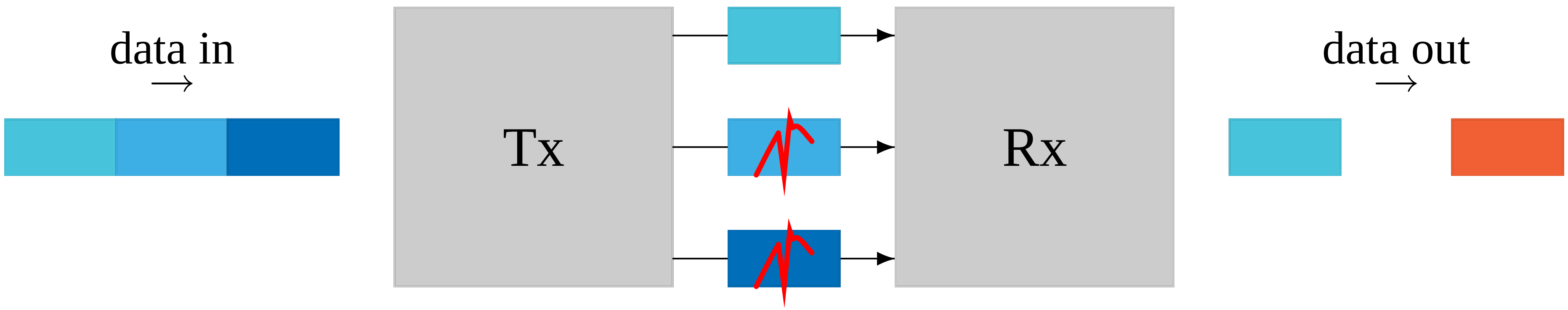
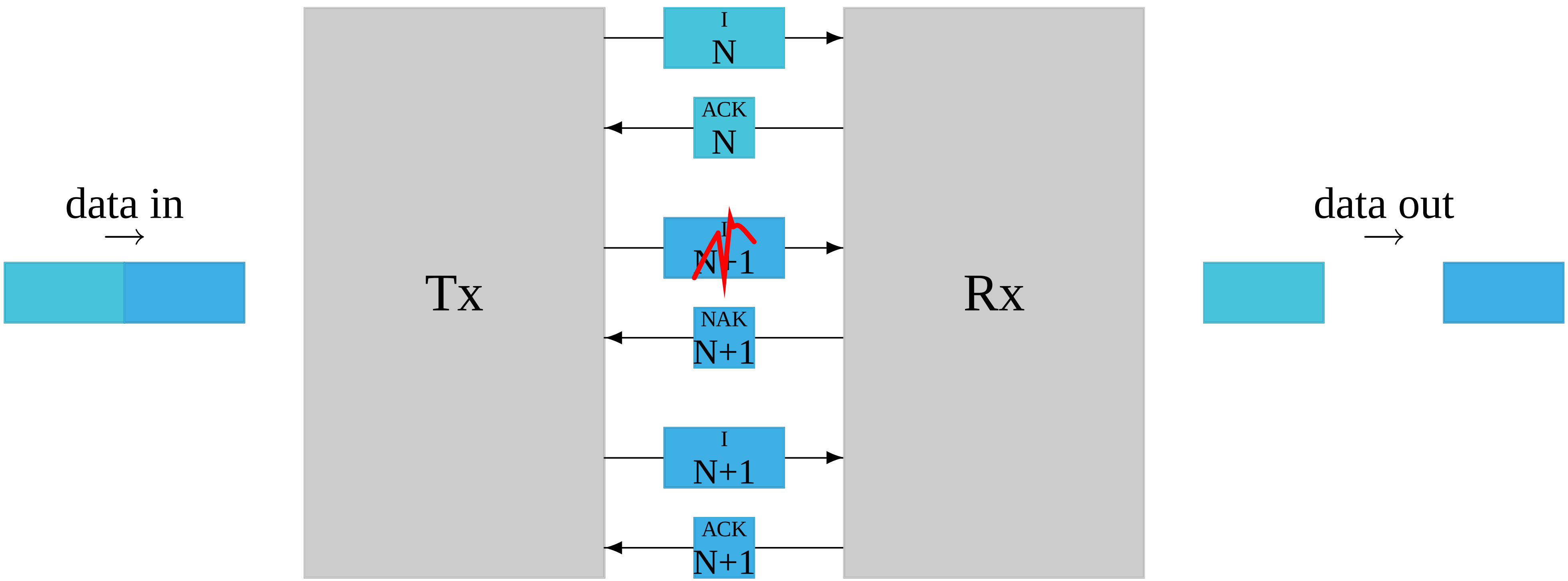
Automatic Repeat Request

The Problem



- Transmission of data requires series of PDUs to be sent
- PDU may be lost
- PDU may be corrupted

Automatic Repeat Request



- **automatic repeat request** (**ARQ**)
- Data link layer (transport layer, application layer, . . .)
- Number PDUs, and add error checking
- Data in I-frames, Acknowledgement in ACK-frames

Two Approaches to ARQ

- **idle RQ**
  - Tx waits after each I(N) until it receives ACK(N) or NAK(N) or times out
  - also called **stop-and-wait** or **synchronous**
- **continuous RQ**
  - Tx sends continuous stream of I-frames
  - can send I(N+1) before receiving ACK(N)
  - also called **asynchronous**

Idle RQ: Tx and Rx Actions

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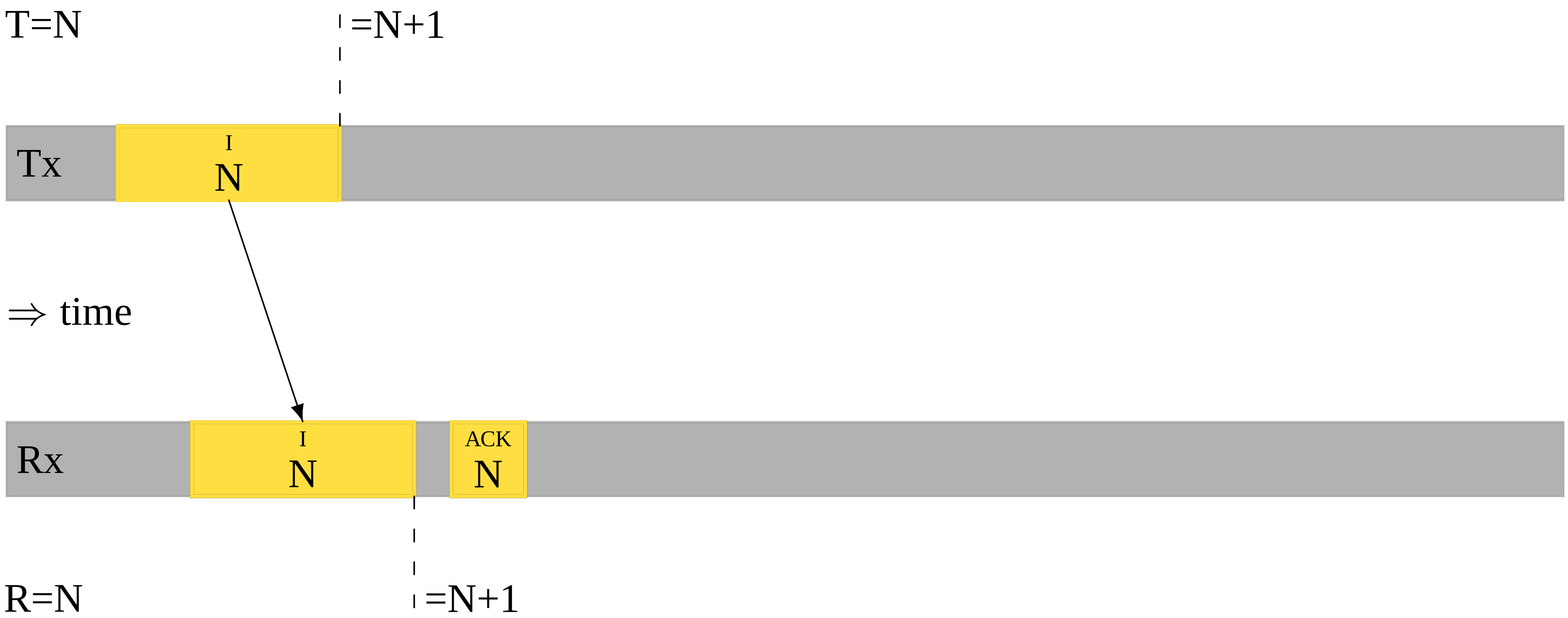
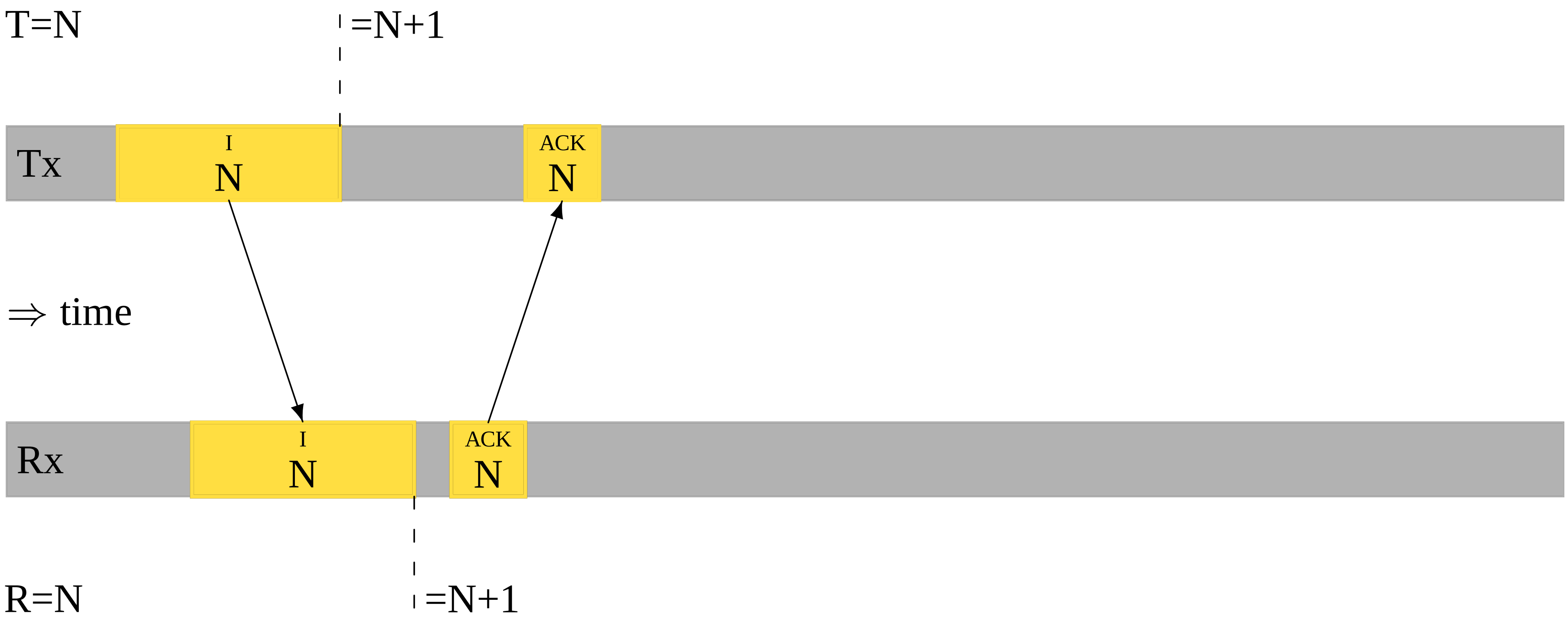
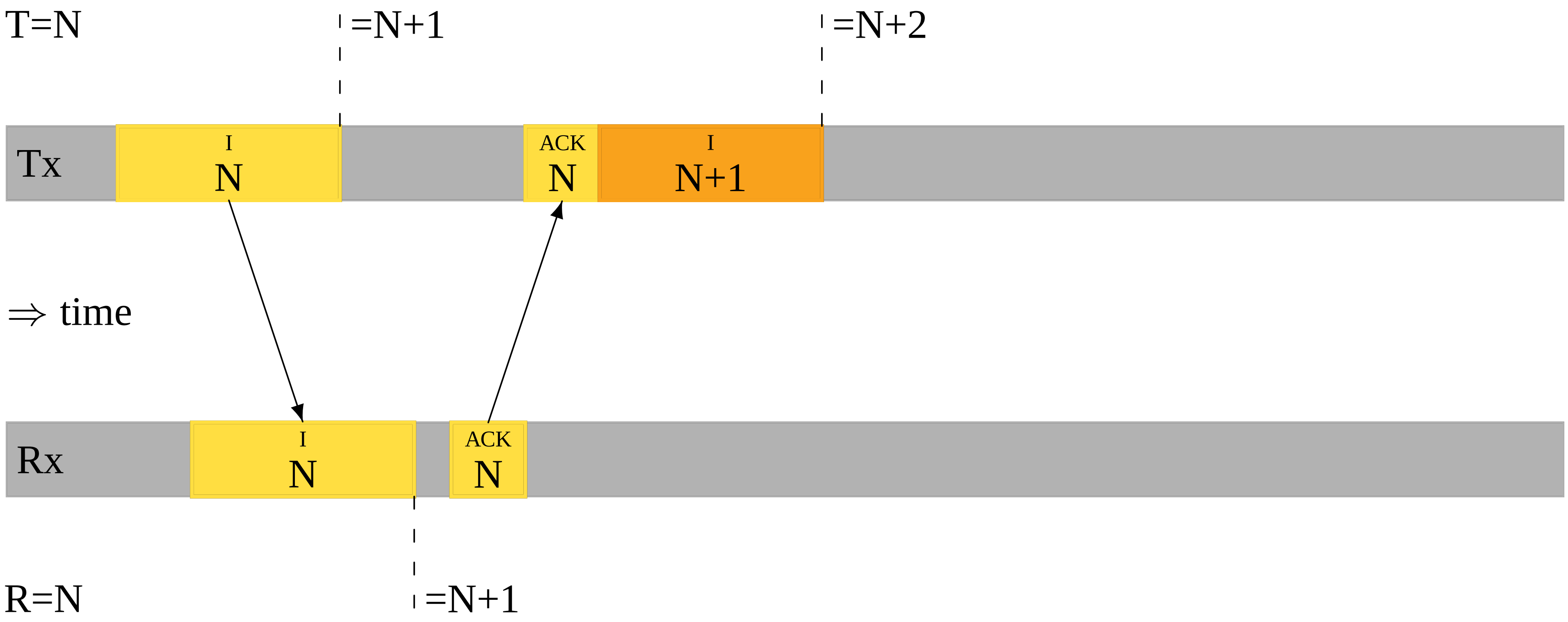


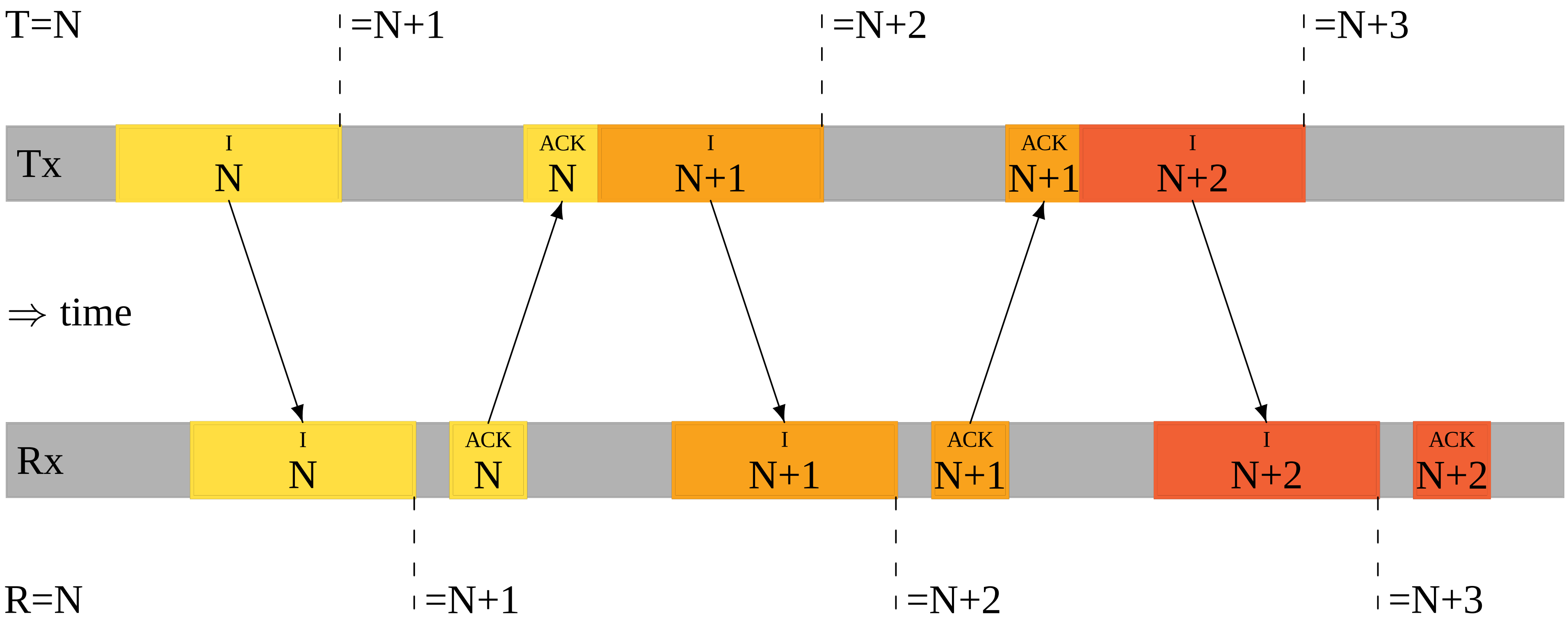
Idle RQ: Tx and Rx Actions



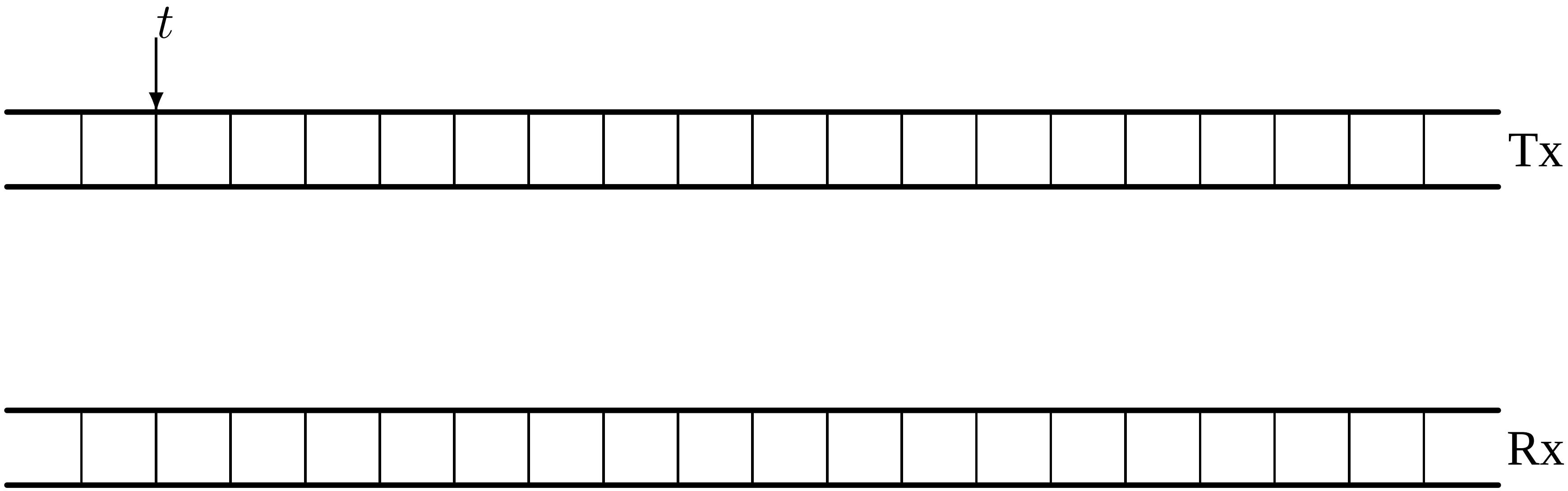
Idle RQ: Tx and Rx Actions



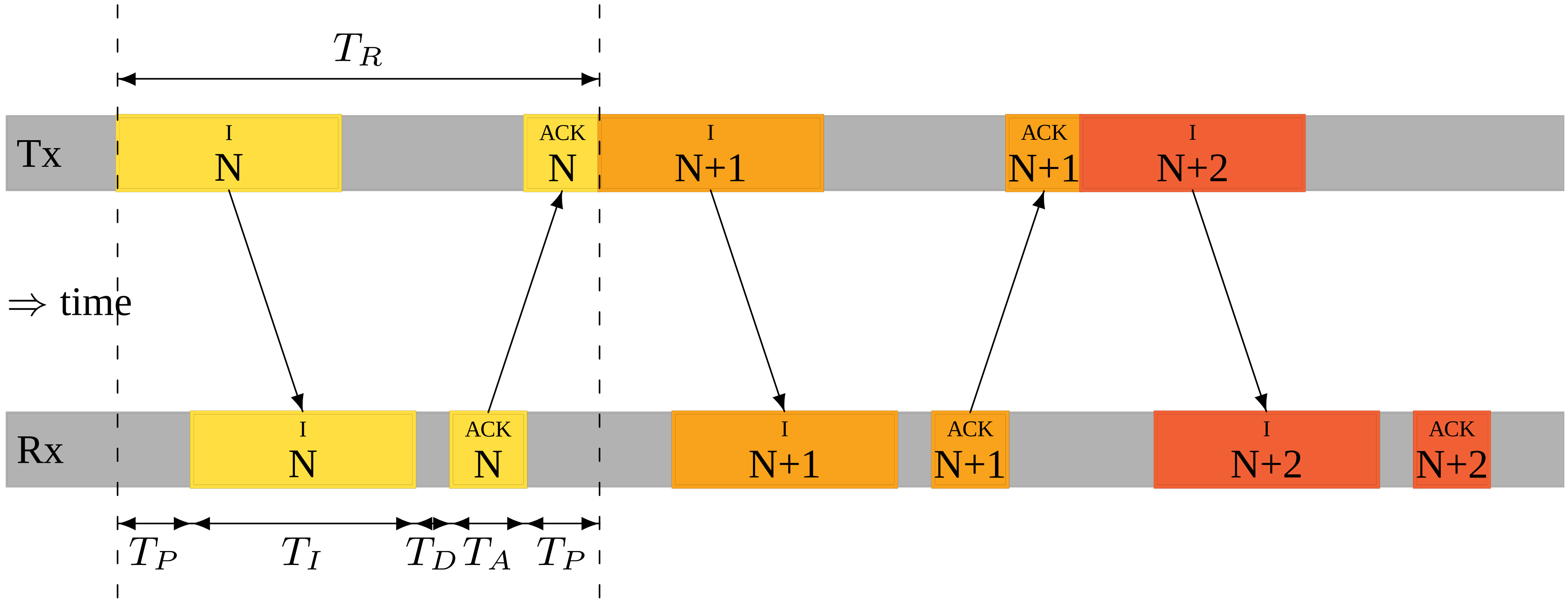
Idle RQ: Tx and Rx Actions



Worksheet: Automatic Repeat Request



Idle RQ: Stop-and-wait efficiency



$$T_R = T_I + 2T_P + T_D + T_A$$

$$\rho_s = \frac{T_I}{T_I + 2T_P + T_D + T_A}$$

Idle RQ: Improving performance

$$\rho_s = \frac{T_I}{T_I + 2T_P + T_D + T_A}$$

Increase ρ_s?

- reduce T_P by decreasing the distance between Tx and Rx
  - usually not possible
- increase T_I by decreasing the bit rate
  - would not want to do this
  - tells us Idle RQ more efficient on slower channels
- increase T_I by increasing the number of bits per I-frame
  - larger I-frames more likely to suffer errors

Idle RQ: Example Protocol Efficiency Calculation

Compute the maximum data throughput of Idle RQ

- *10Mbs^{-1}communications system*
- *I-frame size is 92 bits and the ACK-frame size is 8 bits*
- *via a satellite in orbit at 37,500km above the Earth's surface*
- *propagation speed* $300 \times 10^6 ms^{-1}$

$T_I = \frac{92}{10 \times 10^6} = 9.2 \times 10^{-6} s$

$T_A = \frac{8}{10 \times 10^6} = 0.8 \times 10^{-6} s$

assume $T_D = 0$

$T_P = \frac{2 \times 37.5 \times 10^6}{300 \times 10^6} = 0.25 s$

$\rho_s = \frac{9.2 \times 10^{-6}}{9.2 \times 10^{-5} + 2 \times 0.25 + 0.8 \times 10^{-6}} = 18.4 \times 10^{-6}$

throughput = $\rho_s B = 18.4 \times 10^{-6} \times 10 Mbs^{-1} = 184 bs^{-1}$

Overall Efficiency of Idle RQ

Three factors cause the raw bit-rate of a channel to be wasted (i=no I-frame bits, c=control bits in I-frame, a=no ACK-frame bits)

- Wastage due to stop-and-wait protocol

$$\rho_s = \frac{T_I}{T_I + 2T_P + T_A + T_D}$$

- Wastage due to errors forcing retransmission

$$\rho_e = (1 - \mathrm{BER})^{i+a} \qquad \rho_e \approx \frac{1}{1+p}$$

- Wastage due to control information

$$\rho_c = \frac{i-c}{i+a}$$

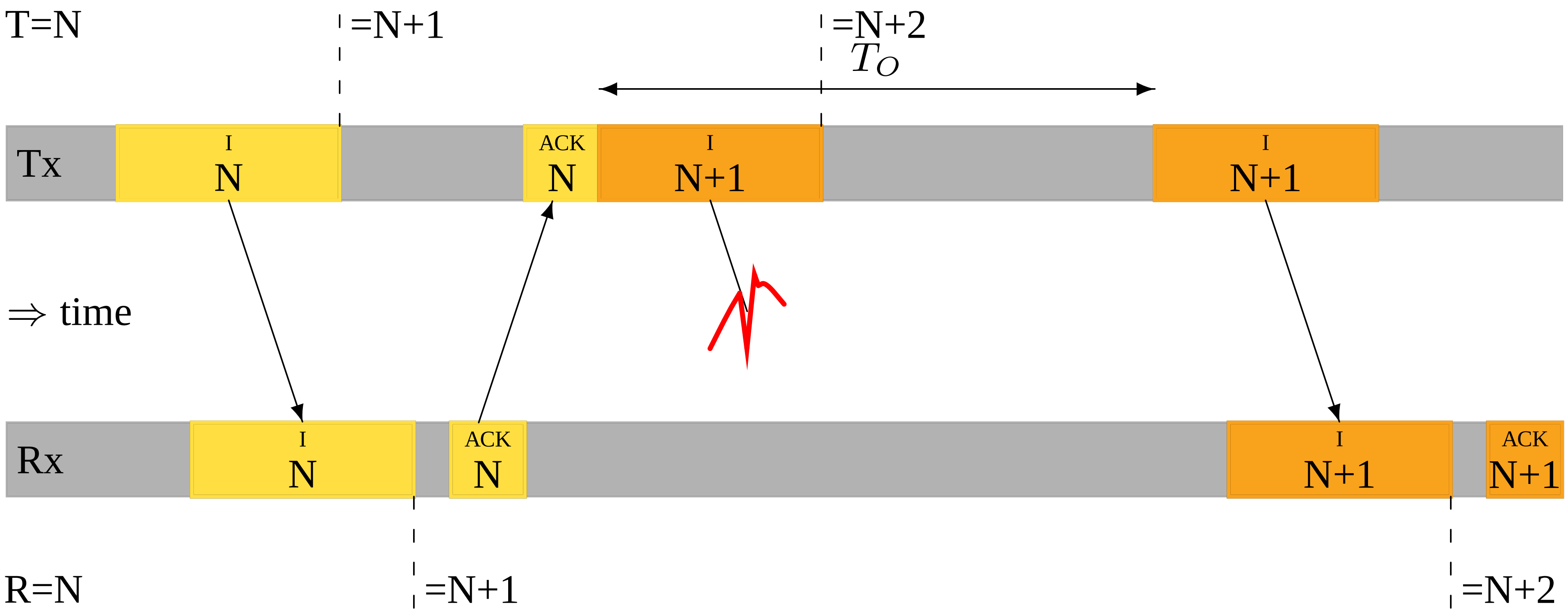
- Overall efficiency $\rho_i = \rho_s \rho_e \rho_c$

Worksheet: Overall Efficiency of Idle RQ

I-frames of 10000 bits; hosts separated by 500km over a 1Mbs^{-1} link. The I-frames consist of 1000 bits of header and 9000 bits of data. The signal propagation speed is $200 \times 10^6 ms^{-1}$, and the BER is 10^{-5}

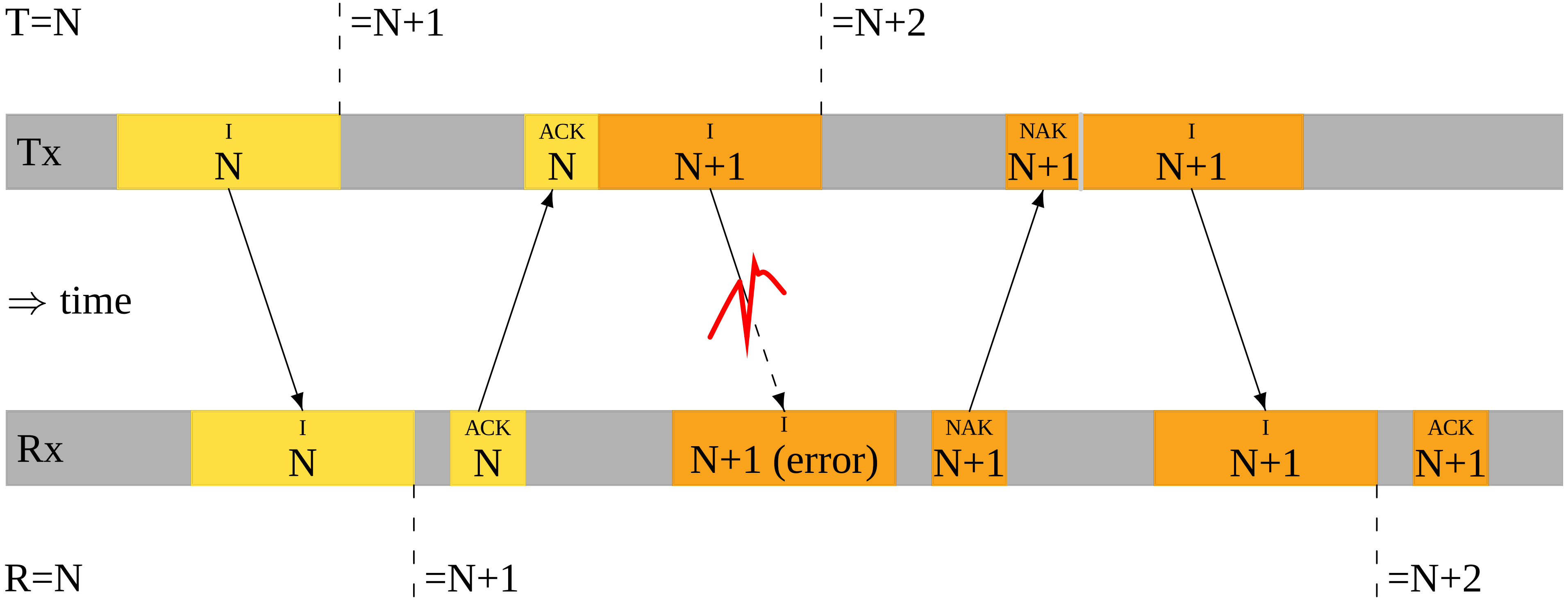
1. Calculate the probability that an I-frame is lost due to an error.
2. What is the *error efficiency* of the system ρ_e?
3. What is the *stop-and-wait efficiency* of the system ρ_s?
4. What is the *control information efficiency* of the system ρ_c?
5. What is the overall efficiency of the Idle RQ protocol?

Idle RQ Error Handling: Loss of I-frame



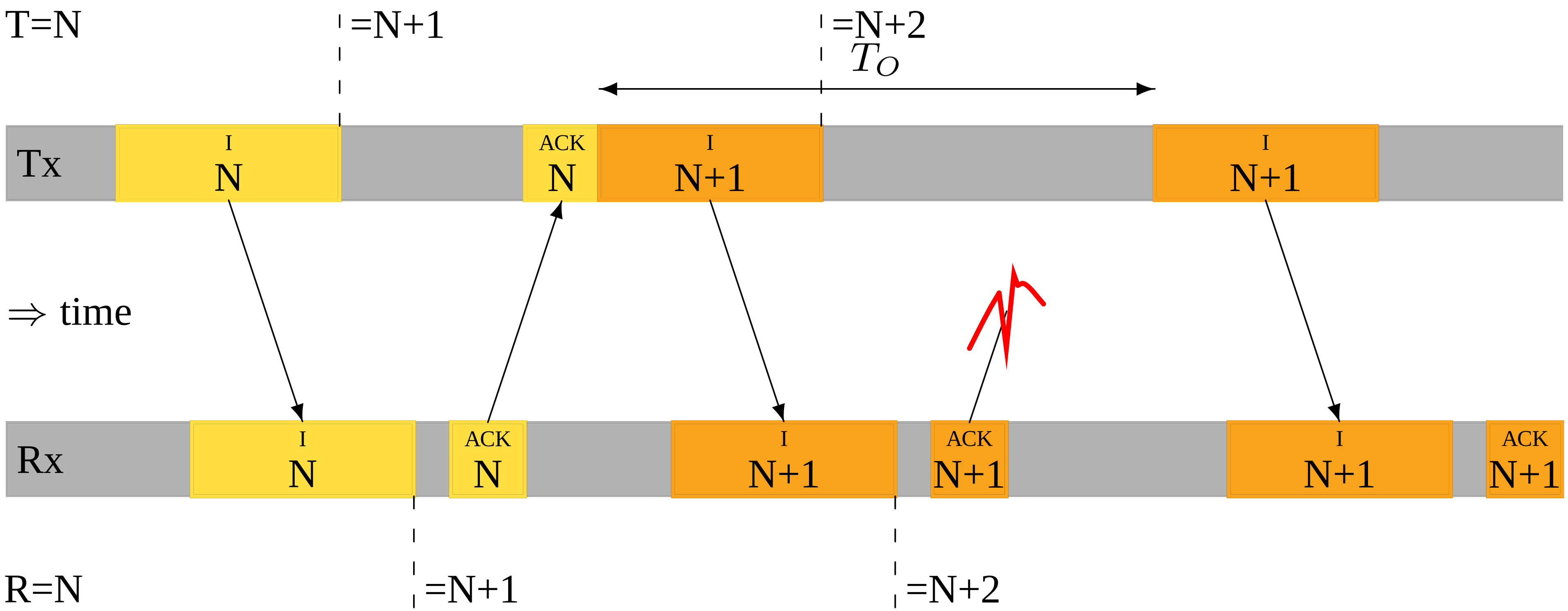
- Timeout T_O must be set at Tx
- $T_O > T_R$

Idle RQ Error Handling: Corrupt I-frame



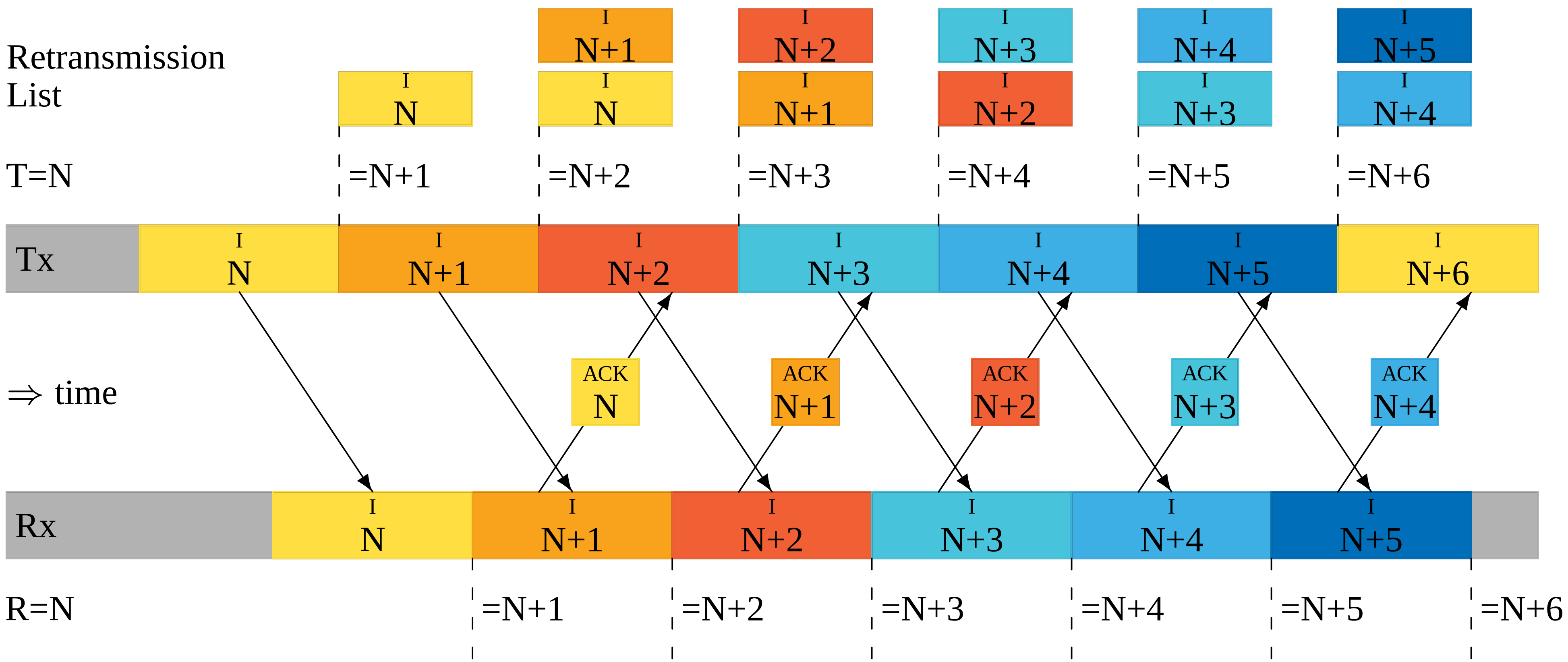
- NAK-frame speeds up retransmission of I-frame
- Do not have to use NAK-frames

Idle RQ Error Handling: Loss of ACK-frame

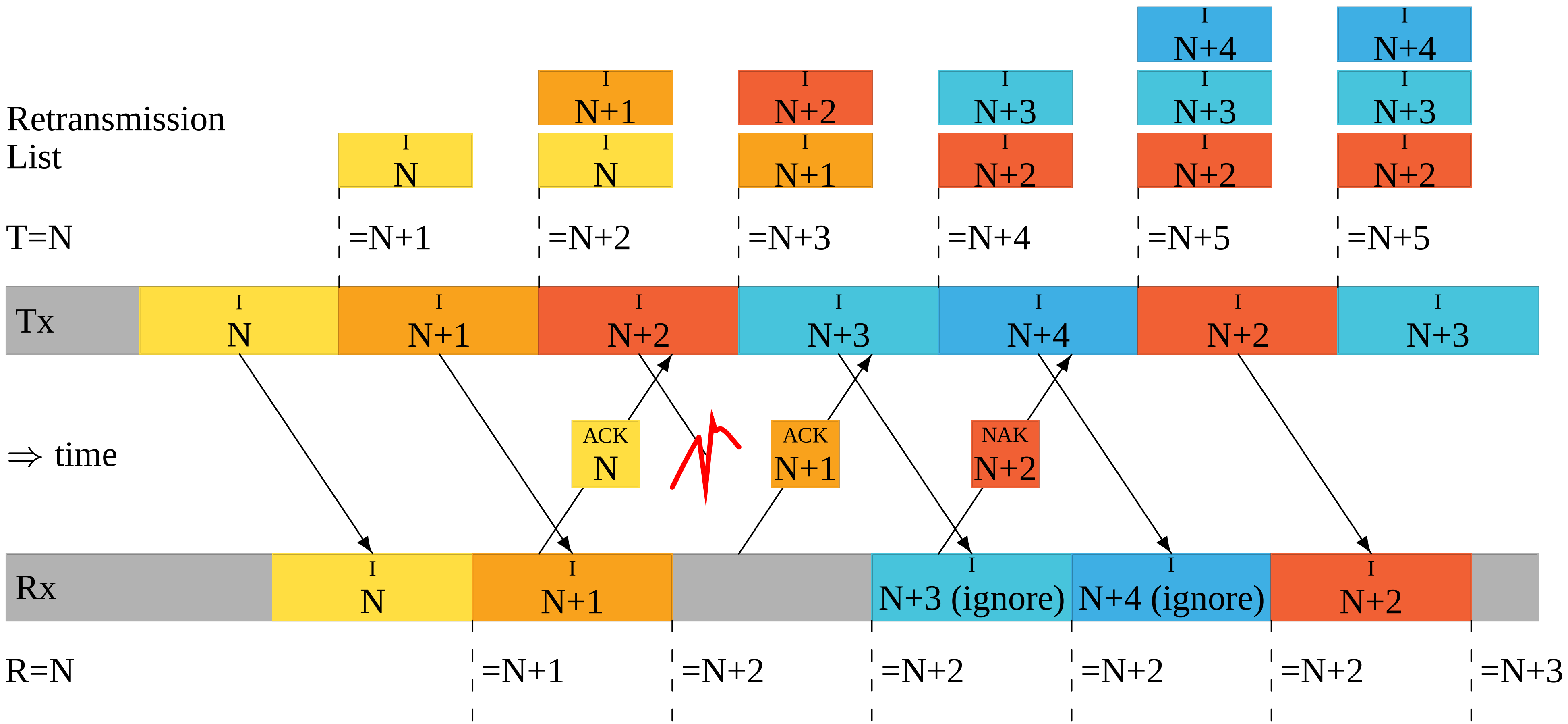


- Rx receives I(N+1) twice
- Really do have to number I-frames!

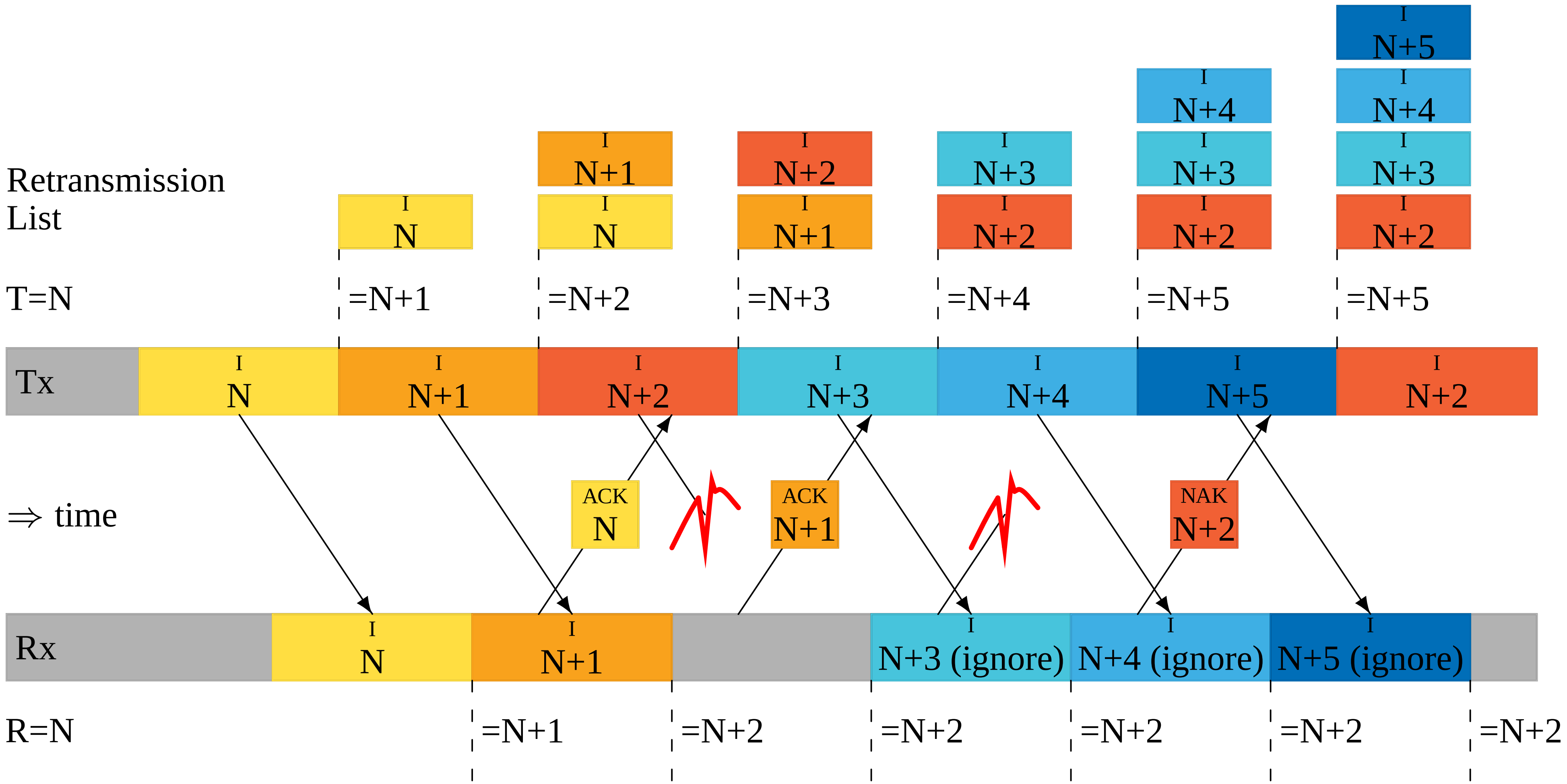
Continuous RQ



Go-Back-N: Loss of I-frame



Go-Back-N: Loss of NAK-frame



Idle RQ: Rough Formula for Efficiency

$r = \lceil \frac{T_R}{T_I} \rceil$= number for frames sent in T_R

p= probability frame suffers error

error efficiency:

$$\rho_e \approx \frac{1}{1+p}$$

protocol efficiency:

$$\rho_s = \frac{1}{r}$$

combined efficiency:

$$\rho = \frac{1}{r + rp}$$

Go-back-N: Efficiency

- $\rho_s = 1$
- send $r = \lceil \frac{T_R}{T_I} \rceil$ I-frames for each erroneous I-frame

$$\rho_e \approx \frac{1}{1 + pr}$$

- ρ_c same as idle RQ

Example: Continuous RQ Go-Back-N protocols

If Continuous RQ Go-Back-N is being used, calculate the efficiency and throughput of a 10Mbs^{-1} satellite communication system with BER of 10^{-6}, a satellite height of 37,500km, propogation speed $300 \times 10^6 ms^{-1}$, I-frames 100 bits.

$p = 1 - 0.9999 = 10^{-4}$

$T_I = \frac{100}{10 \times 10^6} = 10^{-5} s$

$T_P = \frac{2 \times 37.5 \times 10^6}{300 \times 10^6} = 0.25 s$

assume $T_D = 0, T_A = 0$

$T_R = 10^{-5} + 2 \times 0.25 = 0.5 s$

$r = \frac{0.5}{10^{-5}} = 50 \times 10^3$

$\rho_g = \frac{1}{1 + 10^{-4} \times 50 \times 10^3} = \frac{1}{6} = 0.17$

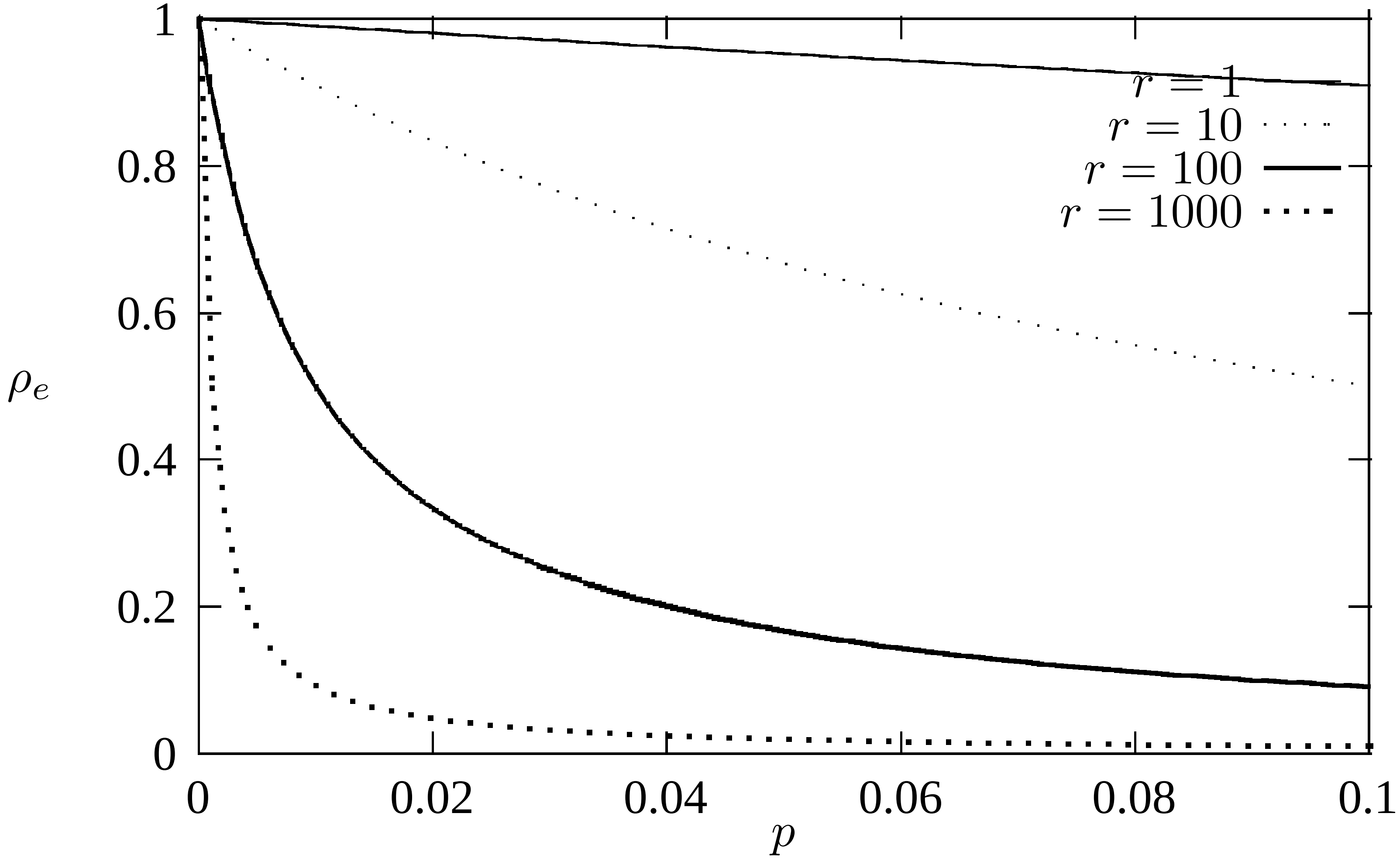
throughput = 1.7 Mbs^{-1}

Worksheet: Efficiency of Continuous RQ Go-Back-N

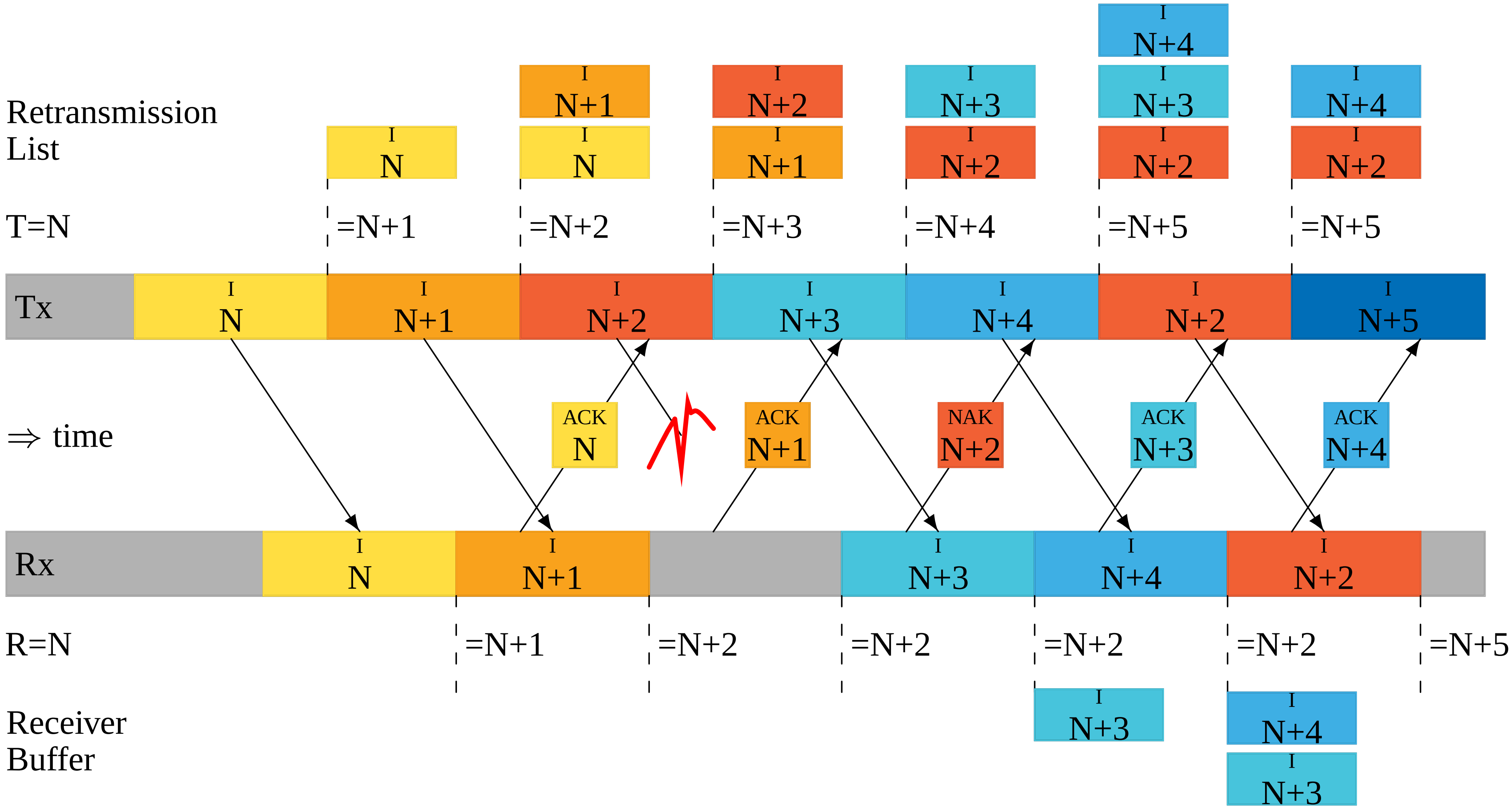
Go-Back-N system uses I-frames of 10000 bits; hosts separated by 500km over a 10Mbs^{-1} link. Signal propagation speed is $200 \times 10^6 ms^{-1}$.

1. If no errors occur, what is the throughput we can expect on the link?
2. If the BER is 10^{-5}, what is the probability of any one frame being lost?
3. What is the throughput with this BER?
4. What would have been the throughput if Idle RQ had been used?

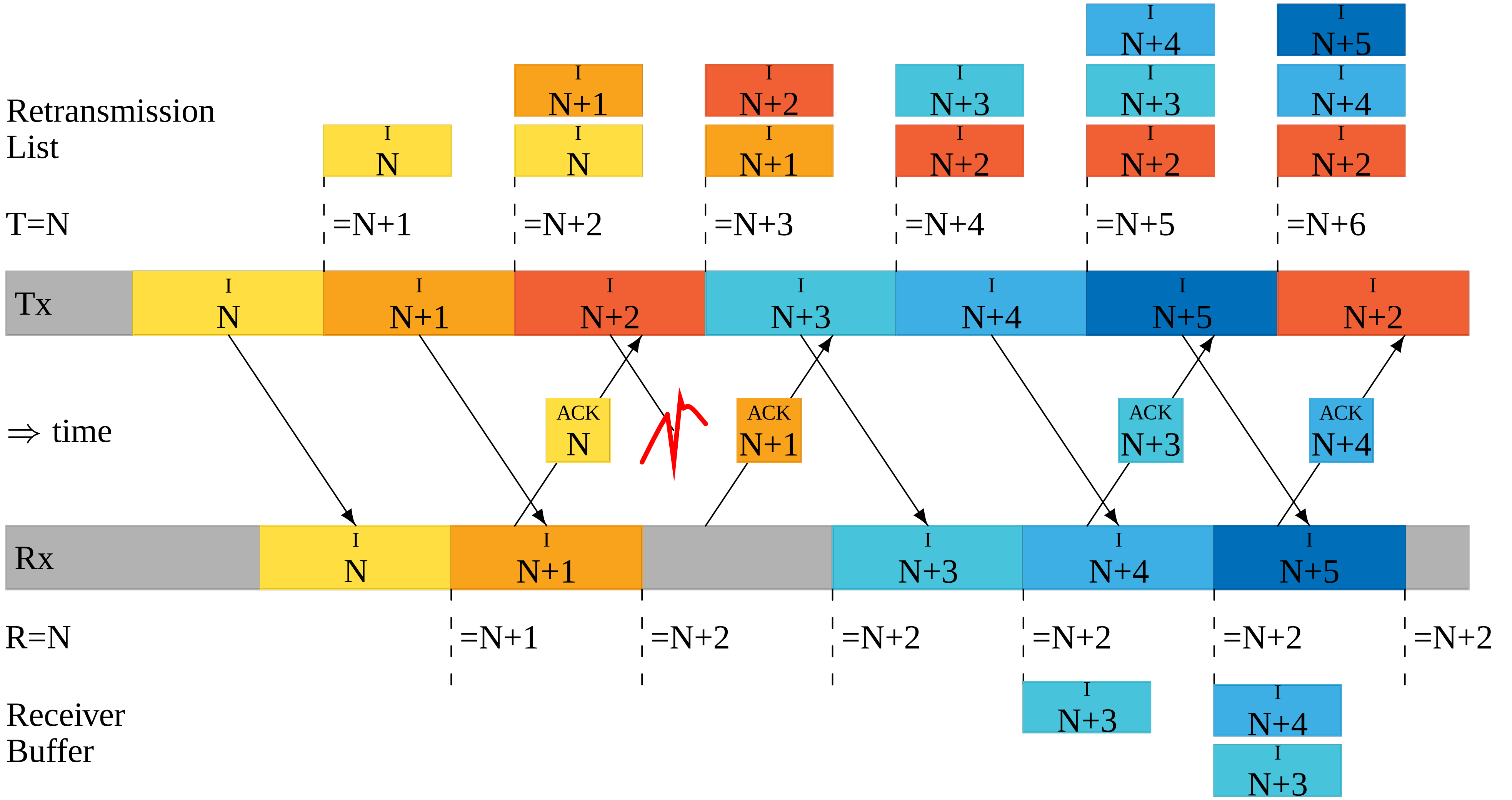
Go-Back-N: Efficiency



Selective Repeat: Explicit Request



Selective Repeat: Implicit Retransmission



Selective Repeat: efficiency

- protocol efficieny $\rho_s = 1$
- error efficiency as idle request

$$\rho_e \approx \frac{1}{1+p}$$

- ρ_c same as idle RQ

Example: Continuous RQ Selective-Repeat protocols

If Continuous RQ selective repeat is being used, calculate the efficiency and throughput of a 10Mbs^{-1} *satellite communication system with BER of* 10^{-6}*, a satellite height of 37,500km, propogation speed* $300 \times 10^6 ms^{-1}$*, I-frames 100 bits.*

$p = 1 - (1 - 10^{-6})^{100} = 10^{-4}$

$\rho_s = \frac{1}{1+10^{-4}} = 0.9999$

throughput = 10.0 Mbs^{-1}

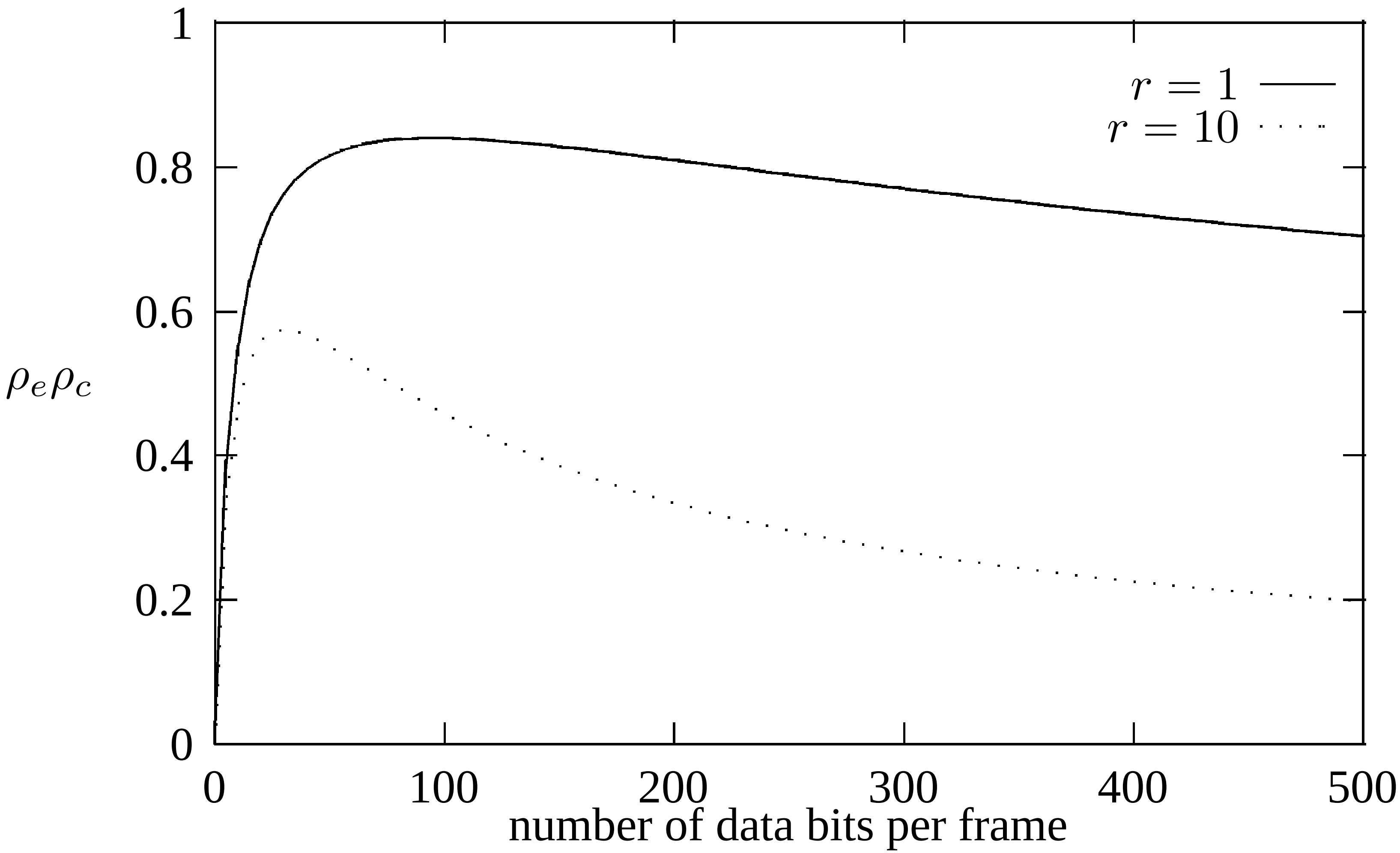
Comparison of ARQ Protocols

	$protocol$	$error$	$combined$
	ρ_s	ρ_e	$\rho_s\rho_e$
Idle RQ	$\frac{1}{r}$	$\frac{1}{1+p}$	$\frac{1}{r+rp}$
Go-Back-N	1	$\frac{1}{1+rp}$	$\frac{1}{1+rp}$
Selective Repeat	1	$\frac{1}{1+p}$	$\frac{1}{1+p}$

- For all, control efficiency

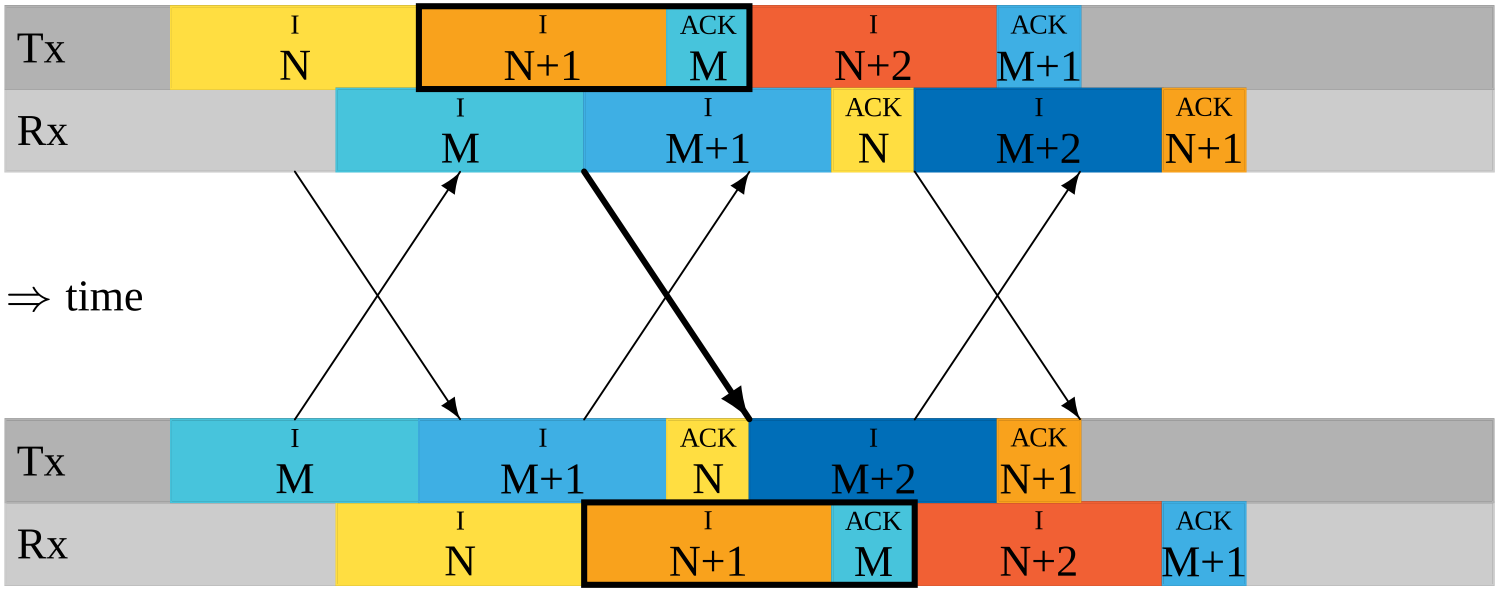
$$\rho_c = \frac{i-c}{i+a}$$

Overall Efficiency for Go-Back-N



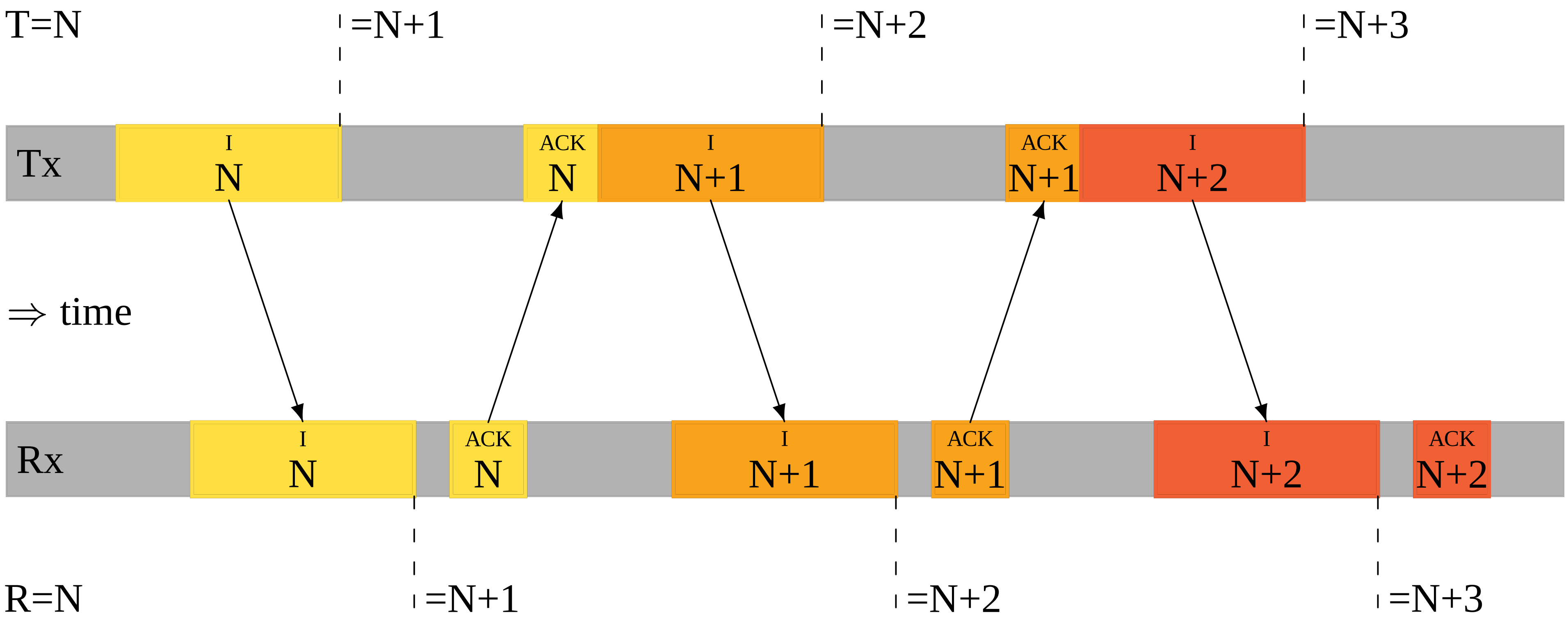
- $r = 1$ graph corresponds to that for Selective Repeat

Duplex Operation



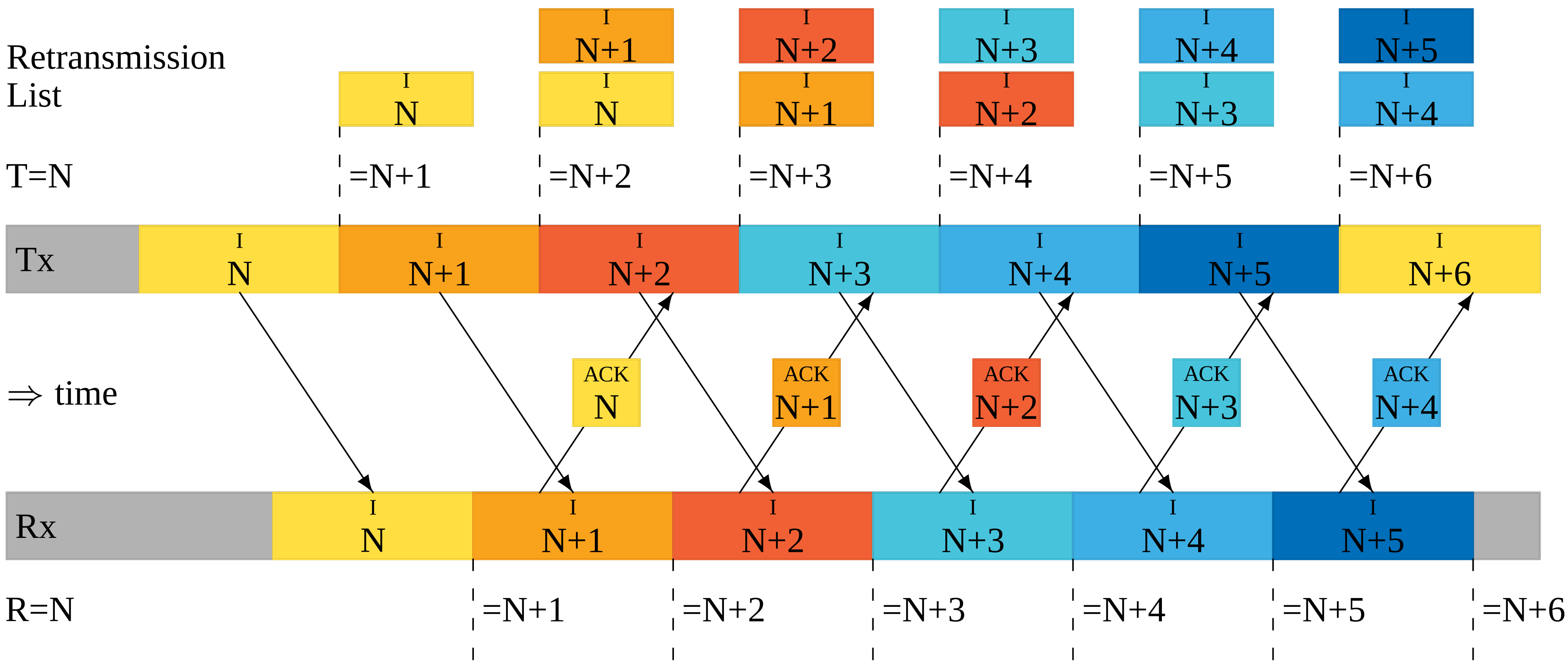
- Can send ACK-frames for I-frame by **piggybacking** it to I-frame in opposite direction

Idle RQ: Window Size



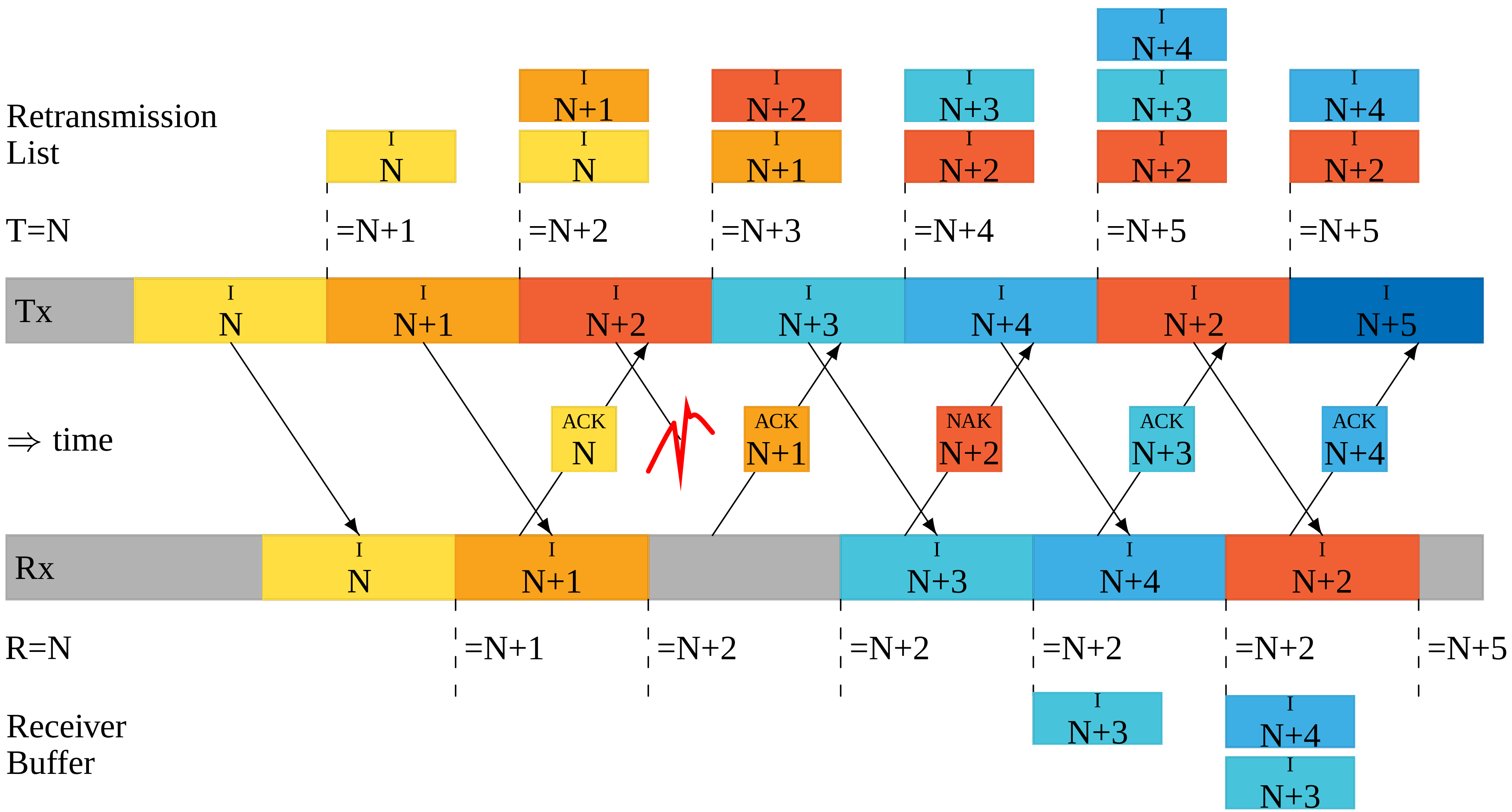
- Tx and Rx only need buffer one I-frame

Continuous RQ Go-Back-N: Window Size



- Tx must buffer r I-frames

Continuous RQ Selective Repeat: Window Size



- Tx and Rx must buffer r I-frames

Sliding Windows

Error protocol	Send window size	Receive window size	S: Maximum sequence number (counting from 1)
Idle RQ	1	1	2
Go-back-N	r	1	$r + 1$
Selective repeat	r	r	$2r$

- N does not need to be an infinite range
- Use modulo S