Protocol Stack

Email

Generally speaking, sending an email message is equivalent to copying a file from sender to receiver.

Networking

Packetization

- It is impossible to send arbitrary long messages.
- The representation program will forward the message to its local packetization program, this in turn, breaks the message into packets, add a header with number, and send these packets to packetization program at the destination computer.
- On arrival the packets will be reassembled at the remote packetization program and passed to the representation program.

Representation

- Correspondents may use different type of computers that represent text characters in different encoding.
- The email program passes the message to the representation program, which adds header that specifies the representation and sends it to the representation program on the destination computer.
- The representation program at the destination forms a translation to local encoding and then passes the message up to the email program at the destination computer.

Error

- Data is sometimes corrupted during transmission due to noise on the communication channels.
- It is possible to devise means to recognize errors.
- If the sender recognized an error the sender is asked to re-send the packet, otherwise, an acknowledgment is sent back to sender.

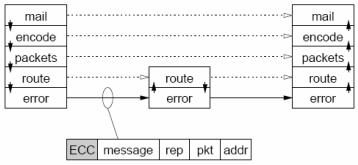
Routing

- The message must be routed through the network.
- The packetization program forwards the each packet to the router, this in turn, adds a routing header and determine where to send them.
- The router on the receiving host check the rout header and forward the packets towards the destination computer.
- Eventually, the packets arrive to the destination computer, and then passed to the packetization program at the destination computer.

ISO-OSI Layered Model

International Standard Organization
Open System Interconnected

Protocol Stack



•The set of programs that the message goes through is called a protocol stack.

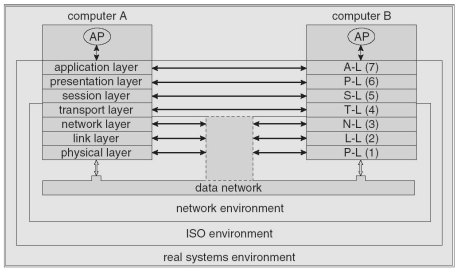
•Logically, each layer talks directly with its counterpart on the other machine, using particular protocol.

ISO-OSI Layered Model

The communication network is partitioned into the following multiple layers:

- **Physical layer** – handles the mechanical and electrical details of the physical transmission of a bit stream
- **Data-link layer** – Flow control over a signal link, buffering, and error correcting.
- **Network layer** – Routing.
- **Transport layer** – Partitioning messages into packets, maintaining packet order, controlling flow.

ISO-OSI Layered Model



The TCP/IP Protocol Suite

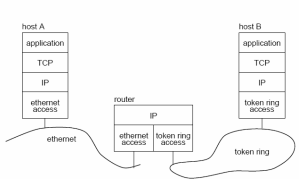
In practice, the TCP/IP protocol suite became a de-facto standard of the Internet before the OSI model was defined.

ISO-OSI Layered Model

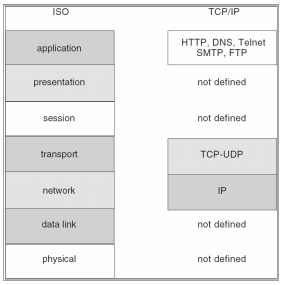
- **Session layer** – implements sessions, or process-to-process communications protocols (often unused).
- **Presentation layer** – resolves the differences in formats among the various sites in the network.
- **Application layer** – interacts directly with the users.

Internet Protocol

- The IP creates an internet: a network that is composed of networks.
- The IP performs the routing of messages across different networks.



The TCP/IP Protocol Layers



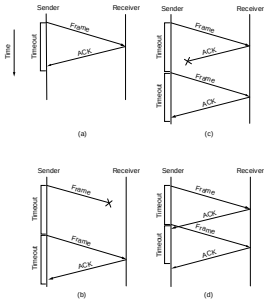
Flow Control

- The recipients must have a buffer large enough to hold at least a single packet.
- If more packets arrive than there is no space in the buffer, the buffer will *overflow*.
- *The situation in which the network is overloaded and drop packets is called congestion.*
- *In order to avoid congestion, flow control is needed.*
- Each sender has to estimate how much free space is available in the recipient's buffer.

Implementation Issues

Flow Control

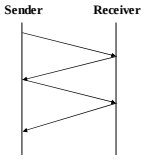
Acknowledgements & Timeouts



Acknowledgements & Timeouts

- An *acknowledgement* (ACK) is a packet sent by one host in response to a packet it has received
- A *timeout* is a signal that an ACK/NACK to a packet that was sent has not yet been received within a specified timeframe.
  - A timeout triggers a *retransmission* of the original packet from the sender.
  - Propagation delay is defined as the delay between transmission and receipt of packets between hosts.
  - Propagation delay (a.k.a. Round Trip Time RTT) can be used to estimate timeout period

Stop-and-Wait Process



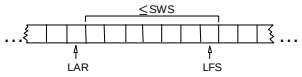
- Sender doesn't send next packet until he's sure receiver has last packet (i.e. buffer can contain a single packet).
- The packet/Ack sequence enables reliability
- Sequence numbers help avoid problem of duplicate packets.
- Leads to large gap between packets, due to RTT.

Buffering

- Sender needs to buffer data so that if data is lost, it can be resent.
- Receiver needs to buffer data so that if data is received out of order, it can be held until all packets are received
  - *Flow control.*
- How can we prevent sender overflowing receiver's buffer?
  - Receiver tells sender its buffer.

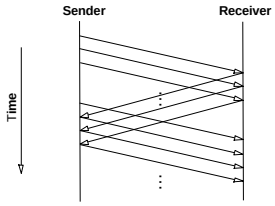
Sliding Window: Sender

- Assign sequence number to each packet
- Maintain three state variables:
  - send window size (**SWS**)
  - last acknowledgment received (**LAR**)
  - last packet sent (**LFS**)
- Maintain invariant: **LFS** - **LAR** <= **SWS**
- Advance **LAR** when ACK arrives
- Buffer up to **SWS** frames

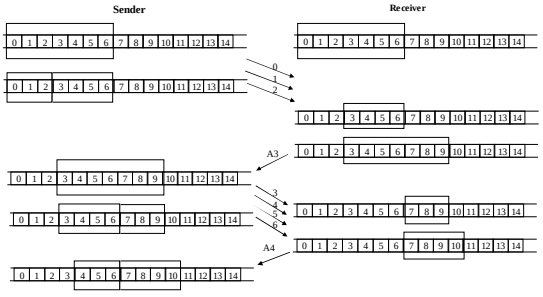


Solution: Pipelining via Sliding Window

- Allow multiple outstanding (un-ACKed) packets.
- Upper bound on un-ACKed packets, called *window.*
- Increased utilization

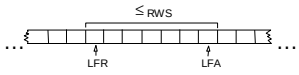


Sliding Window Example



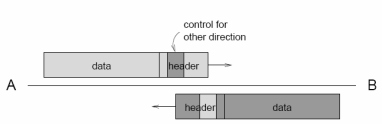
Sliding Window: Receiver

- Maintain three state variables
  - receive window size (**RWS**)
  - largest packet acceptable (**LFA**)
  - last packet received (**LFR**)
- Maintain invariant: **LFA** - **LFR** <= **RWS**
- Packet **SeqNum** arrives:
  - if **LFR** < **SeqNum** < = **LFA** accept
  - if **SeqNum** < = **LFR** or **SeqNum** > **LFA** discarded



Piggybacking

- The recipient needs to inform the sender of two unrelated conditions:
  - The data has arrived correctly or not (ACK or NACK)
  - The buffer space available for additional transmissions.
- If the communication is bidirectional, the control data can be *piggybacked* in the data going on the other direction.



Sliding Window Summary

- First role is to enable reliable delivery of packets:
  - Timeouts and acknowledgements.
- Second role is to enable in order delivery of packets (FIFO):
  - Receiver doesn't pass data up to app until it has packets in order.
- Third role is to enable flow control:
  - Prevents server from overflowing receiver's buffer

TCP Congestion Control

- A special case of flow control is the congestion control algorithm used in TCP.
  - Cooperation: The control is not exercised by a single system, but the combined actions of all the system involved.
  - External resources: The resource being managed is external to the controlling systems.
  - Indirection: The controlling systems do not have direct access to the controlled resource.
- Congestion:
  - Packets are dropped by routers that implement the network.
  - Dropped packets are retransmitted, which incurs additional overhead, thus, communication progressively worse.
  - Communication slows down.

Implementation Issues

Congestion Control

TCP Congestion Control

- Congestion control is manifested in selecting the appropriate window size.
- In actual transmission, the system uses the minimum of the flow-control window size and congestion control window size.
- Start slowly and build up:
  - The initial window size is 1.
  - As each ACK arrives, increased window size by 1.
- Congestion avoidance:
  - Set a threshold window size to half of the current size.
  - Set the window size to 1 and restart the slow-start algorithm.
  - When the window size reaches the threshold, increase it by 1/w on each ACK, where w is the current window size.