Introduction

What is a computer network?

Components of a computer network:

- host devices (PCs, servers, laptops, handhelds)
- routers & switches (IP router, Ethernet switch, WiFi routers)
- links (wired, wireless, quantum)
- protocols (IP, TCP, UDP, CSMA/CA, OSPF, BGP)
- applications (DNS, HTTP, SMTP, SNMP, SSL)
- humans and bots (spam, DoS, worm)

Hosts, routers & links form the *hardware* side.

Protocols & applications form the *software* side.

Protocols can be viewed as the "glue" that binds everything together.

Protocol example: from low- to high-layer

- NIC (network interface card): firmware

  → e.g., Ethernet card, WLAN card, CDMA or TDMA air interface (cellular)

  → mainly ROM code

- device driver: part of OS

  → fast and slow interrupt handlers

- ARP, RARP: OS

  → NICs have two names (e.g., 48 vs. 32 bits): translation

- IP: OS

  → software glue of global Internet

- OSPF, RIP, BGP: routing protocols above IP

  → OFPF, RIP: within organizations (intra-domain)

  → router OS (e.g., IOS)

  → BGP: global Internet (inter-domain)

- TCP, UDP: OS

  → TCP: files (text, image, video)

  → UDP: multimedia streaming

- DNS, HTTP, SMTP, SNMP, SSL: application layer

- ssh, web browser, php, P2P (BitTorrent), YouTube, Facebook, Twitter, bots: application layer

What layers are relevant?

- 1970s: lower layers and hardware
- 1980s: both lower and higher layers
- 1990s: higher layers
- today: both lower and higher layers, and hardware

  → driving force: wireless networks

  → primacy of mobile devices

  → boundary between telephony and data networks is gone

  → ubiquitous Internet of Things (IoT)

Example: Digital TV and freed-up UHF spectra

→ 300–700 MHz frequency targeted for data networking (e.g., super WiFi)

Example: Short-distance services

→ RFID for electronic payments, tolls, inventory control

→ Bluetooth streaming

→ getting rid of wires (e.g., wireless USB, wireless battery charging)

Example: CAN (controller area network) bus and vehicle networks

→ increasingly relevant: self-driving vehicles

→ connected to GPS, cellular, IP networks

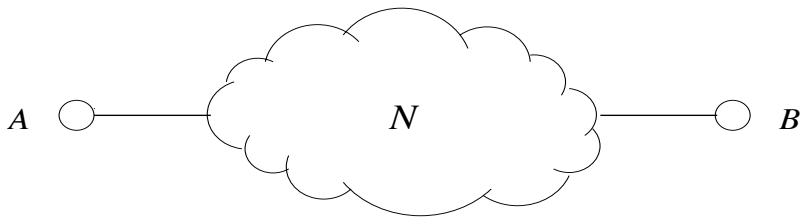
Computer networks enable communication

Simplest instance of communication:

- Two hosts A, B connected by some network N.
- Transmit information between A and B.

  $\rightarrow$ information: analog or digital

  $\rightarrow$ simplest case: single bit



Norm in today's networks: content is digital (i.e., bits) but transmission is analog (i.e., electromagnetic waves).

$\rightarrow$ use analog information to transmit digital information

Network N can take many forms

- point-to-point link: dedicated, direct link between A and B

  $\rightarrow$ e.g., single wire, line-of-sight antenna

- broadcast link: what A sends can be heard by all (not just B)

- internetwork: network of networks

  $\rightarrow$ e.g., Purdue's campus network, global IP Internet

What capabilities must A, B, and N have?

One: information abstraction

- digital content representation: encode/decode information
  - → from little/big endian to message format: header, payload, trailer
  - → app payload: file, streaming media, protocol interaction
- analog representation and transmission of digital content
  - → analog signals over physical media (e.g., copper, fiber, wireless)
  - → once upon a time (80s): tranmission using square waves was popular

Two: information protection

- deal with information corruption: bits flip
  - → bit error rate (BER)
  - → e.g., 10^{-9} for fiber optic cable, 10^{-6} or higher for wireless
- deal with information loss: packet drop at routers and hosts
  - → culprit: buffer overflow
- security
  - → protect against eavesdropping: confidentiality
  - → protect against ID theft: authentication
  - → protect against tampering: integrity
  - → protect against infrastructure attack: denial of service (DoS), intrusion

Three: performance

- file transmission should be fast: bottleneck can be software

  → throughput (bps)

  → e.g., 1 Gbps hardware link does not mean 1 Gbps throughput

  → Why not? What does TCP do? Are there faster methods?

- information latency: time (msec)

  → physical distance: speed-of-light (SOL)

  → buffering of messages at routers and host operating systems

  → bad for video/audio streaming, voice, interactive games

Types of network N:

connectivity:

- point-to-point link
- multi-access link
- internetwork

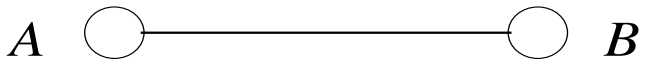
physical medium:

- wired
- wireless

location:

- stationary
- mobile

Point-to-point link



- NIC at A, NIC at B
- wired: physical wire connecting two NICs

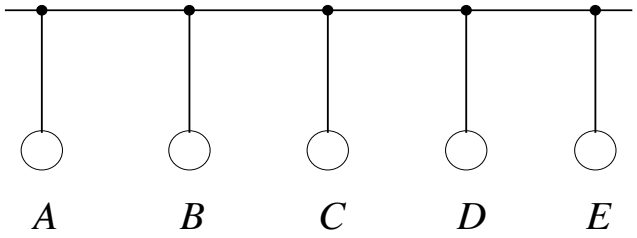
  → various cables: copper, fiber of different quality
- wireless:

  → line-of-sight (LOS) antenna at two NICs: directional

  → e.g., roof-top building-to-building, infrared TV remote, 60 GHz networks
- A and B don't need names

  → at least in principle

Multi-access link



- sometimes called bus (e.g., old Ethernet)
- wireless media with omni-directional antennas

  → e.g., wireless LANs
- wireless media with semi-directional antennas

  → e.g., GPS satellites, cellular tower antenna

  → signal casts a cone

  → broadcast (everyone) or multicast (subgroup)
- names (i.e., addressing) necessary

  → "From" and "To"

  → called local area network (LAN) addresses

- key issue of multi-access link communication: access control

  → link is a shared resource

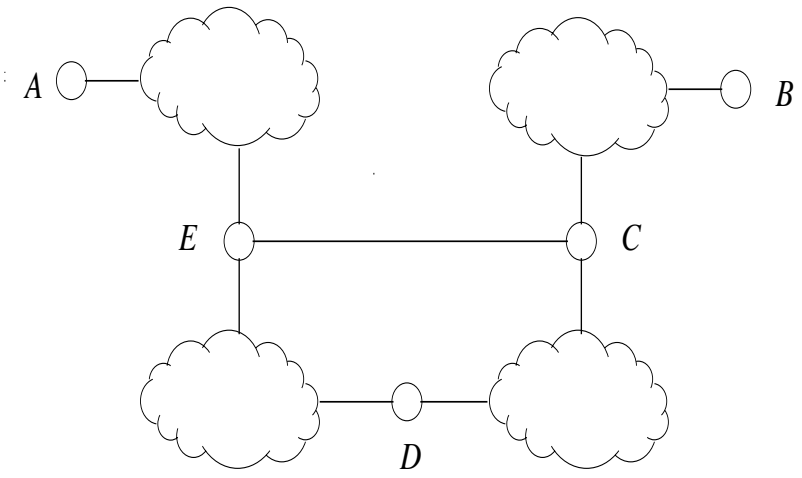
  → how to share?

  → myriad of LAN technologies and protocols

  → e.g., WiFi, Bluetooth, RFID, Ethernet

  → much of LAN technology and protocols revolves around this issue

Internetwork



- recursive definition

  → point-to-point and multi-access are networks

  → network of networks: internetwork

- ultimately networks reduce to

  → point-to-point and multi-access links

  → everything else is their composition

Additional complications introduced by internetworks:

- new names beyond LAN addresses
  - → in principle, LAN addresses are unique and suffice
  - → in practice, new names (i.e., network addresses) bring benefits despite overhead
  - → dominant: IP, in particular, IPv4
- protocol translation
  - → LANs speak different languages (e.g., Ethernet and WLAN)
  - → internetworking overhead
- path selection between sender/receiver
  - → routing: within and across organizations
  - → e.g., routing within Purdue, routing from Purdue to one of its service providers

- how fast to send on a long path
  - → links with different speeds and traffic
  - → how to coordinate sender/receiver to achieve fast speeds: congestion control
- location management
  - → e.g., moving from 1st floor in LWSN to 2nd floor, moving from LWSN to WANG, commuting on a bullet train
  - → handoff of mobile host among multiple networks
  - → LAN handoff, IP handoff (Mobile IP)