Rechnernetze – Computer Networks

Problem Set 4: Automatic repeat request

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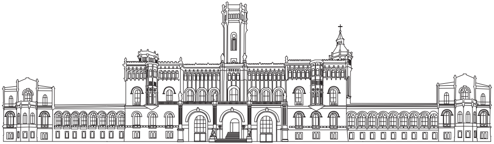

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Why do we do error control and flow control?

Error control:

- you do not usually have an error-free channel,
- so you have to handle errors

Flow control:

- if transmitters are faster than receivers, the receiver will be overwhelmed with data from the transmitter
- flow control is used in order to throttle the transmitter if necessary

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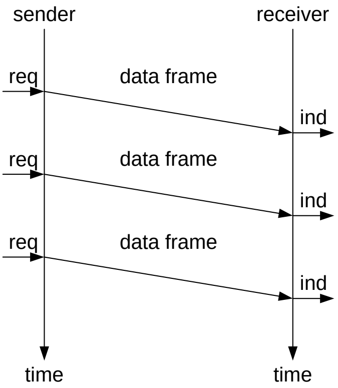
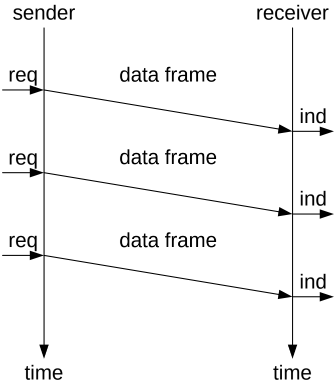
Consider the following protocol. Which assumptions are made?



Consider the following protocol. Which assumptions are made?



Assumptions

- error-free channel
- infinitely large buffer
- infinitely fast receiver

In case the receiver is not infinitely fast, what can we do to avoid overwhelming the receiver?

- introduction of acknowledgements in order to perform flow control
- receiver transmits an acknowledgement if it is ready for the next frame

What can happen if the channel is error-prone rather than error-free?

- data frames can be lost
- acknowledgement frames can be lost

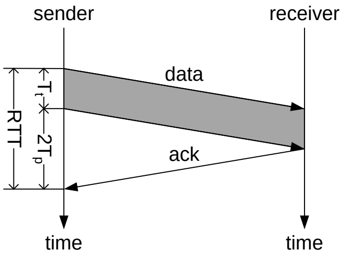
How can one handle the loss of frames?

- use of positive or negative acknowledgements to give feedback whether or not frame has been received
- introduction of timers $\rightarrow$ start retransmission if ack has not been received in time
- introduction of sequence numbers $\rightarrow$ in case an ack is lost, the receiver can identify duplicates

2.1 Stop-and-Wait Channel Utilization

What is the definition of channel utilization?

$$channel\ utilization = \frac{T_t}{T_t + 2T_p},$$



T_t: transmission time: time to get the bits onto the transmission medium

T_p: propagation delay: one bit's travel time on the transmission medium

2.2 Stop-and-Wait Channel Utilization

Consider the following scenarios. What is the corresponding channel utilization (stop-and-wait)?

In each case the frame length is given as 1500 byte.

1. 100 Mbps Ethernet cable of 500 meter length
2. 1 Gbps fibre cable of 10 km length
3. 10 Gbps link of 10,000 km length in vacuum

A: util. $\approx 10\%$ B: util. $<< 1\%$ C: util. $\approx 96\%$

2.2 Stop-and-Wait Channel Utilization

Transmission of $l = 1500$ byte frames via a $C =$100 Mbps Ethernet cable of $d =$500 meter length. We assume $v_p = \frac{2}{3} v_l$.

$$\textit{channel utilization} = \frac{T_t}{T_t + 2T_p} = \frac{\frac{l}{C}}{\frac{l}{C} + 2\frac{d}{v_p}}$$

$$= \frac{\frac{12000 bit}{100 \cdot 10^6 bit/s}}{\frac{12000 bit}{100 \cdot 10^6 bit/s} + 2\frac{500m}{200 \cdot 10^6 m/s}}$$

$$\approx 96\% \rightarrow \text{answer C}$$

[0] T_t: transmission time, T_p: propagation delay, v_p: signal propagation speed, $v_l = 300 \cdot 10^6$ m/s: speed of light

2.2 Stop-and-Wait Channel Utilization

Transmission of l =1500 byte frames via a C =1 Gbps fibre cable of d =10 km length. Again, we assume $v_p = \frac{2}{3} v_l$.

$$\textit{channel utilization} = \frac{T_t}{T_t + 2T_p} = \frac{\frac{l}{C}}{\frac{l}{C} + 2\frac{d}{v_p}}$$

$$= \frac{\frac{12000 bit}{1\cdot 10^9 bit/s}}{\frac{12000 bit}{1\cdot 10^9 bit/s} + 2\frac{10\cdot 10^3 m}{200\cdot 10^6 m/s}}$$

$$\approx 10\% \rightarrow \text{answer A}$$

[0] T_t: transmission time, T_p: propagation delay, v_p: signal propagation speed, $v_l = 300 \cdot 10^6$ m/s: speed of light

2.2 Stop-and-Wait Channel Utilization

Transmission of l =1500 byte frames via a C =10 Gbps link of d =10,000 km length in vacuum. We assume $v_p = v_l$.

$$\text{\textit{channel utilization}} = \frac{T_t}{T_t + 2T_p} = \frac{\frac{l}{C}}{\frac{l}{C} + 2\frac{d}{v_p}}$$

$$= \frac{\frac{12000bit}{10 \cdot 10^9 bit/s}}{\frac{12000bit}{10 \cdot 10^9 bit/s} + 2\frac{10 \cdot 10^6 m}{300 \cdot 10^6 m/s}}$$

$$<< \quad 1\% \rightarrow \text{answer B}$$

[0] T_t: transmission time, T_p: propagation delay, v_p: signal propagation speed, $v_l = 300 \cdot 10^6$ m/s: speed of light

Consider the formula for the channel utilization. In case of N-1 retransmissions due to an error-prone channel, how does the formula change?

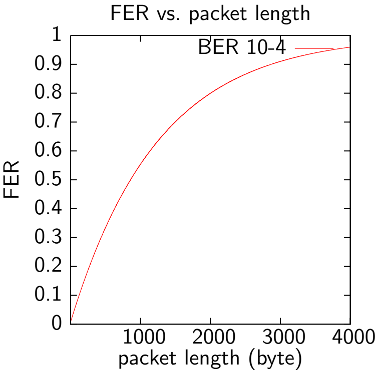
$$channel\ utilization = \frac{T_t}{T_t + 2T_p}$$

$$channel\ utilization = \frac{T_t}{N(T_t + 2T_p)}$$

[0] T_t: transmission time, T_p: propagation delay

Given a bit error rate (BER) and a frame of length l.
How do you determine the frame error rate (FER)?

$$FER = 1 - (1 - BER)^l$$



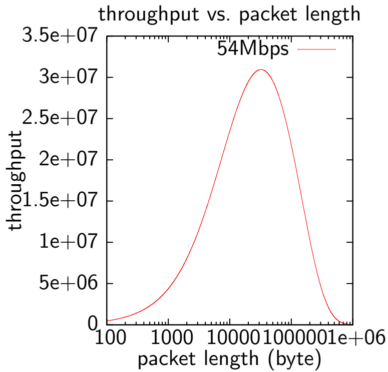
2.5 Stop-and-Wait Channel Utilization

Frames consist of two parts: the payload and an overhead which is independent of the payload length.
How do you determine the effective data rate R in an error free and an error prone environment given capacity C, frame length l, overhead h, propagation time T_P and a bit error rate BER ?

Error free: $R = \frac{(l-h)}{l/C+2T_P}$

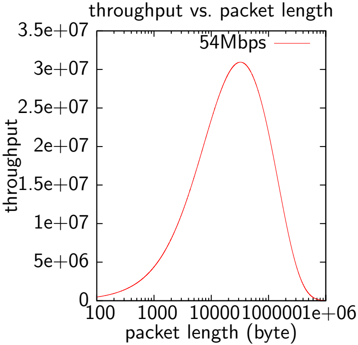
Error prone: $R = \frac{(l-h)}{l/C+2T_P} \cdot (1 - BER)^l$

What are the characteristics of a graph depicting the effective data rate vs. the packet length (assuming an error-prone channel)? Why does it look like this?



What are the characteristics of a graph depicting the effective data rate vs. the packet length (assuming an error-prone channel)? Why does it look like this?

- large overhead due to small frames



- large frame error rate

What is pipelining? (Lecture)

- several frames may be in flight simultaneously
- at any time at most n of the frames transmitted may be unacknowledged (can also be used for flow control)
- stop-and-wait is the special case $n = 1$
- ideally, there is a continuous flow of frames and acknowledgements such that no waiting occurs at all
- each frame can be small to account for high bit error rates

Which condition has to be fulfilled in order to achieve full utilization?

$$n\,l \geq C \cdot RTT$$

[0] n: number of frames, l: frame length, C: capacity, RTT: round trip time

Consider the following scenarios. What is the minimum number of frames needed to achieve full utilization?

In each case the frame length is given as 1500 byte.

1. 100 Mbps Ethernet cable of 500 meter length
2. 1 Gbps fibre cable of 10 km length
3. 10 Gbps link of 10,000 km length in vacuum

Transmission of l = 1500 byte frames via a C =100 Mbps Ethernet cable of d =500 meter length. We assume $v_p = \frac{2}{3} v_l$.

$$
\begin{aligned}
n &\geq \frac{C \cdot RTT}{l} = \frac{C \cdot (T_t + 2T_p)}{l} = \frac{C \cdot (\frac{l}{C} + 2\frac{d}{v_p})}{l} \\
&= \frac{100 \cdot 10^6 bit/s \cdot (\frac{12000bit}{100 \cdot 10^6 bit/s} + 2\frac{500m}{200 \cdot 10^6 m/s})}{12000bit} \\
&= 1.041\overline{6} \rightarrow n \geq 2 \text{ frames}
\end{aligned}
$$

[0] T_t: transmission time, T_p: propagation delay, v_p: signal propagation speed, $v_l = 300 \cdot 10^6$ m/s: speed of light

Transmission of l =1500 byte frames via a C =1 Gbps fibre cable of d =10 km length. Again, we assume $v_p = \frac{2}{3}v_l$.

$$
\begin{aligned}
n &\geq \frac{C \cdot RTT}{l} = \frac{C \cdot (T_t + 2T_p)}{l} = \frac{C \cdot (\frac{l}{C} + 2\frac{d}{v_p})}{l} \\
&= \frac{1 \cdot 10^9 bit/s \cdot (\frac{12000bit}{1 \cdot 10^9 bit/s} + 2\frac{10 \cdot 10^3 m}{200 \cdot 10^6 m/s})}{12000bit} \\
&= 9.\overline{3} \rightarrow n \geq 10 \text{ frames}
\end{aligned}
$$

[0] T_t: transmission time, T_p: propagation delay, v_p: signal propagation speed, $v_l = 300 \cdot 10^6$ m/s: speed of light

Transmission of l =1500 byte frames via a C =10 Gbps link of d =10,000 km length in vacuum. We assume $v_p = v_l$.

$$\begin{aligned} n &\geq \frac{C \cdot RTT}{l} = \frac{C \cdot (T_t + 2T_p)}{l} = \frac{C \cdot (\frac{l}{C} + 2\frac{d}{v_p})}{l} \\ &= \frac{10 \cdot 10^9 bit/s \cdot (\frac{12000bit}{10 \cdot 10^9 bit/s} + 2\frac{10 \cdot 10^6 m}{300 \cdot 10^6 m/s})}{12000bit} \\ &= 55556.\overline{5} \rightarrow n \geq 55557 \text{ frames} \end{aligned}$$

[0] T_t: transmission time, T_p: propagation delay, v_p: signal propagation speed, $v_l = 300 \cdot 10^6$ m/s: speed of light

Consider a serial transmission on a $s_c =$100 meter cable used at $C =$100 Mbit/s. How many bits are in flight at full utilization?

$$C \cdot T_p = C \cdot \frac{s_c}{2/3 v_l} = 100 \cdot 10^6 bit/s \cdot \frac{100m}{200 \cdot 10^6 m/s} = 50 bit$$

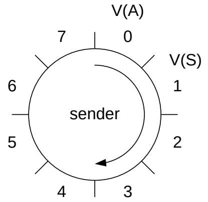
[0] T_p: propagation delay, v_l: speed of light

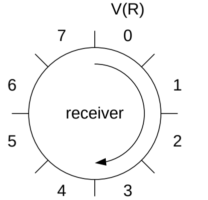
Explain both the receive and the send window. How do they correlate with each other?

- receive window: number of buffers at the receiver, advertised to sender
- send window: number of frames that have been transmitted but not yet acknowledged

State variables

- sender: send window V(S)−V(A)
  - V(A): acknowledge state variable
    - smallest not acknowledged SeqNo
    - increment on receipt of an ack
  - V(S): send state variable
    - next SeqNo to be sent
    - increment when sending a frame
    - largest SeqNo allowed: V(A)+n−1
- receiver: receive window n buffers
  - V(R): receive state variable
    - next SeqNo to be received in sequence
    - increment on receipt of a frame
    - largest SeqNo allowed: V(R)+n−1

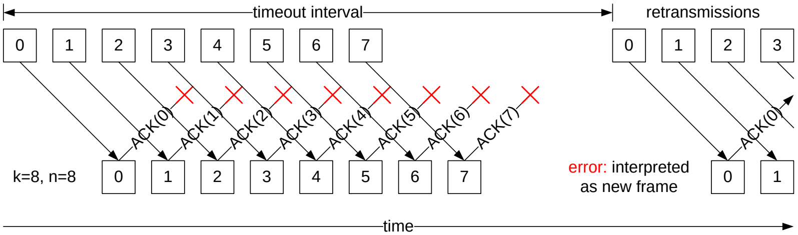




Assume a sliding window protocol with $k = 8$ distinct sequence numbers and a send window size $n = 5$. Describe the following situations:

1. V(A) $= 1$, V(S) $= 3 =$ V(A) $+ 2$
   - two unacknowledged frames
   - another three frames may be transmitted
2. V(A) $= 4$, V(S) $= 4 =$ V(A)
   - no unacknowledged frames
   - another five frames may be transmitted
3. V(A) $= 0$, V(S) $= 5 =$ V(A) $+ 5$
   - five unacknowledged frames
   - sender is not permitted to transmit further frames

What can happen if the window size $n \geq k$ (number of distinct sequence numbers)?



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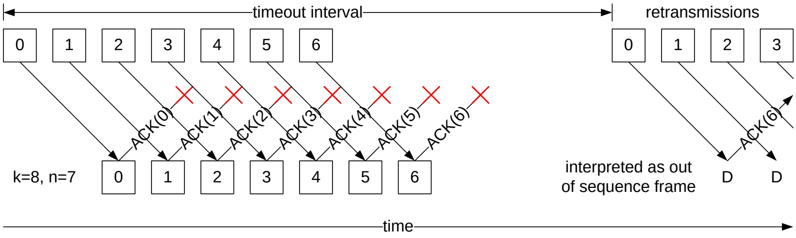
If $n \leq k - 1$, retransmissions can be distinguished:



What is the difference between go-back-n and selective repeat?

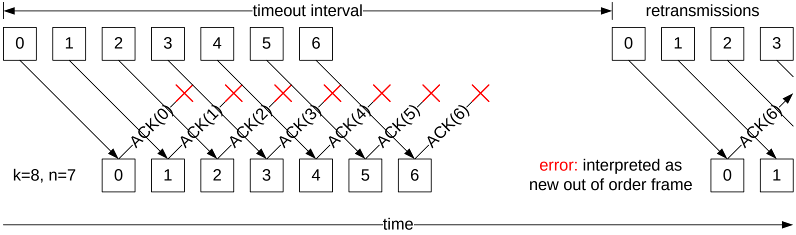
Go-back-n

- receiver accepts frames only in order of increasing SeqNo
- if a frame is erroneous or missing all subsequent frames are discarded
- if a frame with a certain SeqNo is retransmitted all subsequent frames are retransmitted, too

Selective Repeat

- receiver stores all correctly received frames
  - that fall into the receive window
  - regardless whether in sequence or not
- sender seeks to retransmit only erroneous frames (as opposed to all frames starting at the erroneous one)

For selective repeat, what can happen if $n > k/2$?



If $n \leq k/2$, retransmissions can be distinguished: