

Data Link Layer

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Data Link Layer

- Two main functions of the data link layer are:
 - Data link control
 - Media access control.
- Data link control deals with the design and procedures for communication between two adjacent nodes. It includes:
 - Framing
 - Flow control
 - Error control
- Media access control – how to share the link.

FRAMING

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Framing

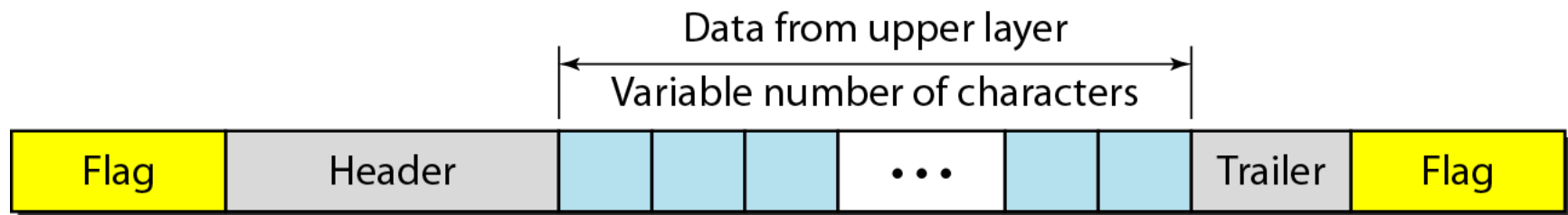
- The data link layer needs to pack bits into **frames**, so that each frame is distinguishable from another.
- Can we pack the whole message in one frame?
 - It can make flow and error control very inefficient.
- Framing separates a message from one source and destination, or other messages to other destinations by adding source and destination address.

Framing

- Fixed-Size Framing
 - There is no need to define the boundaries of the frames, the size it self can act as a delimiter.
- Variable-Size Framing
 - We need to define the end of the frame and the beginning of the next frame.
 - Character-oriented protocol
 - Bit-oriented protocol

Frame in a character-oriented protocol

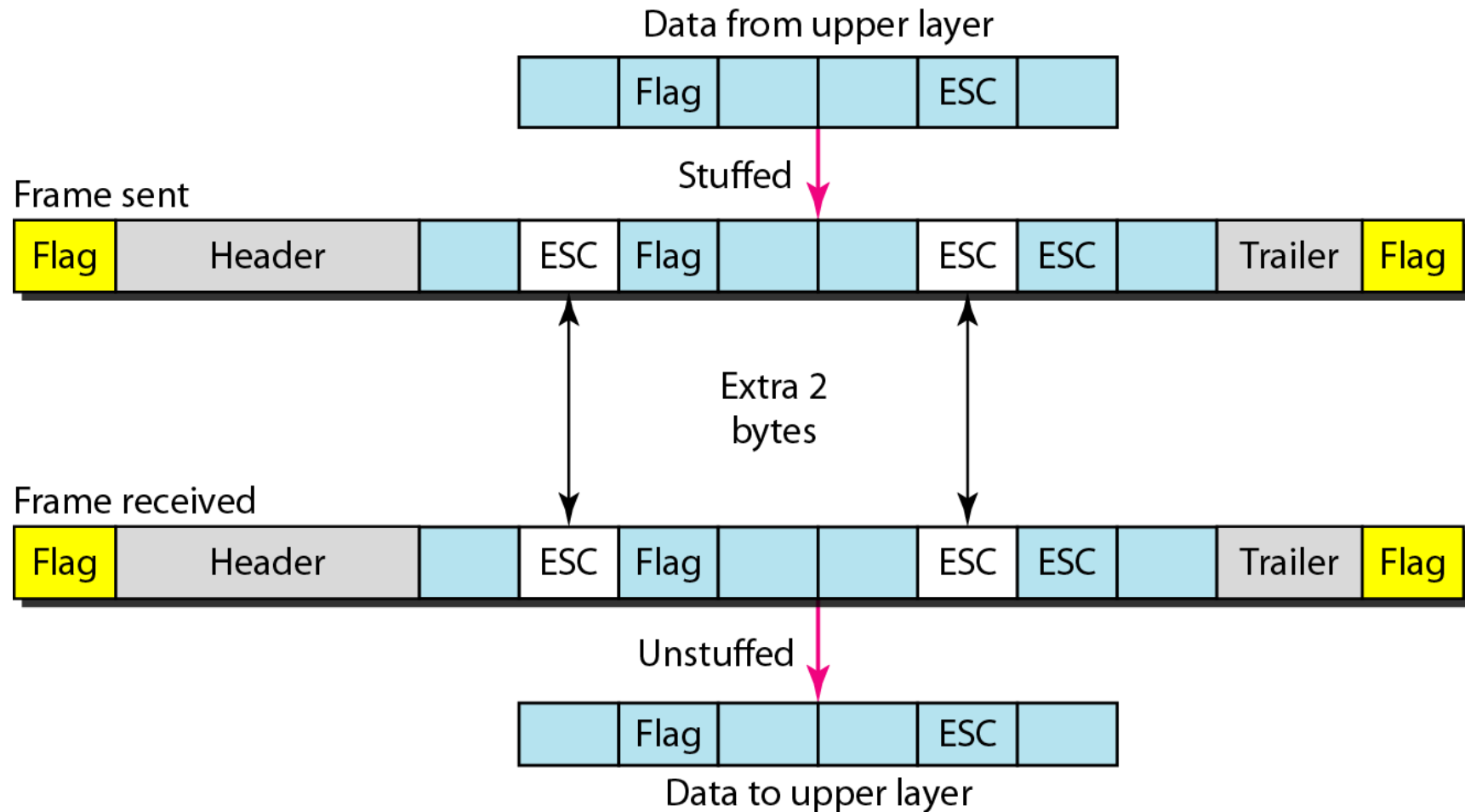
- In character-oriented protocol, data to be carried are 8-bit characters.
- **Header**: normally carries source & destination addresses and other control information.
- **Trailer**: error detection and correction redundant bits, are also multiple of 8 bits.
- **Flags**: used to separate one frame from the next. 1 byte flag.



Byte stuffing and unstuffing

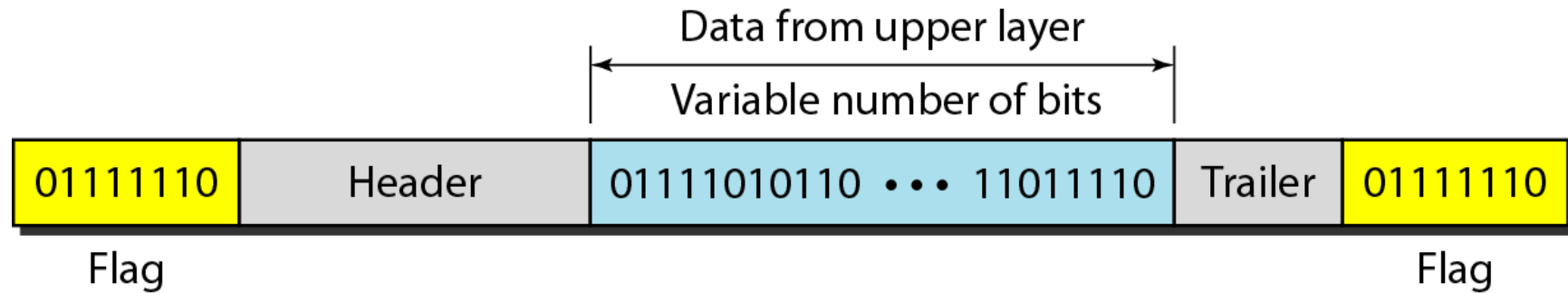
- Any pattern used for flag could also be part of the info... (it can cause problem to the receiver.)
- Byte stuffing is used to fix this problem.
- In Byte stuffing, a special byte (usually called the escape character (ESC)) is added to the data section of the frame when there is a char with the same pattern as the flag.
 - On finding a ESC char, the receiver removes it from the data section and treats the next char as data.
- The ESC char that are part of the text must also be marked by another ESC char.

Byte stuffing and unstuffing



- Byte stuffing is the process of adding 1 extra byte whenever there is a flag or escape character in the text.

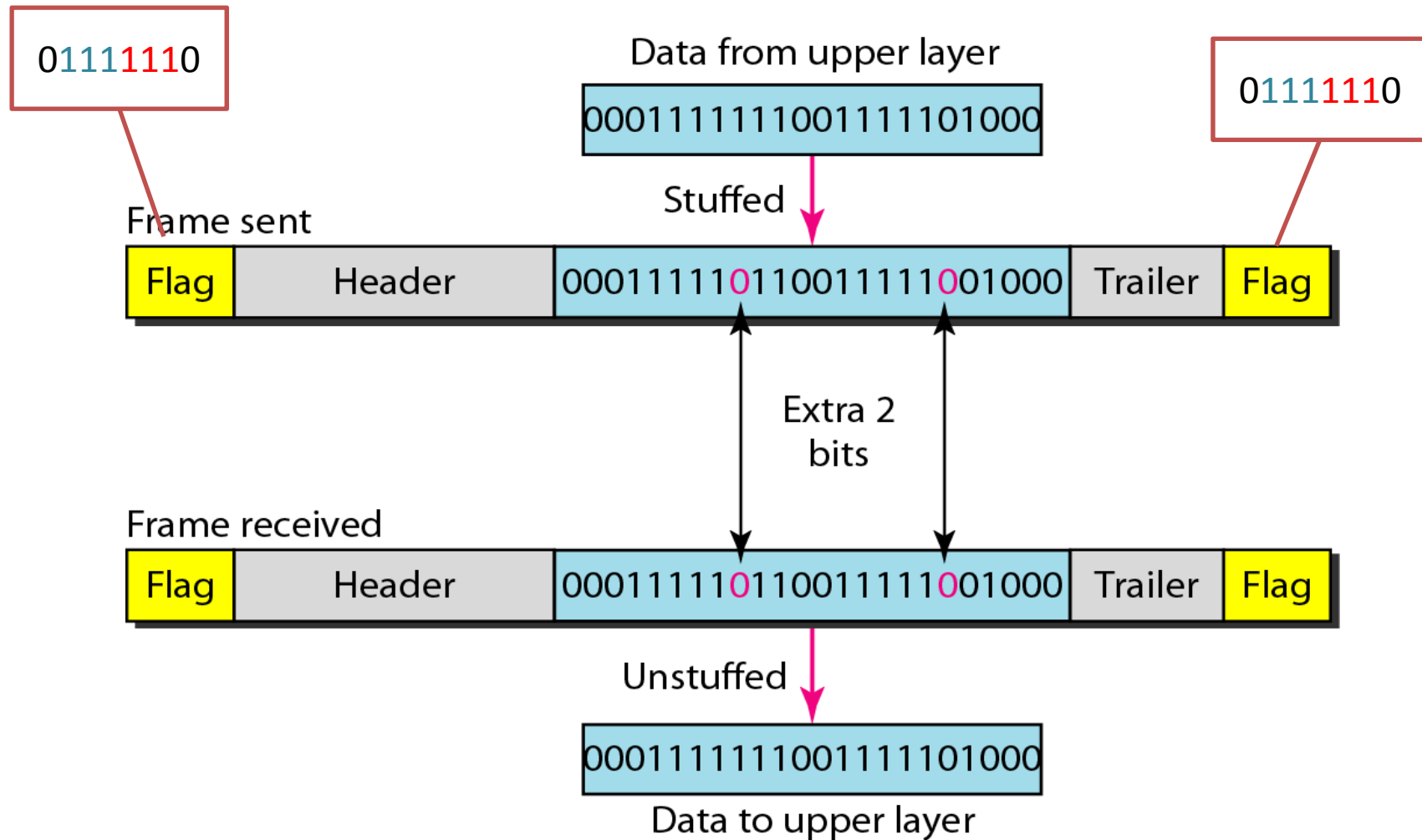
Frame in a bit-oriented protocol



Bit stuffing

- Bit stuffing is the process of adding one extra 0 whenever five consecutive 1s follow a 0 in the data, so that the receiver does not mistake the pattern 011110 for a flag.

Bit stuffing and unstuffing

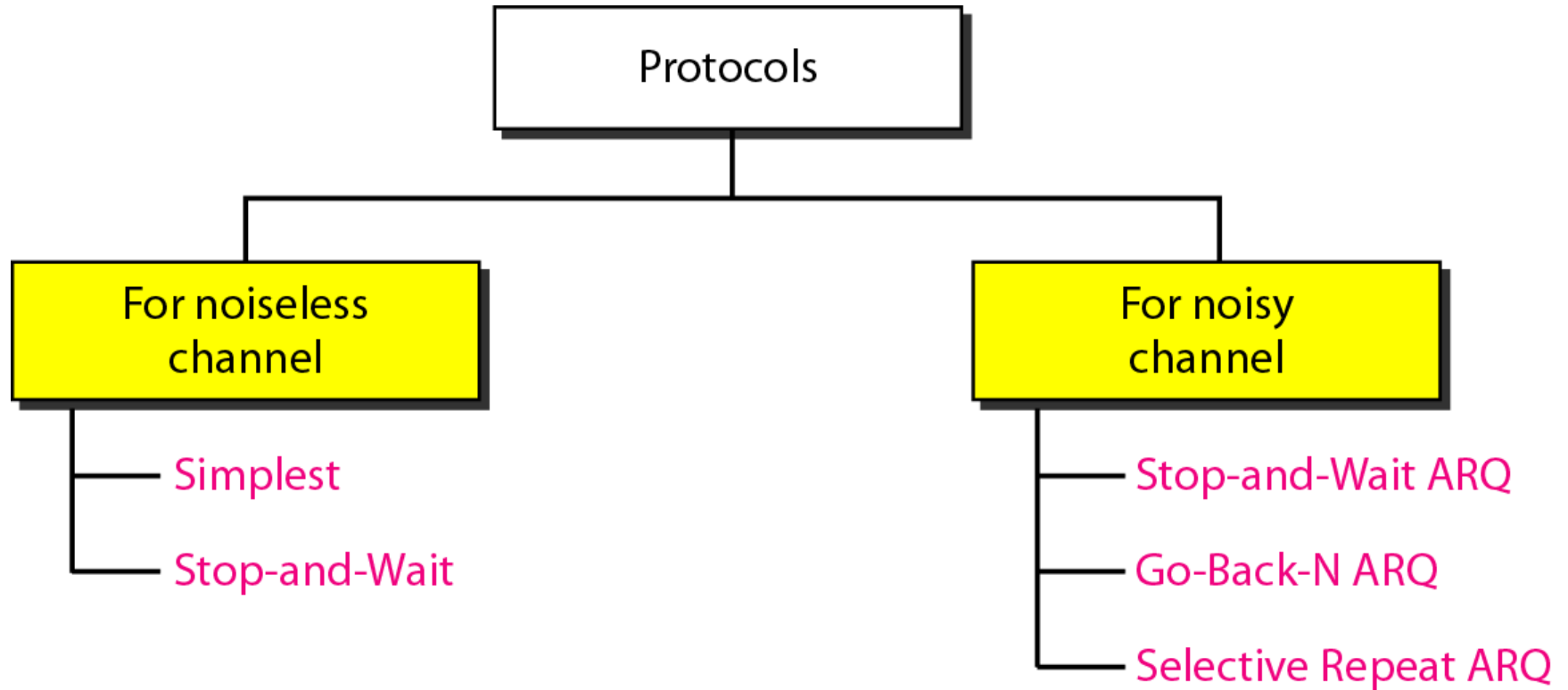


The most important responsibilities of the data link layer are flow control and error control. Collectively, known as data link control.

FLOW AND ERROR CONTROL

Flow & Error Control

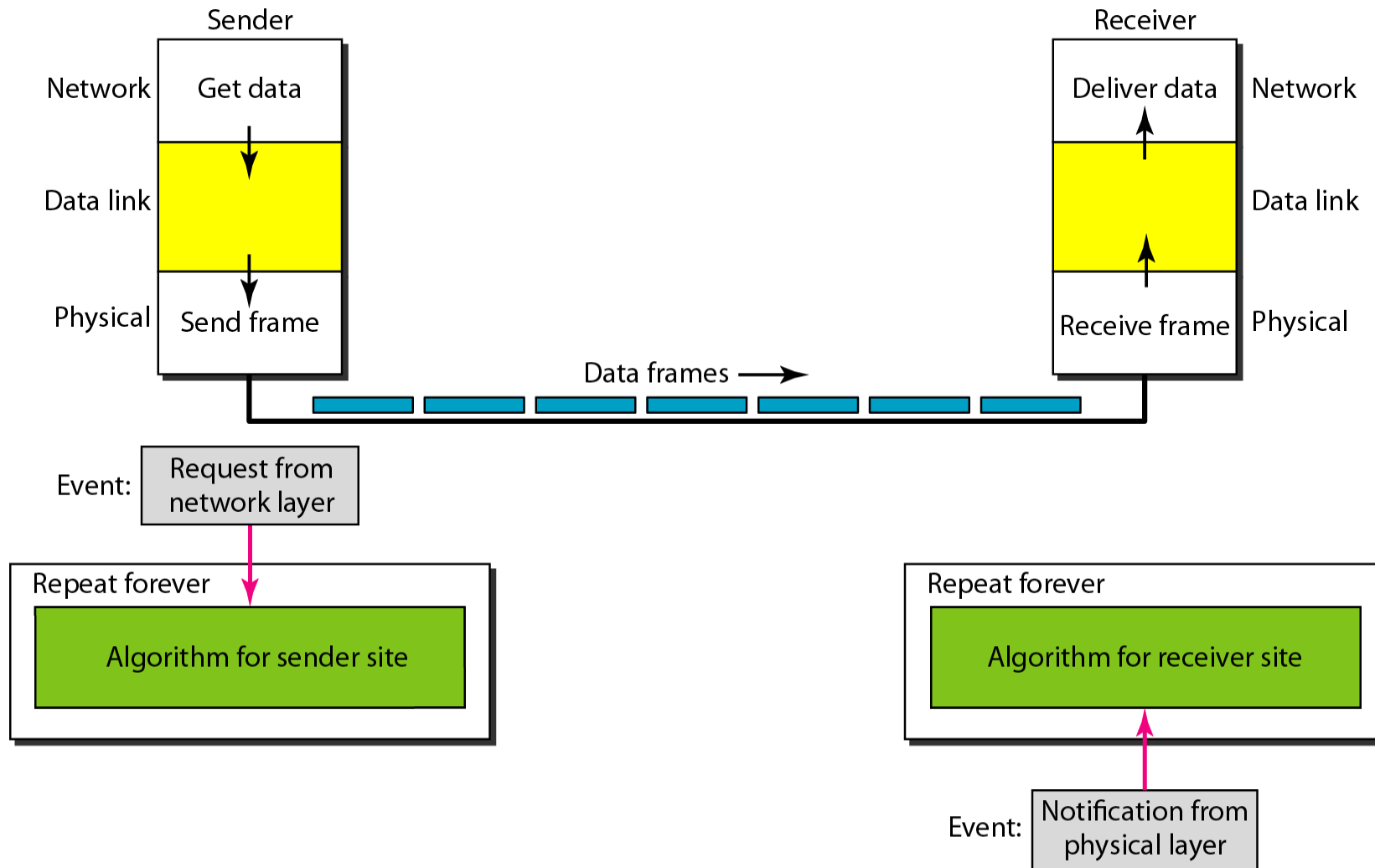
- Flow control refers to a set of procedures used to restrict the amount of data that the sender can send before waiting for acknowledgment.
 - The flow of data must not overwhelm the receiver.
- Error control in the data link layer is based on automatic repeat request, which is the retransmission of data.
 - It allows the receiver to inform the sender of any frame lost or damaged in transmission.



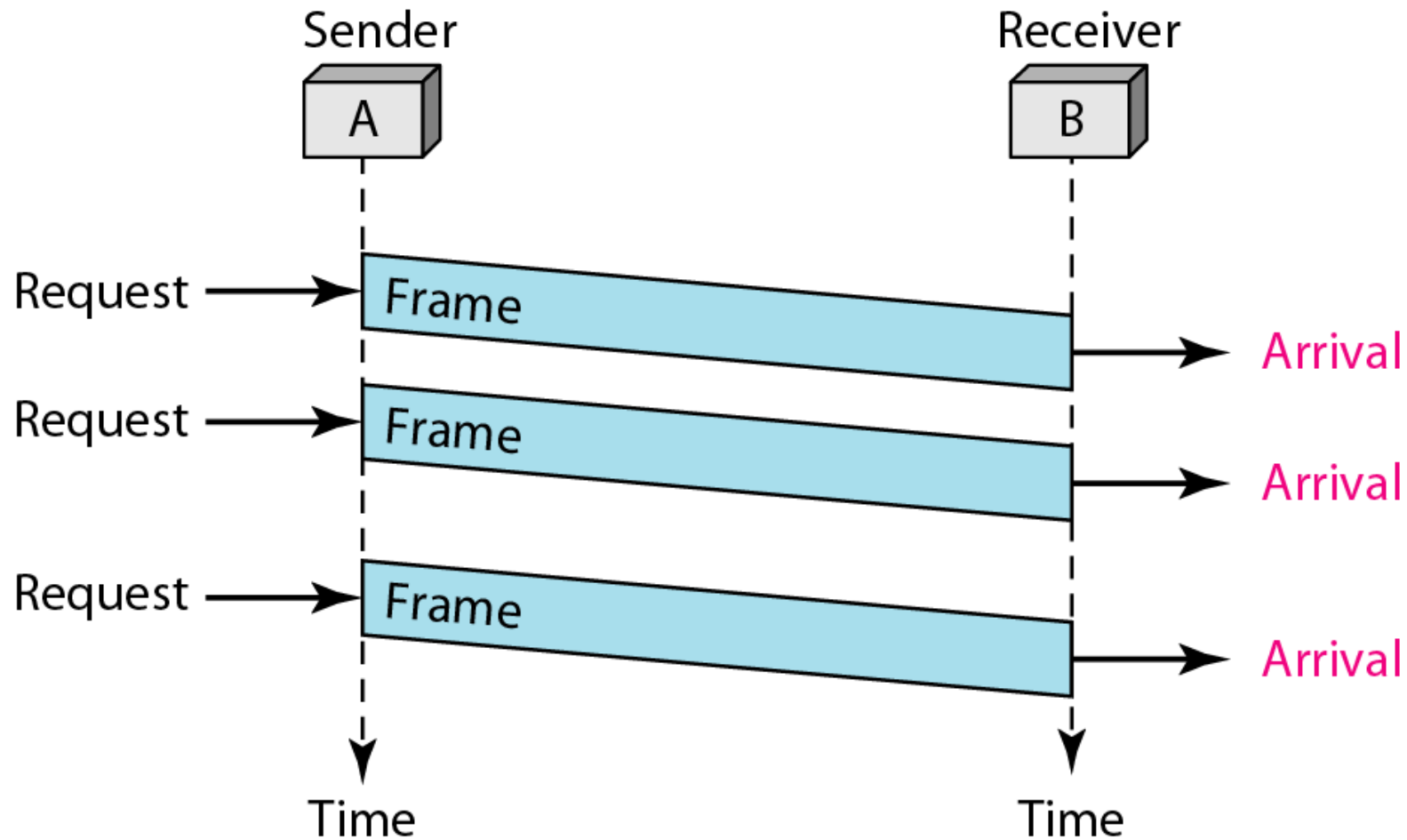
Noiseless Channel

- Noiseless Channel: An ideal channel in which no frames are lost, duplicated, or corrupted.
- Two protocols for this type of channel.
 - Simplest Protocol
 - Stop-and-Wait Protocol

Design of the simplest protocol with no flow or error control



Example of the simplest protocol with no flow or error control



```

1 while(true)                                // Repeat forever
2 {
3     WaitForEvent();                          // Sleep until an event occurs
4     if(Event(RequestToSend))                //There is a packet to send
5     {
6         GetData();
7         MakeFrame();
8         SendFrame();                          //Send the frame
9     }
10 }

```

Sender-site algorithm for the simplest protocol

```

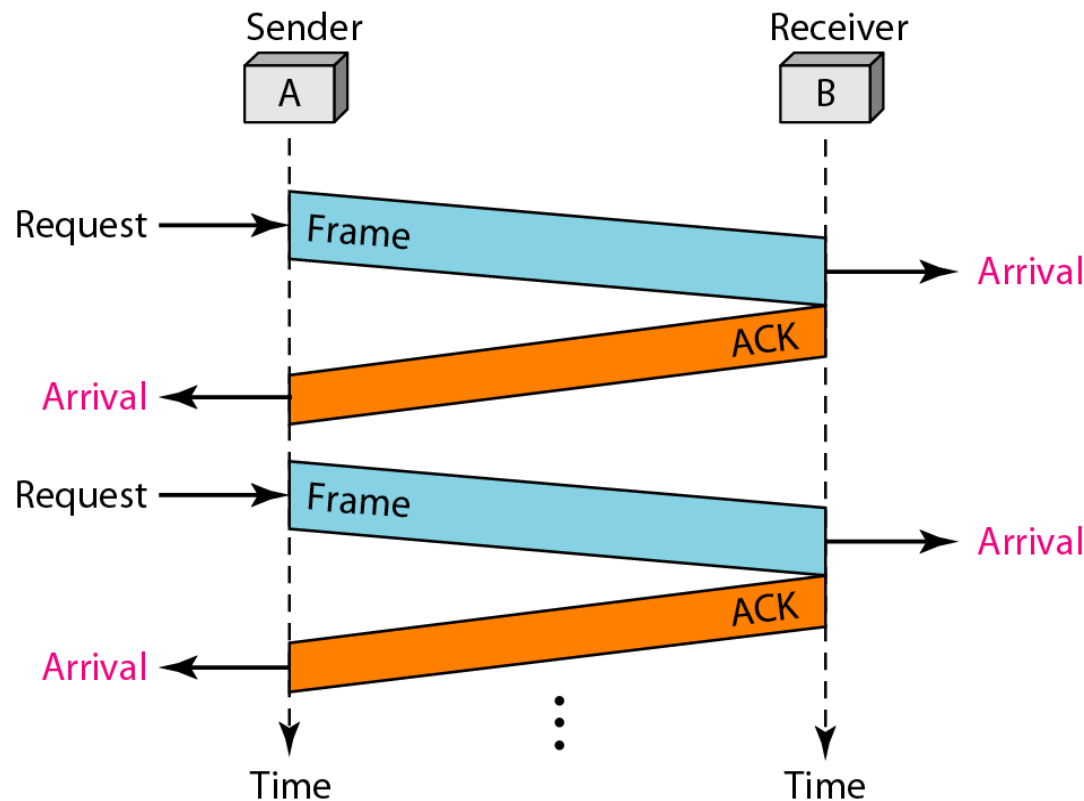
1 while(true)                                // Repeat forever
2 {
3     WaitForEvent();                          // Sleep until an event occurs
4     if(Event(ArrivalNotification))          //Data frame arrived
5     {
6         ReceiveFrame();
7         ExtractData();
8         DeliverData();                       //Deliver data to network layer
9     }
10 }

```

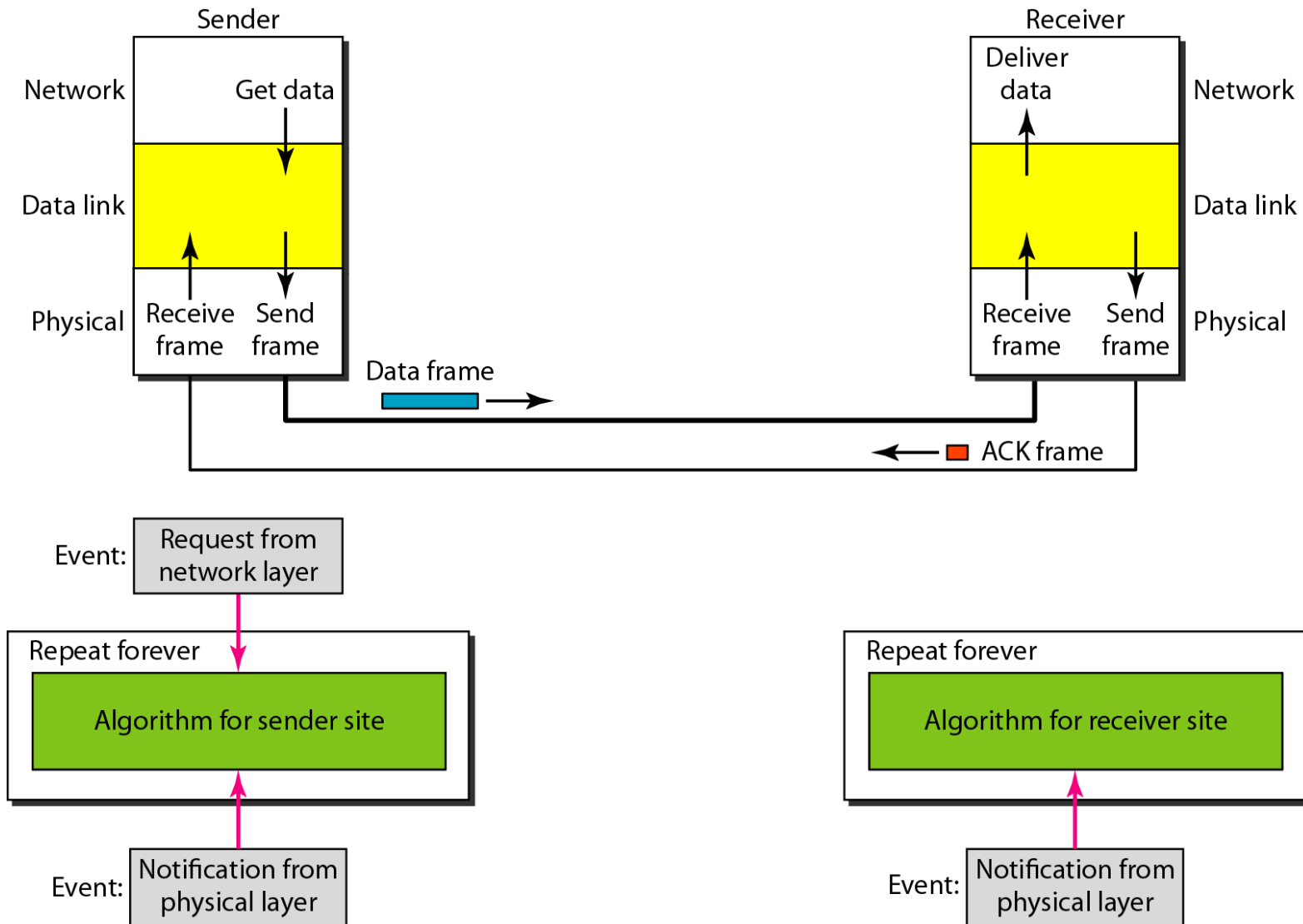
Receiver-site algorithm for the simplest protocol

Stop-and-Wait Protocol

- In this protocol, the sender sends one frame, stops until it receives confirmation from the receiver and then sends the next frame.



Design of Stop-and-Wait Protocol



Sender-site algorithm for Stop-and-Wait Protocol

```
1 while(true)                                //Repeat forever
2 canSend = true                             //Allow the first frame to go
3 {
4     WaitForEvent();                         // Sleep until an event occurs
5     if(Event(RequestToSend) AND canSend)
6     {
7         GetData();
8         MakeFrame();
9         SendFrame();                       //Send the data frame
10        canSend = false;                  //Cannot send until ACK arrives
11    }
12    WaitForEvent();                         // Sleep until an event occurs
13    if(Event(ArrivalNotification) // An ACK has arrived
14    {
15        ReceiveFrame();                   //Receive the ACK frame
16        canSend = true;
17    }
18 }
```

Receiver-site algorithm for Stop-and-Wait Protocol

```
1 while(true)                                //Repeat forever
2 {
3     WaitForEvent();                          // Sleep until an event occurs
4     if(Event(ArrivalNotification))           //Data frame arrives
5     {
6         ReceiveFrame();
7         ExtractData();
8         Deliver(data);                        //Deliver data to network layer
9         SendFrame();                          //Send an ACK frame
10    }
11 }
```

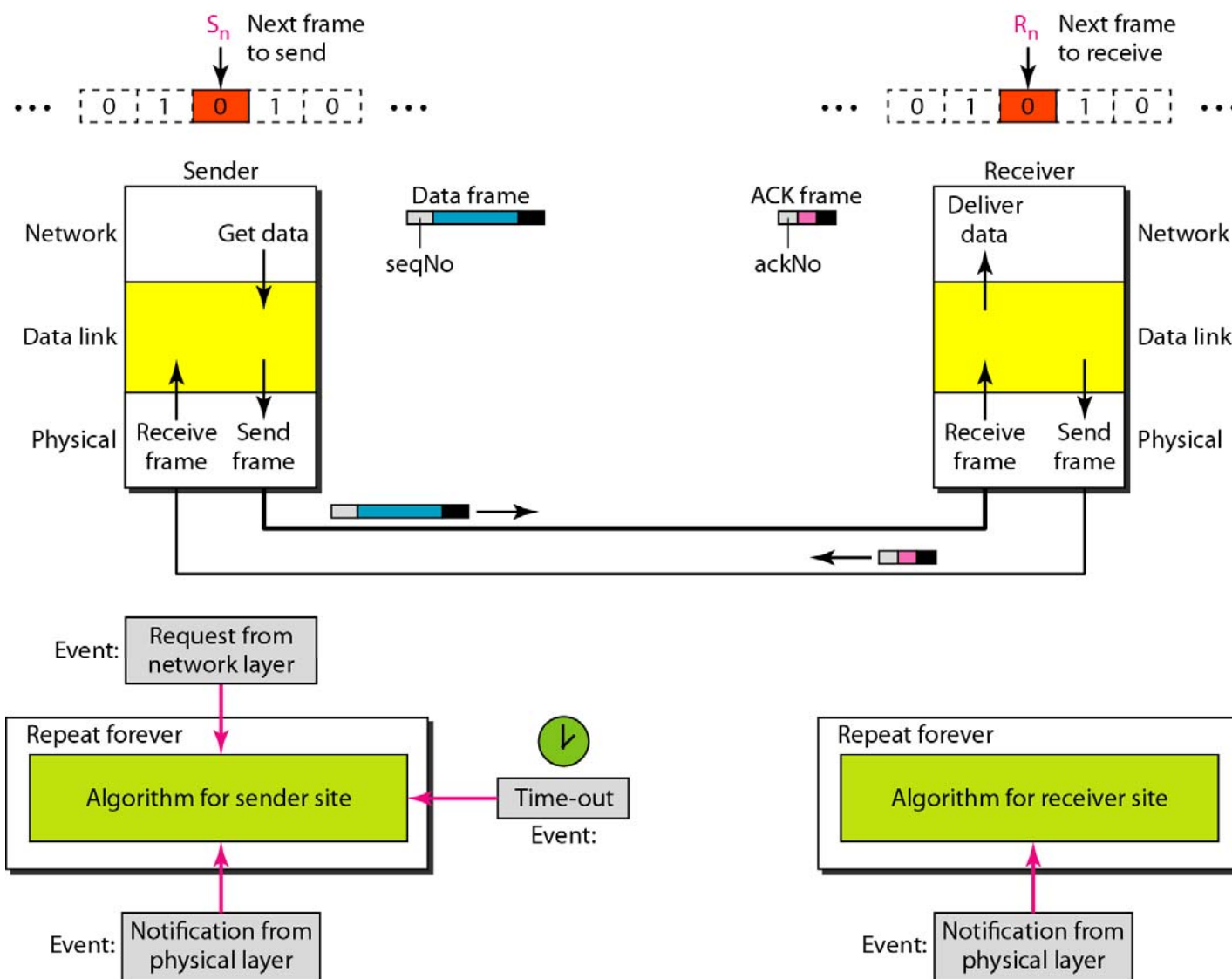
Noisy Channel

- We discuss three protocols in this section that use error control.
 - Stop-and-Wait Automatic Repeat Request (Stop-and-Wait ARQ)
 - Go-Back-N ARQ
 - Selective Repeat ARQ

Stop-and-Wait ARQ

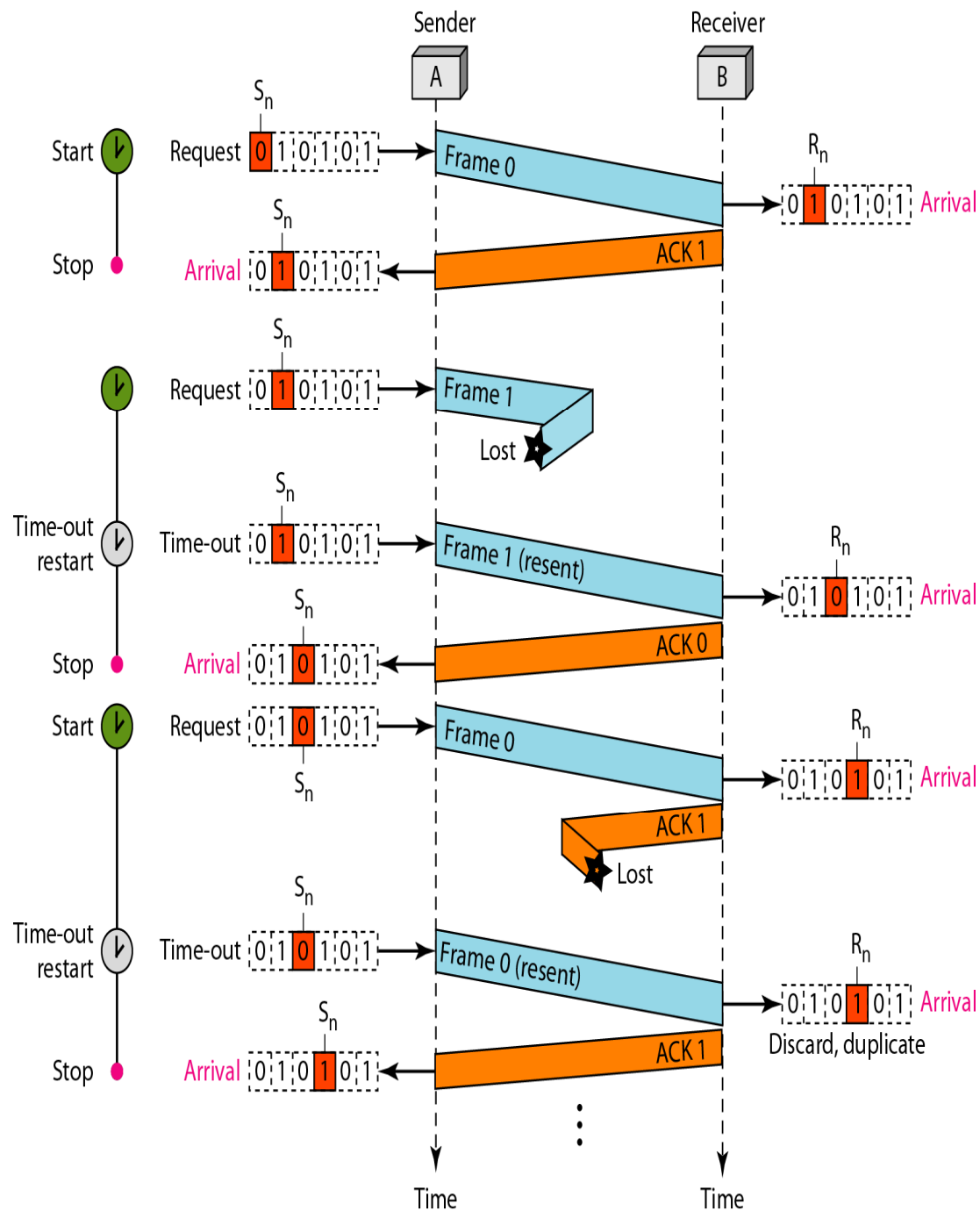
- Error correction in Stop-and-Wait ARQ is done by keeping a copy of the sent frame and retransmitting of the frame when the timer expires.
- In Stop-and-Wait ARQ, we use sequence numbers to number the frames.
- The sequence numbers are based on modulo-2 arithmetic.
- In Stop-and-Wait ARQ, the acknowledgment number always announces in modulo-2 arithmetic the sequence number of the next frame expected.

Design of the Stop-and-Wait ARQ Protocol



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 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 acknowledged.



Sender-site algorithm for Stop-and-Wait ARQ

```
1  Sn = 0;                                // Frame 0 should be sent first
2  canSend = true;                          // Allow the first request to go
3  while(true)                              // Repeat forever
4  {
5      WaitForEvent();                      // Sleep until an event occurs
6      if(Event(RequestToSend) AND canSend)
7      {
8          GetData();
9          MakeFrame(Sn);                  //The seqNo is Sn
10         StoreFrame(Sn);                //Keep copy
11         SendFrame(Sn);
12         StartTimer();
13         Sn = Sn + 1;
14         canSend = false;
15     }
16     WaitForEvent();                      // Sleep
```

(continued)

Sender-site algorithm for Stop-and-Wait ARQ

```
17  if(Event(ArrivalNotification)      // An ACK has arrived
18  {
19      ReceiveFrame(ackNo);           //Receive the ACK frame
20      if(not corrupted AND ackNo == Sn) //Valid ACK
21      {
22          Stoptimer();
23          PurgeFrame(Sn-1);          //Copy is not needed
24          canSend = true;
25      }
26  }
27
28  if(Event(TimeOut)                  // The timer expired
29  {
30      StartTimer();
31      ResendFrame(Sn-1);            //Resend a copy check
32  }
33 }
```

Receiver-site algorithm for Stop-and-Wait ARQ Protocol

```
1  Rn = 0;                                // Frame 0 expected to arrive first
2  while(true)
3  {
4      WaitForEvent();                      // Sleep until an event occurs
5      if(Event(ArrivalNotification))      //Data frame arrives
6      {
7          ReceiveFrame();
8          if(corrupted(frame));
9              sleep();
10         if(seqNo == Rn)                  //Valid data frame
11         {
12             ExtractData();
13             DeliverData();                //Deliver data
14             Rn = Rn + 1;
15         }
16         SendFrame(Rn);                  //Send an ACK
17     }
18 }
```

Stop-and-Wait ARQ

- Assume that, in a Stop-and-Wait ARQ system, the bandwidth of the line is 1 Mbps, and 1 bit takes 20 ms to make a round trip. What is the bandwidth-delay product? If the system data frames are 1000 bits in length, what is the utilization percentage of the link?

- The bandwidth-delay product is

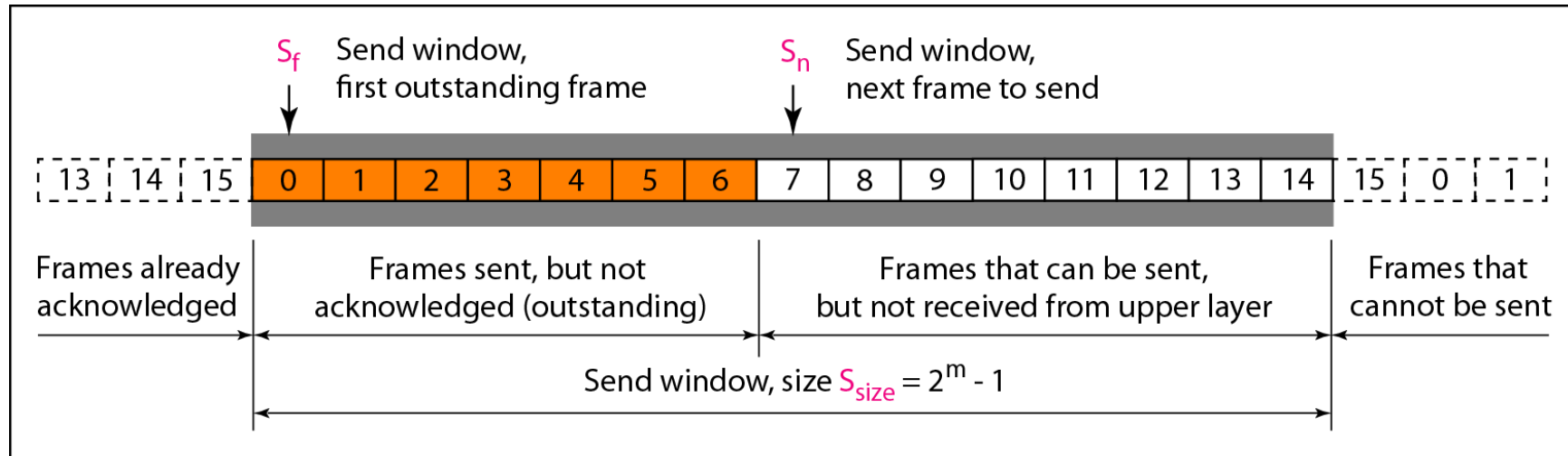
$$(1 \times 10^6) \times (20 \times 10^{-3}) = 20,000 \text{ bits}$$

- The system can send 20,000 bits.
- However, the system sends only 1000 bits.
- So, the link utilization is only $1000/20,000$, or 5 percent.
- For this reason, for a link with a high bandwidth or long delay, the use of Stop-and-Wait ARQ wastes the capacity of the link.

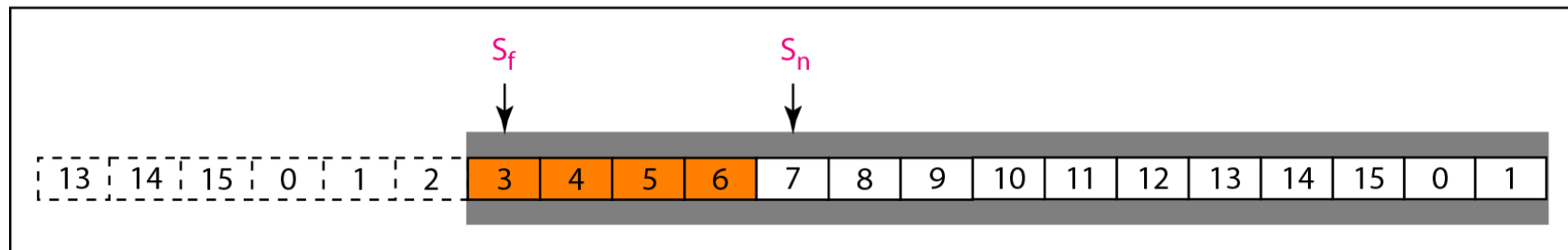
Go-Back-N ARQ

- In Go-Back-N Protocol, the sequence numbers are modulo 2^m , where m is the size of the sequence number field in bits.
- 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} .
- The send window can slide one or more slots when a valid acknowledgment arrives.

Send window for Go-Back-N ARQ



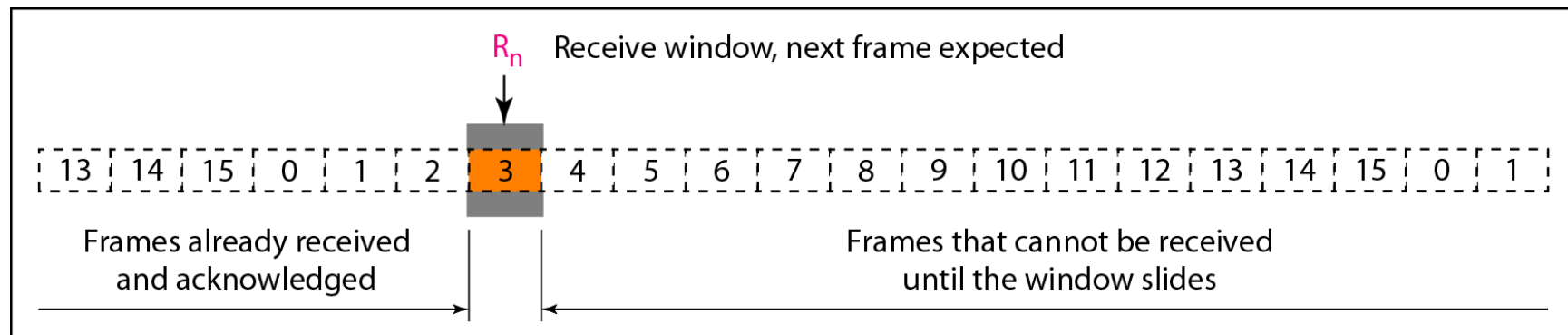
a. Send window before sliding



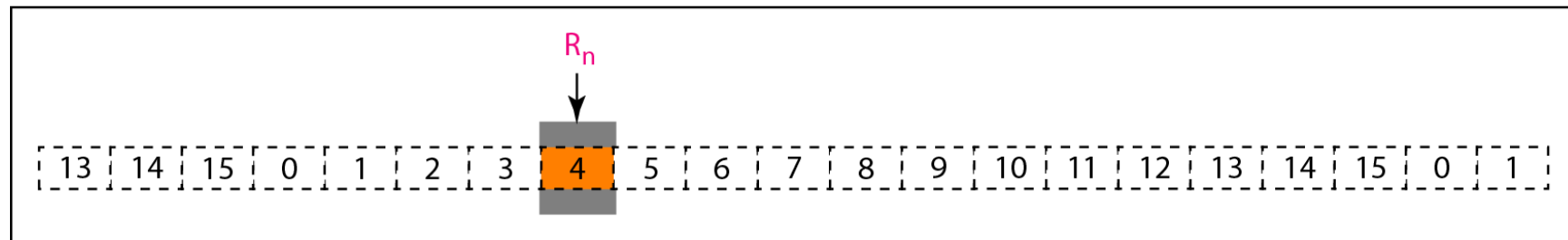
b. Send window after sliding

Receive window for Go-Back-N ARQ

- 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.

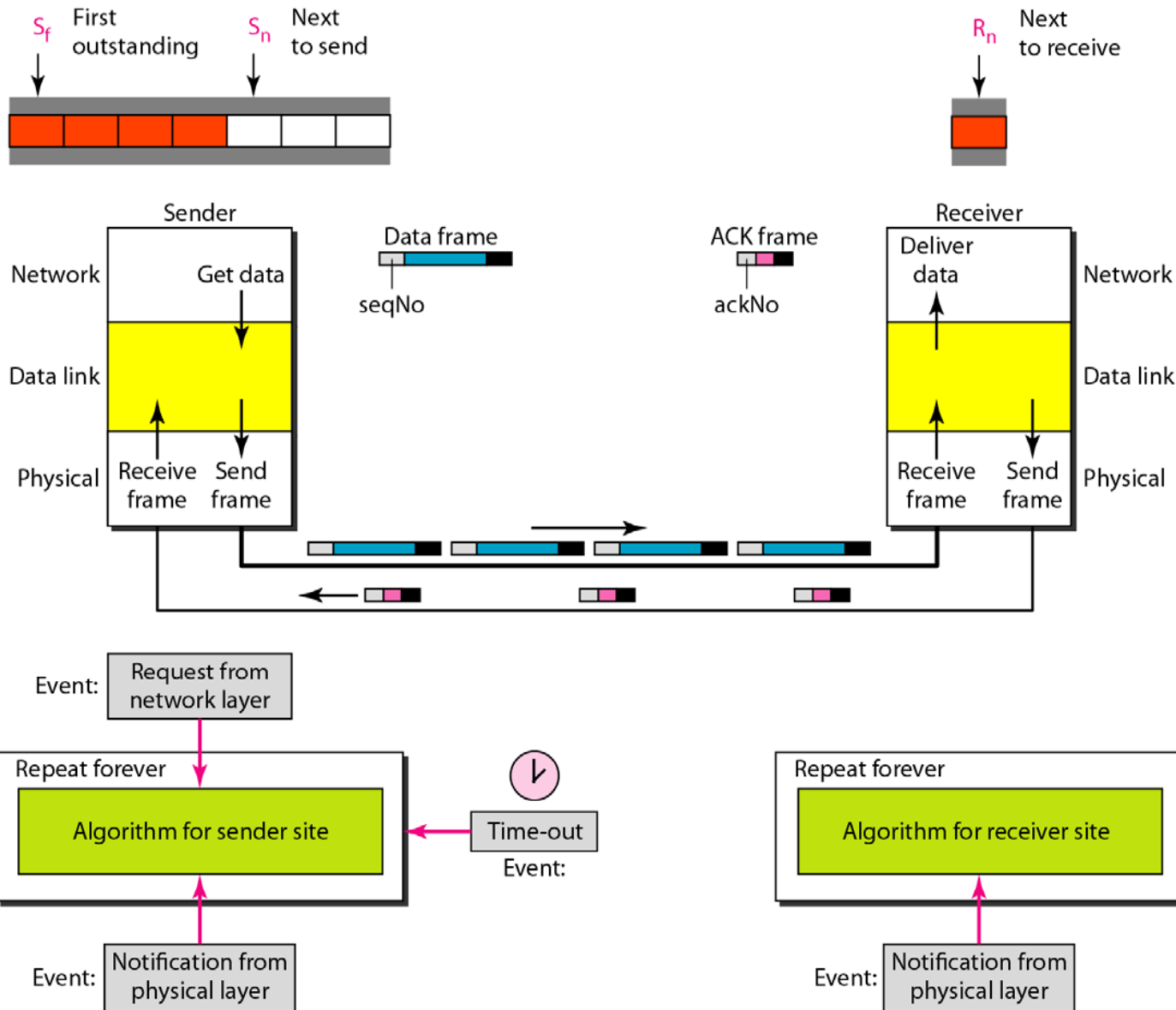


a. Receive window



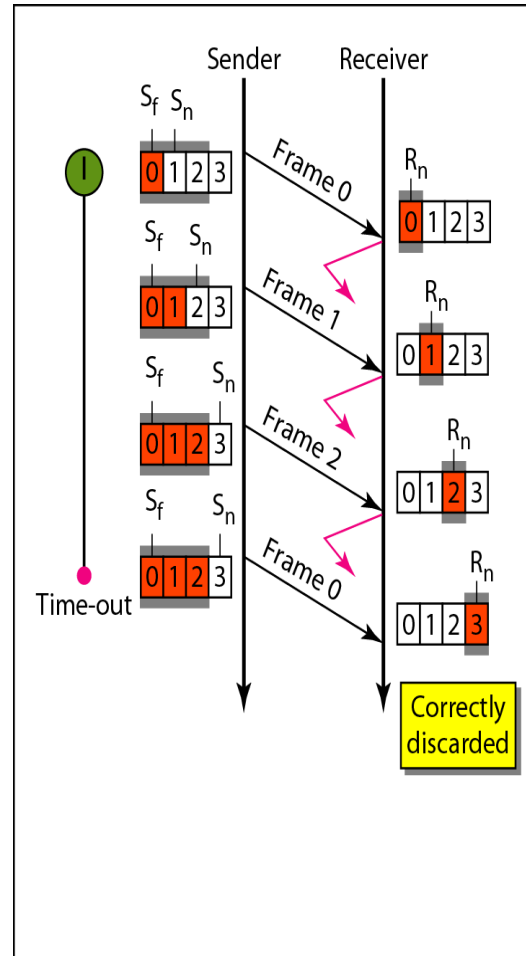
b. Window after sliding

Design of Go-Back-N ARQ

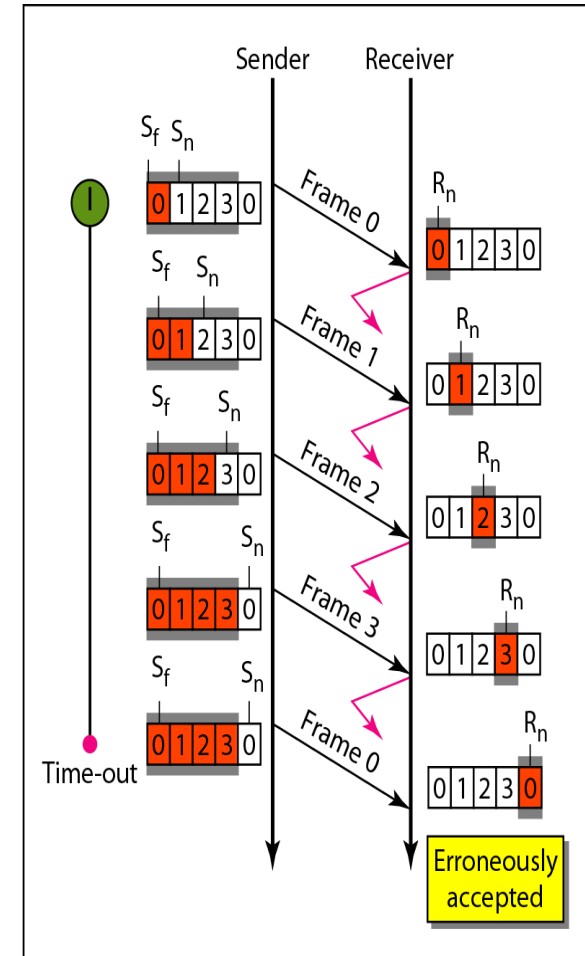


Window size for Go-Back-N ARQ

- In Go-Back-N ARQ, the size of the send window must be less than 2^m .
- The size of the receiver window is always 1.



a. Window size $< 2^m$



b. Window size $= 2^m$

Go-Back-N sender algorithm

```
1  Sw = 2m - 1;
2  Sf = 0;
3  Sn = 0;
4
5  while (true)                                //Repeat forever
6  {
7      WaitForEvent();
8      if(Event(RequestToSend))                //A packet to send
9      {
10         if(Sn-Sf >= Sw)                    //If window is full
11             Sleep();
12         GetData();
13         MakeFrame(Sn);
14         StoreFrame(Sn);
15         SendFrame(Sn);
16         Sn = Sn + 1;
17         if(timer not running)
18             StartTimer();
19     }
20
```

(continued)

Go-Back-N sender algorithm

```
21  if(Event(ArrivalNotification))  //ACK arrives
22  {
23      Receive(ACK);
24      if(corrupted(ACK))
25          Sleep();
26      if((ackNo>Sf)&&(ackNo<=Sn))  //If a valid ACK
27      While(Sf <= ackNo)
28      {
29          PurgeFrame(Sf);
30          Sf = Sf + 1;
31      }
32      StopTimer();
33  }
34
35  if(Event(TimeOut))  //The timer expires
36  {
37      StartTimer();
38      Temp = Sf;
39      while(Temp < Sn);
40      {
41          SendFrame(Sf);
42          Sf = Sf + 1;
43      }
44  }
45  }
```

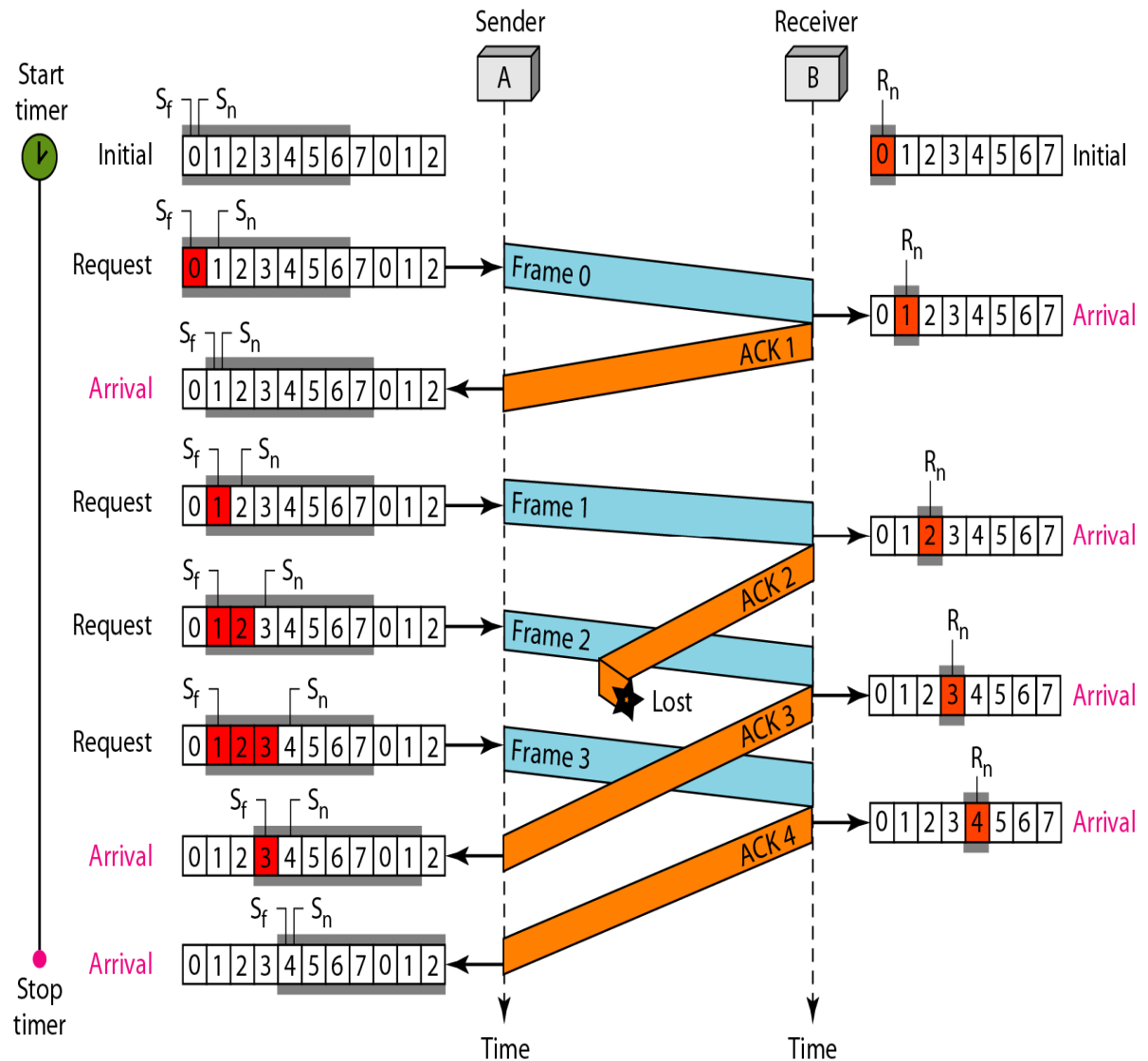
Go-Back-N receiver algorithm

```
1 Rn = 0;
2
3 while (true)                                //Repeat forever
4 {
5     WaitForEvent();
6
7     if(Event(ArrivalNotification))           //Data frame arrives
8     {
9         Receive(Frame);
10        if(corrupted(Frame))
11            Sleep();
12        if(seqNo == Rn)                       //If expected frame
13        {
14            DeliverData();                     //Deliver data
15            Rn = Rn + 1;                       //Slide window
16            SendACK(Rn);
17        }
18    }
19 }
```

Example of Go-Back-N

- The example shows how cumulative acknowledgments can help if acknowledgments are delayed or lost.

- Note that although ACK 2 is lost, ACK 3 serves as both ACK 2 and ACK 3.



- Stop-and-Wait ARQ is a special case of Go-Back-N ARQ in which the size of the send window is 1.

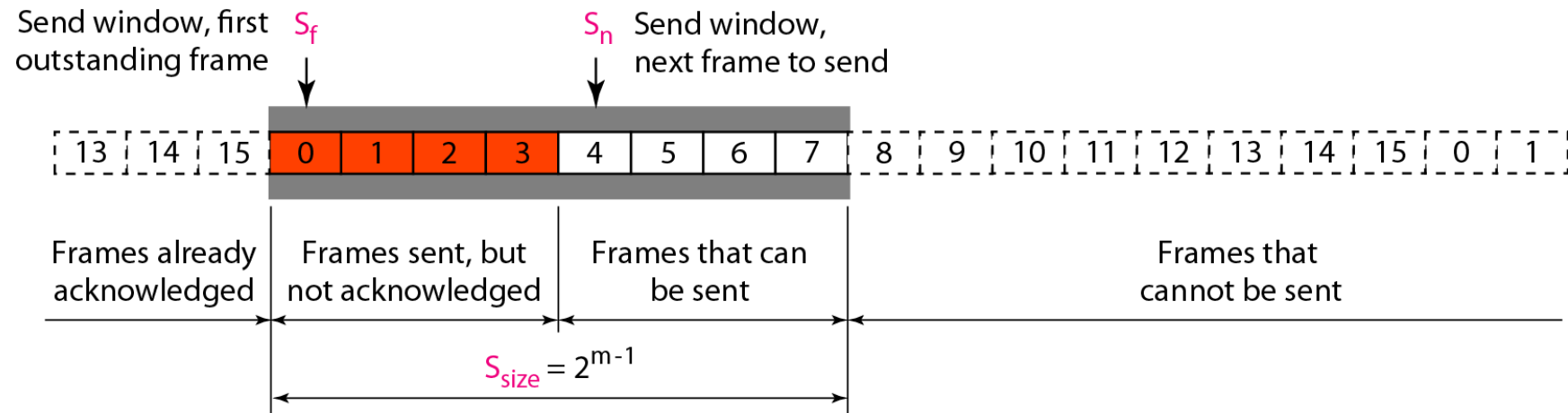
Selective Repeat ARQ

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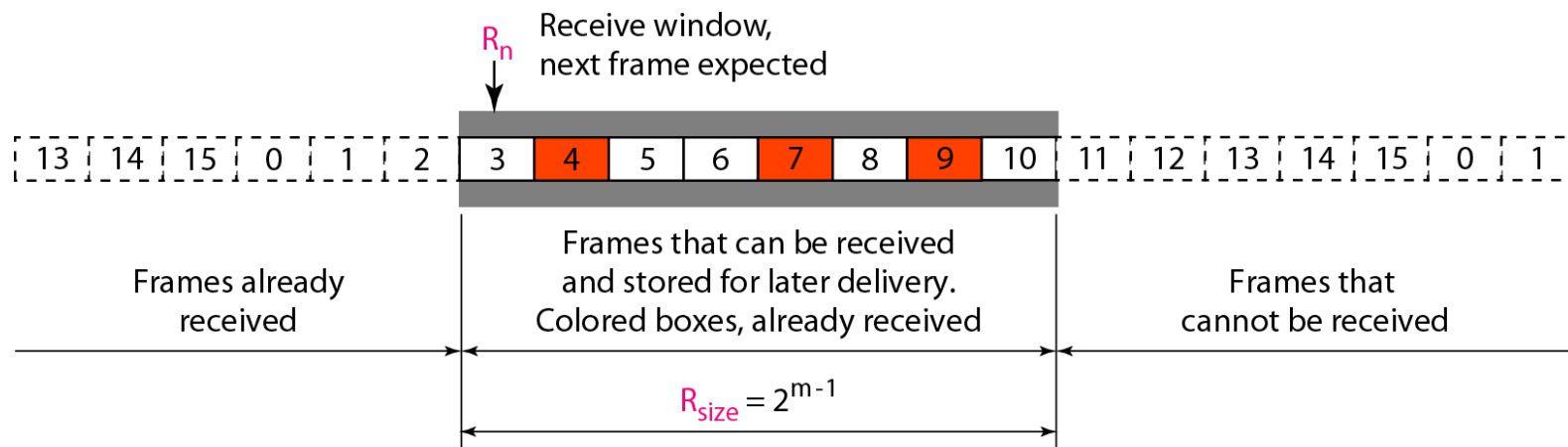
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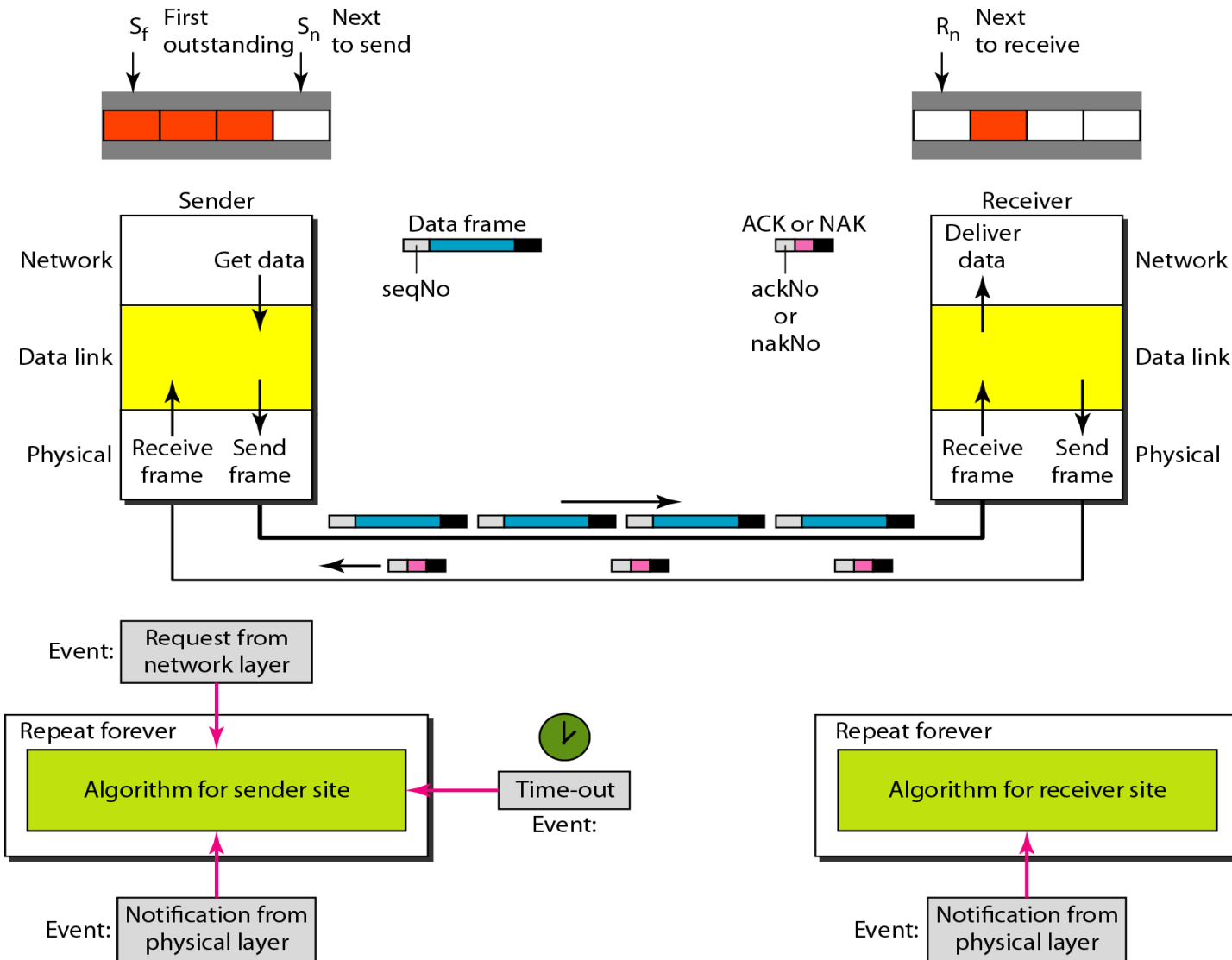
Send window for Selective Repeat ARQ



Receive window for Selective Repeat ARQ

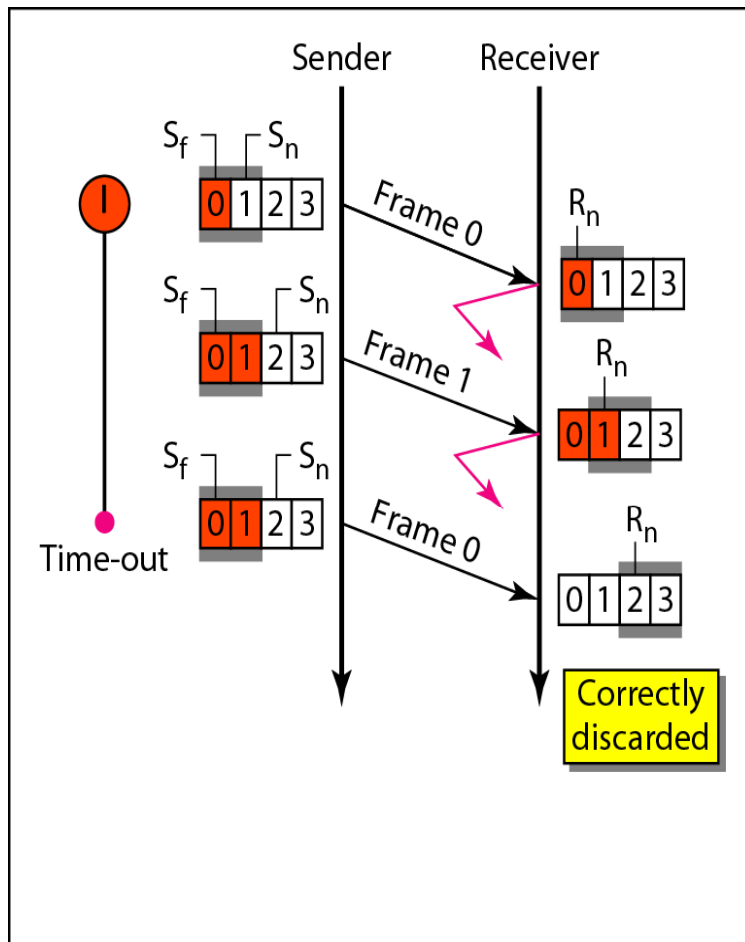


Design of Selective Repeat ARQ

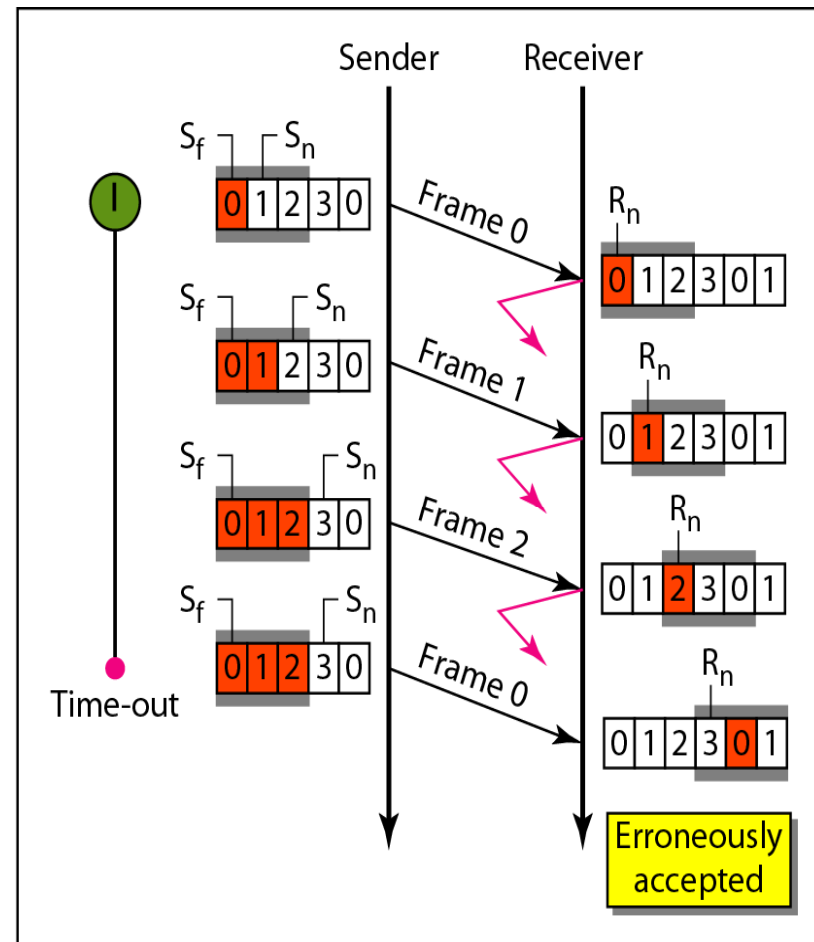


Selective Repeat ARQ, window size

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



a. Window size = 2^{m-1}



b. Window size > 2^{m-1}

Sender-site Selective Repeat algorithm

```
1  Sw = 2m-1 ;
2  Sf = 0;
3  Sn = 0;
4
5  while (true)                                //Repeat forever
6  {
7      WaitForEvent();
8      if(Event(RequestToSend))                //There is a packet to send
9      {
10         if(Sn-Sf >= Sw)                     //If window is full
11             Sleep();
12         GetData();
13         MakeFrame(Sn);
14         StoreFrame(Sn);
15         SendFrame(Sn);
16         Sn = Sn + 1;
17         StartTimer(Sn);
18     }
19
```

(continued)

Sender-site Selective Repeat algorithm

```
20  if(Event(ArrivalNotification)) //ACK arrives
21  {
22      Receive(frame);           //Receive ACK or NAK
23      if(corrupted(frame))
24          Sleep();
25      if (FrameType == NAK)
26          if (nakNo between  $S_f$  and  $S_n$ )
27          {
28              resend(nakNo);
29              StartTimer(nakNo);
30          }
31      if (FrameType == ACK)
32          if (ackNo between  $S_f$  and  $S_n$ )
33          {
34              while( $s_f < \text{ackNo}$ )
35              {
36                  Purge( $s_f$ );
37                  StopTimer( $s_f$ );
38                   $S_f = S_f + 1$ ;
39              }
40          }
41  }
```

(continued)

Sender-site Selective Repeat algorithm

```
42  
43   if (Event (TimeOut (t) ))           //The timer expires  
44   {  
45       StartTimer (t);  
46       SendFrame (t);  
47   }  
48 }
```

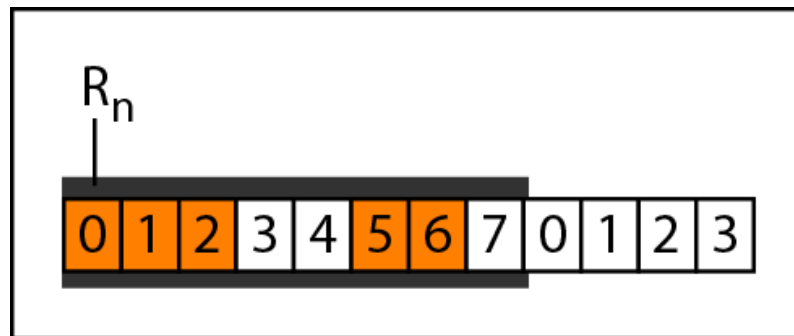
Receiver-site Selective Repeat algorithm

```
1  Rn = 0;
2  NakSent = false;
3  AckNeeded = false;
4  Repeat(for all slots)
5      Marked(slot) = false;
6
7  while (true)                                //Repeat forever
8  {
9      WaitForEvent();
10
11     if(Event(ArrivalNotification))           /Data frame arrives
12     {
13         Receive(Frame);
14         if(corrupted(Frame)) && (NOT NakSent)
15         {
16             SendNAK(Rn);
17             NakSent = true;
18             Sleep();
19         }
20         if(seqNo <> Rn) && (NOT NakSent)
21         {
22             SendNAK(Rn);
```

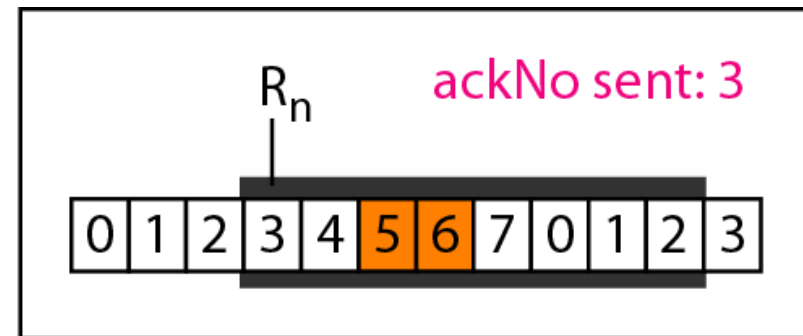
Receiver-site Selective Repeat algorithm

```
23     NakSent = true;
24     if ((seqNo in window)&&(!Marked(seqNo)))
25     {
26         StoreFrame(seqNo)
27         Marked(seqNo)= true;
28         while(Marked(Rn))
29         {
30             DeliverData(Rn);
31             Purge(Rn);
32             Rn = Rn + 1;
33             AckNeeded = true;
34         }
35         if(AckNeeded);
36         {
37             SendAck(Rn);
38             AckNeeded = false;
39             NakSent = false;
40         }
41     }
42 }
43 }
44 }
```

Delivery of data in Selective Repeat ARQ



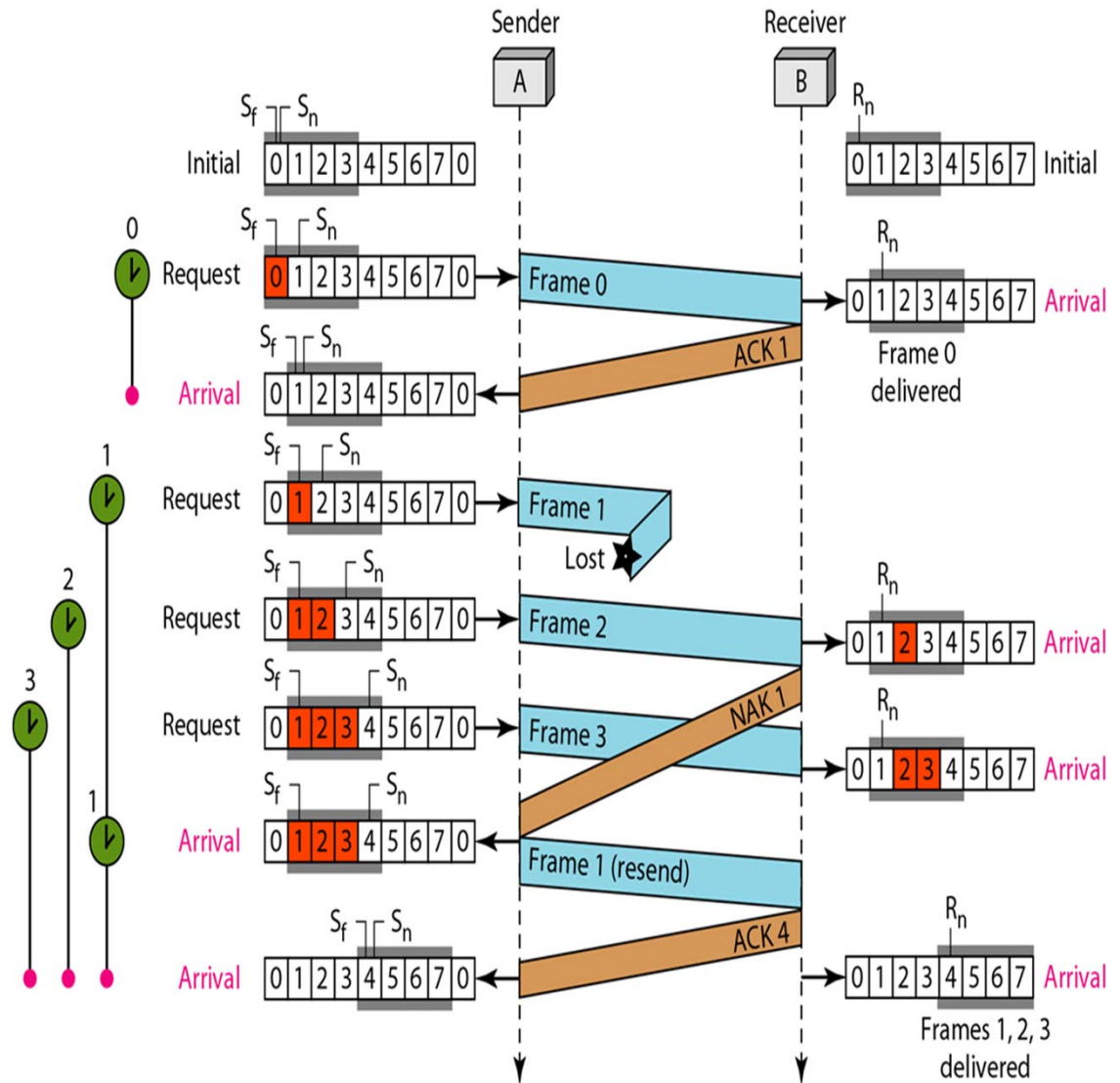
a. Before delivery



b. After delivery

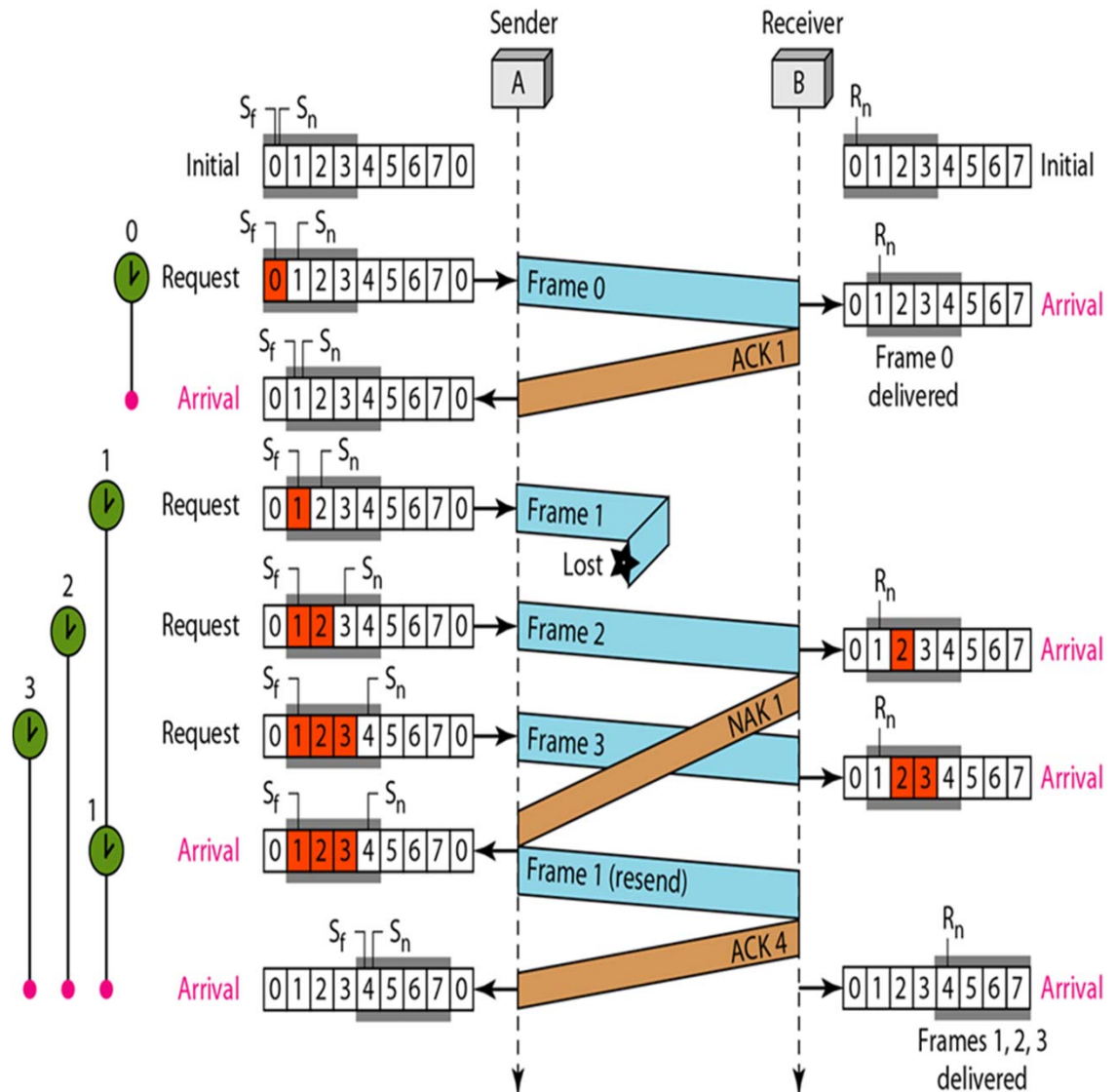
Example of Selective Repeat ARQ

- In this example frame 1 is lost.
- Each frame sent or resent needs a timer, which means that the timers need to be numbered (0, 1, 2, and 3).
- The timer for frame 0 starts at the first request, but stops when the ACK for this frame arrives.
- The timer for frame 1 starts at the second request, restarts when a NAK arrives, and finally stops when the last ACK arrives.
- The other two timers start when the corresponding frames are sent and stop at the last arrival event.



Example of Selective Repeat ARQ (continued)

- At the receiver site, frame 2 arrives before frame 1. It is stored and marked, but it cannot be delivered to the network layer because frame 1 is missing.
- At the next arrival, frame 3 arrives and is marked and stored, but still none of the frames can be delivered.
- Only at the last arrival, when finally a copy of frame 1 arrives, can frames 1, 2, and 3 be delivered to the network layer.



Example of Selective Repeat ARQ (continued)

- Another important point is that a NAK is sent after the second arrival, but not after the third, although both situations look the same.
 - The protocol does not want to crowd the network with unnecessary NAKs and resent frames.
- The next point is about the ACKs. Notice that only two ACKs are sent here. The first one acknowledges only the first frame; the second one acknowledges three frames.

