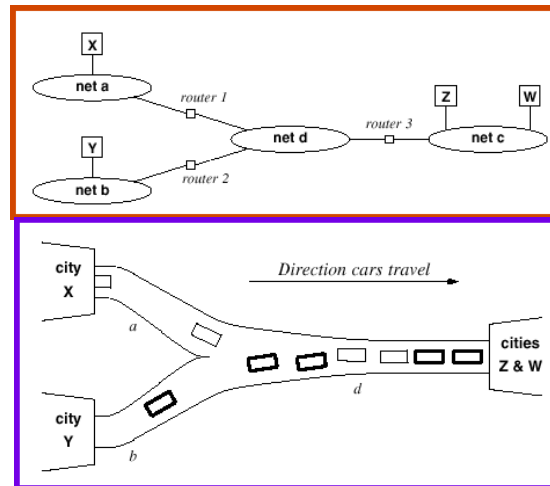


## Packet Switching Can Be Overrun

- Packet switching allows multiple computers to communicate without delay.
  - ❖ Requires that the computers divide data into small packets
  - ❖ Layer 3 (IP) provides deliver mechanism
  - ❖ Requires additional communication software to ensure reliable delivery (TCP)

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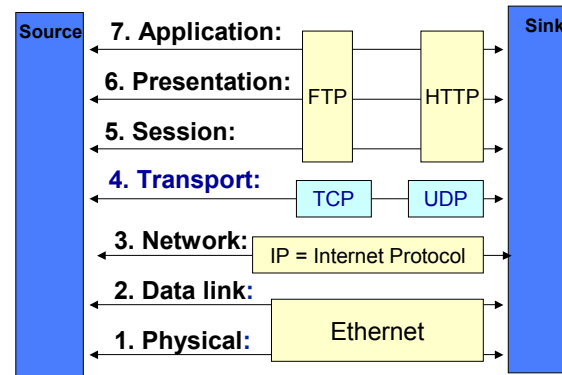


## TCP/IP Protocol Suite

- Internet Protocol (IP) provides “unreliable datagram service” between hosts
- Transport Layer 4 protocols use IP to provide end-to-end datagram delivery between endpoints of a connection
- User Datagram Protocol (UDP) provides datagram service
- Transmission Control Protocol (TCP) provides reliable data delivery

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## OSI Model: TCP & UDP



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## UDP - User Datagram Protocol

- UDP delivers independent messages, (datagrams) between applications or processes on host computers
- Simple “Best effort” delivery - datagrams may be lost, delivered out of order, etc.
- Checksum (optionally) guarantees integrity of data
- For generality, endpoints of UDP are called *protocol ports* or *ports*

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## UDP headers

- UDP datagrams are encapsulated within Hardware Frames and IP Frames
- UDP header is very simple:
  - ⌚ Port numbers
  - ⌚ Message length
  - ⌚ Checksum

UDP source port	UDP destination port
UDP message length	UDP checksum
Data	

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## TCP

- Transmission Control Protocol (TCP) is most widely used transport protocol
- Provides reliable data delivery by using IP unreliable datagram delivery
- Compensates for loss, delay, out of order delivery, duplication and similar problems in Internet components

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## TCP And IP Work Together

- TCP handles the problems that IP does not handle without duplicating the work that IP does.
  - ❖ Designed at the same time to work as a unified system
  - ❖ Engineered to:
    - ◆ Cooperate with each other
    - ◆ Compliment each other

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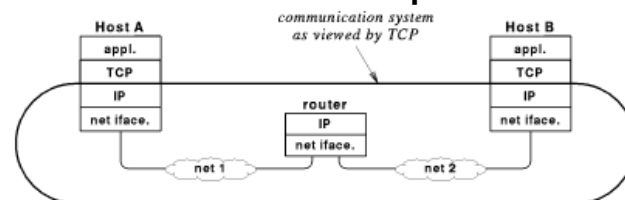
## TCP Provides Connection Between Computer Programs

- TCP software makes it possible for two computer programs to communicate across the Internet.
  - ❖ Establishes a connection
  - ❖ Exchanges data
  - ❖ Terminates communication
- Endpoints identified by ports (like UDP)
  - ❖ Allows multiple connections on each host
  - ❖ Ports may be associated with an application or a process
- IP treats TCP like data and does not interpret any contents of the TCP message

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## Delivering TCP

- TCP travels in IP datagrams
- Internet routers only look at IP header to forward datagrams
- TCP at destination interprets TCP



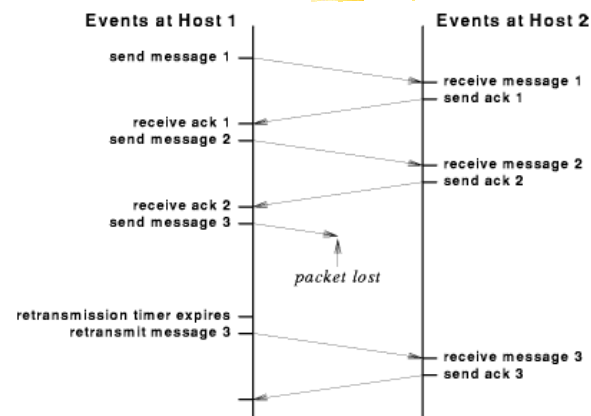
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## How TCP Handles Lost packets

- TCP uses positive acknowledgment with retransmission to achieve reliable data delivery
- Recipient sends acknowledgment control messages (ACK) to sender to verify successful receipt of data
- Sender sets timer when data transmitted; if timer expires before acknowledgment arrives, sender retransmits (with new timer)

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## Lost packets



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## TCP segments and sequence numbers

- Application delivers arbitrarily large chunks of data to TCP as a "stream"
- TCP breaks this data into segments, each of which fits into an IP datagram
- Segment contains sequence number of data bytes
- Receiver sends segment with sequence number of acknowledged *data*.
  - ❖ ACK can acknowledge many segments

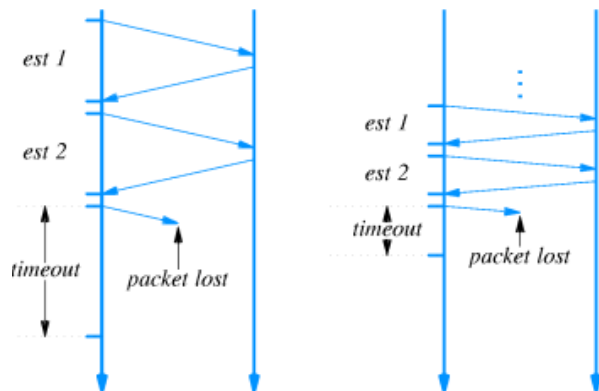
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## Retransmission Time Out

- Inappropriate timeout can cause poor performance:
  - ❖ Too long - sender waits longer than necessary before retransmitting
  - ❖ Too short - sender generates unnecessary traffic
- Timeout must be different for each connection and set dynamically
  - ❖ Host on same LAN should have shorter timeout than host 20 hops away

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## RTOs for different network delays



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## Adaptive Retransmission Algorithm

- Timeout should be based on round trip time (RTT)
- Sender can't know RTT of any packet before transmission
- Sender picks retransmission timeout (RTO) based on previous RTTs

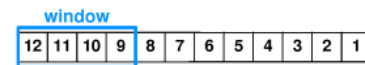
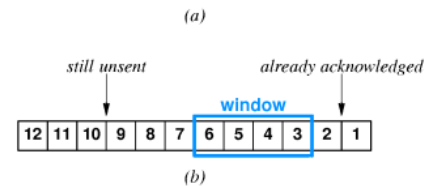
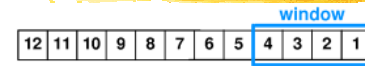
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## TCP sliding window

- TCP uses sliding window for flow control
- Receiver specifies window
  - ❖ Called window advertisement
  - ❖ Specifies which bytes in the data stream can be sent
  - ❖ Carried in segment along with ACK
- Sender can transmit any bytes, in any size segment, between last acknowledged byte and within window size

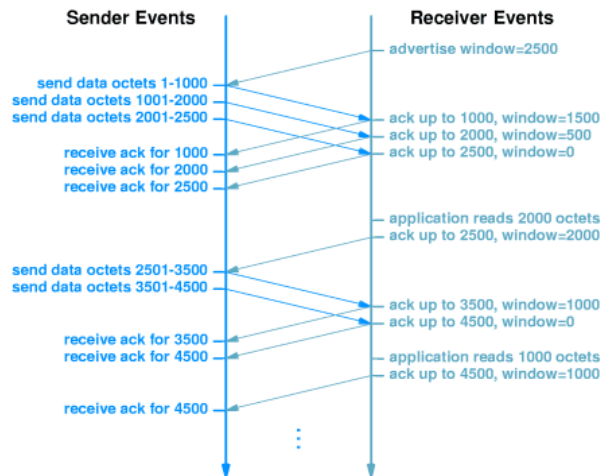
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## TCP sliding window



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## Sliding window with acknowledgments



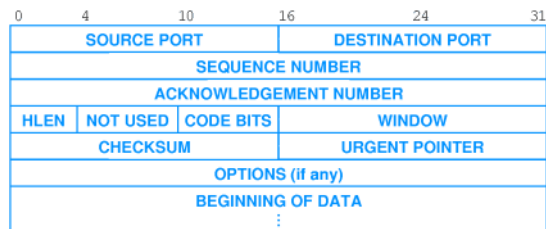
## Sliding Window Animations

- Flow Control Operation
  - ❖ [http://www.islandman.org/umuc/ifsm450/anim20\\_3.htm](http://www.islandman.org/umuc/ifsm450/anim20_3.htm)
- Changing Window Size
  - ❖ [http://www.islandman.org/umuc/ifsm450/anim20\\_4.htm](http://www.islandman.org/umuc/ifsm450/anim20_4.htm)
- Lost Segment Recovery
  - ❖ [http://www.islandman.org/umuc/ifsm450/anim20\\_5.htm](http://www.islandman.org/umuc/ifsm450/anim20_5.htm)

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## TCP segment format

- Same header format used in both directions Segment can carry both data and acknowledgment



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## Summary

- UDP provides end-to-end best-effort message delivery
- TCP provides end-to-end reliable byte stream delivery
- Positive acknowledgment with retransmission
- Sequence numbers detect missing, duplicate and out-of-order data
- Sliding window flow control
- Three-way handshake
- Congestion control

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