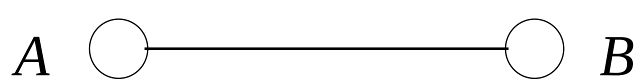
## Fundamentals of information transmission

$\longrightarrow$ applies to both wired and wireless networks

$\longrightarrow$ special wireless features discussed later

## Bits, information, and signals

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)

$\longrightarrow$ signal sent from $A$ to $B$: electromagnetic waves

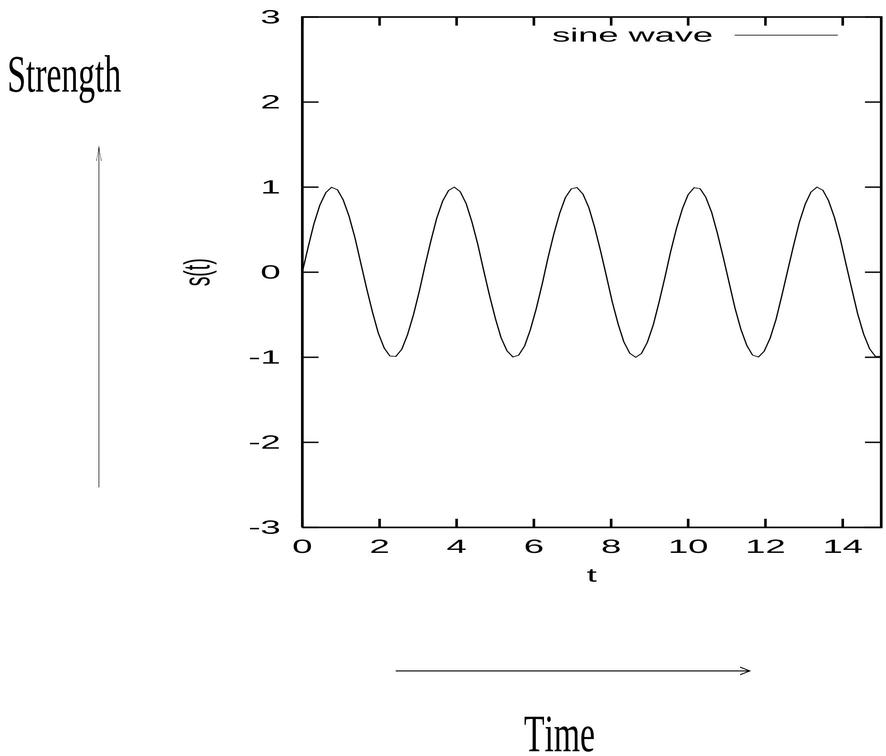
$\longrightarrow$ but could be sound, smoke signals, etc.

What is an electromagnetic wave?

→ oscillating sine curve

→ two dimensions: time and strength

→ strength: also called magnitude, amplitude, power, etc.



Direction of vibration: perpendicular to direction of travel

→ called transverse wave

Sound wave: vibration is longitudinal

→ i.e., same as travel direction

So far looked at electric field component of EM wave

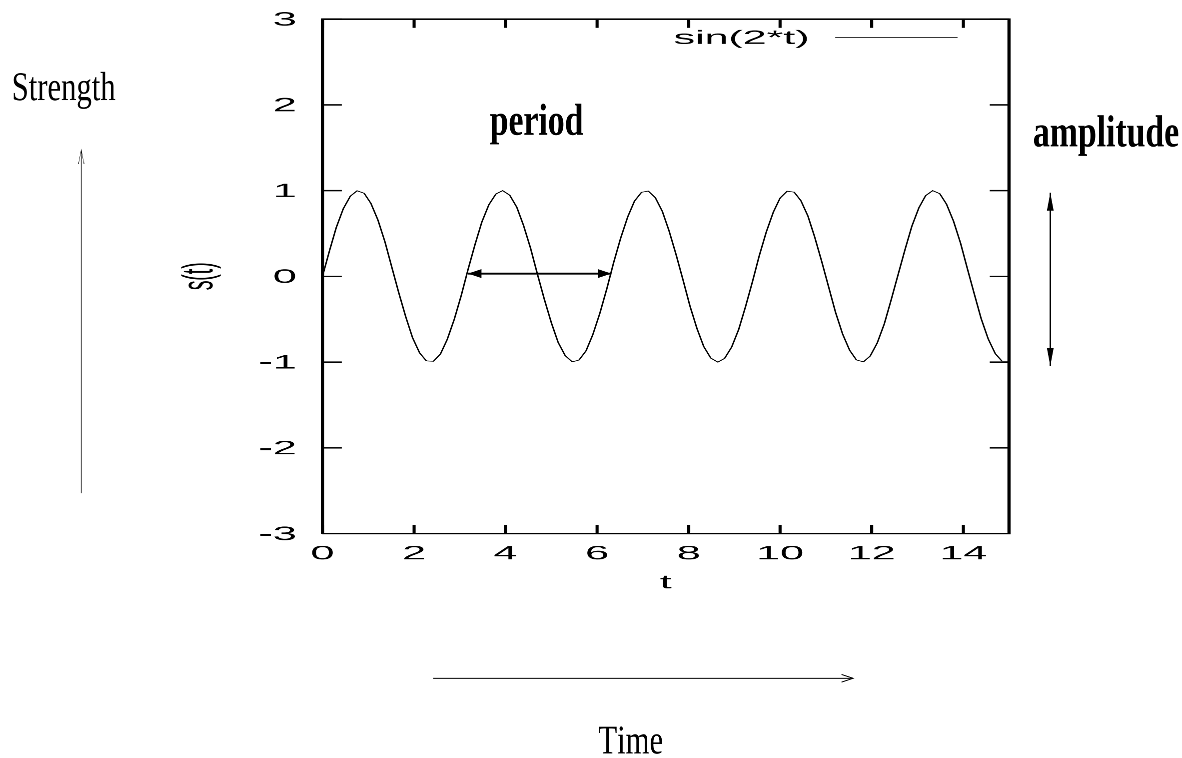
→ but there is also magnetic field: perpendicular to direction of travel

→ but 90 degree to electric field

→ recall hand rule in high school physics

→ application in data networks: passive RFID tags

## Electromagnetic wave: three key features




$\rightarrow$ period: $T$

$\rightarrow$ amplitude

$\rightarrow$ third key feature?

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

$\rightarrow$ $f$: $1/T$

$\rightarrow$ unit: Hz

Ex.: popular kernel software clock (i.e., tick)—10 msec

$\rightarrow$ Hz?

$\rightarrow$ how to configure in Linux?

Ex.: guitar string: note E—82.407 Hz

Ex.: 802.11g WLAN uses 2.4 GHz frequencies for data communication

$\rightarrow$ 1 GHz has 1 nanosecond period

Why are higher frequencies (overall speaking) good for data communication?

Travel speed of EM waves

→ speed of light (in vacuum)

→ constant

→ slower in copper, optical fiber

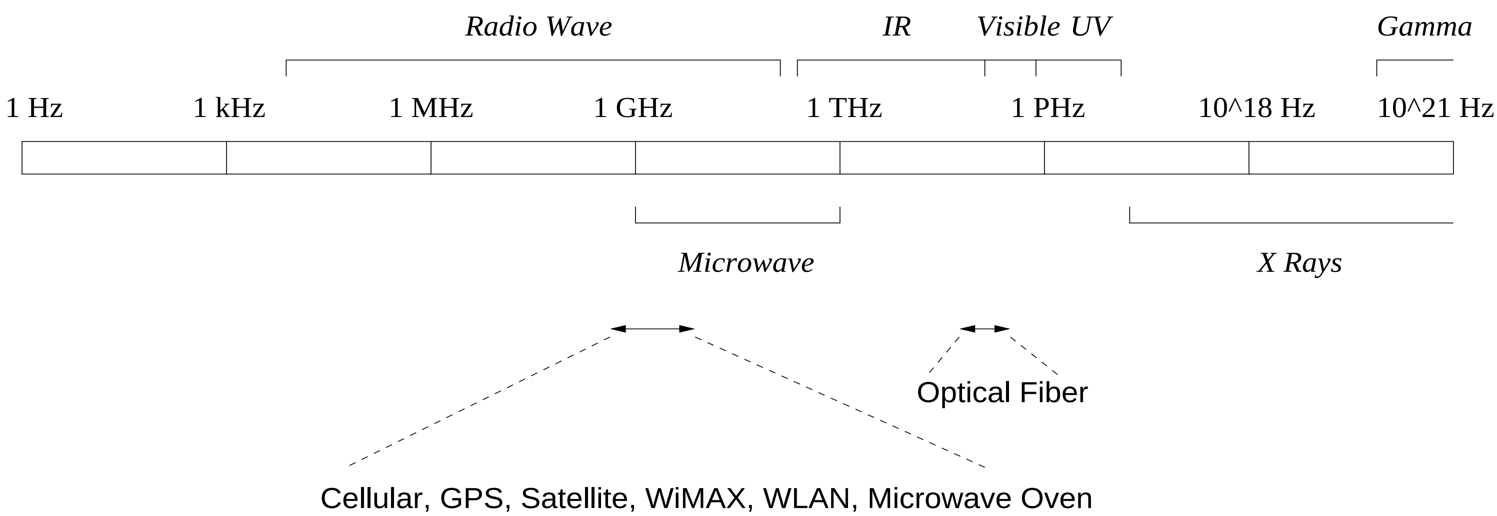
→ also outdoor wireless depends on atmospheric conditions (e.g., humidity/moisture)

→ in both wired and wireless: strength degrades with travel distance

Electromagnetic spectrum:

→ some of its data communication use today

→ logarithmic scale

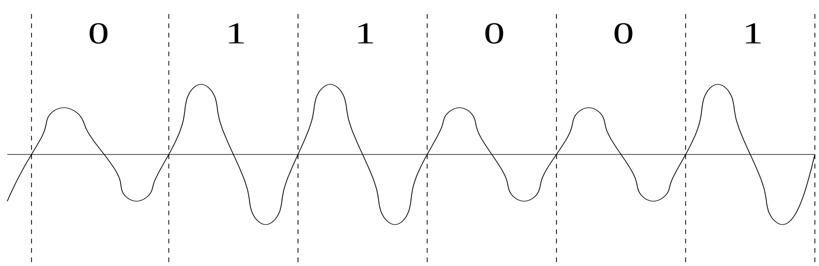



→ crowded near the 1 GHz neighborhood

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

$\rightarrow$ how do sine waves help?

Utilize amplitude to encode 1's and 0's




$\rightarrow$ large amplitude: 1

$\rightarrow$ small amplitude: 0

Method called amplitude modulation (AM)

$\rightarrow$ same concept as AM radio

$\rightarrow$ difference?

Suppose we use previous AM to transmit bits from $A$ to $B$

Throughput (bps) achieved:

$\rightarrow$ 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 ...)

Question: can we get 2 bps from 1 Hz frequency?

Issues with just increasing frequency:

Increasing frequency requires increase in processing speed

$\rightarrow$ higher cost

$\rightarrow$ 3.2 GHz CPU costs more than 2.4 GHz CPU

$\rightarrow$ e.g., Intel Core 2

Another key factor: wireless

$\rightarrow$ above 10 GHz requires line-of-sight (LOS)

Frequency use is tightly regulated by laws

$\rightarrow$ radio stations must get permission to broadcast on specific AM/FM frequencies

$\rightarrow$ not allowed to build WLAN devices running at 7 GHz

Viewpoint: frequency is a scarce resource

$\rightarrow$ e.g., auctioning of 700 MHz UHF frequencies in 2008

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

$\rightarrow$ utilize the band (or range) of frequencies as much as possible

$\rightarrow$ also called "bandwidth"

$\rightarrow$ e.g., bandwidth of 2.4–2.5 GHz?