Flow and congestion control in data networks

TELCOM2321 – CS2520
Wide Area Networks
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Readings

- Textbook Chapters 10 and 11

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Network performance

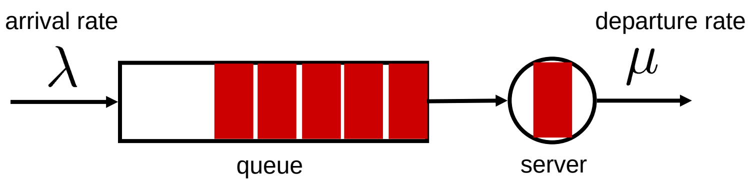
- Depends on
  - traffic requests
  - resources available
- Resource overprovisioning is not always the solution
  - latency-bandwidth tradeoff
- Some form of traffic and resource management is needed
  - to control access to resources
  - to provide required service levels

Traffic and resource management

- Circuit switching
  - call admission control
  - resource planning
- Packet switching
  - flow control
  - congestion control
  - QoS differentiation
- Where to implement functionalities
  - end-to-end argument

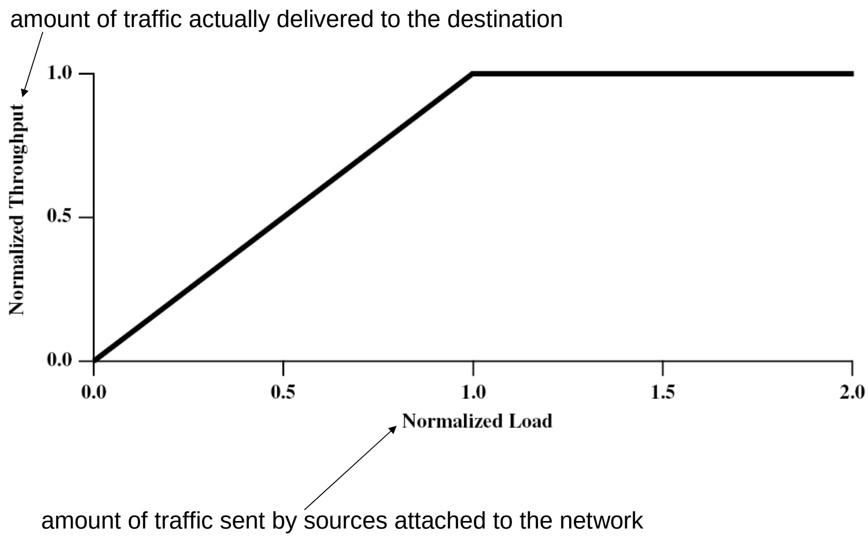
Data network congestion

- When packets being transmitted through a network approach the packet-handling capacity of the network
- Network nodes are overloaded
  - queues start filling up

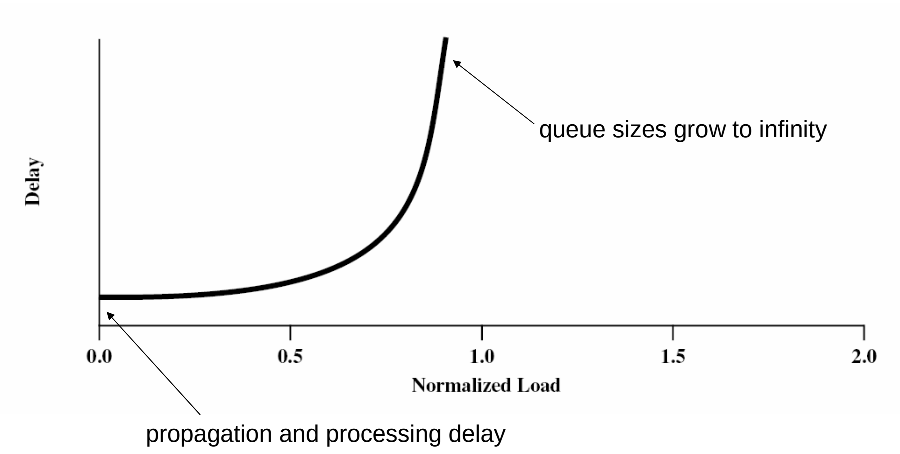


Stability condition: $\frac{\lambda}{\mu} = \rho < 1$

Ideal performance: Throughput



Ideal performance: Delay



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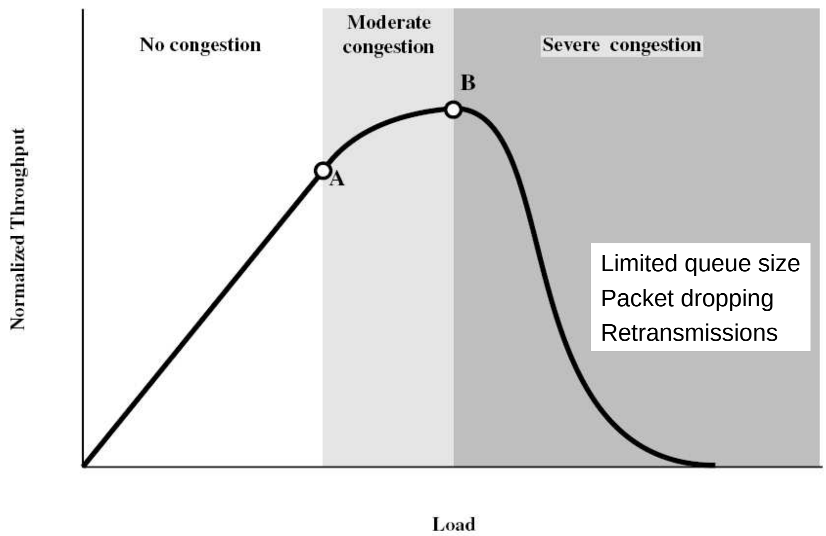
Real performance: Throughput



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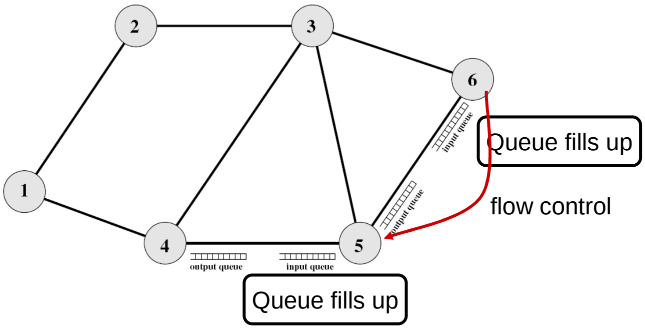
Flow and congestion control

- Need for flow and congestion control schemes
  - to keep the number of packets within the network below a level acceptable for performance
- Network-wide approach
  - otherwise congestion is just moved from one node to another



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Congestion control techniques

- Backpressure
  - Request from destination to source to reduce rate
  - Propagates hop-by-hop backward along path
  - Suitable for virtual circuits
- Choke packet
  - Suitable for datagram networks
  - Ex: ICMP Source Quench

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Congestion control techniques

- Implicit congestion signaling
  - Source detects congestion from transmission delays and discarded packets and reduces flow
  - End system responsibility
    - no action from network
    - reaction depends on round trip time
  - Suitable for datagram networks
  - Ex: TCP

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Congestion control techniques

- Explicit congestion signaling
  - Network responsibility to alert end systems of growing congestion
  - Direction
    - Backward: network notifies the source
    - Forward: network notifies the destination
  - Approaches
    - Binary: on/off approach
    - Credit-based: how much data can be sent
    - Rate-based: how fast data can be transmitted

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Congestion control issues

- Fairness
  - Congestion effects should be distributed equally to traffic flows
    - Last-in-first-discarded may not be fair
- Quality of Service
  - Differentiation based on application requirements
    - Voice, video: delay sensitive, loss insensitive
    - File transfer, mail: delay insensitive, loss sensitive
    - Interactive computing: delay and loss sensitive
- Reservation scheme
  - To provide guaranteed services
    - Traffic policing: excess traffic discarded or handled on best-effort basis

Flow and congestion control implementation

- Provided at different layers

- Data Link Layer Flow and Error Control
  - Stop-And-Wait ARQ
  - Continuous ARQ
    - Selective Repeat ARQ
    - Go-Back-N ARQ

- End-to-End Flow and Congestion Control
  - Closed Loop
  - Open Loop

Data Link Layer
Flow and Error Control

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Data link layer

- It has to provide a reliable communication service to network layer entities over a potentially unreliable transmission link
- Layer 2 functions
  - arrangement of data bits into suitable structures
    - layer 2 PDU is referred as "frame"
    - frames include data and control information
  - transmission error control and management
  - flow control
  - frame sequence control
  - multiple access control for point-to-multipoint links
- All or part of these functions can be implemented

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Flow and Error Control

- Flow Control
  - Regulate the traffic to prevent the sender from overflowing the buffers of the receiver
    - One frame sent at a time (Stop and wait)
    - Multiple frames sent (Sliding window)
- Error Control
  - Detect and recover from potential frame errors
    - Parity bit
    - Longitudinal, Vertical and Cyclic Redundancy Check

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Automatic Repeat reQuest (ARQ)

- Combine both flow and error control
- Assumptions
  - sequential channel
  - all frames experience the same propagation delay
- Receiver
  - acknowledges correct frames
  - detects and ignores frames with errors
  - detects and drops out-of-sequence frames
- Dropped and damaged frames must be retransmitted

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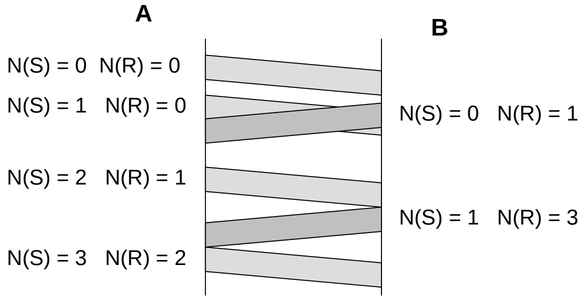
Frame numbering

- Sender and receiver keep two counters
  - N(S): sender counts the frames already sent
    - starting from N(S) = 0
  - N(R): receiver counts the frames received correctly
    - N(R) is the next expected frame number
- Enables frame sequence control



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Frame Acknowledgement

- Receiver must acknowledge the correct frames received
  - explicitly
    - each data frame requires an acknowledgment frame
  - implicitly
    - ACK(n) acknowledges all data frames sent before frame n
  - in piggybacking
    - acknowledgment is included in a data frame sent in the opposite direction (no need to send specific ACK frames)
- ACK frames
  - are only control frames
  - do not need to be acknowledged
  - do not increase N(S)

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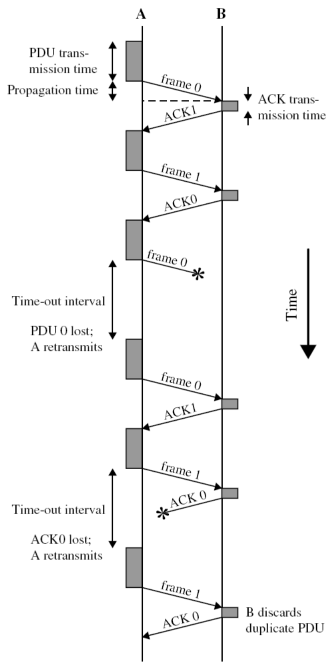
ARQ techniques

- Stop-and-Wait
  - also referred to as idle ARQ
  - used typically with character-oriented data transmission protocols.
- Sliding Window ARQ
  - also referred to as continuous ARQ
  - used primarily with bit-oriented transmission protocols
    - Go-back-N ARQ
    - Selective Repeat ARQ

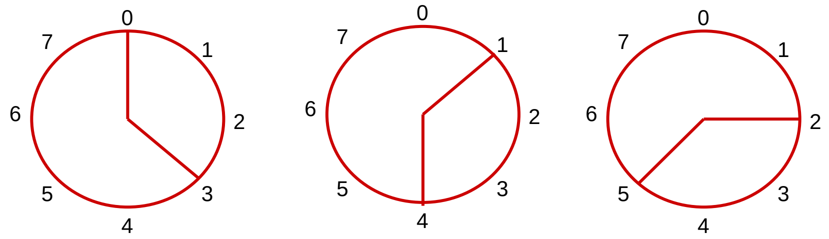
Stop-and-Wait

- The simplest form of flow control
- The sender transmits a frame and waits for an acknowledgement from the receiver
  - 1-bit numbering
- Based on the receiver's response, or lack thereof, the sender either sends the next frame or retransmits the last one
- Drawback: the channel is idle when sender is waiting for the ACK
  - idle time increases when latency increases



Sliding window

- Allows multiple frames to be in transit at one time
- Sender and receiver agree on a window size W
  - maximum number of frames that is possible to send without waiting for ACK
- n-bit frame numbering
  - frames are numbered modulo $M = 2^n$
- Transmission window evolution



W=4, n=3
Frames 0, 1, 2, 3 are sent

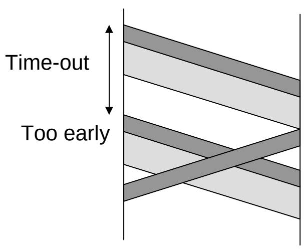
ACK 1 received
Frame 4 is sent

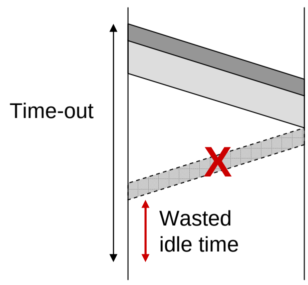
ACK 2 received
Frame 5 is sent

Time-out interval

Must be directly related to round trip delay

- Too short
  - ACKs require more time
  - Unnecessary retransmissions
- Too long
  - ACK would have arrived earlier
  - No need to wait more





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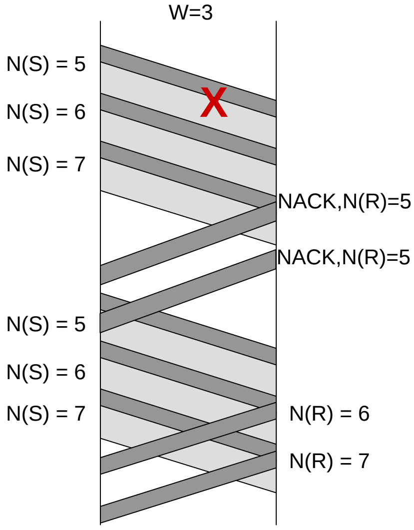
Go-back-n ARQ

- Frame *N* is damaged
- Receiver
  - discards all successive frames
  - notifies the sender with a NACK or a REJ (reject)
- Sender
  - retransmits all frames starting from frame *N*
- Pros
  - simple operations
  - receiver does not need to buffer pending frames
- Cons
  - inefficiency due to retransmission of correct frames



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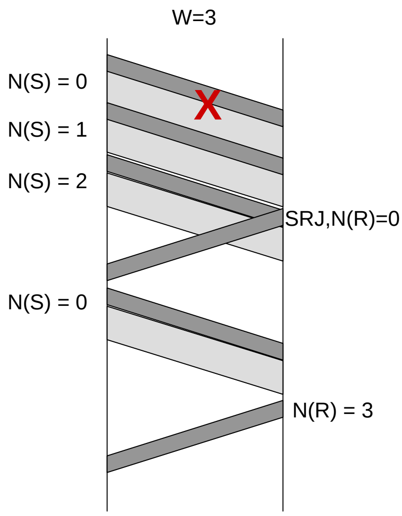
Selective repeat ARQ

- Frame *N* is damaged
- Receiver
  - discards damaged frame only
  - notifies the sender with a SRJ (selective reject)
  - buffers following frames
- Sender
  - retransmits frame *N* only
- Pros
  - higher efficiency
- Cons
  - more complex receiver due to frame buffering and reordering



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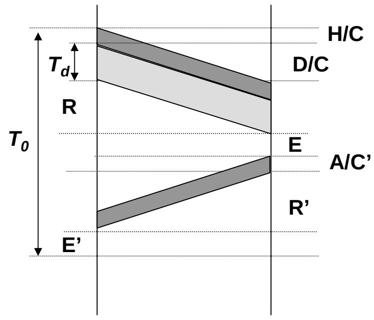
Stop-and-Wait: Performance

- Protocol efficiency or link utilization or normalized throughput:
  - fraction of time that new data are being sent

- **D** : frame data size in bits
- **H** : frame header size in bits
- **F=D+H** : frame size
- **A** : ACK size
- **E**, **E'** : processing times
- **R**, **R'** : propagation times
- **C**, **C'** : channel bit rates



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Efficiency (error-free)

- Total time required to transmit and acknowledge a frame:

$$T_0 = F/C + R + E + A/C' + R' + E'$$

- Time spent to transmit actual data

$$T_d = D/C$$

- Protocol efficiency

$$S = \frac{T_d}{T_0}$$

  – assuming R' = R, E' = E, C' = C

$$S = \frac{D}{D+H+2(R+E)C+A}$$

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Overhead

- Additional bits due to the protocol operation
  - actual bits (header, ACK)
  - delays measured in bits (propagation, processing)
- Assuming **A = H**
- Overhead **O = 2H+2(R+E)C**

$$S = \frac{D}{D+O}$$

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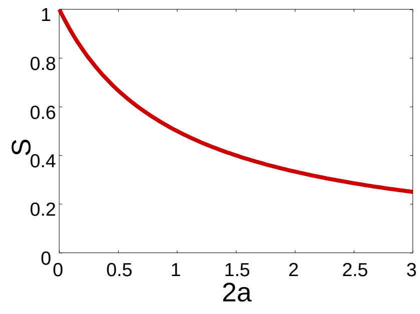
Further approximation

- Assuming E and H negligible

$$S = \frac{D}{D+2RC} = \frac{1}{1+2RC/D} = \frac{1}{1+2a}$$

- Stop-and-Wait suitable for slow, short range networks



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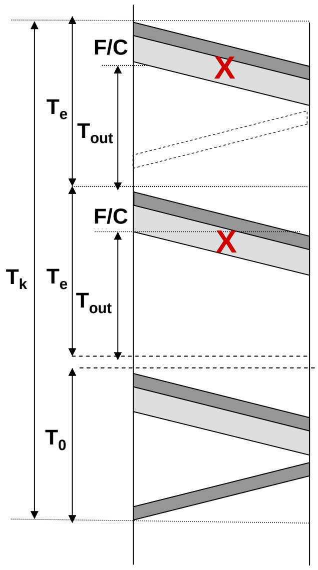
k transmissions due to k–1 errors

- T_e = D/C + H/C + T_{out}
- T_0 = (D+O)/C
- T_k = (k–1)T_e + T_0 (k-1 errors)
- Approx.
  - O = 2RC
  - T_{out} = 2R
- T_k = k (D/C + 2R)



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Efficiency (with errors)

- **P**
  - probability of error on frame
- **$P_k = P^{k-1}$ (1–P)**
  - probability of k transmissions due to k–1 errors
- **E [k] = 1/(1–P)**
  - average number of same frame transmissions
- **E [T_k] = (D/C + 2R)/(1–P)**
  - average frame transmission time (with errors)

$$S = \frac{D\,(1-P)}{D+2RC} = \frac{1-P}{1+2a}$$

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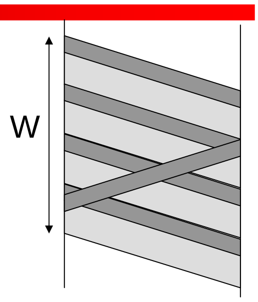
Sliding window ARQ (error-free)

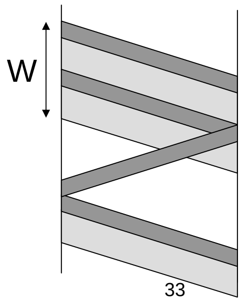
- **WF/C ≥ F/C + 2R**
- **W ≥ 1 + 2a**
- Continuous transmission

  S = 1



- **W < 1 + 2a**
- Sender stops when it reaches W

$$\mathbf{S = \frac{W}{1+2a}}$$



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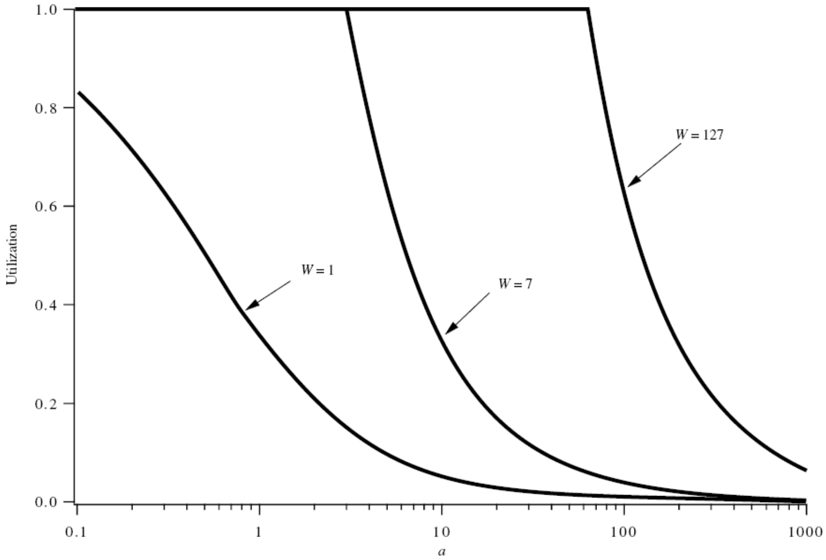
Sliding window: Performance



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Sliding window ARQ (with errors)

- Selective Repeat scheme
  - only the damaged frame must be retransmitted
  - same procedure as Stop-and-Wait

- $\mathbf{E\,[\,T_k\,] = (D/C + 2R)/(1 - P)}$

- $\mathbf{S = 1 - P}$ when $\mathbf{W \geq 1 + 2a}$

- $\mathbf{S = \dfrac{W\,(1 - P)}{1+2a}}$ when $\mathbf{W < 1 + 2a}$

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Summary

- Congestion control
  - needed to ensure network performance

- Data Link Layer Flow and Error Control
  - Stop-And-Wait ARQ
  - Continuous ARQ
    - Go-Back-N ARQ
    - Selective Repeat ARQ

- Performance
  - efficiency

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