Data Link Layer

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

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

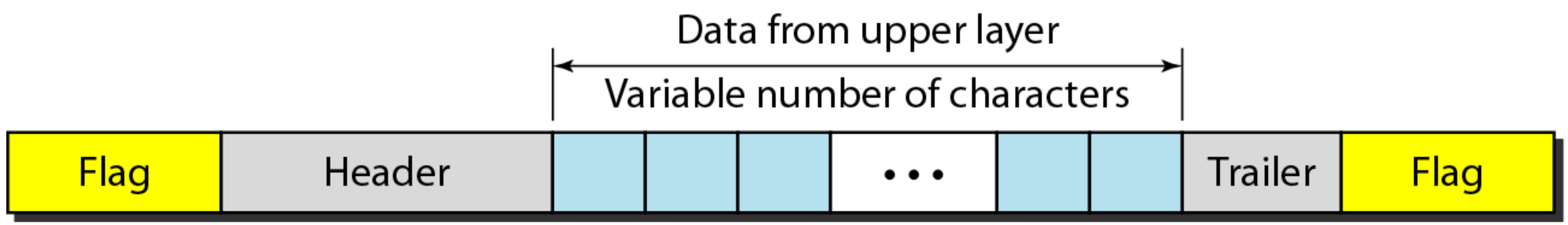
- Fixed-Size Framing
  - There is no need to define the boundaries of the frames, the size it self can act as a delimiter.

- 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.



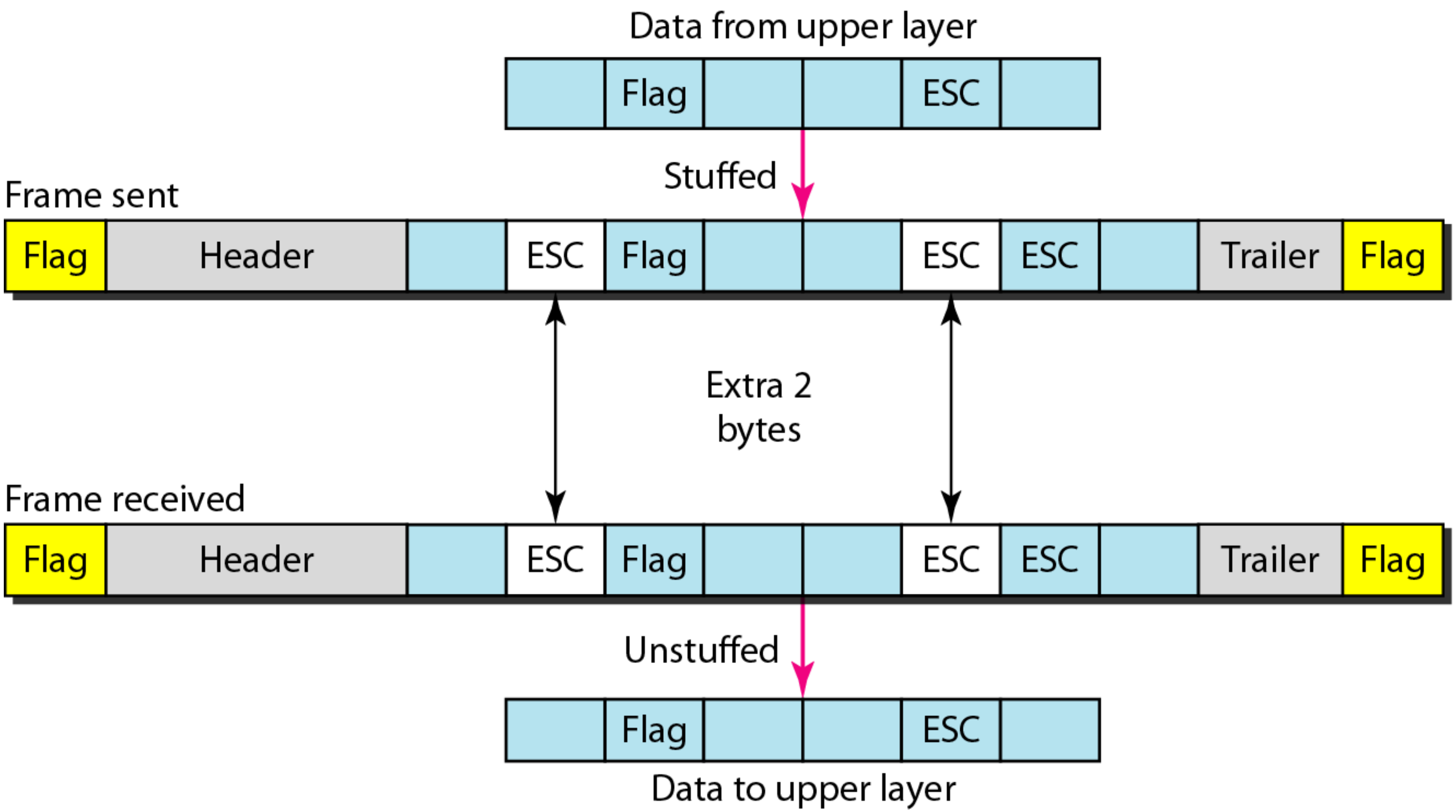
Byte stuffing and unstuffing

- 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.

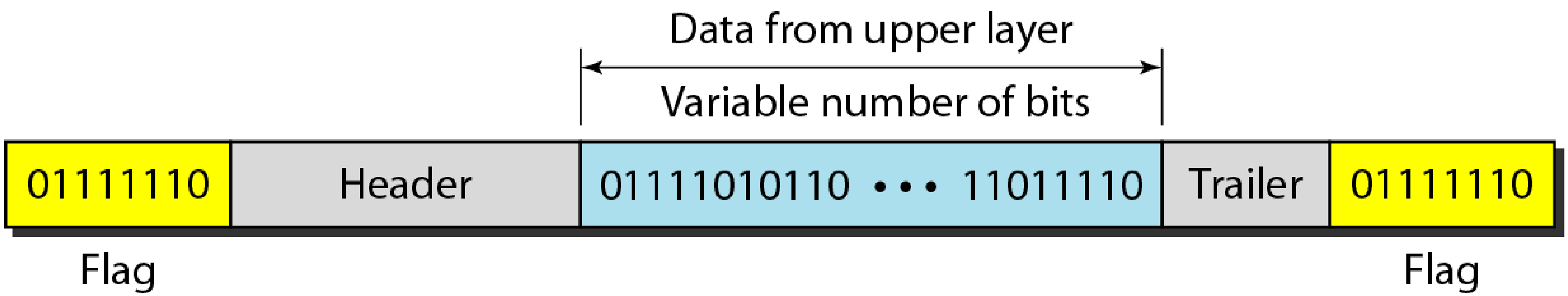
- The ESC char that are part of the text must also be marked by another ESC char.

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.

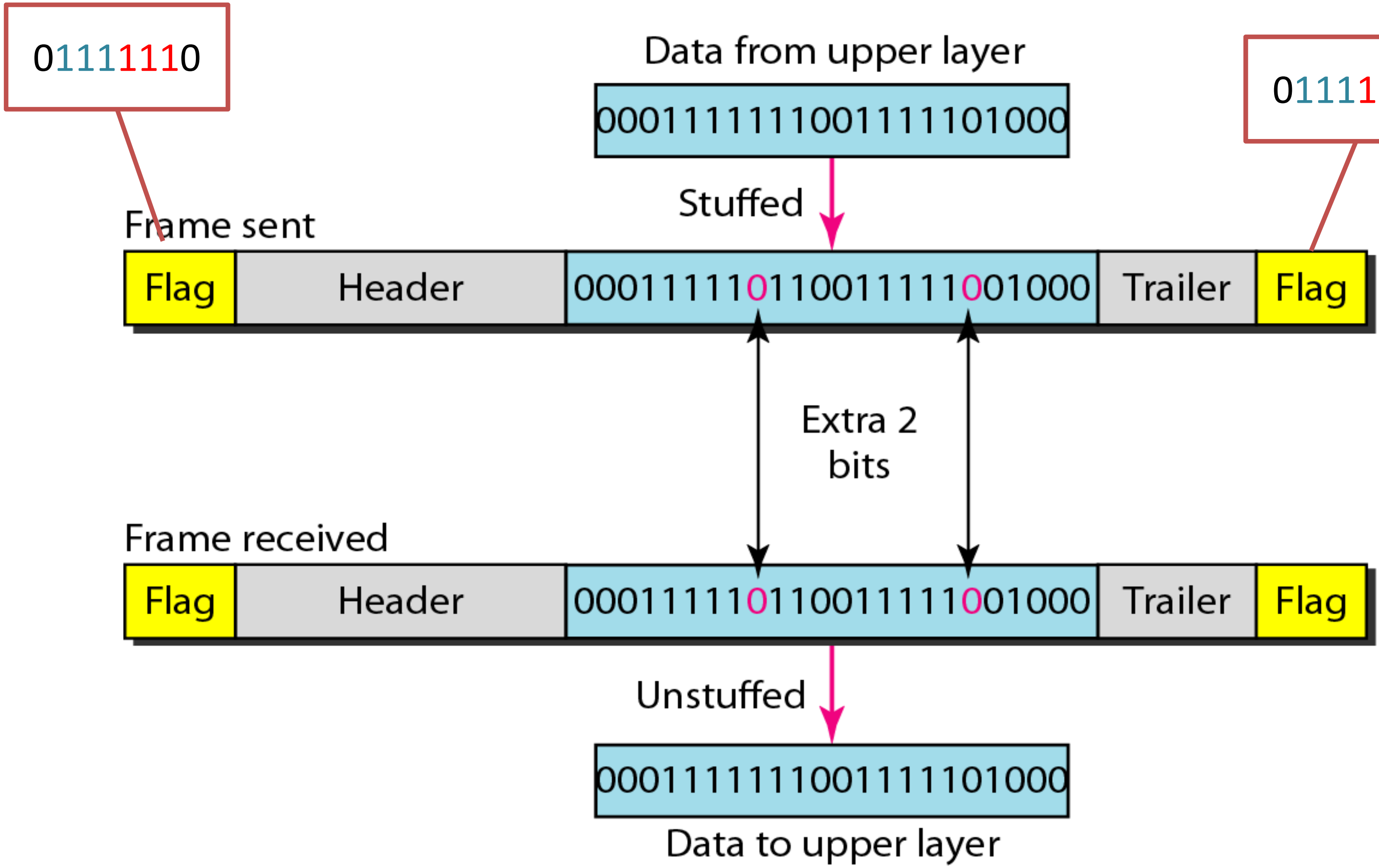
Frame in a bit-oriented protocol



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 0111110 for a flag.

Bit stuffing and unstuffing



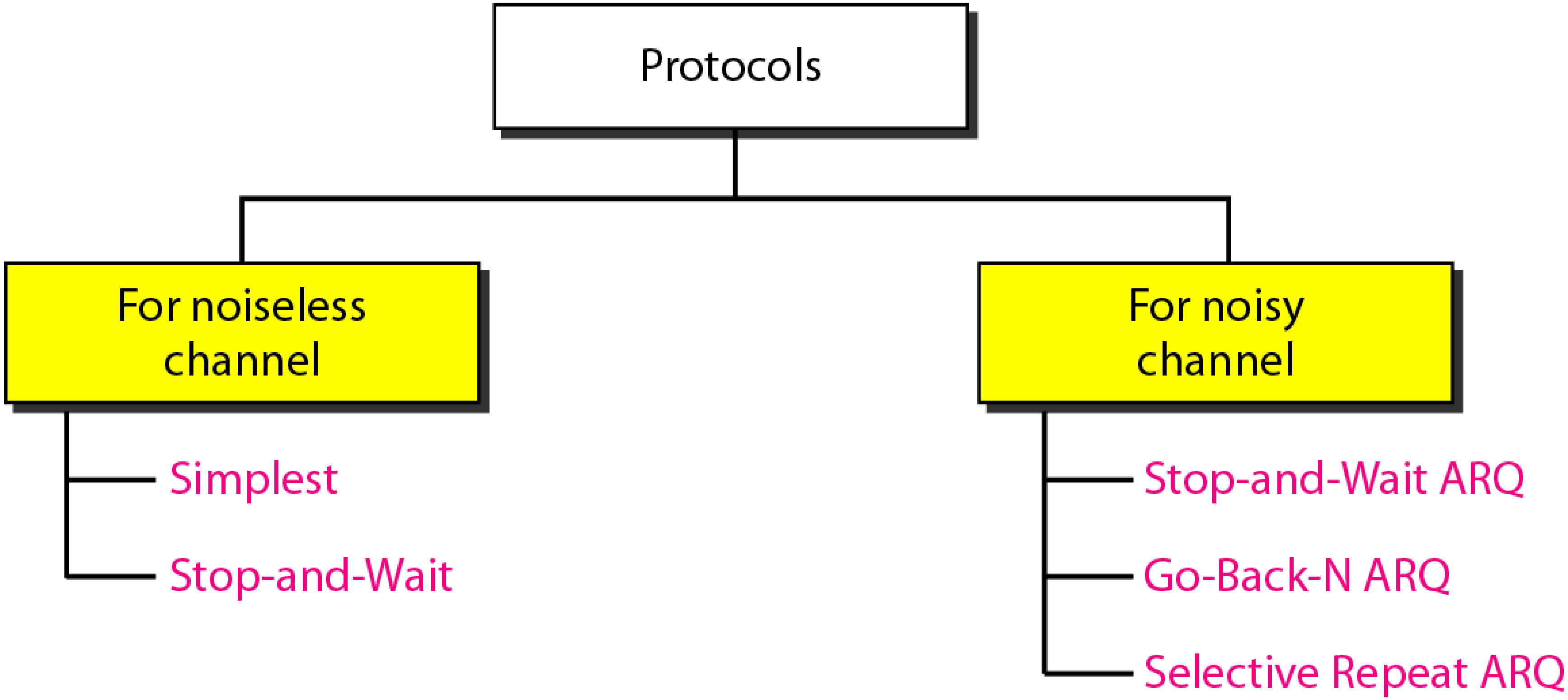
The most important responsibilities of the data link layer are flow control and error control. Collectively, known as data link control.

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.

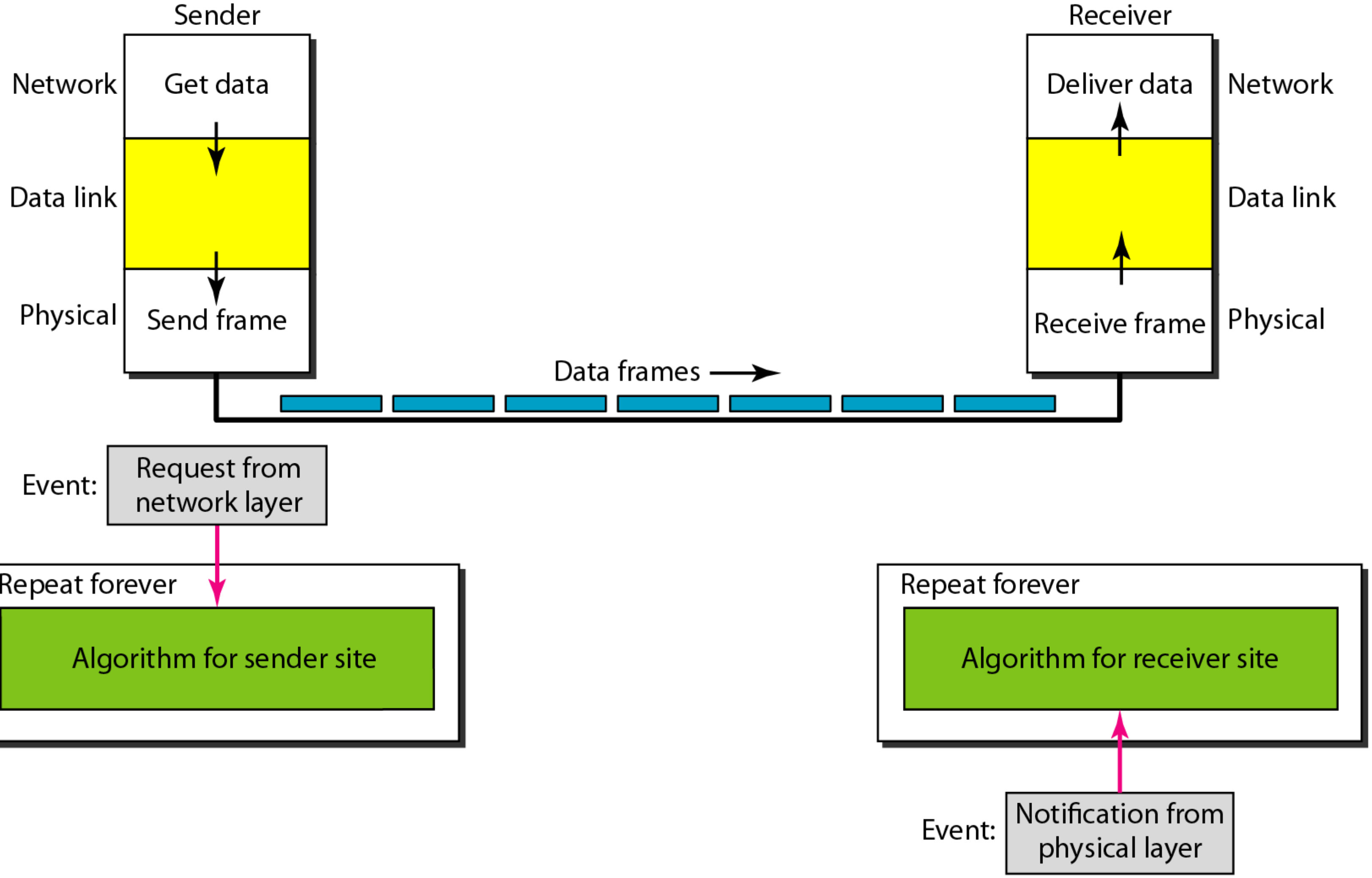

Protocols
For noiseless channel
Simplest
Stop-and-Wait
For noisy channel
Stop-and-Wait ARQ
Go-Back-N ARQ
Selective Repeat ARQ

Noiseless Channel

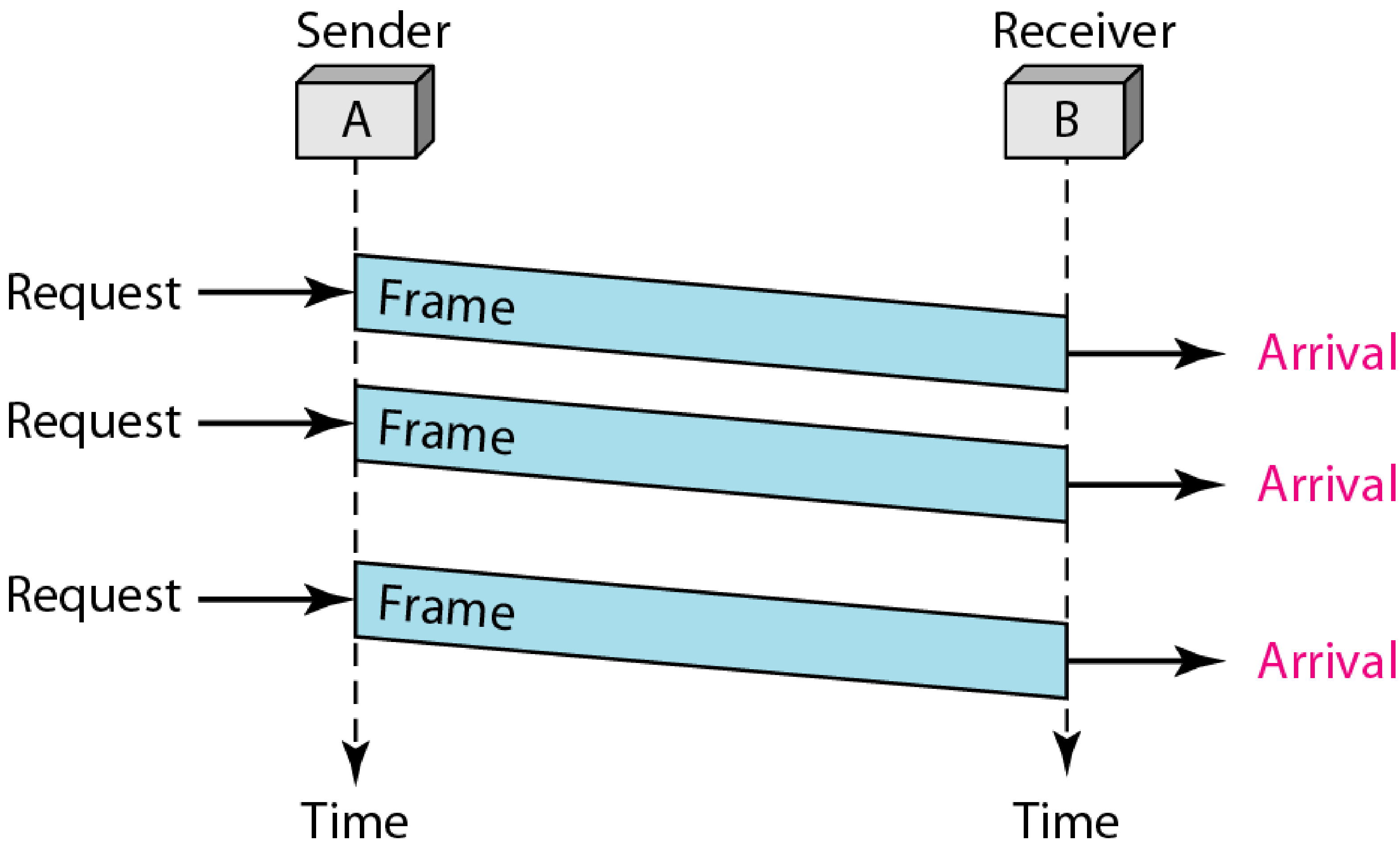
- Noiseless Channel: An ideal channel in which no frames are lost, duplicated, or corrupted.

- 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



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

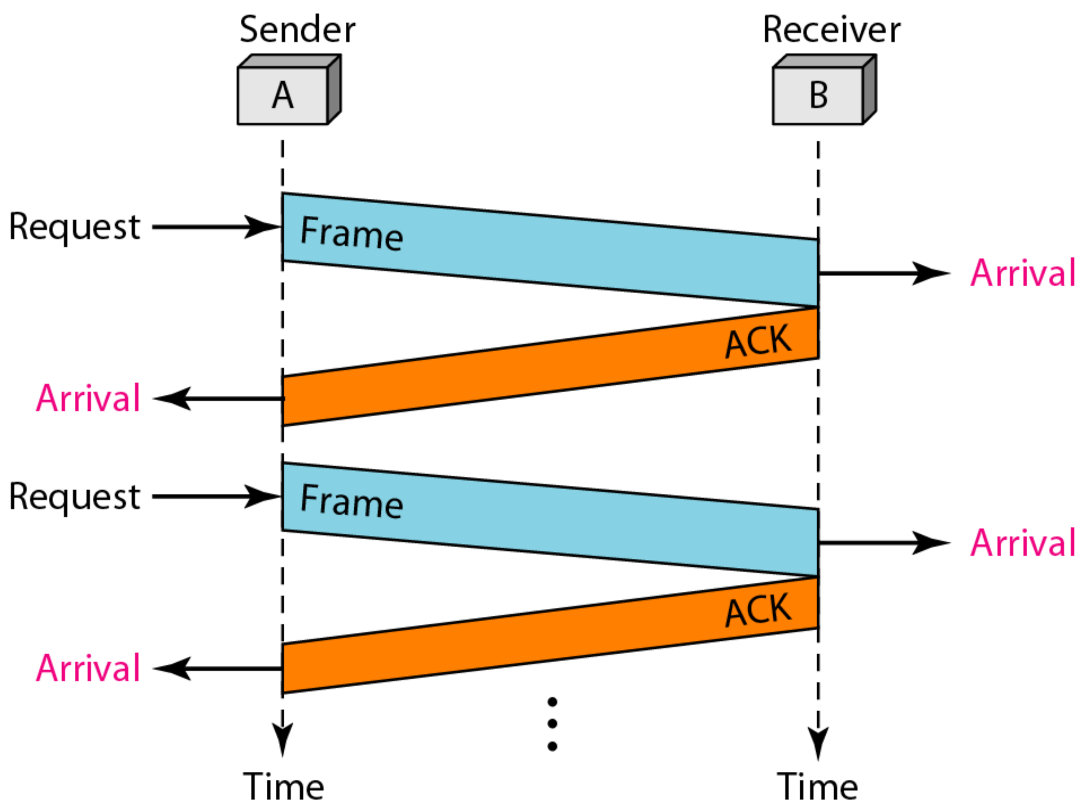
Sender-site algorithm for the simplest protocol

```
while(true)                         // Repeat forever
{
  WaitForEvent();                   // Sleep until an event occurs
  if(Event(ArrivalNotification))    //Data frame arrived
  {
     ReceiveFrame();
     ExtractData();
     DeliverData();                 //Deliver data to network layer
  }
}
```

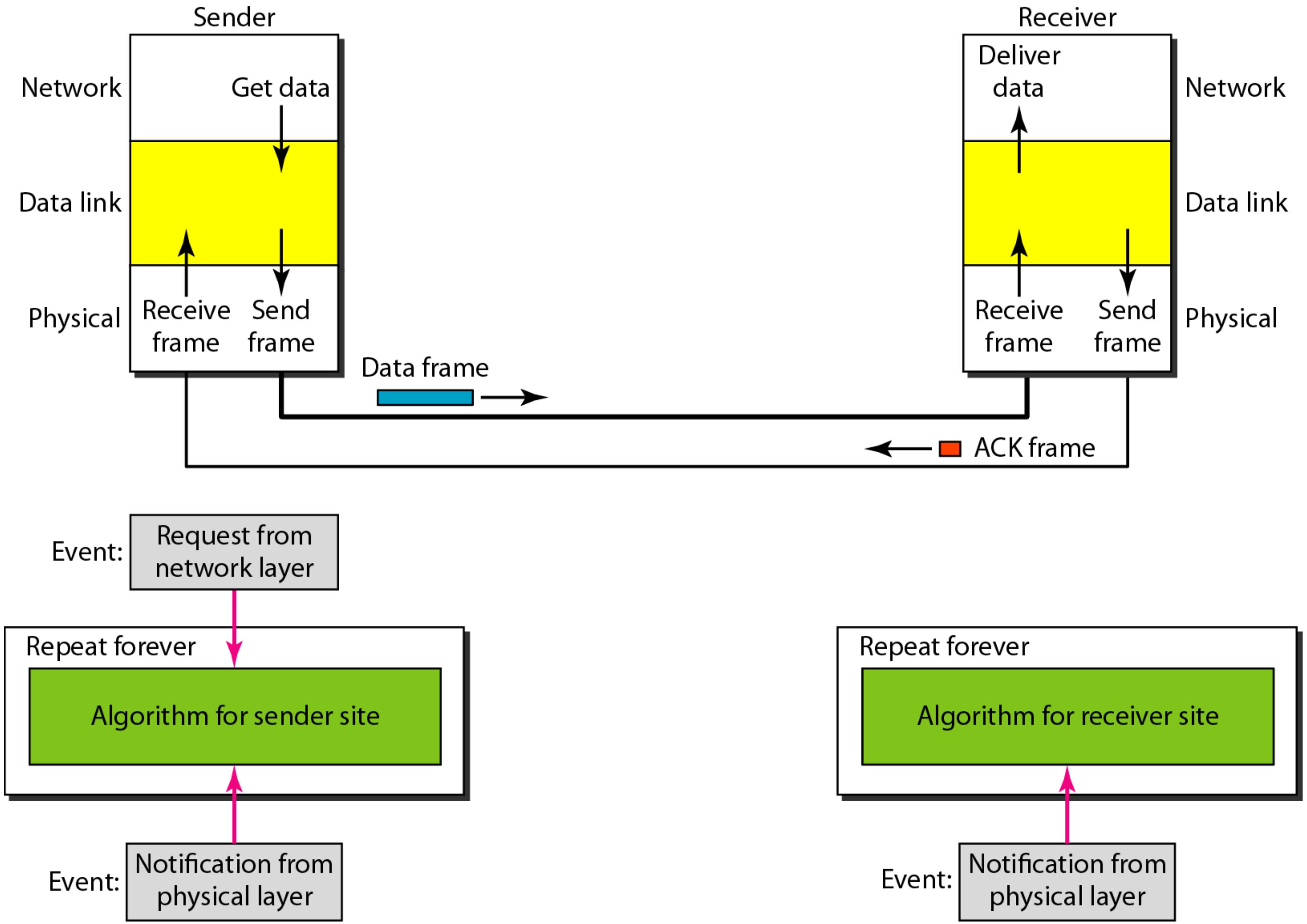
Receiver-site algorithm for the simplest protocol

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

```
while(true)                          //Repeat forever
canSend = true                       //Allow the first frame to go
{
  WaitForEvent();                    // Sleep until an event occurs
  if(Event(RequestToSend) AND canSend)
  {
     GetData();
     MakeFrame();
     SendFrame();                    //Send the data frame
     canSend = false;                //Cannot send until ACK arrives
  }
  WaitForEvent();                    // Sleep until an event occurs
  if(Event(ArrivalNotification)     // An ACK has arrived
   {
     ReceiveFrame();                 //Receive the ACK frame
     canSend = true;
   }
}
```

Receiver-site algorithm for Stop-and-Wait Protocol

```
while(true)                          //Repeat forever
{
  WaitForEvent();                    // Sleep until an event occurs
  if(Event(ArrivalNotification))     //Data frame arrives
  {
     ReceiveFrame();
     ExtractData();
     Deliver(data);                  //Deliver data to network layer
     SendFrame();                    //Send an ACK frame
  }
}
```

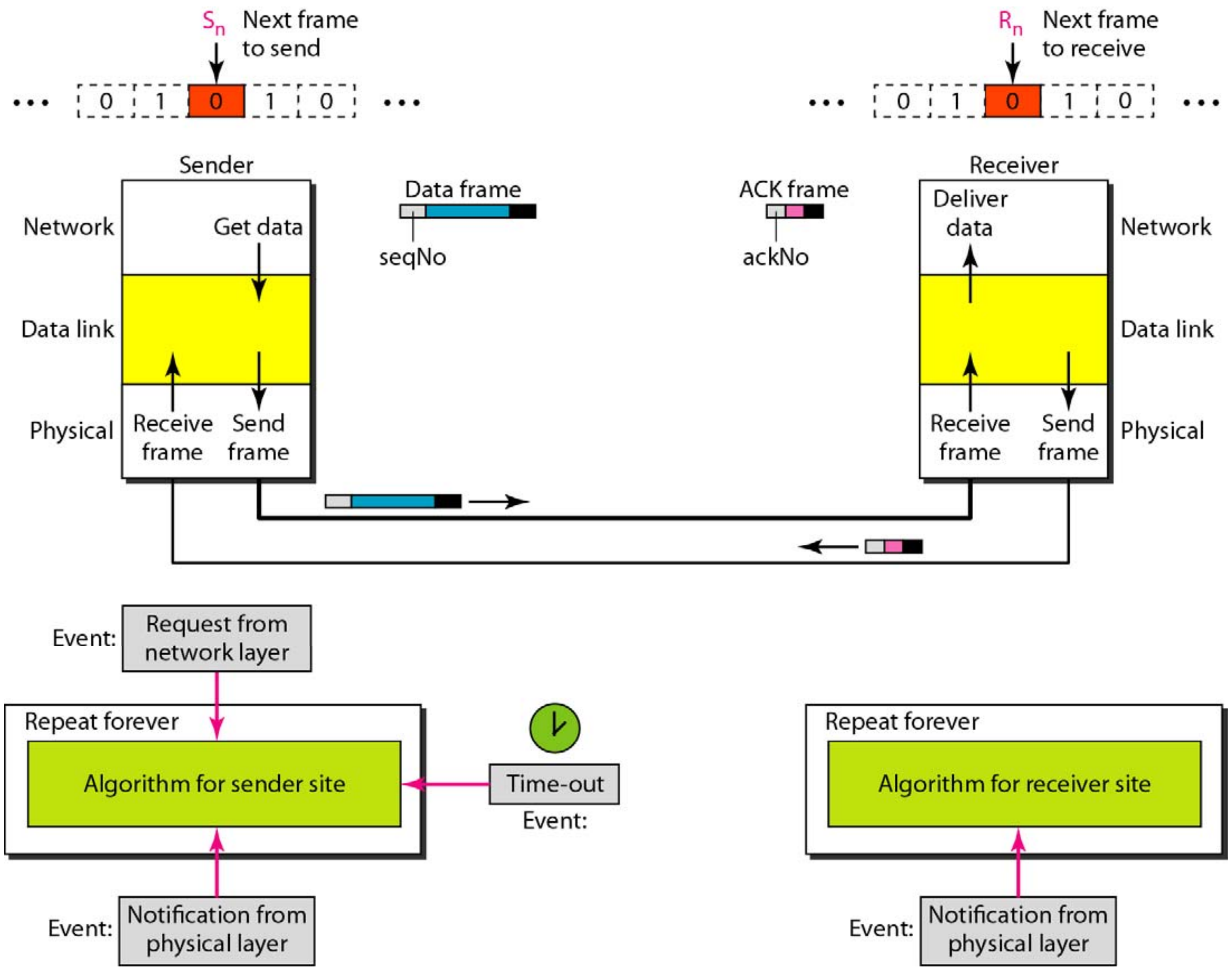
Noisy Channel

- 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

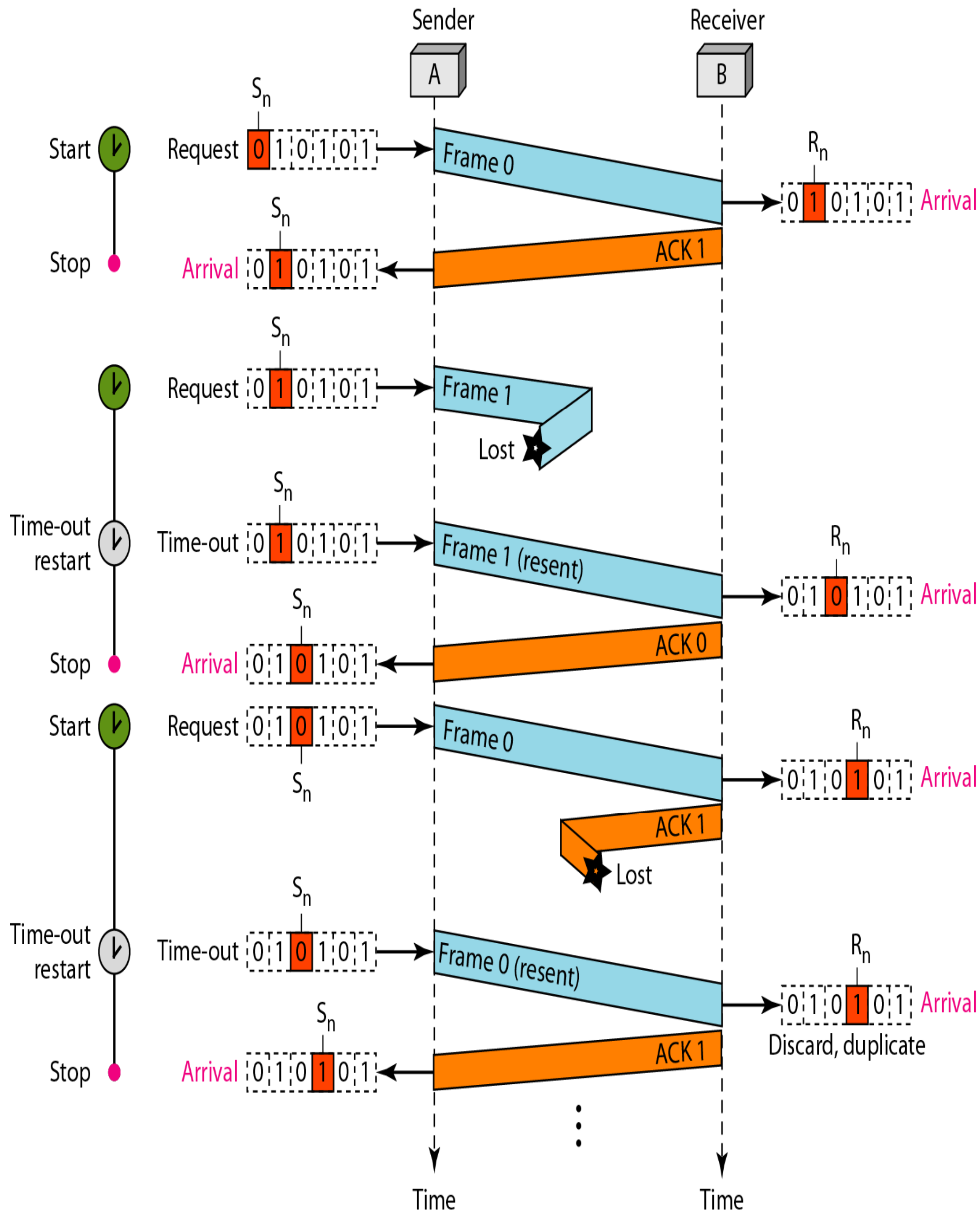
- Error correction in Stop-and-Wait ARQ is done by keeping a copy of the sent frame and retransmitting of the frame when the timer expires.
- In Stop-and-Wait ARQ, we use sequence numbers to number the frames.
- The sequence numbers are based on modulo-2 arithmetic.
- In Stop-and-Wait ARQ, the acknowledgment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

```
Sn = 0;                          // Frame 0 should be sent first
canSend = true;                  // Allow the first request to go
while(true)                      // Repeat forever
{
  WaitForEvent();                // Sleep until an event occurs
  if(Event(RequestToSend) AND canSend)
  {
     GetData();
     MakeFrame(Sn);                    //The seqNo is Sn
     StoreFrame(Sn);                   //Keep copy
     SendFrame(Sn);
     StartTimer();
     Sn = Sn + 1;
     canSend = false;
  }
  WaitForEvent();                      // Sleep
```

(continued)

Sender-site algorithm for Stop-and-Wait ARQ

```
    if(Event(ArrivalNotification)      // An ACK has arrived
    {
      ReceiveFrame(ackNo);             //Receive the ACK frame
      if(not corrupted AND ackNo == Sn) //Valid ACK
        {
          Stoptimer();
          PurgeFrame(Sn-1);            //Copy is not needed
          canSend = true;
        }
     }

    if(Event(TimeOut)                  // The timer expired
    {
     StartTimer();
     ResendFrame(Sn-1);                //Resend a copy check
    }
}
```

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

```
Rn = 0;                              // Frame 0 expected to arrive first
while(true)
{
  WaitForEvent();                    // Sleep until an event occurs
  if(Event(ArrivalNotification))     //Data frame arrives
  {
     ReceiveFrame();
     if(corrupted(frame));
        sleep();
     if(seqNo == Rn)                 //Valid data frame
     {
      ExtractData();
       DeliverData();                //Deliver data
       Rn = Rn + 1;
     }
      SendFrame(Rn);                 //Send an ACK
  }
}
```

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

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

- 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.

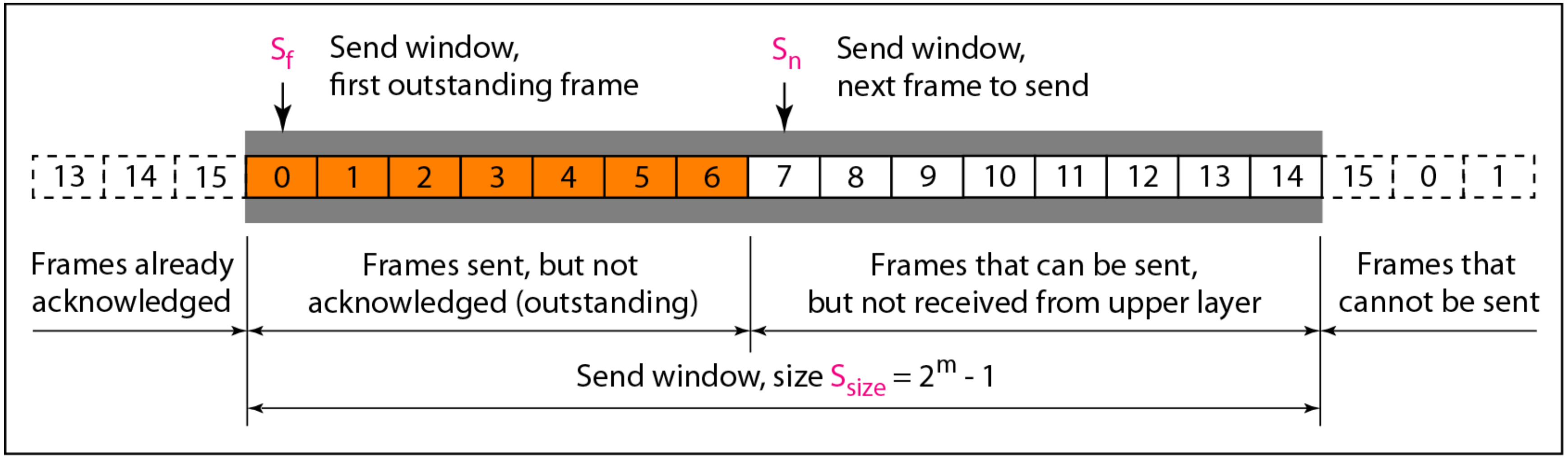
Go-Back-N ARQ

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

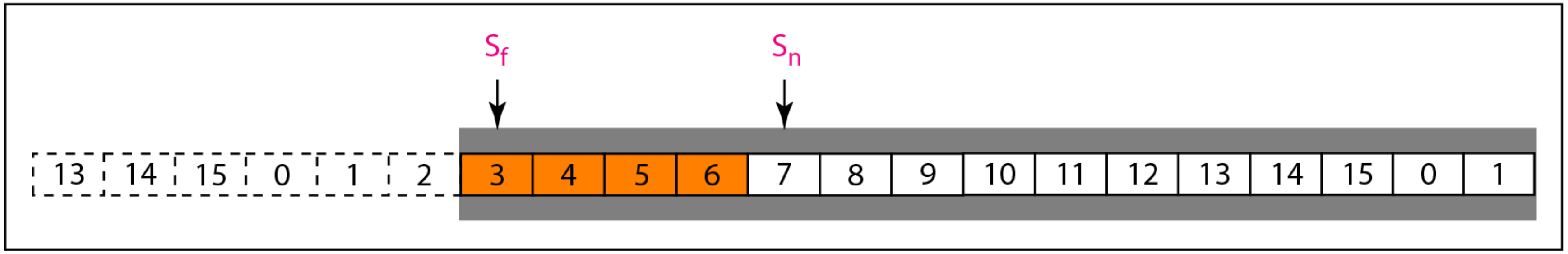
- The send window is an abstract concept defining an imaginary box of size $2^m - 1$ with three variables: S_f, S_n, and S_{size}.

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

Send window for Go-Back-N ARQ



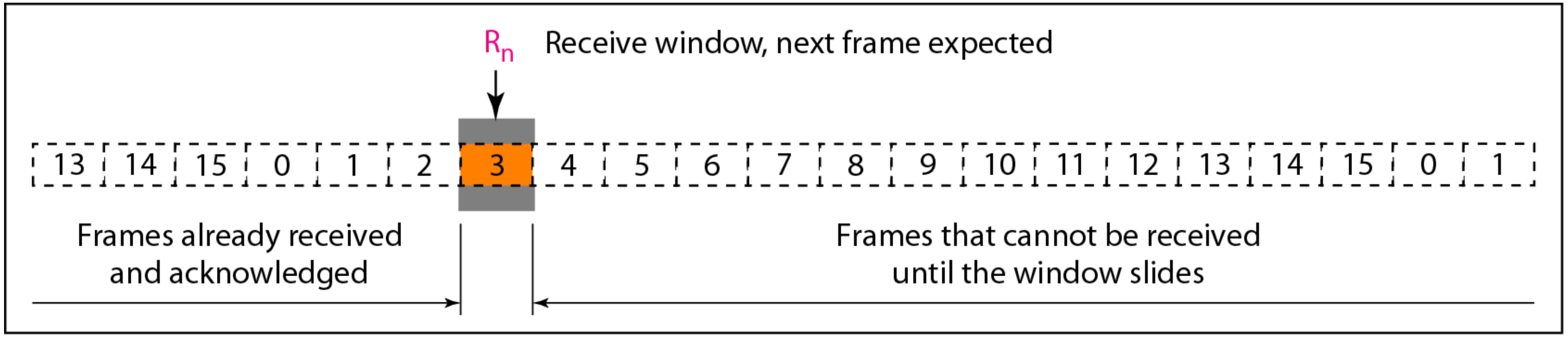
a. Send window before sliding



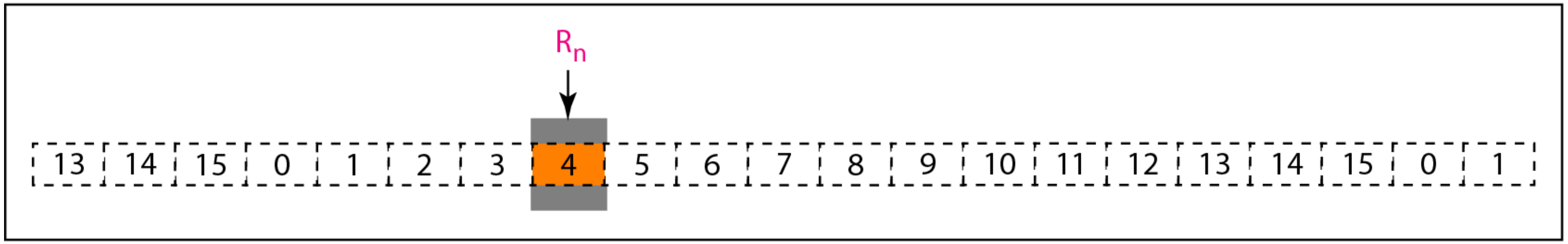
b. Send window after sliding

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.

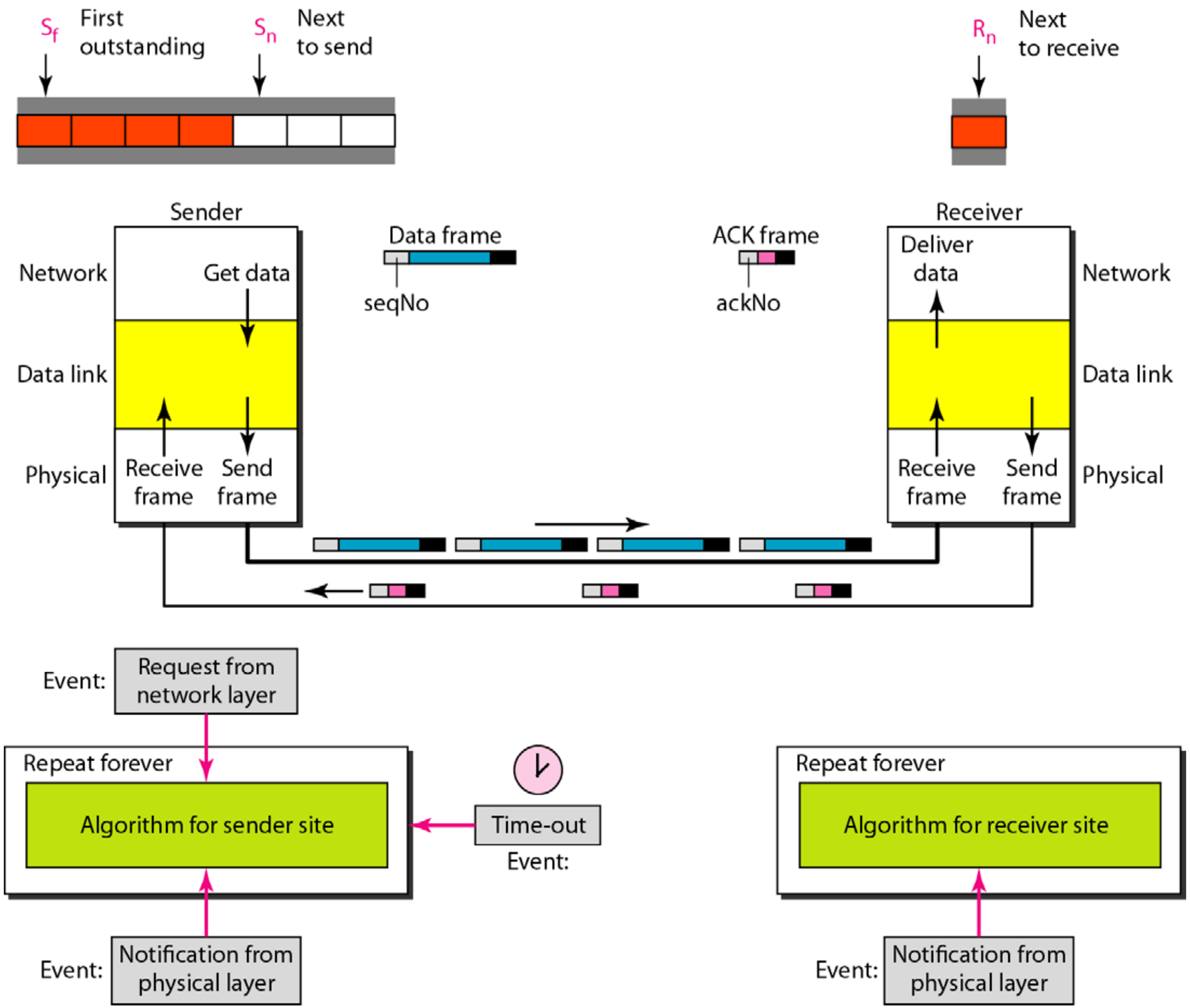


a. Receive window



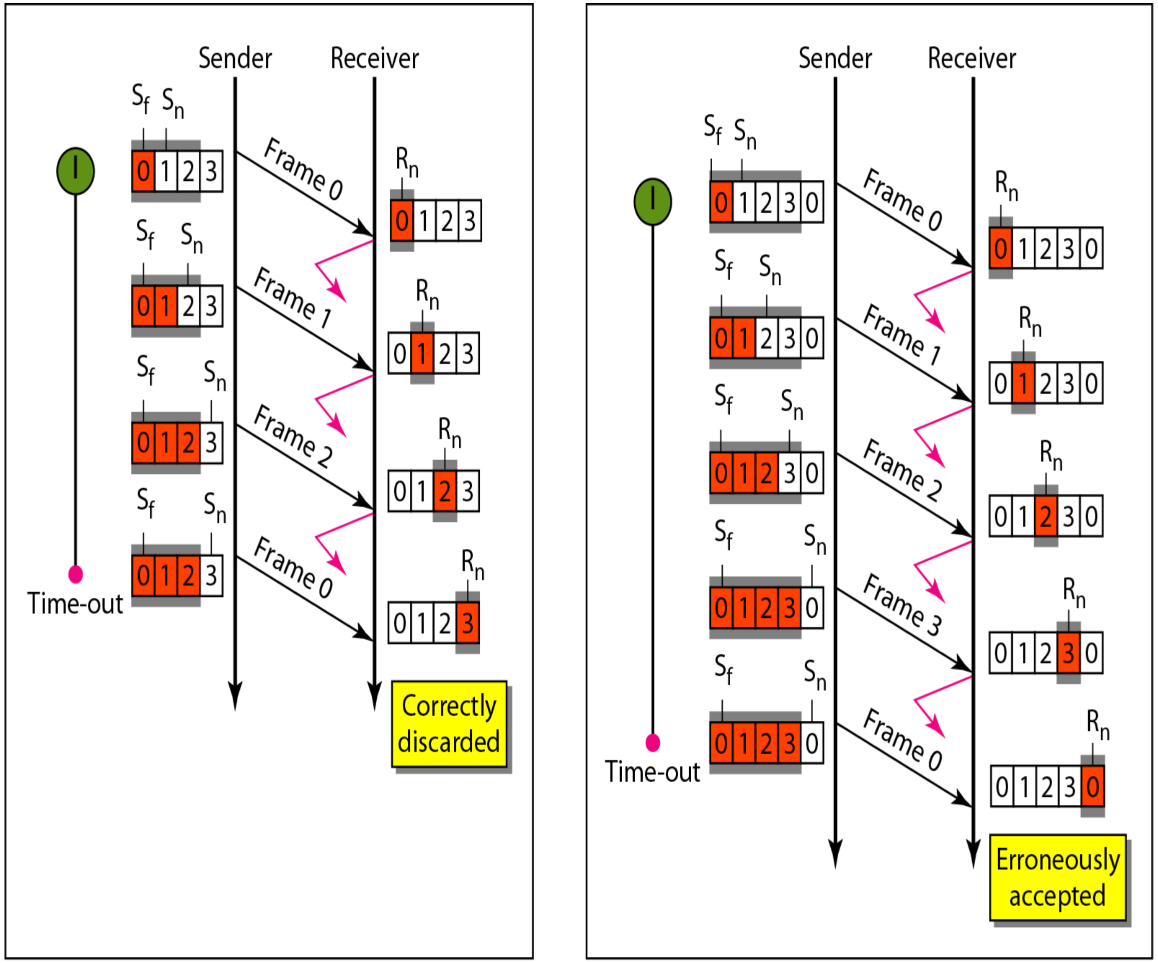
b. Window after sliding

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

```
S_w = 2^m - 1;
S_f = 0;
S_n = 0;

while (true)                              //Repeat forever
{
 WaitForEvent();
  if(Event(RequestToSend))                //A packet to send
  {
     if(S_n-S_f >= S_w)                   //If window is full
           Sleep();
     GetData();
     MakeFrame(S_n);
     StoreFrame(S_n);
     SendFrame(S_n);
     S_n = S_n + 1;
     if(timer not running)
          StartTimer();
  }

```

(continued)

Go-Back-N sender algorithm

```
  if(Event(ArrivalNotification))  //ACK arrives
  {
     Receive(ACK);
     if(corrupted(ACK))
          Sleep();
     if((ackNo>Sf)&&(ackNo<=Sn))  //If a valid ACK
     While(Sf <= ackNo)
      {
       PurgeFrame(Sf);
       Sf = Sf + 1;
      }
      StopTimer();
  }

  if(Event(TimeOut))              //The timer expires
  {
   StartTimer();
   Temp = Sf;
   while(Temp < Sn);
    {
     SendFrame(Sf);
     Sf = Sf + 1;
    }
  }
}
```

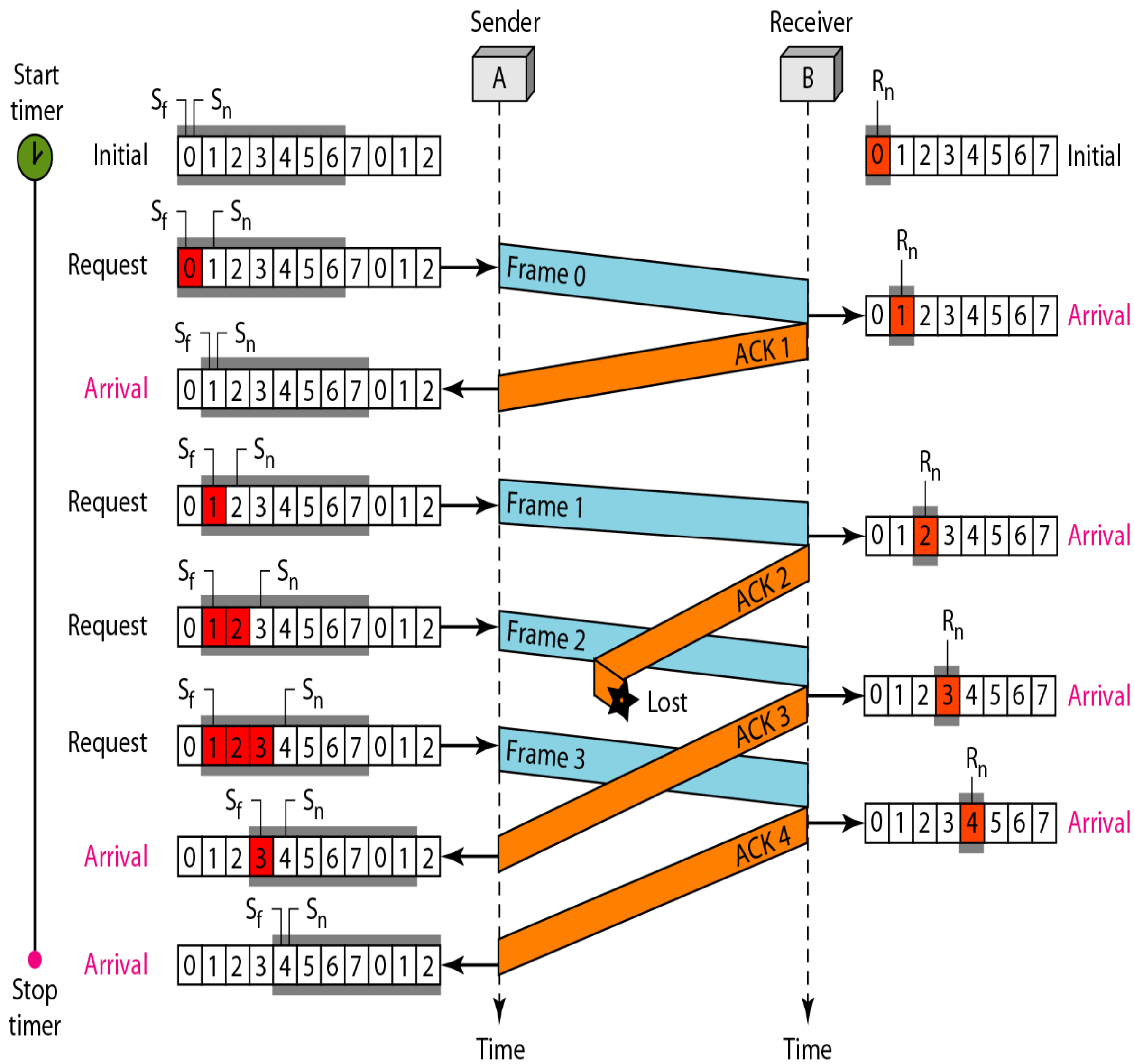
Go-Back-N receiver algorithm

```
Rn = 0;

while (true)                              //Repeat forever
{
  WaitForEvent();

  if(Event(ArrivalNotification)) /Data frame arrives
  {
     Receive(Frame);
     if(corrupted(Frame))
          Sleep();
     if(seqNo == Rn)                      //If expected frame
     {
       DeliverData();                     //Deliver data
       Rn = Rn + 1;                       //Slide window
       SendACK(Rn);
     }
  }
}
```

Example of Go-Back-N

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

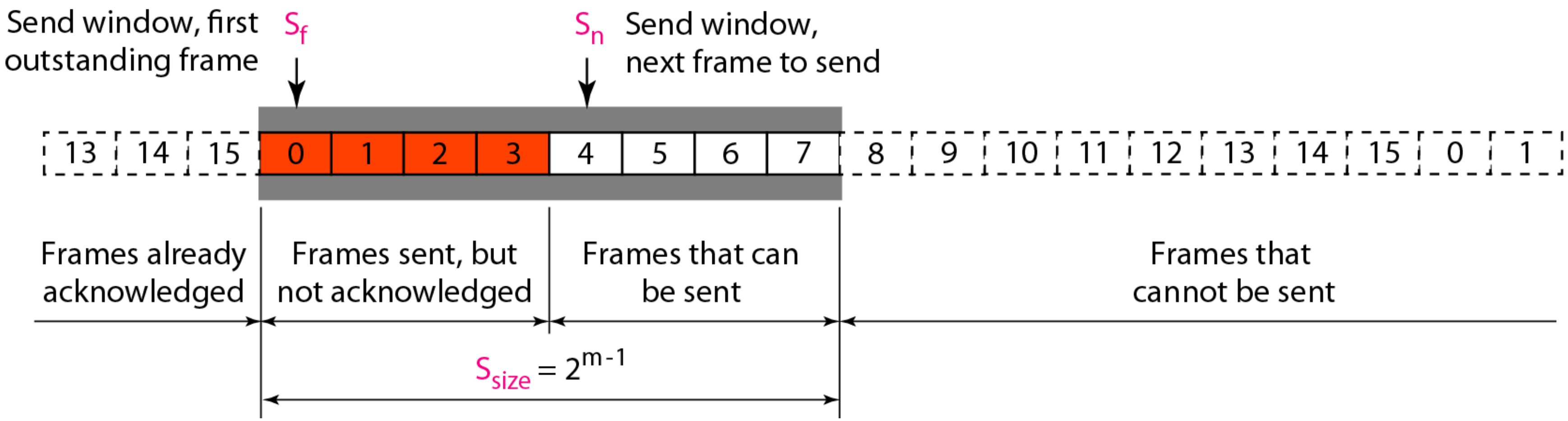
- Note that although ACK 2 is lost, ACK 3 serves as both ACK 2 and ACK 3.



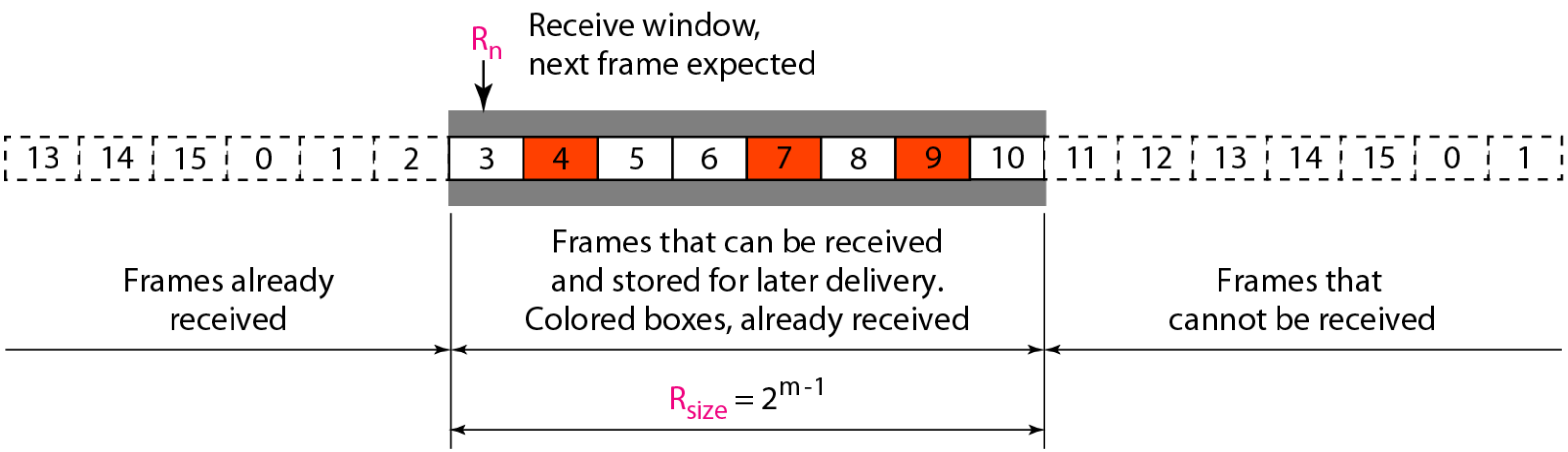
- Stop-and-Wait ARQ is a special case of Go-Back-N ARQ in which the size of the send window is 1.

Selective Repeat ARQ

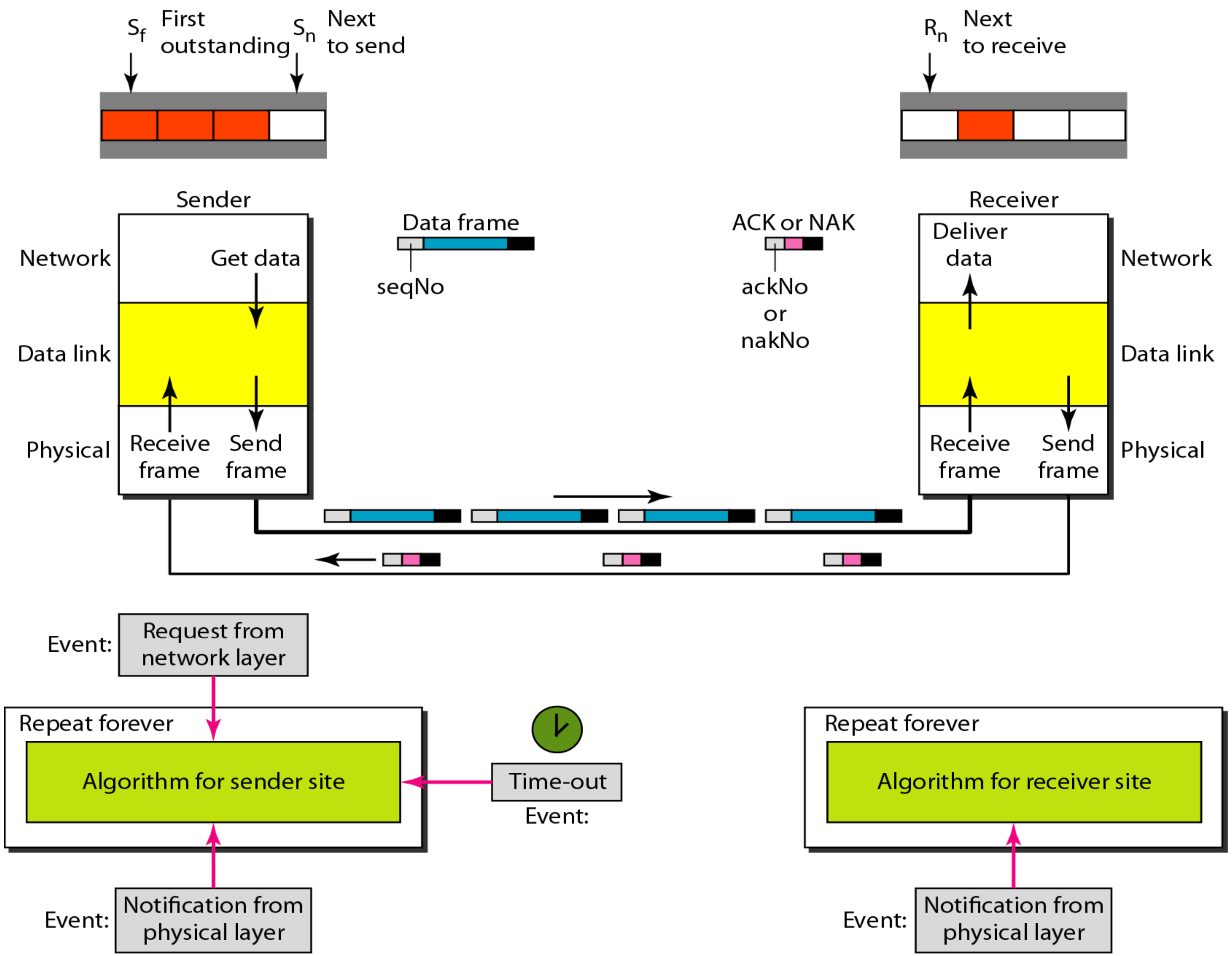
Send window for Selective Repeat ARQ



Receive window for Selective Repeat ARQ

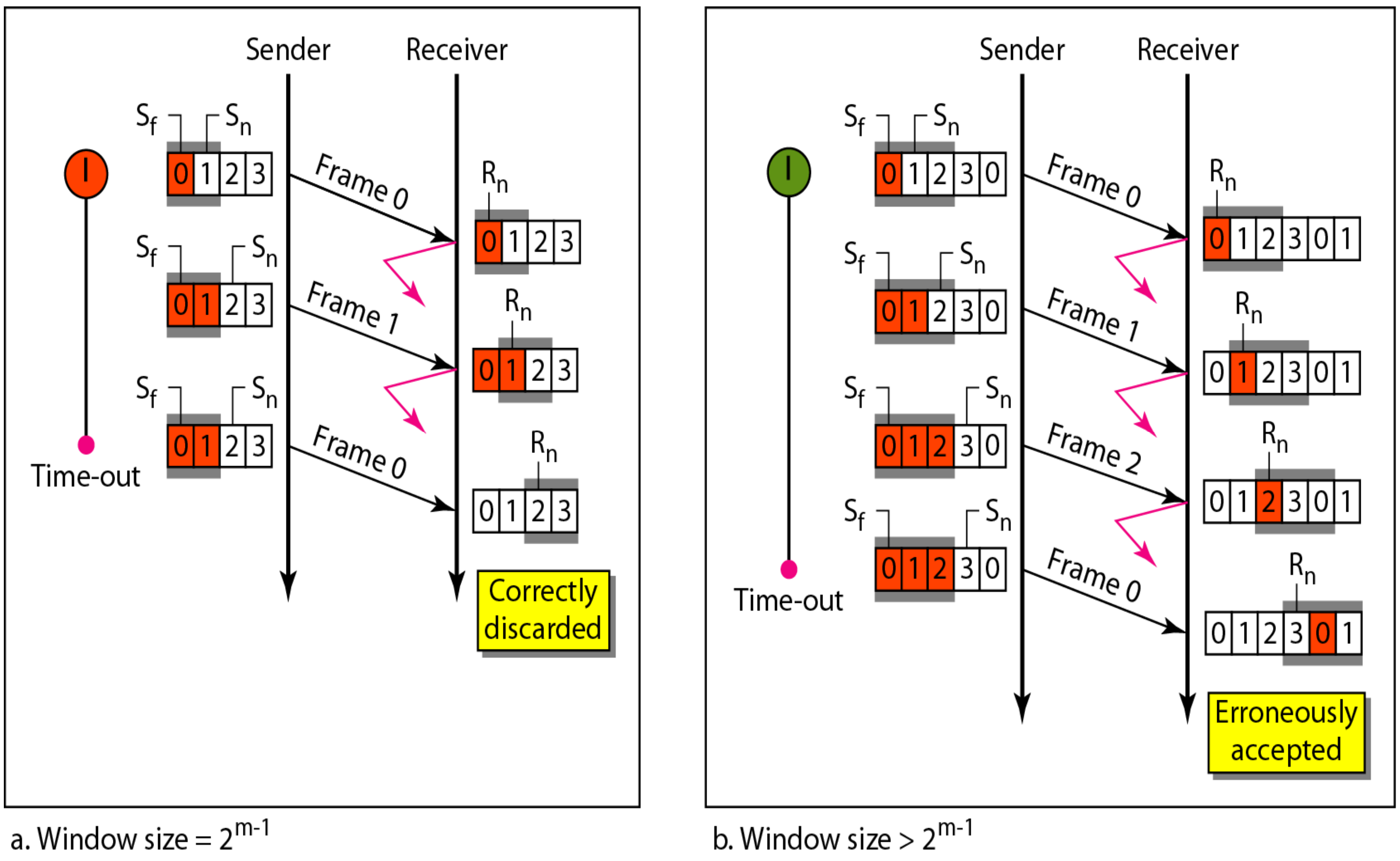


Design of Selective Repeat ARQ



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.



Sender-site Selective Repeat algorithm

```
S_w = 2^(m-1) ;
S_f = 0;
S_n = 0;

while (true)                              //Repeat forever
{
  WaitForEvent();
  if(Event(RequestToSend))                //There is a packet to send
  {
     if(S_n-S_f >= S_w)                   //If window is full
            Sleep();
     GetData();
     MakeFrame(S_n);
     StoreFrame(S_n);
     SendFrame(S_n);
     S_n = S_n + 1;
     StartTimer(S_n);
  }

```

(continued)

Sender-site Selective Repeat algorithm

```
if(Event(ArrivalNotification)) //ACK arrives
{
   Receive(frame);               //Receive ACK or NAK
   if(corrupted(frame))
        Sleep();
   if (FrameType == NAK)
      if (nakNo between Sf and Sn)
      {
       resend(nakNo);
       StartTimer(nakNo);
      }
   if (FrameType == ACK)
      if (ackNo between Sf and Sn)
      {
        while(sf < ackNo)
        {
         Purge(sf);
         StopTimer(sf);
         Sf = Sf + 1;
        }
      }
}
```

(continued)

Sender-site Selective Repeat algorithm

```

  if(Event(TimeOut(t)))               //The timer expires
  {
   StartTimer(t);
   SendFrame(t);
  }
}
```

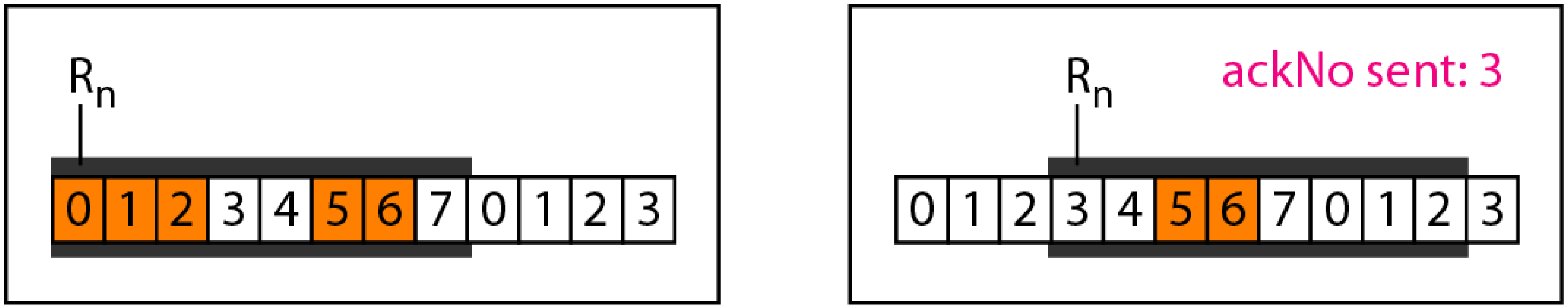
Receiver-site Selective Repeat algorithm

```
Rn = 0;
NakSent = false;
AckNeeded = false;
Repeat(for all slots)
    Marked(slot) = false;

while (true)                                        //Repeat forever
{
  WaitForEvent();

  if(Event(ArrivalNotification))                    /Data frame arrives
  {
     Receive(Frame);
     if(corrupted(Frame))&& (NOT NakSent)
     {
      SendNAK(Rn);
      NakSent = true;
      Sleep();
     }
     if(seqNo <> Rn)&& (NOT NakSent)
     {
      SendNAK(Rn);
```

Receiver-site Selective Repeat algorithm

```
        NakSent = true;
        if ((seqNo in window)&&(!Marked(seqNo))
        {
         StoreFrame(seqNo)
         Marked(seqNo)= true;
         while(Marked(Rn))
         {
          DeliverData(Rn);
          Purge(Rn);
          Rn = Rn + 1;
          AckNeeded = true;
         }
          if(AckNeeded);
          {
          SendAck(Rn);
          AckNeeded = false;
          NakSent = false;
          }
        }
      }
   }
}
```

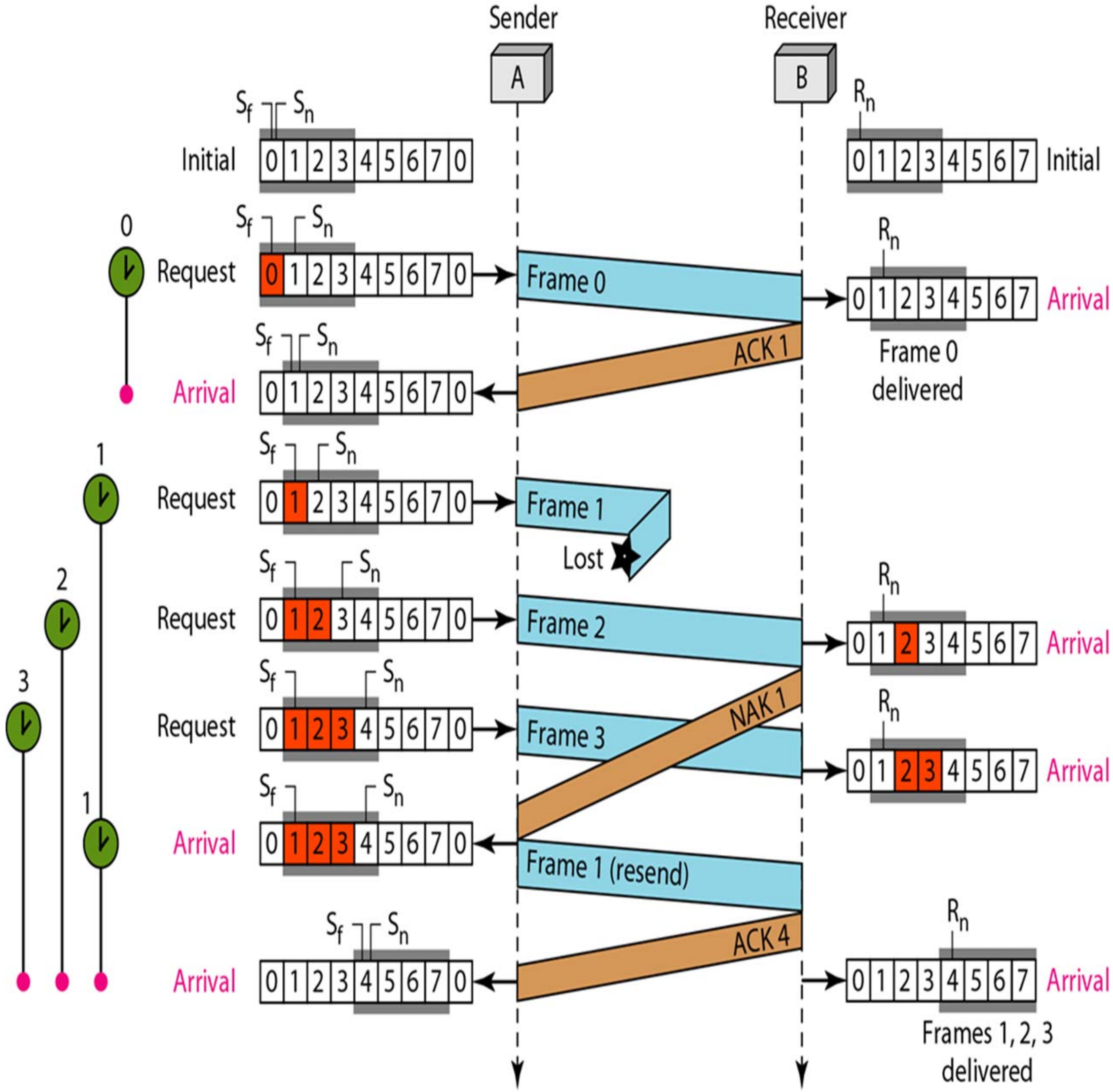
Delivery of data in Selective Repeat ARQ



a. Before delivery   b. After delivery

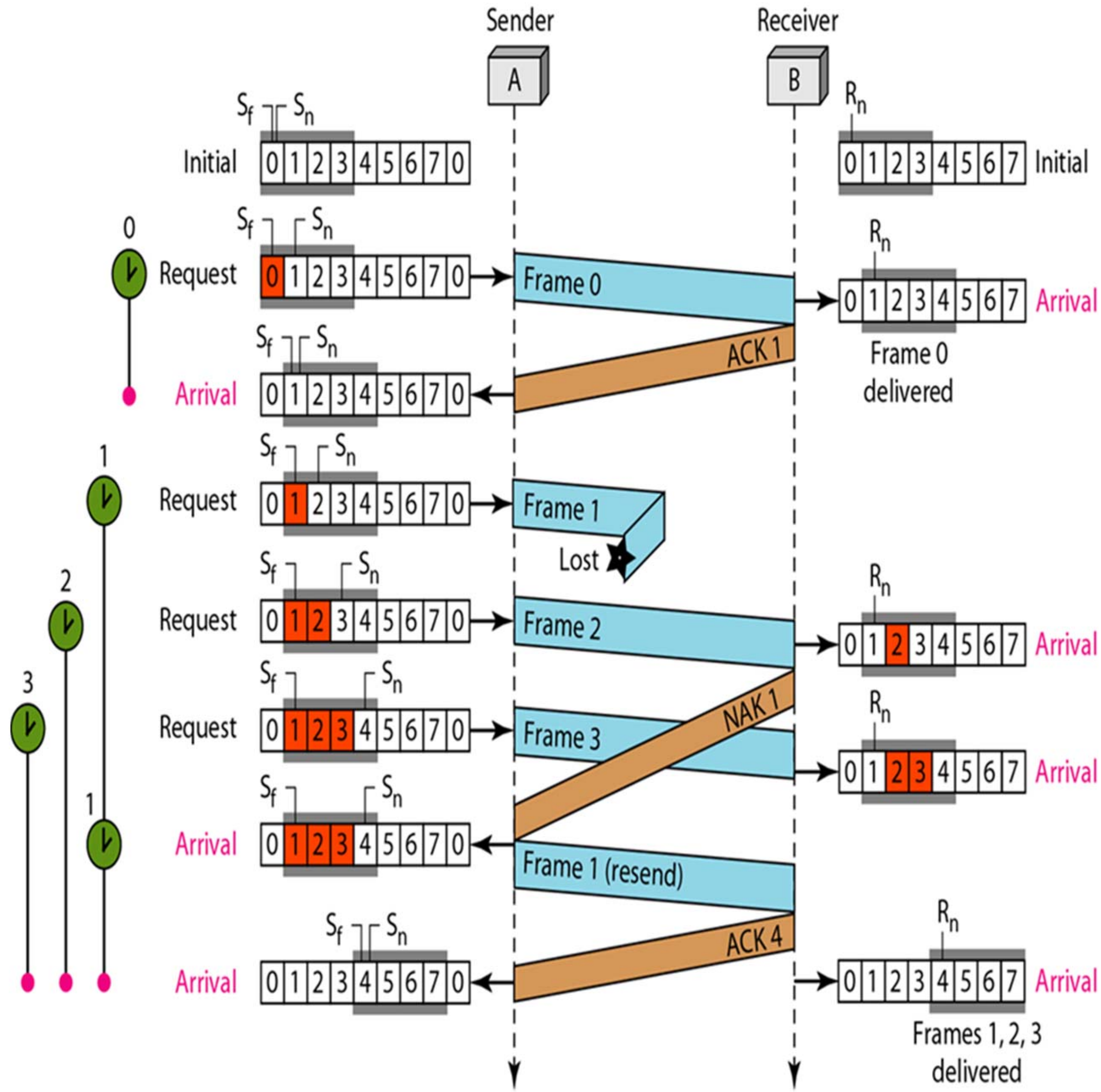
Example of Selective Repeat ARQ

- 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.