Data Communications And Networking fourth Edition

Forouzan

Chapter 11

Data Link Control

Data Link Control

The two main functions of the data link layer are :-

1-data link control (deals with the design and procedures for communication between two adjacent nodes: node-to-node communication).

2- media access control (deals how share the link).

Data link control functions include framing, flow and error control, and software implemented protocols that provide smooth and reliable transmission of frames between nodes.

To implement data link control, we need protocols.

protocol :- is a set of rules that need to be implemented in software and run by the two nodes involved in data exchange at the data link layer.

Data transmission in the physical layer means moving bits in the form of a signal from the source to the destination.

The physical layer provides bit synchronization to ensure that the sender and receiver use the same bit durations and timing.

11-1 FRAMING

The data link layer needs to pack bits into frames, so that each frame is distinguishable from another. Our postal system practices a type of framing. The simple act of inserting a letter into an envelope separates one piece of information from another; the envelope serves as the delimiter.

Topics discussed in this section:

Fixed-Size Framing – no boundaries for frames, size used as the delimeter
Variable-Size Framing – define begining and end of frame, character oriented or bit oriented approach

Framing in the data link layer separates a message from one source to a destination, or from other messages to other destinations, by adding a sender address and a destination address.

The destination address defines where the packet is to go; the sender address helps the recipient acknowledge the receipt.

Fixed-Size Framing

Frames can be of fixed or variable size. In fixed-size framing, there is no need for defining the boundaries of the frames; the size itself can be used as a delimiter.

An example of this type of framing is the ATM wide-area network, which uses frames of fixed size called cells.

ATM: Asynchronous Transfer Mode(connection oriented, high-speed network technology that is used in both LAN and WAN over optical fiber and operates upto gigabit speed.

Variable-Size Framing

We concerns with variable-size framing, prevalent in local area networks.

In variable-size framing, we need a way to define the end of the frame and the beginning of the next.

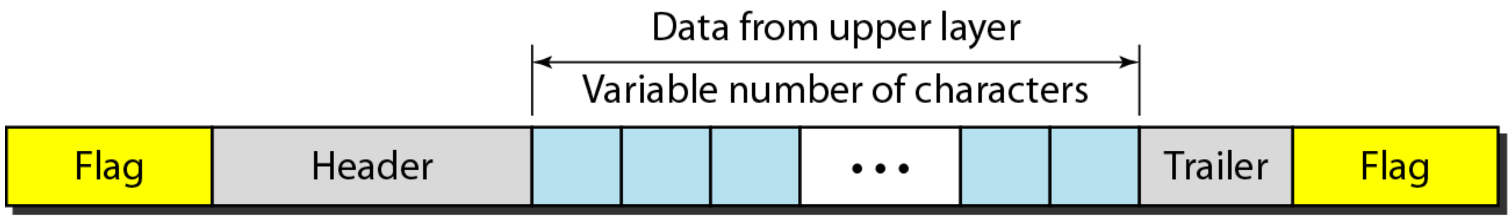
Two approaches were used for this purpose:

a character-oriented approach and a bit-oriented approach.

Character-Oriented Protocols

In a character-oriented protocol, data to be carried are 8-bit characters from a coding system such as ASCII . The header, which normally carries the source and destination addresses and other control information, and the trailer, which carries error detection or error correction redundant bits, are also multiples of 8 bits.

Figure 11.1 *A frame in a character-oriented protocol*



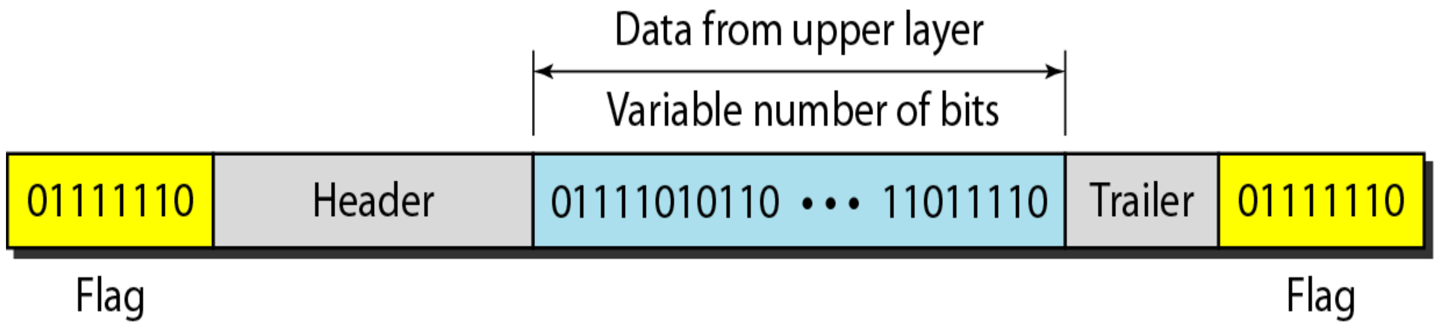
To separate one frame from the next, an 8-bit (1-byte) **flag** is added at the beginning and the end of a frame. The flag, composed of protocol-dependent special characters, signals the start or end of a frame. Figure 11.1 shows the format of a frame in a character-oriented protocol

Bit-Oriented Protocols

In a bit-oriented protocol, the data section of a frame is a sequence of bits to be interpreted by the upper layer as text, graphic, audio, video, and so on. However, in addition to headers (and possible trailers), we still need a delimiter to separate one frame from the other.

Most protocols use a special 8-bit pattern flag 01111110 as the delimiter to define the beginning and the end of the frame, as shown in Figure 11.3.

Figure 11.3 *A frame in a bit-oriented protocol*



11-2 FLOW AND ERROR CONTROL

The most important responsibilities of the data link layer are flow control and error control. Collectively, these functions are known as data link control.

Topics discussed in this section:

Flow Control
Error Control

Flow control refers to a set of procedures used to restrict the amount of data that the sender can send before waiting for acknowledgment.

Each receiving device has a block of memory, called a *buffer, reserved for storing incoming* data until they are processed. **If** the buffer begins to fill up, the receiver must be able to tell the sender to halt transmission until it is once again able to receive.

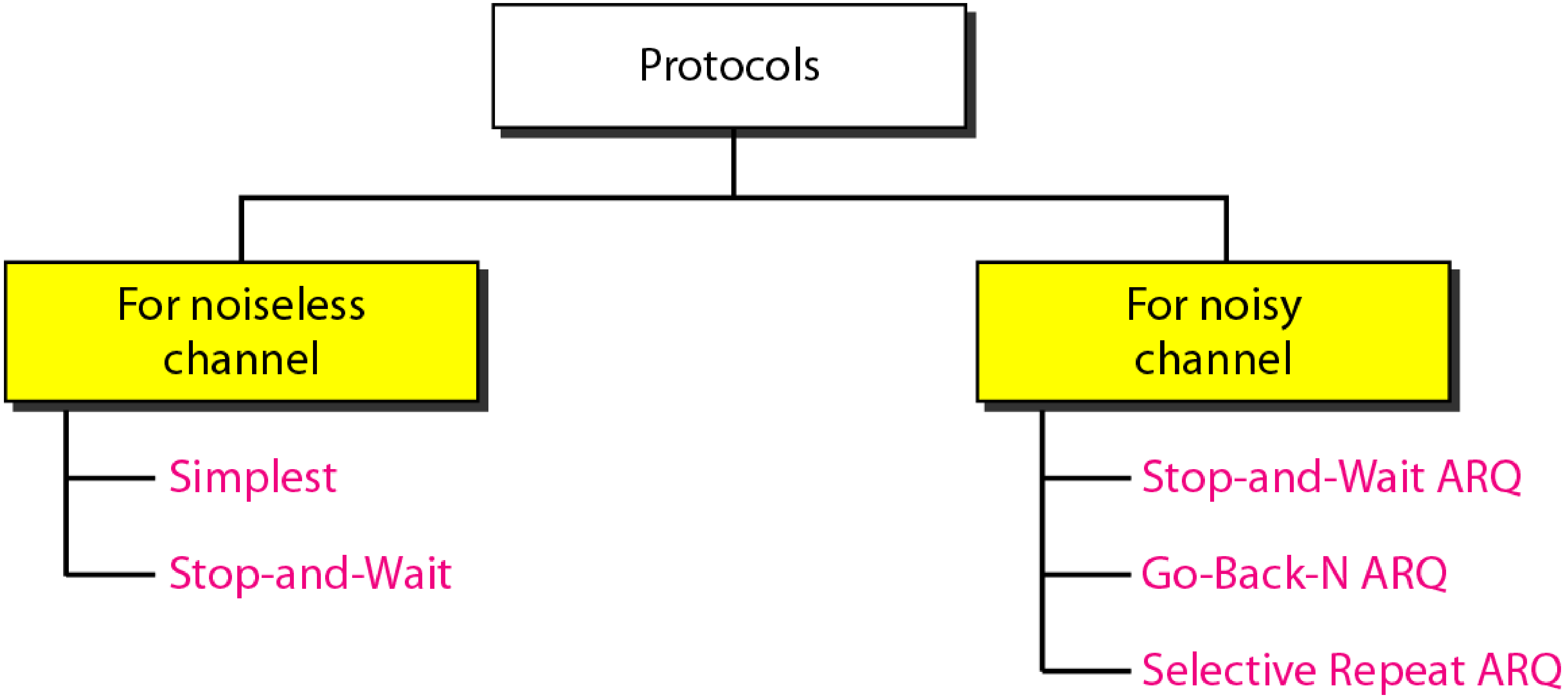
Error control is both error detection and error correction. It allows the receiver to tell the sender of any frames lost or damaged in transmission and coordinates the retransmission of those frames by the sender.

Error control in the data link layer is based on automatic repeat request (ARQ), which is the retransmission of data.

11-3 PROTOCOLS

Now let us see how the data link layer can *combine framing, flow control, and error control* to achieve the delivery of data from one node to another. The protocols are normally implemented in software by using one of the common programming languages. To make our discussions language-free, we have written in pseudocode a version of each protocol that concentrates mostly on the procedure instead of deeply the details of language rules.

Figure 11.5 *classification of protocols discussed in this chapter*



11-4 NOISELESS CHANNELS

Let us first assume we have an ideal channel in which no frames are lost, duplicated, or corrupted. We introduce two protocols for this type of channel.

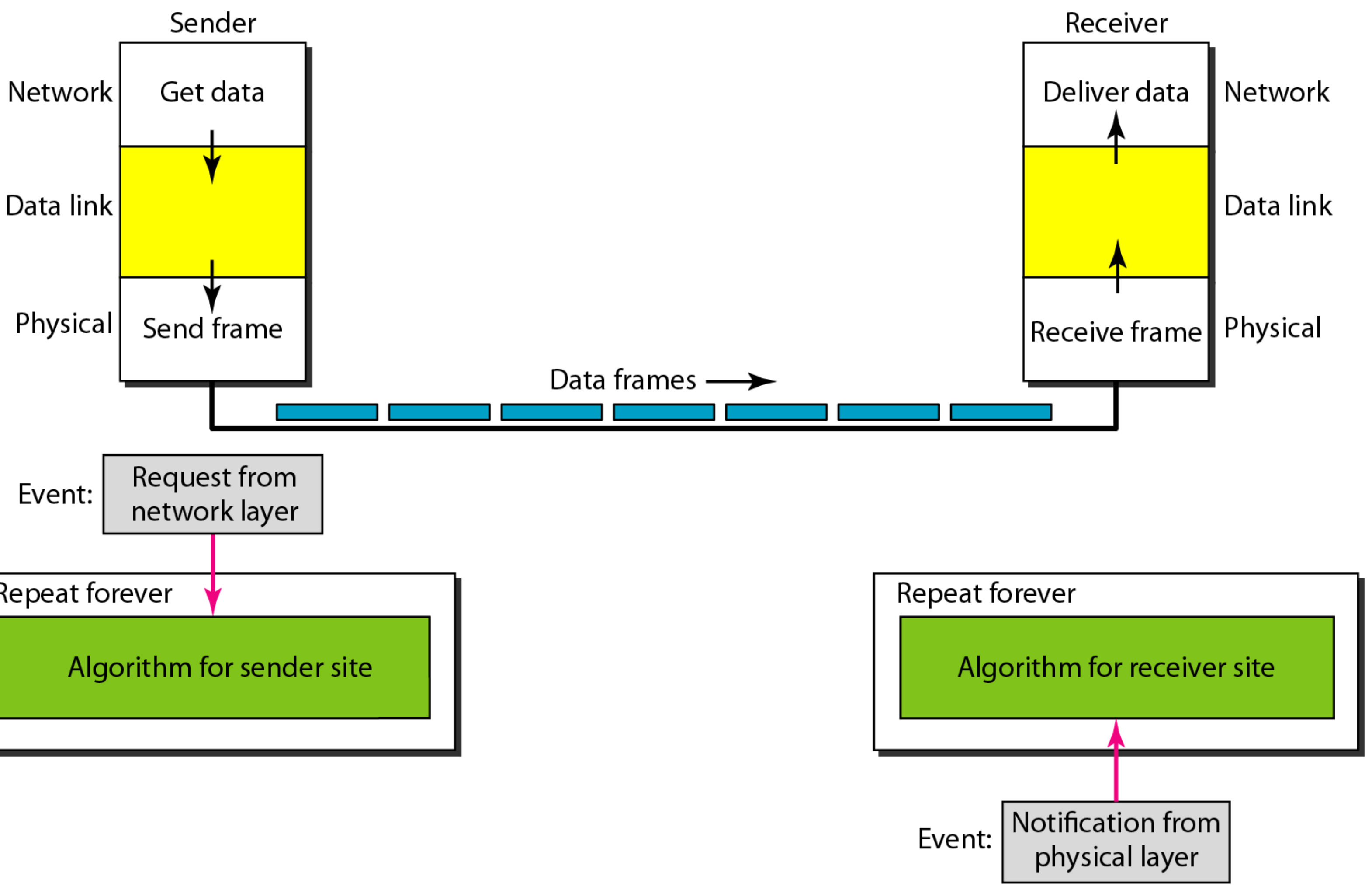
Topics discussed in this section:

Simplest Protocol – has no flow or error control
Stop-and-Wait Protocol – sender sends one frame, stops until it receives agree from receiver and then sends the next frame

1-Simplest Protocol

- Our first protocol, which we call the Simplest Protocol, is one that has no flow or error control. Like other protocols, it is a unidirectional protocol in which *data frames are traveling in only one direction*-from the sender to receiver.
- The receiver can immediately handle any frame it receives with a processing time that is small enough to be negligible.
- The data link layer of the receiver immediately removes the header from the frame and hands the data packet to network layer, which can also accept the packet immediately.
- In other words, the receiver can never be fill out with incoming frames.

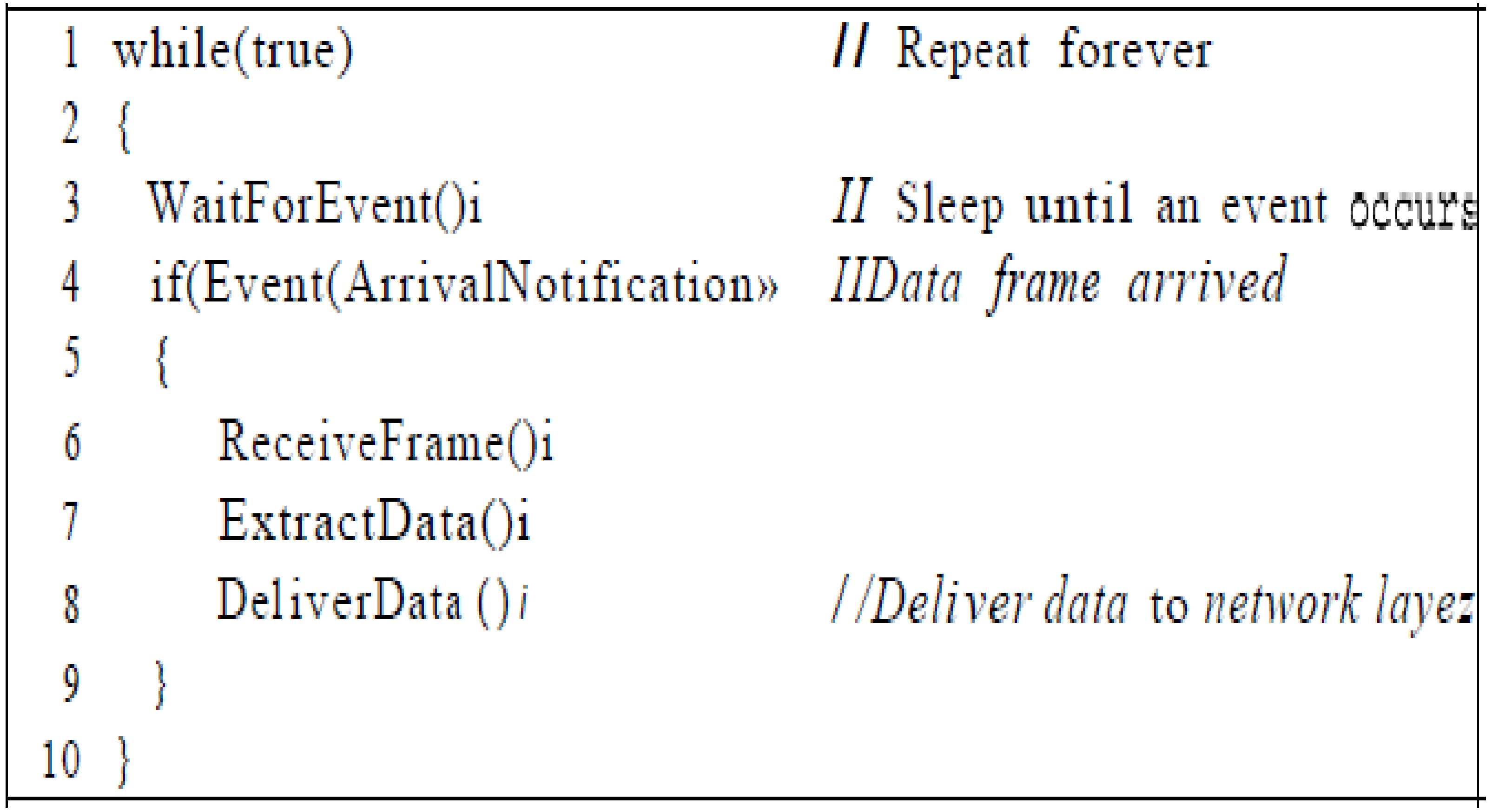
Figure 11.6 *The design of the simplest protocol with no flow or error control*



Algorithm 11.1 *Sender-site algorithm for the simplest protocol*

```
while (true)                      // Repeat forever
{
  WaitForEvent()i                 // Sleep until an event occurs
  if(Event(RequestToSend»         //There is a packet to send
  {
      GetData()i
      MakeFrame()i
      SendFrame()i                //Send the frame
  }
}
```

Algorithm 11.2 *Receiver-site algorithm for the simplestprotocol*

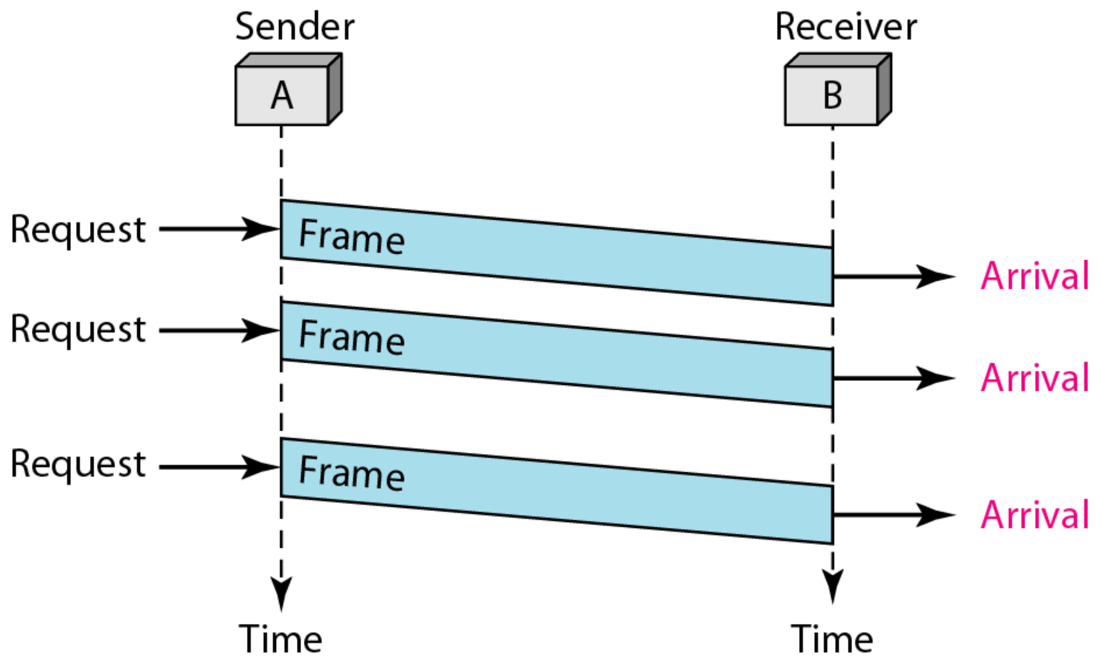


```
while(true)                        // Repeat  forever
{
  WaitForEvent()i                  II Sleep until an event occurs
  if(Event(ArrivalNotification»    IIData  frame  arrived
  {
      ReceiveFrame()i
      ExtractData()i
      DeliverData ()i              //Deliver data to network layez
  }
}
```

Example 11.1

Figure 11.7 shows an example of communication using this protocol. It is very simple. The sender sends a sequence of frames without even thinking about the receiver. To send three frames, three events occur at the sender site and three events at the receiver site. Note that the data frames are shown by tilted boxes; the height of the box defines the transmission time difference between the first bit and the last bit in the frame.

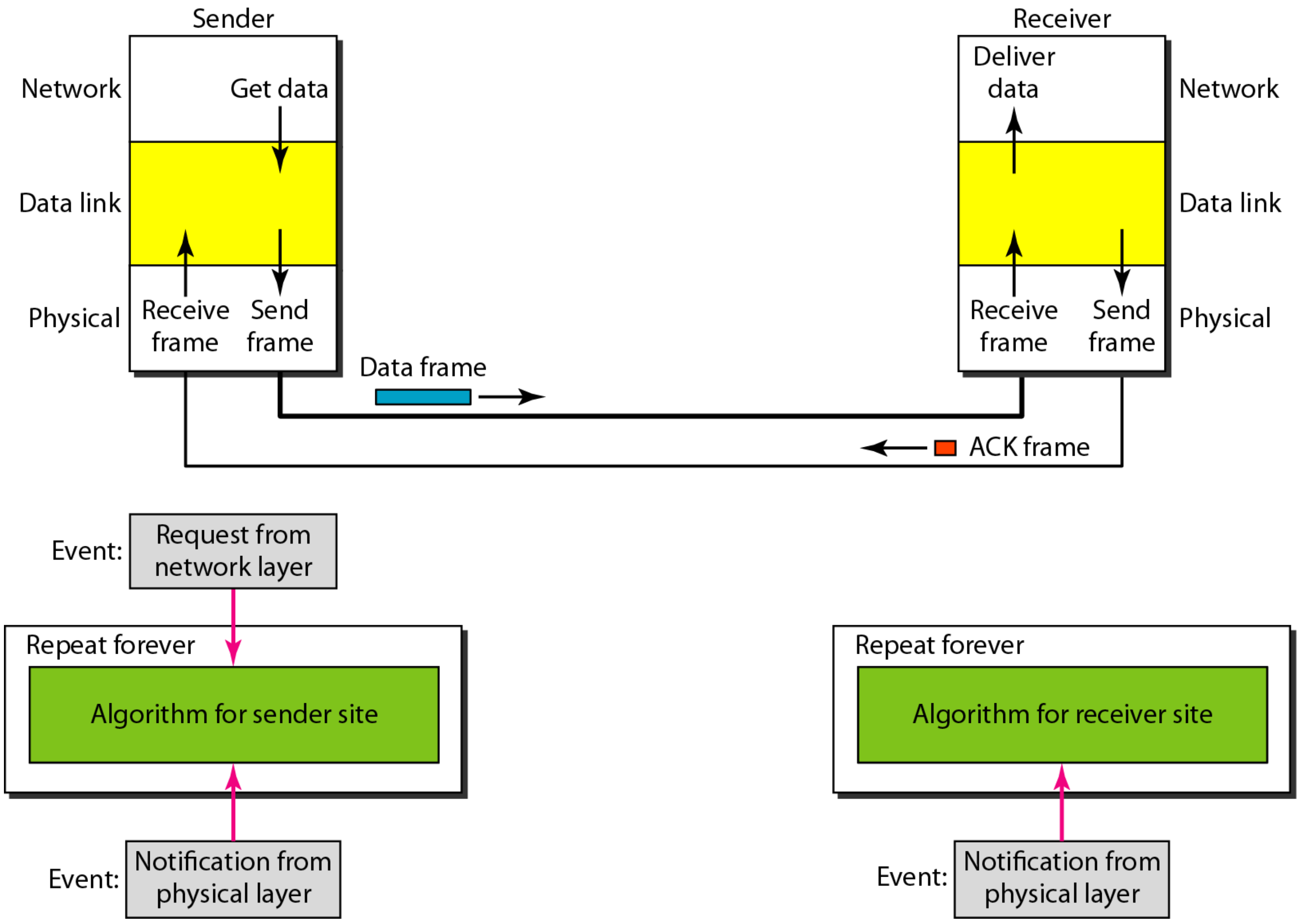
Figure 11.7 *Flow diagram for Example 11.1*



Stop-and-Wait Protocol

- If data frames arrive at the receiver site faster than they can be processed, the frames must be stored until their use. Normally, the receiver does not have enough storage space, especially if it is receiving data from many sources.
- We need to tell the sender to slow down. There must be feedback from the receiver to the sender.
- The sender sends one frame, stops until it receives agreement the receiver (okay to go ahead), and then sends the next frame. We still have unidirectional communication for data frames, but auxiliary ACK frames (simple tokens of acknowledgment) travel from the other direction. We add flow control to our previous protocol.

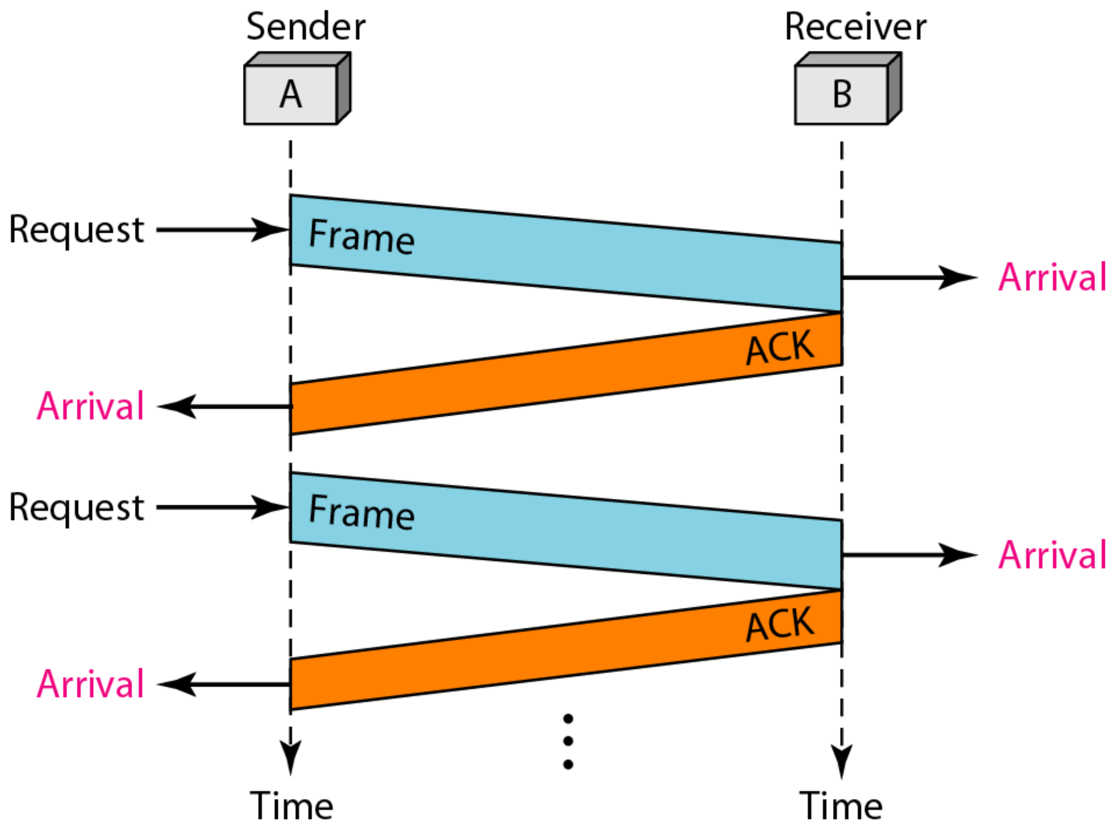
Figure 11.8 *Design of Stop-and-Wait Protocol*



Example 11.2

Figure 11.7 shows an example of communication using this protocol. It is still very simple. The sender sends one frame and waits for feedback from the receiver. When the ACK arrives, the sender sends the next frame. Note that sending two frames in the protocol involves the sender in four events and the receiver in two events.

Figure 11.7 *Flow diagram for Example 11.2*



11-5 NOISY CHANNELS

Although the Stop-and-Wait Protocol gives us an idea of how to add flow control to its predecessor, noiseless channels are nonexistent. We discuss three protocols in this section that use error control.

Topics discussed in this section:

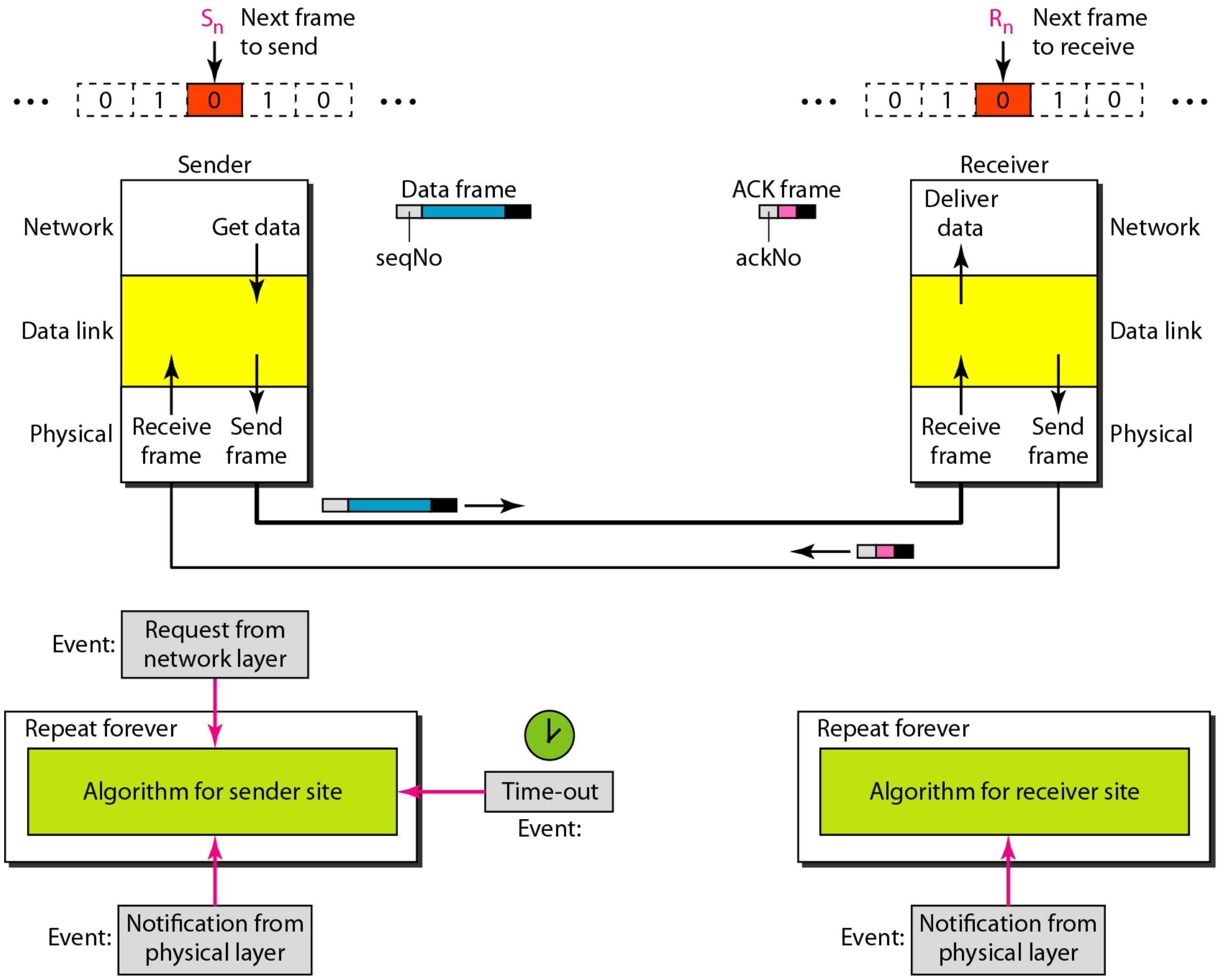
Stop-and-Wait Automatic Repeat Request(ARQ)
Go-Back-N Automatic Repeat Request
Selective Repeat Automatic Repeat Request

Error correction in Stop-and-Wait ARQ is done by keeping a copy of the sent frame and retransmitting of the frame when the timer expires.

In Stop-and-Wait ARQ, we use sequence numbers to number the frames.
The sequence numbers are based on modulo-2 arithmetic.

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

Figure 11.10 *Design of the Stop-and-Wait ARQ Protocol*



Example 11.3

Figure 11.11 shows an example of Stop-and-Wait ARQ. Frame 0 is sent and acknowledged. Frame 1 is lost and resent after the time-out. The resent frame 1 is acknowledged and the timer stops. Frame 0(second) is sent and acknowledged, but the acknowledgment is lost. The sender has no idea if the frame or the acknowledgment is lost, so after the time-out, it resends frame 0, which is

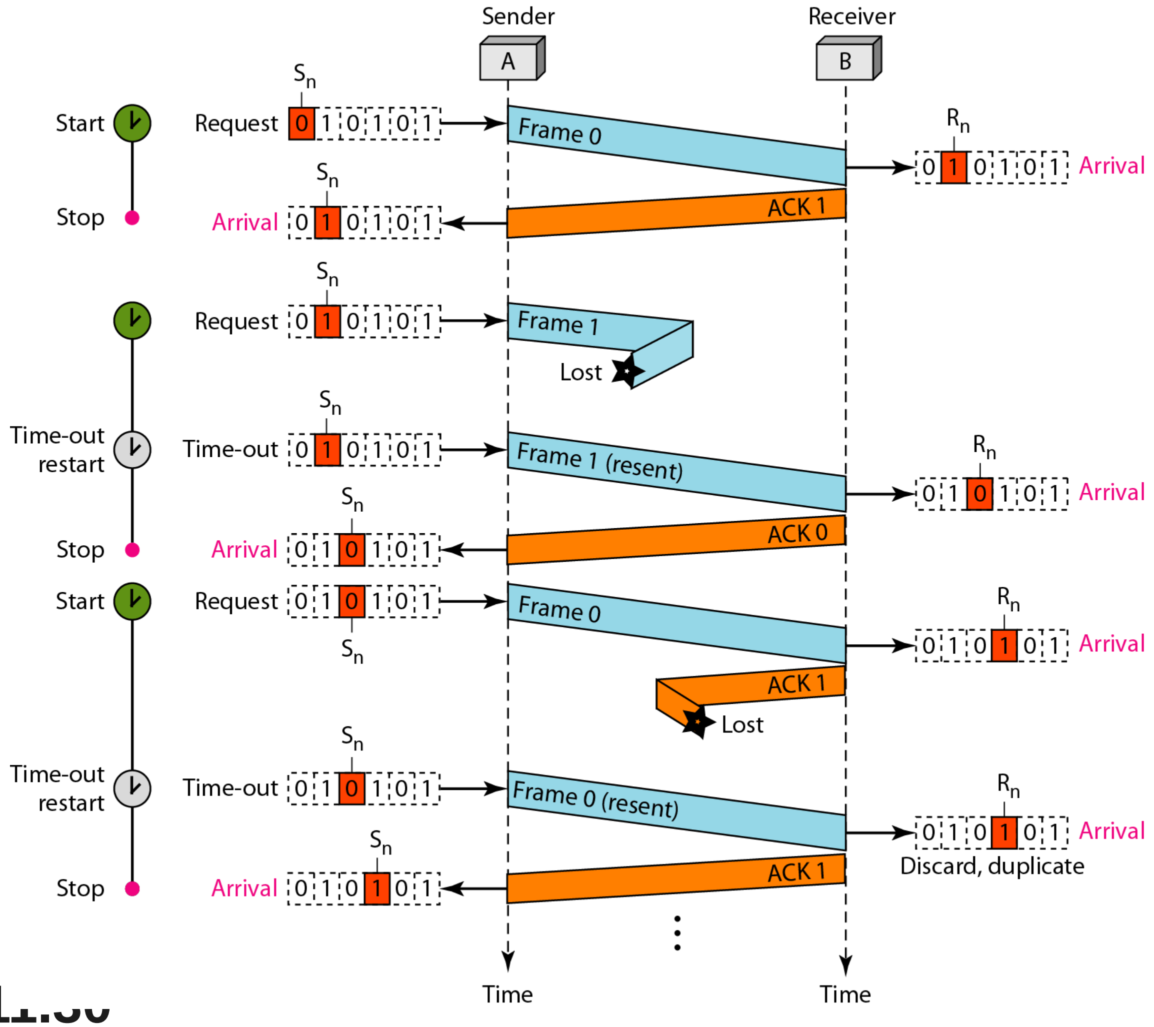


Figure 11.11 ***Flow diagram for Example 11.3***

Pipelining

- In networking and in other areas, a task is often begun before the previous task has ended. This is known as pipelining. There is no pipelining in Stop-and-Wait ARQ because we need to wait for a frame to reach the destination and be acknowledged before the next frame can be sent.

- Pipelining improves the efficiency of the transmission if the number of bits in transition is large with respect to the bandwidth-delay .

Go-Back-N Automatic Repeat Request

- To improve the efficiency of transmission (filling the pipe), multiple frames must be in transition while waiting for acknowledgment. In other words, we need to let more than one frame be outstanding to keep the channel busy while the sender is waiting for acknowledgment.

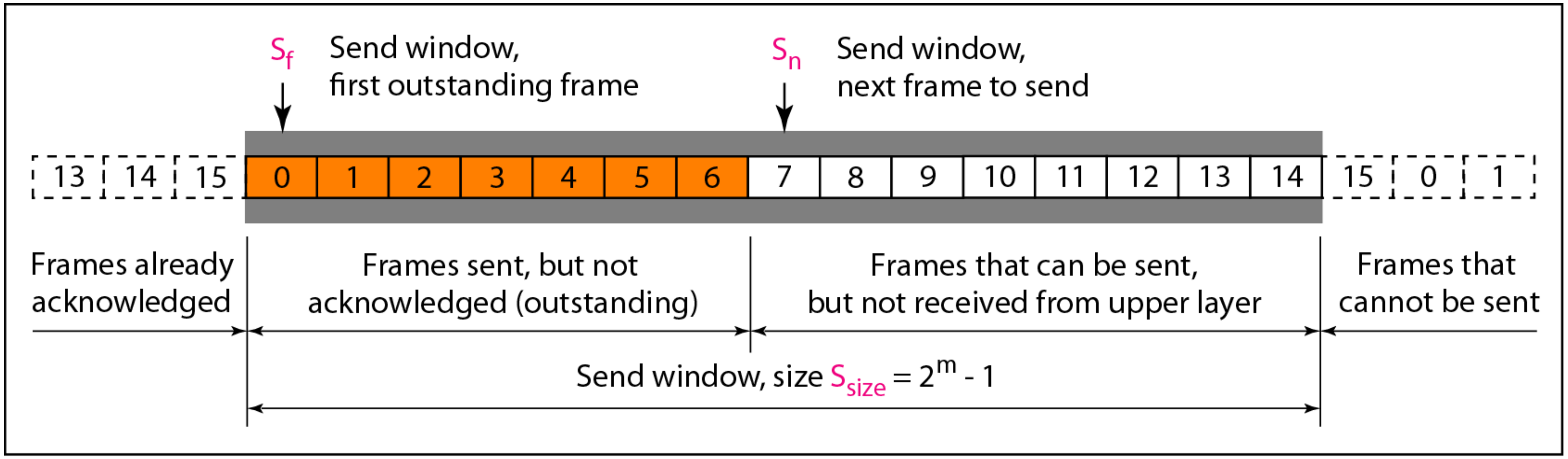
- In this protocol we can send several frames before receiving acknowledgments; we keep a copy of these frames until the acknowledgments arrive, Thus need sequence number for frames.

For example, **if *m is 4, the only sequence numbers are 0* through 15 inclusive. However, we can repeat the sequence.**

Note

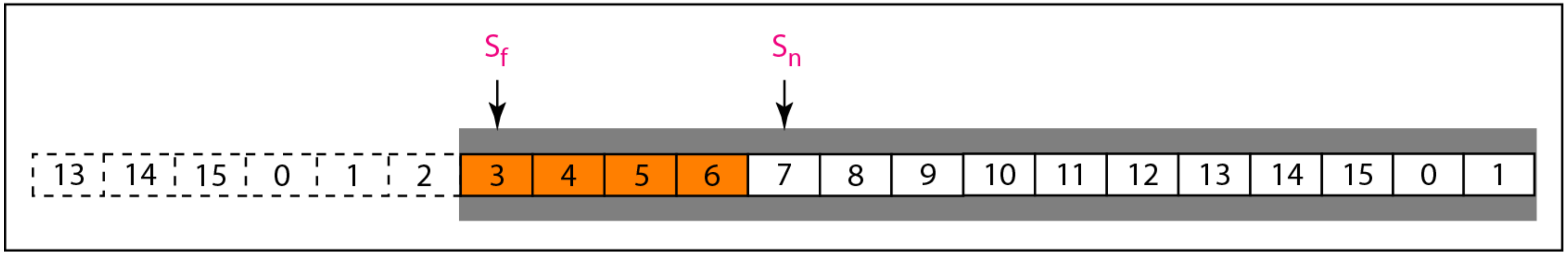
In the Go-Back-N Protocol, the sequence numbers are modulo 2^m, where m is the size of the sequence number field in bits.

Figure 11.12 *Send window for Go-Back-N ARQ*



S_f
Send window, first outstanding frame
S_n
Send window, next frame to send
13 14 15 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 0 1
Frames already acknowledged
Frames sent, but not acknowledged (outstanding)
Frames that can be sent, but not received from upper layer
Frames that cannot be sent
Send window, size $S_{size} = 2^m - 1$

a. Send window before sliding



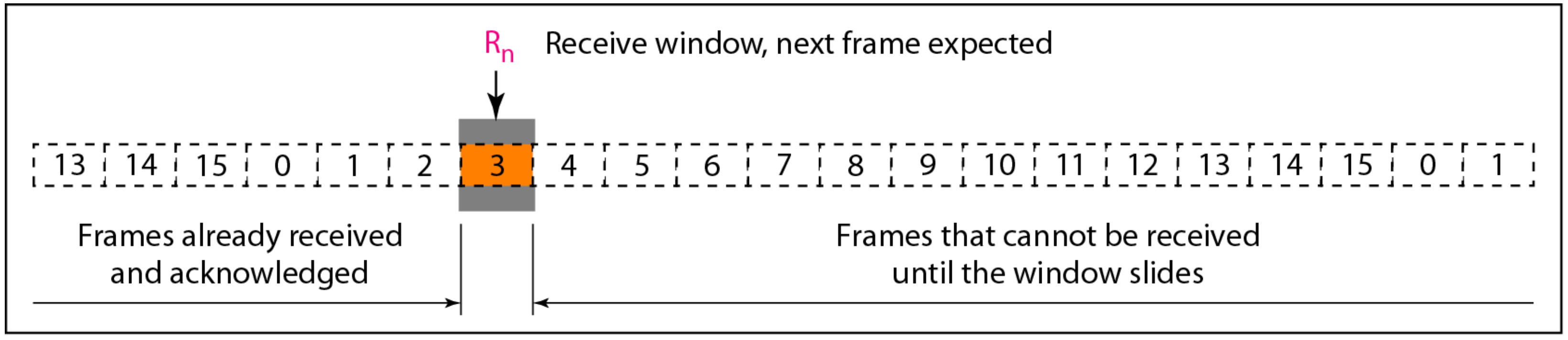
b. Send window after sliding

The send window is an abstract concept defining an imaginary box of size $2^m - 1$ with three variables: S_f, S_n, and S_{size}.

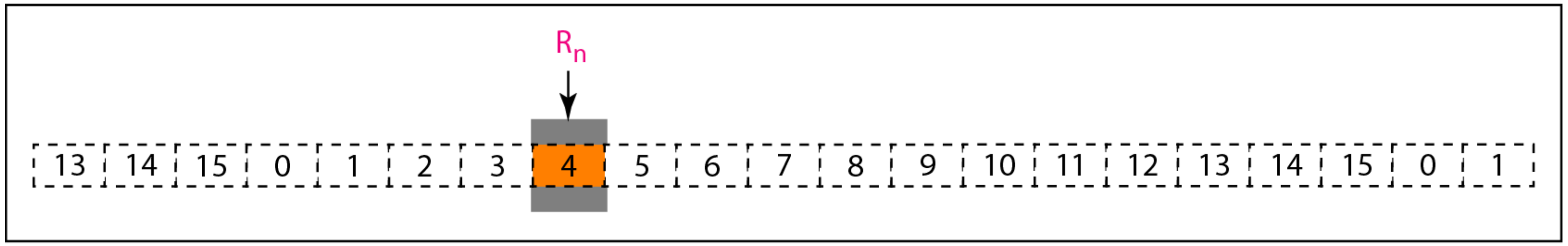
Sf defines **the sequence number of the first (oldest) outstanding frame.**
Sn holds the **sequence number that will be assigned to the next frame to be sent.**
Ssize defines the size of the window, which is fixed in our protocol.

The send window can slide one or more slots when a valid acknowledgment arrives.

Figure 11.13 *Receive window for Go-Back-N ARQ*


R_n
Receive window, next frame expected
13 14 15 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 0 1
Frames already received and acknowledged
Frames that cannot be received until the window slides

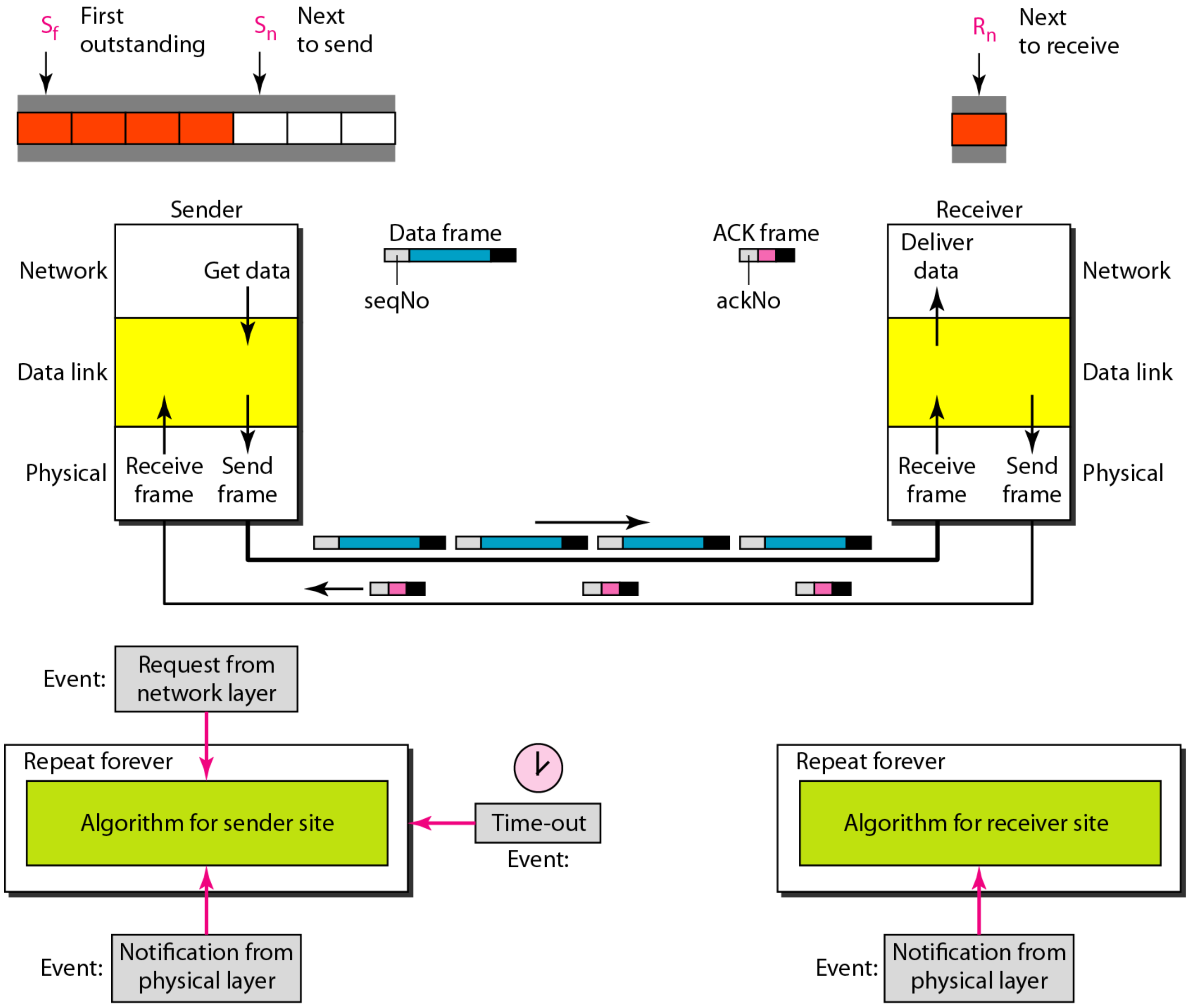
a. Receive window



b. Window after sliding

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 frame has arrived; sliding occurs one slot at a time.

Figure 11.14 *Design of Go-Back-N ARQ*



Go-Back-N ARQ Versus Stop-and- Wait ARQ

- there is a similarity between *Go-Back-N ARQ and Stop-and-Wait* ARQ. We can say that the Stop-and-Wait ARQ Protocol is actually a *Go-Back-N ARQ* in which there are only two sequence numbers and the send window size is 1. In other

words, *$m = 1$, $2^m - 1 = 1$. In Go-Back-N ARQ, we said that the addition is modulo-* 2^m *;*

In Stop-and-Wait ARQ it is 2, which is the same as 2^m *when $m = 1$.*

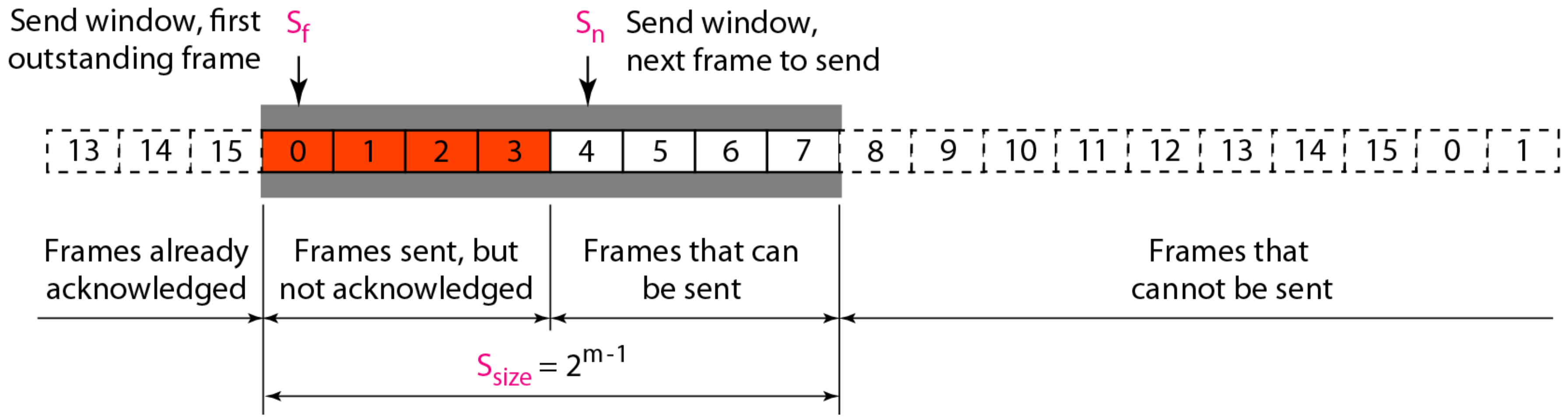
Selective Repeat Automatic Repeat Request

- *Go-Back-N ARQ simplifies the process at the receiver site. The receiver keeps track of* only one variable, and there is no need to buffer out-of-order frames; they are simply discarded. However, this protocol is very inefficient for a noisy link. Why ? *In a noisy link a frame has a higher probability of damage, which means the resending of multiple frames.*

- This resending uses up the bandwidth and slows down the transmission. For noisy links, there is another mechanism that does not resend *N frames when just one frame is damaged;*
- only the damaged frame is resent. This mechanism is called Selective Repeat ARQ. It is more efficient for noisy links, but the processing at the receiver is more complex

- This Protocol also uses two windows: a send window and a receive window.
- There are differences between the windows in this protocol and the ones in Go-Back-N. First, the size of the send window is much smaller; it is 2^{m-1}. *The reason for* this will be discussed later. Second, the receive window is the **same size** as the send window.
- For example, if *m = 4, the* sequence numbers go from 0 to 15, but the size of the window is just 8 (it is 15 in the *Go-Back-N Protocol). The smaller window size means less efficiency in filling the* pipe, but the fact that there are fewer duplicate frames.

Figure 11.18 *Send window for Selective Repeat ARQ*


Send window, first outstanding frame
S_f
S_n
Send window, next frame to send
13 14 15 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 0 1
Frames already acknowledged
Frames sent, but not acknowledged
Frames that can be sent
Frames that cannot be sent
$S_{size} = 2^{m-1}$

- The receive window in Selective Repeat is totally different from the one in Go Back-N. First, the size of the receive window is the same as the size of the send window*(2^{m-1}).* *The Selective Repeat Protocol* ***allows*** *as many frames as the size of the receive* window to arrive out of order and be kept until there is a set of in-order frames to be delivered to the network layer.

- Because the sizes of the send window and receive window are the same, all the frames in the send frame can arrive out of order and be stored until they can be delivered. We need, however, to mention that the receiver never delivers packets out of order to the network layer. Figure 11.19 shows the receive window in this

Figure 11.19 *Receive window for Selective Repeat ARQ*

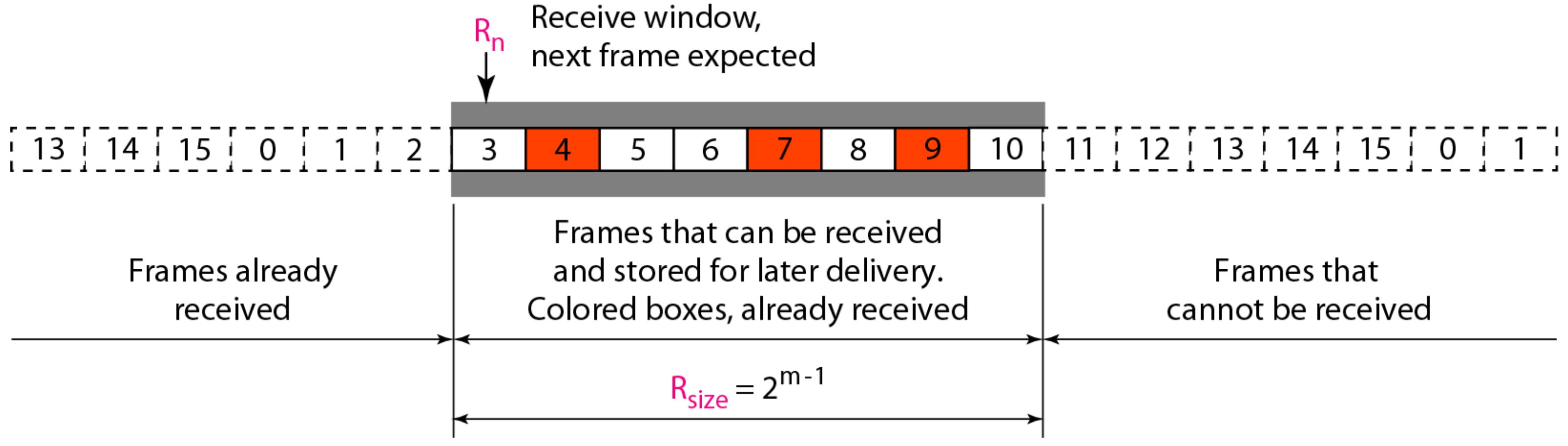
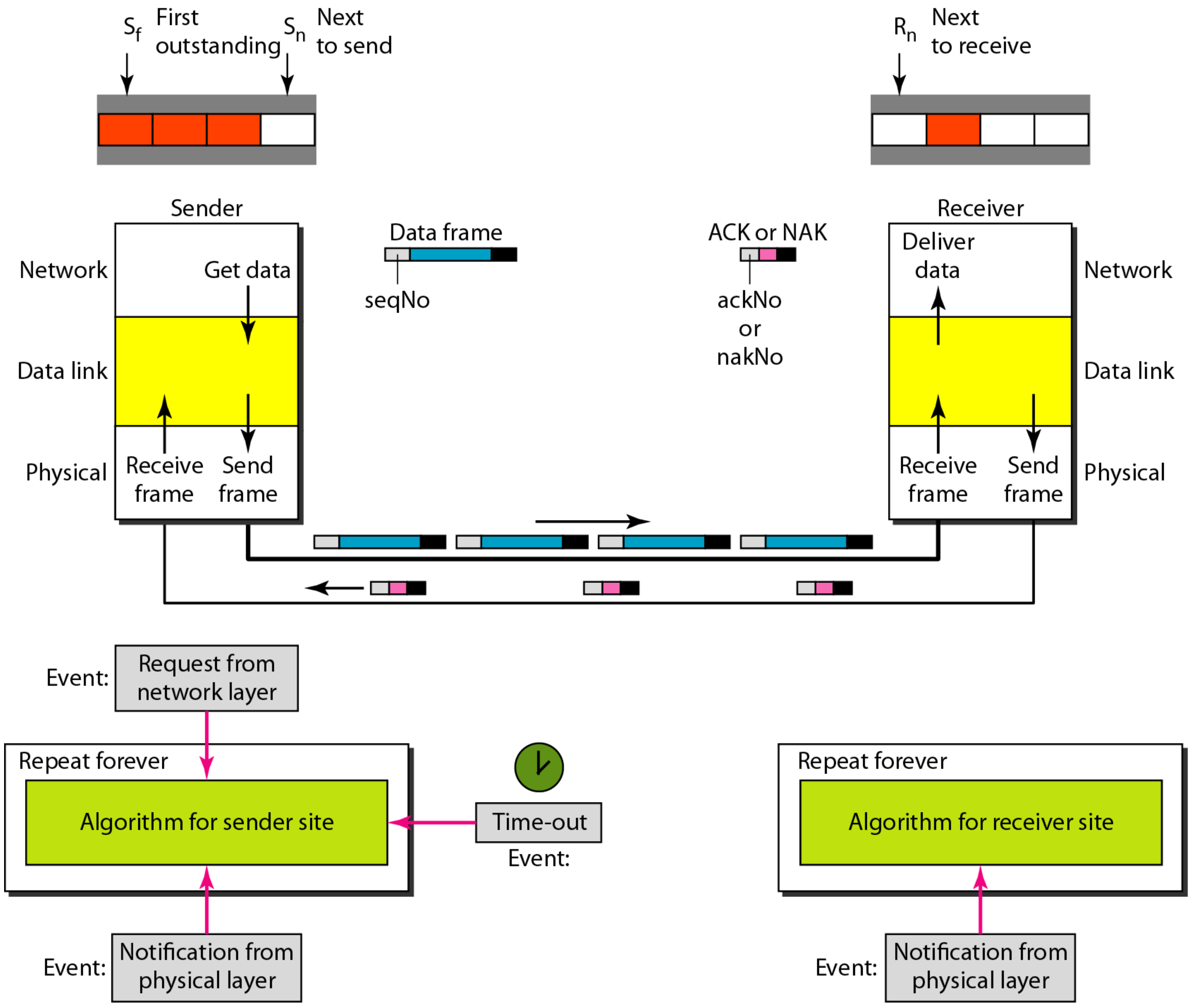

R_n
Receive window, next frame expected
13 14 15 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 0 1
Frames already received
Frames that can be received and stored for later delivery. Colored boxes, already received
Frames that cannot be received
$R_{size} = 2^{m-1}$

Figure 11.20 *Design of Selective Repeat ARQ*



Note

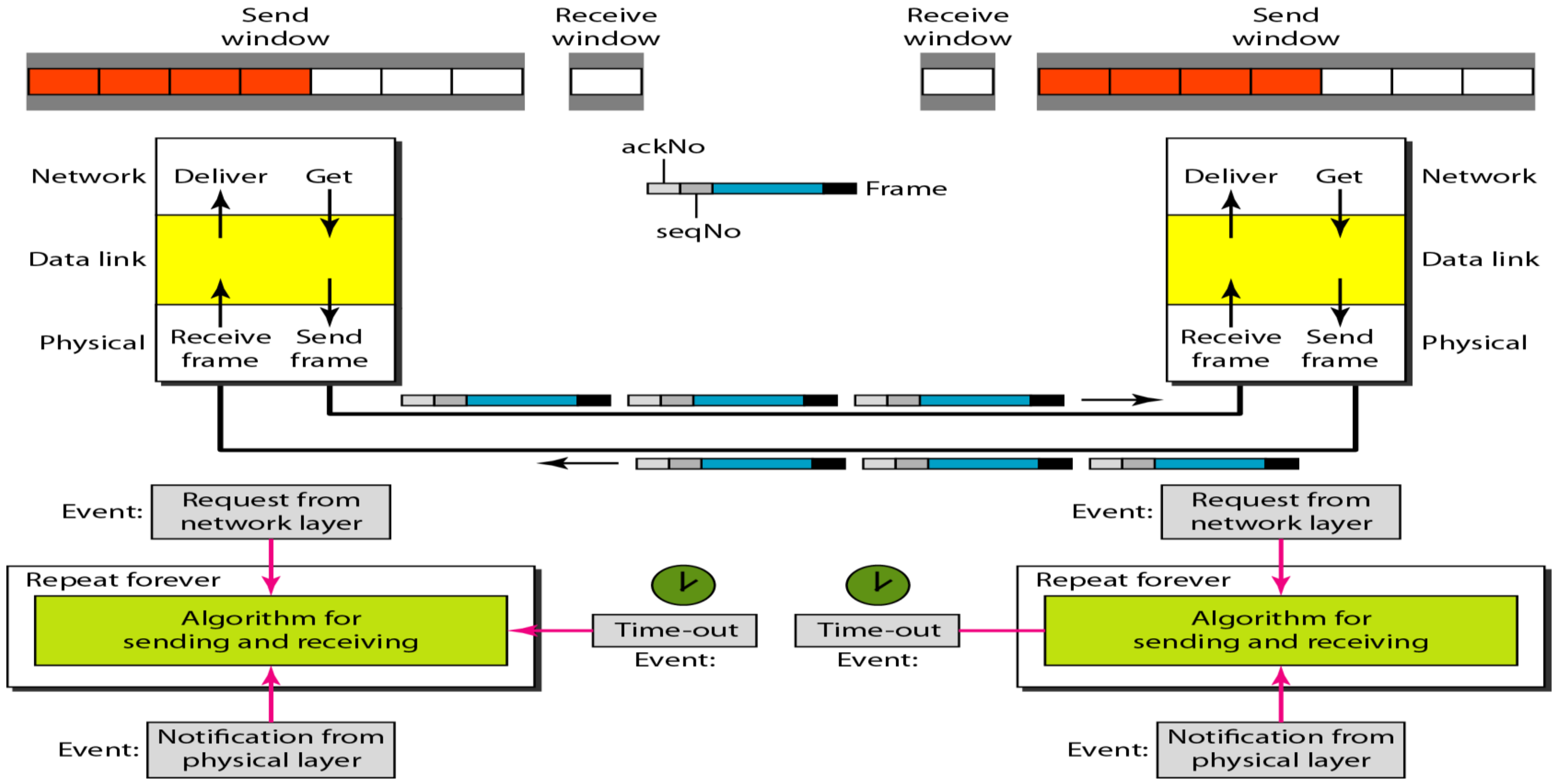
In Selective Repeat ARQ, the size of the sender and receiver window must be at most one-half of 2^m.

Piggybacking

- The three protocols we discussed in this section are all unidirectional: data frames flow in only one direction although control information such as ACK and NAK frames can travel in the other direction. In real life, data frames are normally flowing in both directions: from node A to node B and from node B to node A. This means that the control information also needs to flow in both directions.
- A technique called **piggybacking is** used to improve the efficiency of the bidirectional protocols. When a frame is carrying data from A to B, it can also carry control information about arrived (or lost) frames from B; and verse versa.

Figure 11.24 *Design of piggybacking in Go-Back-N ARQ*

Piggybacking – control information flow in both directions and improves the efficiency of bidirectional protocols



- Note that each node now has two windows: one send window and one receive window. Both also need to use a timer.
- An important point about piggybacking is that both sites must use the same algorithm.
- This algorithm is complicated because it needs to combine two arrival events into one.

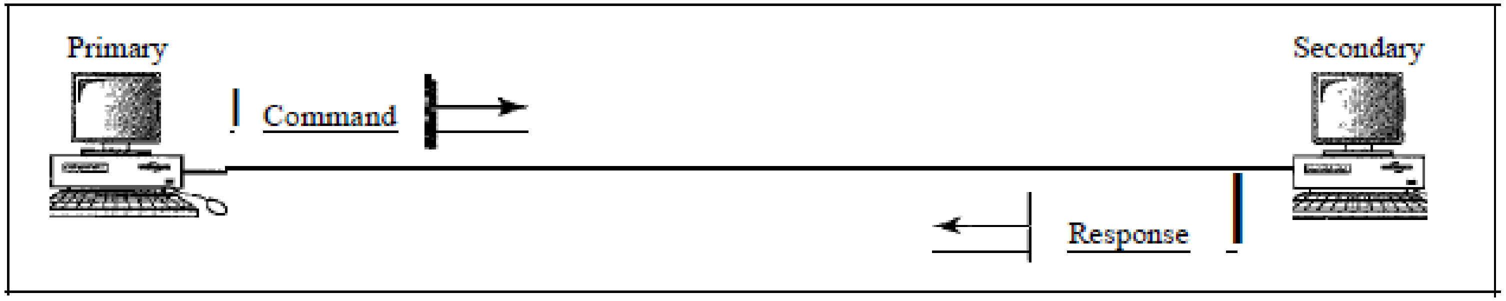
HDLC

High-level Data Link Control (HDLC) is a bit-oriented protocol for communication over point-to-point and multipoint links. It implements the ARQ mechanisms .

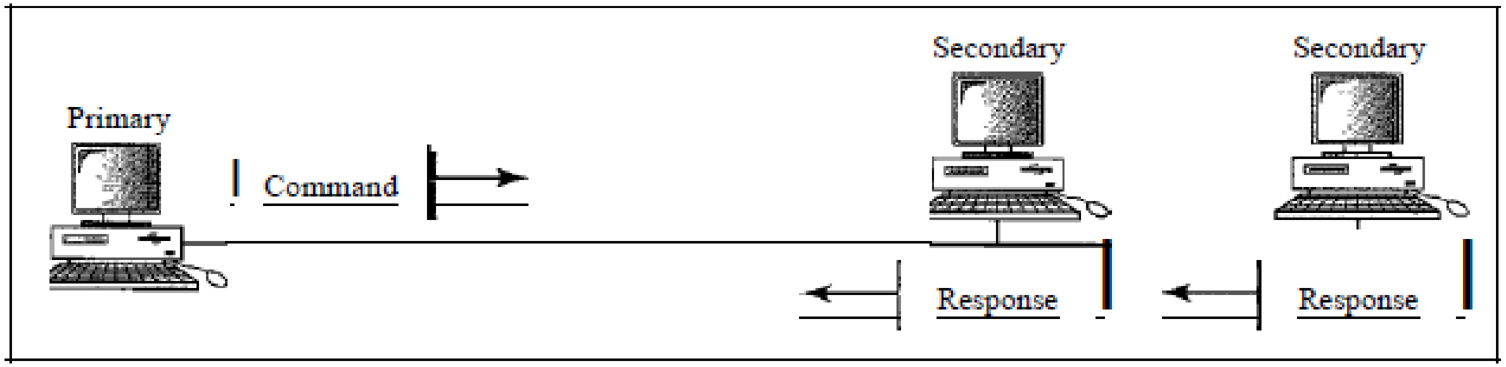
HDLC provides two common transfer modes that can be used in different configurations: normal response mode (NRM) and asynchronous balanced mode (ABM).

In normal response mode (NRM), the station configuration is unbalanced. We have one primary station and multiple secondary stations. A primary station can send commands; a secondary station can only respond. The NRM is used for both point-to-point and multiple-point links, as shown in Figure 11.25.

Figure 11.25 *Normal response mode*



a. Point-to-point

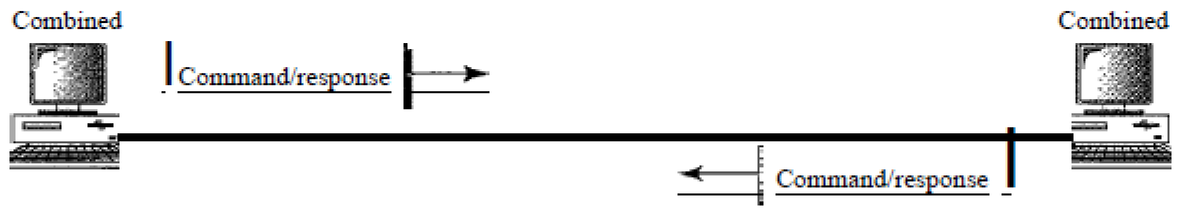


b. Multipoint

- *Asynchronous Balanced Mode*

In asynchronous balanced mode (ABM), the configuration is balanced. The link is point-to-point, and each station can function as a primary and a secondary (acting as peers), as shown in Figure 11.26. This is the common mode today.

Figure 11.26 *Asynchronous balanced mode*


Combined
Command/response
Combined
Command/response