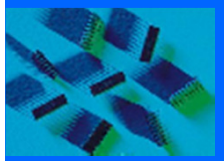


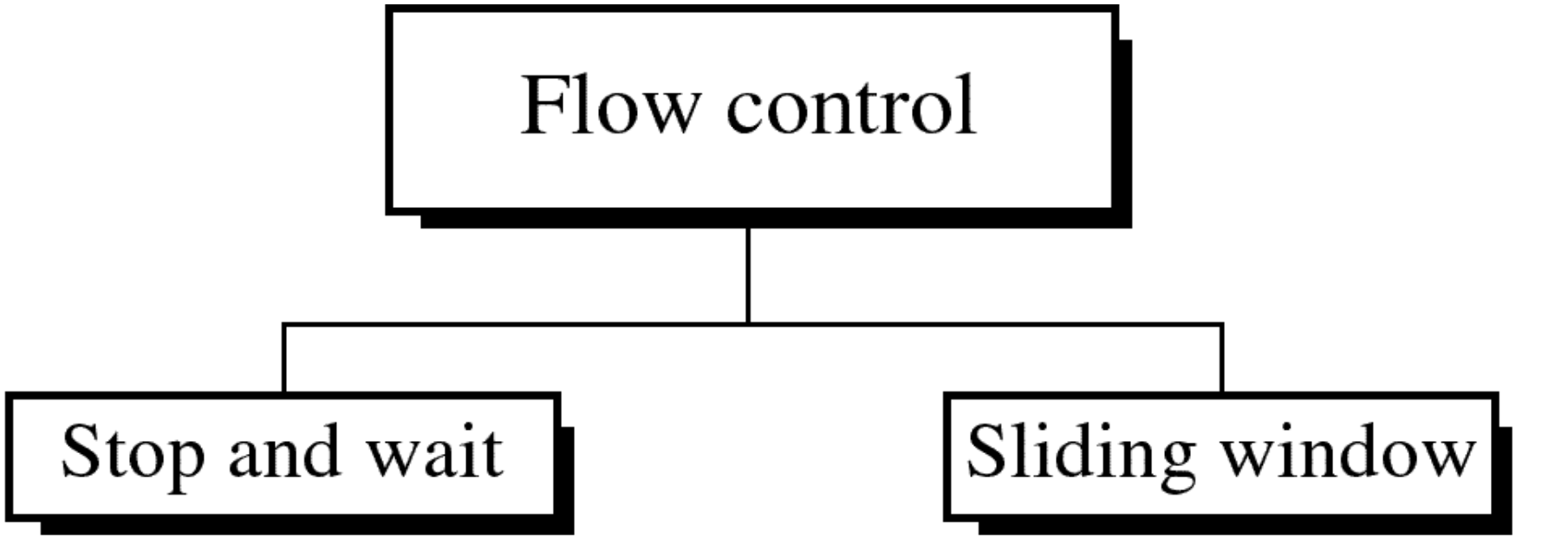
Lecture 9
Automatic Repeat Request (ARQ) Protocols

Textbook: Ch.23

Main Topics

A. Sliding Window
B. Revision on Stop-and-Wait ARQ
C. Go-Back-N ARQ
   - Cumulative ACK
   - Window size
D. Selective Repeat ARQ
   - Individual Acknowledgement
   - Sender and Receiver Window Size

Flow & Error Control Mechanisms



Send one frame at a time

- ***Stop and Wait ARQ***

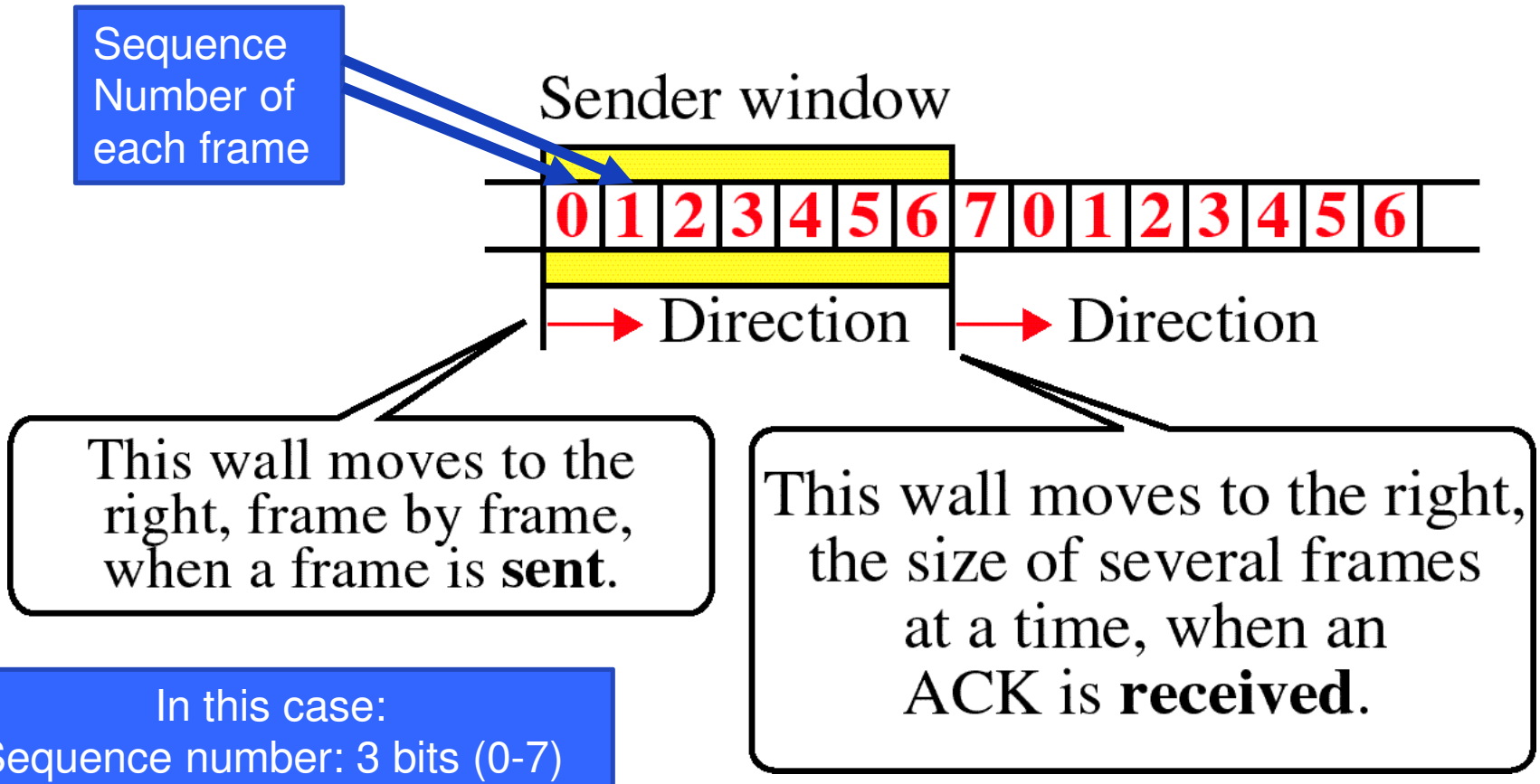
Send several frames at a time

- ***Go-Back-N ARQ***
- ***Selective Repeat ARQ***

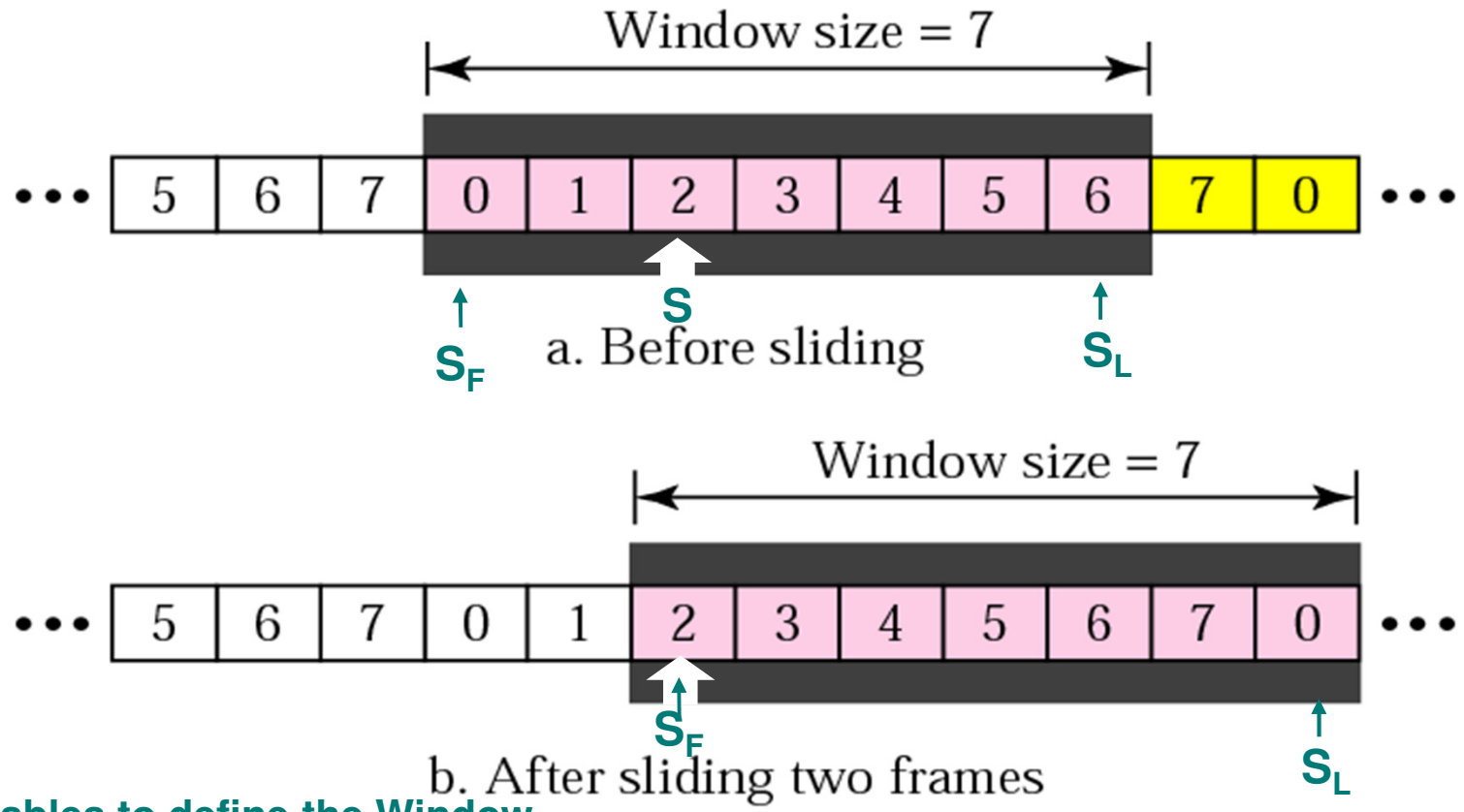
A. Sliding Window

- The sender can transmit several data frames before needing (receiving) an ACK
- A (logical) window is used to control the maximum no. of frames can be transmitted
- When the (variable) window size becomes zero, the sender stops transmissions and waits for an ACK
- A single ACK can be used to confirm the receipt of multiple data frames

Sender Sliding Window



Sender Sliding Window



Variables to define the Window

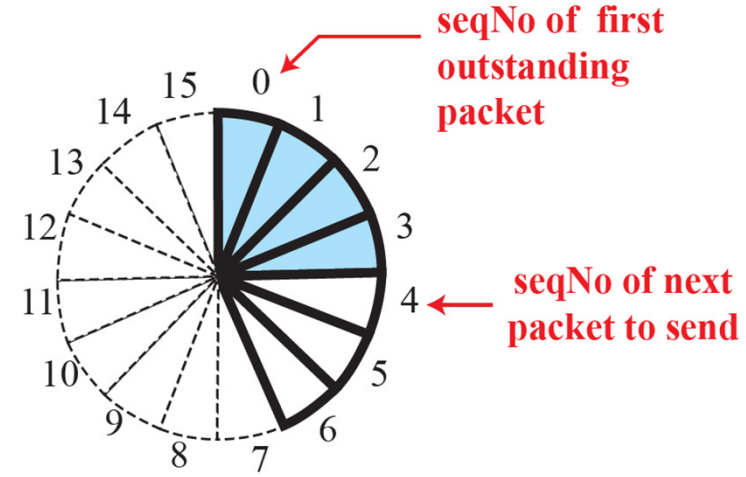
S_F: Seq. No. of 1st frame

S_L :Seq. No. of Last frame

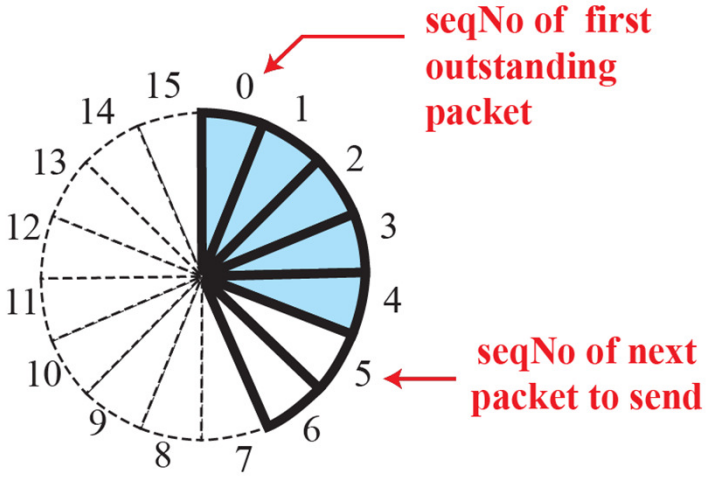
S: Seq. No. of next frame to be sent

Figure 23.12: Sliding window in circular format

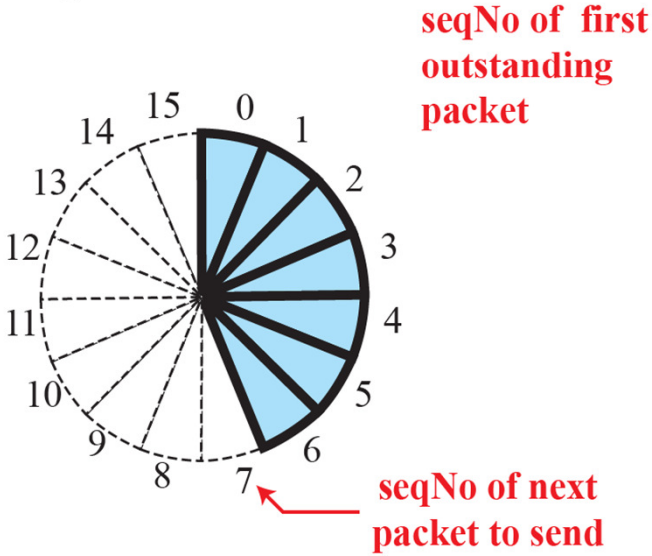
e.g. Window size = 7 ; Seq. no. has 4 bits (i.e. 0 -15)



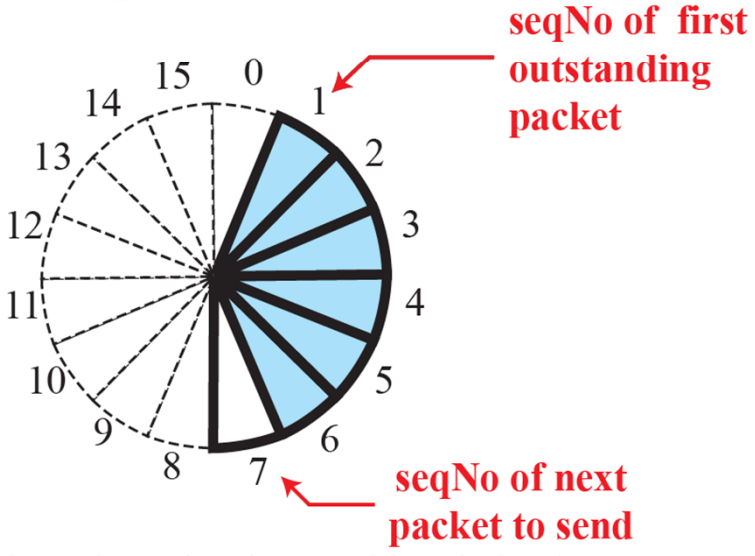
a. Four packets have been sent.



b. Five packets have been sent.

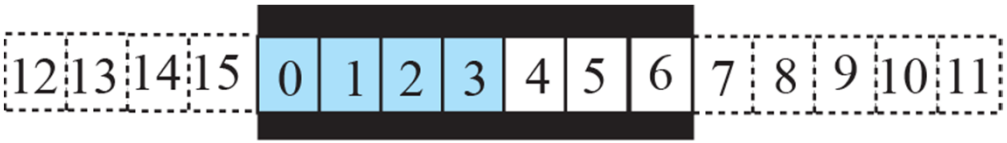


c. Seven packets have been sent; window is full.

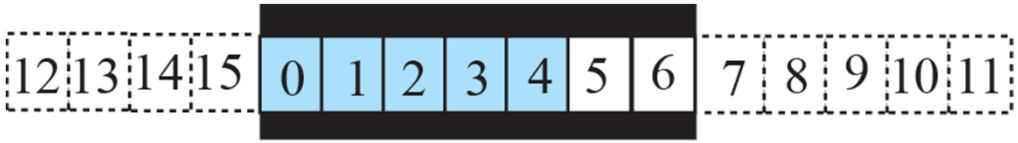


d. Packet 0 has been acknowledged; window slides.

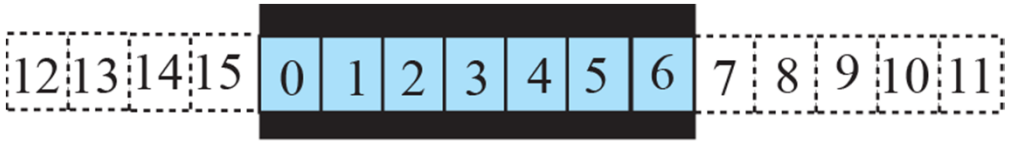
Figure 23.13: Sliding window in linear format e.g. Window size = 7 ; Seq. no. has 4 bits (i.e. 0 -15)



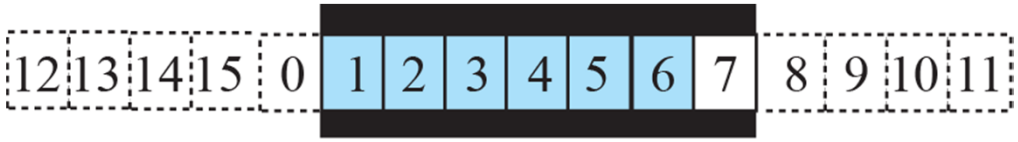
a. Four packets have been sent.



b. Five packets have been sent.

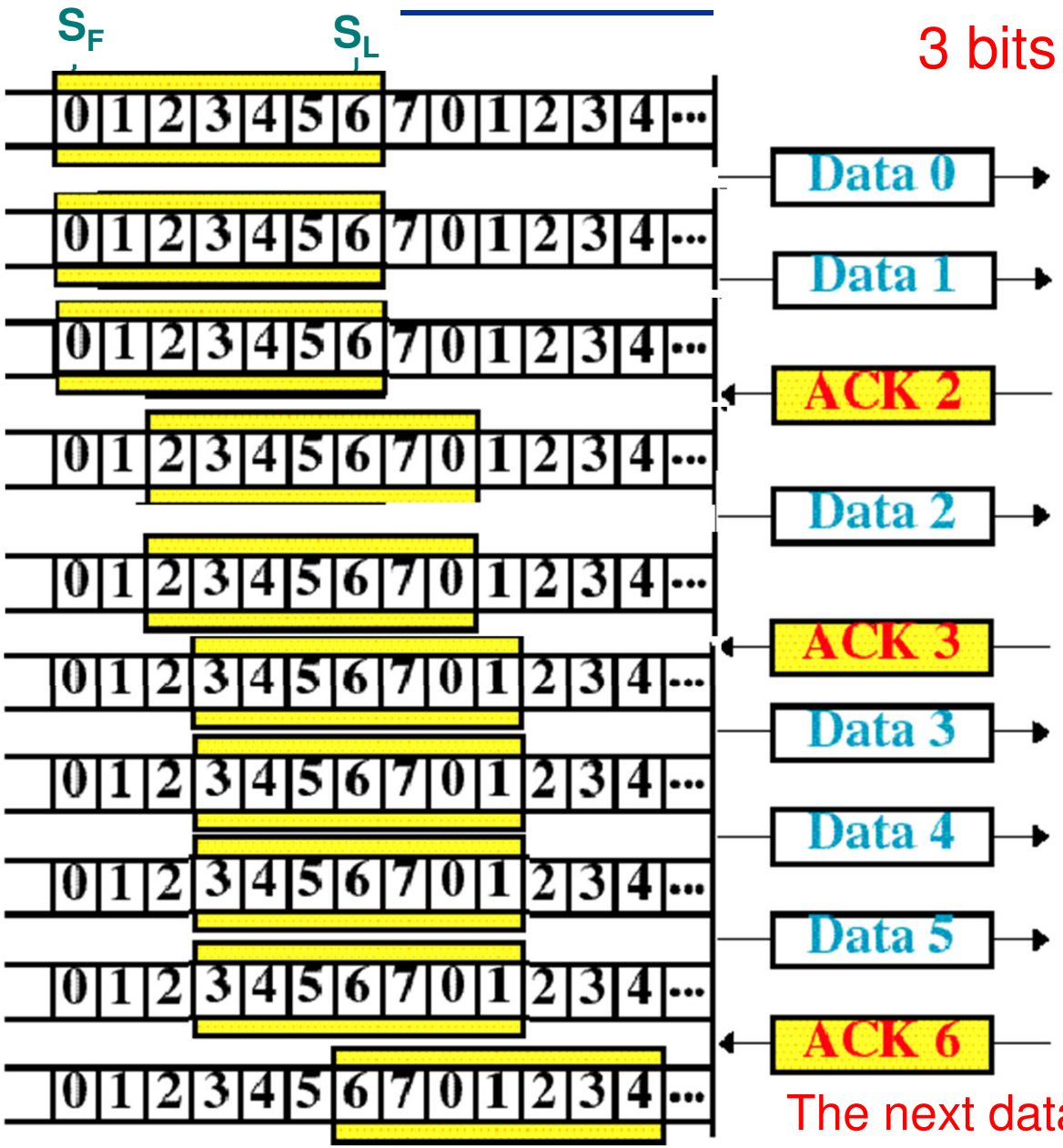


c. Seven packets have been sent; window is full.



d. Packet 0 has been acknowledged; window slides.

Sender



3 bits for Seq. no.

The next data is …?

B. Stop-and-Wait ARQ

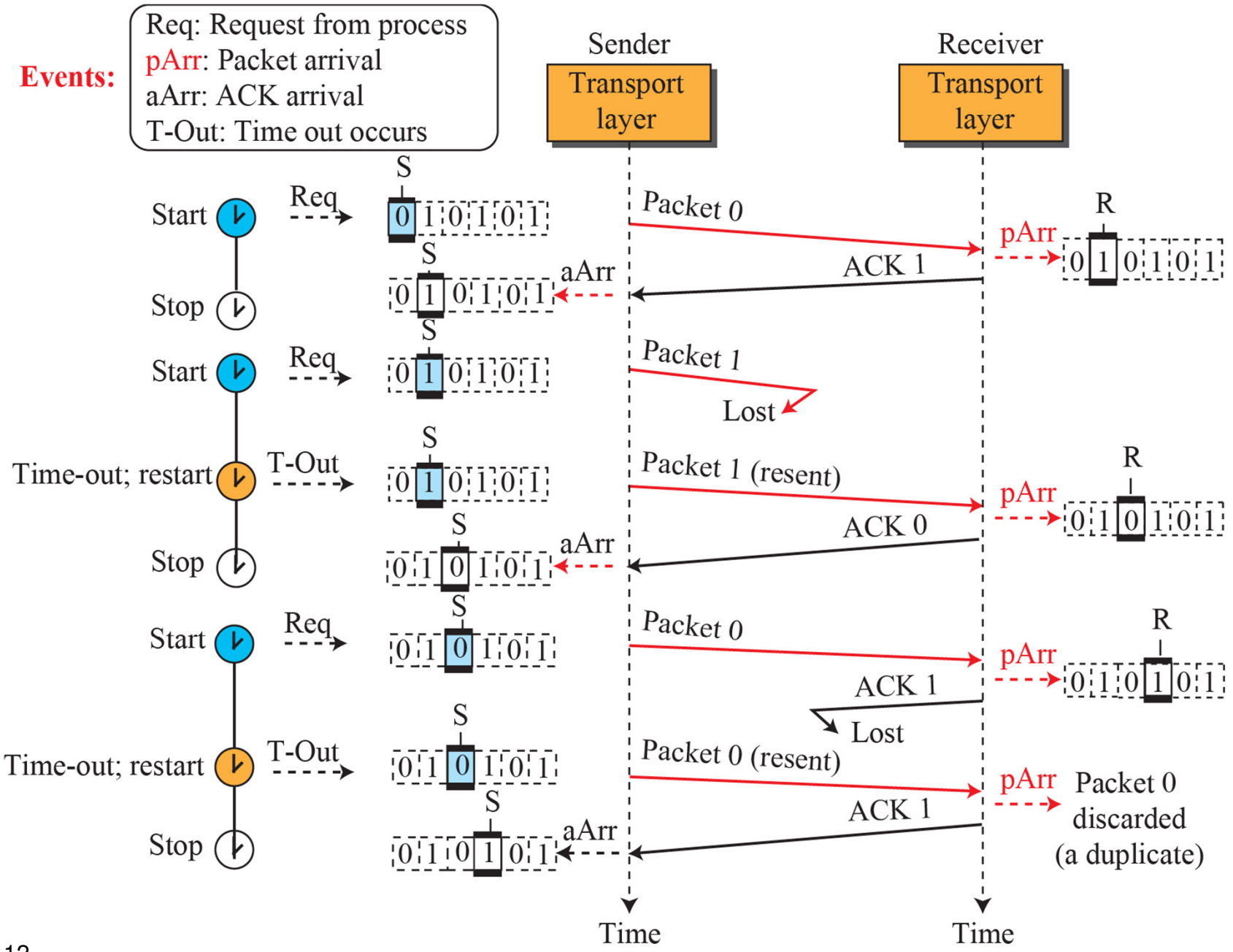
- The sender sends one frame and waits for an ACK before sending the next frame
- If no ACK is received after a period of time (timeout), the sender retransmits
- Use **1 bit sequence number**
- Both the sender and the receiver use a **sliding window of size 1**
- Advantage: Simple
- Disadvantage: Inefficient

Example 23.4

Figure 23.22 shows an **example of the Stop-and-Wait protocol**.

1. Packet 0 is sent and acknowledged.
2. Packet 1 is lost and resent after the time-out.
3. The resent packet 1 is acknowledged and the timer stops.
4. Packet 0 is sent and acknowledged, but the acknowledgment is lost. The sender has no idea if the packet or the acknowledgment is lost, so after the time-out, it resends packet 0, which is acknowledged.

Figure 23.22: Flow diagram for Example 3.4



C. Go-back-N (GBN) ARQ

- Use the concept of sliding window
  - Multiple frames are in transit while waiting acknowledgement
- At sender, the sliding window (buffer) holds the outstanding frames until they are acknowledged.
- Operation:

  Sender sends multiple frames and set ***a timer for each frame sent***. (The receiver has no timer)

  S: Sequence no. of the recently sent frame

Go-Back-N ARQ, normal operation

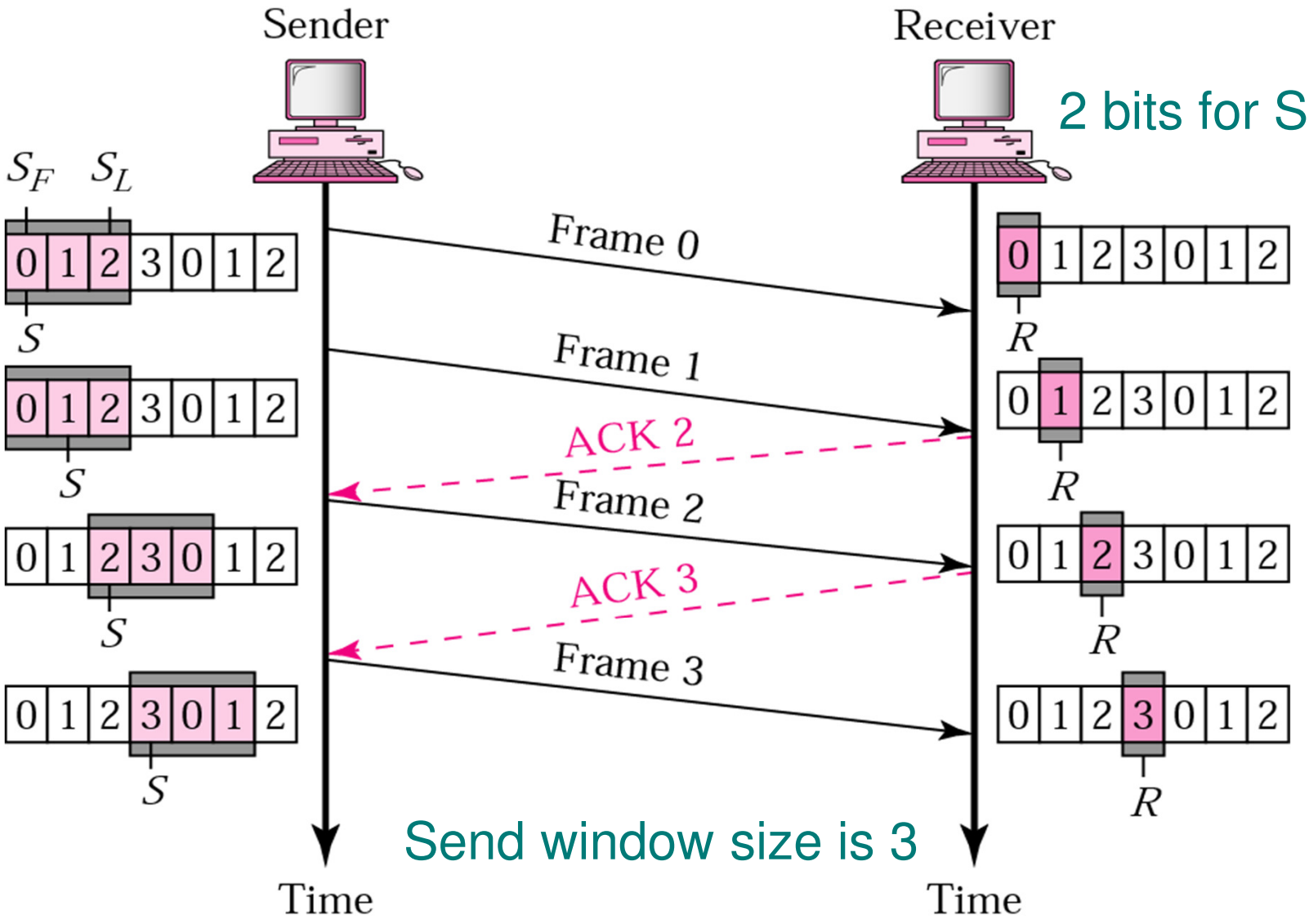
Receiver side

Case 1: frames arrived safe and in order

Receiver sends positive acknowledgements

R: Sequence number of the frame it ***expects*** to receive (R is contained in ACK packet)

Go-Back-N ARQ, normal operation

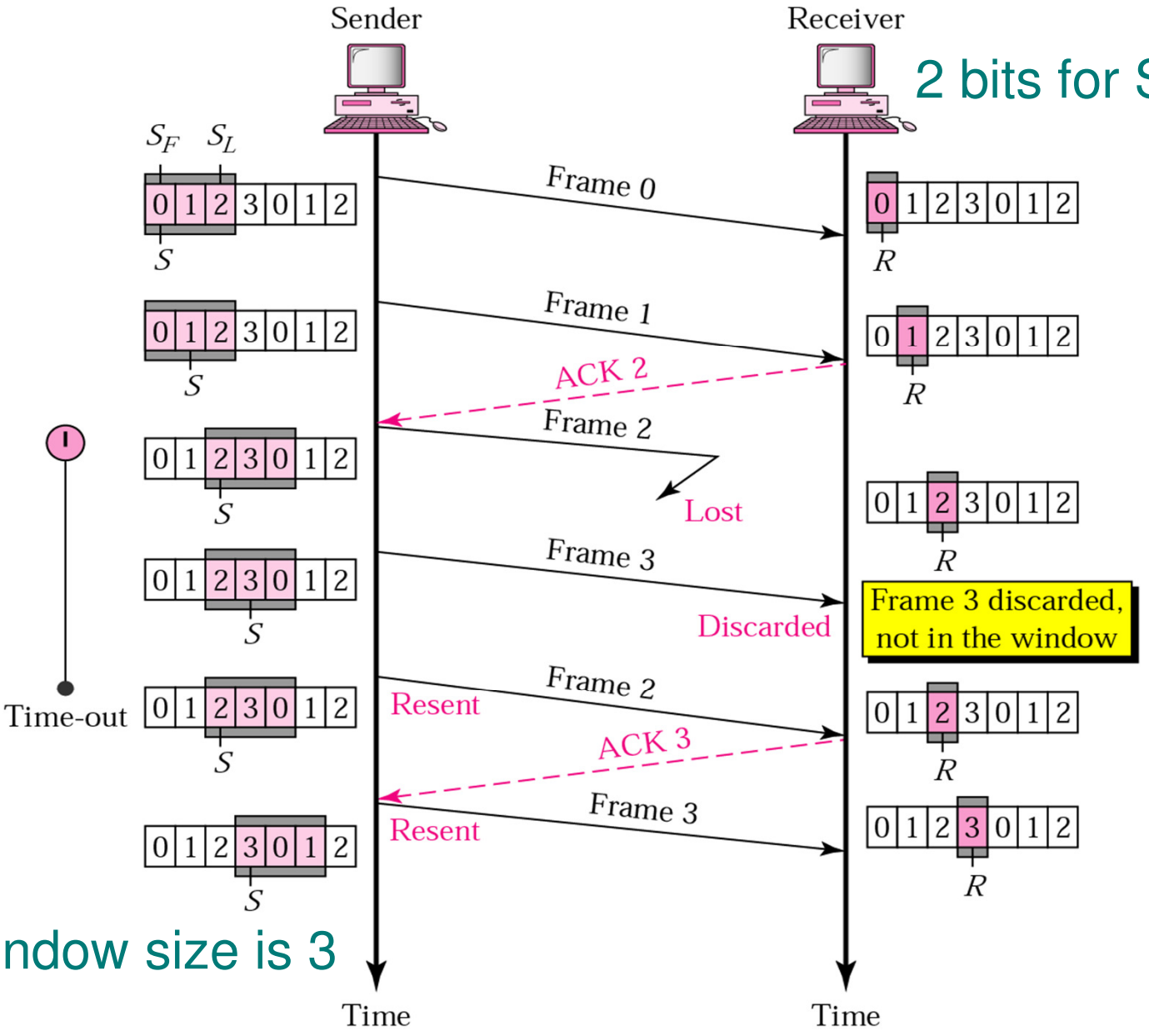


Go-Back-N ARQ, lost frame

Case 2: Frame is damaged or out of order

- ***Receiver is silent*** (send nothing) and discards all subsequent frames ***until*** it receives the one it is *expecting*
- In sender, the timer for the unacknowledged frame expires
- The sender goes back and ***resends all frames***, ***beginning from the one with the expired timer***

Go-Back-N ARQ, lost frame



2 bits for Seq. no.

Send window size is 3

Figure 23.24: Send window for Go-Back-N

3 bits for Seq. no.

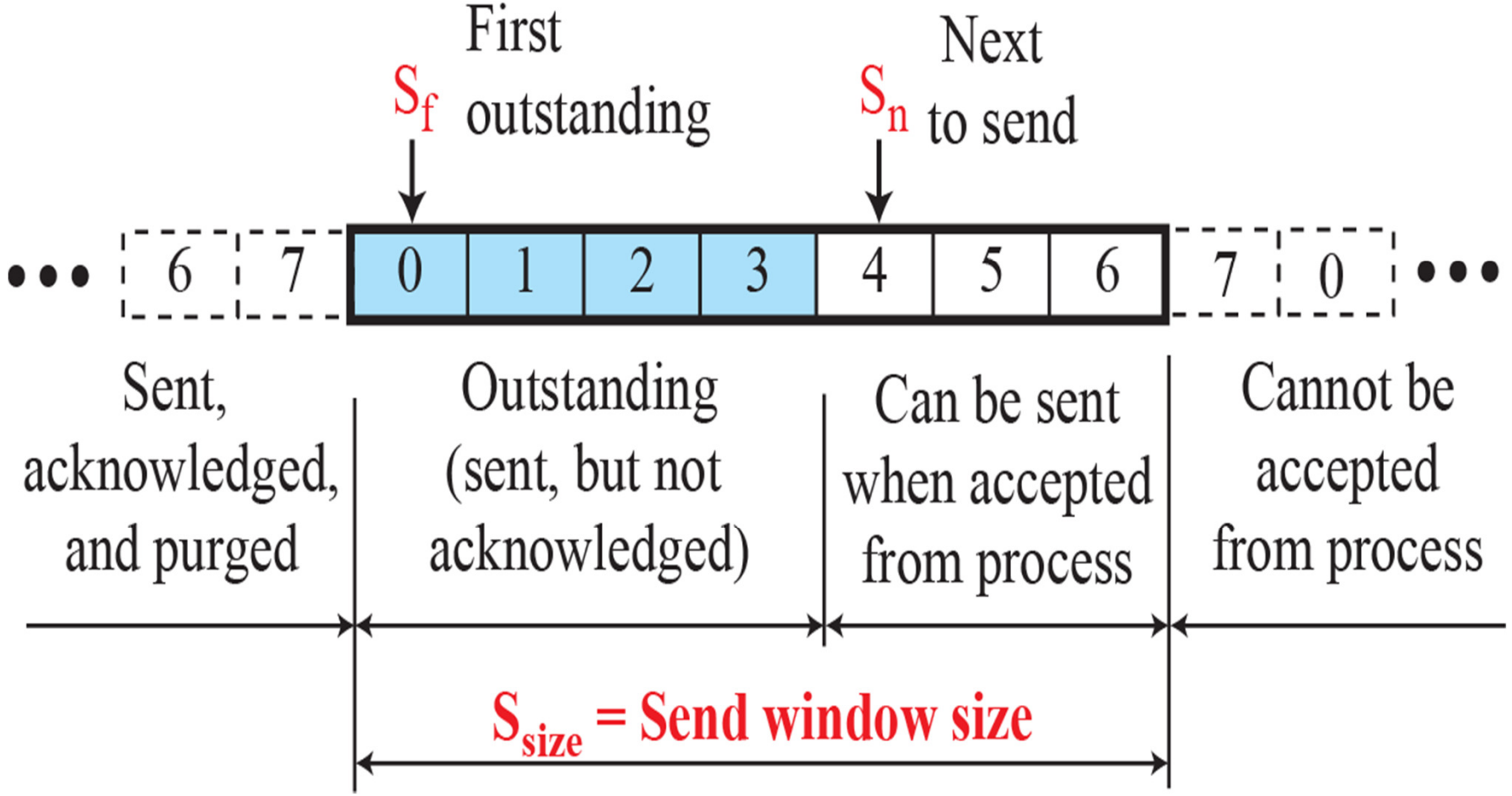


Figure 23.25: Sliding the send window

3 bits for Seq. no.

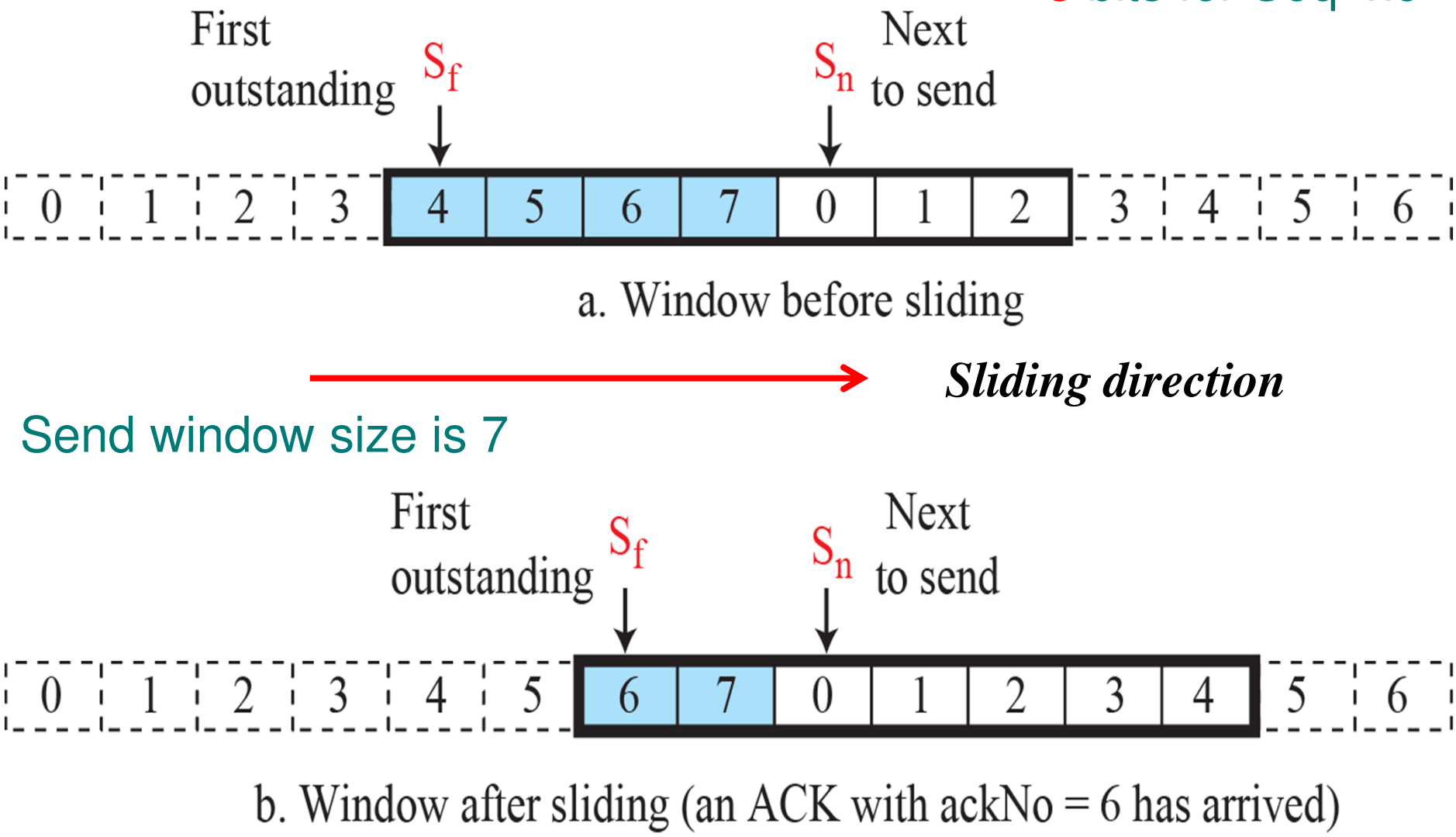
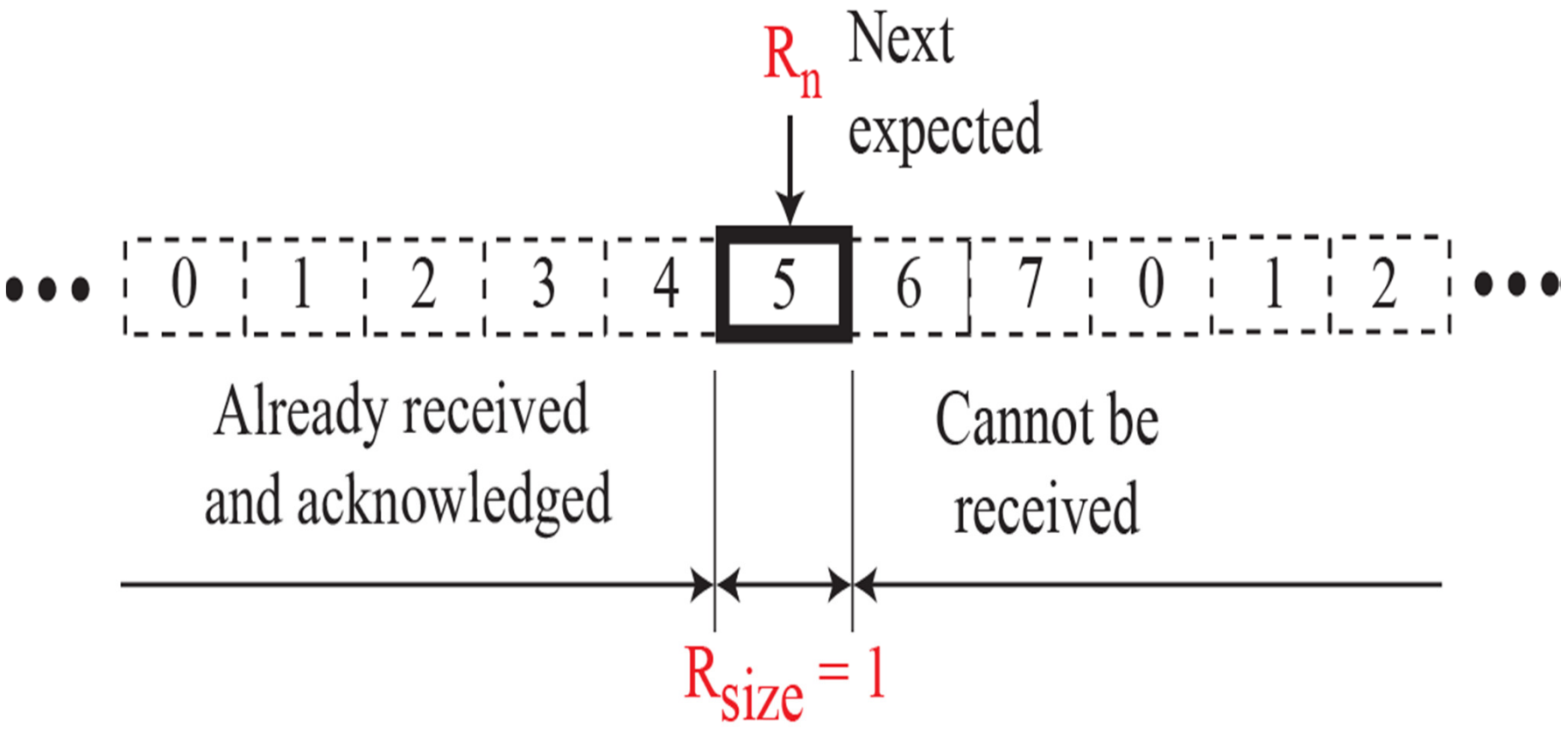


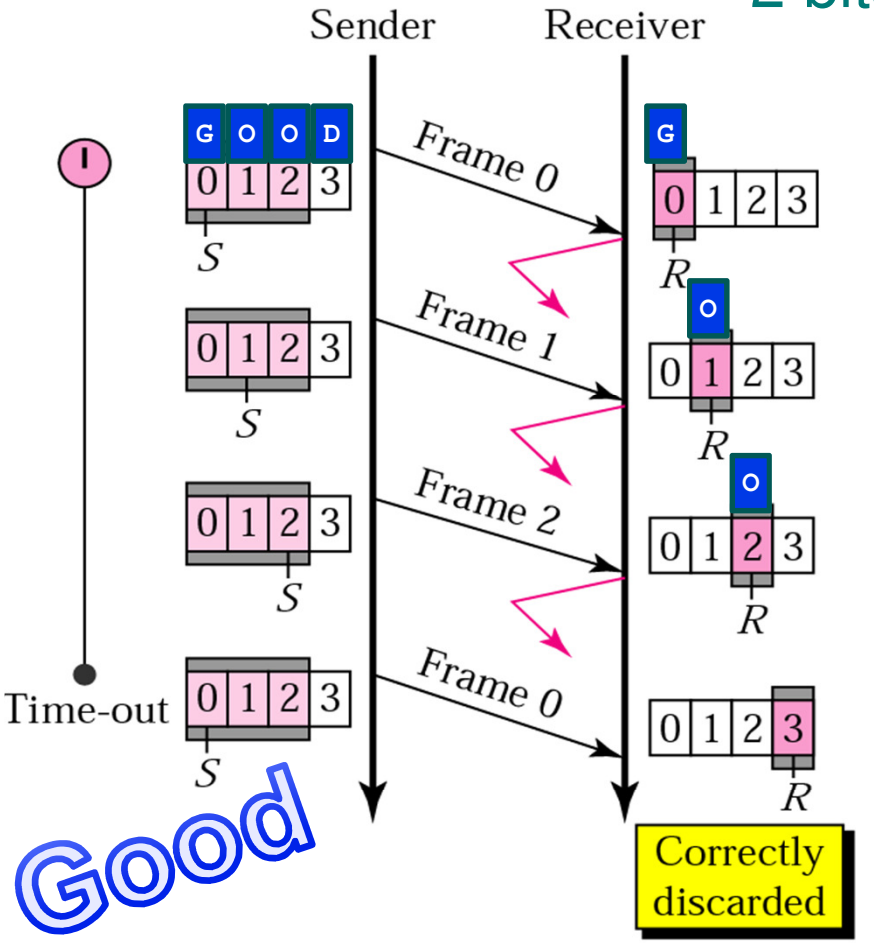
Figure 23.26: Receive window for Go-Back-N

3 bits for Seq. no.



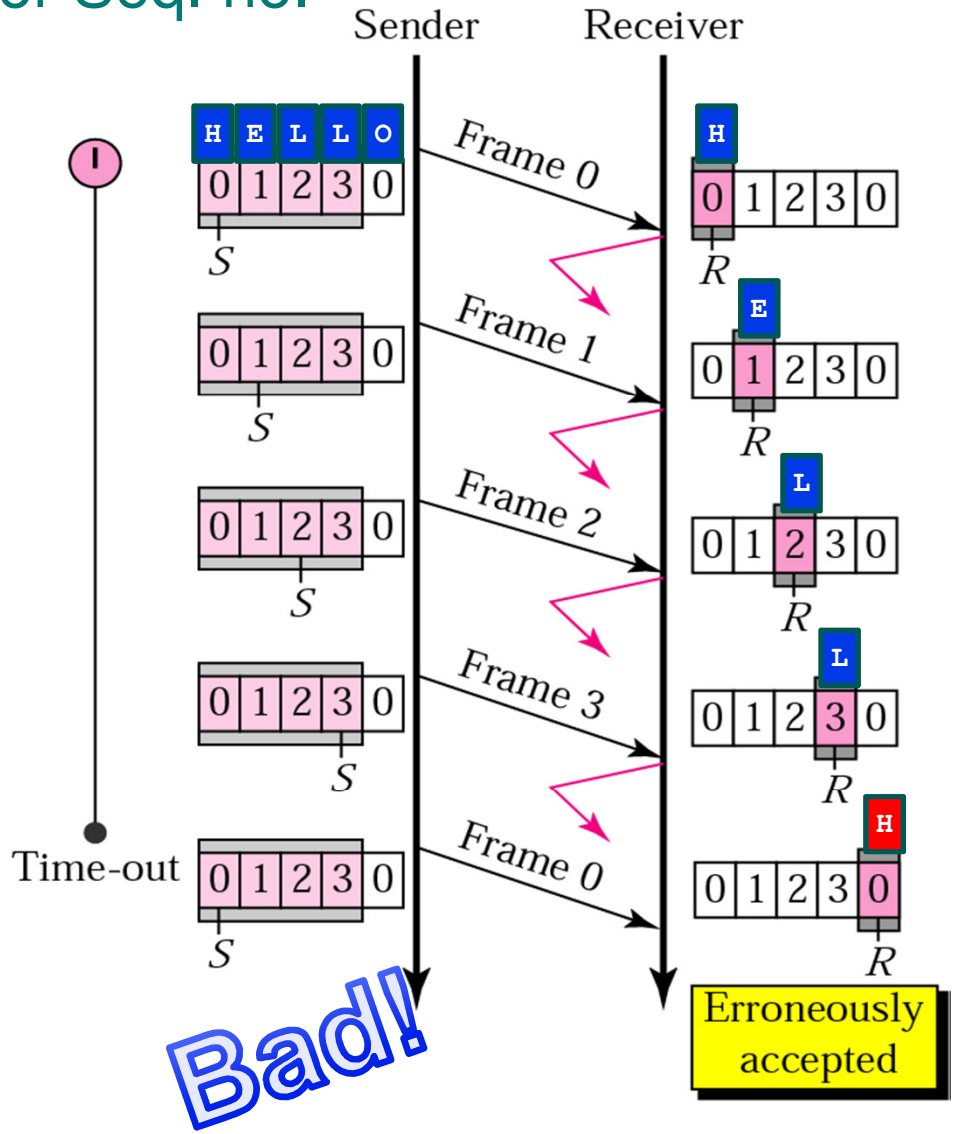
Go-Back-N ARQ: sender window size

2 bits for Seq. no.



m - no. of bits for Seq. no.

a. Window size < 2^m



b. Window size = 2^m

Sender Window Size

In Go-Back-N ARQ, the size of the sender window must be less than 2^m;

the size of the receiver window is always 1.

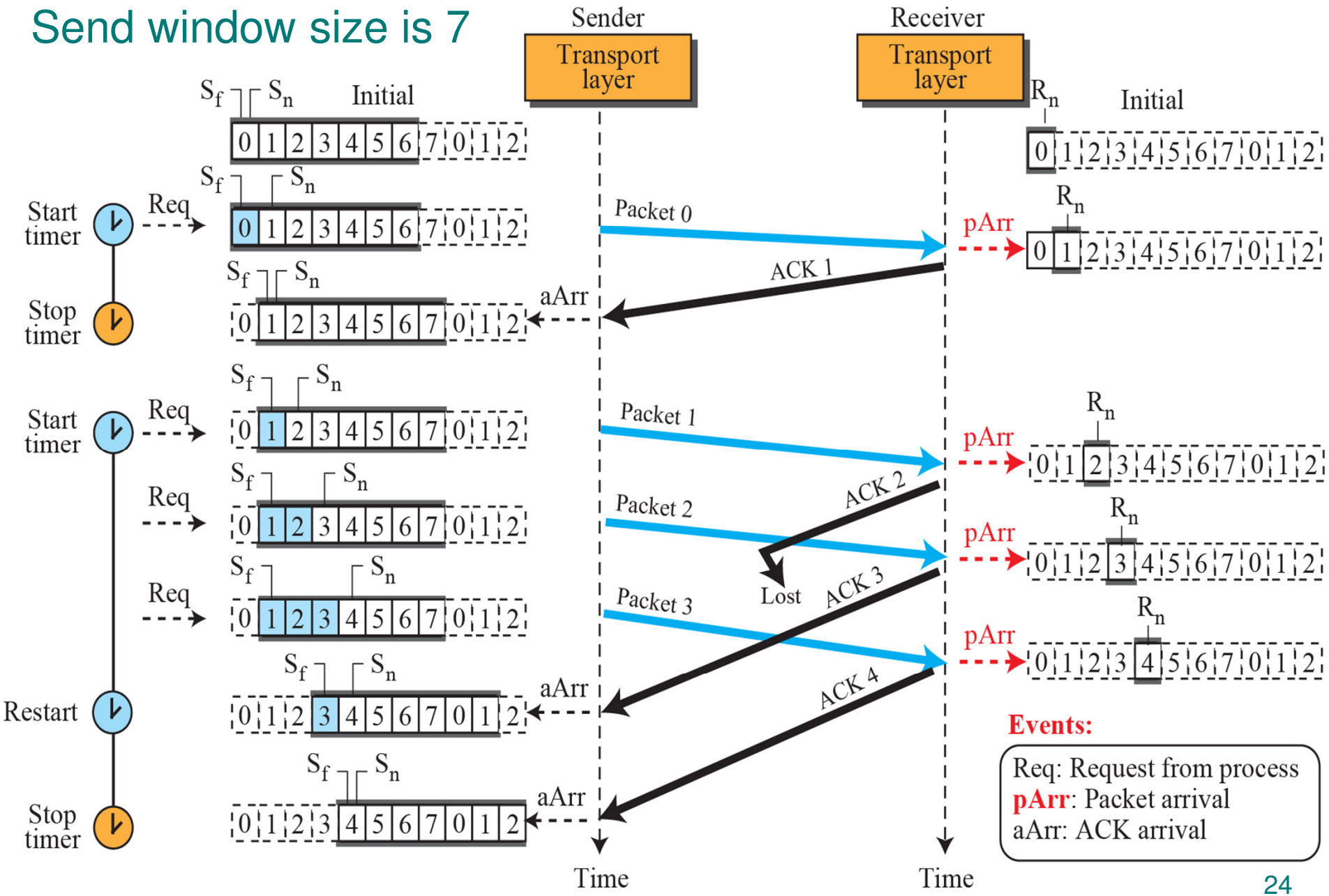
where m is the number of bits of the sequence number

Example 23.7

Figure 23.29 shows **an example of Go-Back-*N***. This is an example of a case where the forward channel is reliable, but the reverse is not. No data packets are lost, but some ACKs are delayed and one is lost. The example also shows how **cumulative ACKs** can help if acknowledgments are delayed or lost.

Figure 23.29: Flow diagram for Example 3.7

Send window size is 7

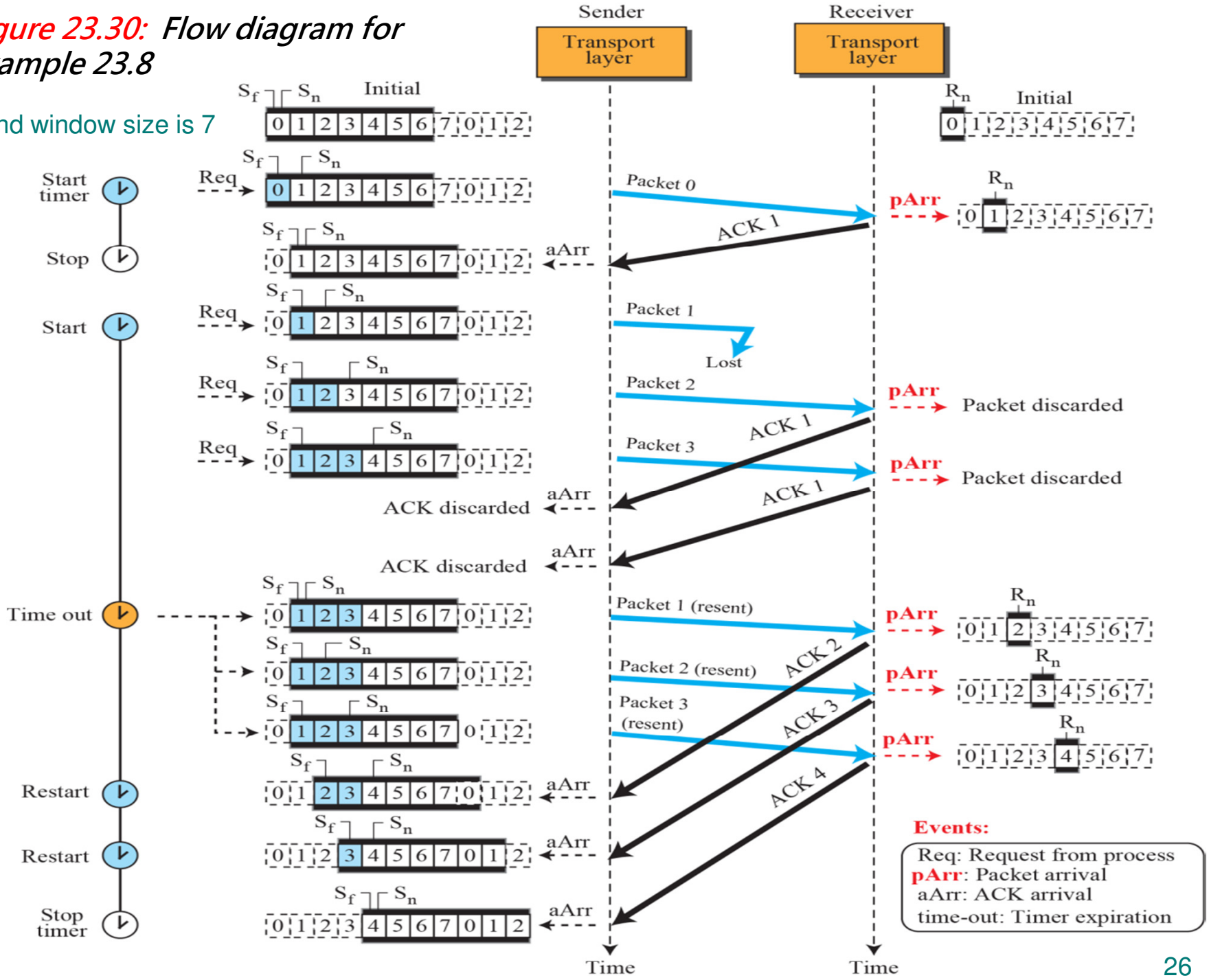


Example 23.8

Figure 23.30 shows what happens when a packet is lost. Packets 0, 1, 2, and 3 are sent.

- However, packet 1 is lost. The receiver receives packets 2 and 3, but they are **discarded because they are received out of order** (packet 1 is expected).
  - When the receiver receives packets 2 and 3, it sends ACK1 to show that it expects to receive packet 1.
  - However, these ACKs are not useful for the sender because the ackNo is equal to S_f, not greater that S_f. So the sender discards them.
- **When the time-out occurs, the sender resends** packets 1, 2, and 3, which will then be acknowledged.

Figure 23.30: Flow diagram for Example 23.8



Go-Back-N Advantages & Disadvantages

- Maintain correct sequence
- Minimize the receiver buffer storage
- 1 storage unit is enough in the receiver buffer
- But need to retransmit some already correctly received frames
- Less efficient than selective-repeat

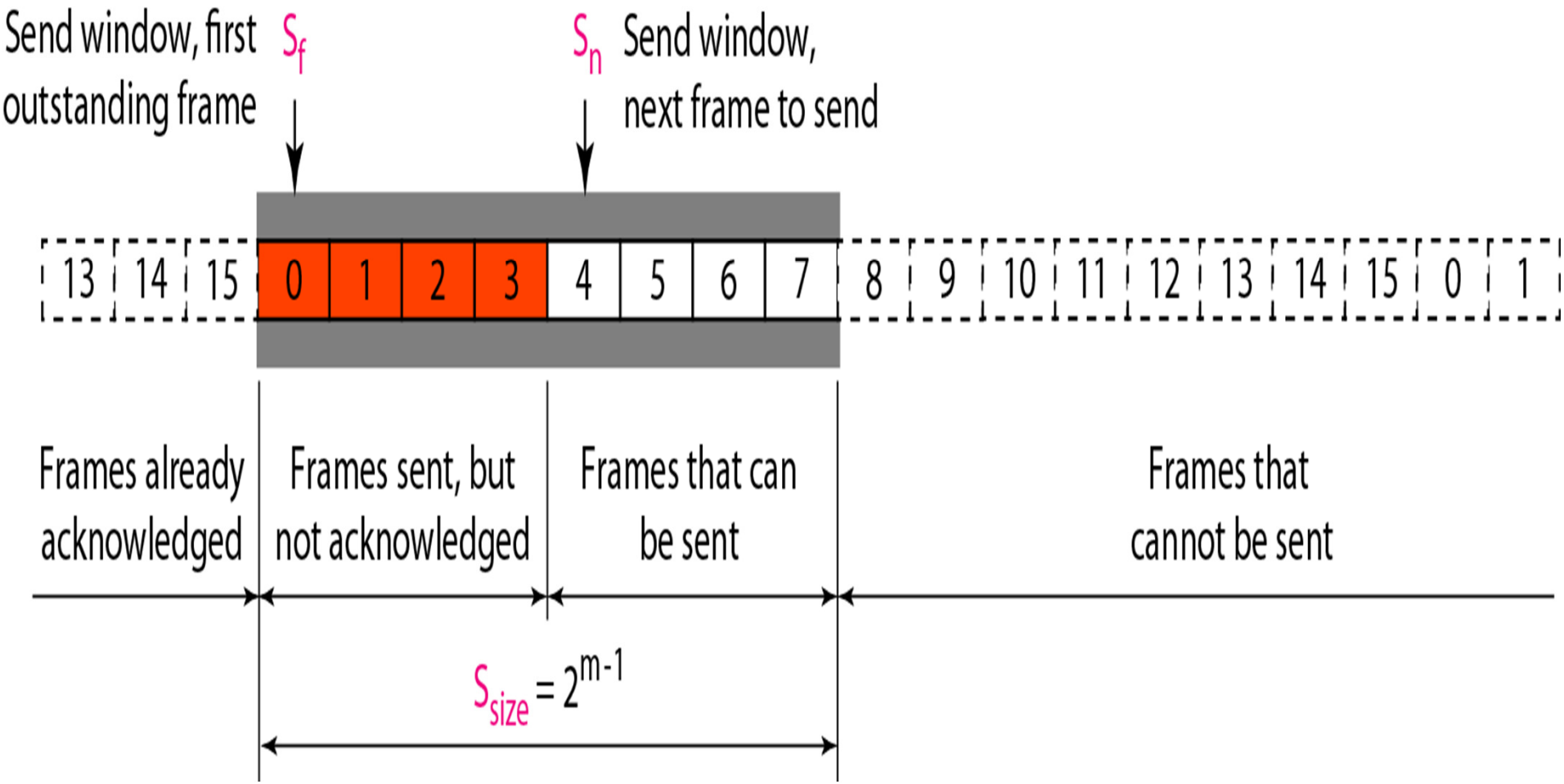
D. Selective Repeat ARQ

- In Go-back-N ARQ, the process at the receiver is simple
  - Receiver keeps track of only one variable
  - No need to buffer out-of-order frames
  - But multiple frames are resent when one frame is damaged
  - Use up bandwidth and slow down transmission
- Selective Repeat ARQ
  - Does not resent *N* frames when just one frame is damaged
  - Only the damaged frame is resent

Receiver in Selective Repeat ARQ

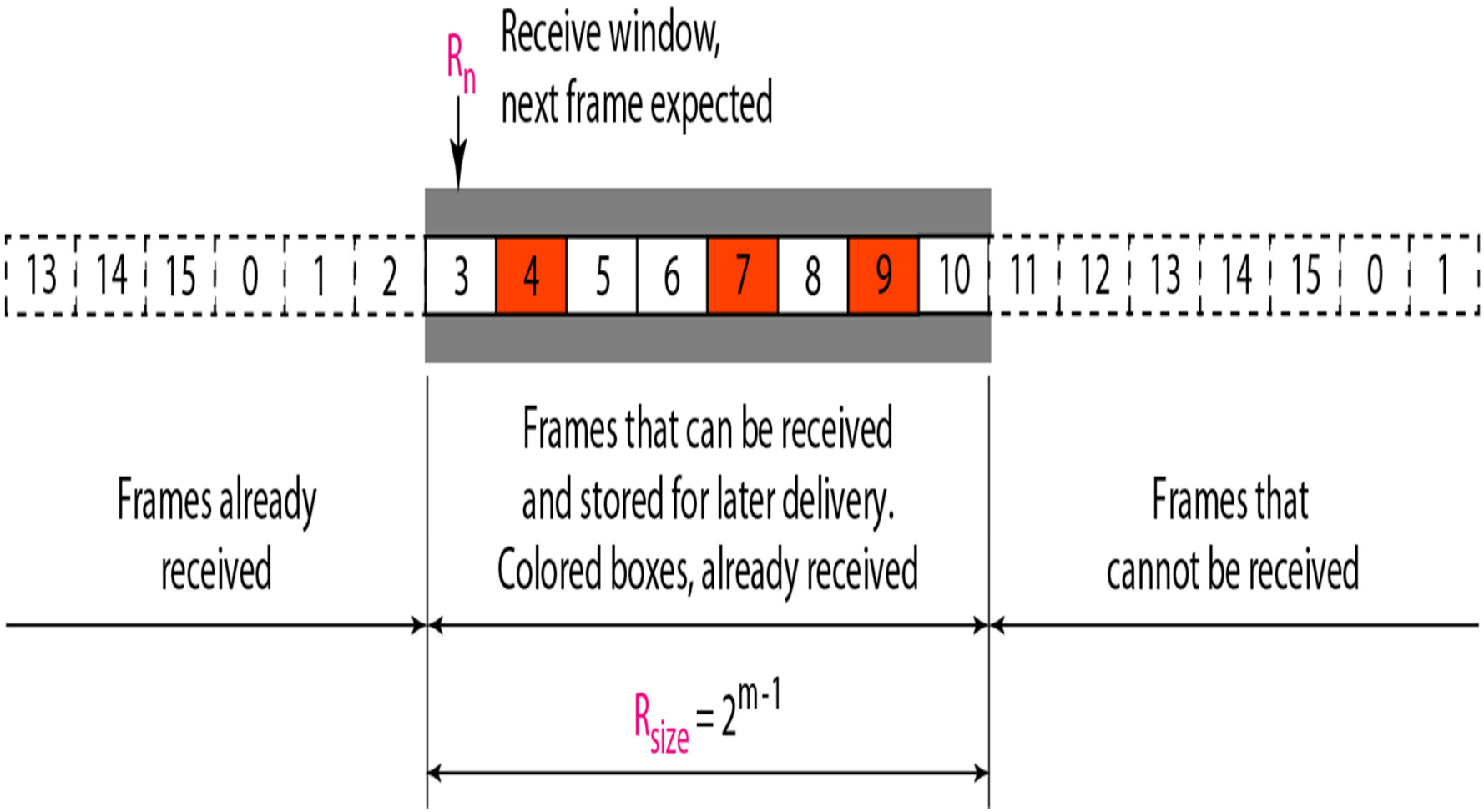
- Receiver detects those frames that are damaged
- Receiver retains out-of-sequence frames (without errors) in the **link receive list** until the next in-sequence frame is received; then a set of consecutive frames could be delivered to the upper layer
- ***Individual ACK***
  - **ACK(N)** *acknowledges only a single frame* with sequence number N
- In the sender, when a timer (waiting for ACK) expires, only the corresponding frame is resent

Send Window for Selective Repeat ARQ



Similar to Figure 23.32

Receive Window for Selective Repeat ARQ



Similar to Figure 23.33

Sender and Receiver Window Size

In Selective Repeat ARQ, the sender and receiver window have the same size and it must be

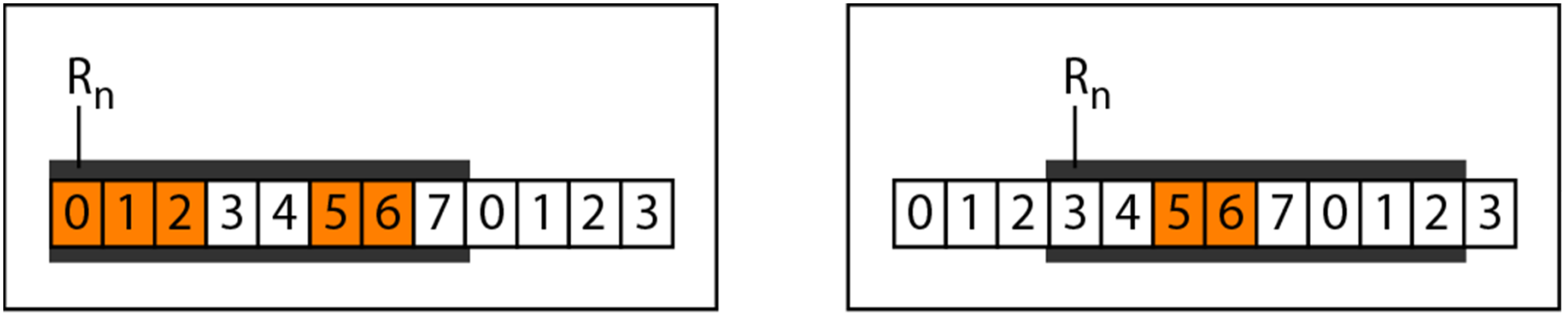
at most one-half of 2^m

where m is the number of bits of the sequence number

(skip the explanation)

Window Slide and Change of R_n

- At the **receiver**, if the received frame is not damaged and the sequence no. is within the window,
- Receiver will store the frame and mark the slot (e.g. slot 5 and 6 on orange.)
- If contiguous frames, starting from R_n have been marked, data is delivered to the upper layer, and the window *slides.*



a. Before delivery

(Say just received data No. 0)

b. After delivery

(data No. 0, 1 and 2 are delivered)

Figure ***Delivery of data in Selective Repeat ARQ***

Example 23.9

Assume a sender sends 6 packets: packets 0, 1, 2, 3, 4, and 5. The sender receives an ACK with ackNo = 3. What is the interpretation if the system is using GBN or SR?

Solution

If the system is using GBN, it means that packets 0, 1, and 2 have been received uncorrupted and the receiver is expecting packet 3.

If the system is using SR, it means that packet 3 has been received uncorrupted; the ACK does not say anything about other packets.

Example 23.10

Similar to Example 23.8 (Figure 23.30) in which packet 1 is lost but using **Selective-Repeat**.

At the sender, packet 0 is transmitted and acknowledged. Packet 1 is lost. Packets 2 and 3 arrive out of order and are acknowledged. When the timer times out, packet 1 (the only unacknowledged packet) is resent and is acknowledged. The send window then slides.

Timer

Theoretically, Select-Repeat uses one timer for each outstanding (unacknowledged) packet. When a timer expires, only the corresponding packet is resent. However, ***implementation with a single timer*** also works, as shown in this example.

Example 23.10 (continued)

At the receiver site we need to distinguish between the acceptance of a packet and its delivery to the application layer.

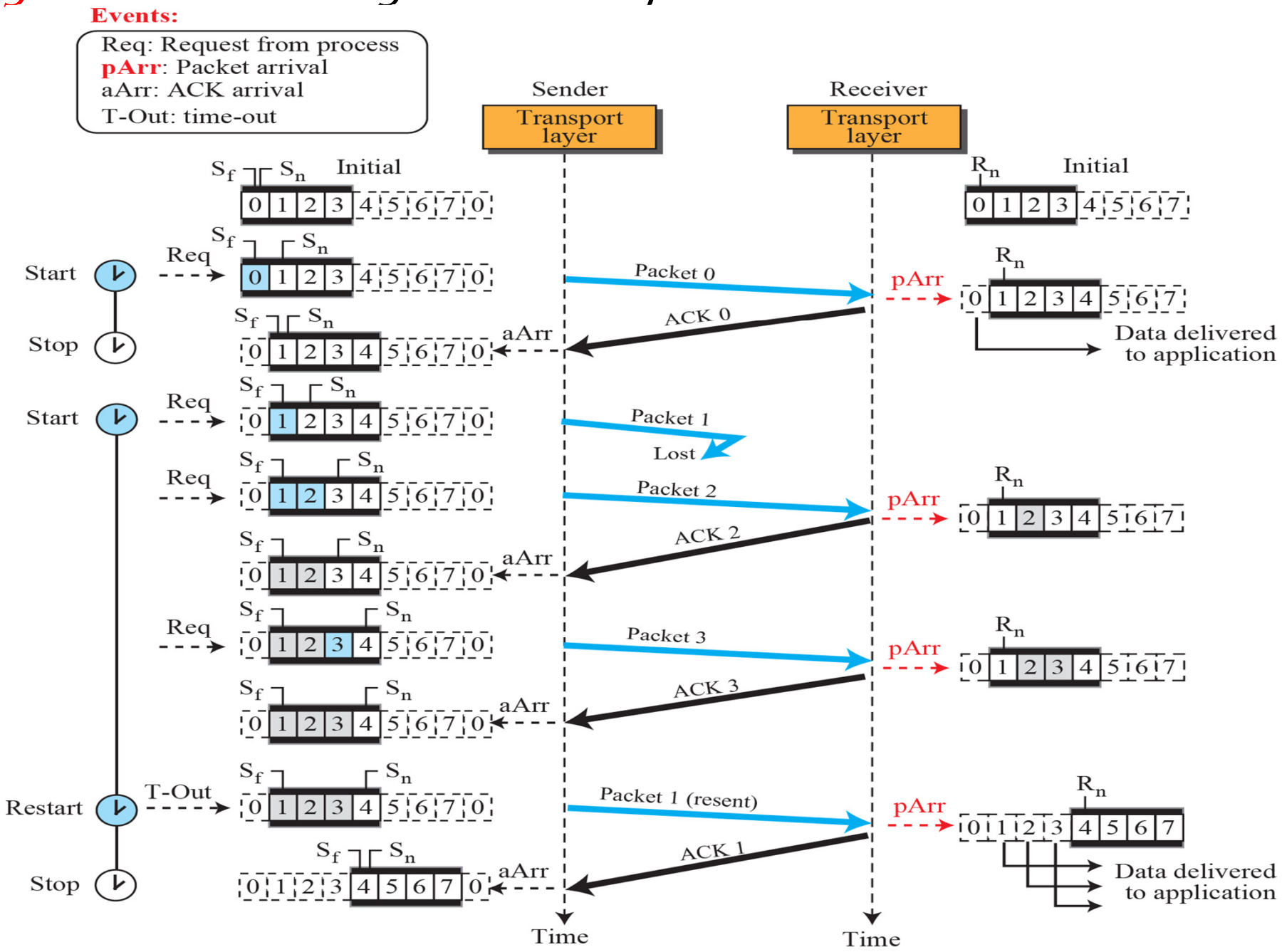
- At the second arrival, packet 2 arrives and is stored and marked (shaded slot), but it cannot be delivered because packet 1 is missing.
- At the next arrival, packet 3 arrives and is marked and stored, but still none of the packets can be delivered.
- Only at the last arrival, when finally a copy of packet 1 arrives, can packets 1, 2, and 3 be delivered to the application layer.

- There are **two conditions for the delivery of packets to the application layer**:

❖ ***A set of consecutive packets must have arrived.***

❖ ***The set starts from the beginning of the window.***

Figure 23.35: Flow diagram for Example 3.10



Selective Repeat Disadvantages

- Order of receiving data frames is not maintained
- Re-sequencing is required in Receiver
- Number of buffers can be large and non-deterministic
- (***Advantage***: but the channel is more efficient than Go-Back-N)

Summary on Sliding Window ARQ

- The link utilization is much improved at the expense of larger buffer storage requirements
- Sender sends data frame continuously without waiting for an ACK
- Sender retains a copy of each transmitted data frame in a ***retransmission list***
- Receiver returns an ACK for each correctly received data frame

Sliding Window ARQ (cont.)

- Each data frame contains a unique identifier (the sequence number)
- On receipt of an ACK the corresponding data frame is removed from the retransmission list by Sender
- Receiver retains a ***link receive list*** containing the correctly received data frames (but may be out-of-order for selective-repeat)
- Retransmission strategies when an error occurs
  - Go-Back-N
  - Selective Repeat

Summary

- **Stop-and-Wait**
  - Simplest but least efficient
  - Minimum buffer storage (only 1 in sender & receiver)
- **Go-Back-N**
  - Maintain correct sequence
  - Less demand on the buffer storage (1 in receiver)
  - But need to retransmit some already correctly received frames
  - Channel less efficient than selective-repeat
- **Selective Repeat**
  - Re-sequencing (and more buffers) required in receiver
  - Number of buffers can be large and non-deterministic
  - Channel more efficient than Go-Back-N

References

- Go-Back-N Video
  - http://www.youtube.com/watch?v=yT8SkFyRRrI
- Simulation on Go-Back-N and Selective Repeat
  - http://www.ccs-labs.org/teaching/rn/animations/gbn_sr/
- Revision Quiz
  - http://highered.mheducation.com/sites/0073376221/student_view0/chapter23/quizzes.html