Reliable Data Transfer II

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Outline

- Performance of the stop-and-wait protocol
- Go-Back-N
- Selective repeat

Back to Reliable Data Tranfer

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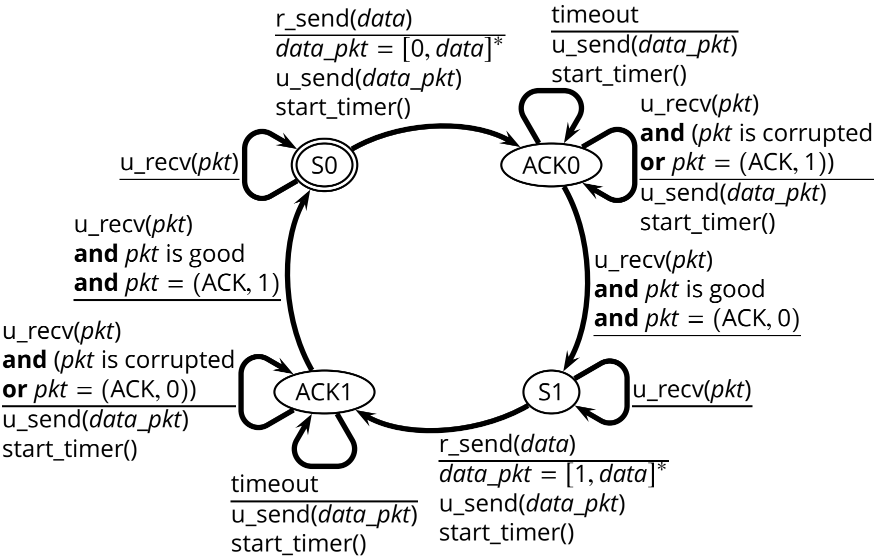

r_send(*data*)
data_pkt = [0, *data*]*
u_send(*data_pkt*)
start_timer()

timeout
u_send(*data_pkt*)
start_timer()

u_recv(*pkt*)
and (*pkt* is corrupted
or *pkt* = (ACK, 1))
u_send(*data_pkt*)
start_timer()

u_recv(*pkt*)

u_recv(*pkt*)
and *pkt* is good
and *pkt* = (ACK, 1)

u_recv(*pkt*)
and *pkt* is good
and *pkt* = (ACK, 0)

u_recv(*pkt*)
and (*pkt* is corrupted
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u_send(*data_pkt*)
start_timer()

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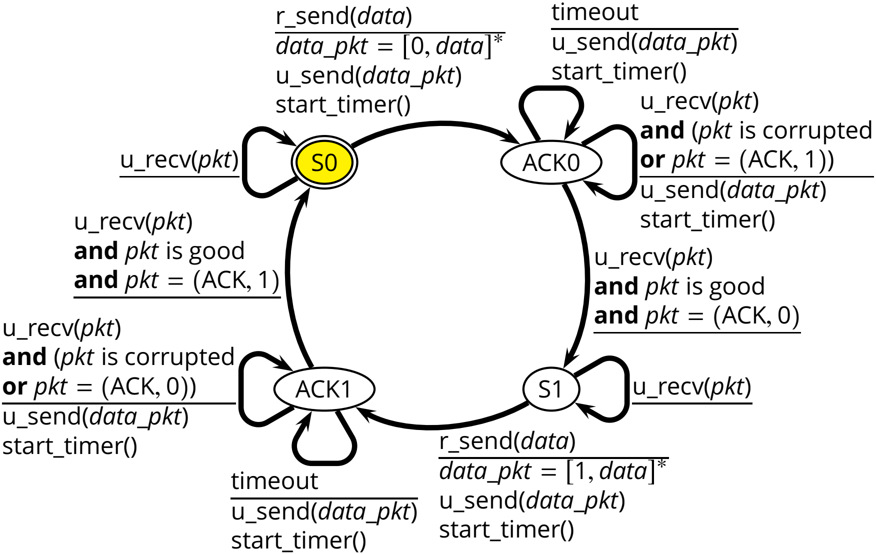
Back to Reliable Data Tranfer



S0

ACK0

S1

ACK1

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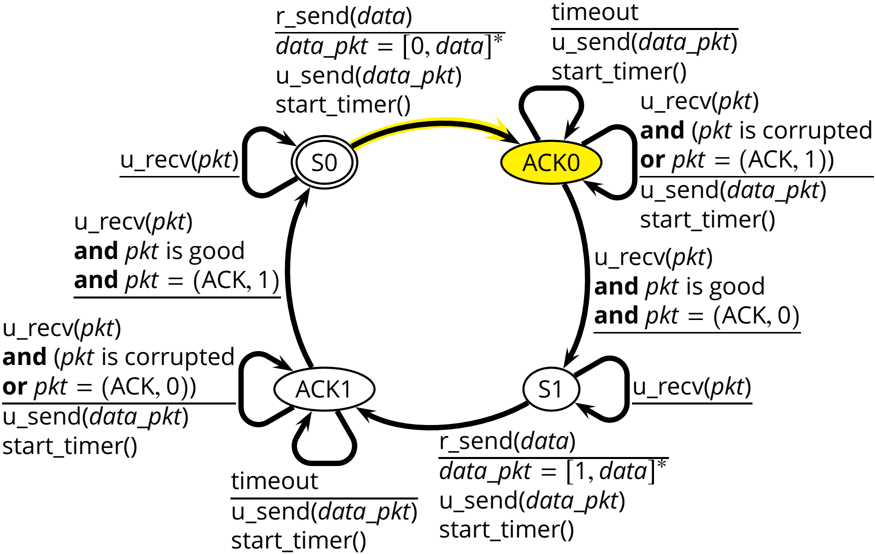

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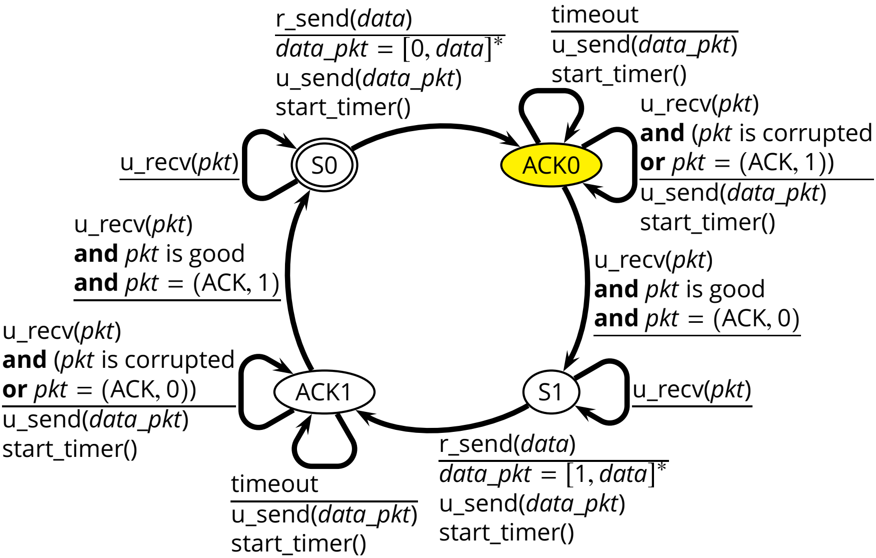

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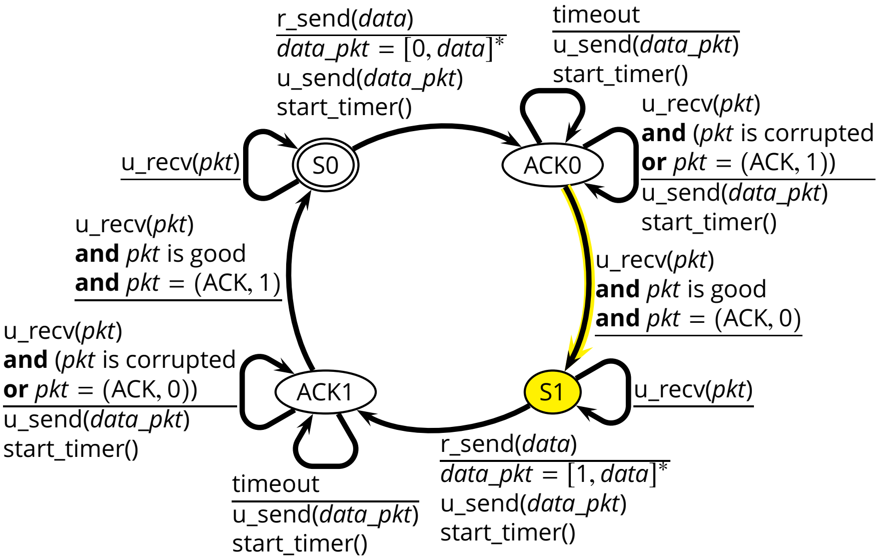

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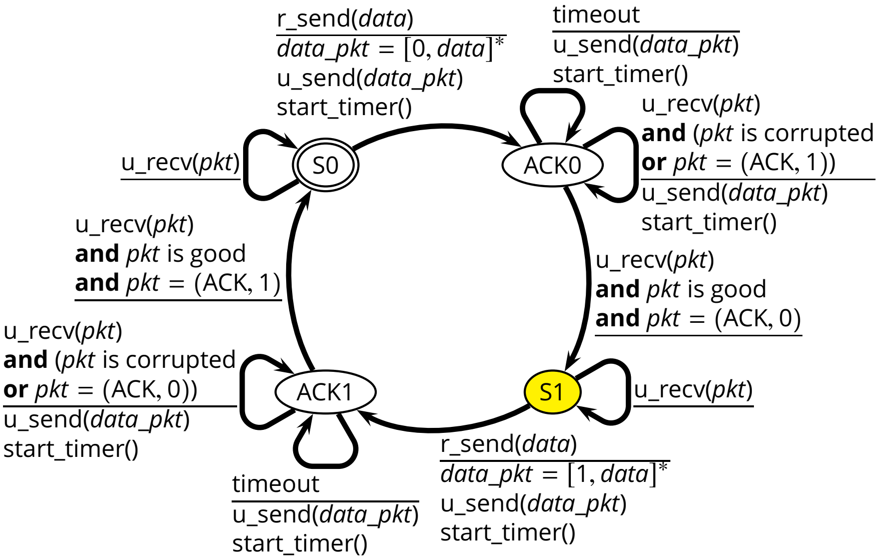

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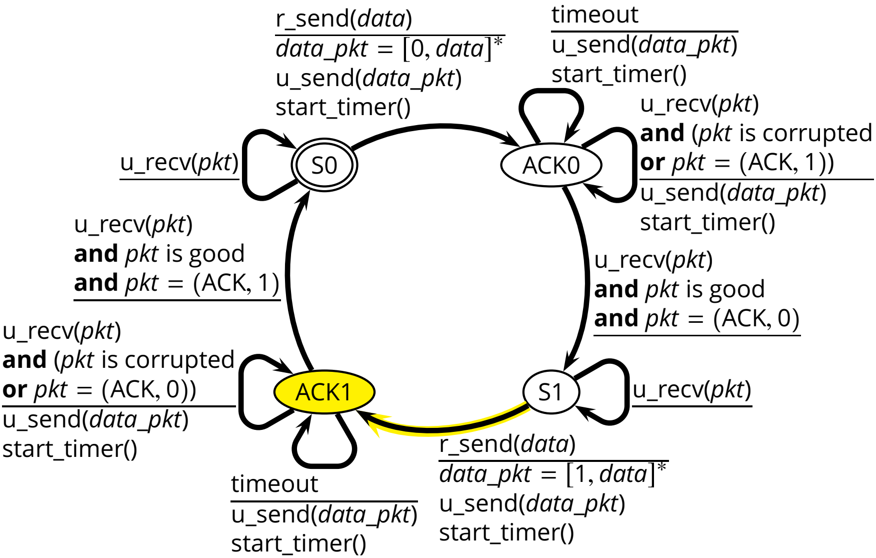

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u_send(*data_pkt*)

start_timer()

timeout

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start_timer()

u_recv(*pkt*)

S0

ACK0

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u_recv(*pkt*)

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u_send(*data_pkt*)

start_timer()

ACK1

S1

u_recv(*pkt*)

timeout

u_send(*data_pkt*)

start_timer()

r_send(*data*)

$\mathit{data\_pkt} = [1, \mathit{data}]^*$

u_send(*data_pkt*)

start_timer()

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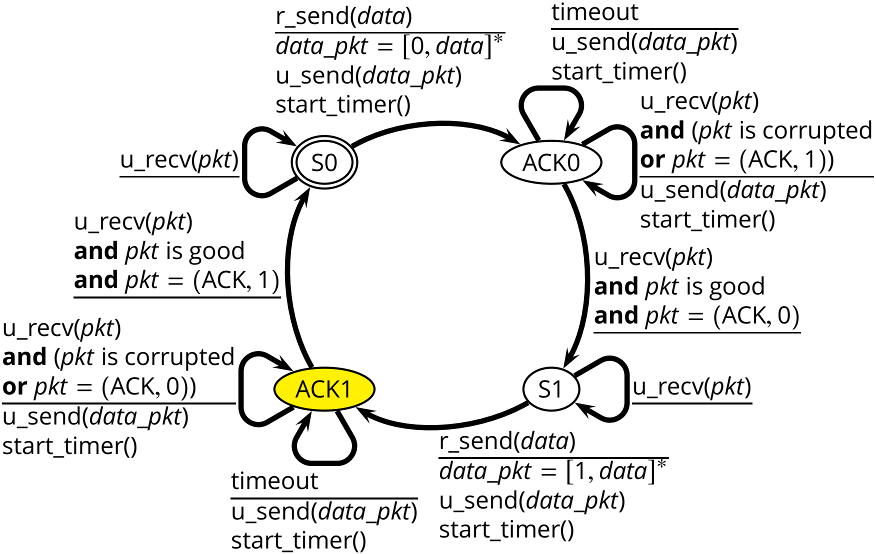

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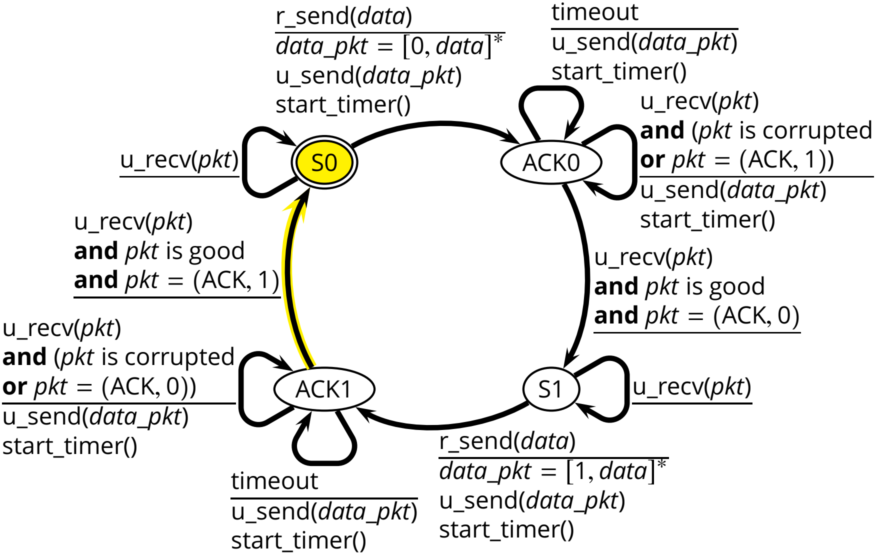

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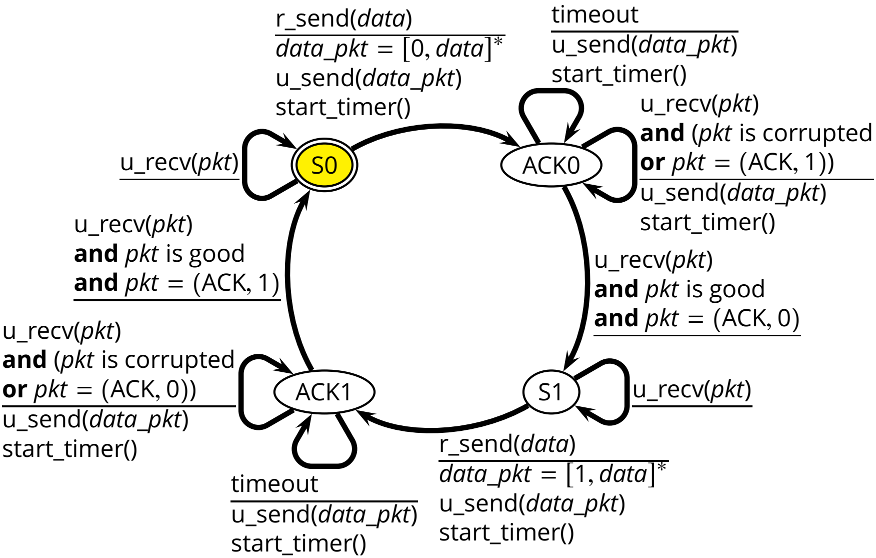
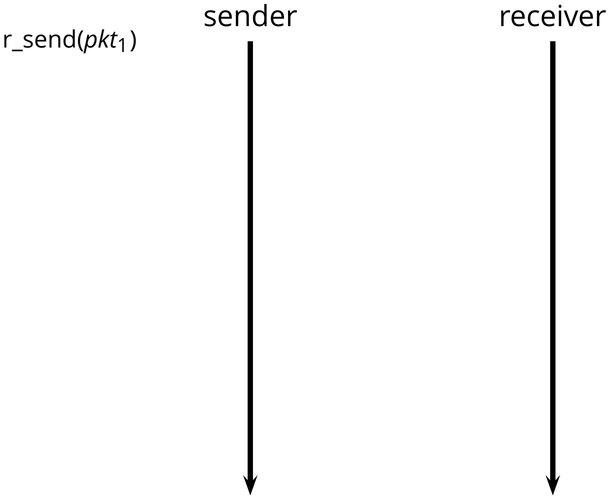


Network Usage

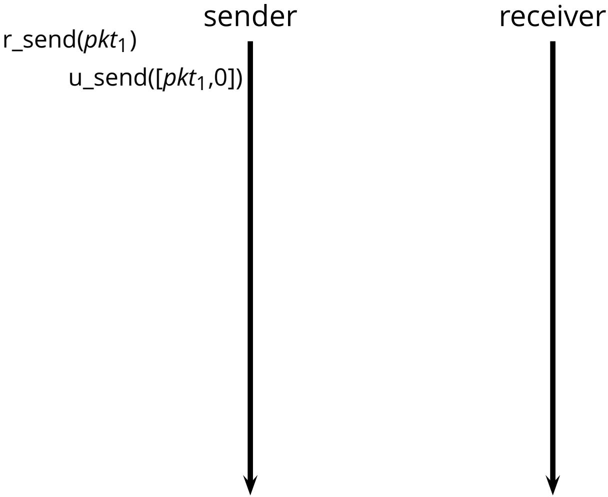


sender

receiver

r_send(pkt_1)

Network Usage



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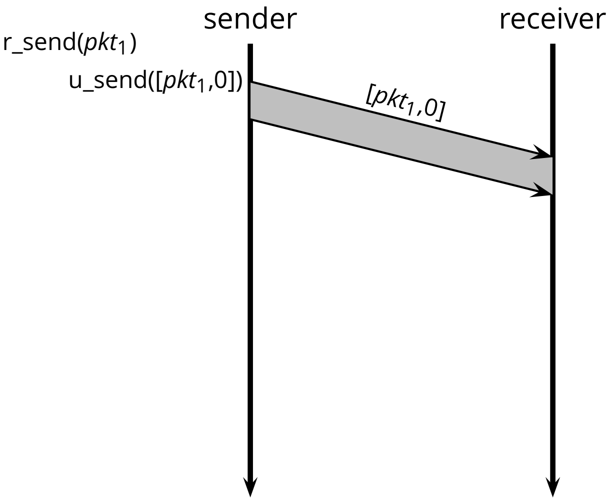

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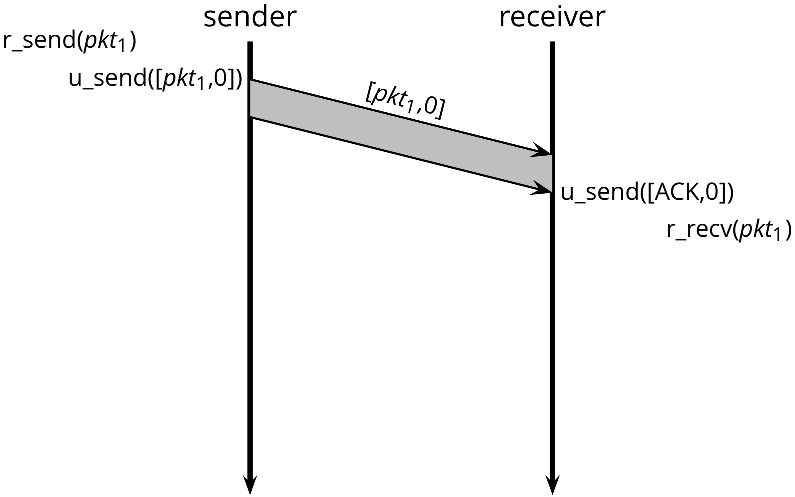

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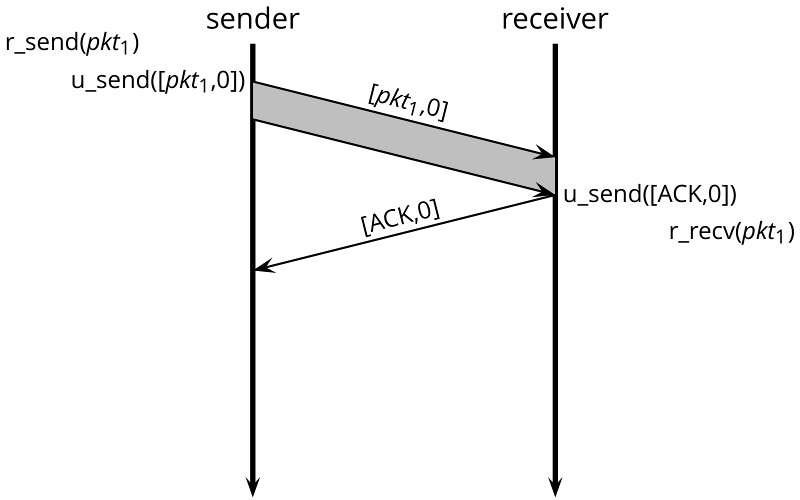

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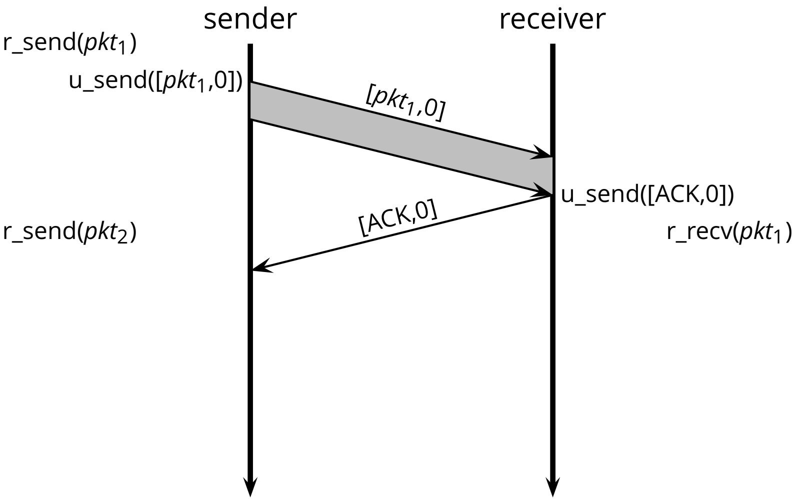

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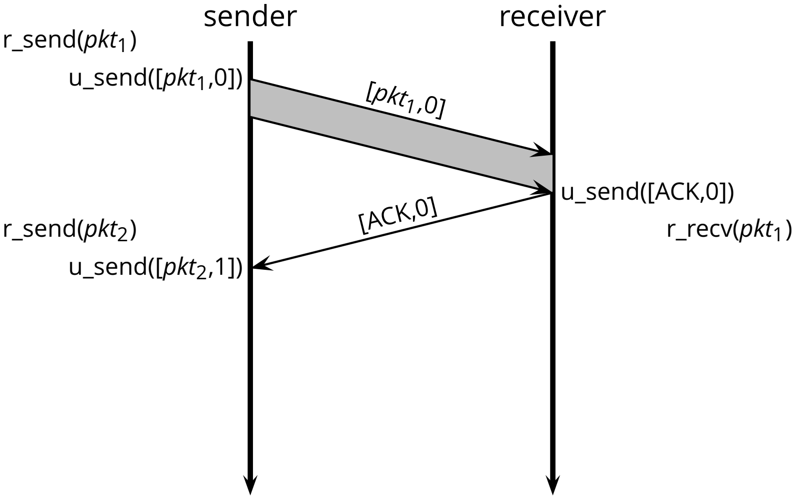

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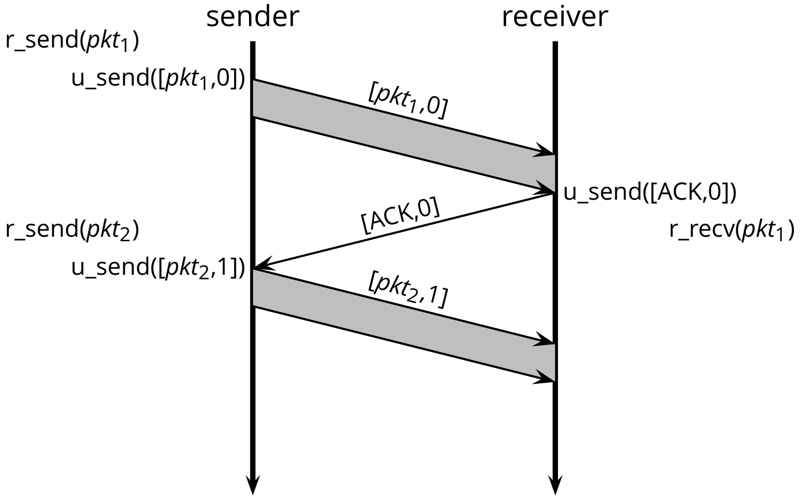

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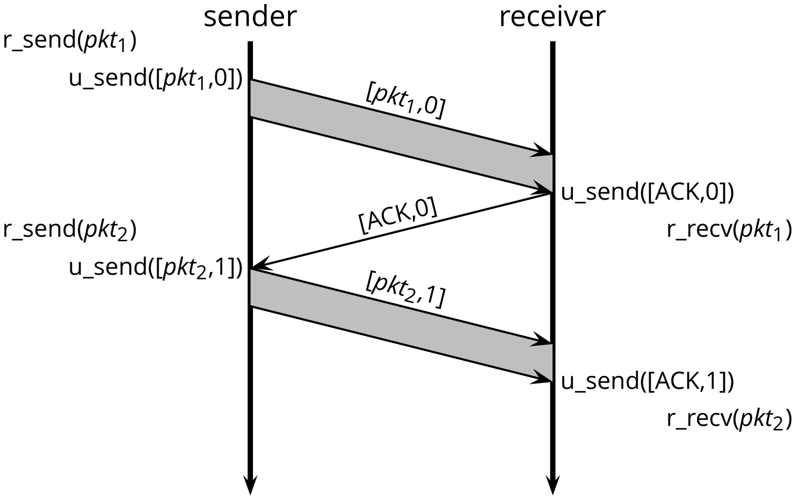

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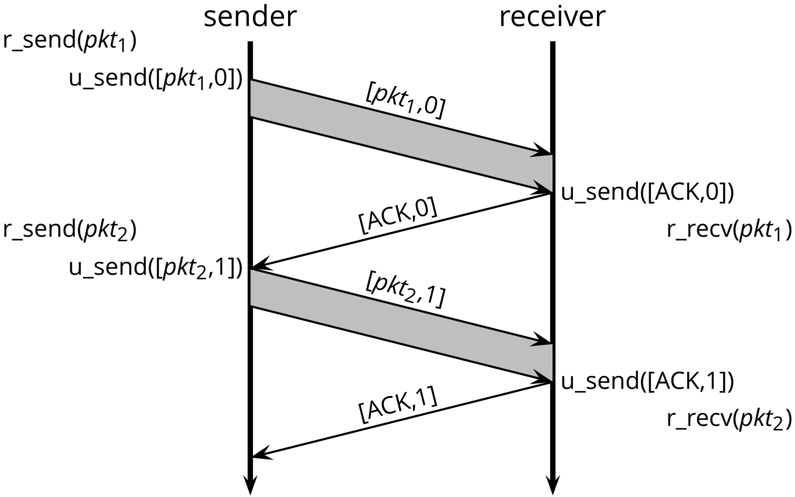

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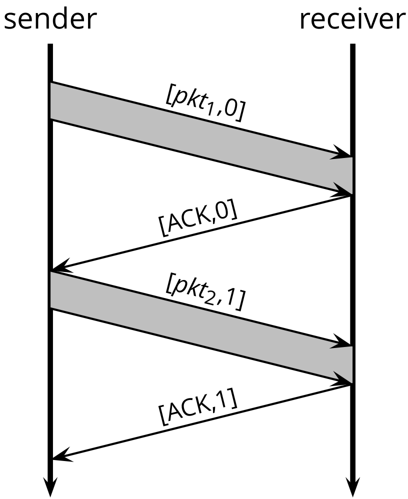

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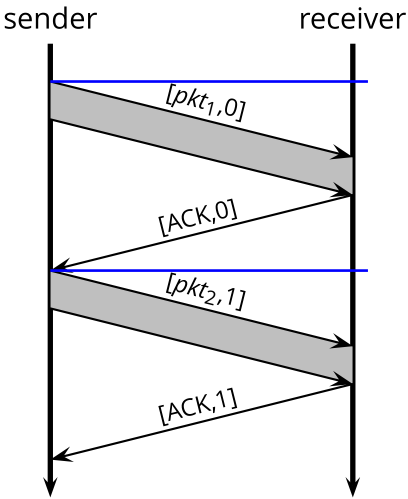

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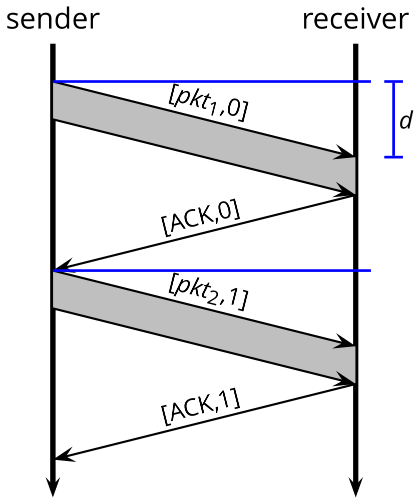

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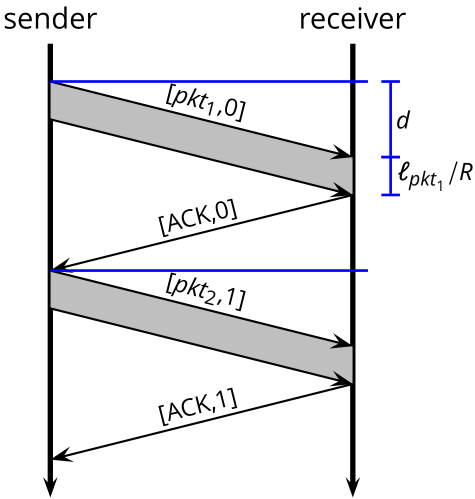

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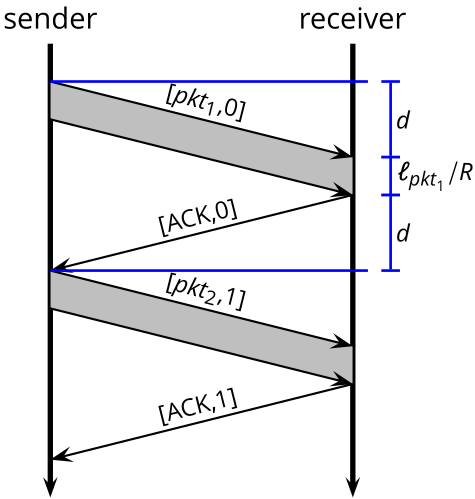
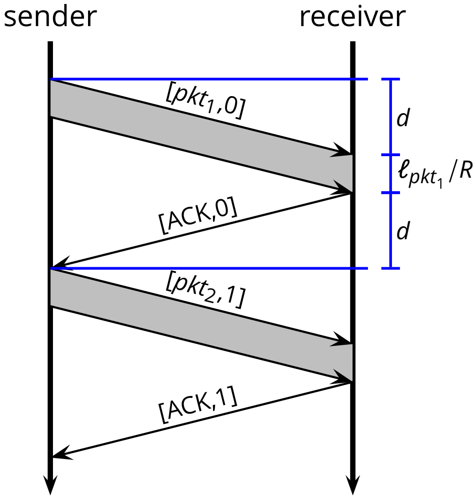


Network Usage

utilization factor

$U = \frac{\ell_{pkt}/R}{2d+\ell_{pkt}/R}$



Improving Network Usage

- How do we achieve a better *utilization factor*?

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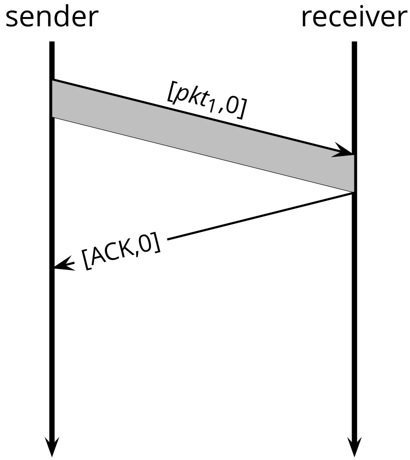

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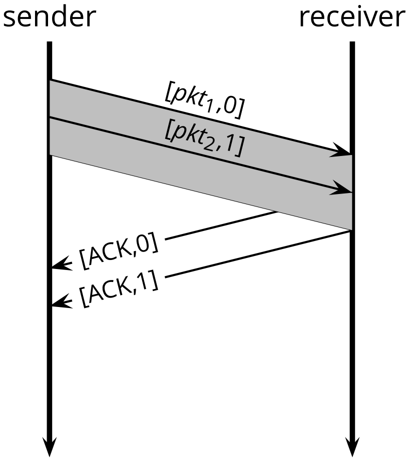

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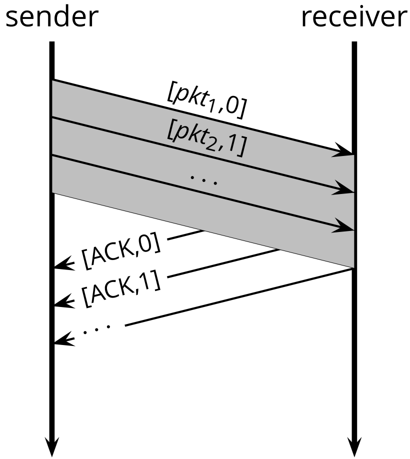

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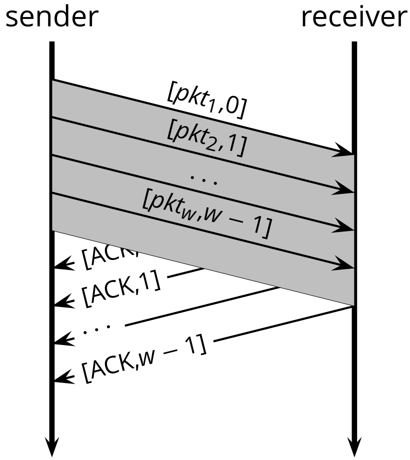

Go-Back-N

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- Sender has up to *W* unacknowledged packets in the pipeline
  - the sender's state machine gets very complex
  - we represent the sender's state with its queue of acknowledgements

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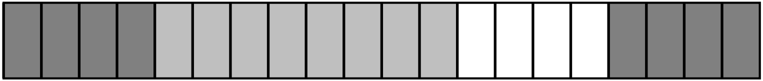

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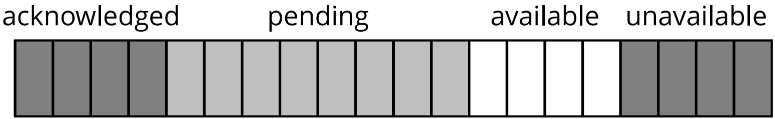

acknowledged pending available unavailable

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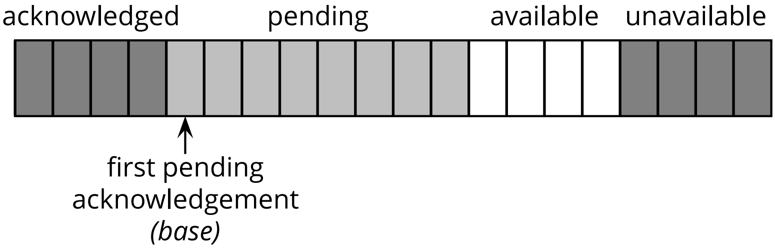

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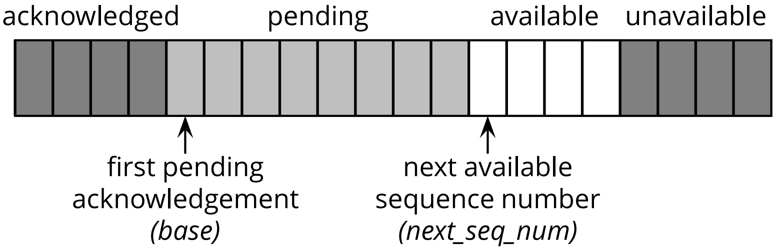
acknowledged
pending
available
unavailable
first pending acknowledgement *(base)*
next available sequence number *(next_seq_num)*

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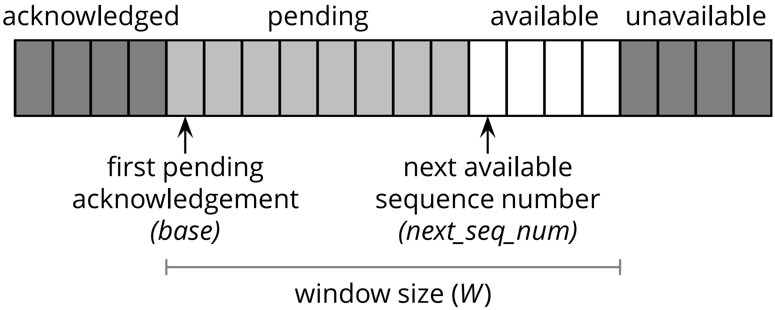
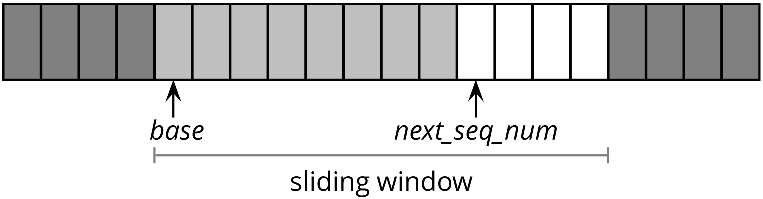

acknowledged
pending
available
unavailable
first pending acknowledgement *(base)*
next available sequence number *(next_seq_num)*
window size (*W*)

Sliding Window Protocol: Sender



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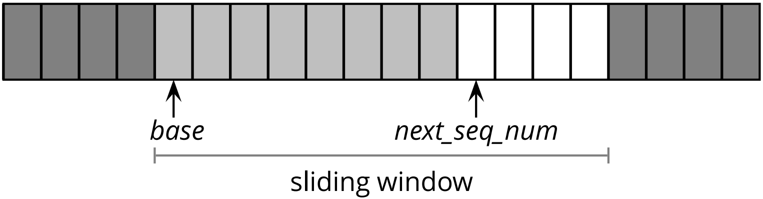
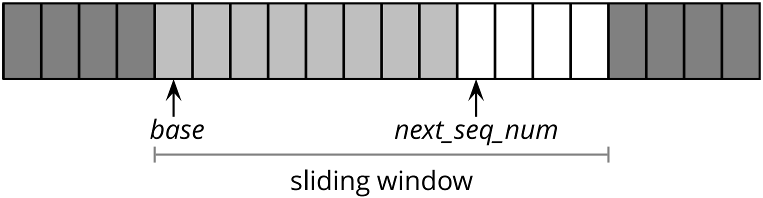


- r_send(pkt_1)

Sliding Window Protocol: Sender



- r_send(pkt_1)
  - u_send([pkt_1,*next_seq_num*])

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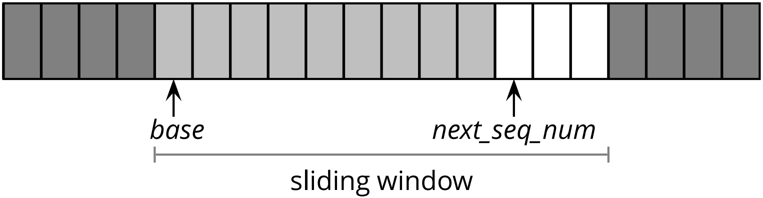

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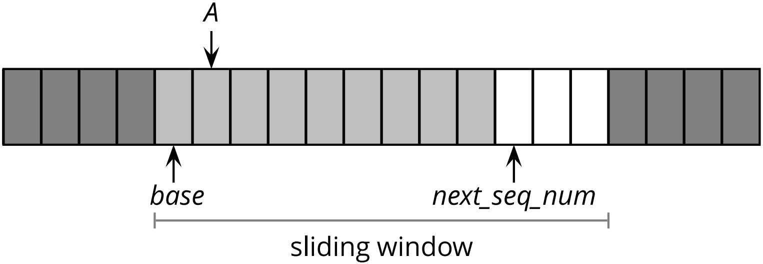

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- u_recv([ACK,*A*])

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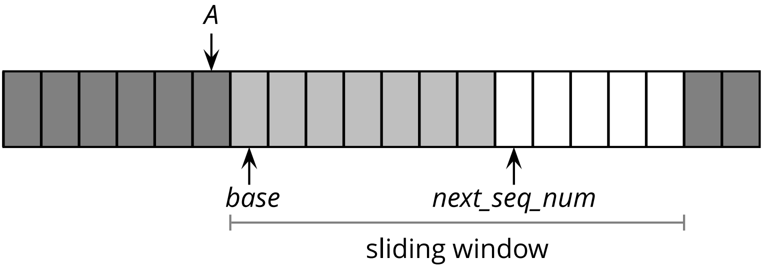

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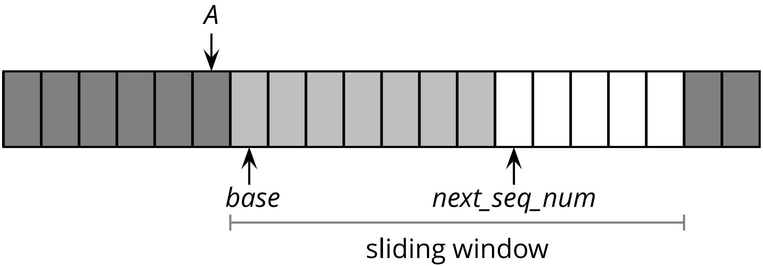
Sliding Window Protocol: Sender



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  - notice that acknewledgements are “cumulative”

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  - or the highest acknowledged sequence number

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- The sender responds to three types of events

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  - *r_send():* invocation from the application layer: send more data if a sequence number is available
  - *ACK:* receipt of an acknowledgement: shift the window (it’s a “cumulative” ACK)
  - *timeout:* “Go-Back-N.” I.e., resend all the packets that have been sent but not acknowledged

Sliding Window Protocol: Sender

- *init*

  ---

  base = 1

  next_seq_num = 1

Sliding Window Protocol: Sender

- *init*

```
$base = 1$
$next\_seq\_num = 1$
```

- r_send(*data*)

```
if $next\_seq\_num < base + W$:
    $pkt[next\_seq\_num] = [next\_seq\_num, data]^*$
    u_send($pkt[next\_seq\_num]$)
    if $next\_seq\_num == base$:
        start_timer()
    $next\_seq\_num = next\_seq\_num + 1$
else:
    refuse_data(data)      // block the sender
```

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base = ack_num + 1        // resume the sender
if next_seq_num == base:
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```

- timeout

```
start_timer()
foreach i in base ... next_seq_num − 1:
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```

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  - the receiver may buffer out-of-order packets. . .

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- The problem may seem a bit underspecified. What is the (average) packet size?

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  - $W \times \ell_{pkt} \leq 2d \times R$
    - why $W \times \ell_{pkt} > 2d \times R$ doesn't make much sense?
  - maximum channel utilization when $W \times \ell_{pkt} = 2d \times R$
  - $2d \times R$ can be thought of as the *capacity* of a connection

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- Is there a better way to deal with retransmissions?

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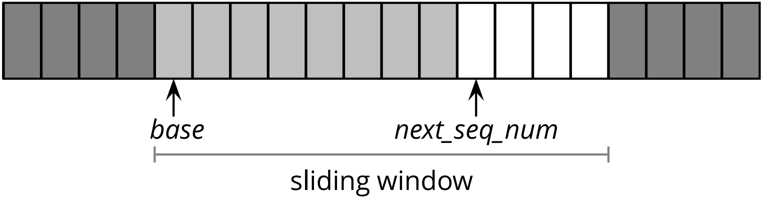
  - sender resends a packet when its timer expires
  - sender slides the window when the lowest pending sequence number is acknowledged

Selective Repeat: Sender



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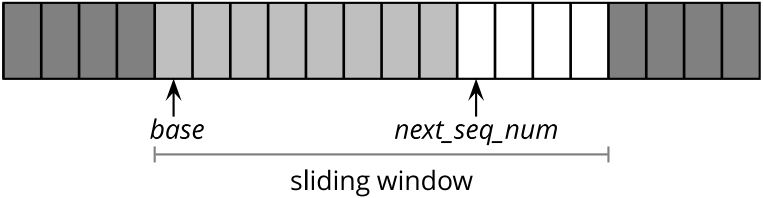

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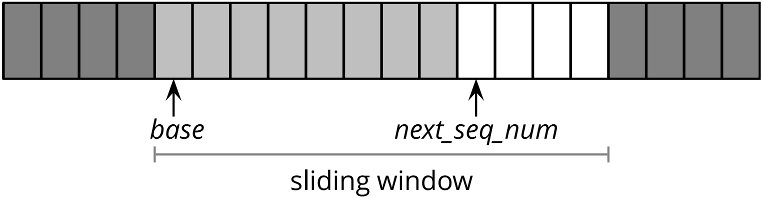

- r_send(pkt_1)
  - u_send([pkt_1,*next_seq_num*])
  - start_timer(*next_seq_num*)

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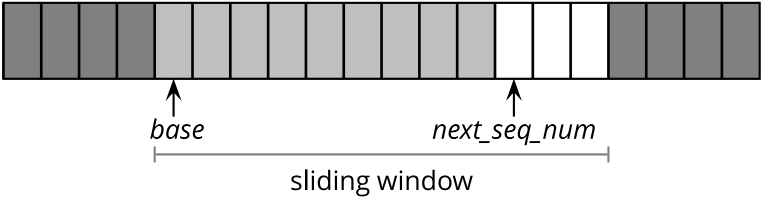

- r_send(pkt_1)
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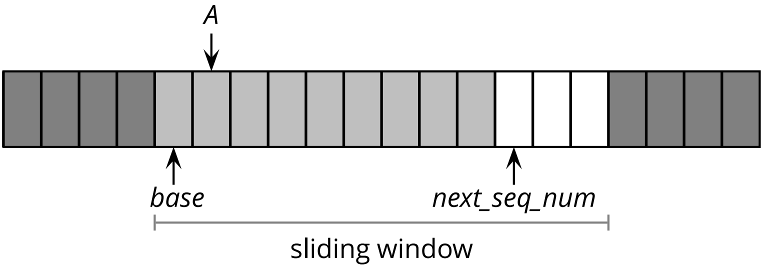

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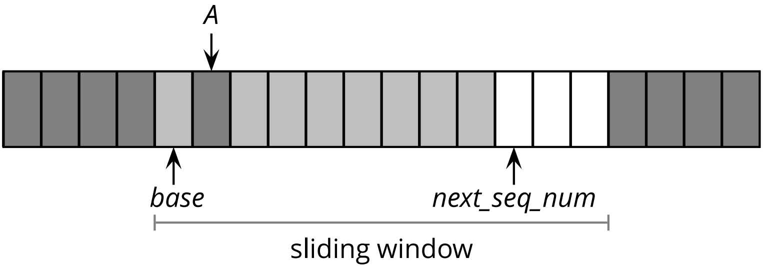

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    - $acks[A] = 1$ *// remember that A was ACK'd*

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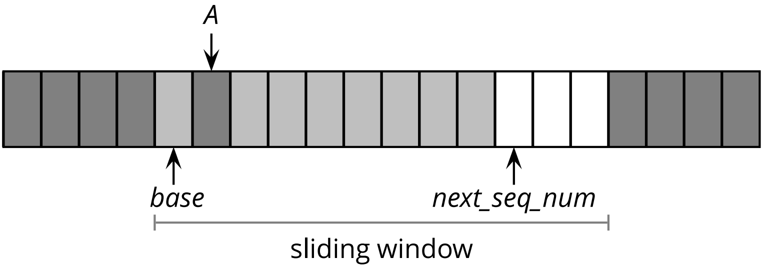

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- u_recv([ACK,*A*])
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  - acknewledgements are no longer "cumulative"

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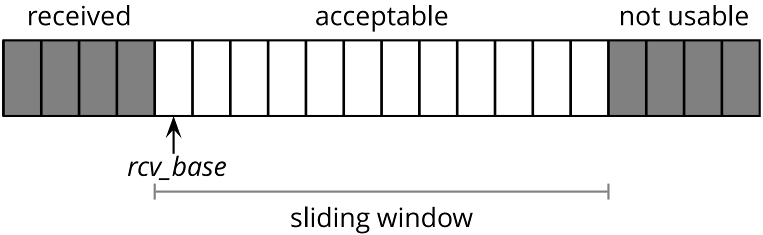

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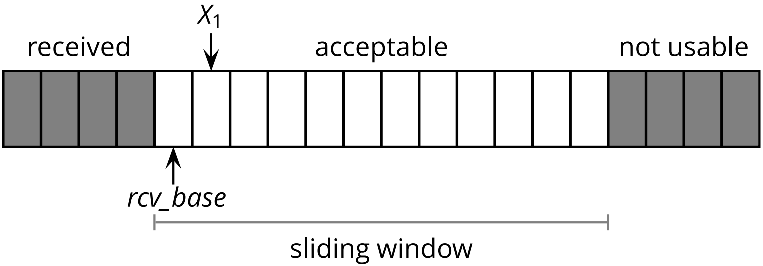
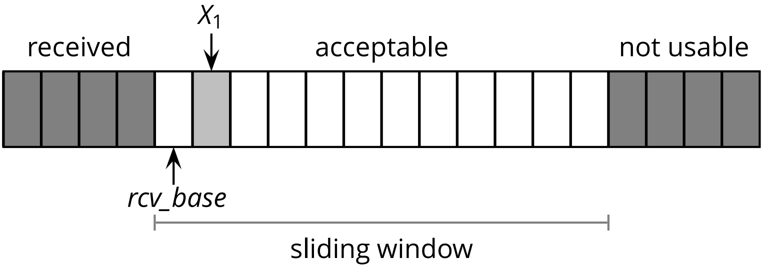


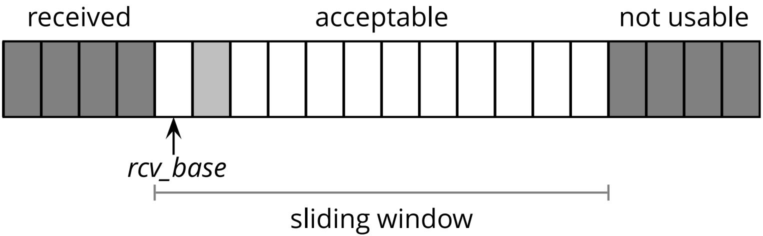
- u_recv([pkt_1,X_1]) **and** $rcv\_base \leq X_1 < rcv\_base + W$

Selective Repeat: Receiver



- u_recv($[pkt_1, X_1]$) **and** $rcv\_base \leq X_1 < rcv\_base + W$
  - $buffer[X_1] = pkt_1$
  - u_send($[ACK, X_1]^*$) *// no longer a "cumulative" ACK*

Selective Repeat: Receiver



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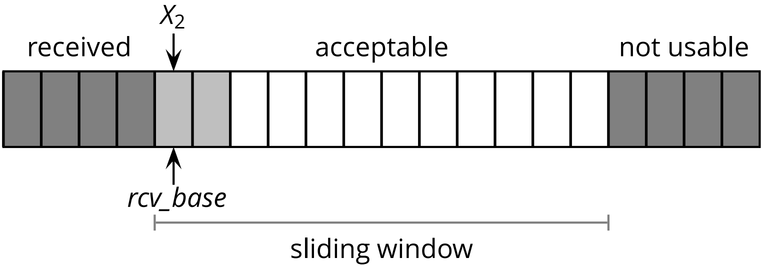
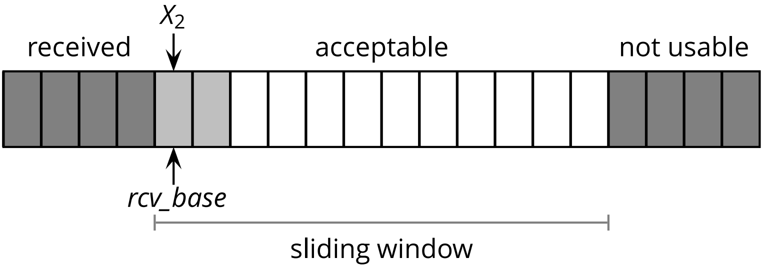


- u_recv([pkt_2,X_2]) **and** $rcv\_base \leq X_2 < rcv\_base + W$
  - $buffer[X_2] = pkt_2$
  - u_send($[ACK, X_2]^*$)

Selective Repeat: Receiver



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  - **if** X_2 == *rcv_base*:

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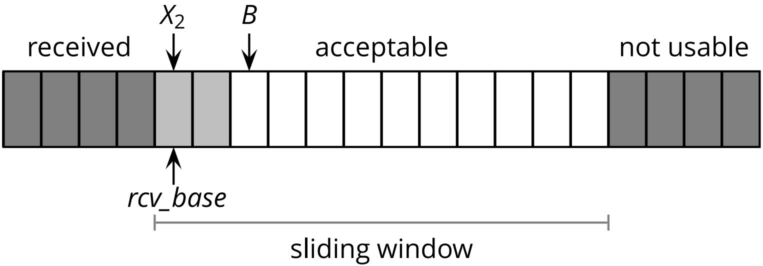

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```
▸ $buffer[X_2] = pkt_2$
▸ u_send($[ACK, X_2]^*$)
▸ if $X_2 == rcv\_base$:
      $B = first\_missing\_seq\_num()$
      foreach $i$ in $rcv\_base \ldots B - 1$:
          r_recv($buffer[i]$)
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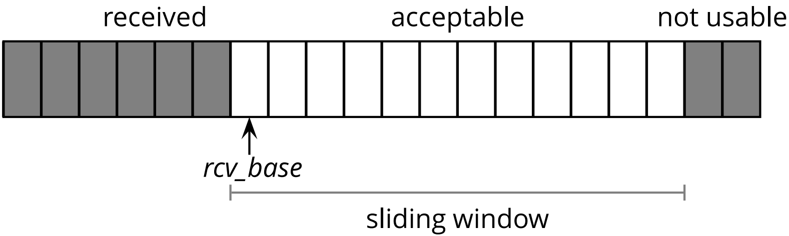

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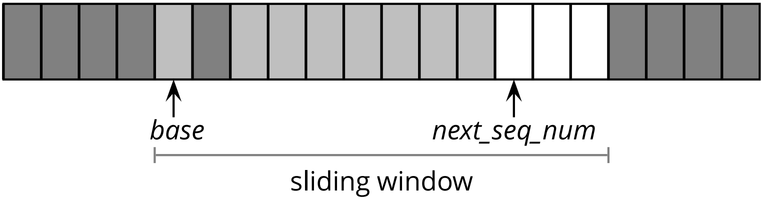

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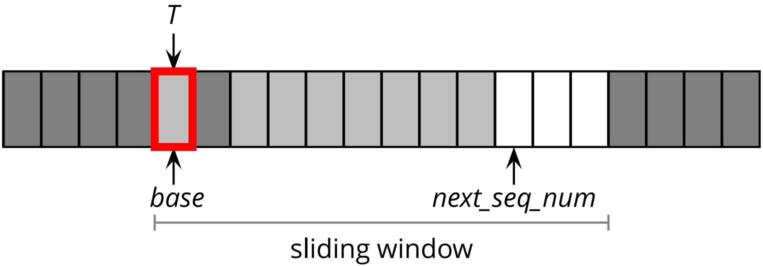

- Timeout for sequence number *T*

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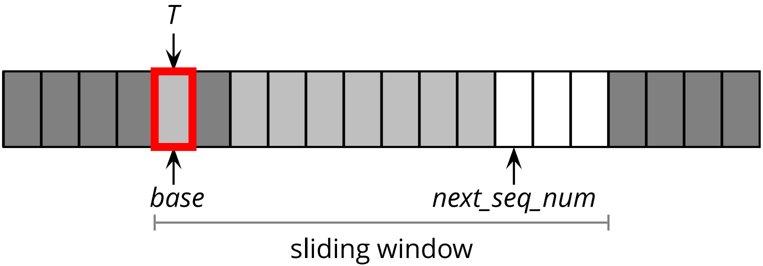

- Timeout for sequence number *T*
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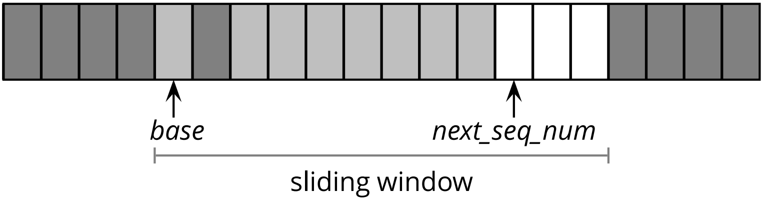

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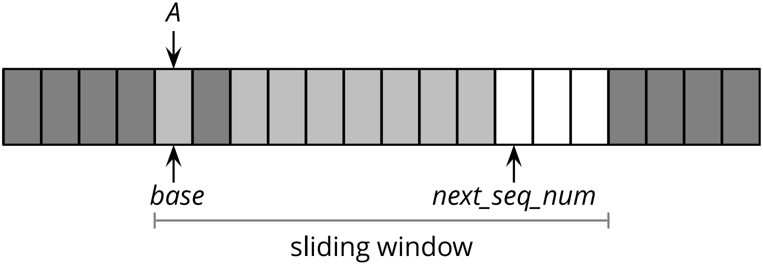

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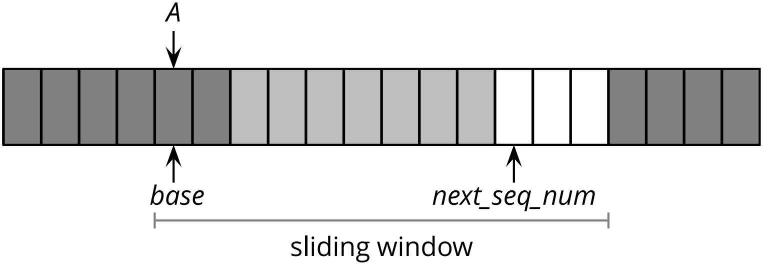

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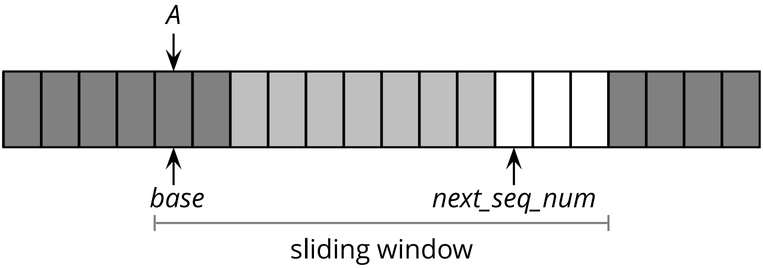

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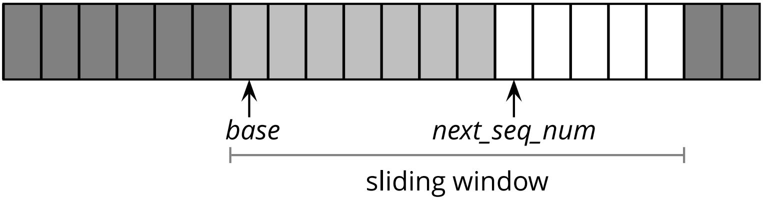

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