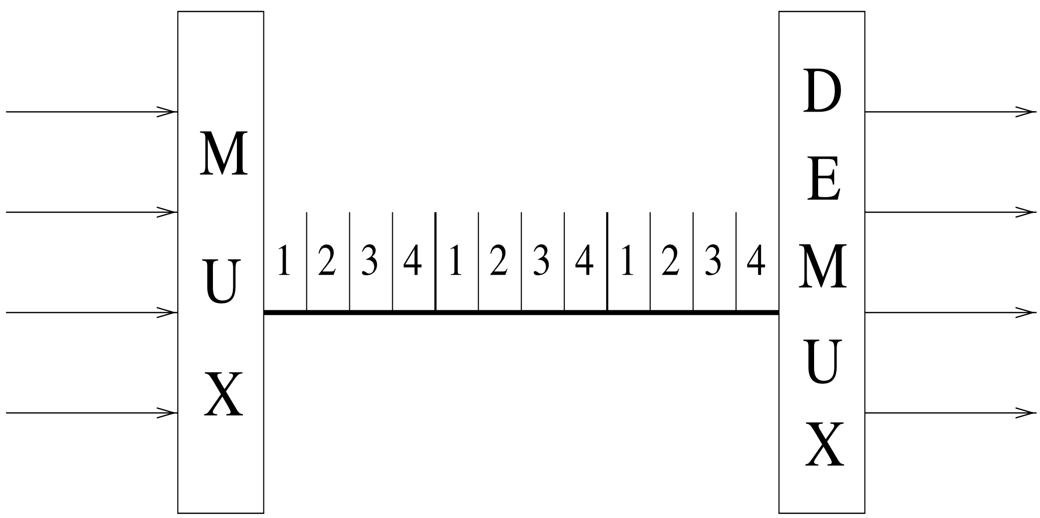
→ share a single lane by time reservation

→ time division multiplexing (TDM)

Ex.: 4 users sharing a single lane, i.e., frequency

→ divide time into blocks

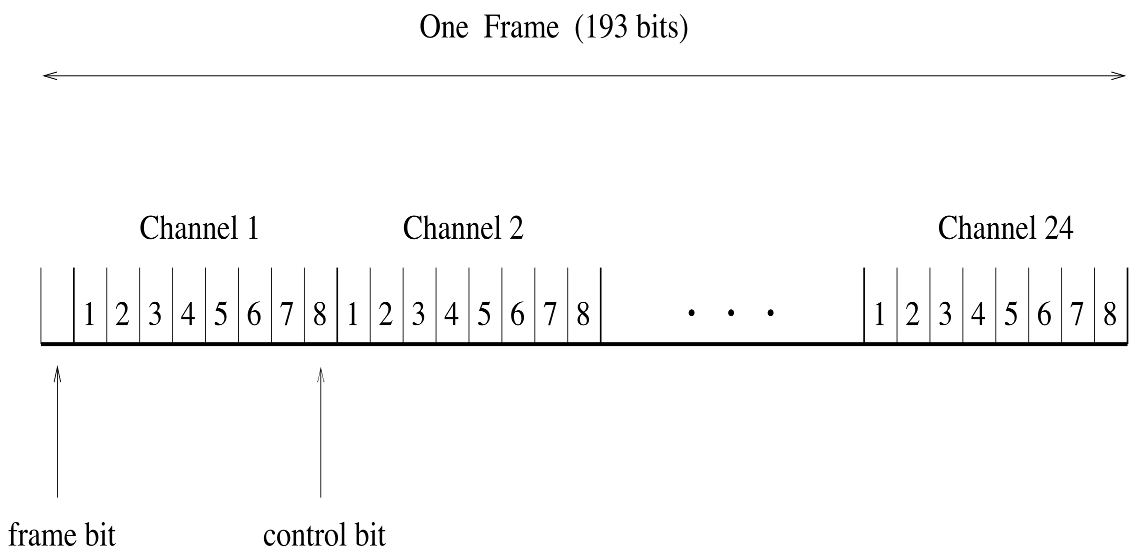
→ reserve blocks to 4 users: 1, 2, 3, 4, 1, 2, 3, 4, . . .



→ each block can carry multiple bits: block size

→ 1, 2, 3, 4: frame or packet

Real-world example: T1 carrier (1.544 Mbps)



- 24 simultaneous users
- 8-bit block size
- squeeze 8000 frames into 1 second

  $\rightarrow$ frame duration: 125 μsec
- bandwidth: $8000 \times 193 = 1.544$ Mbps
- drawbacks of using TDM for multi-user communication?

TDM allows sharing of single lane—called carrier frequency—by multiple users

→ baseband communication

→ users alternate in time: not truly simultaneous

→ what we want is broadband: multiple lanes

→ increase the "size of the pie"

→ truly simultaneous

Key problem of broadband or high-speed networks:

Given a frequency band (wired or wireless), how to create as many parallel lanes as possible

→ frequency band or "bandwidth" (Hz): scarce resource

→ especially wireless

→ utilize multiple frequencies for parallel transmission

→ frequency division multiplexing (FDM)

→ how many lanes are possible?

State-of-the-art: OFDM (orthogonal FDM)

→ ubiquitous in wireless networks

→ IEEE 802.11g/n WLANs (not 802.11b)

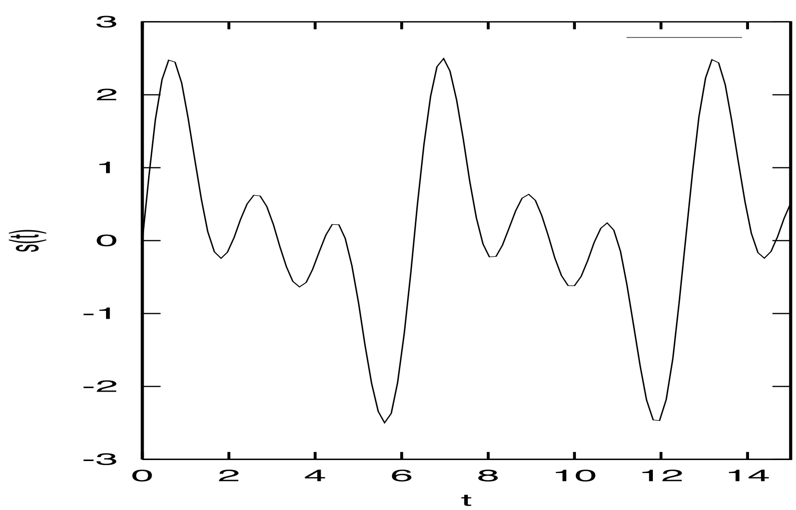
→ WiMAX, cellular, etc.

Practical dilemma:

- three wireless hosts are sending bits to base station
- each host uses its own carrier frequency

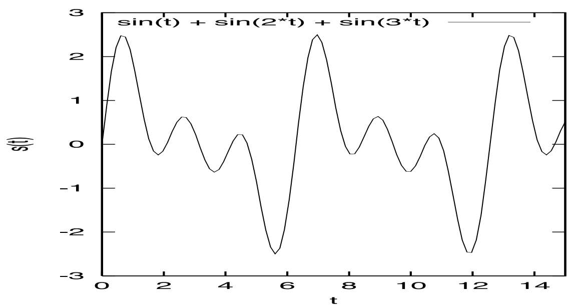
  $\rightarrow f_1, f_2, f_3$

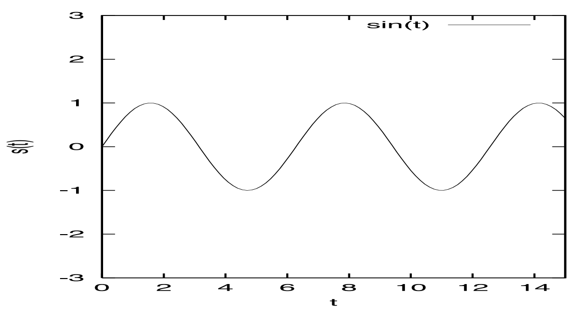
  $\rightarrow$ e.g., 2.42 GHz, 2.44 GHz, 2.46 GHz
- base station receives

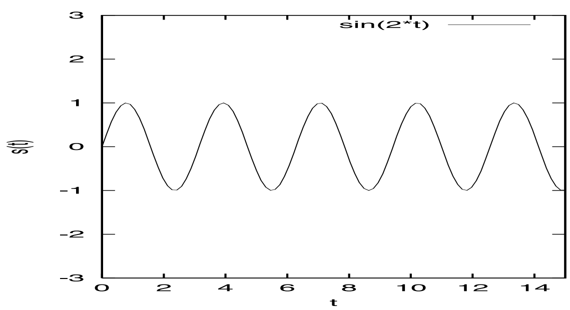


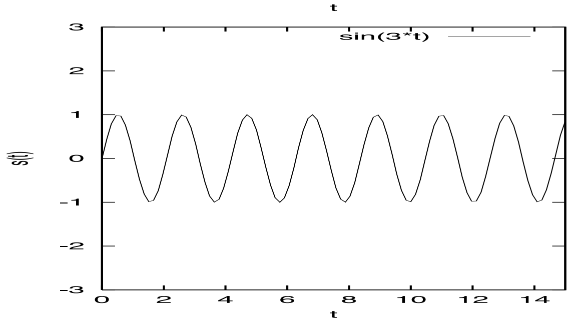
$\rightarrow$ what bits did the 3 hosts send?

The signal received is the sum of









A receiver only sees the combined signal

→ to recover the bits sent requires recovering the shape of the individual carrier waves

→ with hundreds, thousands of carrier frequencies, how to do that?

Note: same problem applies to wireline broadband communication

Ex.: point-to-point link from A to B

→ A transmits bits to B over 3 parallel lanes

→ faster file exchange