Activities on TCP

TCP behavior (summary)

- State variables:
  - CWND = Congestion Window (Congestion Control)
  - RCWND = Receiver Window (Flow Control)
  - SSTHRESH = Slow Start Threshold
  - MSS = Maximum Segment Size
  - RTO = Retransmission TimeOut

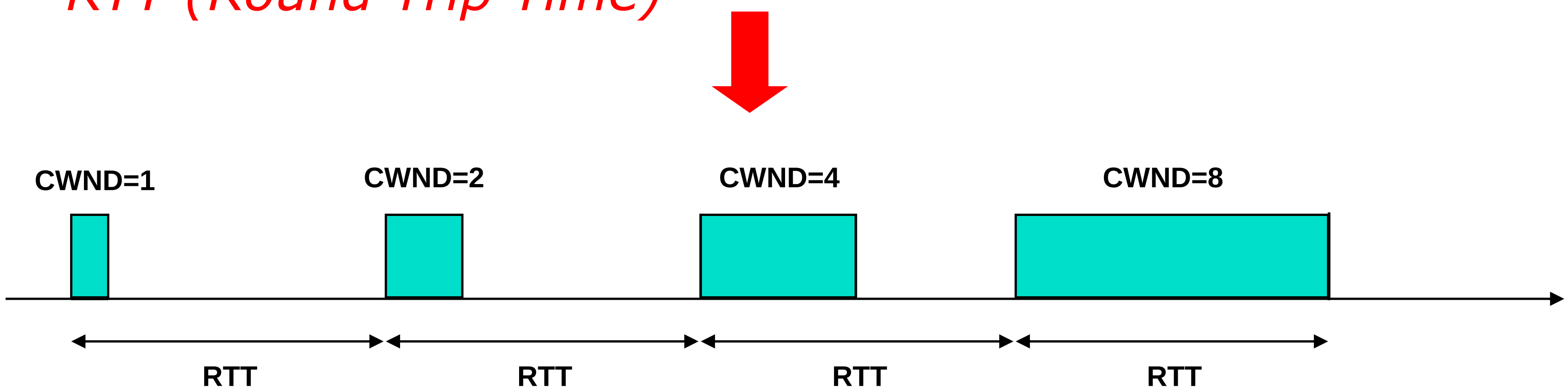
All expressed as multiples of MSS

- Initial values for all state variables (i.e., when the TCP connection is created):
  - CWND=1
  - RCWND = it depends (it's the dimension of the receiver buffer. In our exercises it will be explictly given. Otherwise, we will assume it is *infinite*)
  - SSTHRESH = infinite (sometimes, in our exercises, I will specify a finite, given value)
  - MSS = it is determined in the 3-way handshake phase (MSS option). In our excercises, its value will always be explicitly given.
  - RTO = in our excercises, its value will always be explicitly given

•For every sent packet, the sender starts a timer
•If the sender does *not* receive an ACK for a segment BEFORE the timer = RTO, the segment is considered lost and is retransmitted

TCP behavior (Slow Start)

- At the beginning of the TCP connection:
  CWND < SSTHRESH (in fact, 1 < infinite !!!)
- Since CWND < SSTHRESH, the TCP connection is in *Slow Start*
- *In Slow Start:*
  - *CWND is incremented by 1 for each received ACK (exponential increase)*
- *In practice: in Slow Start, the CWND doubles in each RTT (Round Trip Time)*



TCP Congestion Event (= packet loss)

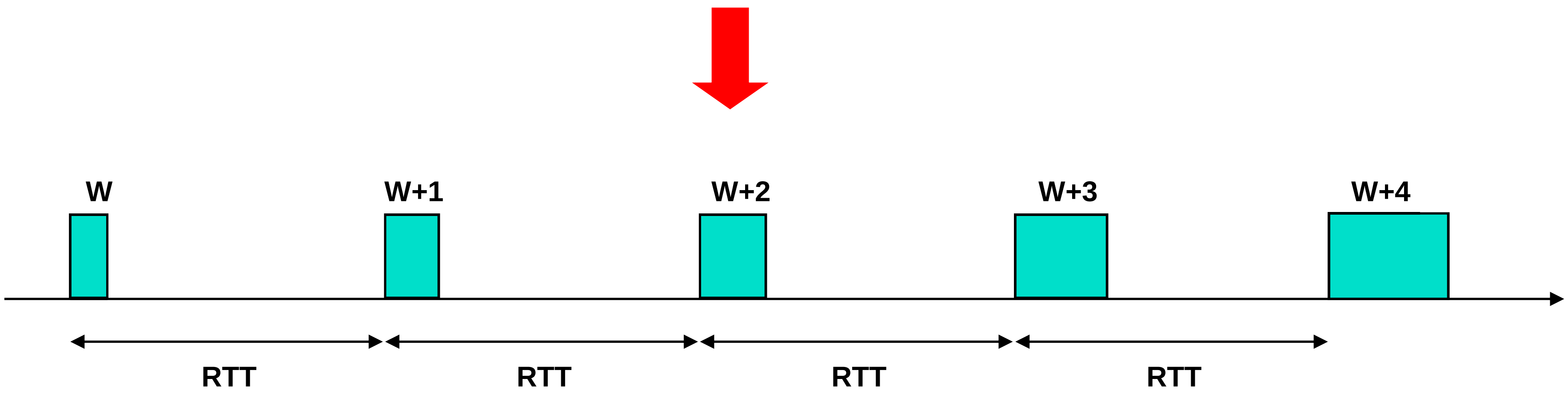
- When a packet is lost (the corresponding RTO expires), TCP performs the following operations:
  - TCP first updates the SSTHRESH value according to the following equation

$$SSTHRESH = \max\left(2, \frac{\text{CWND}}{2}\right)$$

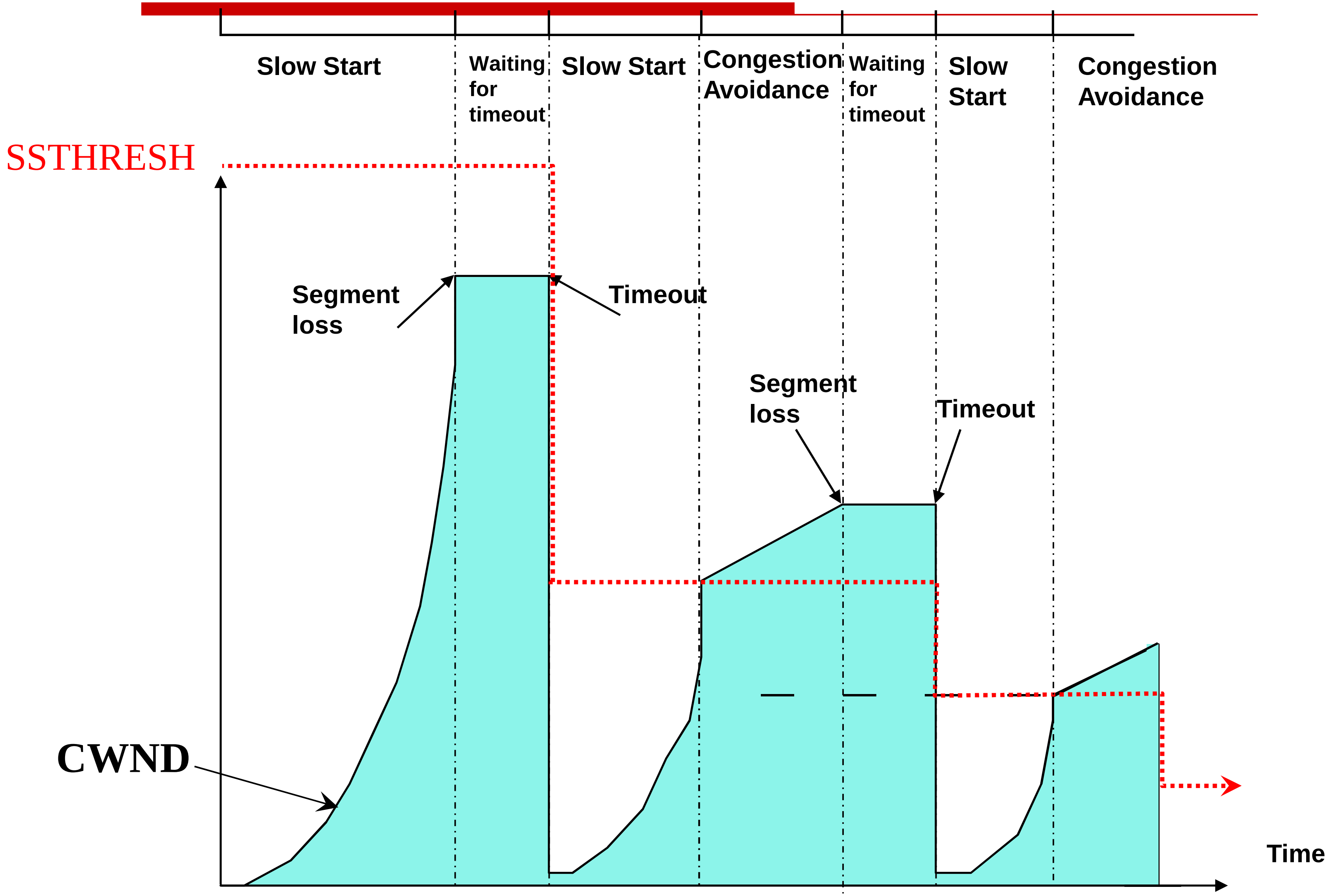
  - And then sets CWND = 1

TCP behavior (Congestion Avoidance)

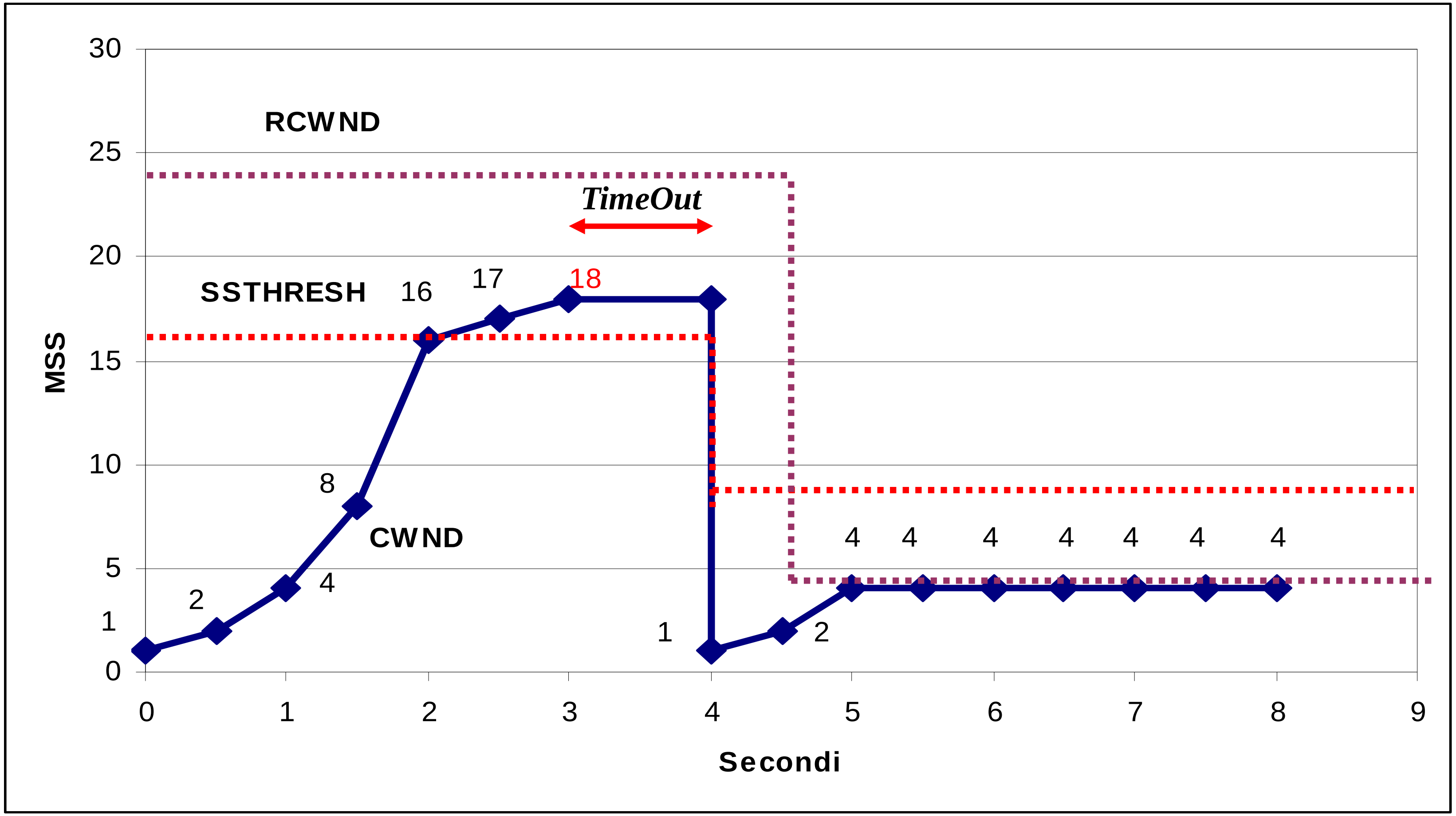
- If CWND >= SSTHRESH, TCP is in the so-called *Congestion Avoidance* phase
- In *Congestion Avoidance*:
  - CWND is incremented by 1/CWND for each received ACK (linear increase)
- In other words, the CWND increases by 1 in each RTT (linear increase)



TCP Connection Lifetime: example 1 (here RCWND = Infinite)

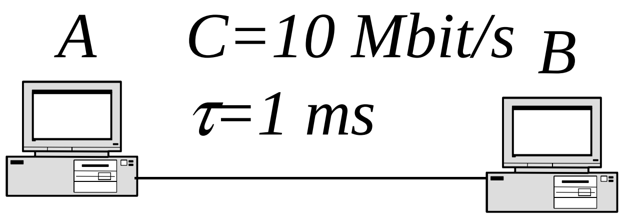


TCP Connection Lifetime: example 2 (here both SSTHRESH and RCWD are GIVEN)



Activity 1 (“Warm Up”)

A single-hop TCP connection, running since long time (*steady state*) on a single link of capacity C and propagation delay τ, is characterized by the following parameters:



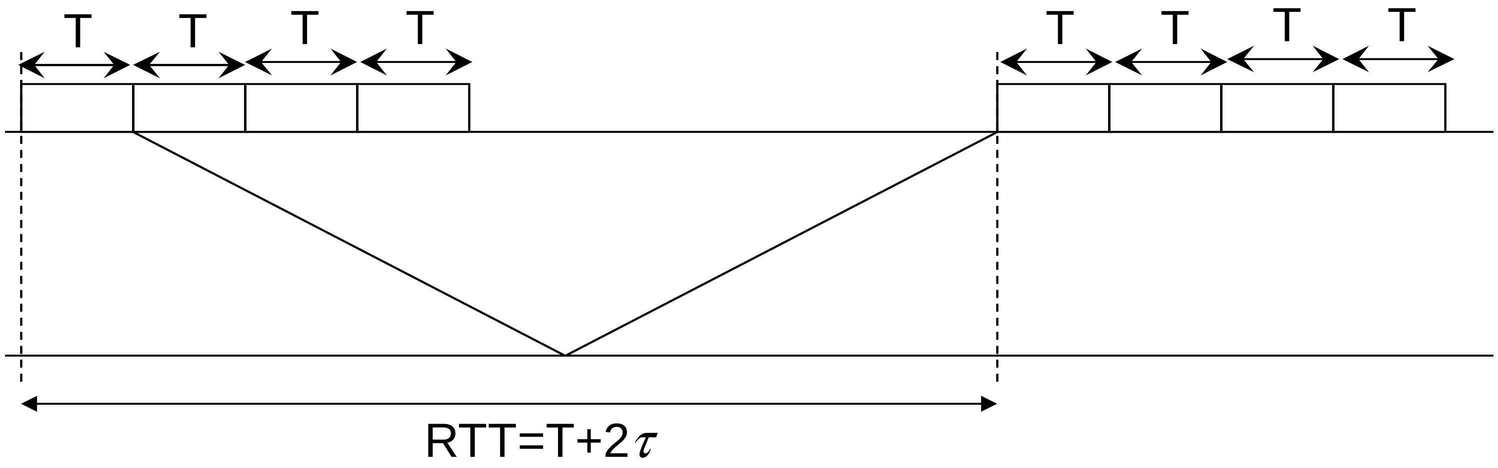
1. Link capacity C = 10 [Mbit/s]
2. Propagation delay τ = 1 [ms]
3. MSS = 100 [byte]
4. RCWND = 4 MSS and RCWND << CWND (this means that the connection is “dominated” by flow control, that is, by the RCWND value)
5. Let us assume the TCP *ACK* segments have negligible length (i.e., length = 0)

D1. What is the average transmission rate of the TCP connection?

D2. Answer to the same question assuming MSS=1000 byte.

Solution 1 ("Warm Up")

- T = 100x8 [bits] / 10 [Mbit/s] =0.08 ms,
- RTT = T + 2τ =2.08 ms
- Hence 4T < RTT (see figure below). Consequently, the transmission is *never* continuous, in this case.

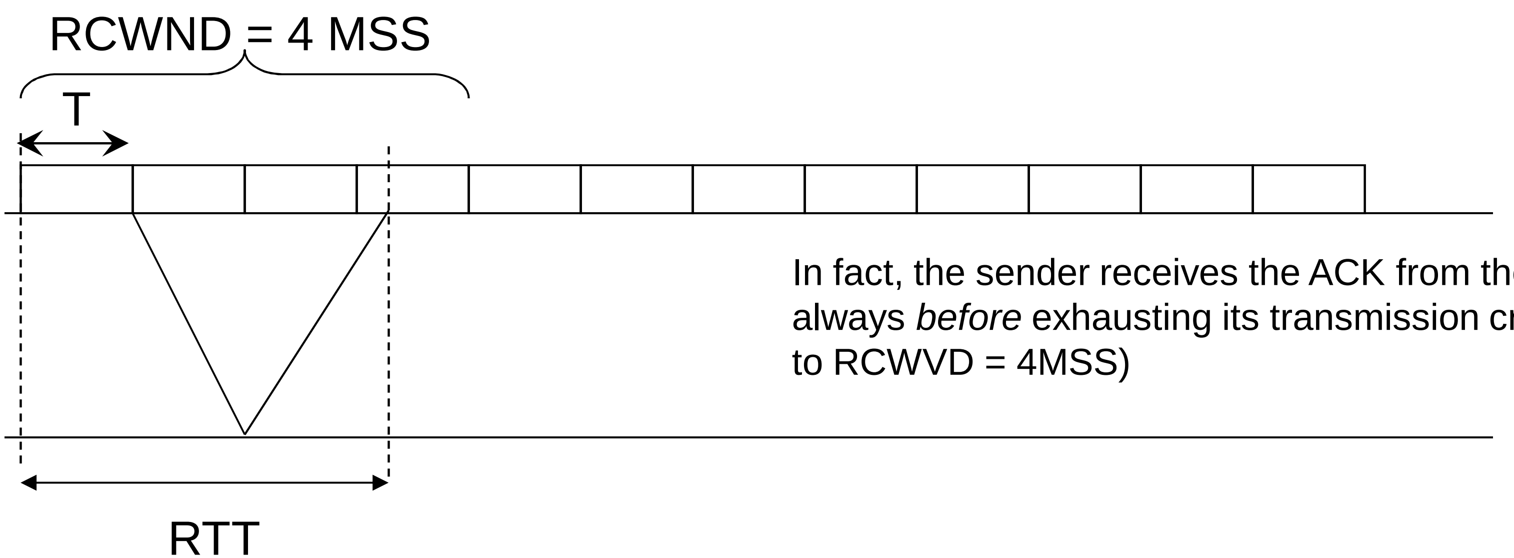


- Thus, the connection delivers 4 MSS for each RTT. Therefore, the average transmission rate, *R*, is:

$$R = \frac{4 \cdot (100 \cdot 8) bit}{RTT} = \frac{3200 bit}{2.08 ms} \approx 1.54 Mbit/s$$

Solution 1 ("Warm Up")

- In the second case
  - T = 1000x8 [bits] / 10 [Mbit/s] =0.8 ms,
  - RTT = T + 2τ =2.8 ms
  - Hence, 4T = 3.2 ms. Therefore, 4T > RTT, and consequently the transmission is <u>continuous</u> and the rate is R = C = 10 Mbit/s.



In fact, the sender receives the ACK from the receiver always *before* exhausting its transmission credit (equal to RCWVD = 4MSS)

Activity 2

- A TCP connection is used to transfer a 39.5 [kbyte] file.
  - MSS=500 [byte]
  - RTT = 500 [ms]
  - Retransmission TimeOut RTO = 2*RTT.
- Assume the following parameter setting:
  - RCWND = 12 [kbyte]
  - SSTHRESH = 8 [kbyte]
  - CWND = 500 [byte]
- And further,
  - All the segments transmitted at time 3 [s] are lost
  - At time 4,5 [s] the receiver signals to the sender that RCWND = 2 [kbyte]

1. Plot the time behavior of the following state variables:
   - CWND
   - SSTHRESH
   - RCWND

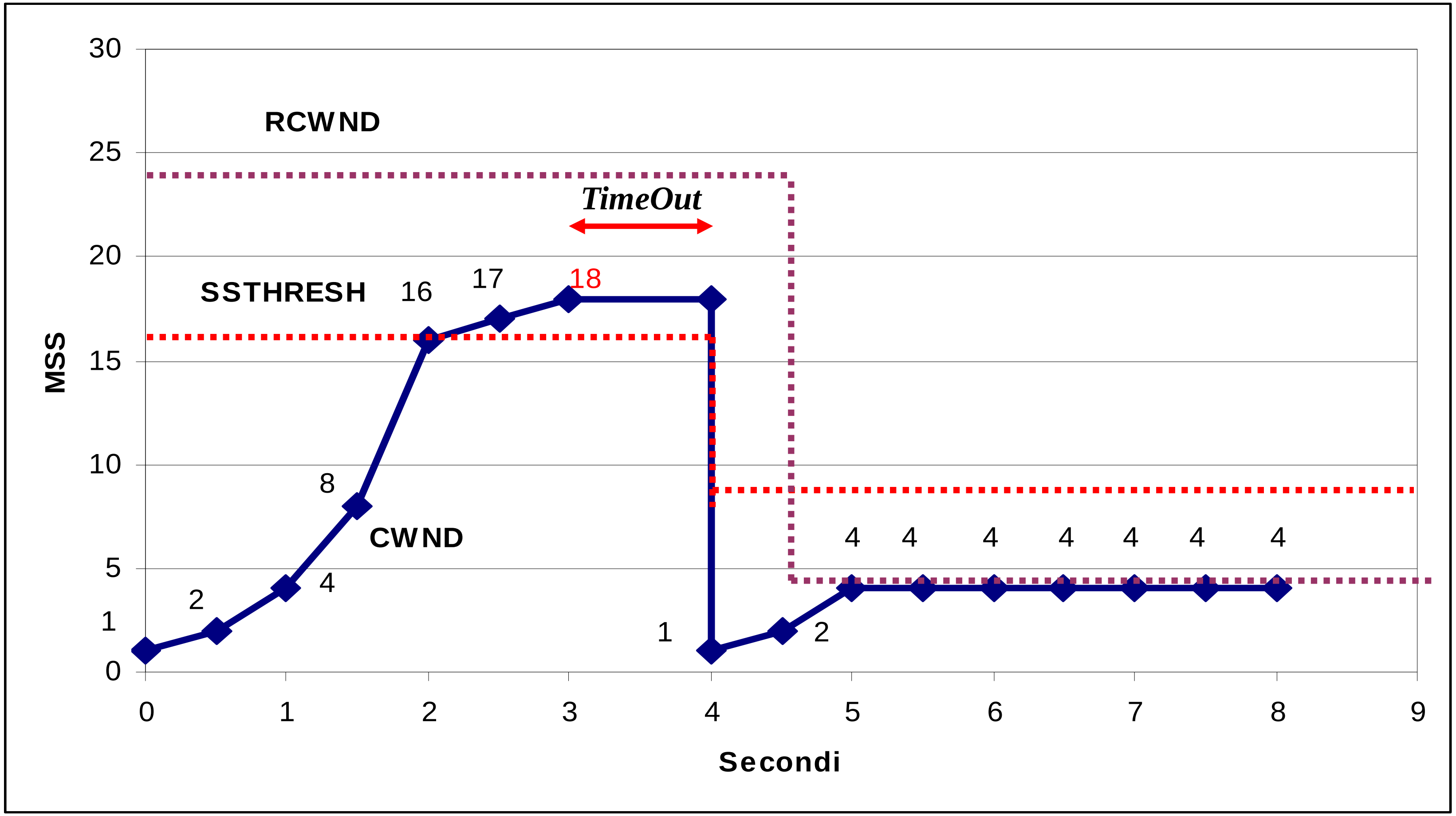
2. Find out the total delivery time for the aforementioned file.

Solution 2

- File dimension (in MSS) = 39,5 [kbyte] / 500 [byte] = 79 MSS
- Total delivery time = time to transfer 79 MSS

- RCWND = 12 [kbyte] / 500 [byte] = 24 MSS
- SSTHRESH = 8 [kbyte] / 500 [byte] = 16 MSS
- Time Out = 1 [s]

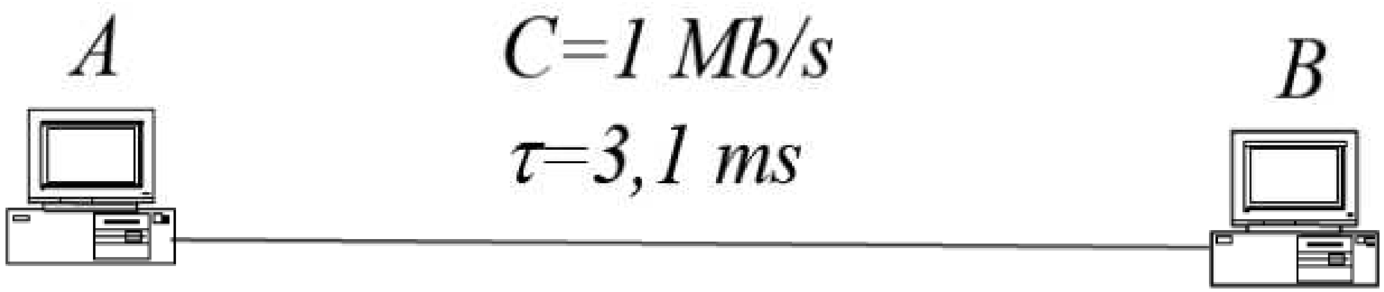
Solution 2



- Total delivery time, T=8.5s

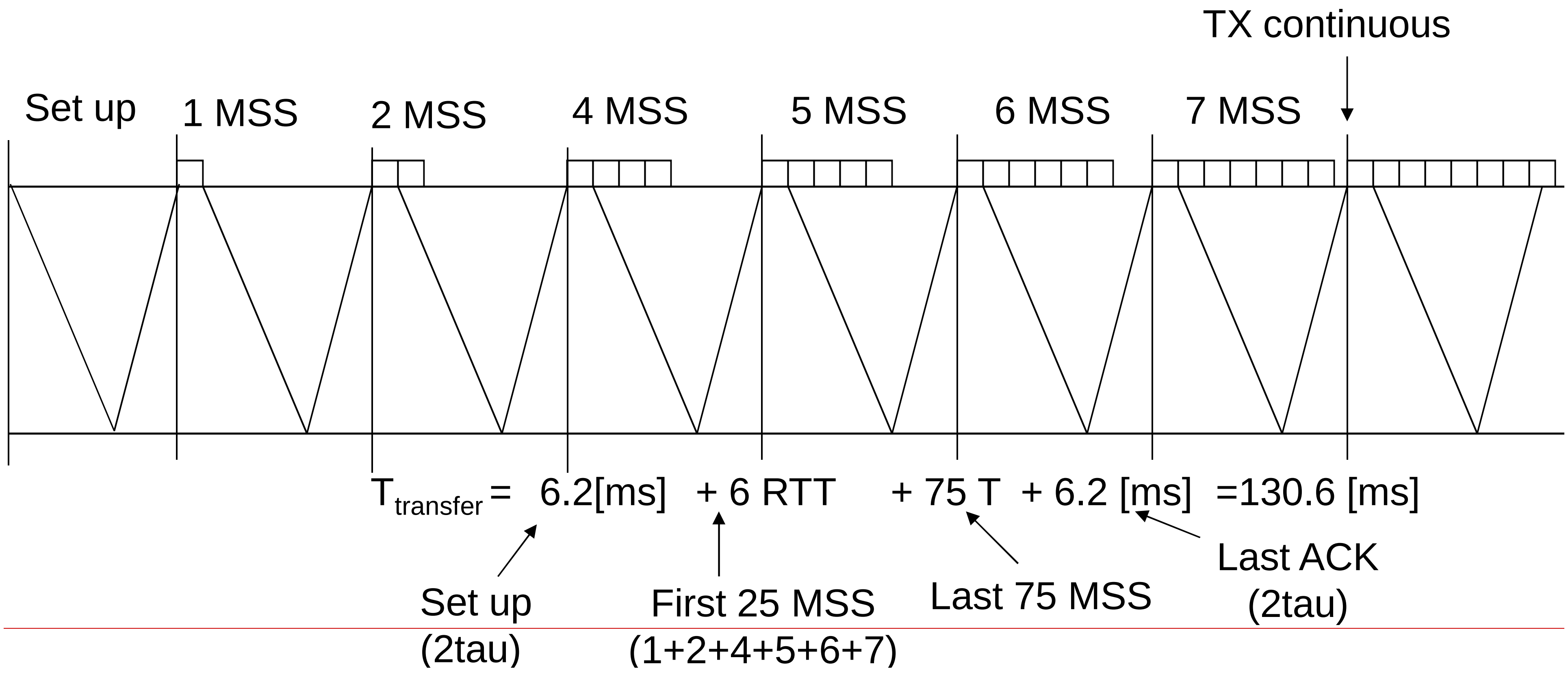
Activity 3

- A must transfer 100 MSS segments to B through a TCP connection. Find out the total data delivery time, assuming:
  - MSS=1000 [bit]
  - Negligible headers
  - Connection is initiated by A, connection opening segment of negligible length
  - ACK segment length negligible
  - SSTHRESH = 5 MSS



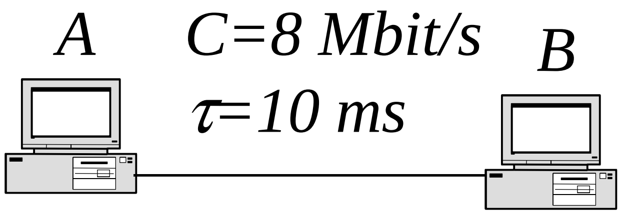
Solution 3

- T=1000 [bit] / 1 [Mbit/s] = 1 [ms]
- RTT = T+2tau = T +2*3.1 [ms] = 7.2 [ms]
- Transmission is continuous when WT > RTT, hence until W=8



Activity 4, case A

- Let us consider the following network

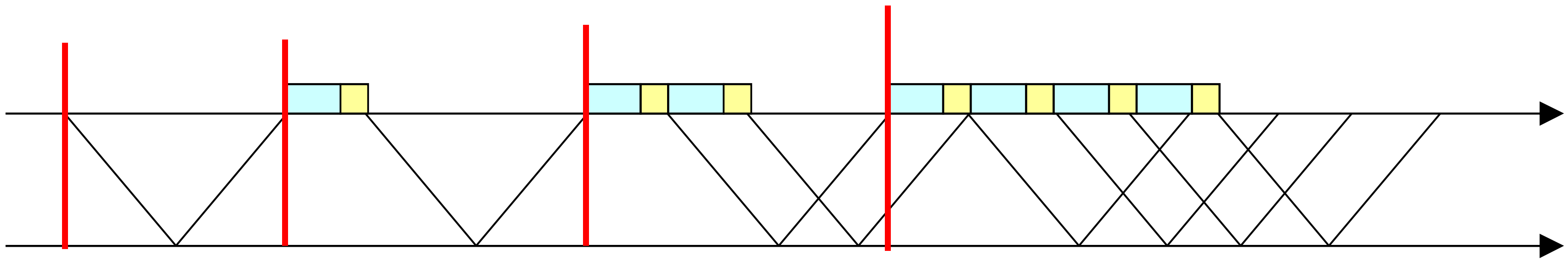


- **A establishes a TCP connection with B, and transfers *18* kbytes towards B**
  - **Find out the total delivery time with the following assumptions:**
    - **MSS=1000 byte**
    - **Negligible header lengths**
    - **The connection is opened by A, and the messages exchanged during the connection setup have negligible length**
    - **Negligible ACK lengths**
    - **SSTHRESH = 4 MSS**

Solution 4, case A

$T = 1\,\text{ms}$

$n = 18\,\text{segments}$



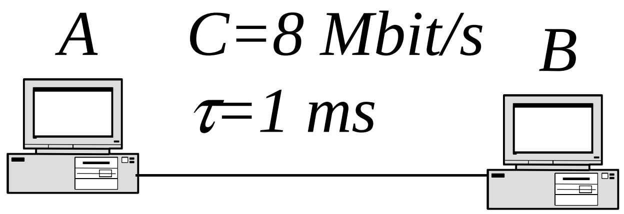
1 + 2 + 4 + 5 + 6 = 18

$$Ttot = 2\tau + (T + 2\tau) + (T + 2\tau) + (T + 2\tau) + (T + 2\tau) + (T + 2\tau) + (6-1)T$$

$$Ttot = 2\tau + 5(T + 2\tau) + (6-1)T = 12\tau + 10T = 130\,\text{ms}$$

Activity 4, case B

- Let us consider the following network

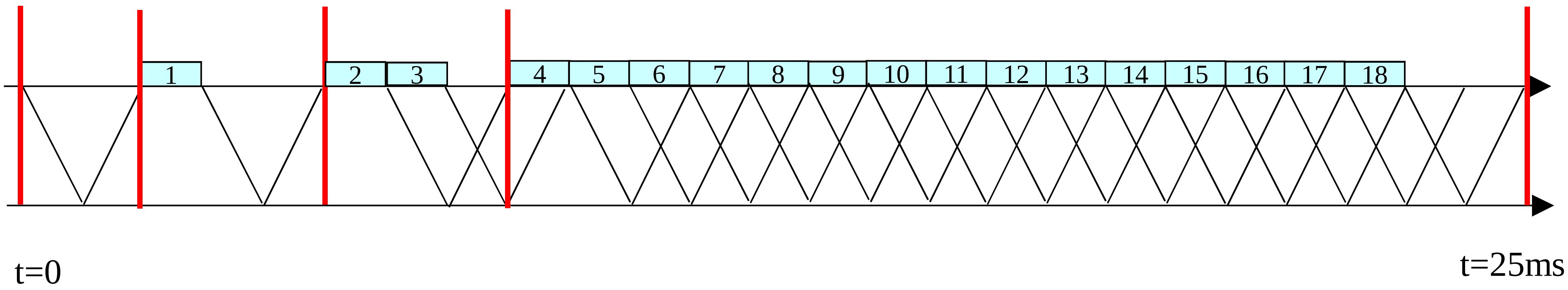


- **A establishes a TCP connection with B, and transfers *18* kbytes towards B**
  - **Find out the total delivery time with the following assumptions:**
    - **MSS=1000 byte**
    - **Negligible header lengths**
    - **The connection is opened by A, and the messages exchanged during the connection setup have negligible length**
    - **Negligible ACK lengths**
    - **SSTHRESH = 4 MSS**

Solution 4, case B

$T = 1\,\text{ms}$

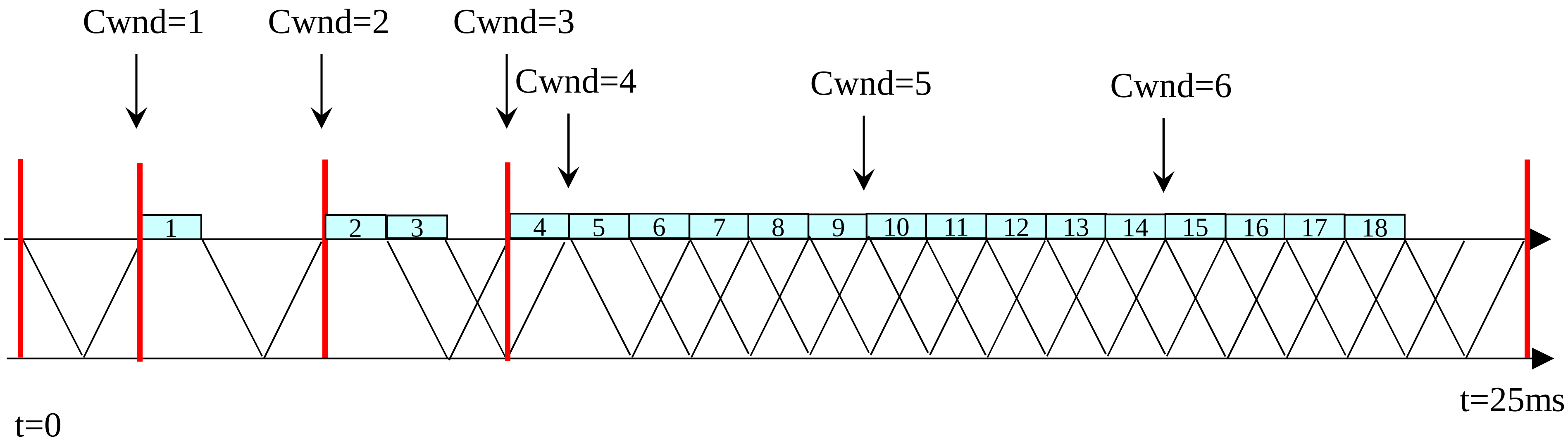
$n = 18\,\text{segments}$



$$Ttot = 2\tau + (T + 2\tau) + (T + 2\tau) + (15T + 2\tau)$$

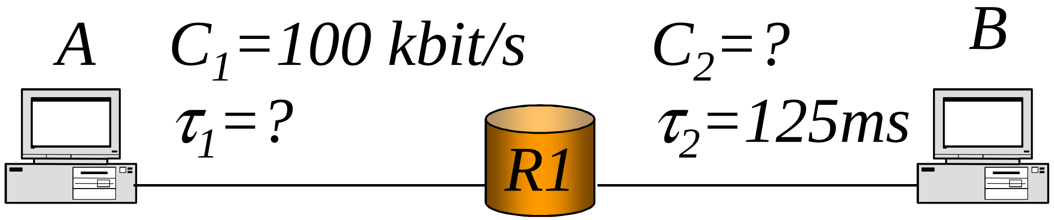
$$Ttot = 8\tau + 17T = 8 + 17\text{ ms} = 25\text{ ms}$$

Solution 4, case B



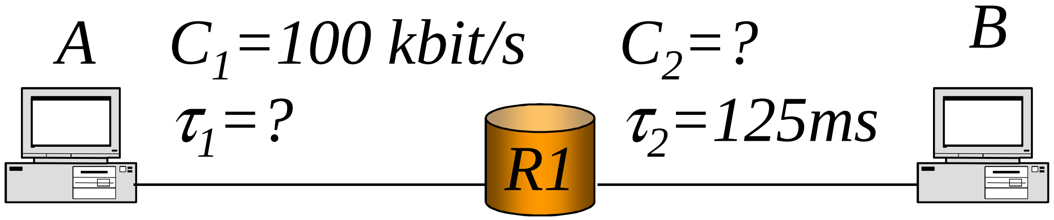
Exercise 5 ("Network Tomography")

- Given the multi-hop link in the figure:

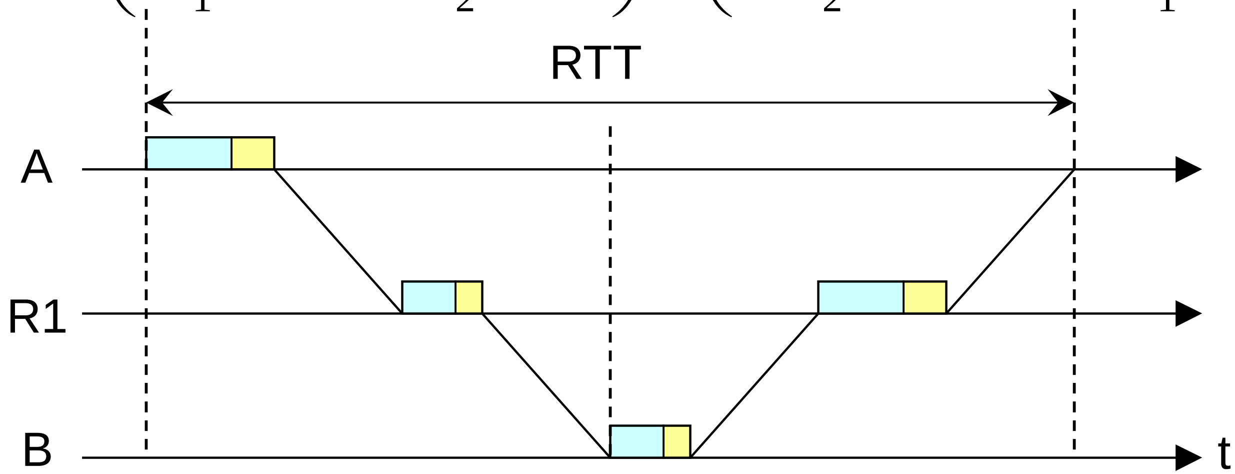


- A wants to estimate the propagation delay (τ_1) on link 1 and the Capacity (C_2) on link 2.
- To this end, A sends 2 packets (that is, two *echo requests*) to B (with length m_1=500 [byte], m_2=1000 [byte], respectively), and B answers (immediately after he receives the packet form A) each time with packets of *fixed length (echo replies)*. The length of each reply is m_{ACK} = 125 [byte].
- A measures the following RTTs for the two packets:
  - RTT_1 = 420 [ms]
  - RTT_2 = 540 [ms]
- Find out τ_1 and C_2 as estimated by A

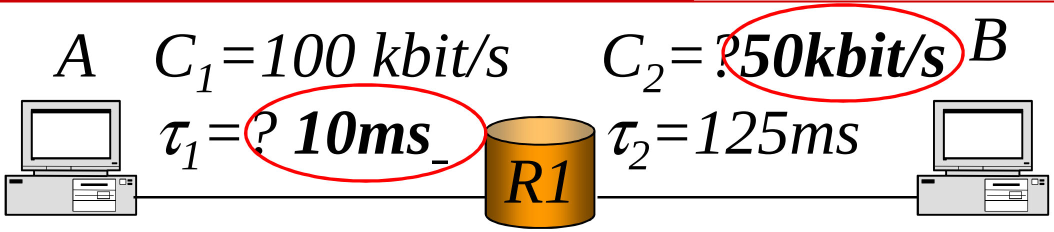
Solution 5



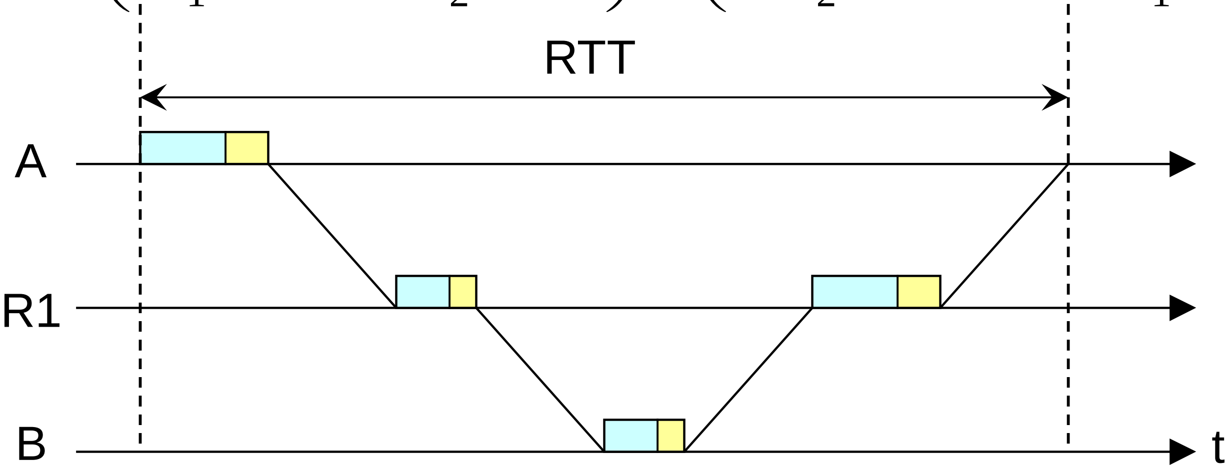
$$\begin{cases} RTT_1 = \left(\dfrac{m_1}{C_1} + \tau_1 + \dfrac{m_1}{C_2} + \tau_2 \right) + \left(\dfrac{m_{ACK}}{C_2} + \tau_2 + \dfrac{m_{ACK}}{C_1} + \tau_1 \right) \\ RTT_2 = \left(\dfrac{m_2}{C_1} + \tau_1 + \dfrac{m_2}{C_2} + \tau_2 \right) + \left(\dfrac{m_{ACK}}{C_2} + \tau_2 + \dfrac{m_{ACK}}{C_1} + \tau_1 \right) \end{cases}$$



Solution 5

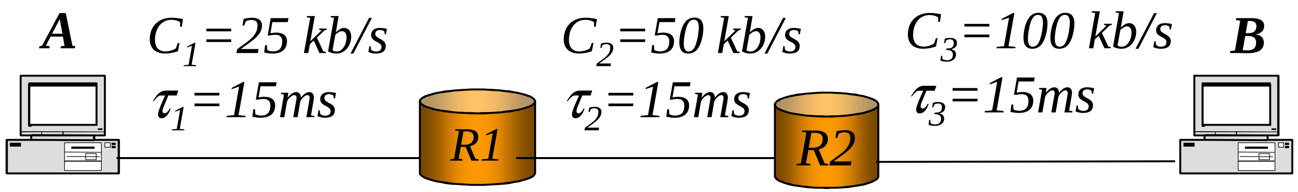


$$\begin{cases} RTT_1 = \left(\frac{m_1}{C_1} + \tau_1 + \frac{m_1}{C_2} + \tau_2 \right) + \left(\frac{m_{ACK}}{C_2} + \tau_2 + \frac{m_{ACK}}{C_1} + \tau_1 \right) \\ RTT_2 = \left(\frac{m_2}{C_1} + \tau_1 + \frac{m_2}{C_2} + \tau_2 \right) + \left(\frac{m_{ACK}}{C_2} + \tau_2 + \frac{m_{ACK}}{C_1} + \tau_1 \right) \end{cases}$$

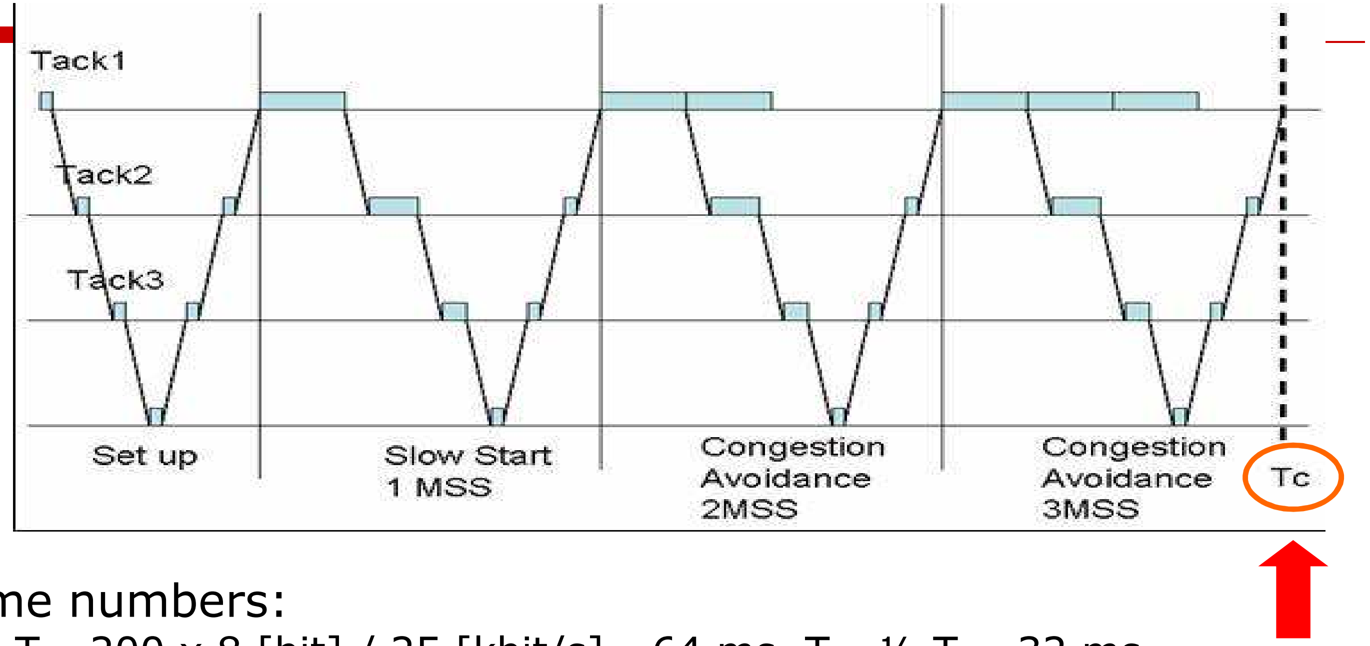


Activity 6

1. At time t=0, A initiates a TCP connection towards B. Find out the time T_C at which the transmission on link 1 becomes <u>continuous</u>, assuming:
   - *Negligible header lengths*
   - *Bidirectional links*
   - RCWND = 4000 [byte] and SSTHRESH = 400 [byte]
   - MSS = 200 [byte]
   - ACK length = opening connection segments length = 20 [byte]
2. Find out the total delivery time for a file of 2 [kbyte] (including connection set-up time)
   - (1 byte = 8 bit, 1 kbyte = 1000 byte = 8000 bit)



Solution 6



- Some numbers:
  - T_1=200 x 8 [bit] / 25 [kbit/s] =64 ms, T_2=½ T_1 =32 ms, T_3= ½ T_2= 16 ms
  - Tack1=6.4 ms, Tack2=3.2 ms, Tack3=1.6 ms
  - RTT= T_1+ T_2+T_3+ 2(τ_1+ τ_2+τ_3)+ Tack1 + Tack2 + Tack3 = 213.2ms
  - T_{setup} = 2(Tack1 + Tack2 + Tack3) + 2(τ_1+ τ_2+τ_3) = 112.4 ms
- Link 1 is the bottleneck, transmission is continuous when:
  - WT_1 > RTT
- thus
  - W > RTT/ T_1=3,3
- Consequently, the time for the transmission to become continuous is
  - T_c= T_{setup} + 3 RTT =112.4 [ms] +649.6 [ms] = 752 [ms]

Solution 6

- 2 [kbyte] file is equivalent to 10 MSS.
- Total delivery time is given by:
  - $T_{tot} = T_{setup} + 4\ RTT + 3\ T_1 = 1.15\ [s]$