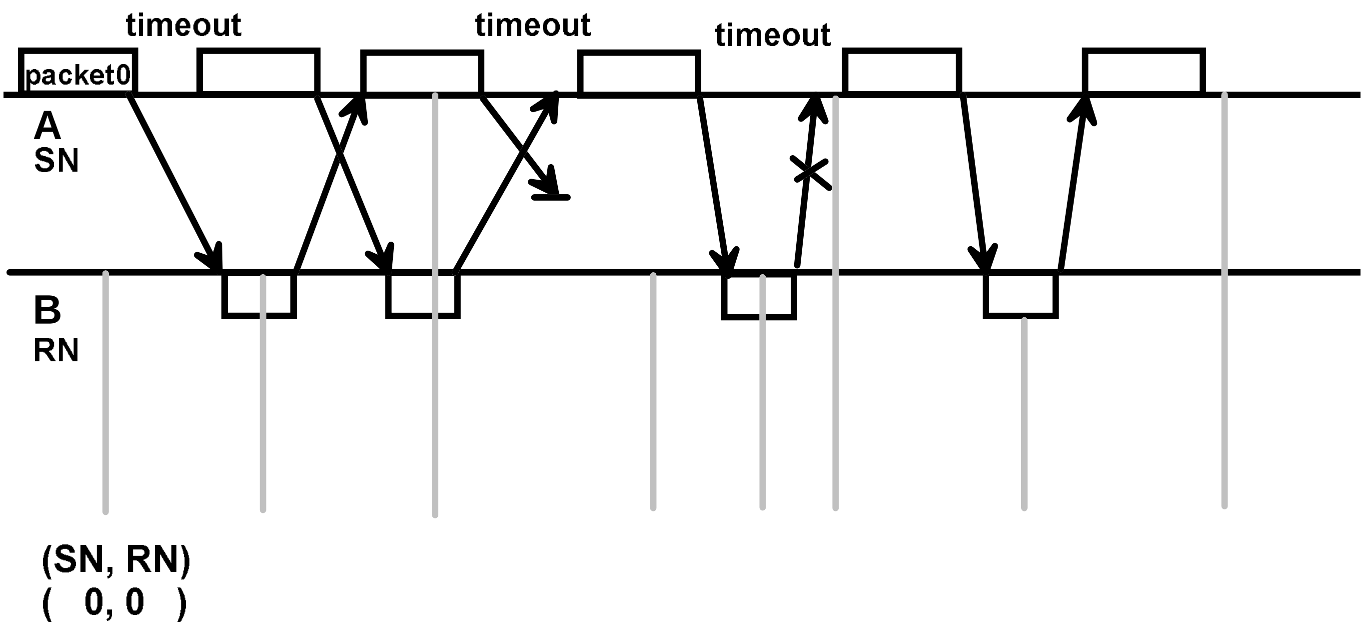
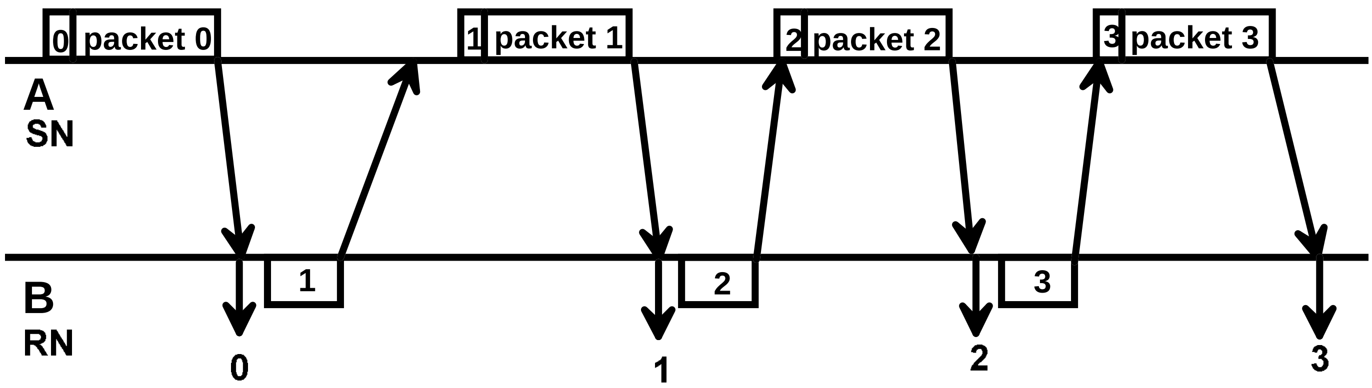
Exercise for the stop and wait protocol

1. Write down the numbers of packets transmitted.



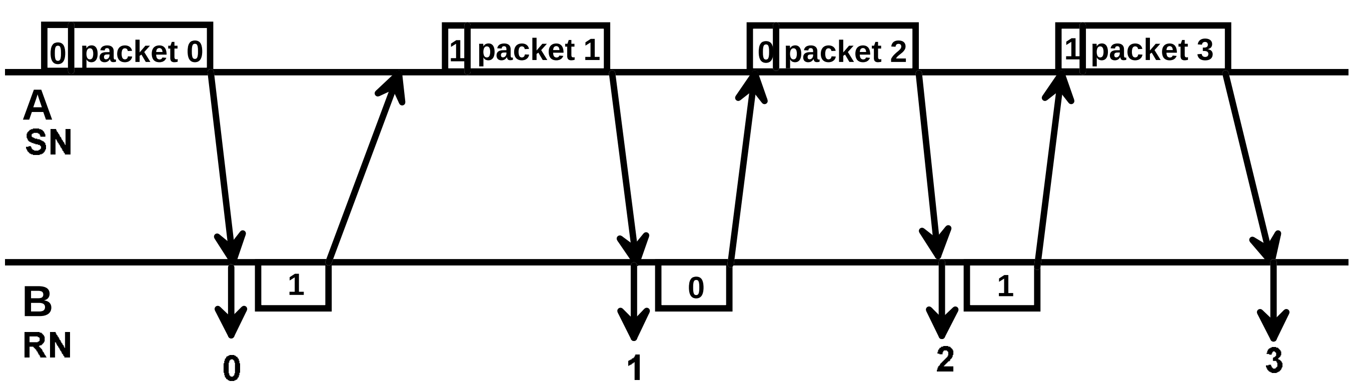
2. Write down the state (SN of A mod 2, RN of B mod 2) of the system for traffic from node A to node B.

Stop and wait protocol



Request Numbers

- **Instead of sending "ACK" or "NAK", the receiver sends the number of the packet currently awaited.**
- **Sequence numbers and request numbers can be sent modulo 2 (because packets n & n+2 cannot be simultaneously in the system.)**
-



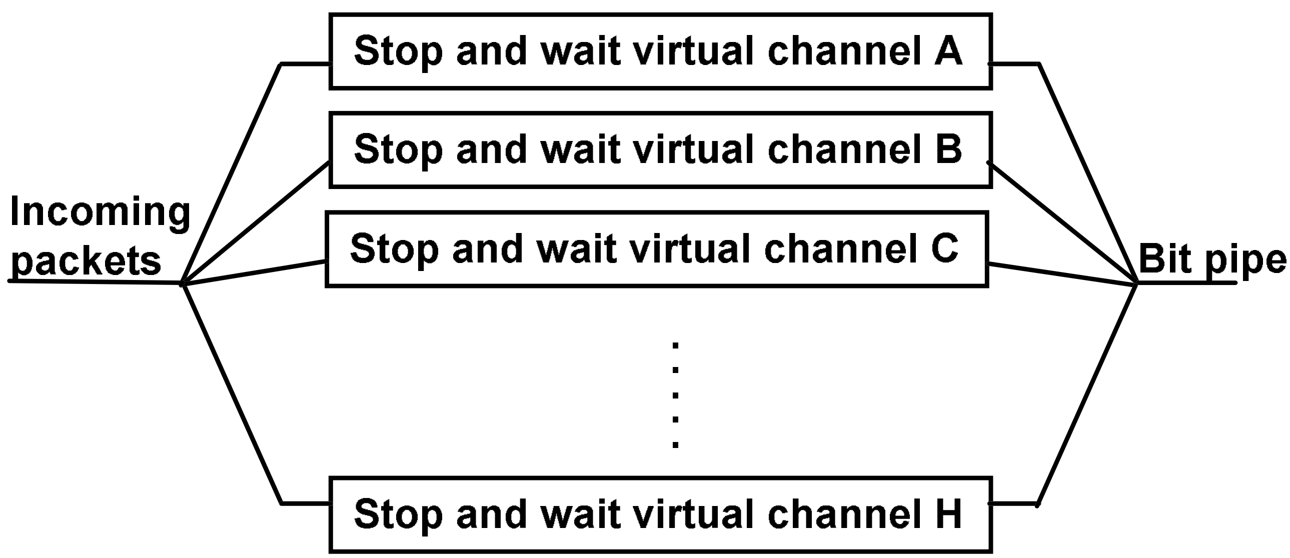
More efficient retransmission protocols

1) ARPANET ARQ

2) Go back n

3) Selective repeat

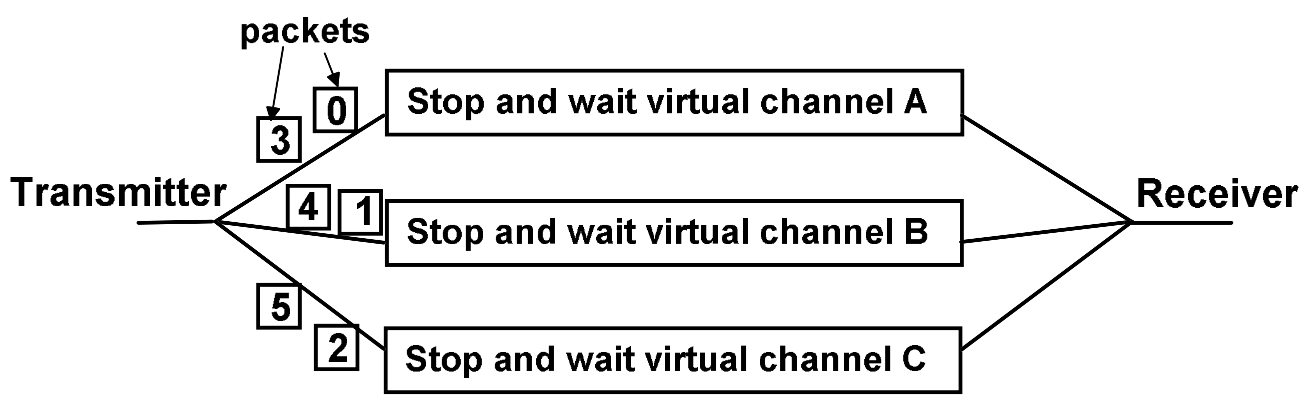
ARPANET ARQ

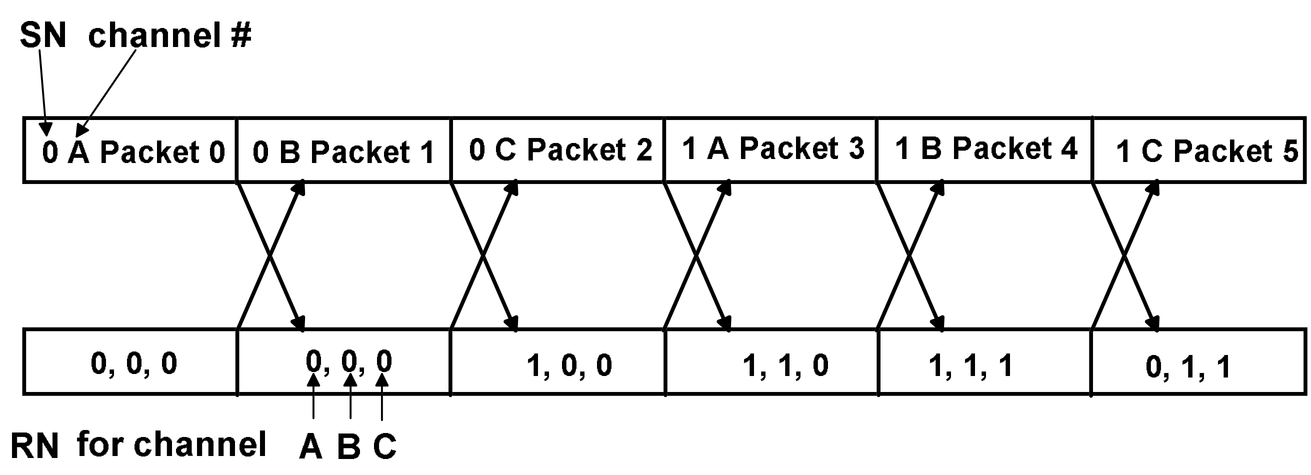


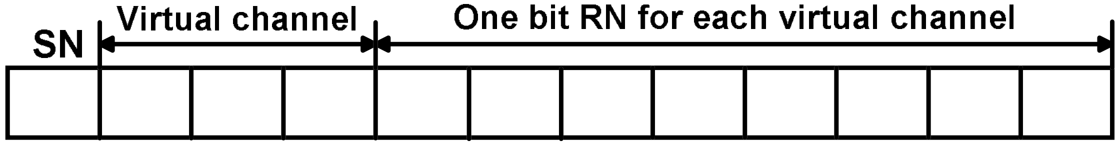
- Packets are assigned to one of 8 virtual channels which are served in a round-robin order.
- If a virtual channel's turn comes before an ACK for that virtual channel is received, the packet is resent.

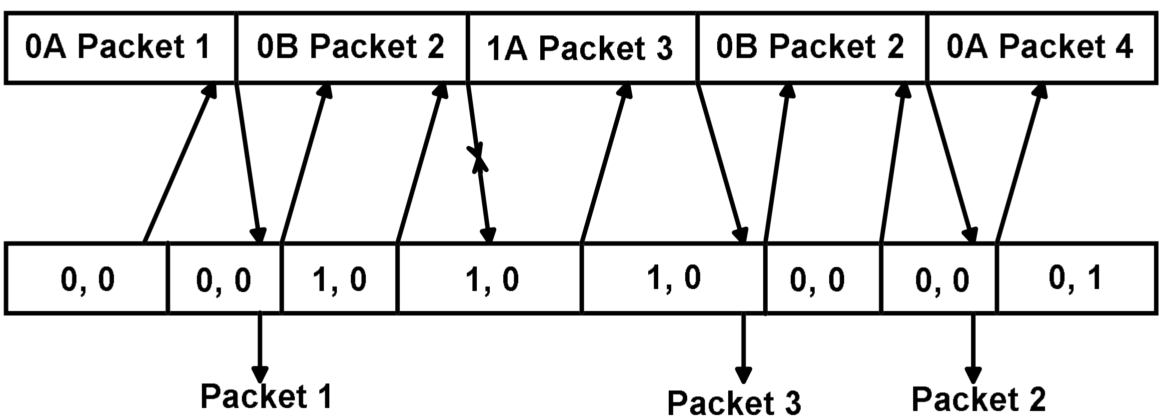
ARPANET ARQ

3 virtual channels A,B,C

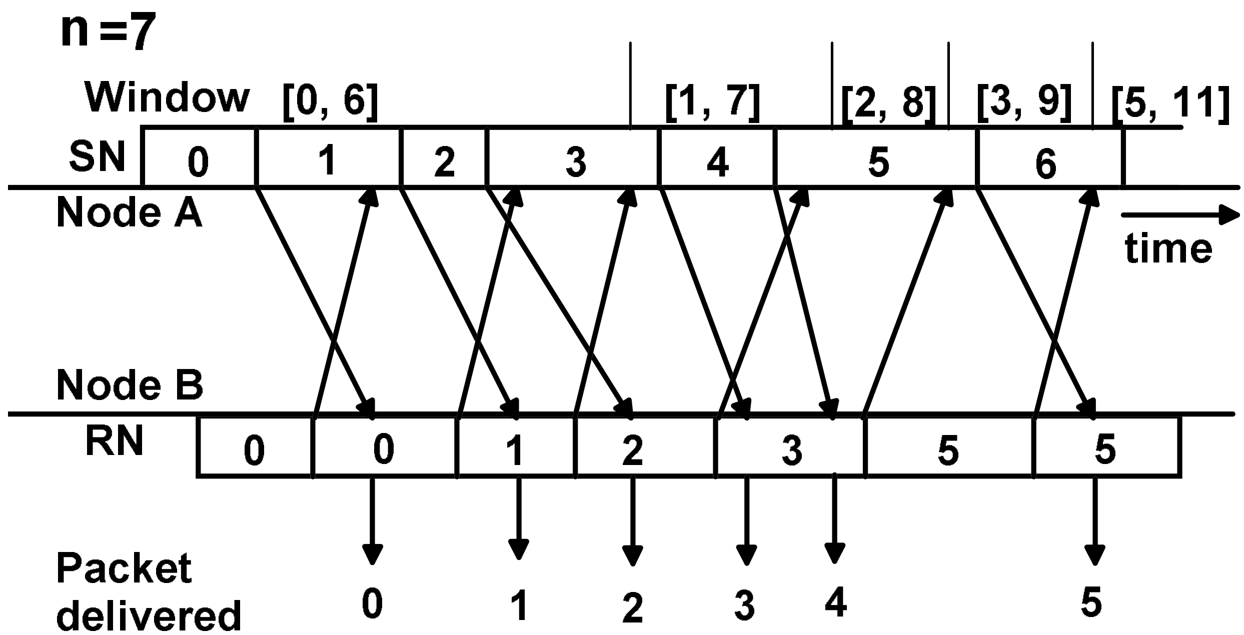





SN
Virtual channel
One bit RN for each virtual channel


0A Packet 1
0B Packet 2
1A Packet 3
0B Packet 2
0A Packet 4
0, 0
0, 0
1, 0
1, 0
1, 0
0, 0
0, 0
0, 1
Packet 1
Packet 3
Packet 2

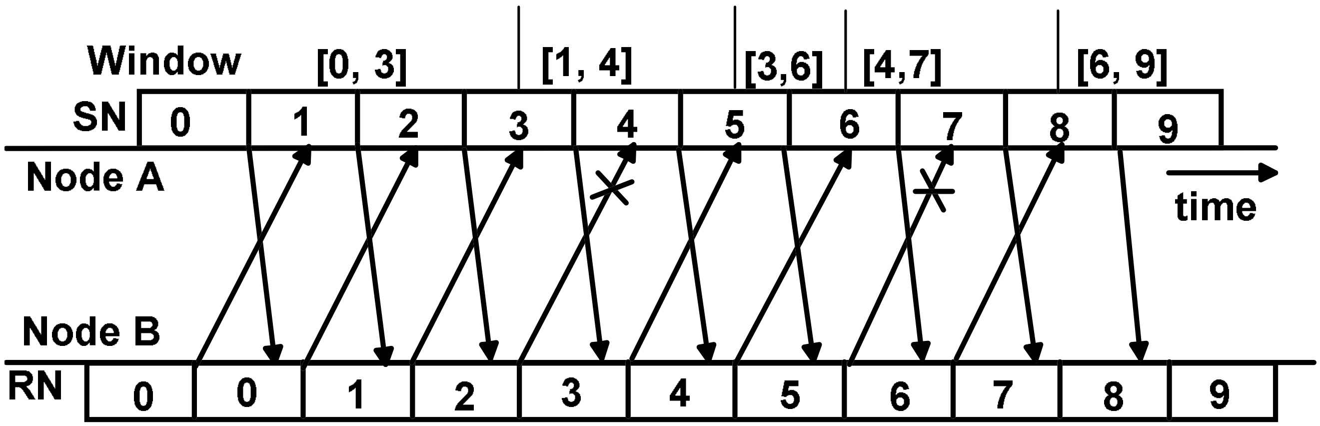
Go back n



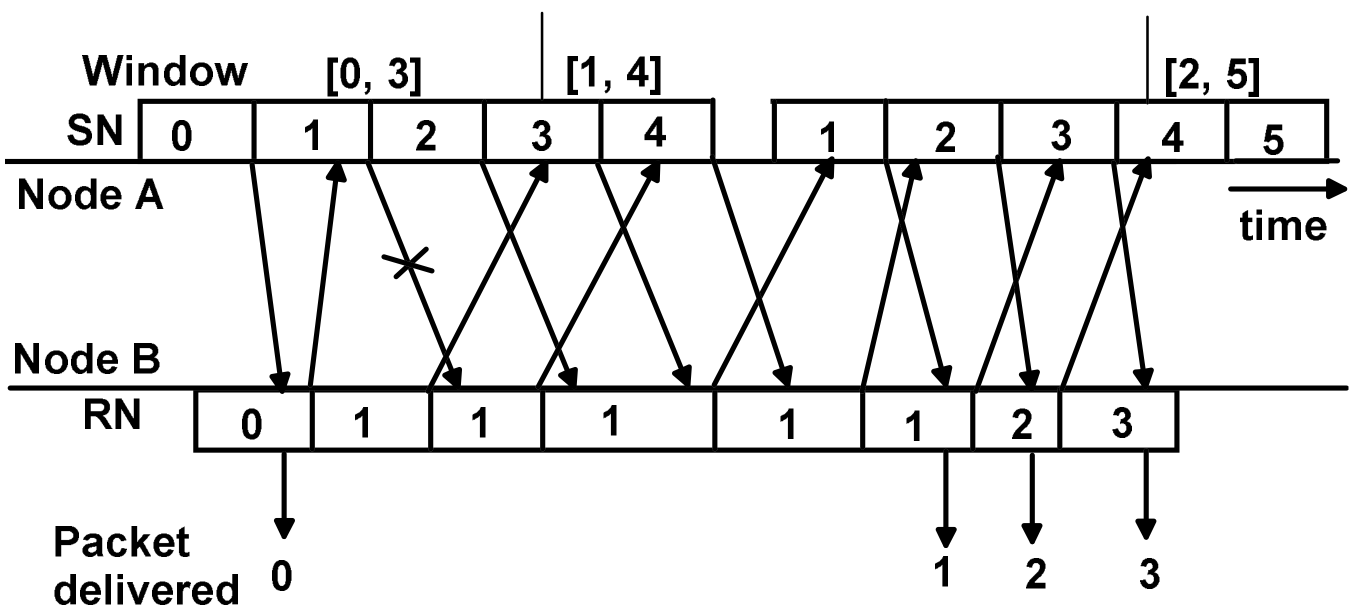
- Transmitter A sends packets sequentially. (SN= sequence number)
- Receiver B acknowledges by sending the packet number next awaited. (RN= request number)
- Receiver accepts packets in order .(if RN $\neq$ SN, the packet is discarded)
- The transmitter can send any packet within the window $[\underline{SN_{min}}, SN_{min}+n-1]$.

  last RN received
- When the end of the window is reached, transmitter A retransmits packet SN_{min}, (a) after it times out , or (b) immediately

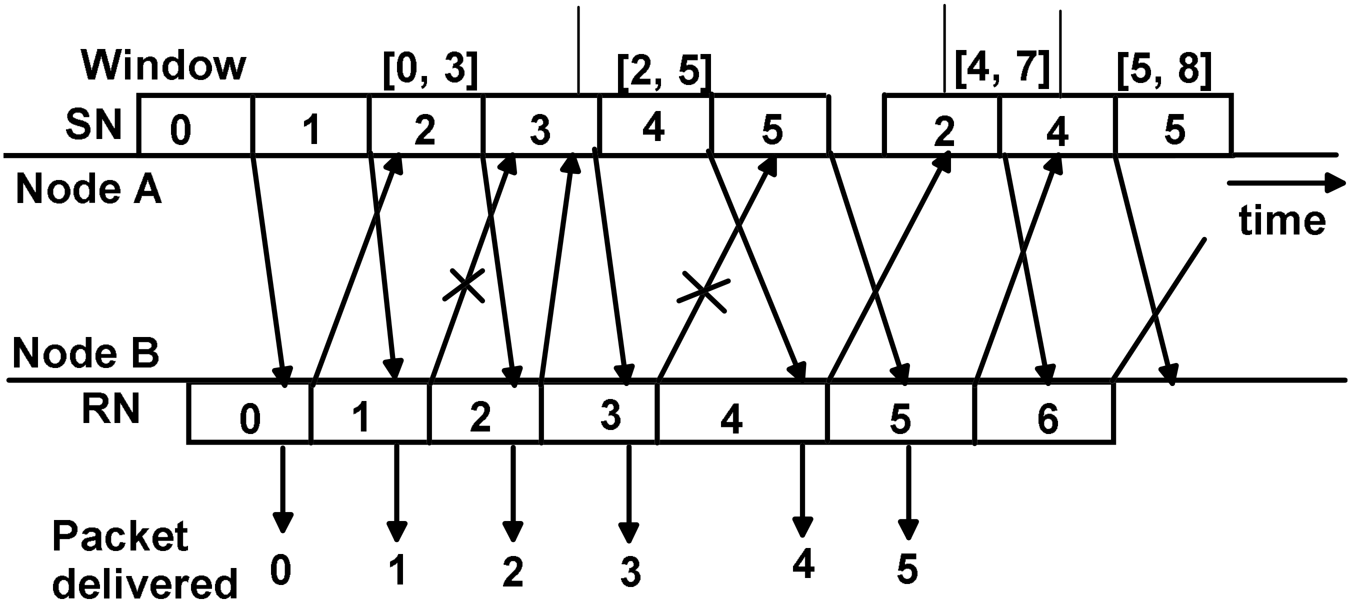
Example 1: (no retransmissions required due to feedback errors)



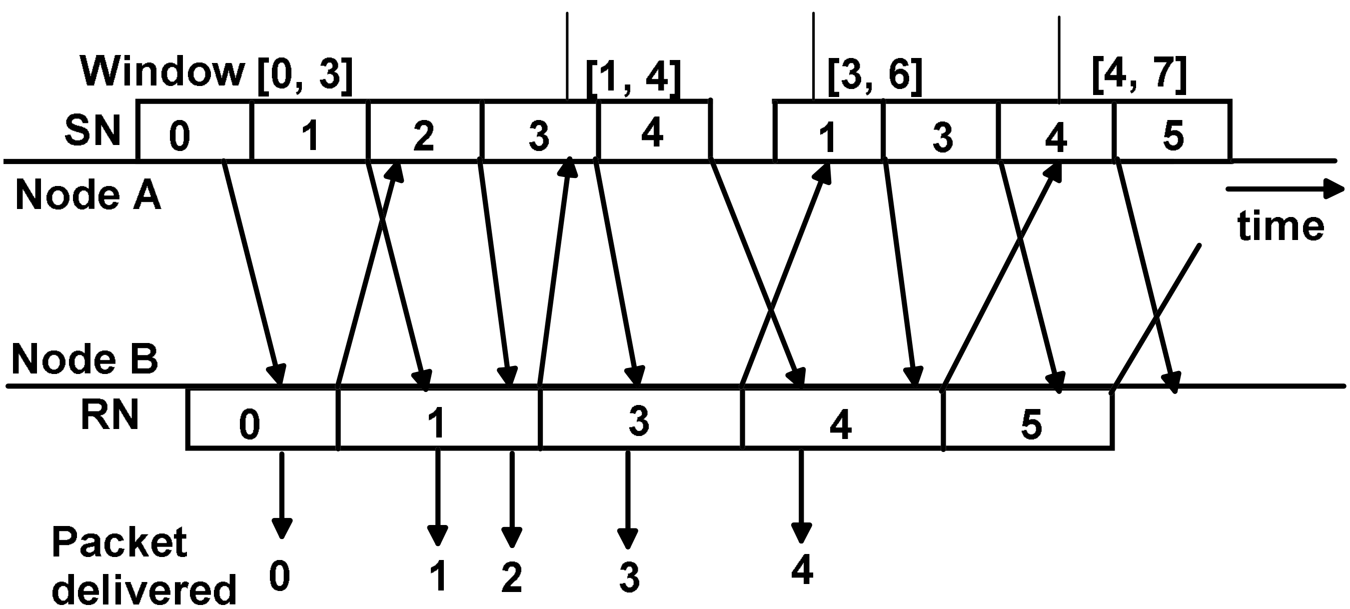
Example 2: (retransmissions because of errors for go back 4)



Example 3: (retransmissions due to feedback errors for go back n)



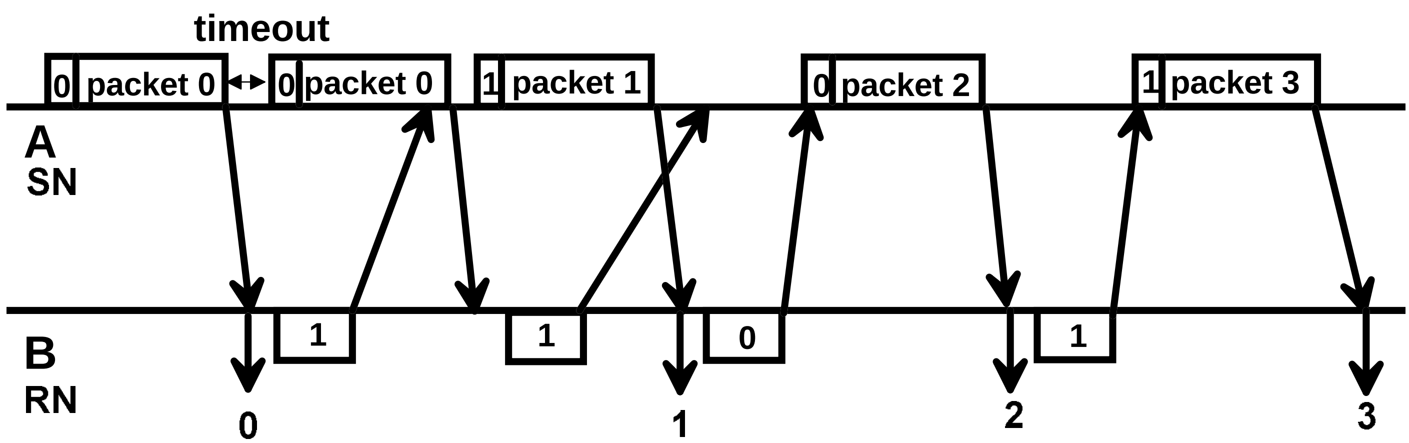
Example 4: (effect of long frames in reverse direction)



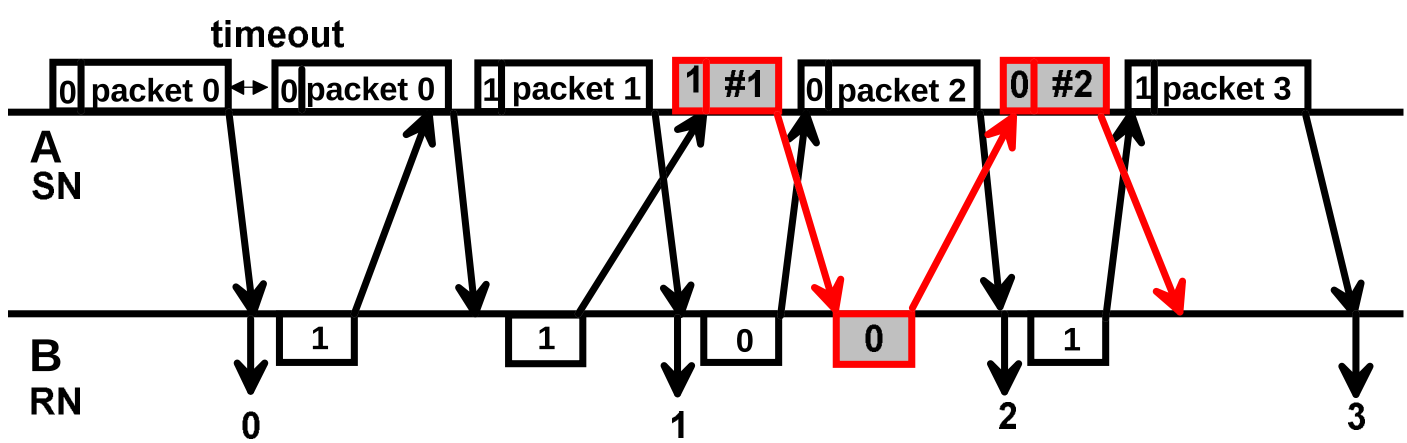
- Long frames in the feedback direction slow down ACKs and may cause a transmitter with short frames to wait or (if time-out expires) to go back.

Stop and wait protocol

Packet 1 is not retransmitted right away.

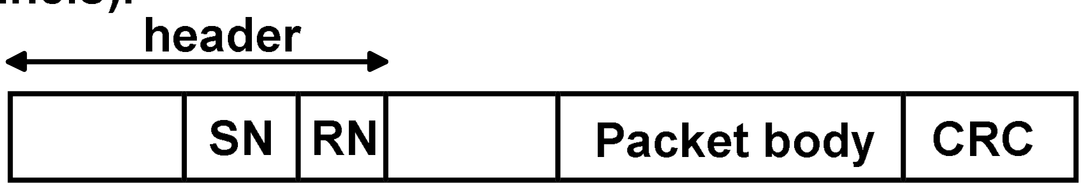


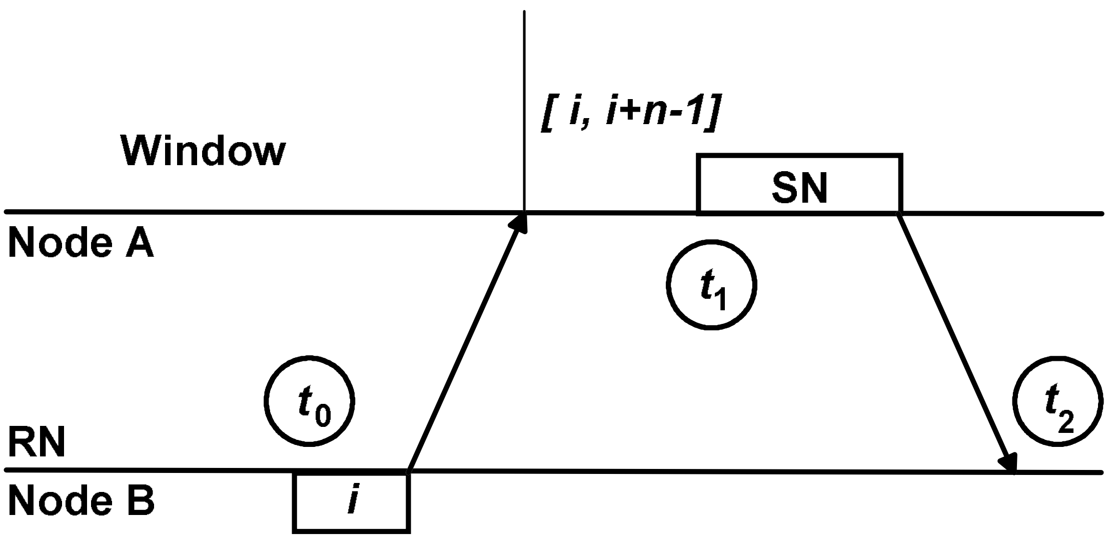
Redundant packets are transmitted, if retransmitted right away.



Correctness of go back n with modulus m >n

SN and RN are sent modulo m, where m>n.
Standard choices are m=8 and m=128 (for satellite channels).





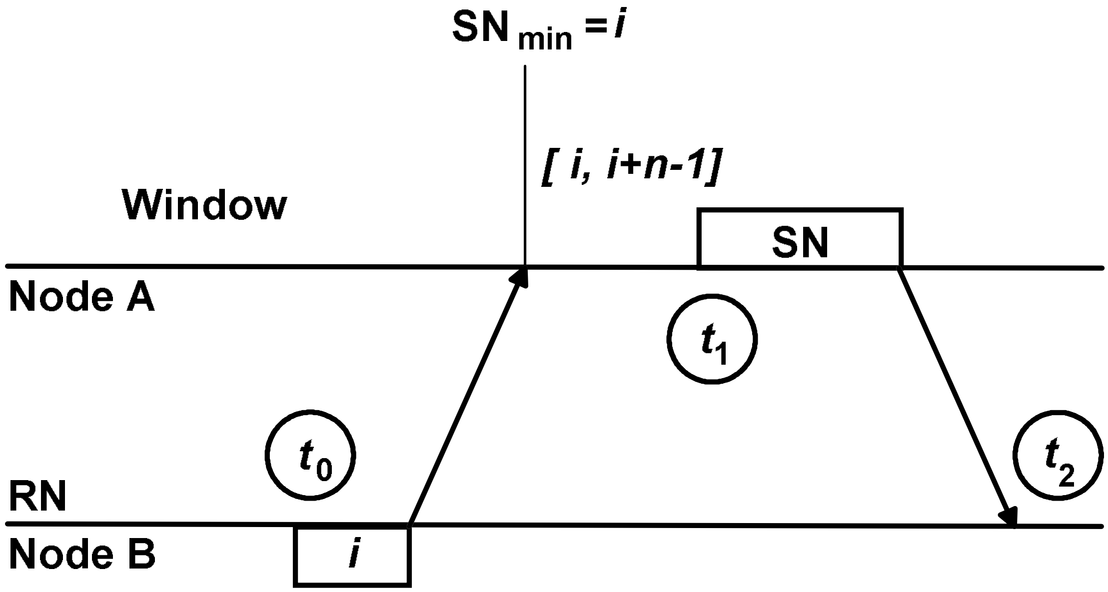
$$SN_{\min}(t_1) \le SN \le SN_{\min}(t_1) + n - 1$$

$$SN_{\min}(t_1) = i = RN(t_0) \le RN(t_2) \le SN_{\min}(t_1) + n$$

$$\left| SN - RN(t_2) \right| \le n$$

Correctness proof continued

consider now numbering mod m



Let rn = RN mod m

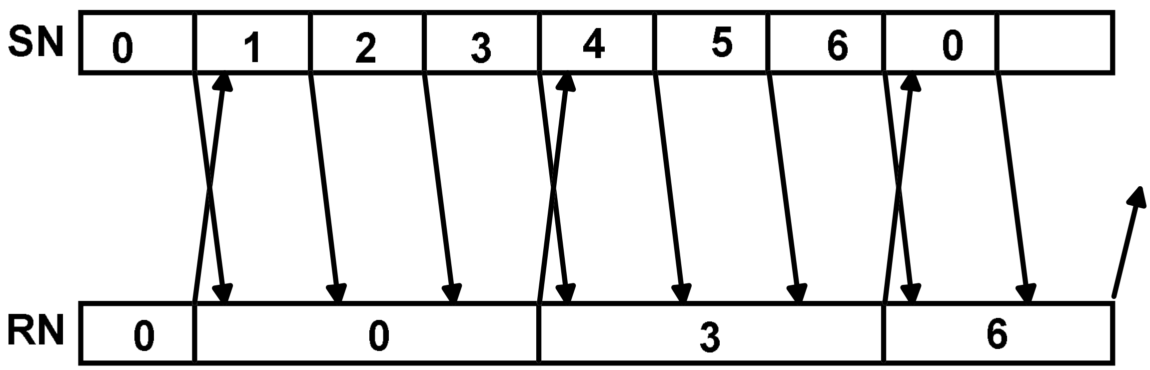
sn_{min} = SN_{min} mod m

sn = SN mod m

Old rules	Modified rules
the receiver accepts a packet when $SN = RN(t_2)$	**the receiver accepts a packet when** $sn = rn(t_2)$
at transmitter, if $RN \neq SN_{\min}$ **then set** $SN_{\min} = RN$	**at transmitter, if** $rn \neq sn_{\min}$ **then set** $sn_{\min} = rn$

Comments on go back n

- **Using 3 bits for SN and RN may be too restrictive, since n $\leq$ 7.**

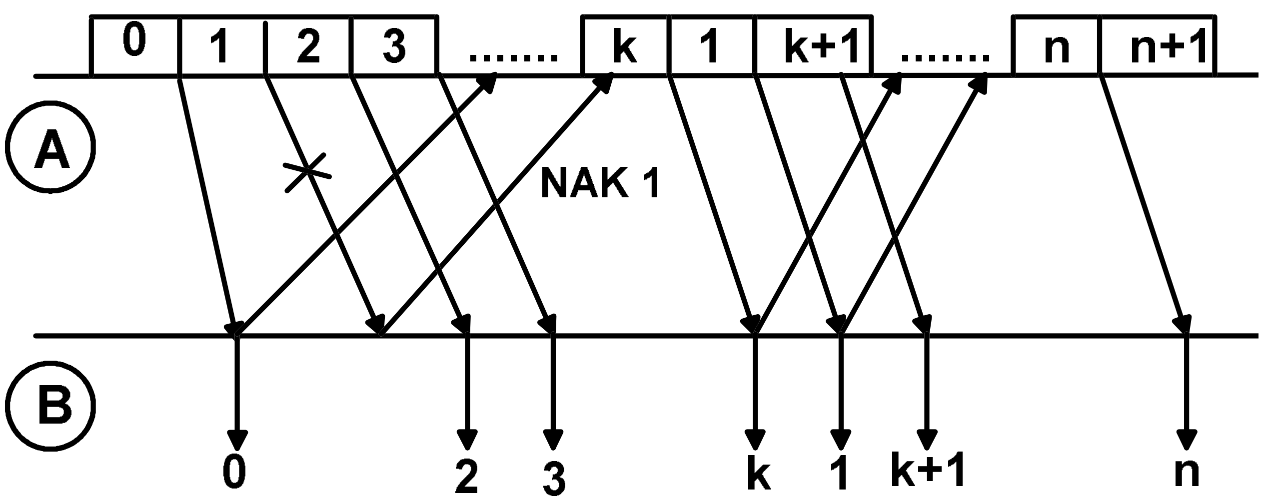


If frames one way are more than three times those the other way, retransmissions are common.

- **Putting RN in frame trailer would ease the problem of delayed ACKs.**
- **Sending RN in short supervisory frames is another solution.**
- **Sending explicit NAKs when errors are received would also improve efficiency.**

Selective repeat ARQ

Efficiency of go back n can be increased by accepting packets out of order (this requires memory at the receiver)



- **An explicit NAK can request retransmission of just one packet.**
- **Buffer size should be at least as large as the number of packets transmitted in a roundtrip delay.**
- **Modulus m used should be** $m \geq 2n$.

Efficiency

p = probability of frame received with error.

β = expected # of frames per rountrip delay interval.

η = expected # of frames sent per accepted packet.

For ideal selective repeat transmitter goes back only on an error $\eta = 1 - p + p(1+\eta)$

efficiency $\frac{1}{\eta} \leq 1 - p$

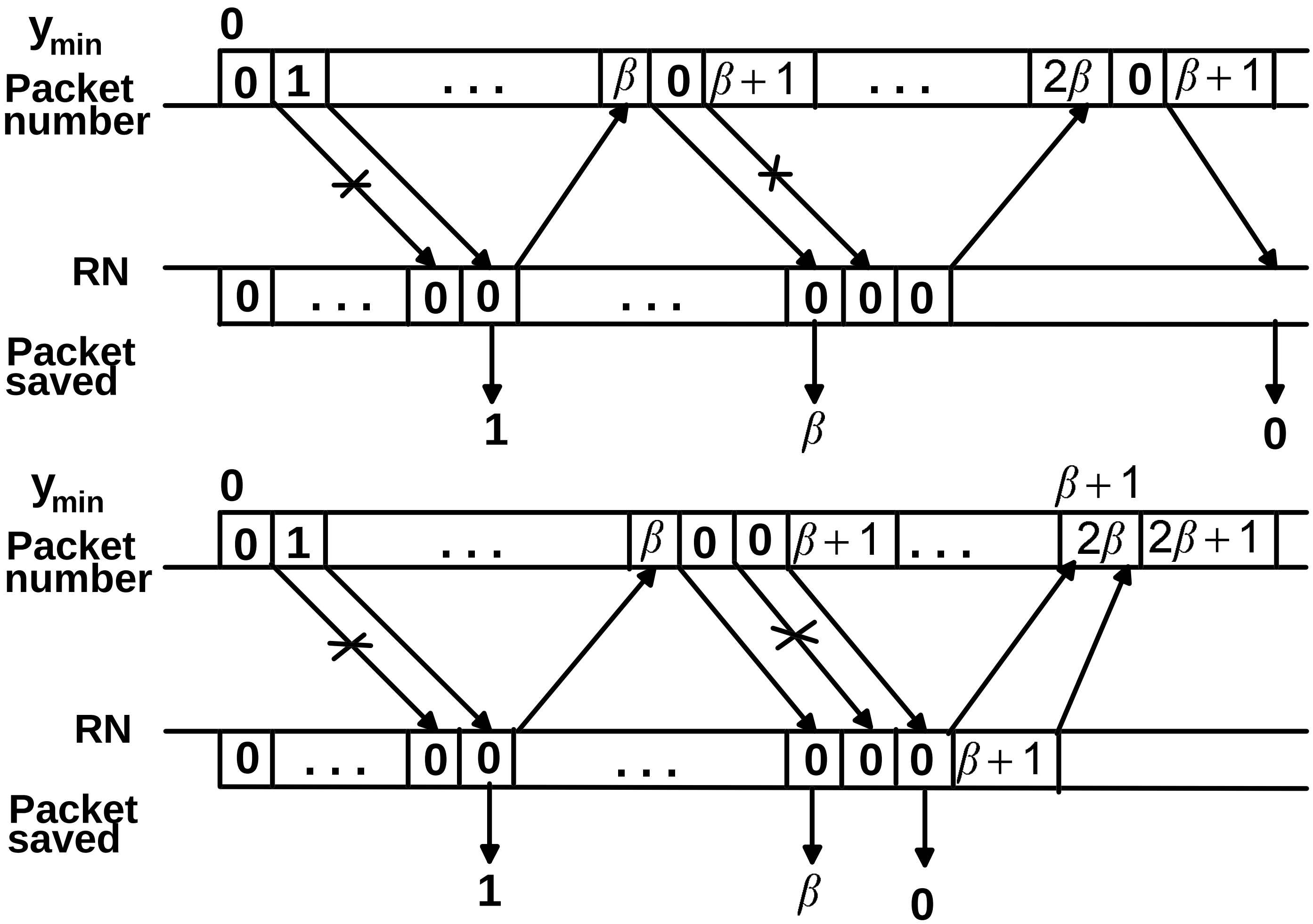
For ideal go back n ,

$$\eta = 1 - p + p(1 + \beta + \eta)$$

$$\frac{1}{\eta} \leq \frac{1-p}{1+p\beta}$$

Note: typical error rates are <0.0001; selective repeat does not gain much in efficiency unless there are many frames in a roundtrip delay (e.g. satellite communications, optical fiber networks, etc..).

Selective repeat ARQ with $n = 2\beta + 2$ and receiver storage for $\beta + 1$ packets.



Variability of delay is reduced