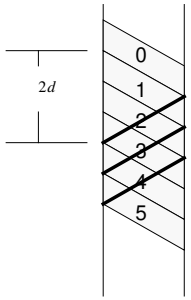
# CprE 489
# Lecture 13

Fall Semester 1997



## 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




Pipelining



## 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 the 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 the 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 | | | | | | | | | | | |

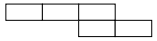
- The sender's buffers contain all frames sent but not yet acknowledged

  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.

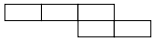
## Normal Operation of Sliding Windows

| 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 | | | | | | | | | | | |



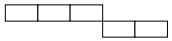
ack with seq_no 3 arrives

| 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 | | | | | | | | | | | |





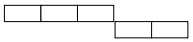
## How Many Sequence Numbers

- 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 ≥ x+y.

Too few Sequence Numbers

| 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 | | | | | | | | | | | |

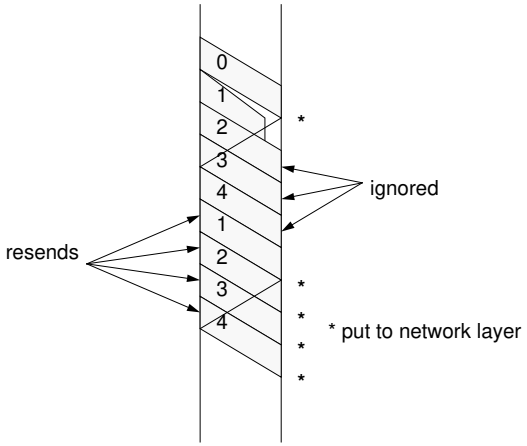
| Frame no. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Seq no. | 0 | 1 | 2 | 3 | 4 | 0 | 1 | 2 | 3 | 4 | 0 |
| Send Window | | | | | | | | | | | |
| Rec. Window | | | | | | | | | | | |



These situations appear identical to the sender!



## Example of Go-Back-N (N = 4)





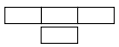

## Go-Back-N The Sliding Windows

- 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 | 4 | 0 | 1 | 2 | 3 | 4 | 0 |
| Send Window | | | | | | | | | | | |
| Rec. Window | | | | | | | | | | | |

ack with seq_no 3 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 4 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 | | | | | | | | | | | |

## 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 has seq_no i + 1 mod s, then advance window by 1, and send new frame in the window.

  - if start of window has a timeout then resend the entire window.
- Receiver's Policy

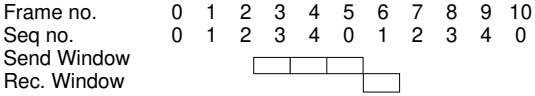
  - if window is at i and frame i arrives then put data to network layer, advance window by 1 and send ack with seq_no = i +1 mod s.

  - If window is at i and a frame j arrives where j different from i then ignor the frame, but send ack with seq_no = i.
- We must have $s \geq N + 1$

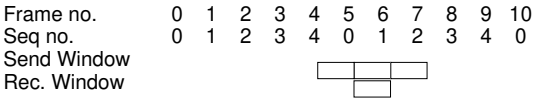


## Advancing the Sender's Window by More than 1

- An ack with seq_no i acknowledges all frames earlier in the window.



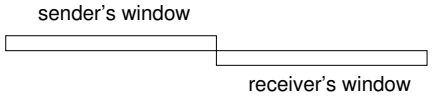

Suppose ack with seq_no = 0 is lost but ack with seq_no = 1 arrives, then advance Sender's window by 2





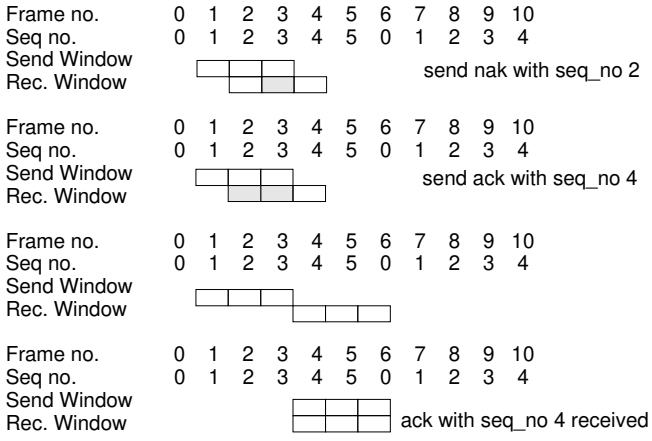

## Selective Repeat

- Normally, the sender and receiver each have window size N.
- If the sequence numbers are {0,1,2,...,s-1} then we must have $s \geq 2N$, that is there are at least 2N sequence numbers.




If sender's window covers frame i and the receiver's covers frame j and i mod s = j mod s then we must have i = j. Otherwise the sender and receiver could be out of synchronization and an error could occur.

- Frames are resent selectively when a timeout occurs or negative acknowledgement (nak) arrives.
- A nak with seq_no = i sent by the receiver means that a frame with seq_no = i that was expected did not arrive.
- An ack with seq_no = i acknowledges receipt of all frames in the sender's window to the left of the ack.



## Example