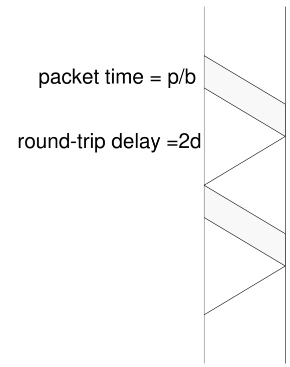
CSE and EE 461
Lecture 11

Summer Quarter 1998

Underutilization of Stop-and-Wait

- All stop-and-wait protocols suffer from underutilization if propogation delay is high.

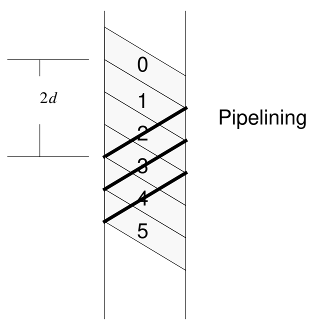


$$U = \frac{\frac{p}{b}}{\frac{p}{b} + 2d} = \frac{1}{1 + \frac{2db}{p}}$$

Utilization can be very small.

Sliding Window Protocols

- Choose N, such that (N-1) p/b $\geq$ 2d where 2d is the approximate round-trip bit delay.
- Window size is N.
- Sender can send upto but not more than N frames at a time



Error Control

- The Sender must store N frames because there are as many as N frames or their acks in transit. Some of the N frames might need to be resent.
- **Go-back-N** resend strategy:

  If a frame is lost then resend that frame and all the frames after it that have been stored.

  At least N + 1 sequence numbers are needed for go-back-N
- **Selective Repeat** strategy:

  If a frame is lost then just resend that frame and no others.

  At least 2N sequence numbers are needed for selective repeat.

Sender's and Receiver's Buffers

Frame no.	0	1	2	3	4	5	6	7	8	9	10
Seq no.	0	1	2	3	4	0	1	2	3	4	0
Send Window											
Rec. Window											

- The sender's buffers contain all frames sent but not yet acknowledged

  The sender advances its window when acknowledgements arrive.
- The receiver's buffers are empty awaiting data. A buffer may be full if an earlier buffer is empty.

  The receiver advances its window when frames arrive.
- Ack number k means that the frame with seq number k has arrived or that all frames with sequence numbers at or to the left of k have arrived.

Normal Operation of Sliding Windows

Frame no.	0	1	2	3	4	5	6	7	8	9	10
Seq no.	0	1	2	3	4	0	1	2	3	4	0
Send Window											
Rec. Window											

ack 2 arrives

Frame no.	0	1	2	3	4	5	6	7	8	9	10
Seq no.	0	1	2	3	4	0	1	2	3	4	0
Send Window											
Rec. Window											

frame with seq_no 0 arrives

Frame no.	0	1	2	3	4	5	6	7	8	9	10
Seq no.	0	1	2	3	4	0	1	2	3	4	0
Send Window											
Rec. Window											

How Many Sequence Numbers

- There are s sequence numbers, {0,1,2,,...s-1}.
- The sender and receiver cycle through them.
- If the sender has x buffers and the receiver y buffers then $s \geq x+y$.

To few sequence numbers

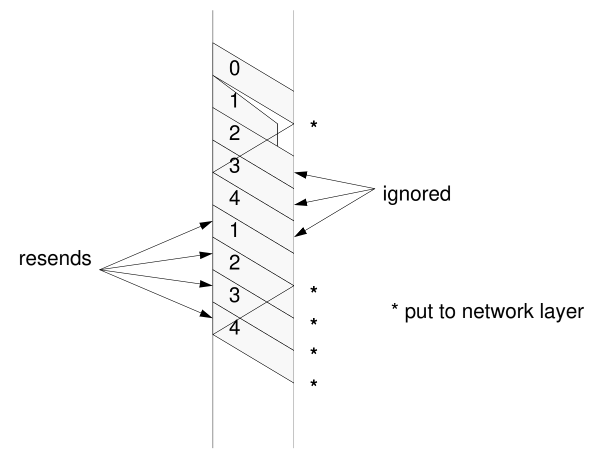
Frame no.	0	1	2	3	4	5	6	7	8	9	10
Seq no.	0	1	2	3	0	1	2	3	3	0	1
Send Window											
Rec. Window											

Frame no.	0	1	2	3	4	5	6	7	8	9	10
Seq no.	0	1	2	3	0	1	2	3	3	0	1
Send Window											
Rec. Window											

These situations appear identical to the sender!

Example of Go-Back-N

- N = 4



Go-Back-N The Sliding Windows

- The receiver has only one buffer in Go-Back-N. N = 3 in this case.

Frame no.	0	1	2	3	4	5	6	7	8	9	10
Seq no.	0	1	2	3	0	1	2	3	0	1	2
Send Window											
Rec. Window											

ack 2 arrives

Frame no.	0	1	2	3	4	5	6	7	8	9	10
Seq no.	0	1	2	3	0	1	2	3	0	1	2
Send Window											
Rec. Window											

frame with seq_no 3 arrives

Frame no.	0	1	2	3	4	5	6	7	8	9	10
Seq no.	0	1	2	3	0	1	2	3	0	1	2
Send Window											
Rec. Window											

Go-Back-N Policies

The number of sequence numbers = {0,1,2,...s-1}

- Sender's Policy
  - if start of window is at i and the ack (i + j) mod s arrives, then advance window by j + 1, and send new frames in the window.
  - if start of window has a timeout then resend the entire window.
- Receiver's Policy
  - if window is at i and frame i arrives then put data to network layer, advance window by 1 and send ack with i.
  - If window is at i and a frame j arrives where j different from i then ignor the frame, but send ack (i-1) mod s.

We must have $s \geq N + 1$

Advancing the Sender's Window by More than 1

- Ack i acknowledges all frames in the senders window at or to the left of the frame with sequence number i.

Frame no.	0	1	2	3	4	5	6	7	8	9	10
Seq no.	0	1	2	3	0	1	2	3	0	1	2
Send Window											
Rec. Window											

Suppose ack 3 is lost but ack 0 arrives, then advance Sender's window by 2

Frame no.	0	1	2	3	4	5	6	7	8	9	10
Seq no.	0	1	2	3	0	1	2	3	0	1	2
Send Window											
Rec. Window											