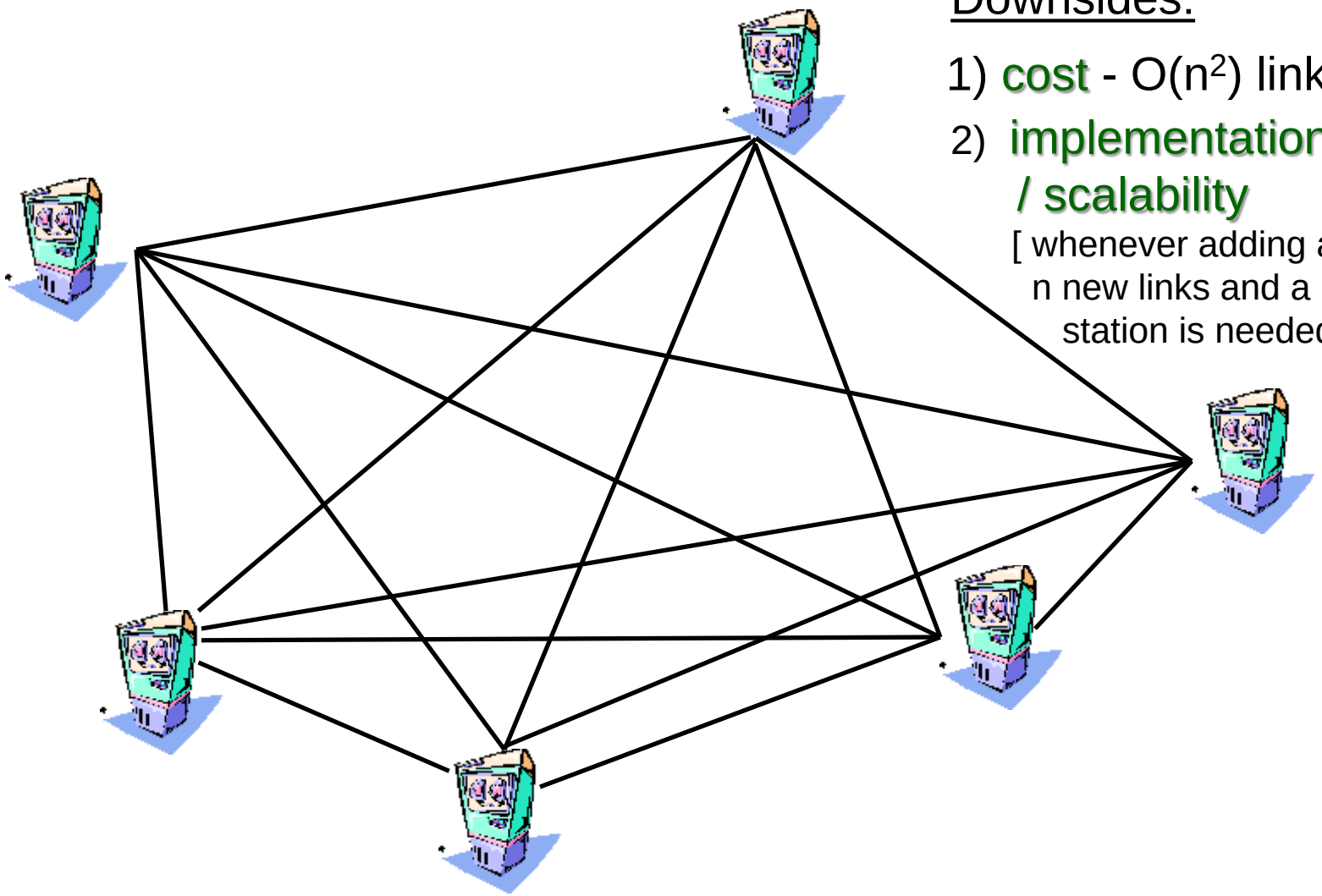
Connecting Mainframes - Option 1:
Full Mesh / Direct Link Infrastructure



Downsides:

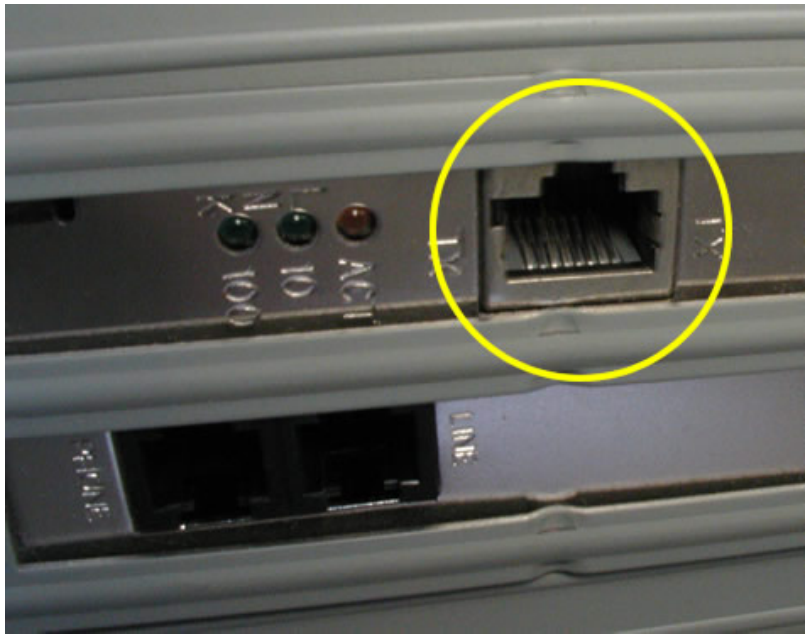
1) cost - $O(n^2)$ links and NICs

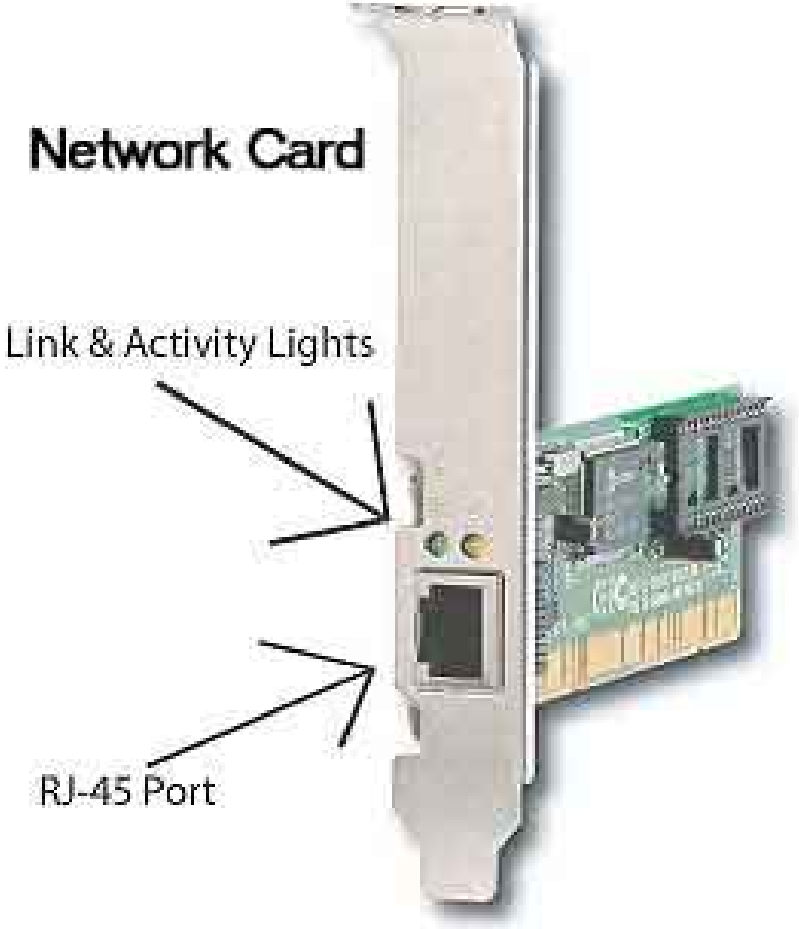
2) implementation complexity / scalability

[whenever adding a new station, n new links and a NICs at each station is needed]

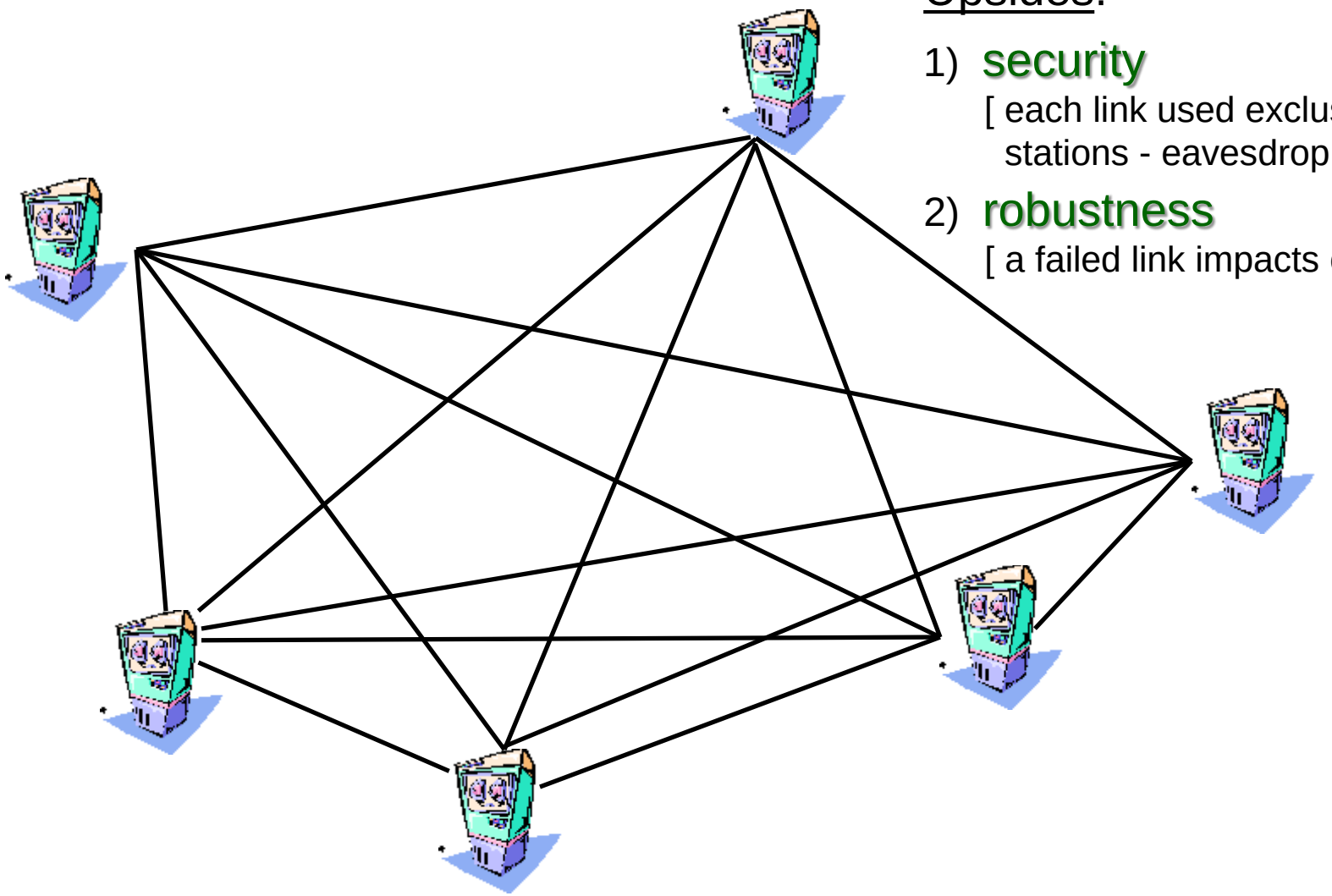
NIC (Network Interface Card)

- **piece of hardware that allows a computer to 'communicate' with other computers over a network**





Connecting Mainframes - Option 1:
Full Mesh / Direct Link Infrastructure

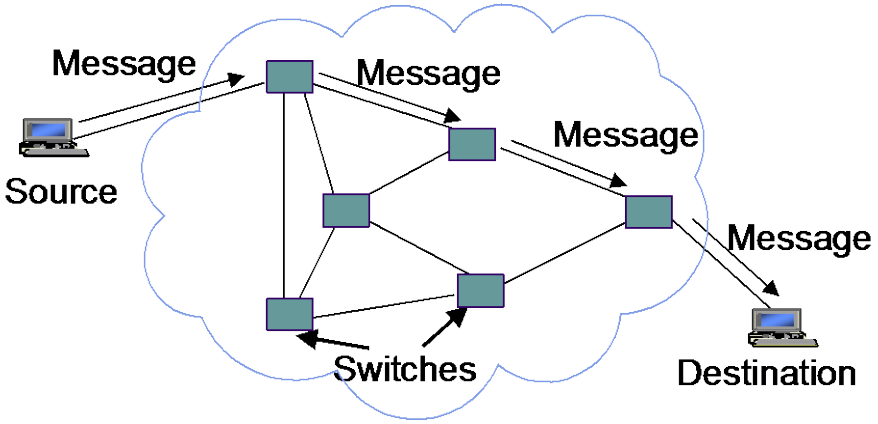


Upsides:

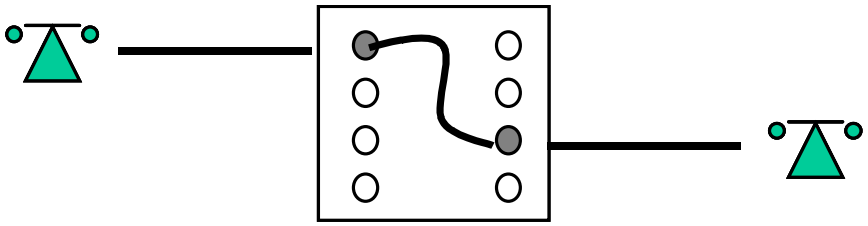
1) security
   [each link used exclusively by 2 stations - eavesdrop. impossible]
2) robustness
   [a failed link impacts only 2 stations]

Connecting Mainframes - Better Solution:

Networked (Switched) Infrastructure!!!

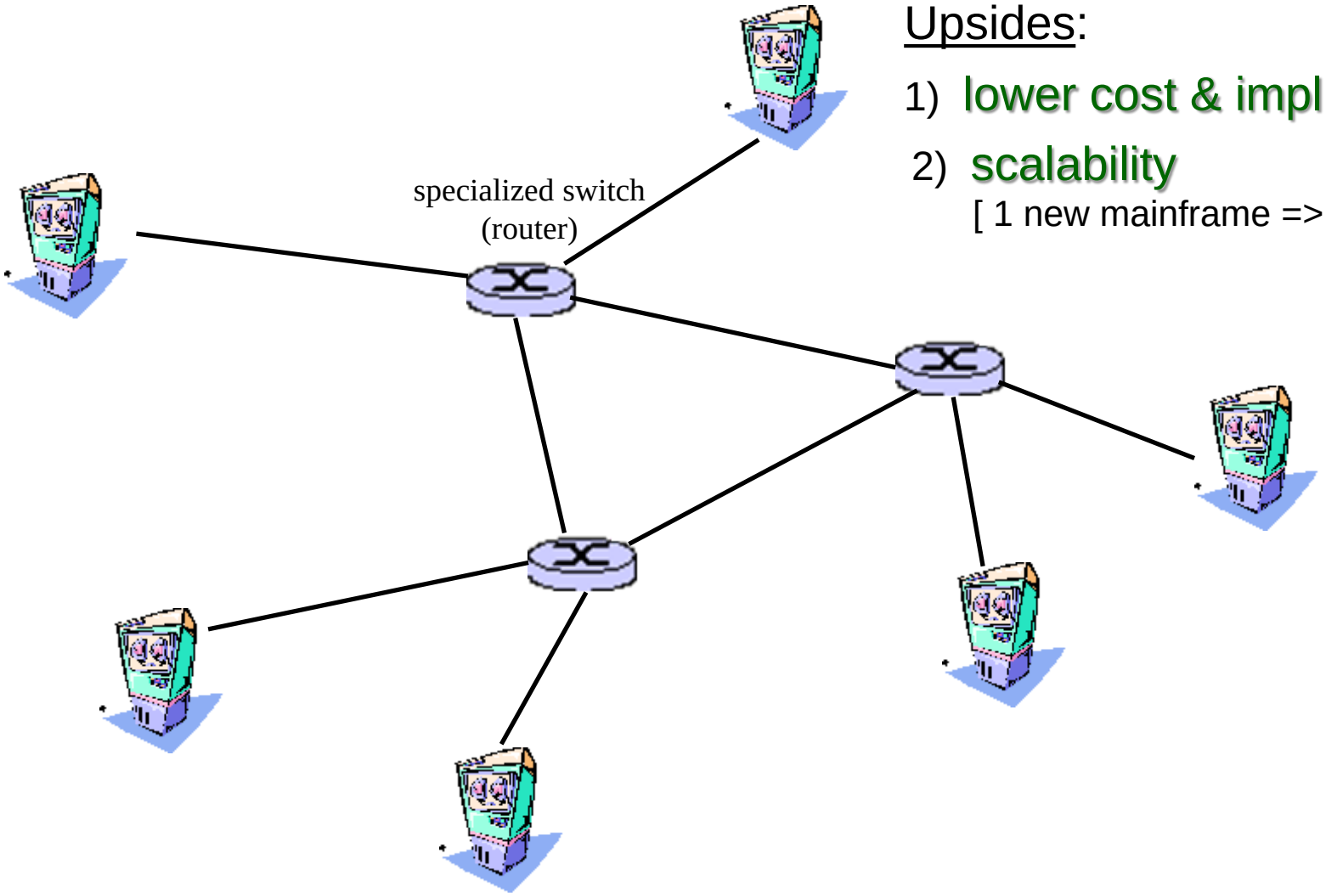


telegraph network



telephone network

Connecting Mainframes - Option 1:
Switched Network Infrastructure



Upsides:

1) lower cost & impl. complexity
2) scalability
   [1 new mainframe => 1 new link]

Router / Packet Switch

- **dedicated device/computer that forwards data packets between computer networks**

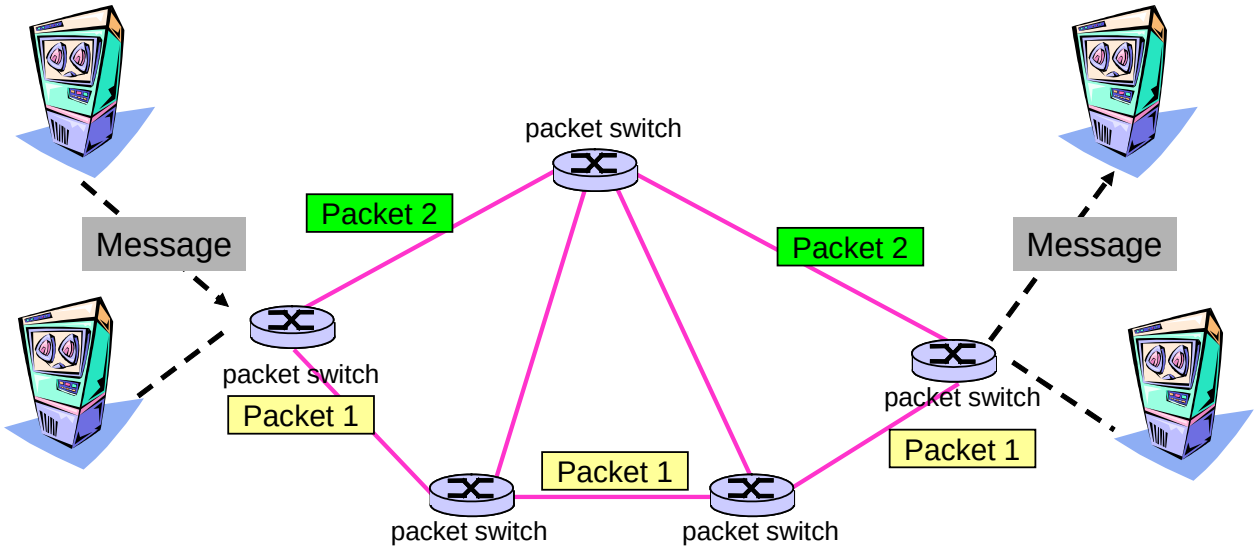
Cisco 1800

Cisco 7200

Computer-to-Computer Networks (cont.)

ARPANET: Architecture

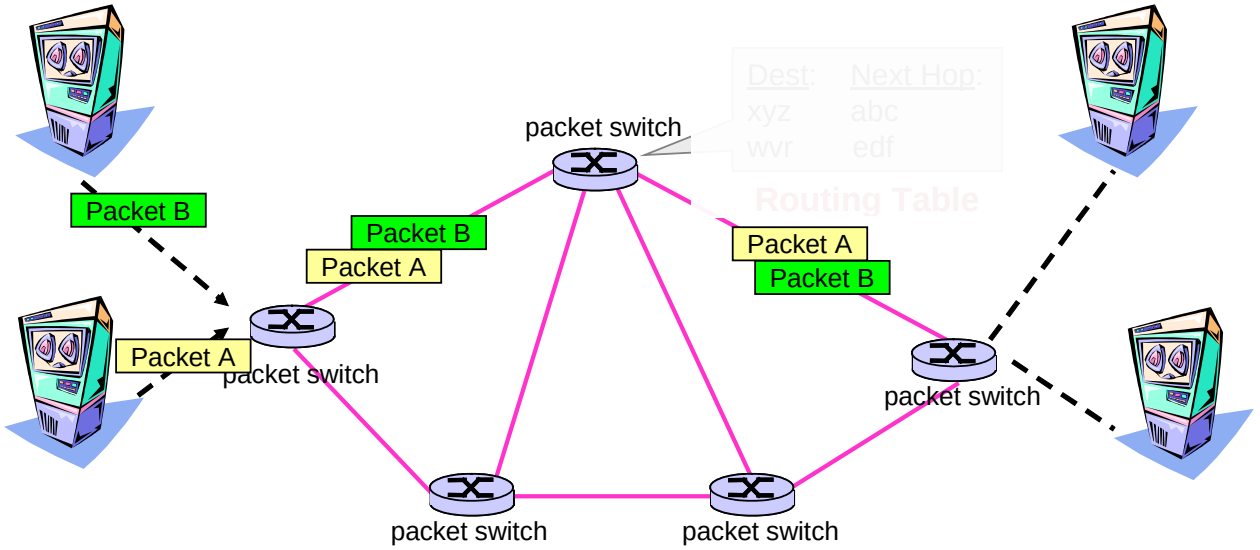
- network core consists of packet switches (dedicated minicomputers) to avoid costly full mesh topology
  - each packet switch connects to at least two other switches to provide alternative paths in case of failure
- network transfer messages by breaking them into packets of fixed size
  - long messages ⇒ long delays & higher prob. of error
  - each packet has a header with destination address – packets are transmitted independently !!!
- network transfers packets using "store and forward" principle



Computer-to-Computer Networks (cont.)

ARPANET: Distinguishing Features

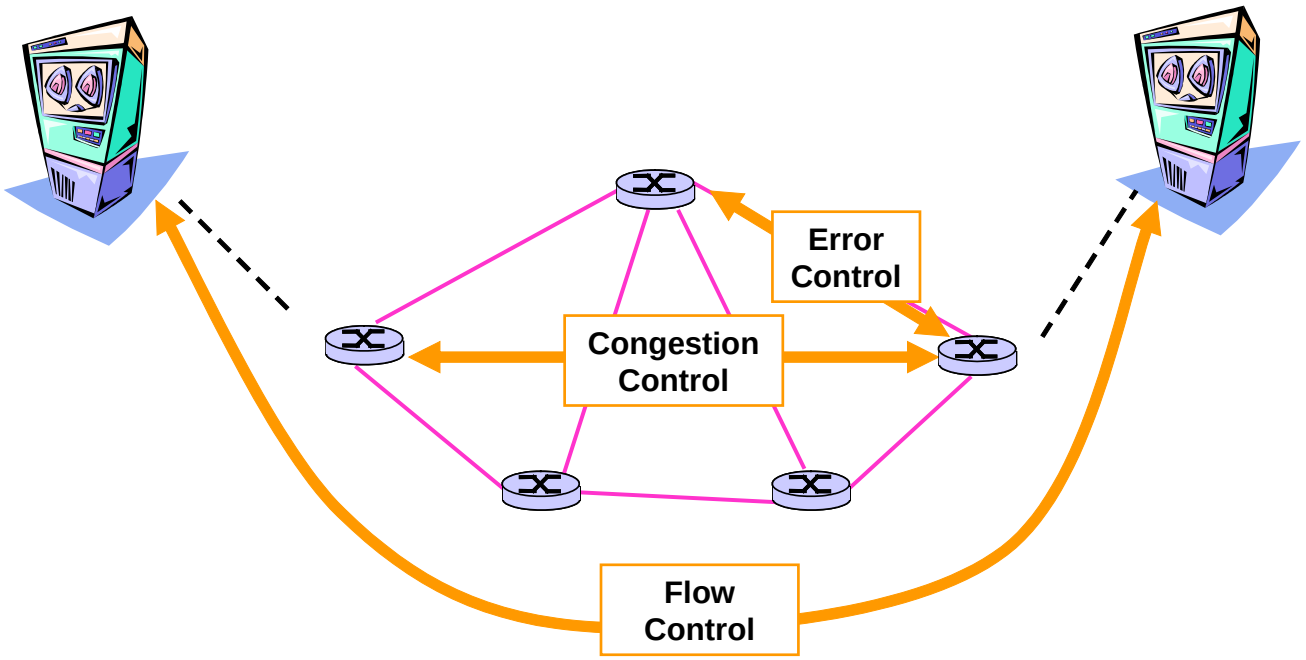
- each packet switch contains routing / forwarding tables ('next hop per destination' tables)
  - each packet contains destination address ⇒ packet switch looks at routing table and forwards packet in right direction
- connectionless service (QoS not guaranteed)
  - no connection setup is required prior to packet transmission
  - packets are buffered at packet switches to await transmission on appropriate link
  - packets from different users are multiplexed on links between packet switches



Computer-to-Computer Networks (cont.)

ARPANET: Distinguishing Features

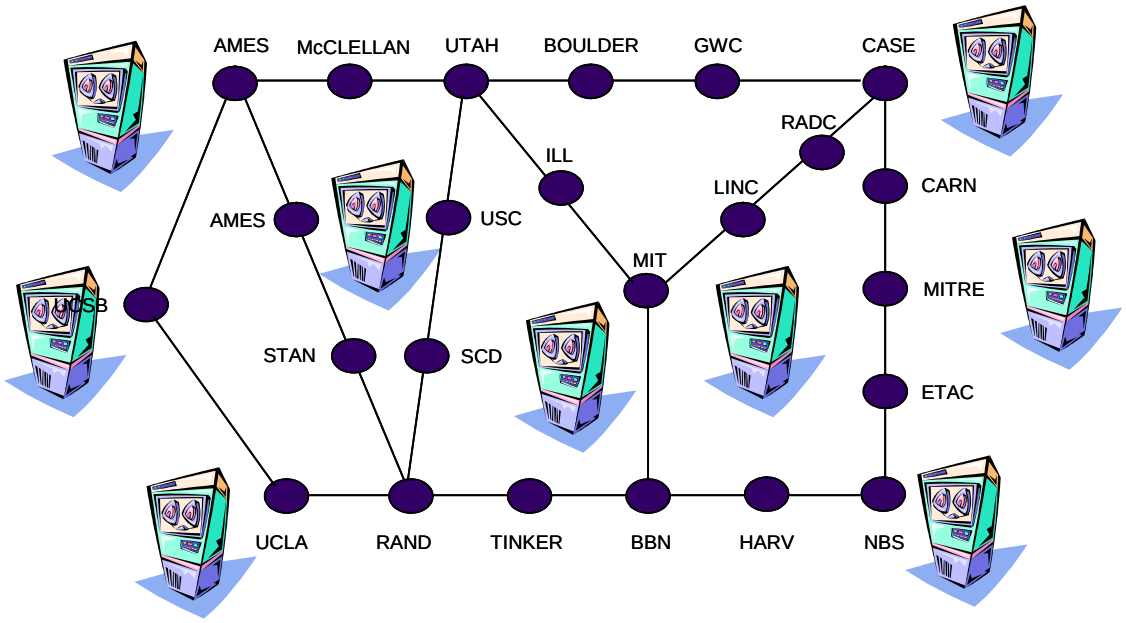
- **error control** between adjacent packet switches enables faster error recovery
  - partial responsibility of IP protocol
- **congestion control** inside the network prevents buffer overflow at core packet switches
- end-to-end **flow control** prevents buffer overflow at receiver / sender
  - responsibility of TCP protocol



Computer-to-Computer Networks (cont.)

ARPANET: Applications

- "**dumb core, intelligent edges**" enabled development of many interesting and useful applications: e-mail, file transfer (FTP), remote login (Telnet)
  - **dumb core** – packet switches are only required / capable of packet forwarding
  - **intelligent edges** – end-devices have considerable CPU and memory capabilities

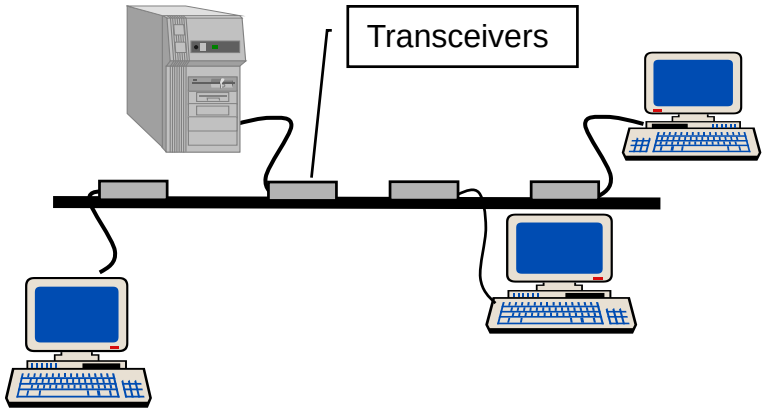


1950s - 1960s:	Terminal-Oriented Computer Networks
1960s – 1970s:	Computer-to-Computer Networks: the ARPANET – first Wide Area Network (WAN)
1980s:	**Local Area Networks (LANs)**
1980s:	The Internet

Local Area Networks

LAN History

- in 1980s affordable computers become available
- subsequently, need for low-cost, high-speed, and low error-rate networks arose
  - to interconnect local workstations over small radius < 1km
  - to enable sharing of local resources (printers, servers, etc.)
- complex packet switching, congestion and flow control were unnecessary
- variety of LAN topologies emerged, including: bus, ring

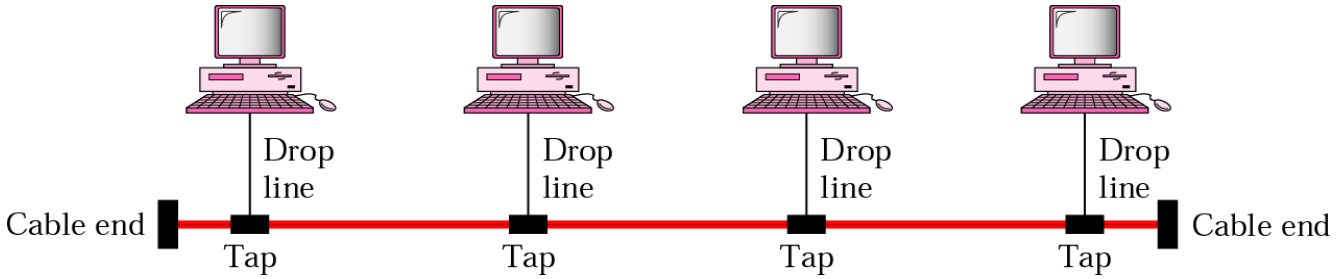


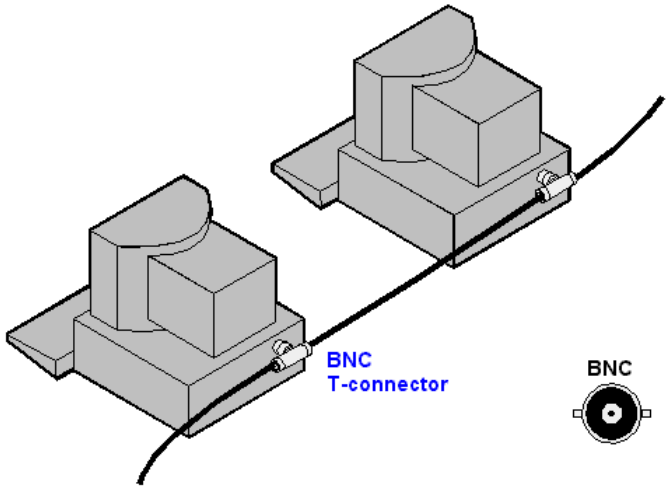
Local Area Networks (cont.)

Bus Topology (Ethernet)

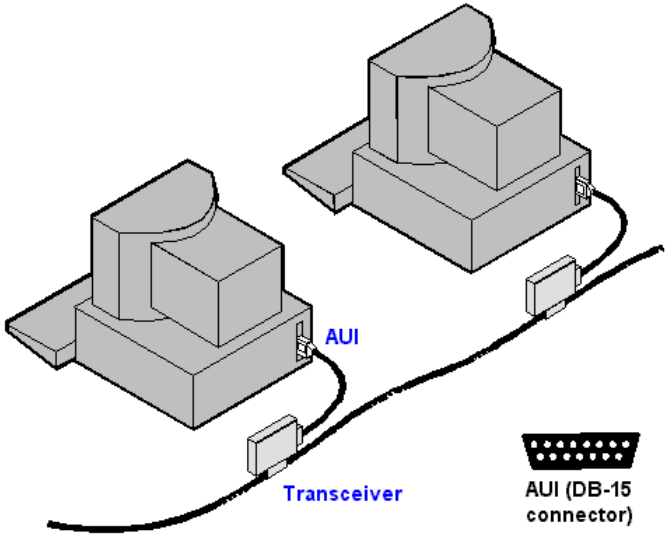
– one long cable, so-called **backbone**, links all devices in the network – similar to single-line mainframe architecture

- each workstation connects to backbone through Network Interface Card (NIC); each NIC has globally unique address
- data frames are broadcast into coaxial cable
- **receive**: NIC listens to medium for frames with its address
- **send**: NIC listens to medium for presence of ongoing transmission – if no transmission is found, send frame
- **collision**: if frame collides with somebody else's frame, abort transmission and retry later

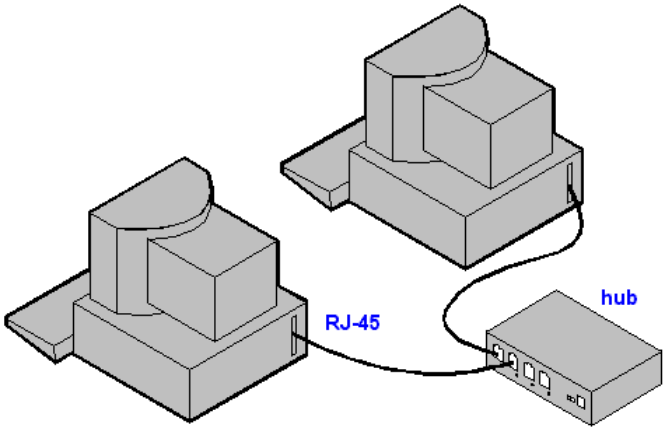


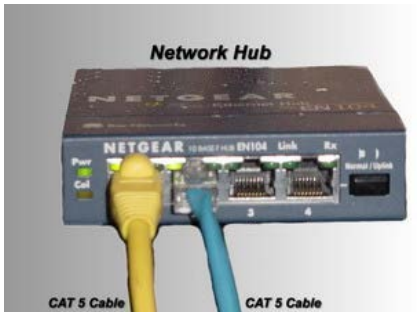


BNC



AUI (DB-15 connector)

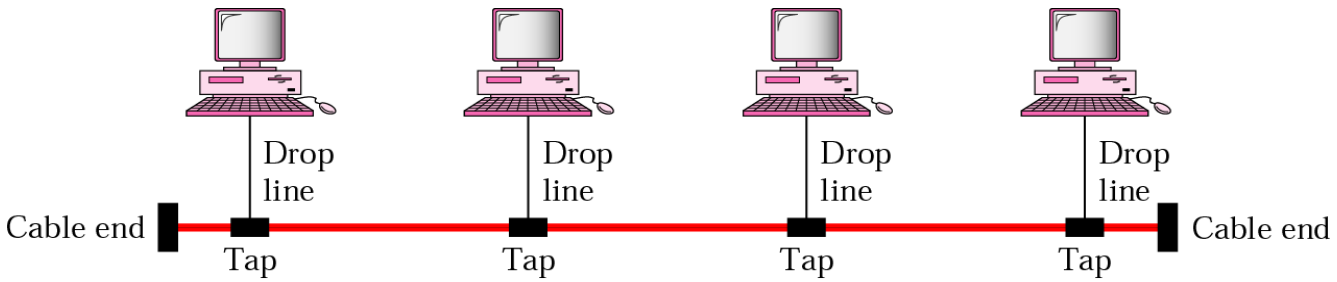




Local Area Networks (cont.)

Bus Topology (Ethernet)

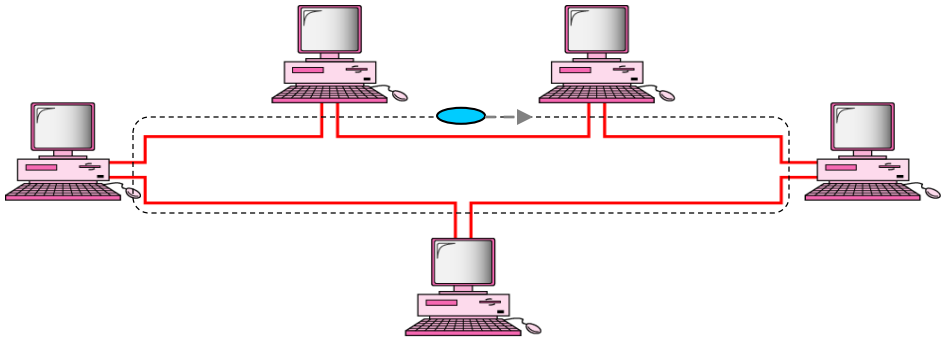
- **advantages**: simple & inexpensive installation
- **disadvantages**: 1) backbone = single point of failure
  2) collisions ⇒ diminishing capacity
  - if two or more devices transmit simultaneously their signals will interfere



Local Area Networks (cont.)

Ring Topology – each device has a dedicated point-to-point connection only with the two devices on either side of it

- a small frame – token – circulates around the ring; only the station that possesses the token is allowed to transmit at any given time
- signal is passed along the ring in one direction, from device to device, until it reaches its destination
- **advantages**: fairness in access / effective use of bandwidth – token-passing provides each station with a turn to transmit
- **disadvantages**: entire network will fail if there is a failure in any transmission link or in the mechanism that relays the token



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1980s:	**The Internet**

The Internet

Internet = Internetwork – two or more interconnected networks –
– network of networks

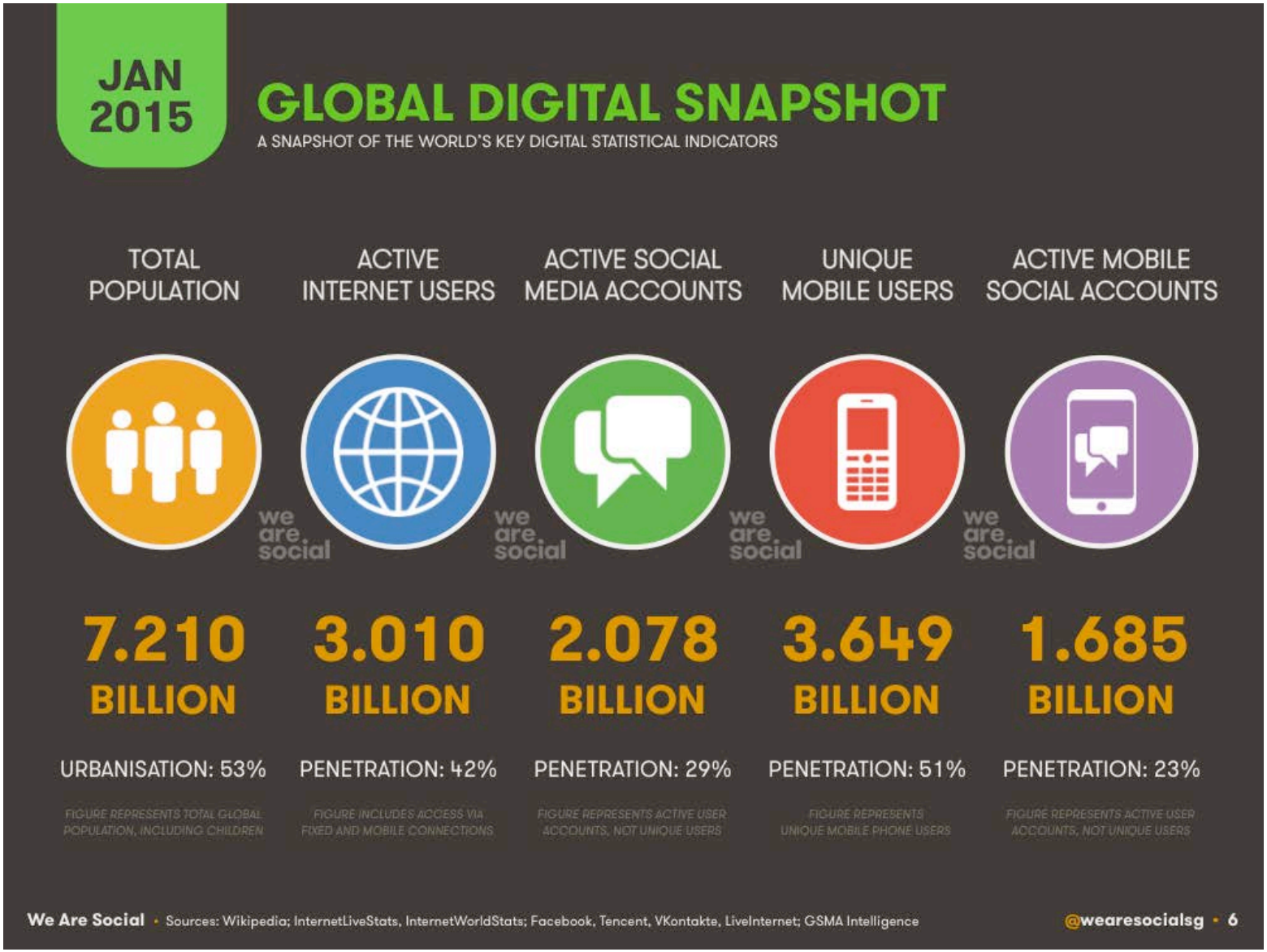
The Internet: Past

- LANs that emerged in 1970s were different in terms of their underlying technology and operation
- a protocol that would enable communication across multiple dissimilar networks was needed
  - "higher level of abstraction" protocol – IP Protocol
- Internet Protocol / Addressing were soon developed and enabled creation of a single global internetwork

The Internet: Present

- spread over 200 countries
- made up of 100,000s of interconnected networks, 10,000,000s of interconnected hosts, and 100,000,000s of users
- still grows exponentially …

The Internet (cont.)

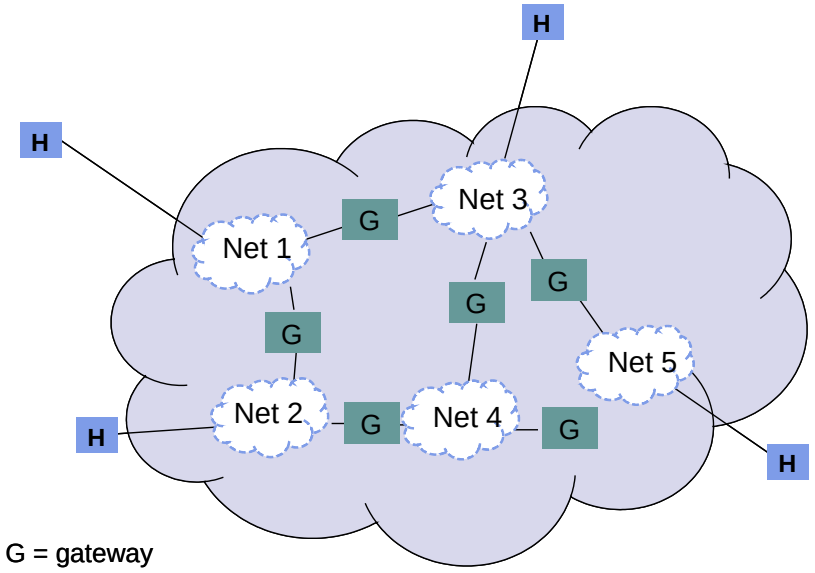


http://thenextweb.com/socialmedia/2015/01/21/2015-worldwide-internet-mobile-social-media-trends-get-376-pages-data/

The Internet (cont.)

The Internet = IP Network

- each component network must contain special packet switch, gateway / router, through which it interconnects with rest of the Internet
- host computers place data in IP packets (data + IP header) and deliver them to nearest router
- router, with help of other routers, attempts to forward packet across the Internet
- "best effort service" – IP provides no mechanism to deal with packet loss, corruption, reordering



G = gateway
H = host

The Internet (cont.)

IP Addressing

- addressing scheme that fits (inter)network structure:
  IP address = Net ID + Host ID
- IP packets are routed only based on Net ID in destination IP address
  - routers have to know only major networks, not every single host ⇒ less memory / network update requirements
  - smaller routing tables ⇒ faster routing