Network Routing and the Internet

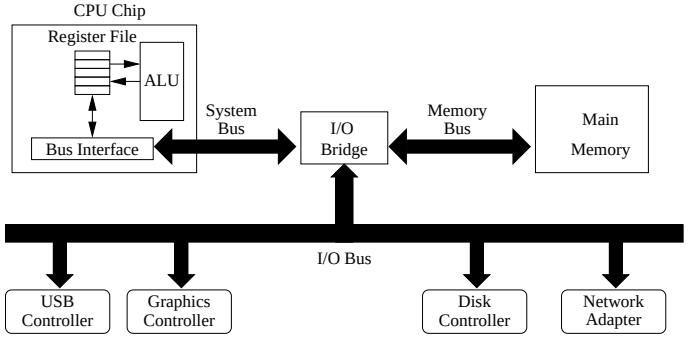
- Network switching
- Network routing
- Local area networks (LANs)
- Inter-networking
- Redundancy
- Internet protocols and addressing
- References:
  - Bryant and O'Hallaron, Sect 12.1 – 12.3
  - (Data and Computer Communications, Stallings, chapters 8 – 11)

Network switching

- Communication networks can be categorised based on the techniques used to transfer data
  - Circuit switched networks (a dedicated **communication channel** is established between two stations)
    Example: Telephone network
  - Packet switched networks (data is sent in a sequence of **packets**)
    Example: Internet, Ethernet
  - Broadcast networks (no intermediate switching nodes, one sender and one/many receivers on a shared medium)
    Examples: Radio, TV, Ethernet

Hardware Organisation of a Network Host

- Just another I/O device
- Data copied from network adapter to memory using DMA



Network routing (1)

- How does a packet of information get from the PC on my desk to a computer across the campus or across the world?
- Direct communication between computer:
  - Would require too many connections to be practical (in theory could have up to 4.3 billion computers in the Internet, with 32 bit addresses $\rightarrow 2^{32}$ address space)
  - Inefficient use of resources: 99% of the time is spent with communicating with only 1% of the computers

Network routing (2)

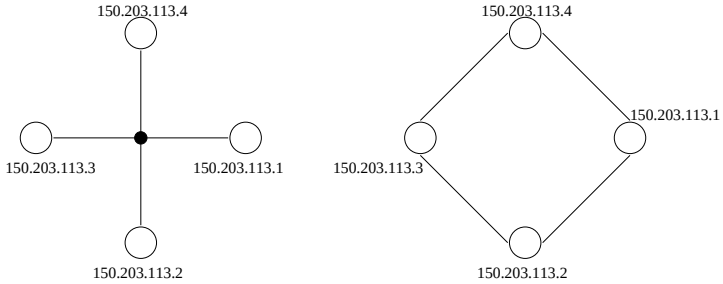
- Most of the computers you regularly communicate with will be in your local area (e.g. on the same ISP or in the same office building)
- Break the problem into two parts:
  - Communication within the local area (**local area networks**)
  - Communication between LANs (**inter-net**work communication)

Local area networks (1)

- Several configurations (called **network topologies**)

  Examples: Star, ring, or bus
- Widespread: Token-ring, Ethernet, Fast-Ethernet
- Each computer in a LAN has its own unique address
- A message (packet) is broadcast on the LAN, and each computer reads the message header to determine if the message is intended for it
  - Star/bus topology: Messages for other computers are ignored
  - Ring topology: Messages for other computers are passed around the ring

LAN topologies



STAR RING

Local area networks (2)

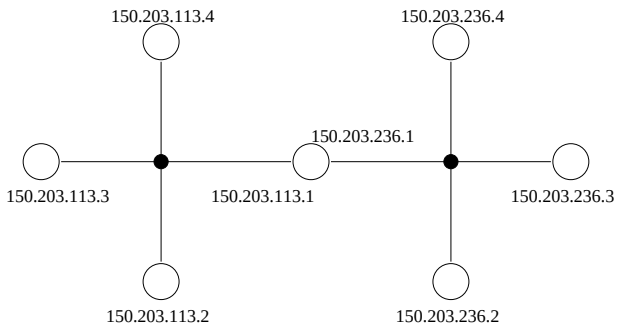
- The broadcast of packets makes **packets sniffing** possible. Using **switching** with the star topology can alleviate this security problem
- For LANs based upon the **Internet Protocol** (IP) the computers on the LAN typically have IP numbers from a small range

  Example: `150.203.160.`**0** → `150.203.160.`**255**

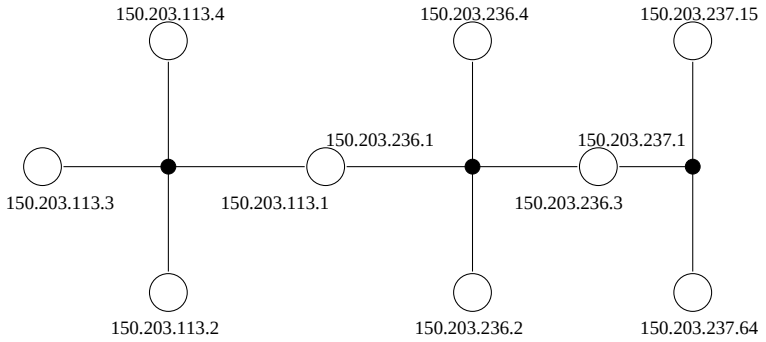
Inter-network communication

- If one computer is a member of two LANs, it can pass packets back and forth between the LANs
- This enables computers on one LAN to communicate with computers on the other LAN
- The computer passing the packets back and forth between the LANs is called:
  - **Gateway** (from the perspective of other computers in the network), or
  - **Router** (from the perspective of the network engineer)
- A gateway/router is **routing** the network traffic
- IP based LANs have IP numbers from different ranges

Two-LAN example



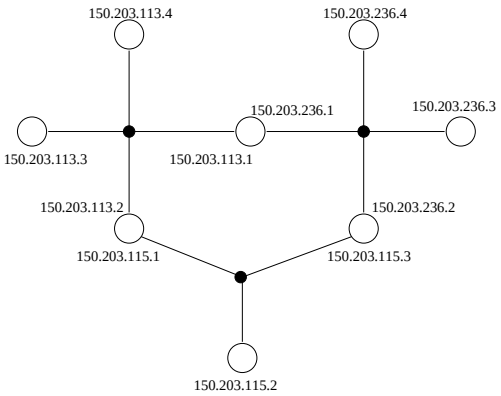
Three-LAN example



Redundancy

- Connecting several LANs together can result in there being multiple path between two LANs
- This gives some redundancy to the inter-network communication
  - Enables automatic by-passing of network problems (e.g. interruptions due to crashed/switched off routers)
  - IP routing will *automatically* choose to route traffic by the shortest path (generally in terms of network hops)

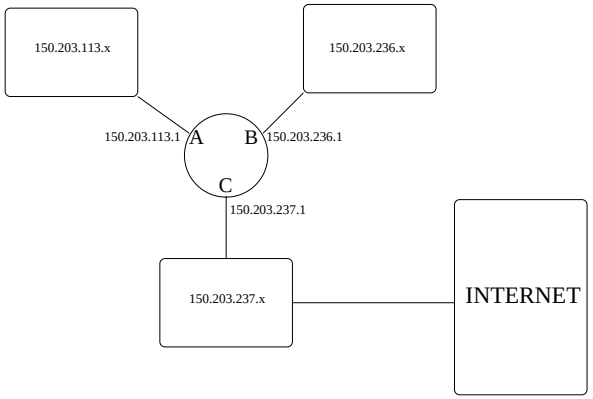
Redundancy example



Routing decisions

- How does a router know what to do with a packet?
- It makes a decision based upon the destination address of the packet and the routing rules (tables) it has been programmed with
- Example:
  - Packets for `150.203.113.xx` go out on link **A**
  - Packets for `150.205.236.xx` go out on link **B**
  - Packets for `150.203.237.xx` go out on link **C**
  - Packets for other (sub)nets go out on link **C**

Routing example



Routers

- The first routers were simply computers connecting two or more LANs
- Today a router can be anything from an old *i386-based Linux box*, through to a specialised *black box* from CISCO that costs tens of thousands of dollars
- Modern routers do much more than just forward packets:
  - Network monitoring (notify if congestion or outages)
  - Filtering (reducing traffic on local LANs, preventing hacking from external sites)
  - Packet logging (pay-per-Megabyte, eavesdropping)

Internet protocols (1)

- Developed in th 1970s (ARPANET, DoD) as a robust military network
- Today: The Internet is based on TCP/IP
- Many applications: WWW, E-Mail, FTP, Telnet, ...
- TCP/IP is based on packet switching
- Internet protocol (IP)
  - Provides non-reliable, connectionless network service
  - A packet consists of a header and user data (maximal 64 Kilobytes)
  - Header contains sender and receiver address, segmentation information, maximal life time, checksum, etc.

Internet protocols (2)

- Transmission Control Protocol (TCP)
  - Provides reliable, connection-oriented network service (connection has to be acknowledged)
  - TCP header contains source and destination **port** numbers, sequence- and acknowledge numbers, priority and checksum
  - Port numbers refer to processes on computers. Examples FTP 21, Telnet 23, WWW 80, etc.
  - The TCP packet is forwarded to IP
- User Datagram Protocol (UDP)
  - Provides functionality of IP to upper layers
  - Expanded with port numbers, checksum and length
  - Maximal length around 64 Kilobytes (header takes space!)

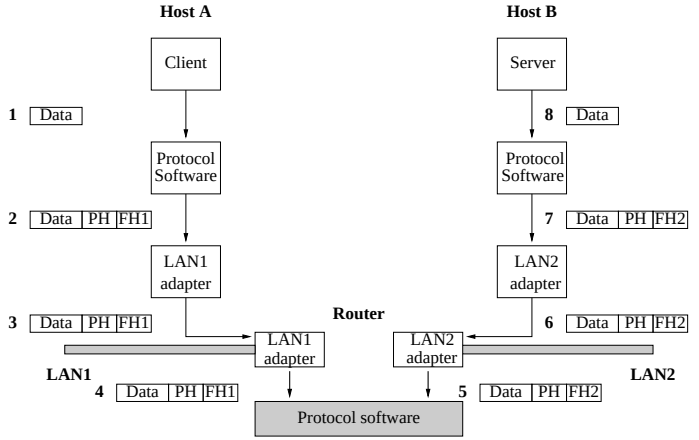
Internet protocols (3)

- Addressing of computers in the Internet
  - Each computer on the Internet is identified with a unique 32 bit number
- Split into four 8-bit numbers
  - Examples:
    `150.203.99.8` (www.anu.edu.au)
    `150.203.164.35` (cs.anu.edu.au)
    `144.135.8.151` (www.abc.net.au)
    `202.125.14.192` (www.act.gov.au)

Internet protocols (4)

- One part of the 32 bits addresses the network(s), the other part the computer in a local network
- Three classes of networks
  - **Class A** for large networks
    - 8 bits network, 24 bits computers
    - Maximal 16,777,216 computers
  - **Class B** for middle sized networks
    - 16 bits network, 16 bits computers
    - Maximal 65,536 computers
  - **Class C** for small networks
    - 24 bits network, 8 bits computers
    - Maximal 256 computers

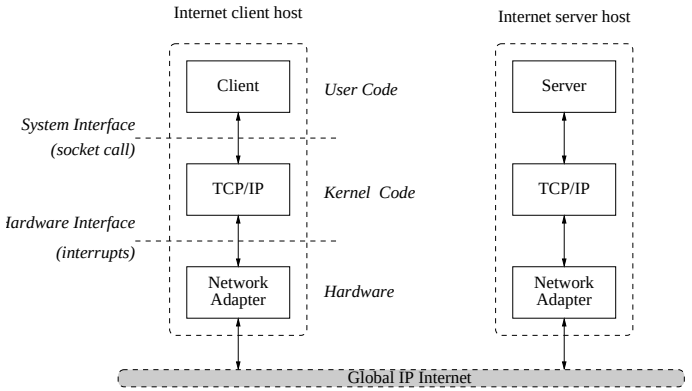
Data Transfer over Internet



Data Transfer over Internet (cont)

1. Client on host A invokes system call
2. Host A creates a LAN1 frame by appending internet header and LAN1 frame header to data
3. LAN1 adapter copies frame to network
4. At router LAN1 adapter reads packet and passes it to protocol software
5. Router determines how to route packet and appends new LAN2 frame header as required
6. Router LAN2 adapter copies frame to network
7. At host B adapter reads frame and passes it to protocol software
8. Protocol software on B strips off packet header and frame header and places data into server's virtual address space

Hardware/Software Organisation of Internet Application



Internet and WWW: Major Challenges

- how can a single site deal with an intense period of (world-wide) demand?

  e.g. 2006 World Cup Soccer site?

- how can the (exponentially increasing) WWW be so efficiently searched?

  e.g. Google

- approaches are similar to that used in other computer systems
  - virtualization and caching (e.g. AKAMAI)
  - precomputation and parallelism (over and within queries)

- the future: semantic (rather than keyword) -based World Wide Web