Transport Layer

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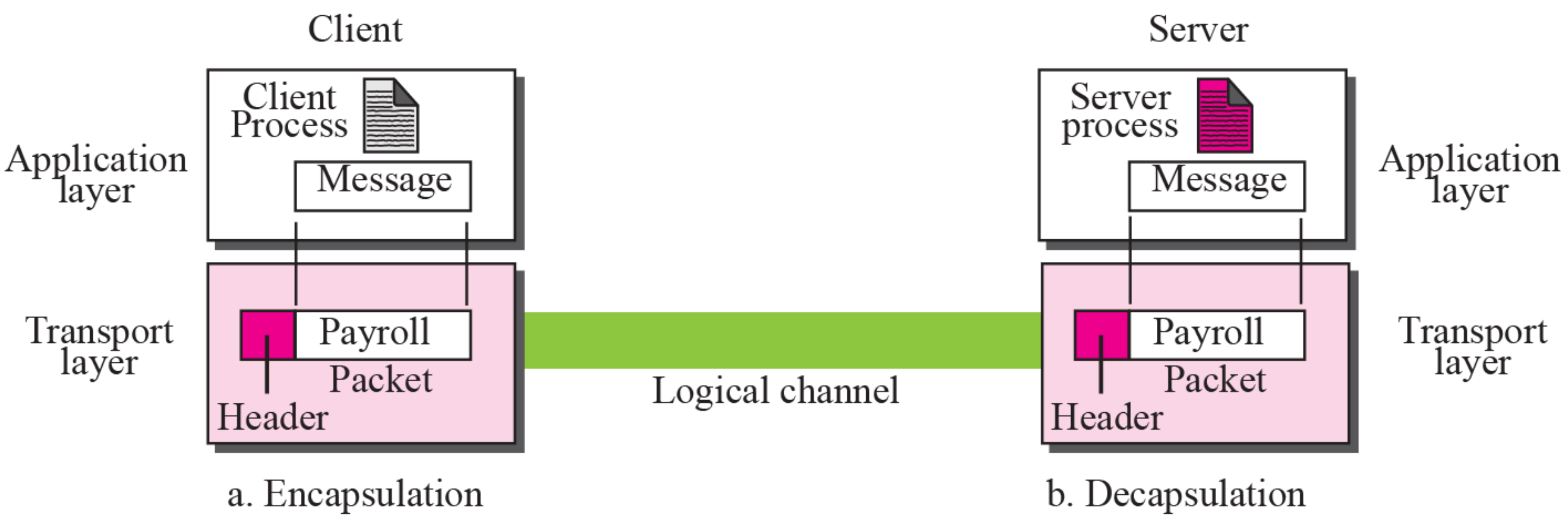
Transport Layer Services

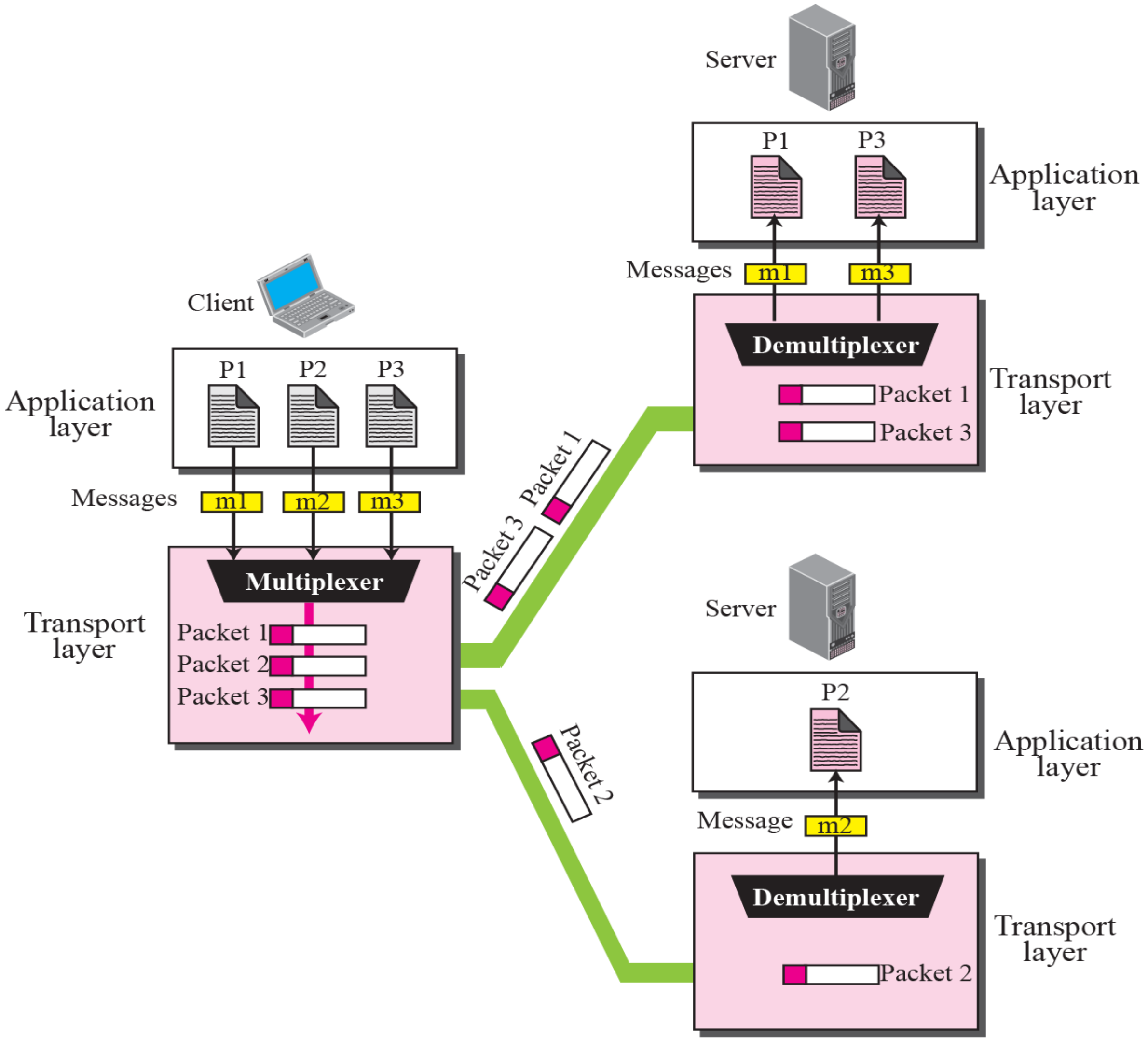
- ✓ Encapsulation and Decapsulation
- ✓ Multiplexing and Demultiplexing
- ✓ Flow Control
- ✓ Error Control
- ✓ Congestion Control
- ✓ Connectionless and Connection-Oriented Services

Encapsulation and Decapsulation



TCP/IP Protocol Suite

Multiplexing and Demultiplexing



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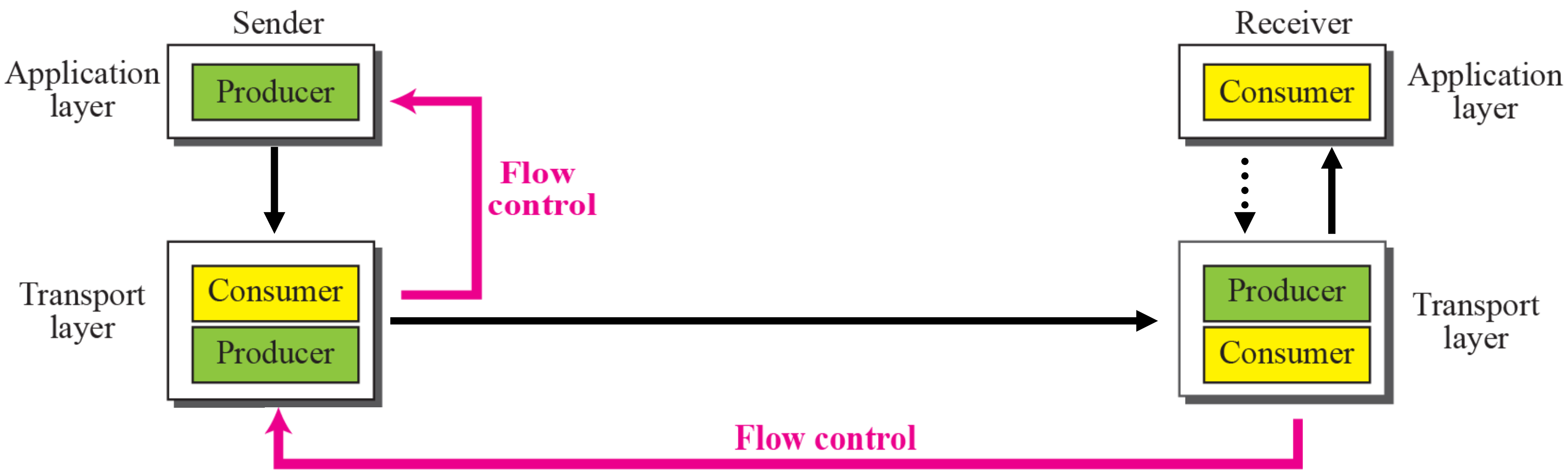
Flow control



TCP/IP Protocol Suite

Error Control

1. **Checksum**
2. **Acknowledgement**
3. **Retransmission**

Error Control Service is responsible for:

1. Detecting and discarding corrupted packets.
2. Keeping track of lost and discarded packets and resending them
3. Recognizing duplicate packets and discarding them.
4. Buffering Out-of-Order packets until the missing packets arrive.

TCP/IP Protocol Suite

Flow Control and Error Control Protocol

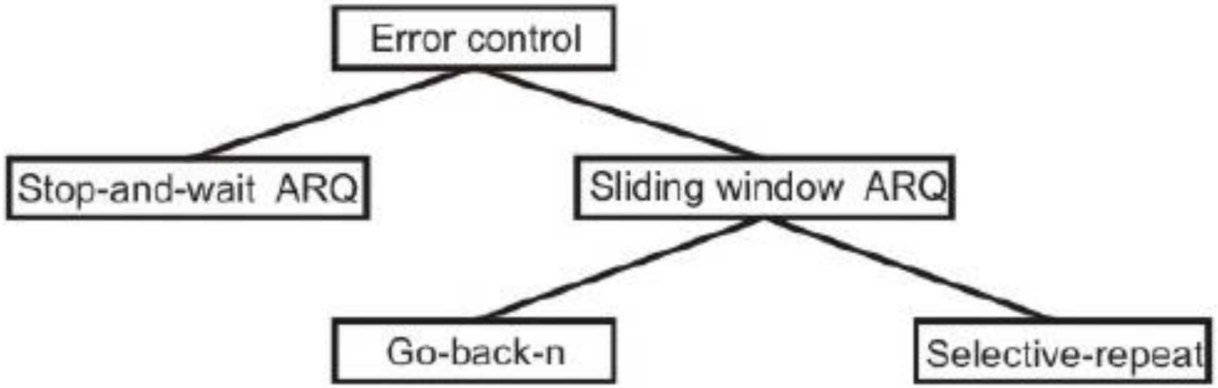
- ✓ Simple Protocol
- ✓ Stop-and-Wait Protocol
- ✓ Go-Back-*N* Protocol
- ✓ Selective-Repeat Protocol

Flow Control and Error Control Protocol Cont..

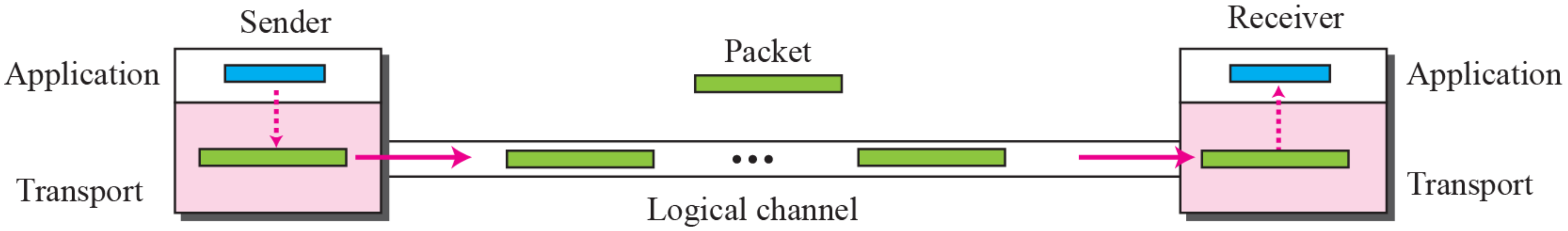
Flow control: It coordinates amount of data that can be sent before receiving an ack.

- Stop and Wait
- Sliding window

Error Control: It is referred to the methods of error detection and retransmission. The most popular retransmission scheme is known as Automatic-Repeat-Request (ARQ). Three popular ARQ techniques

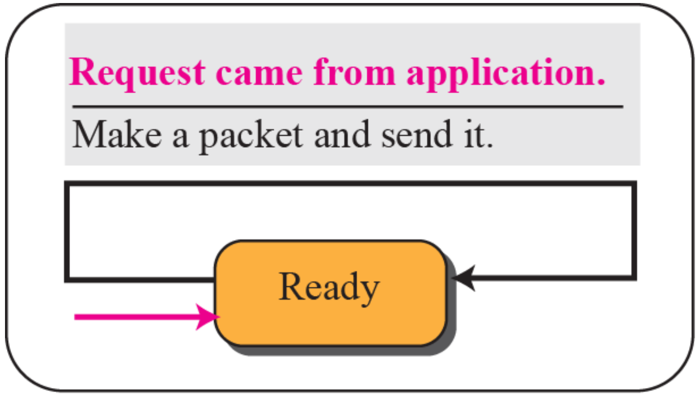


Simple Protocol

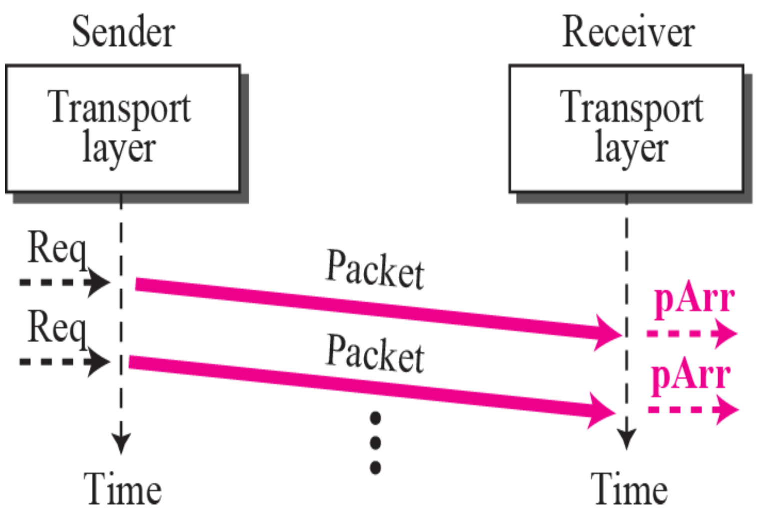


The simple protocol is a connectionless protocol that provides neither flow nor error control.

FSMs (Finite State Machines) for simple protocol



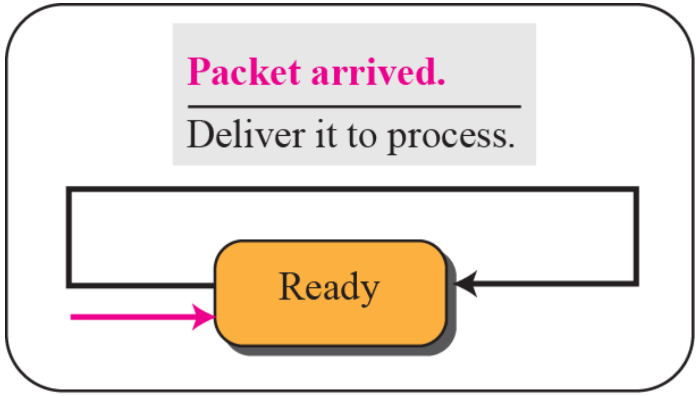
Sender



Example

Events:

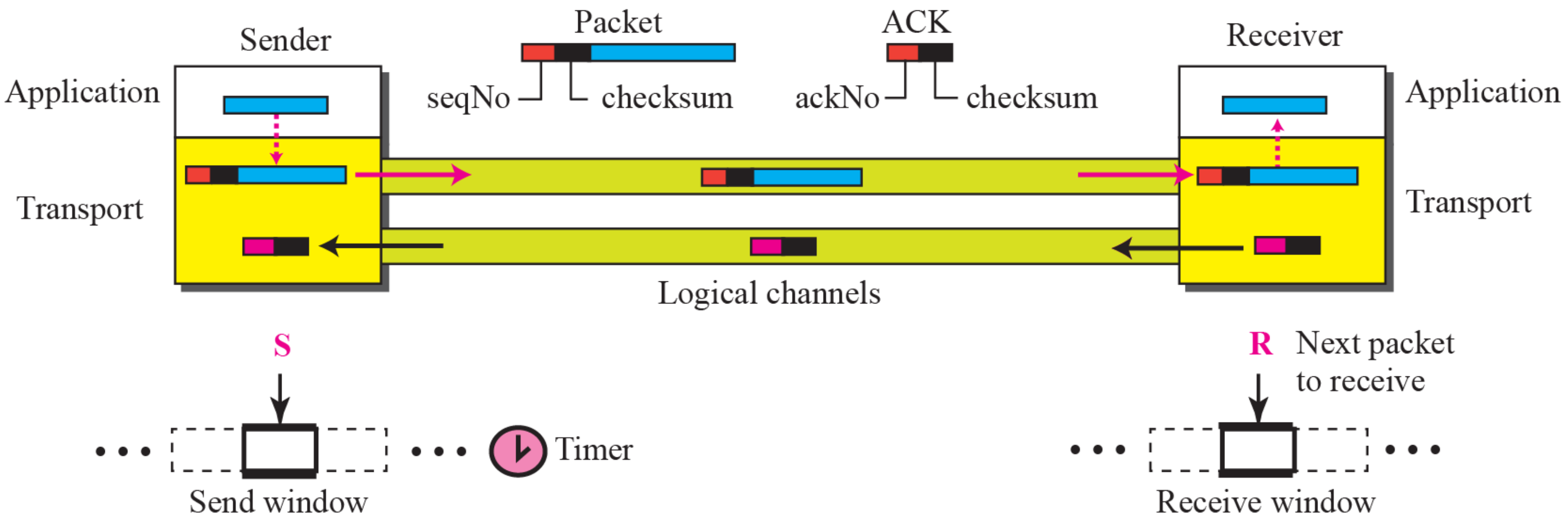
Req: Request came from process
pArr: Packet arrived



Receiver

FSMs are used to represent and control execution flow.

Stop-and-wait protocol



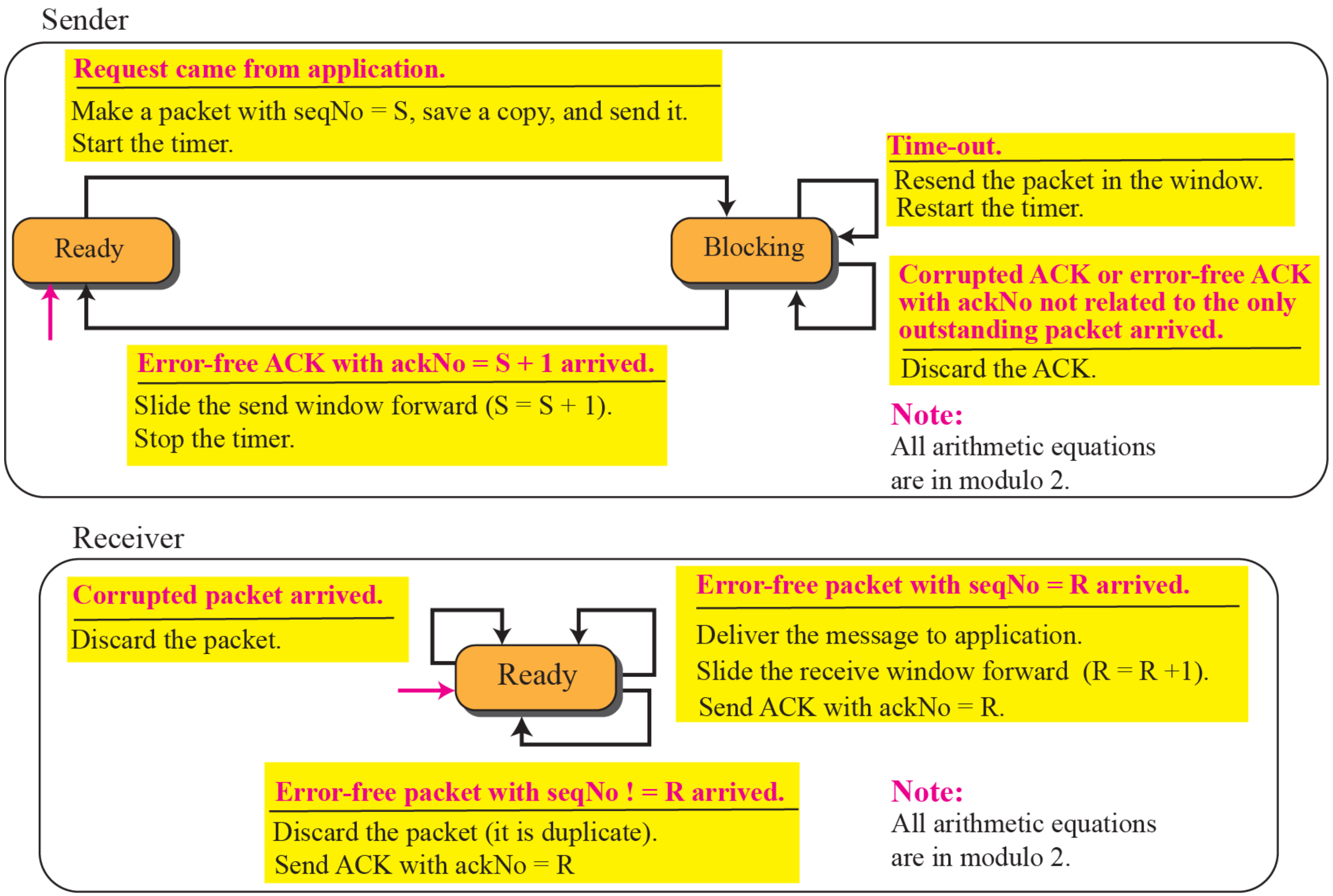
Stop-and-wait protocol Cont..

- In Stop-and-Wait protocol, flow control is achieved by forcing the sender to wait for an acknowledgment, and error control is achieved by discarding corrupted packets and letting the sender resend unacknowledged packets when the timer expires.

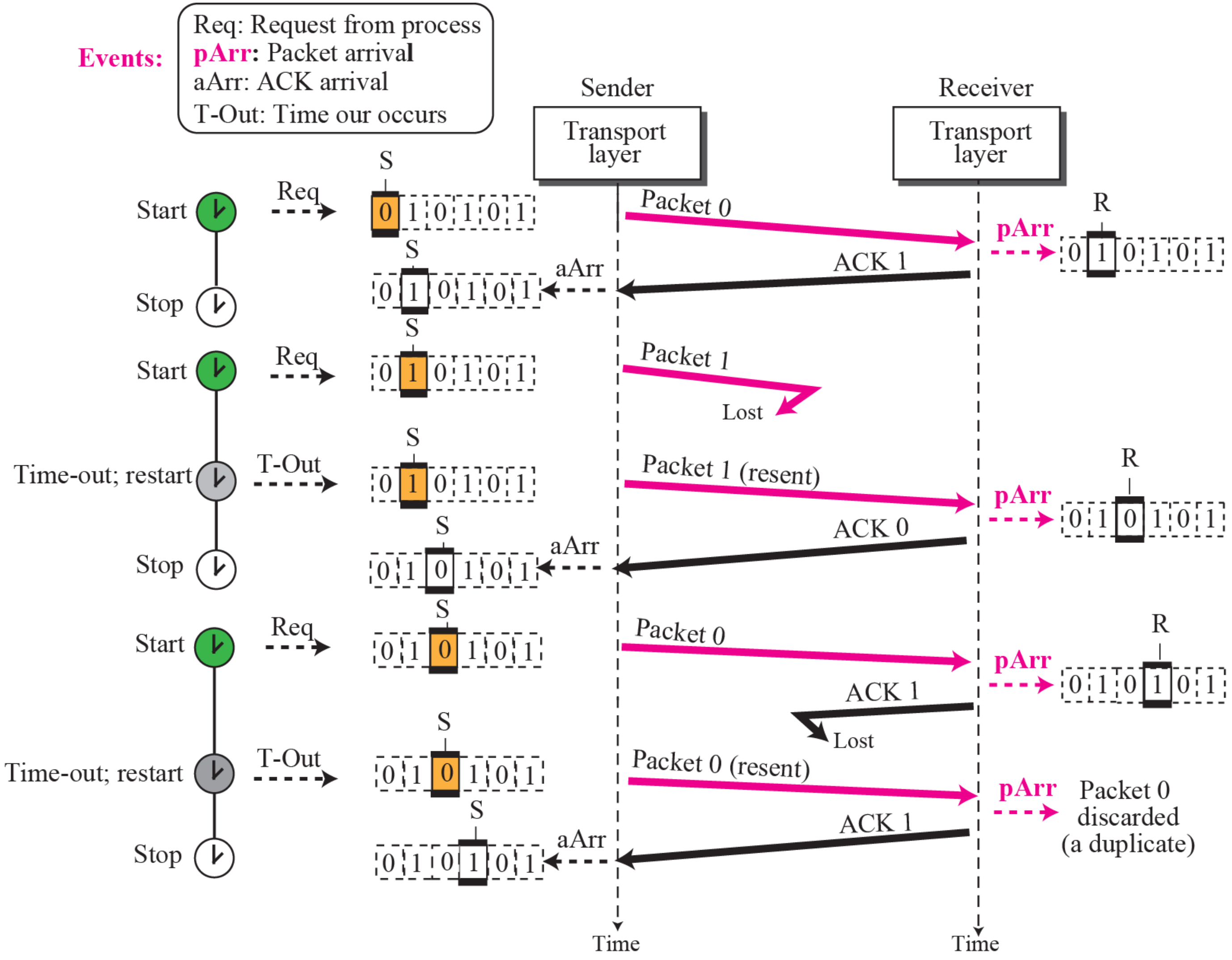
- In the Stop-and-Wait protocol, we can use a 1-bit field to number the packets. The sequence numbers are based on modulo-2 arithmetic.

- In the Stop-and-Wait protocol, the acknowledgment number always announces in modulo-2 arithmetic the sequence number of the next packet expected.

FSMs for stop-and-wait protocol

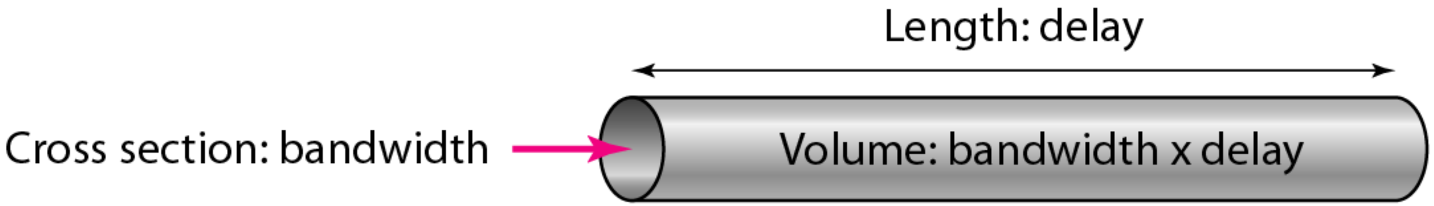


Example



Events:
Req: Request from process
pArr: Packet arrival
aArr: ACK arrival
T-Out: Time our occurs
Sender
Transport layer
Receiver
Transport layer
Start
Req
S
Packet 0
pArr
R
ACK 1
aArr
Stop
Start
Req
Packet 1
Lost
Time-out; restart
T-Out
Packet 1 (resent)
pArr
ACK 0
aArr
Stop
Start
Req
Packet 0
pArr
ACK 1
Lost
Time-out; restart
T-Out
Packet 0 (resent)
pArr
Packet 0 discarded (a duplicate)
ACK 1
aArr
Stop
Time
Time

Bandwidth Delay Product



- The bandwidth-delay product defines the number of bits that can fill the link.

- **BW * RTT:** It's the maximum amount of data that can left the sender before the first acknowledgement was received by the sender. That is, bandwidth * round trip time = the desired window size of sender under perfect conditions.

Example

Assume that, in a Stop-and-Wait system, the bandwidth of the line is 1 Mbps, and 1 bit takes 20 milliseconds to make a round trip. What is the bandwidth-delay product? If the system data packets are 1,000 bits in length, what is the utilization percentage of the link?

Solution

The bandwidth-delay product is $(1 \times 10^6) \times (20 \times 10^{-3}) = 20{,}000$ bits. The system can send 20,000 bits during the time it takes for the data to go from the sender to the receiver and the acknowledgment to come back. However, the system sends only 1,000 bits. We can say that the link utilization is only 1,000/20,000, or 5 percent. For this reason, for a link with a high bandwidth or long delay, the use of Stop-and-Wait wastes the capacity of the link.

What is the utilization percentage of the link in above example if we have a protocol that can send up to 15 packets before stopping and worrying about the acknowledgments?

Solution

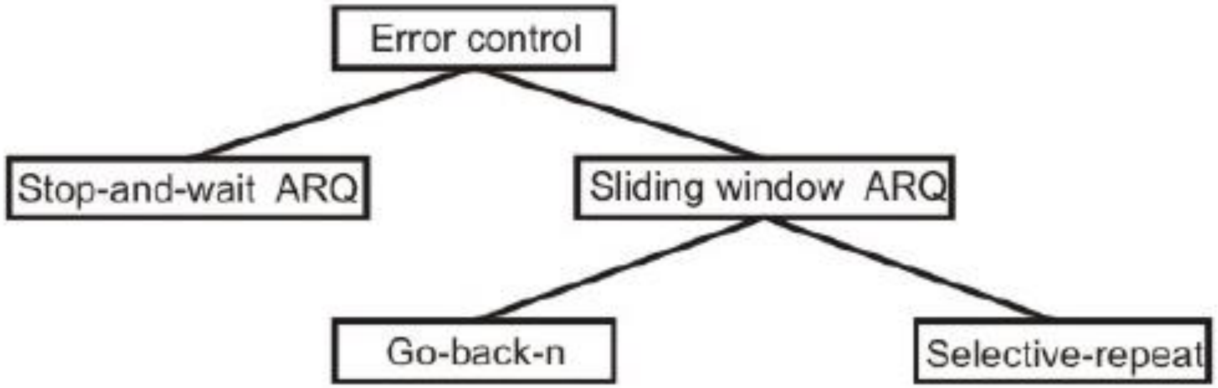
The bandwidth-delay product is still 20,000 bits. The system can send up to 15 packets or 15,000 bits during a round trip. This means the utilization is 15,000/20,000, or 75 percent. Of course, if there are damaged packets, the utilization percentage is much less because packets have to be resent.

Flow Control and Error Control Protocol Cont..

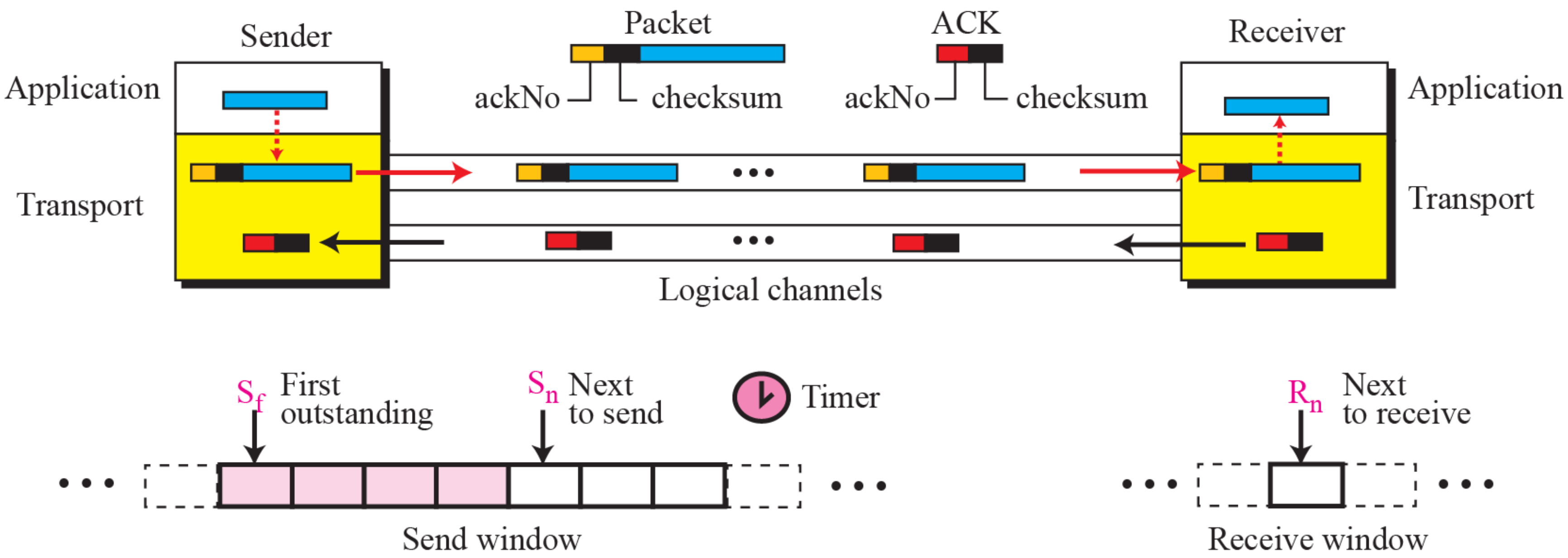
Flow control: It coordinates amount of data that can be sent before receiving an ack.

- Stop and Wait
- Sliding window

Error Control: It refers to the methods of error detection and retransmission. The most popular retransmission scheme is known as Automatic-Repeat-Request (ARQ). Three popular ARQ techniques



Go-Back-N protocol



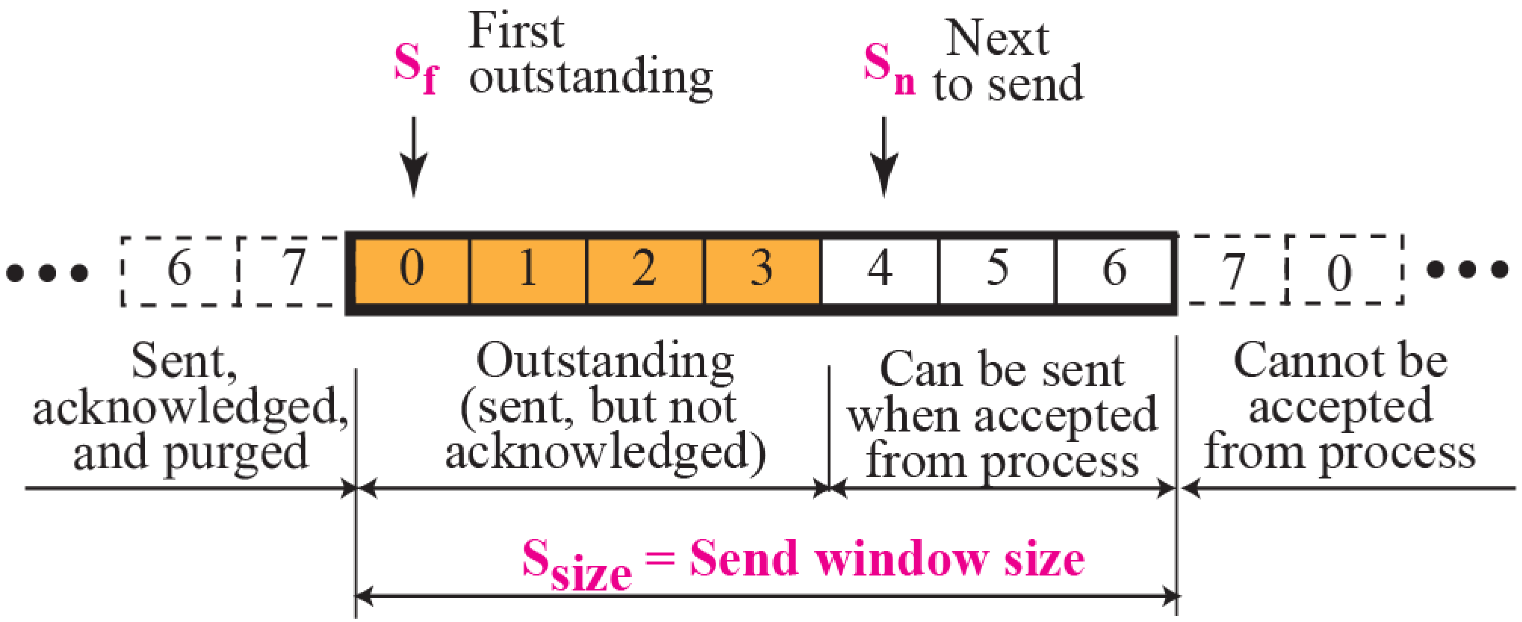
When the sender doesn’t receive ACK, it retransmits the packet in error plus all the succeeding packets. Hence, the name of the protocol is go-back-N ARQ.

Go-Back-N protocol Cont..

- In the Go-Back-N Protocol, the sequence numbers are modulo 2^m, where m is the size of the sequence number field in bits.

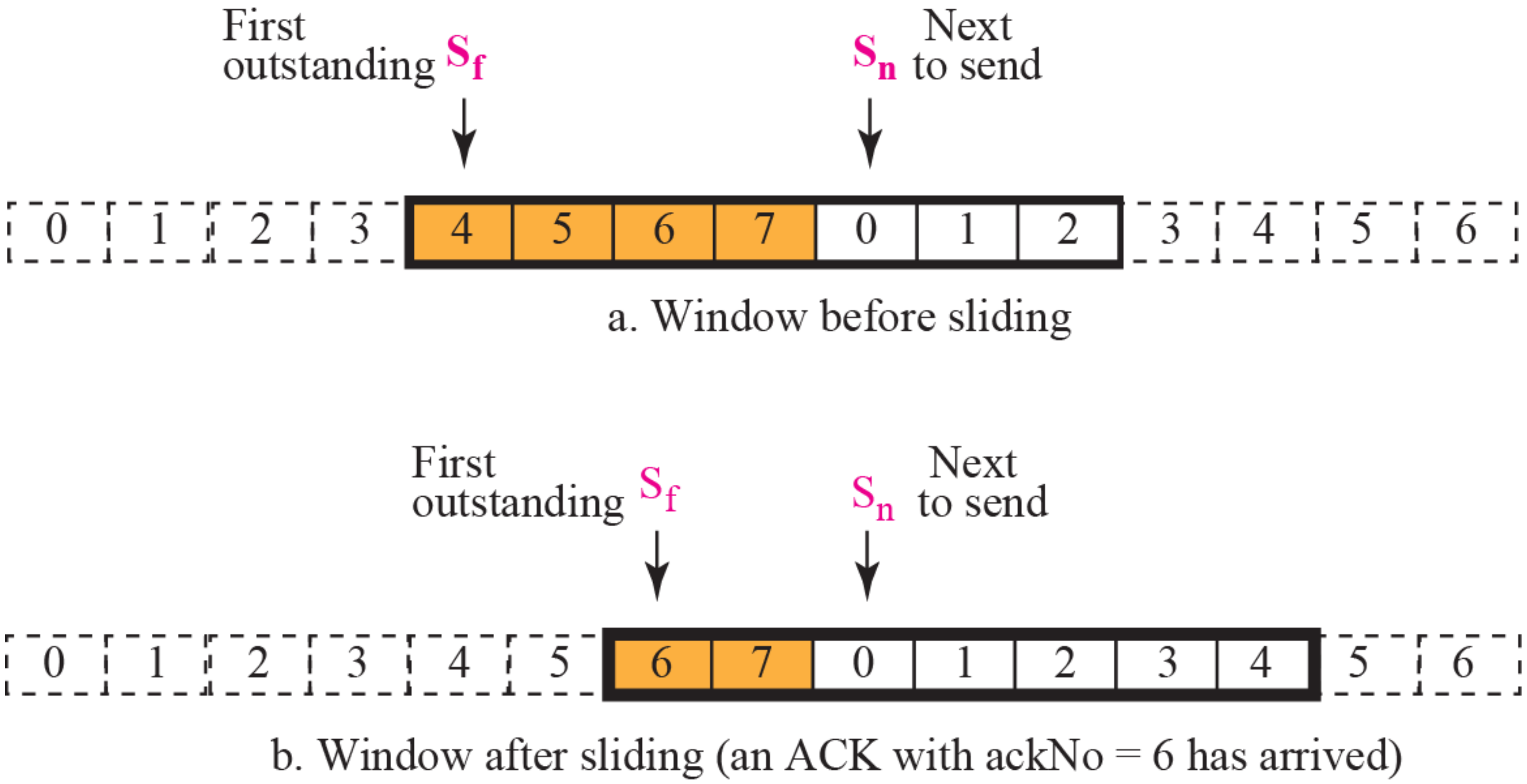
- In the Go-Back-N protocol, the acknowledgment number is cumulative and defines the sequence number of the next packet expected to arrive.

Send window for Go-Back-N

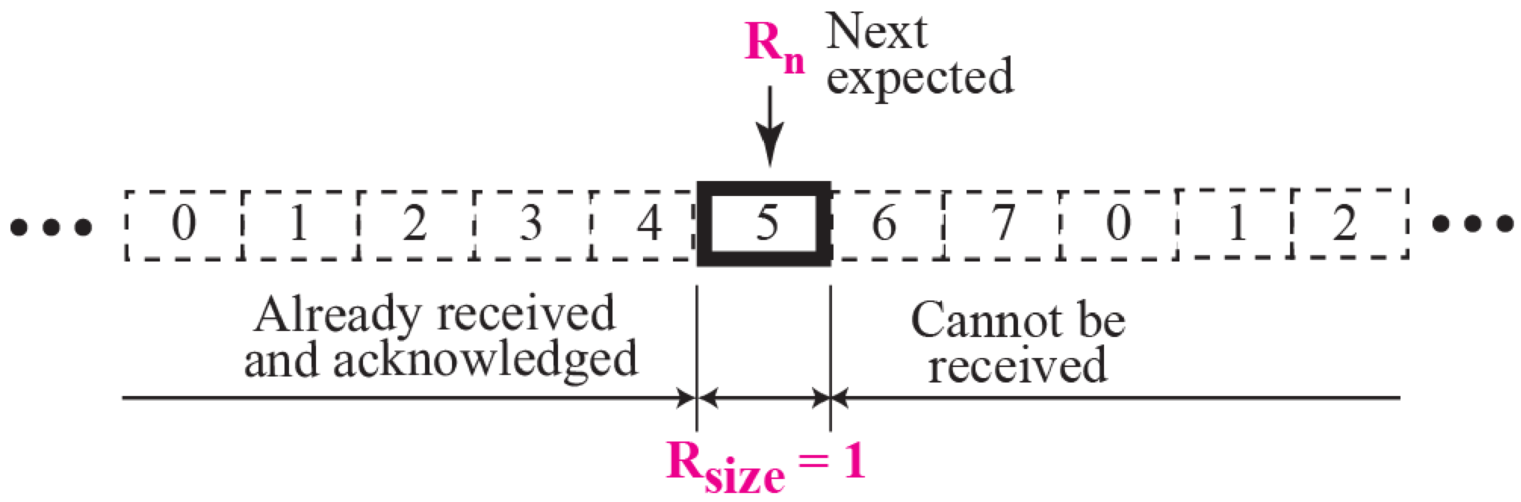


- *The send window is an abstract concept defining an imaginary box of maximum size = $2^m - 1$ with three variables: S_f, S_n, and S_{size}.*
- *The send window can slide one or more slots when an error-free ACK with ack No. between S_f and S_n (in modular arithmetic) arrives.*

Sliding the send window

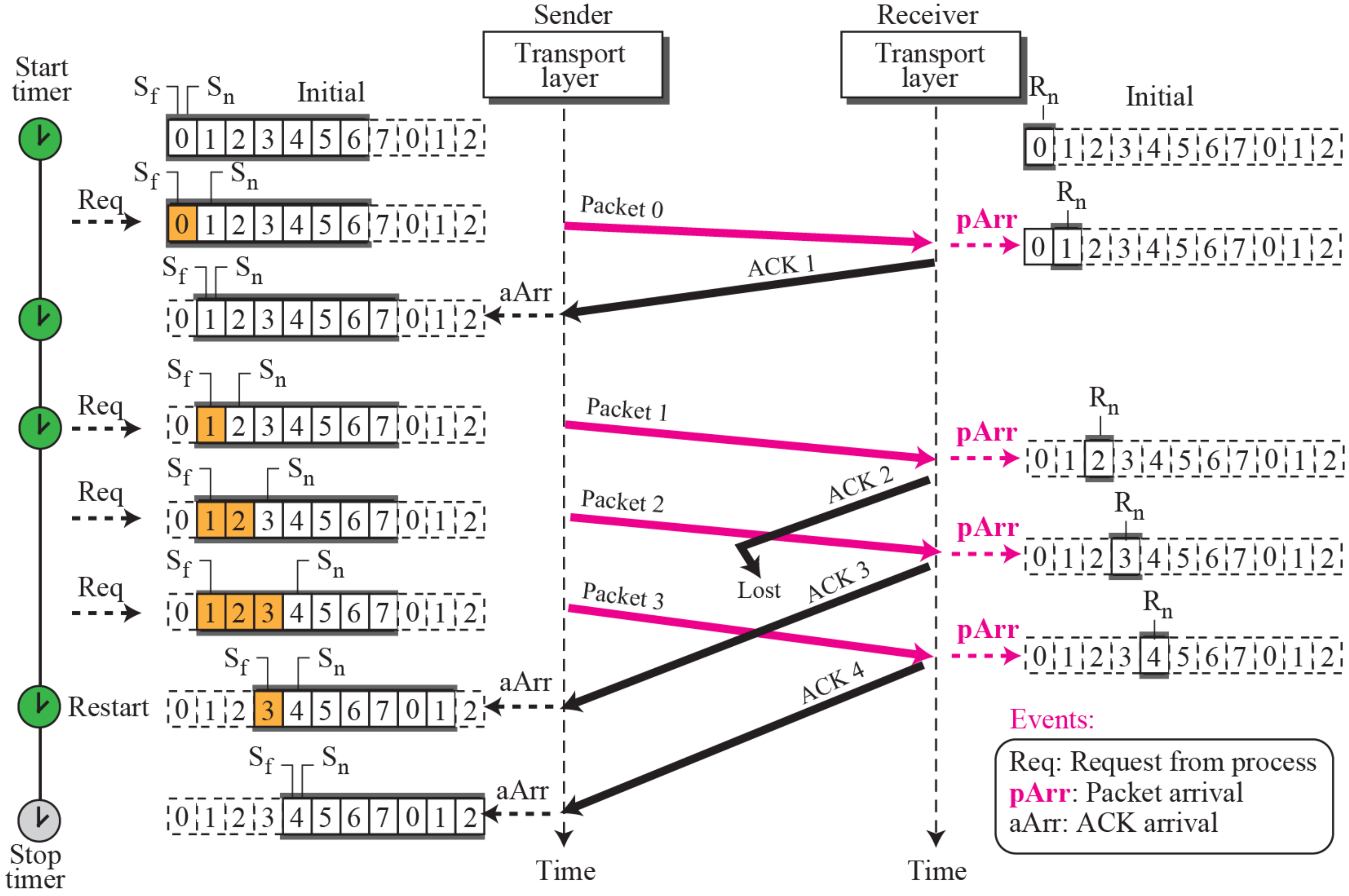


Receive window for Go-Back-N



- The receive window is an abstract concept defining an imaginary box of size 1 with one single variable R_n.
- The window slides when a correct packet has arrived; sliding occurs one slot at a time.
- *In the Go-Back-N protocol, the size of the send window must be less than 2^m; the size of the receive window is always 1.*

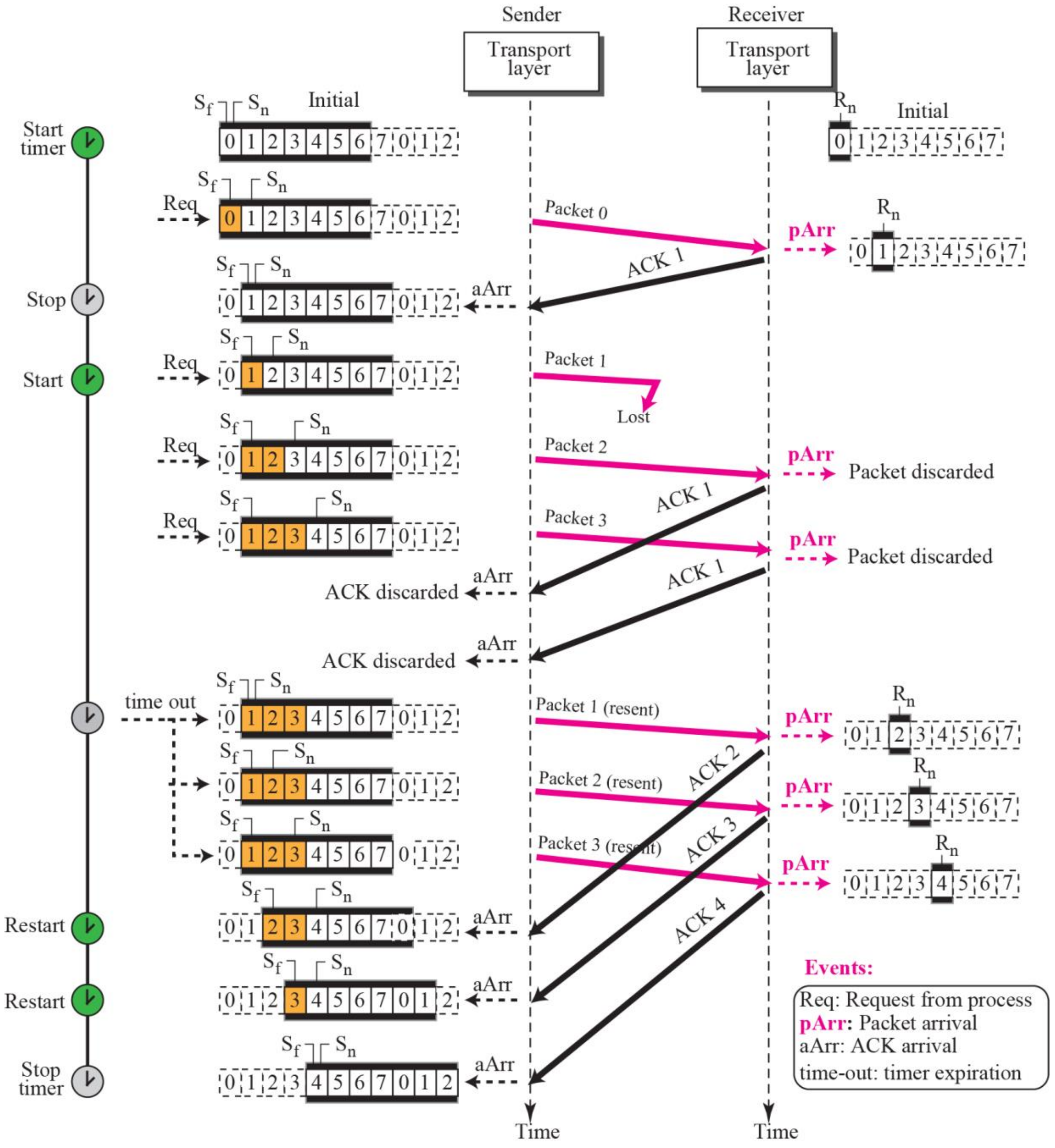
Example



Cumulative acknowledgments can help

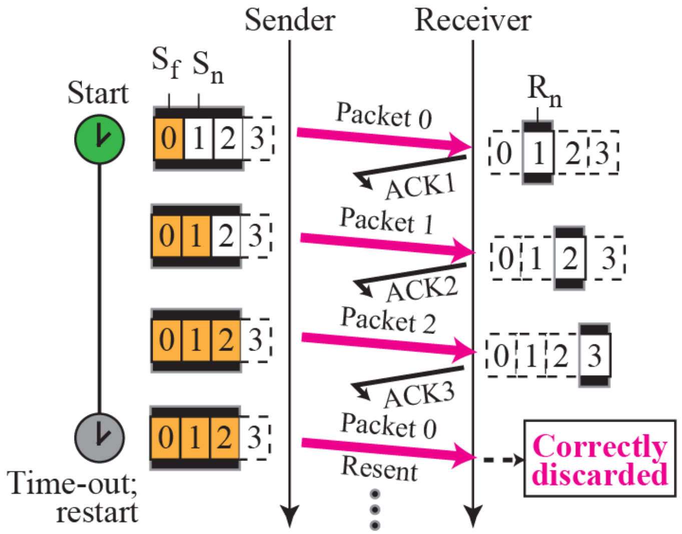
TCP/IP Protocol Suite

Example 2

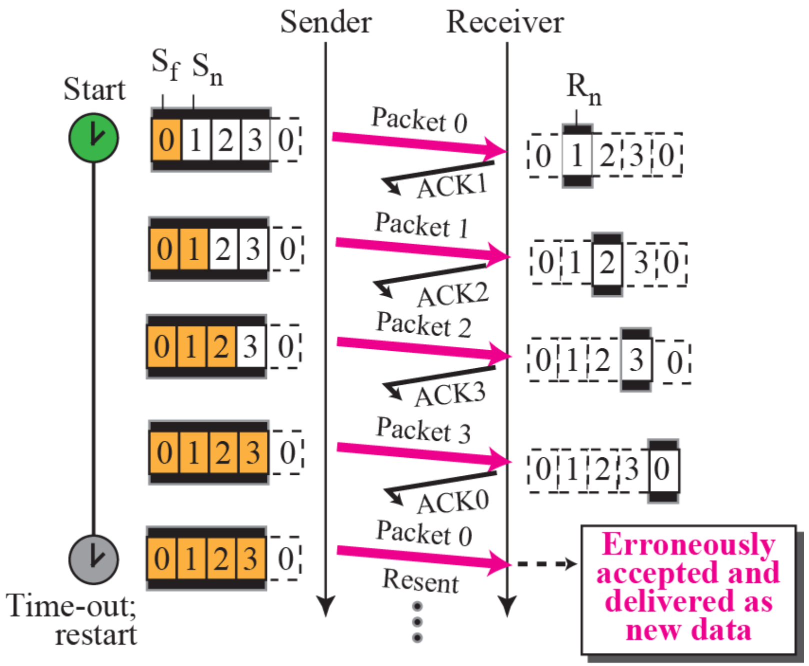


TCP/IP Protocol Suite

Send window size for Go-Back-N



a. Send window of size < 2^m



b. Send window of size = 2^m

FSMs for Go-Back-N