HW Problems (RTT)

- What is the RTT over a 10 Mbps line of length 2500 m, if the packet size (both sent and ACK) is 100 bytes, and the processing delay is 5 $\mu$s?
  - $\text{RTT} = 2 \times (\tau_p + \tau_c + \tau_r)$
  - Propagation delay $\tau_c = 2500/250 = 10\mu s$
  - Bit duration = $1/10 \text{ MBps} = 0.1\mu s$
  - Packet duration $\tau_p = 100 \times 8 \times 0.1 = 80\mu s$
  - $\text{RTT} = 2(10 + 80 + 5) = 190\mu s$

- For the same length, packet size, and processing delay, what is the RTT if the bit-rate is 1 Gbps?
  - Bit duration is one nano second = $0.001 \mu s$
  - packet duration is $100 \times 8 \times 0.001 = 0.8\mu s$.
  - $\text{RTT} = 2(10 + 0.8 + 5) = 31.6\mu s$
Apparent and Actual Data Paths

AL → App. Message → AL

Virtual Link
Apparent and Actual Data Paths

- App. Message
- Trans. Segment
- Virtual Link
Apparent and Actual Data Paths

- **AL** → **TL** → **NL**
  - Net. Packet: **NH||TH||AM**

- **AM** → **TH||AM** → **Trans. Segment**

- **AL** → **AM** → **AL**

- **TL** → **AM** → **TL**
Apparent and Actual Data Paths

App. Message

Trans. Segment

Net. Packet

DL Frame = DH||NH||TH||AM||DF
Apparent and Actual Data Paths

App. Message

Trans. Segment

Net. Packet

DL Frame = DH||NH||TH||AM||DF

Virtual Link
Apparent and Actual Data Paths

App. Message

Trans. Segment

Net. Packet

DL Frame

Virtual Link
Apparent and Actual Data Paths

App. Message

Trans. Segment

Net. Packet

DL Frame

DL Frame = DH||NH||TH||AM||DF

Virtual Link
Apparent and Actual Data Paths

**Virtual Link**

- **Net. Packet**
  - [NH||TH||AM]

- **DL Frame**
  - DL Frame = DH||NH||TH||AM||DF

**App. Message**

**Trans. Segment**

**AL**

**TL**

**NL**

**DL**

**PL**
Achievable Rate

- Shannon’s capacity theorem
- \[ R = H \log_2(1 + S/N) \text{ bps} \]
- \( H \) is available bandwidth
- \( S/N \) is signal to noise ratio, usually expressed in dB
- \( \{S/N\}_dB = 10 \log_{10}(S/N) \)
- 30 dB \( \rightarrow \) \( S/N = 1000 \).
- \( R \) is theoretical limit. The goal is to get as close as possible to it.
Delays and Switching

- Delays
  - Propagation delay \( d/c + \) repeater delay
  - Packet duration = bit duration \( \times \) packet size = packet size / bit-rate
  - Processing delay

- switching (circuit switching and packet switching)

  Consider \( n \) hops,
  - propagation delay over each hop is \( \tau_c \ \mu s \)
  - let \( \tau_p \) be packet duration
  - let \( \tau_r \) be processing delay at each hop

  Packet switching: total one way delay is \( n(\tau_c + \tau_p + \tau_r) \)
  Circuit switching: total one way delay is \( n\tau_c + (\tau_p + \tau_r) \)
Reliable Data Transfer

- ARQ (automatic repeat request) protocols
- ABP (or Stop and Wait) for half-duplex channels
  - ABP: Window size 1. Packets and ACKs numbered 0 or 1
  - Channel used only for one packet duration during each RTT
- Effective throughput \( \frac{\tau_p}{2(\tau_p + \tau_c + \tau_r)} \times R \)
- Pipelining protocols: SRP and GBN
- Choose window size \( W \geq \frac{\text{RTT}}{\tau_p} \)
- Only for full duplex channels.
SRP: Selective Repeat Protocol

- SRP: Tx uses window size $W$.
- Window blocked by earliest unacknowledged packet.
- Rx has two windows: future window and past window.
- Rx does not know the position of the tx window.
- Future window is the optimistic estimate (assuming all acks sent by Rx have been received by the Tx).
- Past window is a pessimistic estimate.
- $2W$ unique numbers needed to resolve ambiguity.
- If received packet in past window ACK and drop.
- If received packet in future window ACK and store.
- Worst case buffer requirement is for $W$ packets for both Tx and Rx.
**SRP Protocol**

### Sender Window (size 5)

- Not yet sent
- ACK pending
- Sent and ACKed

### SRP Rules

- Legal to send any packet within the window
- Head of the queue blocked by an outstanding ACK.
- Sender window cannot advance until ACK is received for the blocking packet.
- Sender may have to buffer up to $W$ packets.
- Normally next unsent packet (blue) is sent.
- On time-out for the blocking red packet resend the packet.
- $2W$ unique packet numbers — 0 to $2W - 1$. 

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[Diagram of Sender Window with colors indicating sent, ACK pending, and not yet sent packets.]

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[Diagram of SRP Rules with bullet points listed above.]
**Receiver Rules**

1. Past Window and Future Window; each of size $W$.
2. Future Window blocked by earliest pending packet.
3. If next packet from past window ACK and drop packet.
4. If next packet from future window ACK and store packet.
5. Up to $W$ packets may need to be buffered.
6. $2W$ possibilities for next packet. Using $2W$ numbers eliminates ambiguities.
7. If next received packet is numbered 4, 5, 6, 7 or 8 ACK and discard.
8. If next received packet is numbered 9, 0, 1, 2 or 3 ACK and store.
- Rx does not buffer packets.
- Packets received out of order are dropped and not ACKed.
- Cumulative ACKs possible (ACK is the highest packet number received).
- Tx will still need buffer space for $W$ packets.