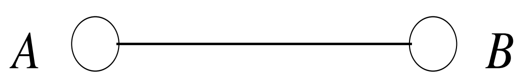
Fundamentals of information transmission

⟶ applies to both wired and wireless networks

⟶ wireless-specific features discussed separately

Sending bits using physical signals

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



→ e.g., A wants to send bits 011001 to B

Choices for physical signals

- sound waves: air pressure changes
- underwater sonar: water pressure changes
- light: electromagnetic waves
- couriers: UPS, FedEx, pigeons, etc.

Preferred mode for data communication:

→ electromagnetic (EM) waves

→ low latency (SOL) and large bandwidth (bps)

→ some undesirable properties too

What is an electromagnetic wave?

→ in principle: a complicated question in physics

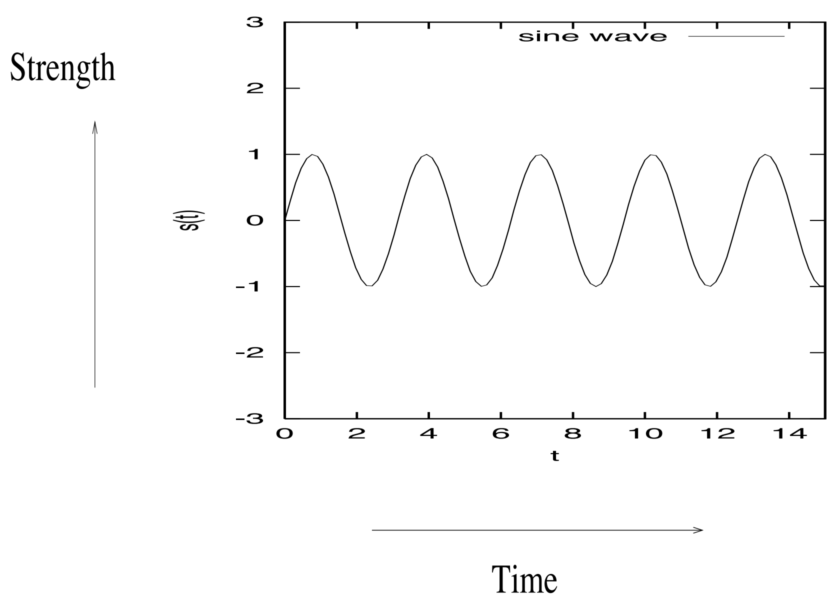
→ we will utilize basic textbook properties

→ applies to most real-world systems

View EM as a physical phenomenon which has a strength (or magnitude) that varies over time.

Purest form

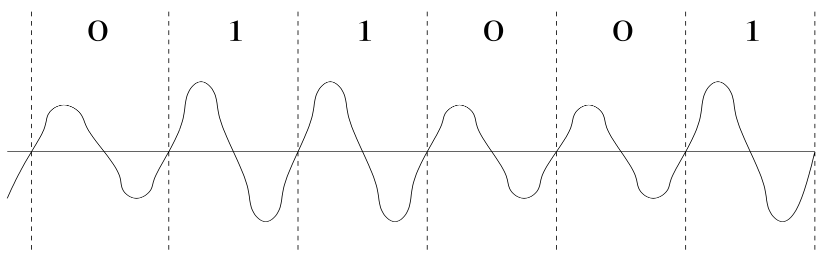
$\rightarrow$ oscillating sine curve



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

$\rightarrow$ use magnitude of sine waves

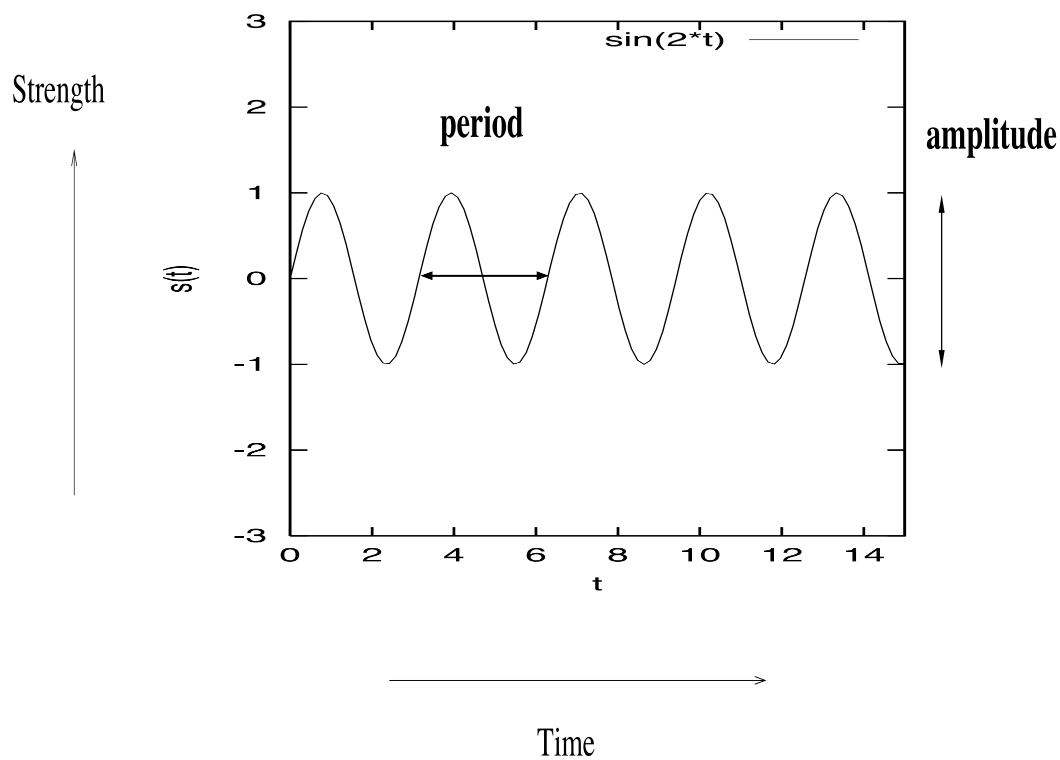
Ex.: high amplitude represents 1, low amplitude 0 (or vice versa)



$\rightarrow$ called amplitude modulation (AM)

$\rightarrow$ manipulate amplitude to represent bits

Four features of EM wave as sinusoid:



$\rightarrow$ period: T

$\rightarrow$ strength: amplitude

$\rightarrow$ phase: shift in time

Most important feature: frequency $f = 1/T$

How many periods can we squeeze in per second.

→ e.g., if period is 1 msec then frequency is 1000 cycles/sec

→ unit called Hertz (Hz)

Another unit: length (m)

→ distance: how long is a period

→ i.e., footprint in space

→ empty space: e.g., 1 GHz EM sinusoid about 11.8 inches long

By default: in computer networks frequency is used to specify EM wave

Example: frequency to calculate bps of AM transmission

$\longrightarrow$ bandwidth (bps) of point-to-point link

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

$\rightarrow$ if 1 MHz then 1 Mbps

$\rightarrow$ if 1 GHz then 1 Gbps

$\rightarrow$ if 1 THz then 1 Tbps

Networking problem solved!

$\rightarrow$ not quite

Issues with increasing frequency:

One: increasing frequency requires increase in clock rate and processing speed

→ high cost

→ computing systems that control hardware operate at much lower speeds

→ since software drives hardware must make hardware match software

→ heavy lifting: software

Two: wireless propagation

→ above ∼10 GHz requires line-of-sight (LOS)

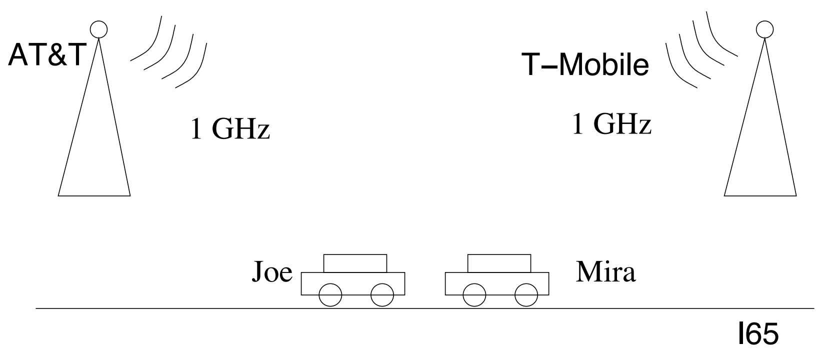
→ below ∼10 GHz: echos can cause confusion

→ called multi-path propagation

Three: multi-user communication

→ not just point-to-point links connecting two parties

Example: wireless interference



Joe receives bits from AT&T's cell tower, Mira from T-Mobile.

→ Joe also hears T-Mobile's signal, Mira hears AT&T's signal

→ Joe's NIC receives bits carried by two EM waves

→ called interference

Joe's NIC equipped with antenna hears the sum of the EM waves

→ property of electromagnetic waves

→ i.e., superposition

→ fortunate that universe is nice

Since EM waves just sum up

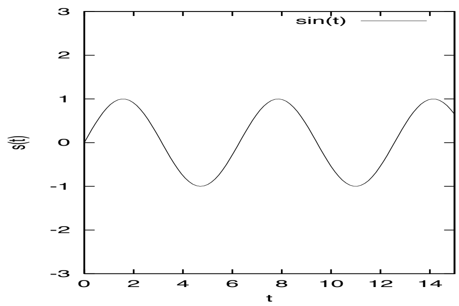
→ amenable to analysis and manipulation

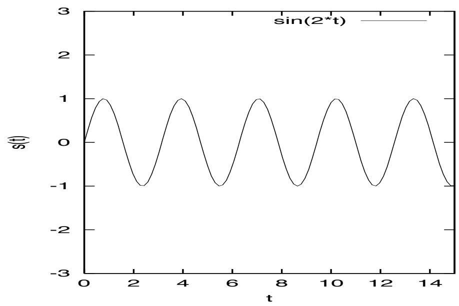
→ relevance of linear algebra

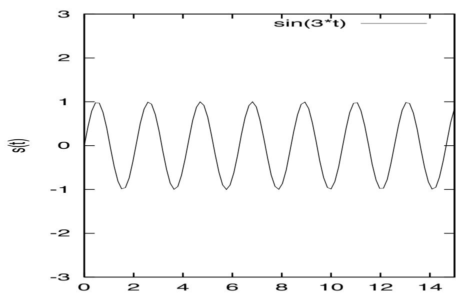
→ foundation of modern communication systems

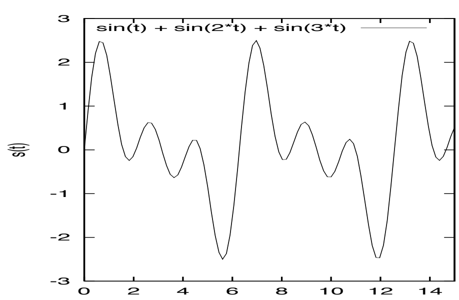
→ wireless and wired

Superposition of three sine waves:



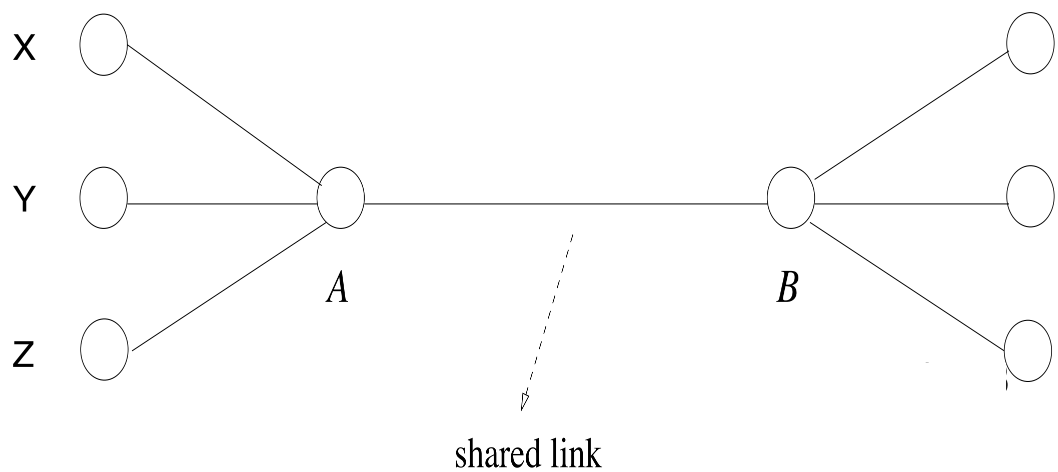






How far can we get while by-passing/ignoring interference?

Example: multiplexing (i.e., sharing) of link between routers A and B



→ use single sinusoid between A and B

→ divide time into slots belonging to sender hosts (left)

→ router A needs memory to temporarily store bits

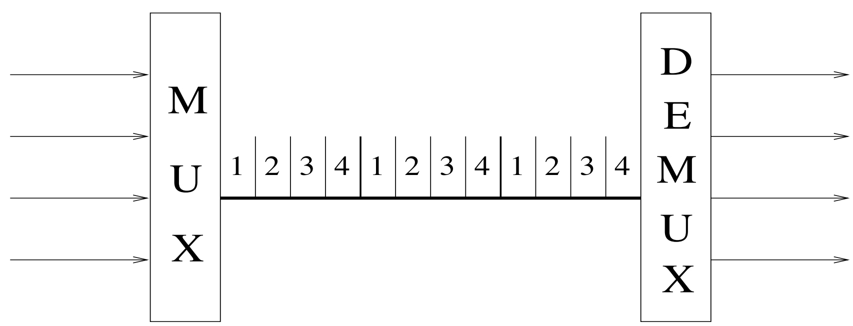
→ called buffer

Splitting time based on AM method of sending bits using sine waves:

→ time-division multiplexing (TDM)

Ex.: four bit streams sharing same link

→ reserve time slots for each bit stream



→ user 1 gets slots 1, 5, 9, etc.

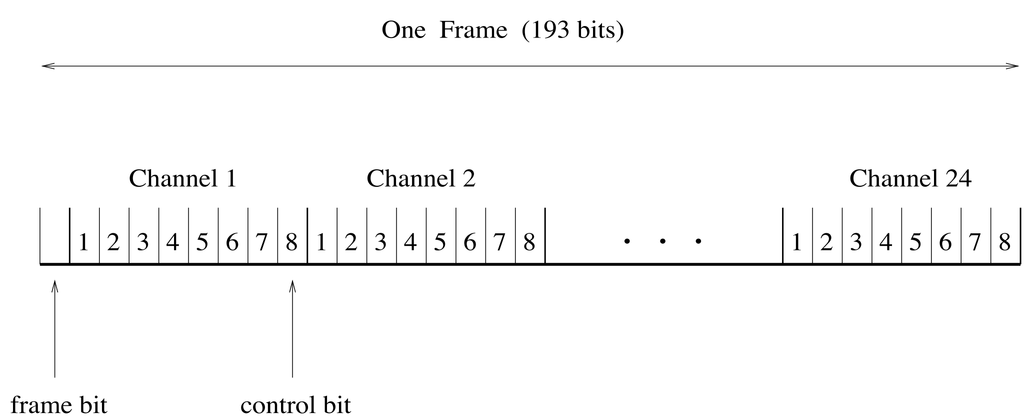
→ user 2 gets slots 2, 6, 10, etc.

TDM, or TDMA (time-division multiple access) when slots belong to multiple users, is a basic technique for sharing link.

Real-world TDMA example from wired world:

→ T1 carrier (1.544 Mbps)

→ goal: support 24 simultaneous users ("channels")



Specs of T1 carrier:

- 24 channels (i.e., users)
- time slot: 8-bit block
- $24 \times 8 = 192$ bits of payload
- plus 1 control bit: total 193 bits in a frame
- squeeze 8000 frames into 1 second interval

  → frame duration: 125 μsec
- total bandwidth (bps): $8000 \times 193 = 1.544$ Mbps

  → per user: $8000 \times 8 = 64$ Kbps

  → landline quality telephony service

  → cellular: significantly lower

At one time, T1 popular service sold by ISPs (mainly) to companies

→ many moons back, Purdue leased 6–7 T1 lines for the entire WL campus

→ next level up T3 line: 44.736 Mbps

Today: residential subscriber can get 1+ Gbps or faster download speed

→ uplink: significantly slower

→ bandwidth asymmetry

→ reflects client/server environment

Limitations of TDMA using single carrier wave (also called baseband):

→ software cannot keep up with fast clock rate

→ in general: interference unavoidable

Want: parallel lanes where multiple bit streams are transmitted simultaneously

→ each lane is not super fast

→ many lanes yields high bps

→ essence of modern high-speed networks

→ each lane: EM wave of different frequency

→ hence transmission of multiple bit streams carried by multiple frequencies