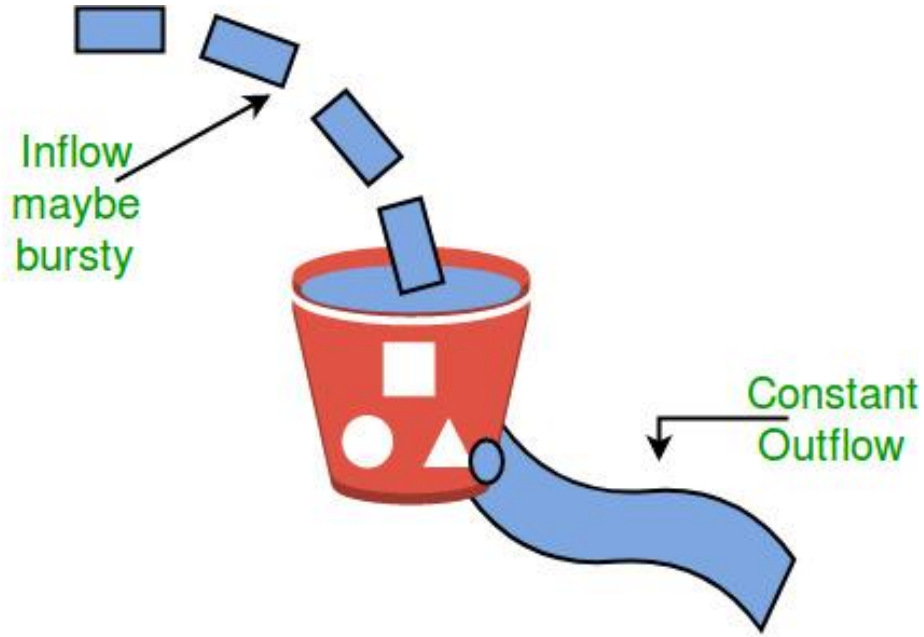
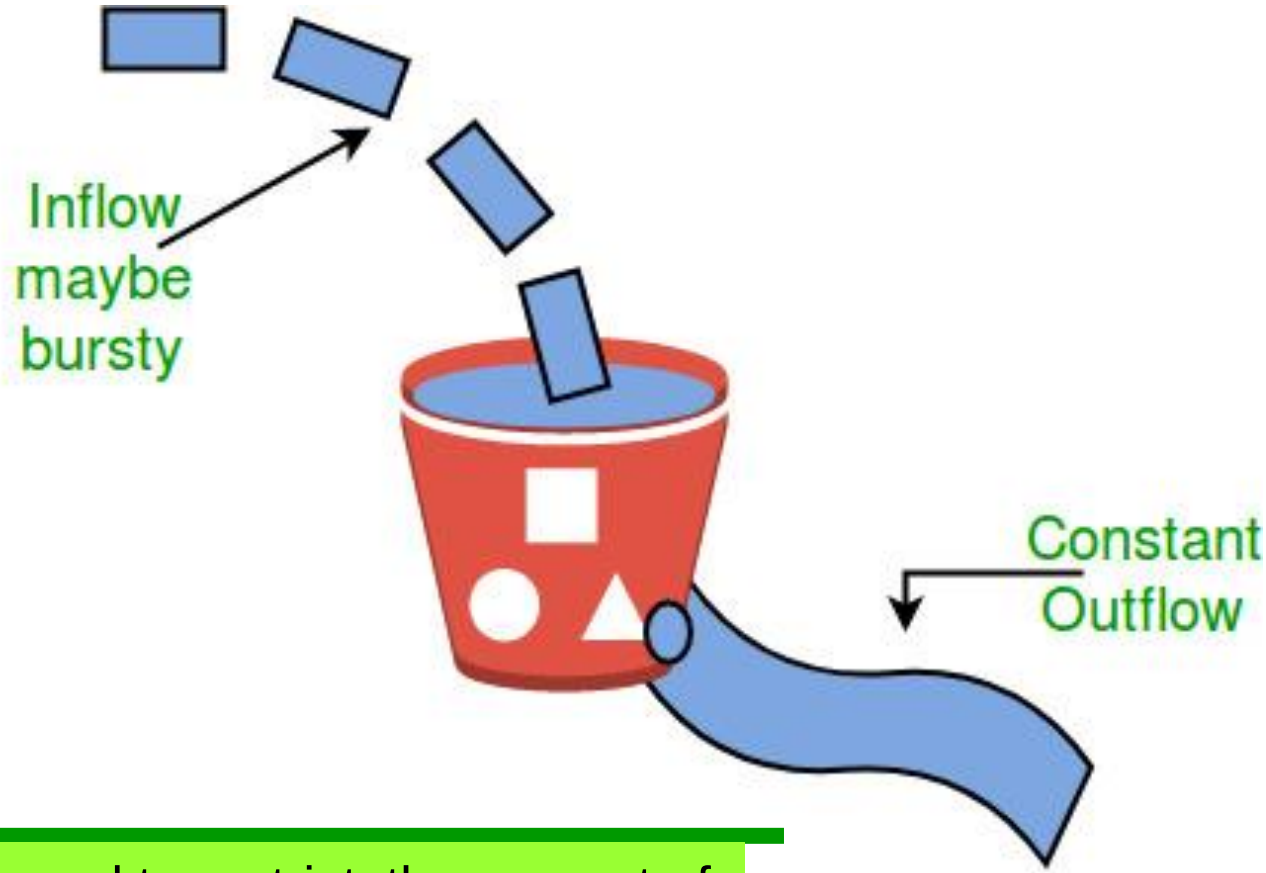



# Data link Layer
# Flow Control

# Flow Control

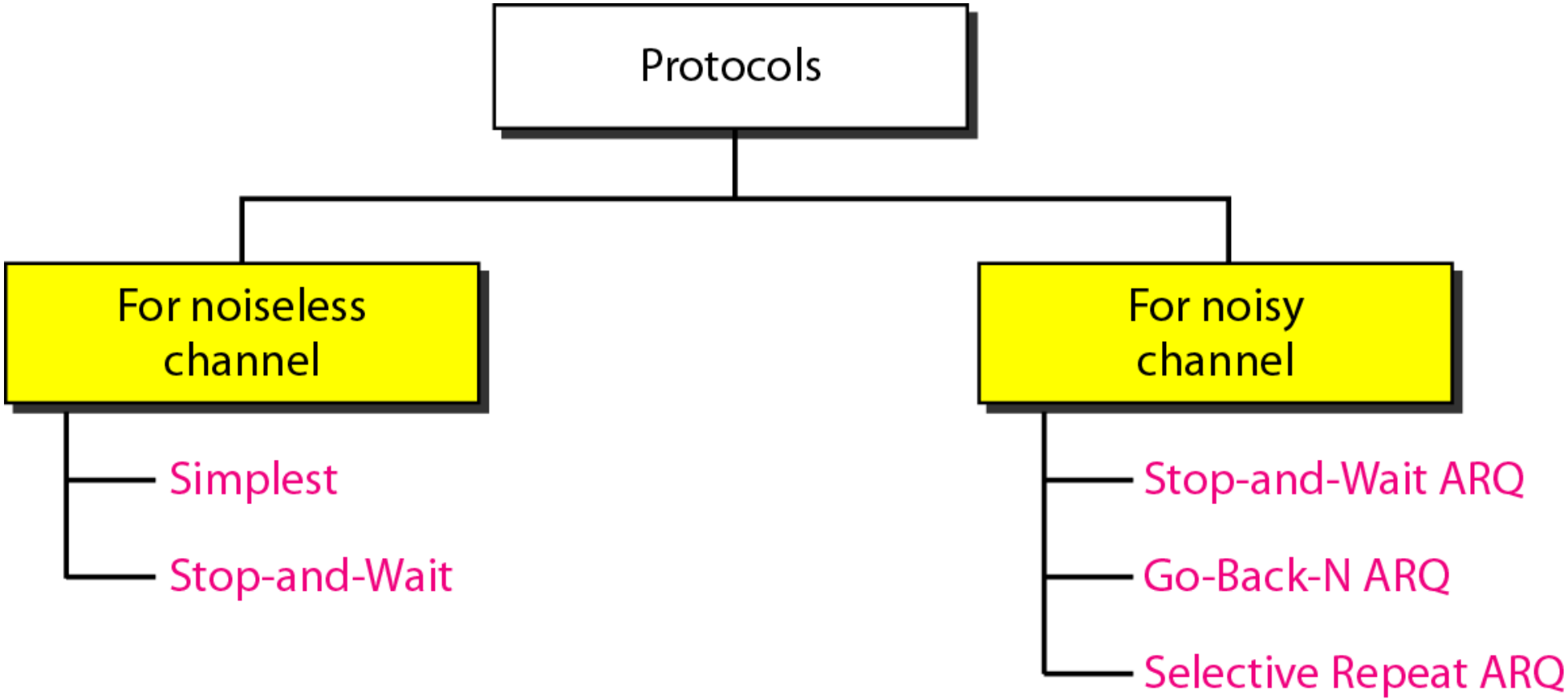
- Flow Control coordinates the amount of data that can be sent before receiving an acknowledgement.
- The  flow of data must not be allowed to overwhelm the receiver.
- Any receiving device has a limited speed at which it can process incoming data and a limited amount of memory in which to store incoming data.
- The rate of such processing is often slower than the rate of transmission. For this reason, 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.

# Flow 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.

# Taxonomy of protocols



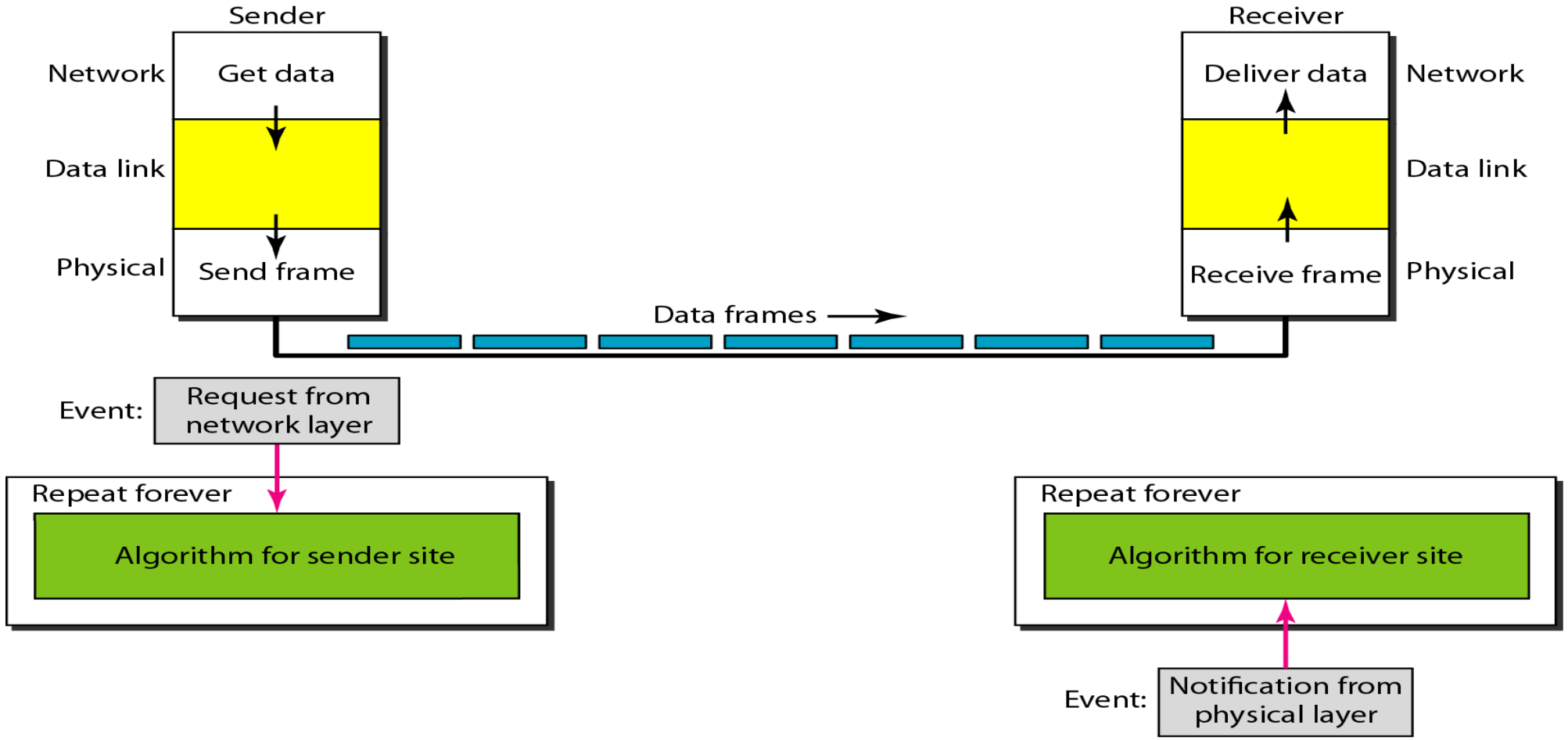
# Flow Control Protocols

- The protocols in the first category(**noiseless**) cannot be used in real life, but they serve as a basis for understanding the protocols of noisy channels.
- All the protocols  are unidirectional in the sense that the data frames travel from one node, called the sender, to another node, called the receiver.
- Although special frames, called acknowledgment **(ACK)** and negative acknowledgment **(NAK)** can flow in the opposite direction for flow and error control purposes, data flow in only one direction.
- In a real-life network, the data link protocols are implemented as bidirectional; data flow in both directions.
- In these protocols the flow and error control information such as ACKs and NAKs is included in the data frames in a technique called piggybacking.

# Simplest Protocol

- We divide the discussion of protocols into those that can be used for noiseless (error-free) channels and those that can be used for noisy (error-creating) channels.
- The protocols in the first category cannot be used in real life, but they serve as a basis for understanding the protocols of noisy channels

# Simplest Protocol with no Flow or Error control



# Simplest Protocol with no Flow or Error control

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

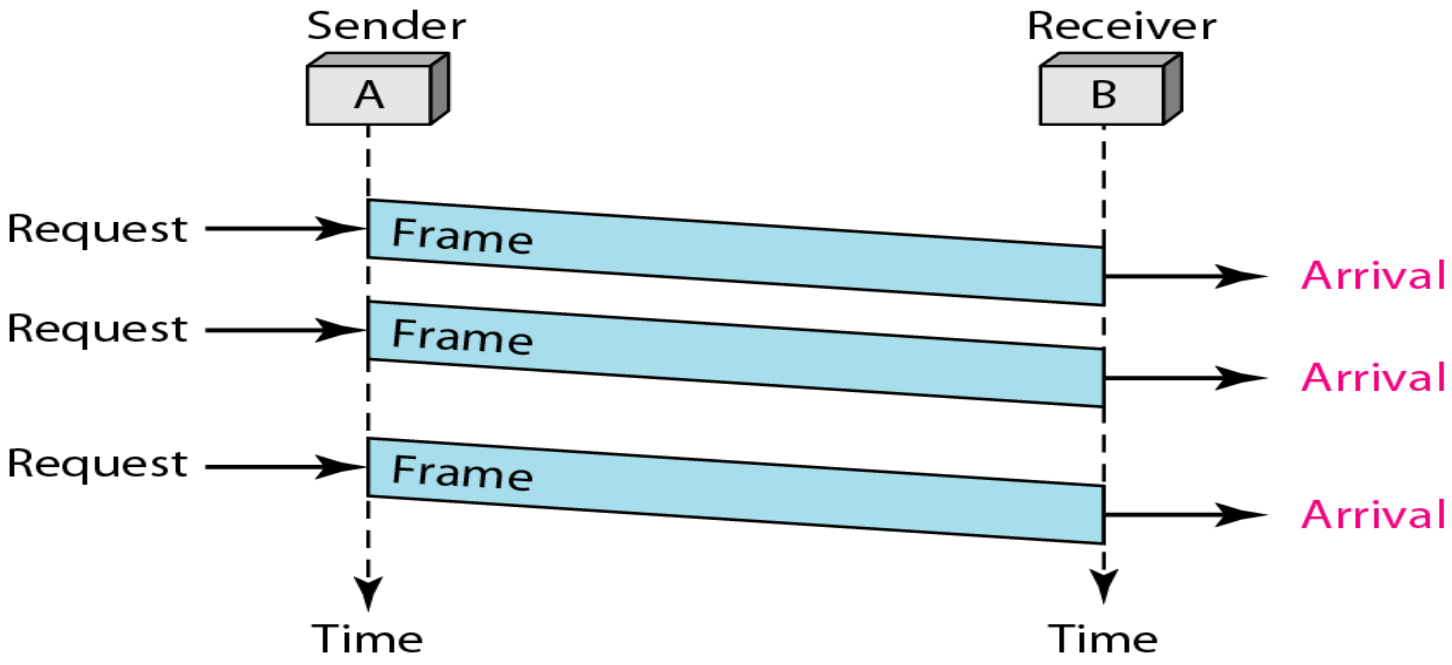
```
 1  while(true)                          // Repeat forever
 2  {
 3    WaitForEvent();                    // Sleep until an event occurs
 4    if(Event(RequestToSend))           //There is a packet to send
 5    {
 6        GetData();
 7        MakeFrame();
 8        SendFrame();                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

## Algorithm *Receiver-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  }
```

# Simplest Protocol

To send three frames, three events occur at the sender site and three events at the receiver site.



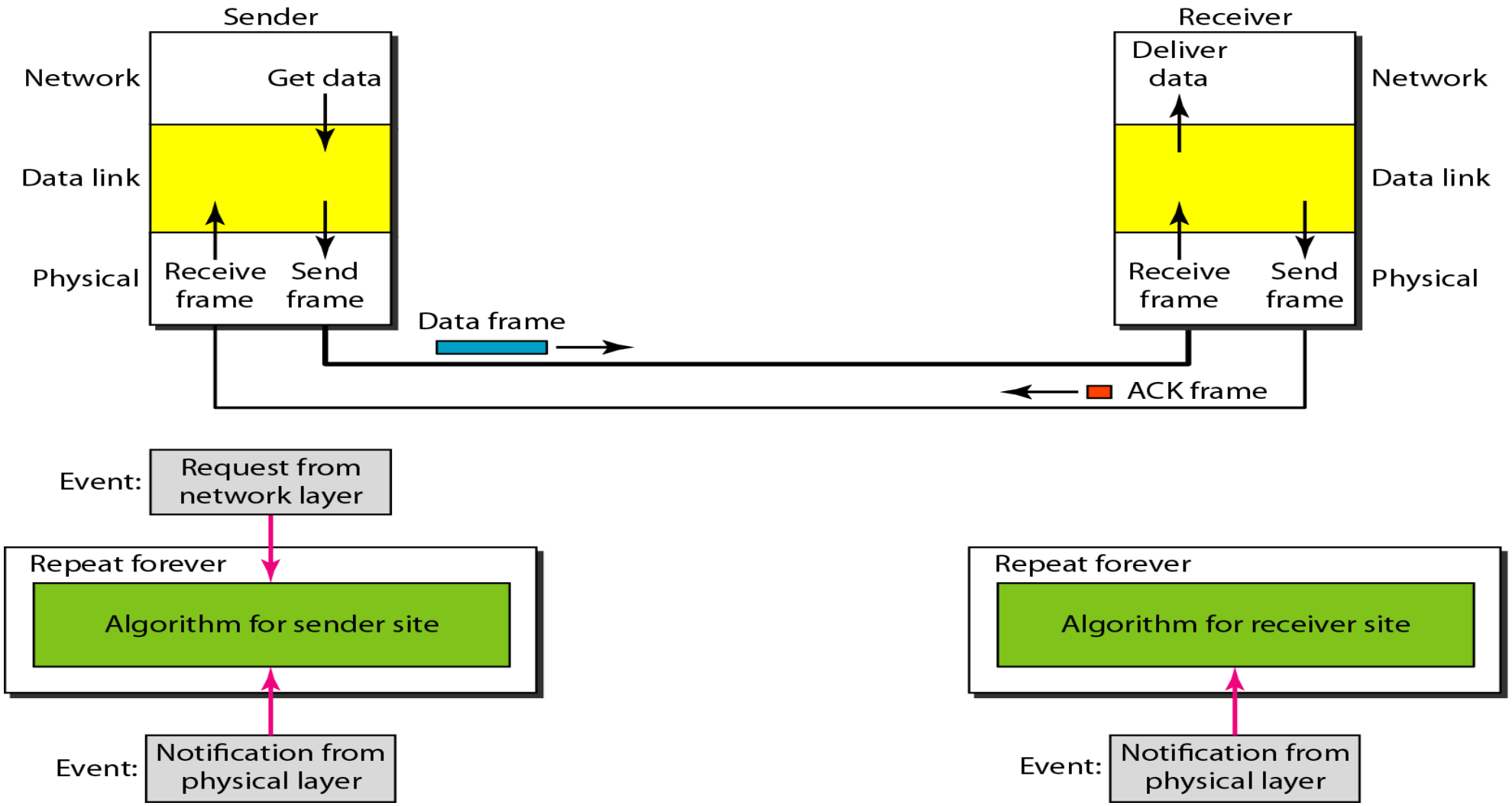
# Problem with Simplest Protocol

- 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.
- This may result in either the discarding of frames or denial of service.
- To prevent the receiver from becoming overwhelmed with frames, we somehow need to tell the sender to slow down.
- There must be feedback from the receiver to the sender

# Stop and Wait Protocol

- Sender sends one frame, stops until it receives confirmation from 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 simplest protocol.

# Stop and Wait Protocol



# Stop and Wait Protocol

## Algorithm *Sender-site algorithm for Stop-and-Wait Protocol*

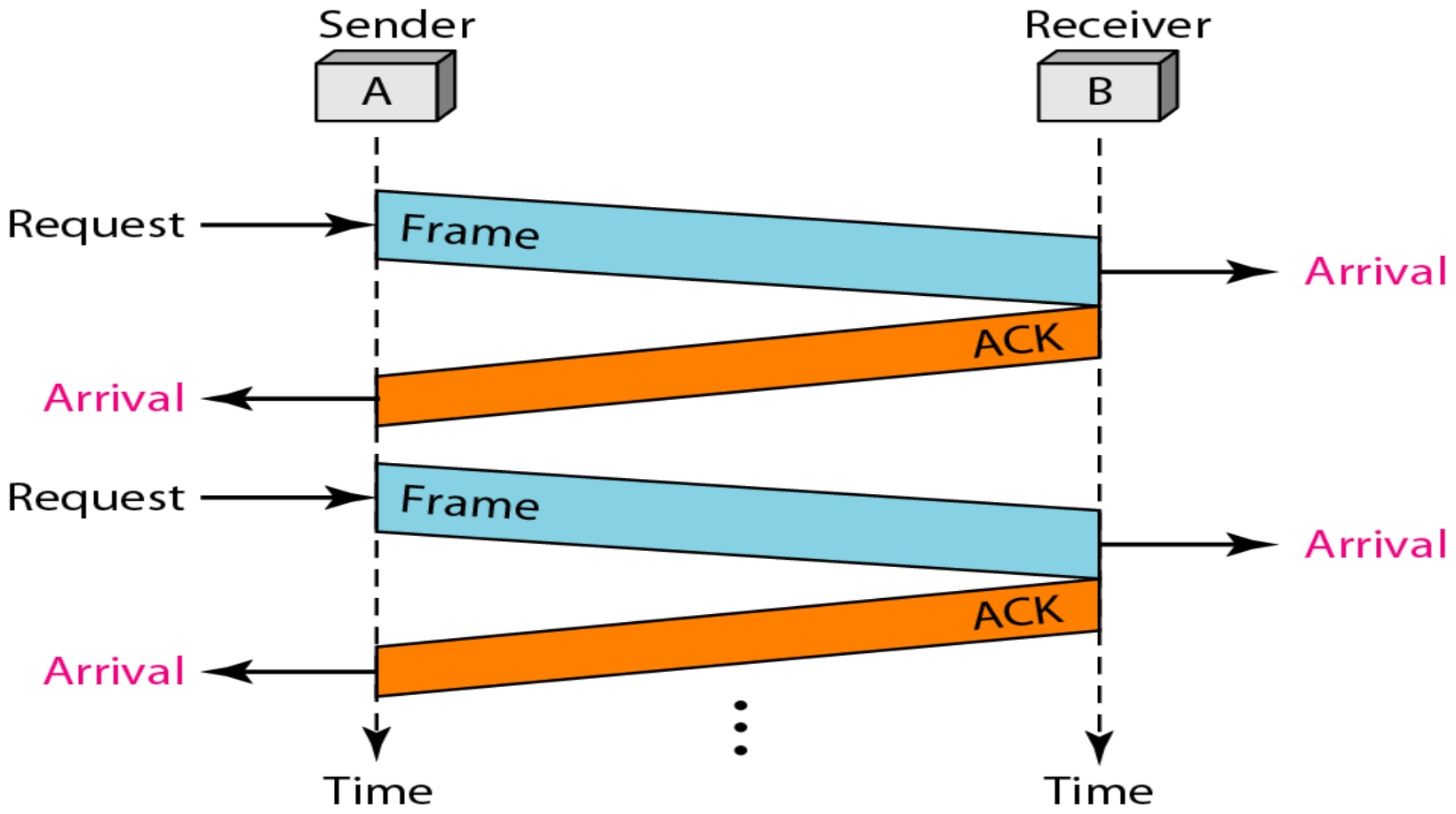
```
1  while(true)                          //Repeat forever
2  canSend = true                       //Allow the first frame to go
3  {
4    WaitForEvent();                    // Sleep until an event occurs
5    if(Event(RequestToSend) AND canSend)
6    {
7       GetData();
8       MakeFrame();
9       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 }
```

# Stop and Wait Protocol

Algorithm *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  }
```

# Stop and Wait Protocol



# 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.

## Noisy Channels Flow control Protocols

- Stop-and-Wait Automatic Repeat Request
- Go-Back-N Automatic Repeat Request
- Selective Repeat Automatic Repeat Request

# Stop and Wait Automatic Repeat Request (1 bit protocol)

- The Error control mechanism added in Stop and Wait Protocol.
- To detect and correct corrupted frames, we need to add **redundancy bits** to our data frame.
- Lost frames are more difficult to handle than corrupted ones. In our previous protocols, there was no way to identify a frame.
- The received frame could be the correct one, or a duplicate, or a frame out of order. The solution is to number the frames.
- When the receiver receives a data frame that is out of order, this means that frames were either **lost** or **duplicated**

# Stop and Wait Automatic Repeat Request (1 bit protocol)

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.

# Stop and Wait Automatic Repeat Request

- If the timer expires and there is no ACK for the sent frame, the frame is resent, the copy is held, and the timer is restarted.
- Since an ACK frame can also be corrupted and lost, it too needs redundancy bits and a sequence number.
- The ACK frame for this protocol has a sequence number field.
- In this protocol, the sender simply discards a corrupted ACK frame or ignores an out-of-order one.

# Stop and Wait Automatic Repeat Request

**Sequence Number :**

- A field is added to the data frame to hold the sequence number of that frame.
- We want to minimize the frame size, we look smallest range that provides unambiguous communication.

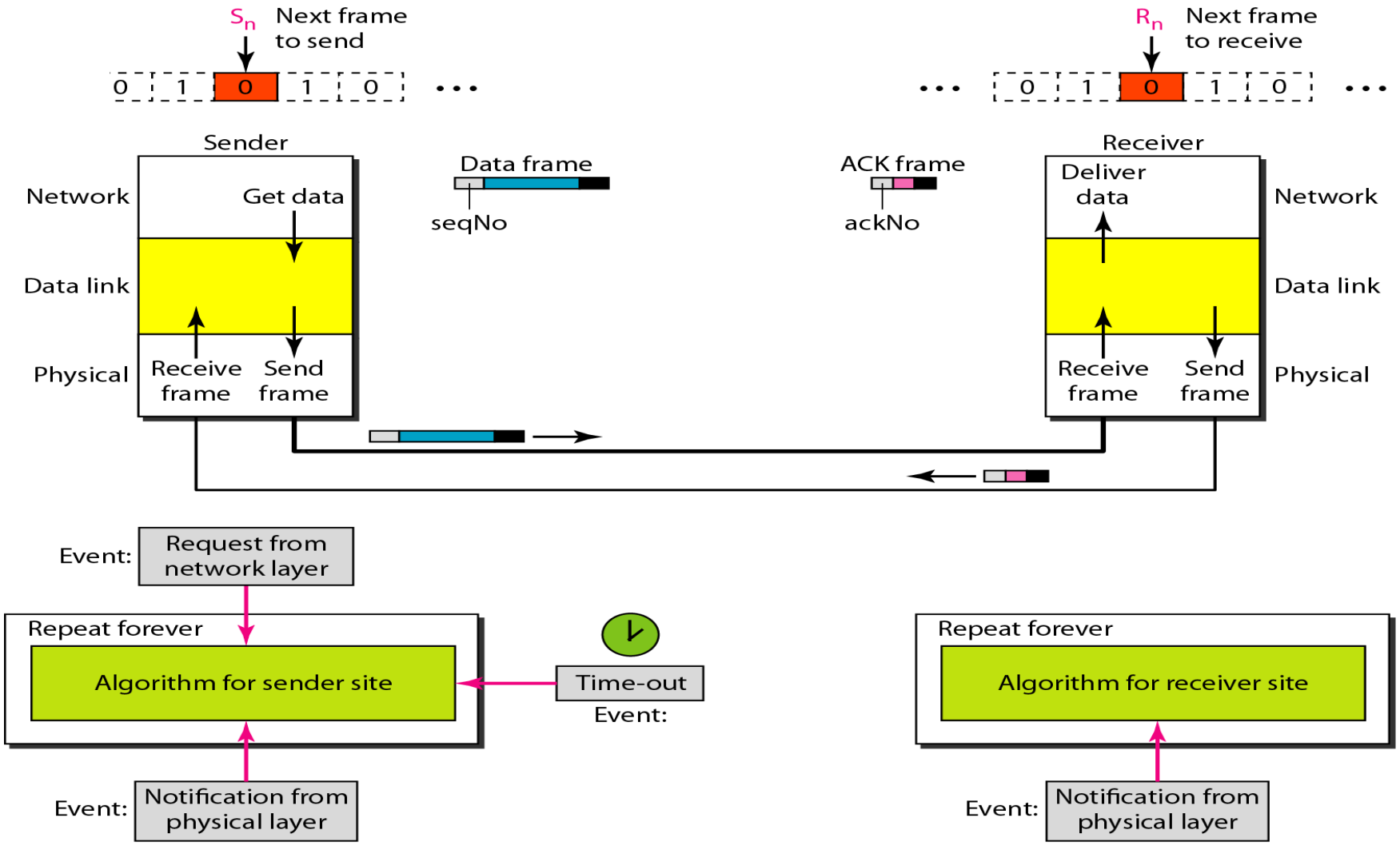
In Stop-and-Wait ARQ, we use sequence numbers to number the frames.
The sequence numbers are based on modulo-2 arithmetic.

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

# Stop and Wait Automatic Repeat Request

Design of

Stop-and-wait ARQ



# Stop and Wait Automatic Repeat Request

Algorithm *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)*

# Stop and Wait Automatic Repeat Request

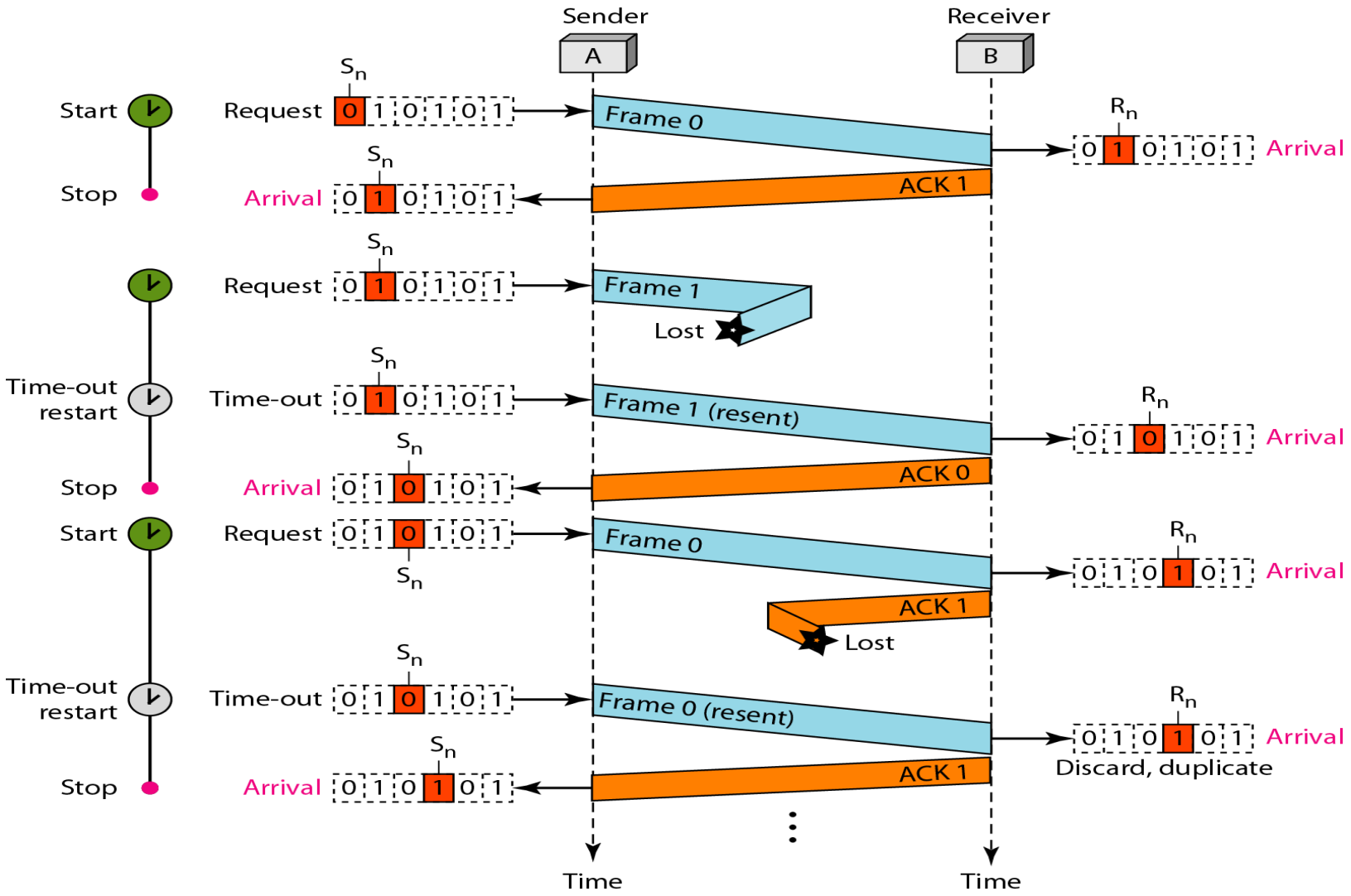
```
17      if(Event(ArrivalNotification)          // An ACK has arrived
18      {
19        ReceiveFrame(ackNo);                 //Receive the ACK frame
20        if(not corrupted AND ackNo == Sn)    //Valid ACK
21          {
22            Stoptimer();
23            PurgeFrame(Sn-1);                //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  }
```

# Stop and Wait Automatic Repeat Request

## Algorithm *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 - Example



# Stop and Wait ARQ - Efficiency

- The Stop-and-WaitARQ is very inefficient if our channel is thick and long. By thick, we mean that our channel has a large bandwidth; by long,
- we mean the round-trip delay is long. The product of these two is called the bandwidth delay product(BDP).
- We can think of the channel as a pipe. The
- bandwidth-delay product then is the volume of the pipe in bits. The pipe is always there.
- If we do not use it, we are inefficient. The bandwidth-delay product is a measure of the number of bits we can send out of our system while waiting for news from the receive.

## Example 11.4

*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?*

### Solution

The bandwidth-delay product is

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

## Example 11.4 (continued)

*The system can send 20,000 bits during the time it takes for the data to go from the sender to the receiver and then back again.*
*However, the system sends only 1000 bits.*

*We can say that 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.*

## Example 11.5

*What is the utilization percentage of the link in Example 11.4 if we have a protocol that can send up to 15 frames before stopping and worrying about the acknowledgments?*

### *Solution*

*The bandwidth-delay product is still 20,000 bits. The system can send up to 15 frames or 15,000 bits during a round trip.*

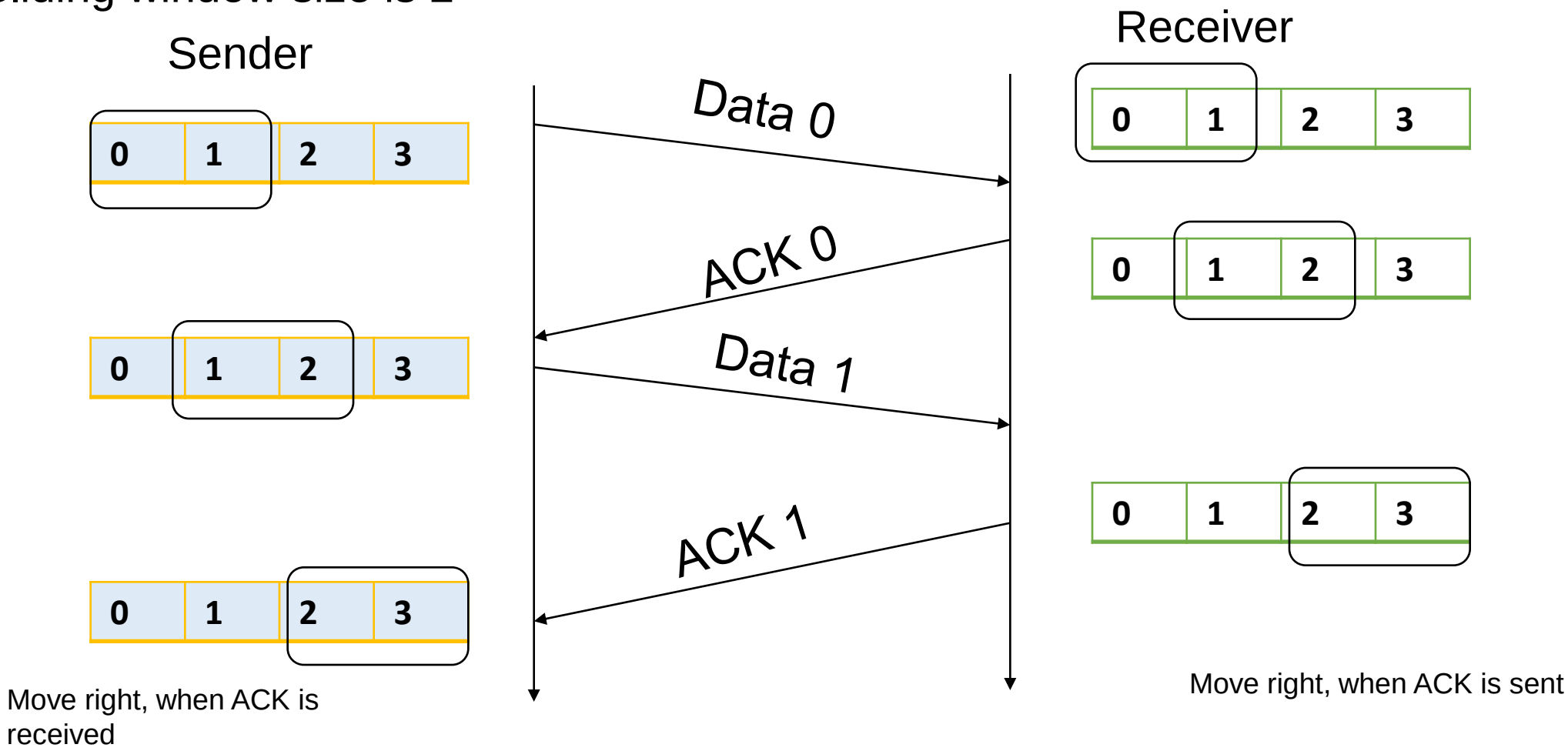
*This means the utilization is 15,000/20,000, or 75 percent. Of course, if there are damaged frames, the utilization percentage is much less because frames have to be resent.*

# Sliding window protocol

- Sequence number is given to each out bound  frame from 0 to N.
- If the m bits allow for sequence number , the sequence number from 0 to 2m - 1.
- Sliding window : these are the imaginary boxes of transmitter and receiver ( buffer).

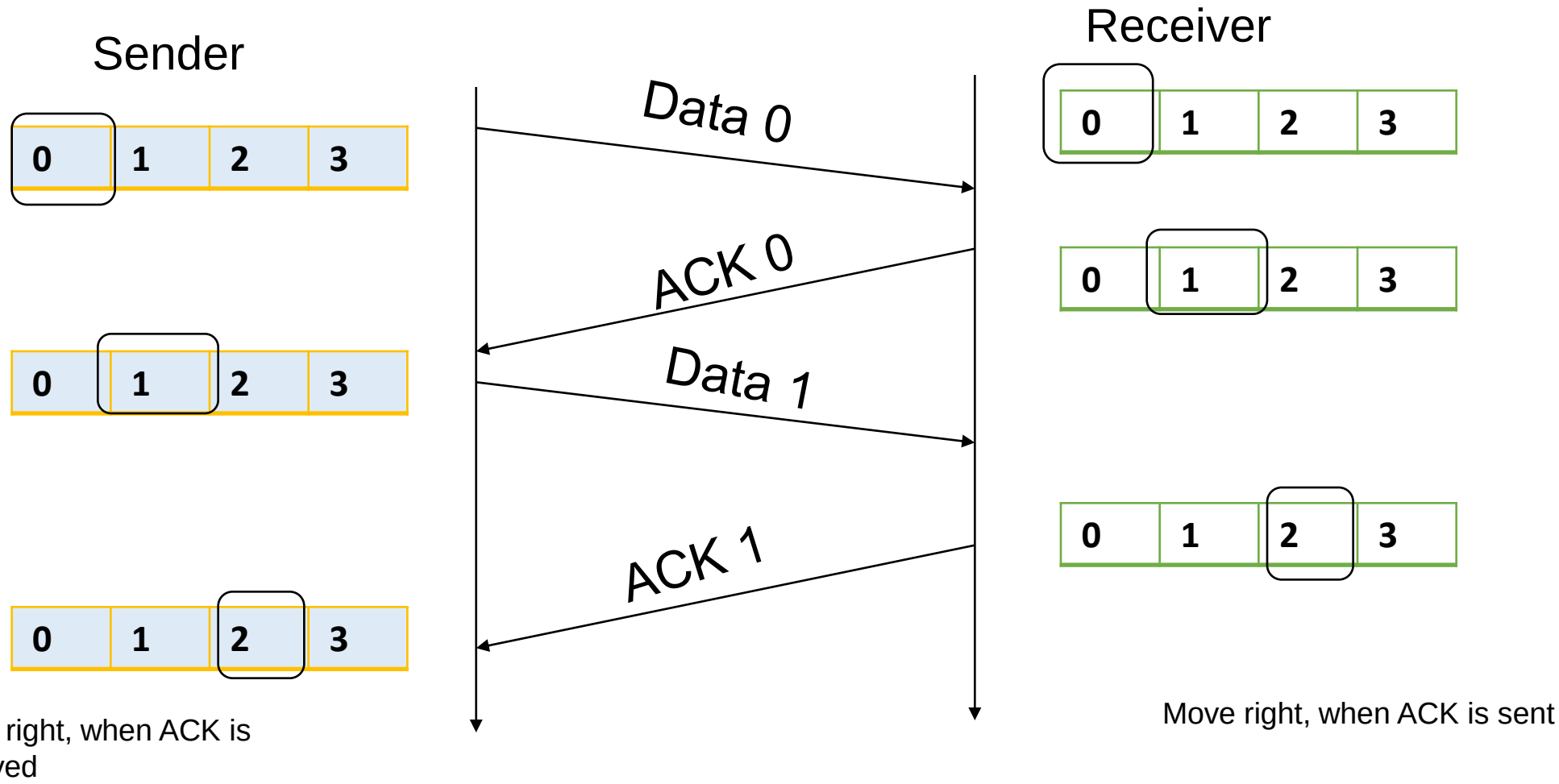
# Basic Sliding window protocol

- Sliding window size is 2



# Stop and Wait ARQ ( with sliding window)

- Maximum window size is 1 ( one bit protocol)



# Go-Back-N ARQ ( Automatic Repeat Request) Protocol

- To improve the efficiency of transmission (filling the pipe), multiple frames must be in transition while waiting for acknowledgment.
- Keep copy of frames until the acknowledgment arrive.
- Sender windows size is **N** and receiver window size is **1**
- If the m bits allow for sequence number , the sequence number from 0 to $2^m - 1$.

  if m=2 then frame number from 0 to 3

  *0,1,2,3, 0,1,2,3, 0,1,2,3, 0,1,2,3, 0,1,2,3, 0,1,2,3,*

# Go-Back-N ARQ ( Automatic Repeat Request) Protocol

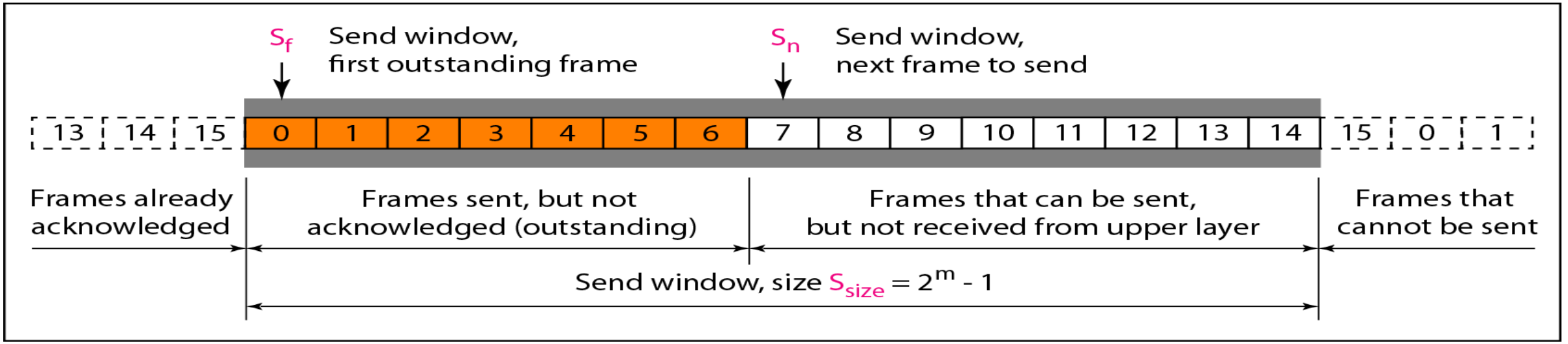
In the Go-Back-N Protocol, the sequence numbers are modulo $2^m$, where m is the size of the sequence number field in bits.

# Go-Back-N ARQ ( Automatic Repeat Request) Protocol

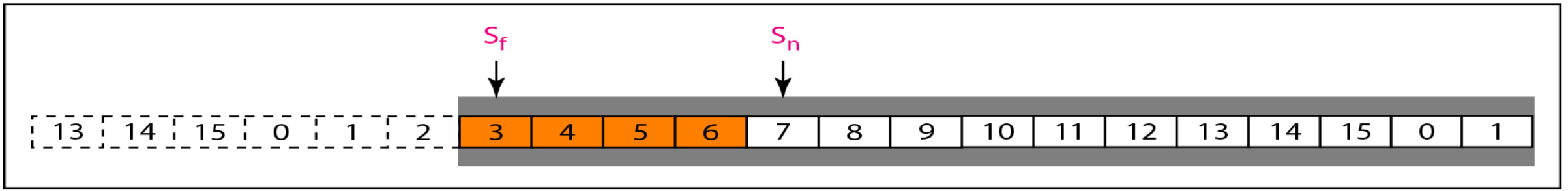
## Sliding Window

- Sliding window define the range of sequence numbers that is concern of the sender and receiver.
- The range which is the concern of the sender is called the ***send sliding window***
- The range that is the concern of the receiver is called the ***receive sliding window.***
- consider window size is m = 4 , so frame sequence number is from 0 to 15.
- The window at any time divides the possible sequence numbers into four regions.

# Send window for Go-Back-N ARQ




a. Send window before sliding




b. Send window after sliding

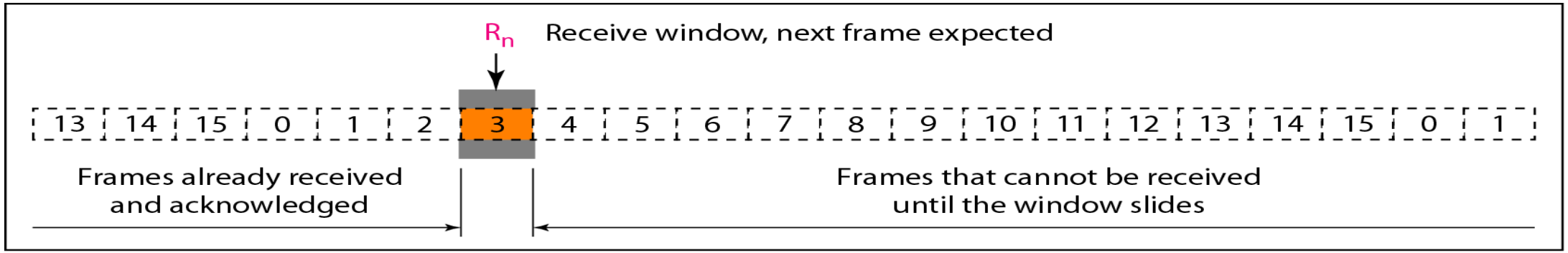
# Send window for Go-Back-N ARQ

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

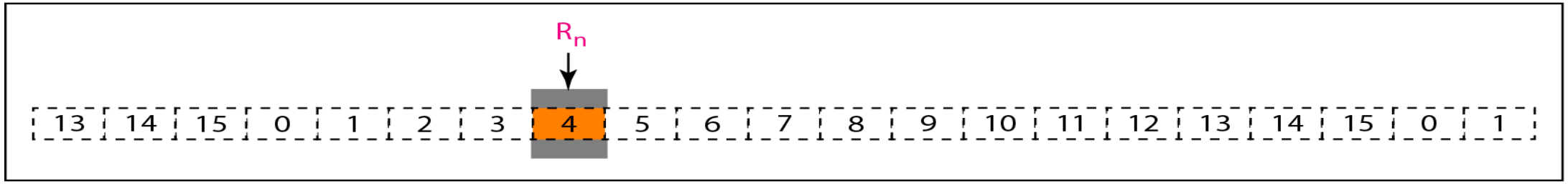
# Send window for Go-Back-N ARQ

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

# Receiver window for Go-Back-N ARQ




a. Receive window

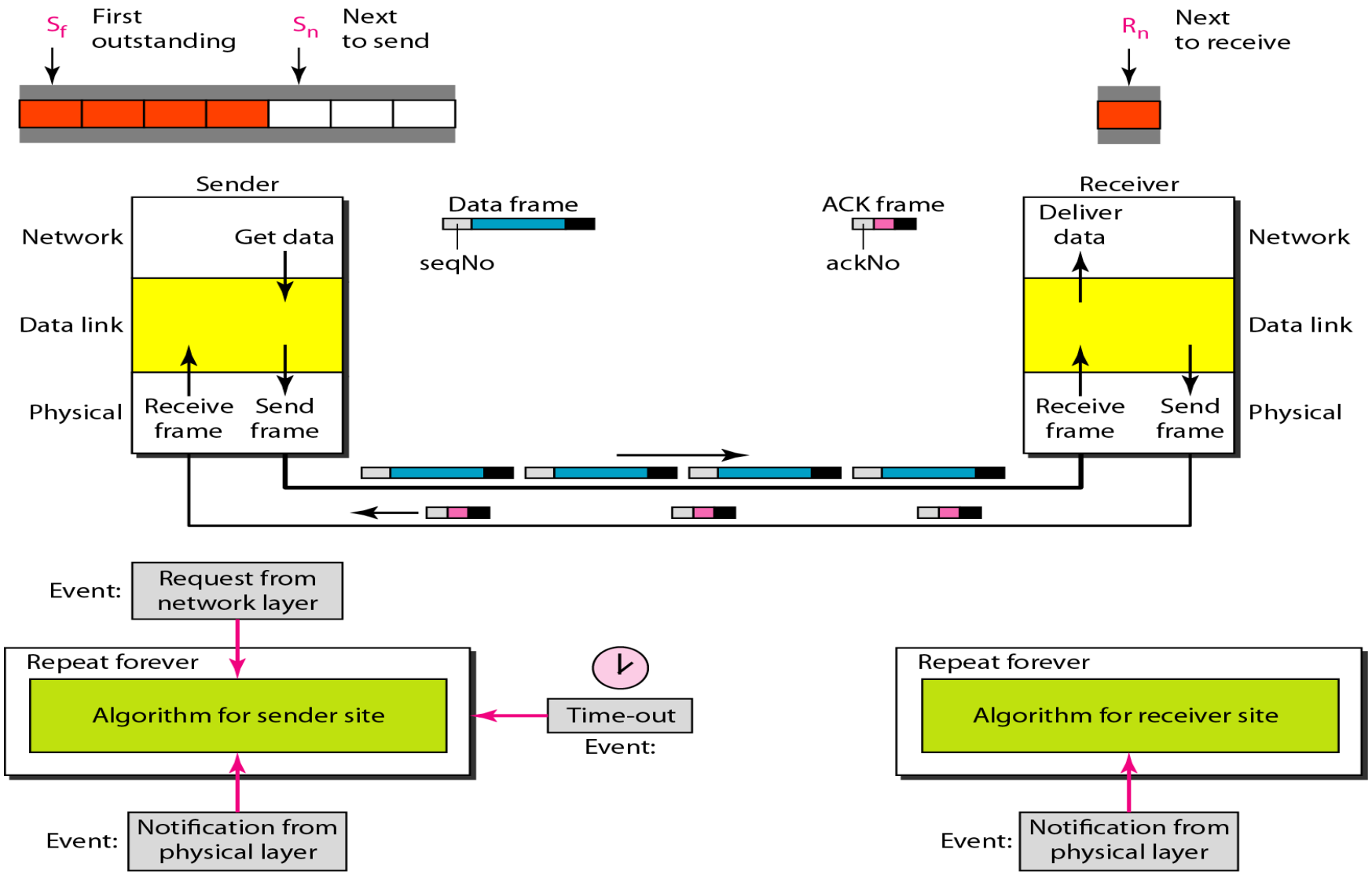



b. Window after sliding

# Receiver 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.

# Design of Go-Back-N ARQ



## Note

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.

## *Go-Back-N sender algorithm*

```
 1  Sw = 2^m - 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 *(continued)*

```
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*

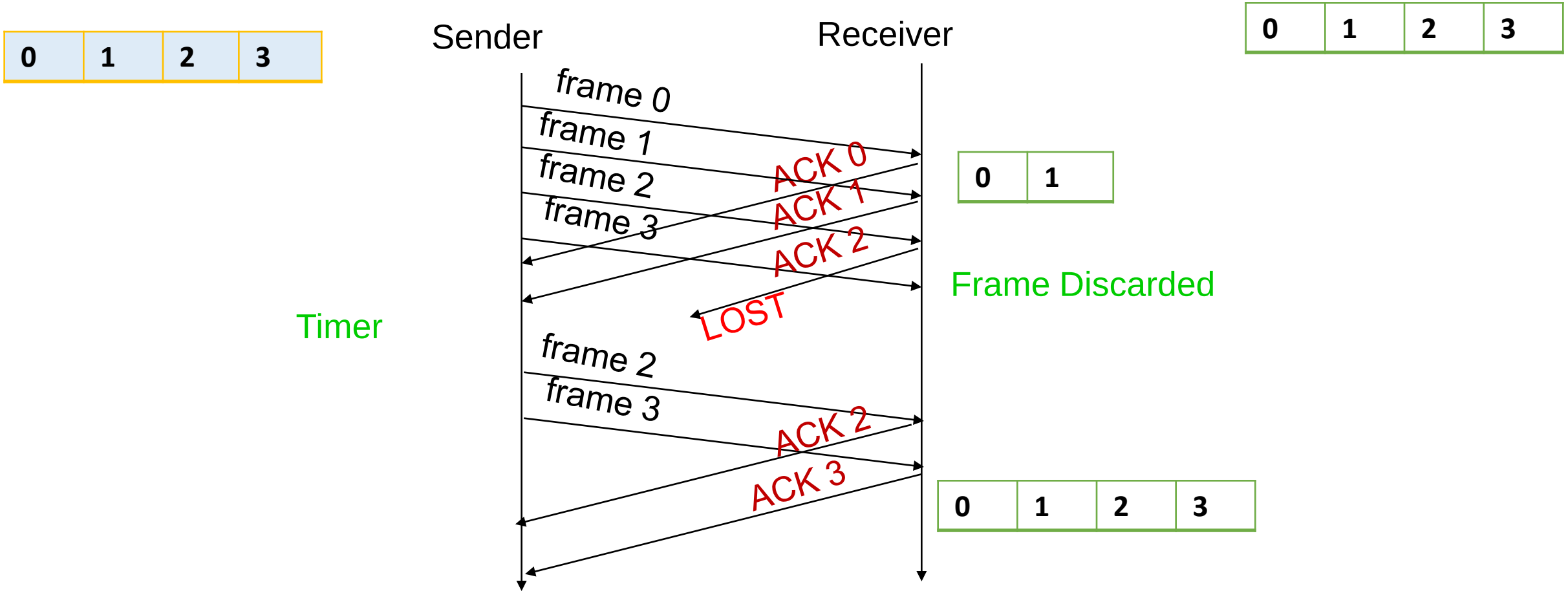
```
 1  Rn = 0;
 2
 3  while (true)                          //Repeat forever
 4  {
 5    WaitForEvent();
 6
 7    if(Event(ArrivalNotification)) /Data frame arrives
 8    {
 9       Receive(Frame);
10       if(corrupted(Frame))
11            Sleep();
12       if(seqNo == Rn)                  //If expected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

*Note*

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

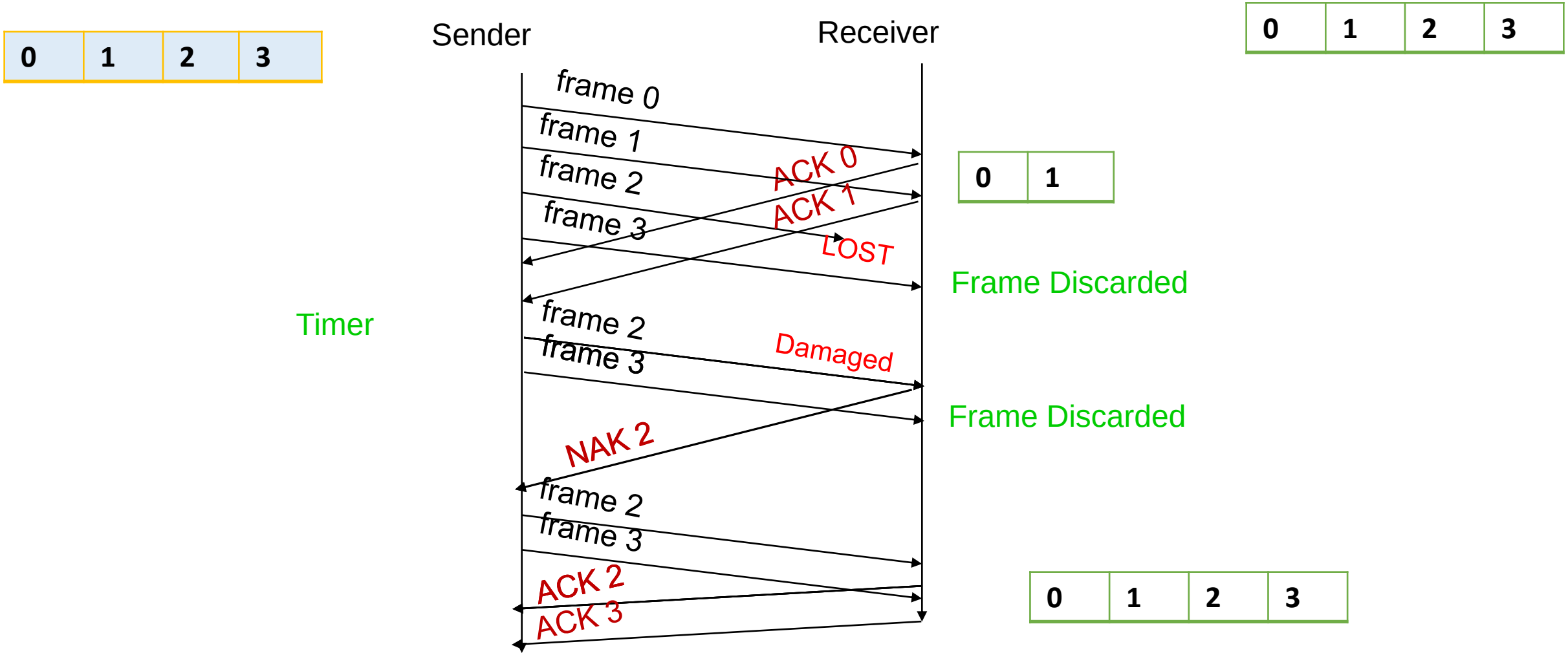
# Go-Back-N

- Sliding window size is 4, ACK is lost



# Go-Back-N

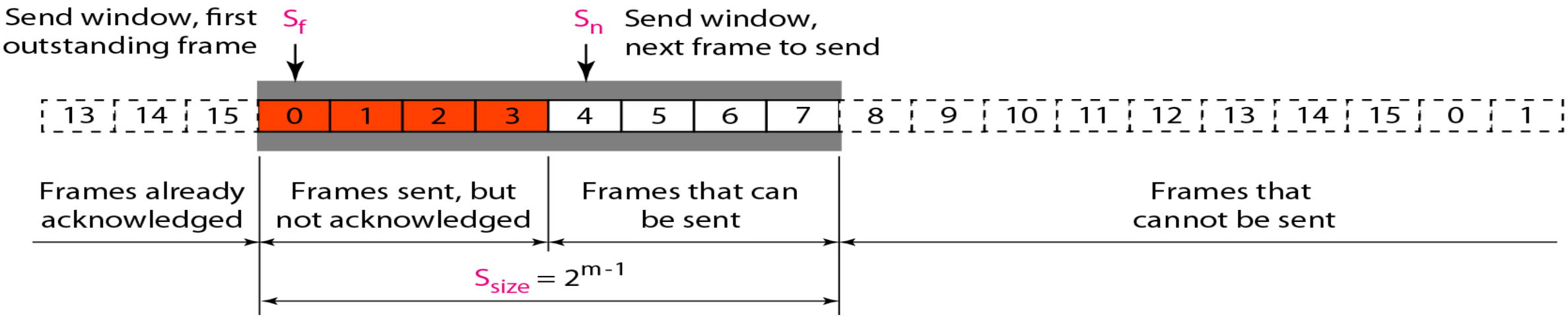
- Sliding window size is 4, Frame lost/damaged



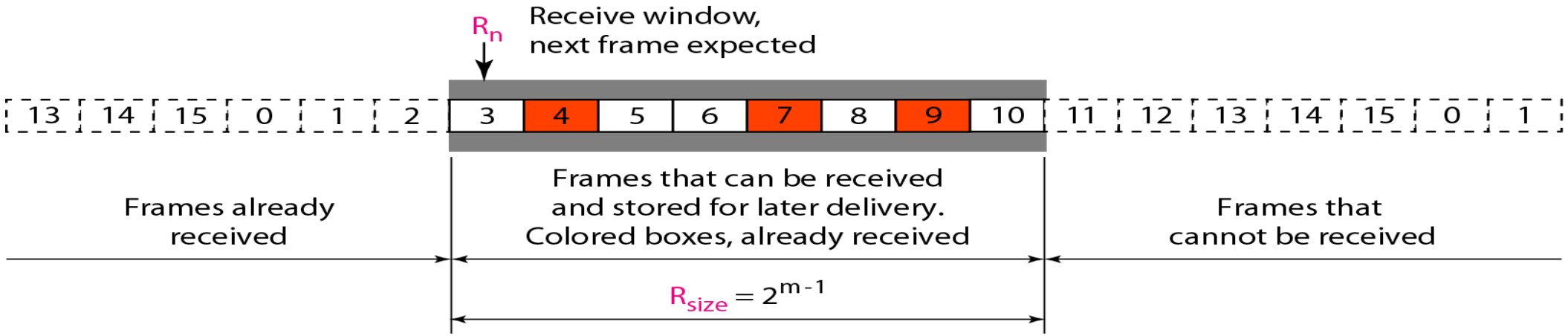
# Selective Repeat – ARQ ( Automatic Repeat Request) Protocol

- In Go-Back-N , the Sender windows size is N and receiver window size is 1. so at receiver there is no need to buffer out-of-order frames.
- However, Go-Back-N is very inefficient for a noisy link. 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 RepeatARQ.
- It is more efficient for noisy links, but the processing at the receiver is more complex.
- In Selective Repeat ARQ , the Sender windows size is N and receiver window size is N.

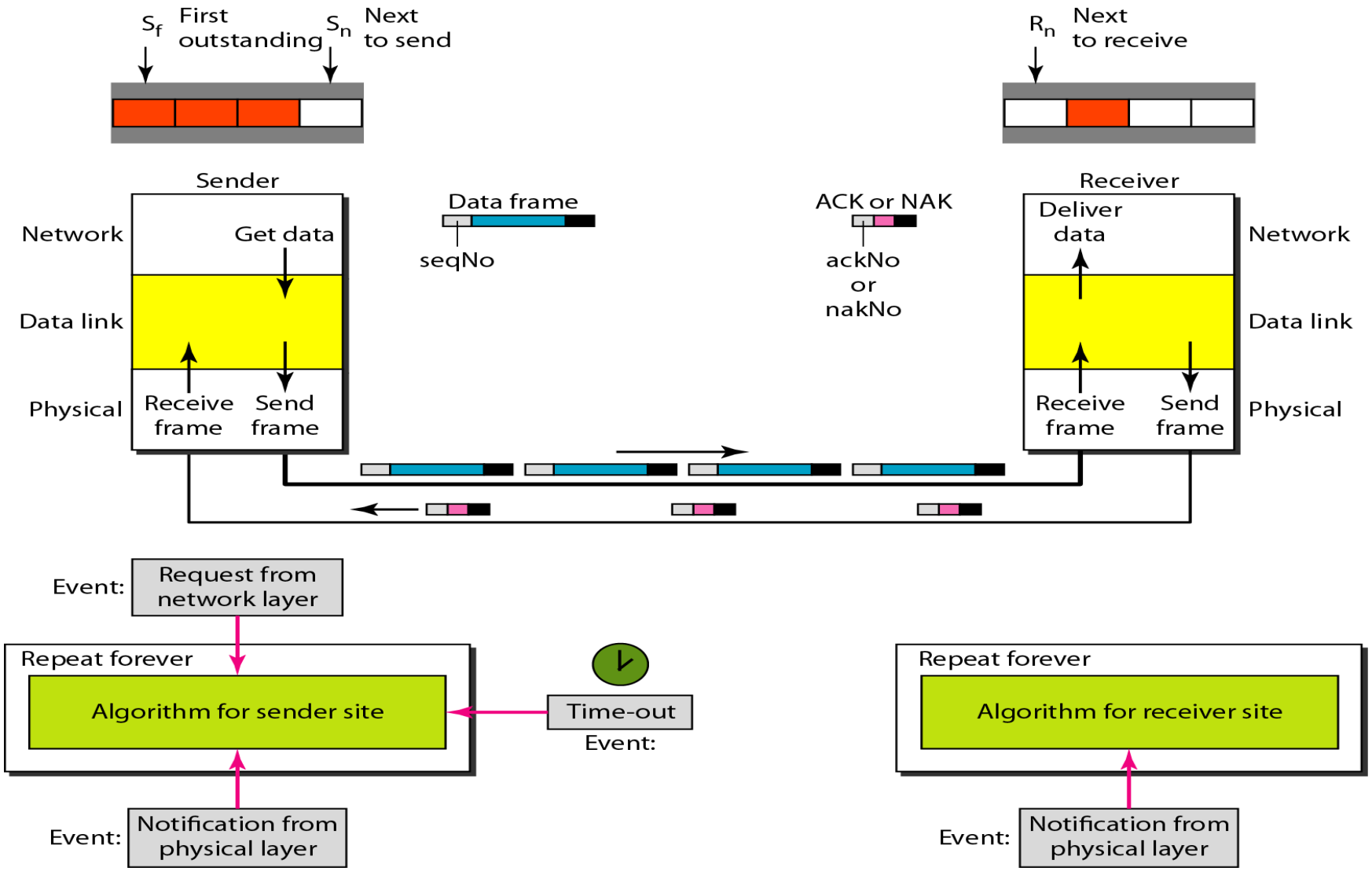
# Send window for Selective Repeat ARQ



# Receive window for Selective Repeat ARQ



# Design of Selective Repeat ARQ



# *Sender-site Selective Repeat algorithm*

```
1  Sw = 2^(m-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

(continued)

```
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 Sf and Sn)
27          {
28           resend(nakNo);
29           StartTimer(nakNo);
30          }
31      if (FrameType == ACK)
32          if (ackNo between Sf and Sn)
33          {
34            while(sf < ackNo)
35            {
36             Purge(sf);
37             StopTimer(sf);
38             Sf = Sf + 1;
39            }
40          }
41  }
```

(continued)

# *Sender-site Selective Repeat algorithm*

*(continued)*

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

# *Receiver-site Selective Repeat algorithm*

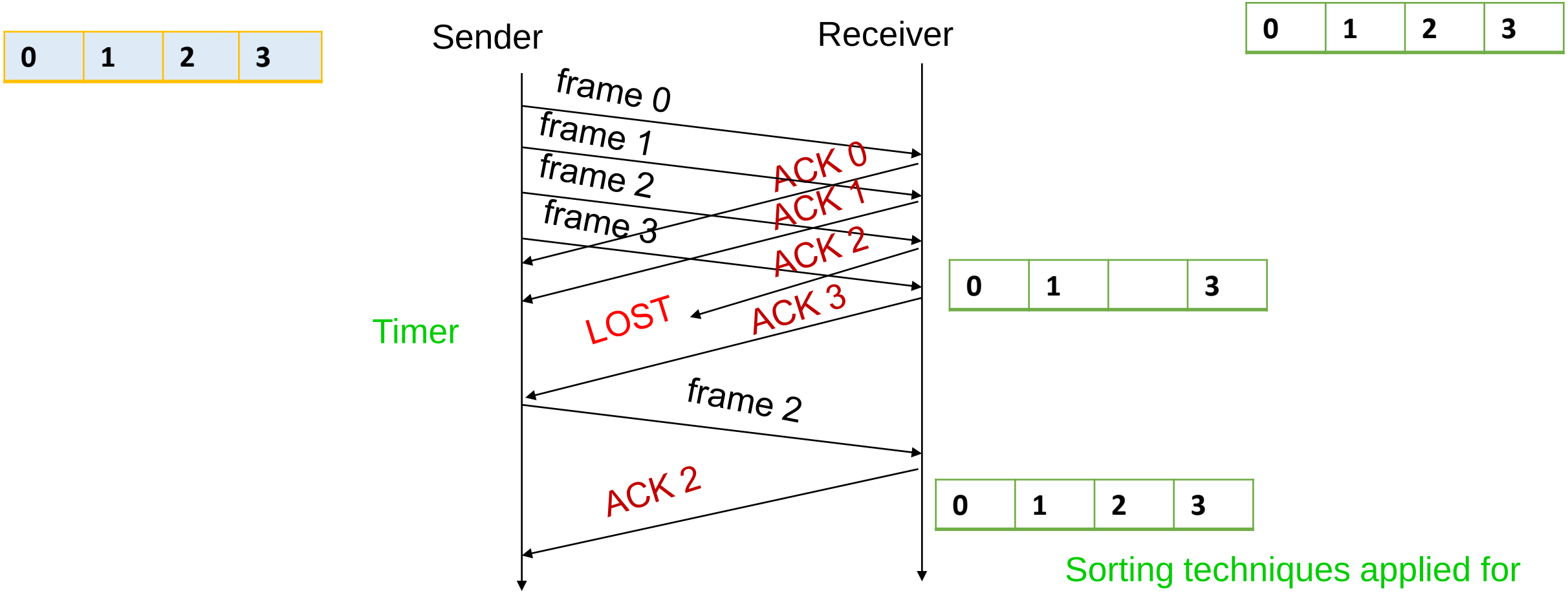
```
 1  Rn = 0;
 2  NakSent = false;
 3  AckNeeded = false;
 4  Repeat(for all slots)
 5       Marked(slot) = false;
 6
 7  while (true)                                   //Repeat forever
 8  {
 9    WaitForEvent();
10
11    if(Event(ArrivalNotification))               /Data frame arrives
12    {
13       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  }
```

# Selective Repeat – ARQ Example

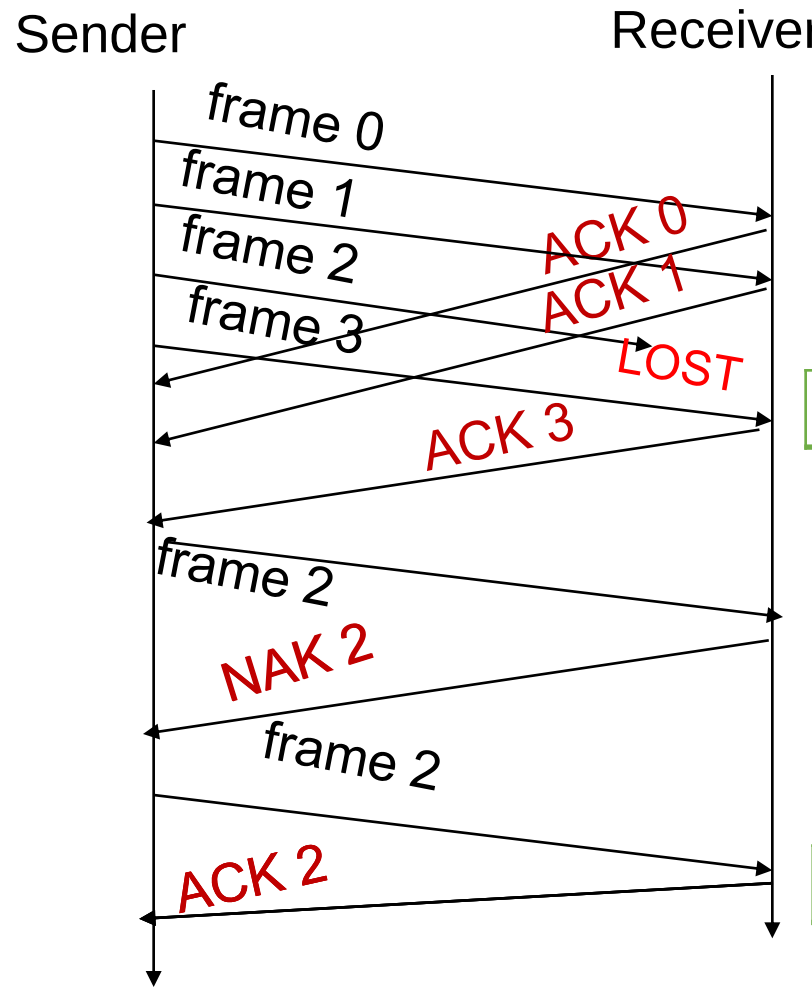
- Sliding window size is 4, ACK is lost



# Selective Repeat – ARQ Example

- Sliding window size is 4, Frame lost/damaged

| 0 | 1 | 2 | 3 |
|---|---|---|---|




| 0 | 1 | 2 | 3 |
|---|---|---|---|

| 0 | 1 | | 3 |
|---|---|---|---|

Timer

Frame Discarded

| 0 | 1 | | 3 |
|---|---|---|---|

| 0 | 1 | 2 | 3 |
|---|---|---|---|

Sorting techniques applied for synchronization of frame

# Go- Back –N ARQ and Selective Repeat ARQ

## Go- Back –N ARQ

- Retransmitted rest of ‘N’ no of frames in case of any problem.
- If error – rate is high, it wastes lot of bandwidth.
- Less complicated.
- Sorting is not require.
- Most often used.

## Selective Repeat ARQ

- Retransmitted only those frames that have problem.
- Less wastage of bandwidth.
- More complicated.
- Sorting is require.
- Rarely used, due to complexity of algorithm.

# piggybacking in Go-Back-N ARQ

- 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; when a frame is carrying data from B to A, it can also carry control information about the arrived (or lost) frames from A.

# Design of piggybacking in Go-Back-N ARQ