Week 6: Data Link Layer (Cont’d)

EE3017/IM2003 Computer Communications

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Topic Outline

Introduction to Computer Communications 01

Data Communications Fundamentals 02

Data Link Layer 03

Overview, Framing and Stuffing, Flow Control, **Error Control**

- Application
- Transport
- Network
- **Link**
- Physical

Learning Objectives

By the end of this topic, you should be able to:

- Explain the importance of sequence number in Automatic Repeat reQuest (ARQ).
- Construct the comprehensive delay model for stop-and-wait ARQ and perform mathematical analysis to the model constructed.
- Explain the principles of Go-back-N ARQ and Selective-Repeat ARQ.

Automatic Repeat Request (ARQ)

Automatic Repeat Request (ARQ)

Purpose

To ensure a sequence of information packets is delivered **in order** and **without errors or duplications** despite transmission errors and losses.

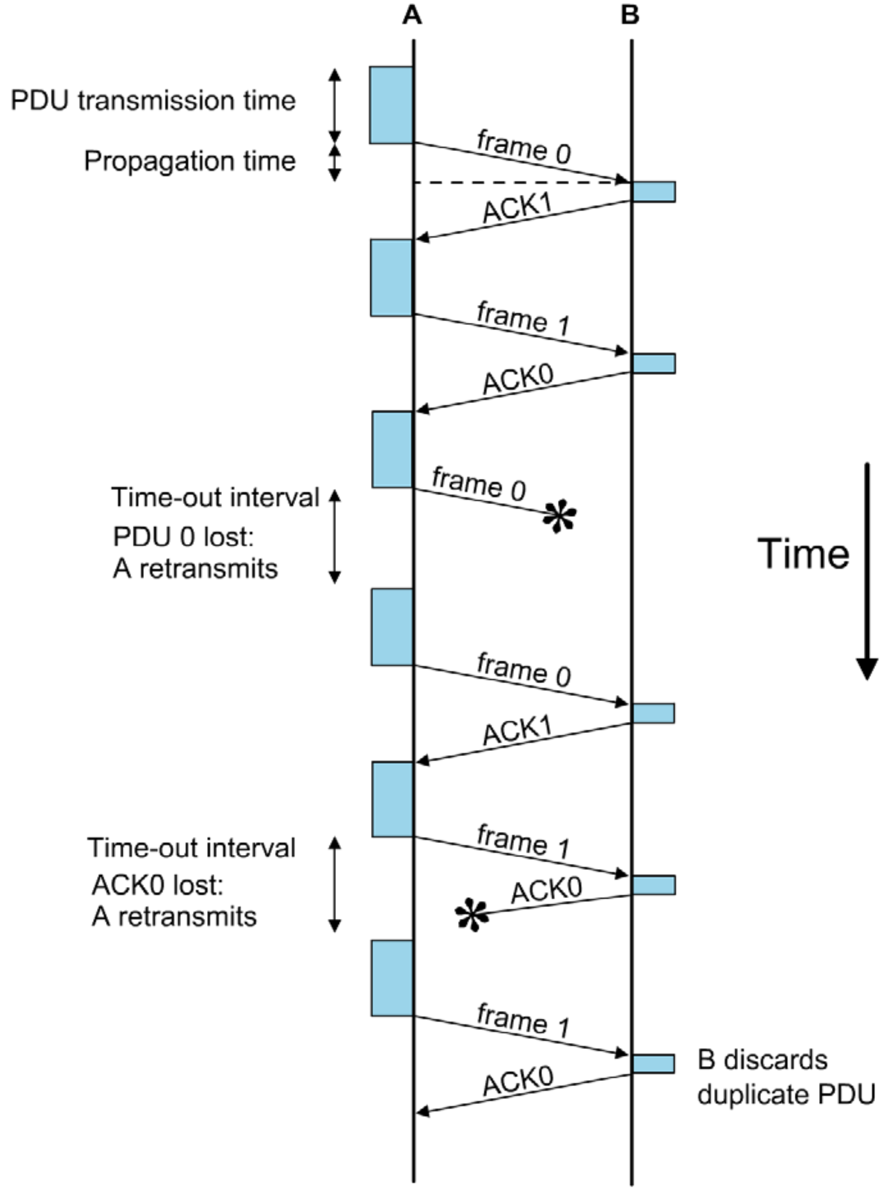
Effect of ARQ is to turn an unreliable data link into a reliable one.

We will look at:

- Stop-and-Wait ARQ
- Go-Back-N ARQ
- Selective-Repeat ARQ

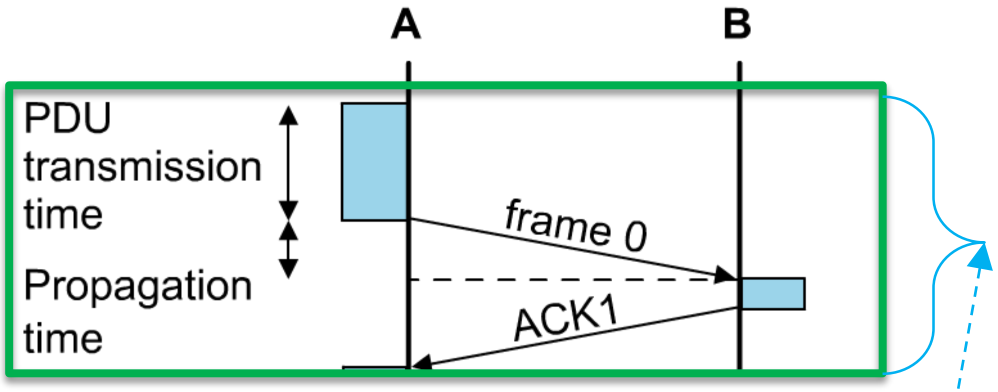
Stop-and-Wait ARQ

- Based on the stop-and-wait flow control protocol.
- After transmitting a single frame, the source sets a timer (stop-and-wait).
  - o No other data can be sent until receiver's reply arrives.
  - o If no ACK is received within the timeout period, source retransmits the frame, resets the timer.
- If (data) frame is damaged, receiver discards it.
  - o Source timeout.
  - o No ACK reaches source within timeout ⟶ retransmits, and resets timer.
- If ACK is damaged, transmitter will not recognise.
  - o Source timeout ⟶ retransmits and resets timer.
- Pro: simplicity
- Con: inefficient

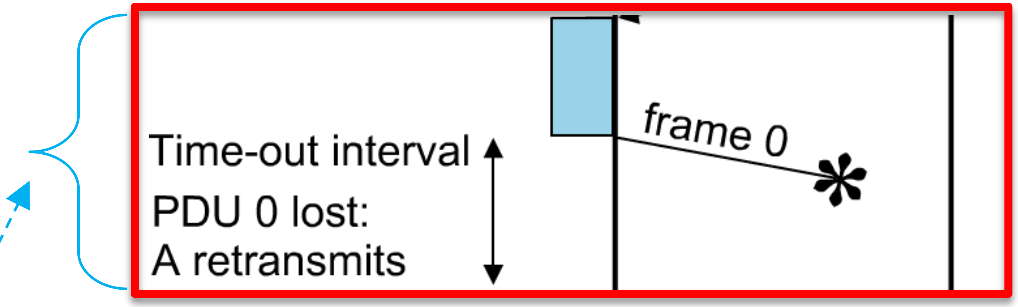


Stop-and-Wait ARQ

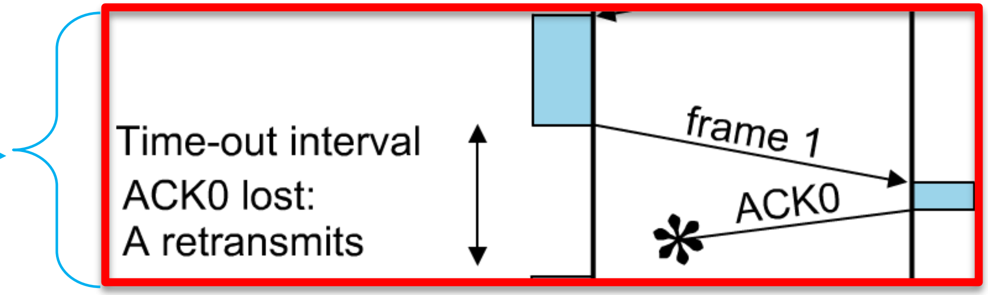
Case 1: Success



Case 2: Failure (due to data frame error/loss)



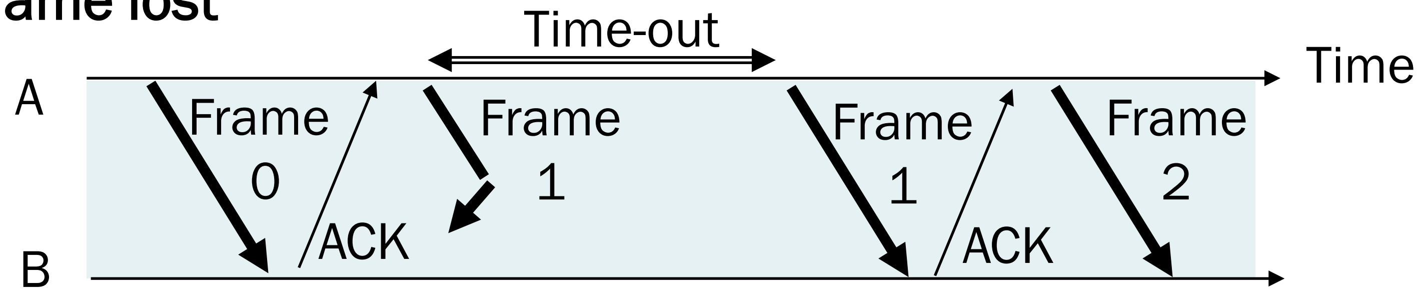
Case 3: Failure (due to ACK error/loss)



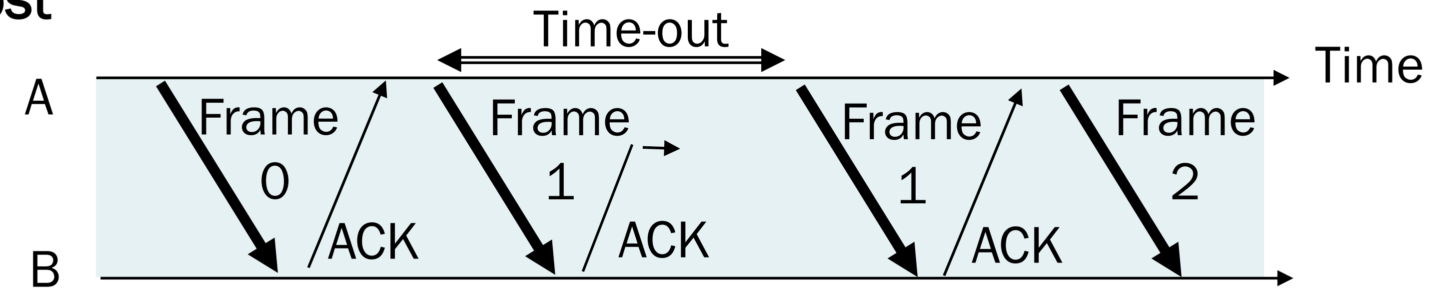
Same time taken.

S&W – Need for Sequence Numbers

(a) Data frame lost



(b) ACK lost



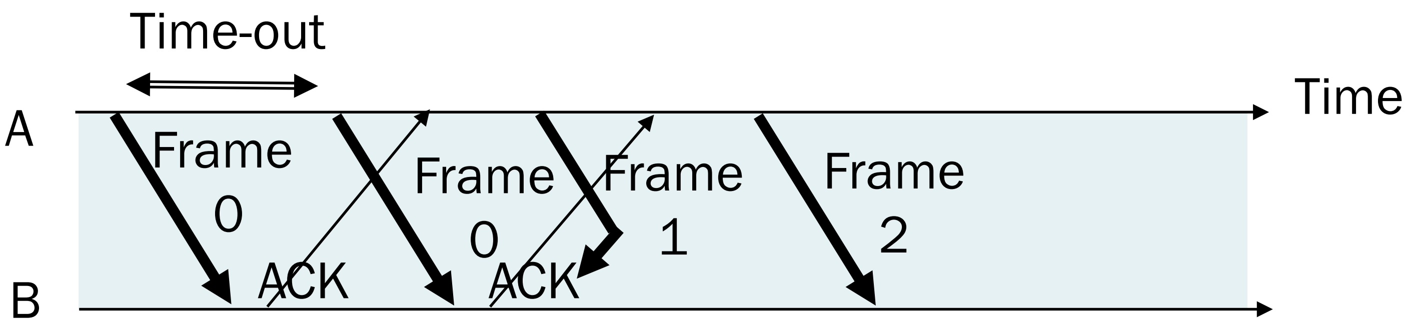
- In cases (a) and (b), source A acts the same way.
- But in case (b), destination B accepts duplicates of frame 1.

? How does the B detect the duplicate frame?

A Add frame sequence number in **data frame** header.

S&W – Need for Sequence Numbers

(c) Premature Time-out



- The transmitting station A misinterprets duplicate ACKs.
- Incorrectly assumes second ACK, acknowledges Frame 1.

How does the A know second ACK is for frame 0?

A

- **Add frame sequence number in ACK header** (sequence number of next frame expected by the receiver).
- Implicitly acknowledges receipt of all prior frames.

How many sequence numbers do we need for stop-and-wait ARQ?

Hint: Page 6

Performance of S&W ARQ

- We define utilisation as:

$$U = \frac{t_{frame}}{t_{total}}$$

t_{frame}: time for the transmitter to transmit a single frame.

t_{total} : total time engaged in the transmission of a single frame.

- For error-free operation using stop-and-wait ARQ (simplified model):

$$U = \frac{t_{frame}}{t_{frame} + 2t_{prop}} = \frac{1}{1 + 2a}$$

where t_{prop} is the propagation delay

$$a = t_{prop}/t_{frame}$$

Assumption: Overhead in the data frame is ignored. ACK time, nodal processing time, queuing time is negligible.

Performance of S&W ARQ

- If errors occur then U is changed to

$$U = \frac{t_{frame}}{N_r t_{total}}$$

- where N_r is the expected number of attempts for one successful frame transmission.

- For the stop-and-wait ARQ (simplied model):

$$U = \frac{t_{frame}}{N_r(t_{frame} + 2t_{prop})} = \frac{1}{N_r(1 + 2a)}$$

Assumption: ACK and NAK are error-free

- N_r is obtained by considering probability p that a single data frame is erroneous.

Performance of S&W ARQ

Let p = probability that a frame arrives with errors

then, $1 - p$ = probability a frame arrives without errors

The probability that it will take exactly i attempts to transmit a (data) frame successfully is:

$$Pr[i \text{ transmissions}] = p^{i-1}(1-p)$$

$$N_r = \mathrm{E}[i \text{ transmissions}] = \sum_{i=1}^{\infty} i Pr[i \text{ transmissions}]$$

Thus N_r is:

$$N_r = \sum_{i=1}^{\infty} i p^{i-1}(1-p) = \frac{1}{1-p}$$

$$\sum_{k=1}^{\infty} k(1-b)^{k-1} = \frac{1}{b^2}$$

$$\sum_{k=1}^{\infty} k(1-b)^{k-1} b = \frac{1}{b}$$

Thus U for S&W ARQ (simplified model) is:

$$U = \frac{1}{N_r(1+2a)} = \frac{1-p}{1+2a} = (1-p) \cdot \frac{1}{1+2a}$$

Performance of S&W ARQ

Therefore, for a S&W ARQ (simplified model) $\Rightarrow$ $U = \dfrac{1-p}{1+2a}$

For a channel with bit error probability BER, the probability that a L-bit frame is error-free will be $(1-BER)^L$.

Hence, $p = 1-(1-BER)^L$

$$\Rightarrow \quad U = \frac{(1-BER)^L}{1+2a}$$

- Noisy channel $\Rightarrow$ $p \uparrow \Rightarrow U \downarrow$
- Long frame $\Rightarrow$ $L \uparrow$ but $a \downarrow$

Example

- For the same system as in Week 4, Example 3, if the bit error rates of a transmitted frame are $p = 10^{-4}$ and 10^{-5}, compare the link efficiency for a frame size of 1000 bytes and 5000 bytes.

Recall Example 3: $t_{prop} = 5$ ms, $R = 4$ Mbps,
$L = 1000$ bytes ($t_{frame} = 2$ ms)
or $L = 5000$bytes ($t_{frame} = 10$ ms)

P_f :frame error probability

Error Free
$U = 0.17$

When L = 1000 bytes = 8000 bits, we get $a = 2.5$

For $p = 10^{-4}$, $(1 - P_f) = (1-10^{-4})^{8000} = 0.45$ => $\boxed{U = 0.075}$

For $p = 10^{-5}$, $(1 - P_f) = (1-10^{-5})^{8000} = 0.92$ => $\boxed{U = 0.153}$

Error Free
$U = 0.5$

When L = 5000 bytes = 40000 bits, we get $a = 0.5$

For $p = 10^{-4}$, $(1 - P_f) = (1-10^{-4})^{40000} = 0.018$ => $\boxed{U = 0.009}$

For $p = 10^{-5}$, $(1 - P_f) = (1-10^{-5})^{40000} = 0.67$ => $\boxed{U = 0.335}$

Go-Back-N ARQ

- Keep channel busy by continuously sending frames based on sliding window (Transmission Window > 1).

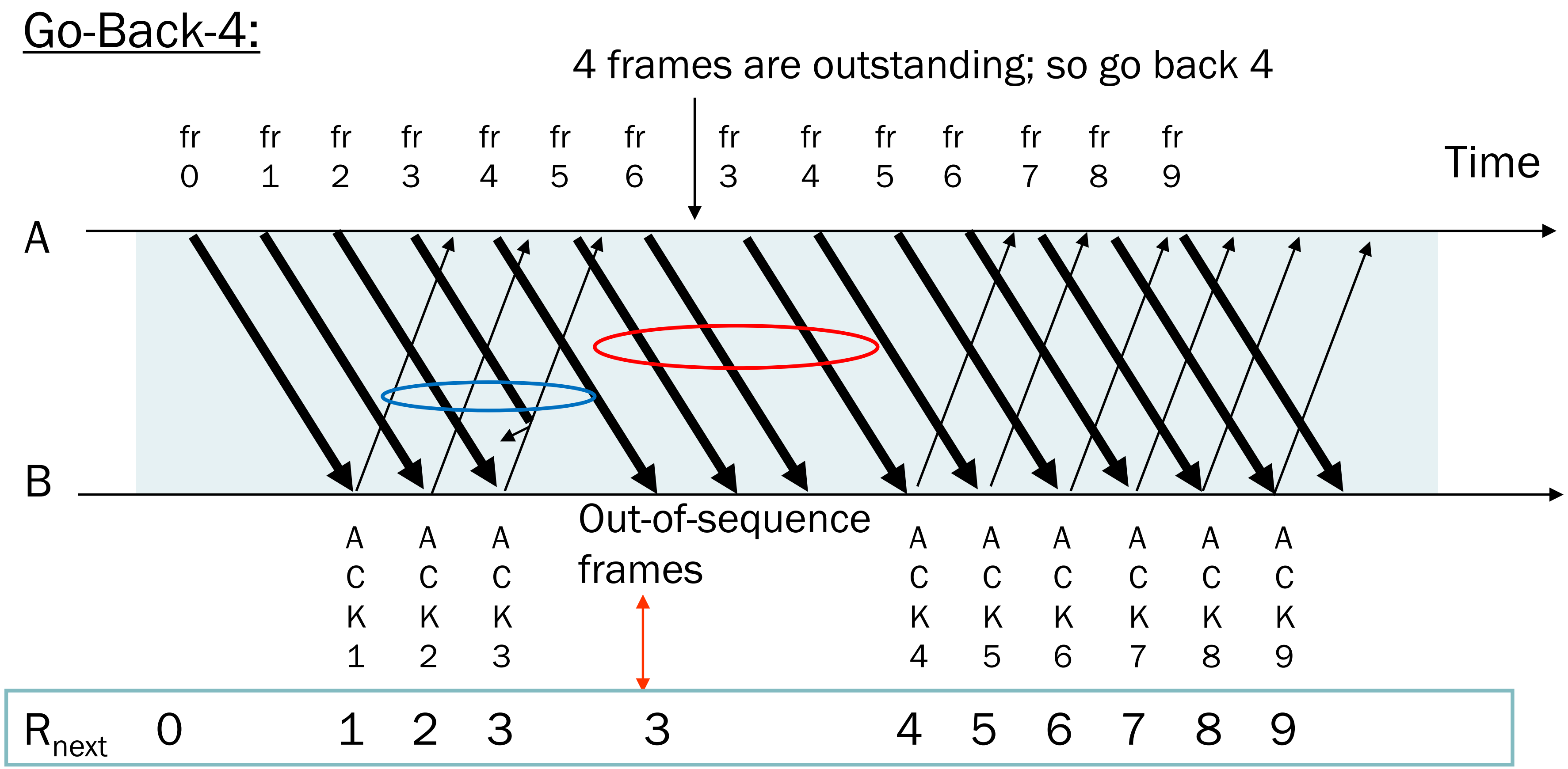
- If no error, ACK as usual with next frame expected.

- Use window to control number of outstanding frames.

- After transmission window is exhausted, retransmit from last acknowledged frame (i.e. the frames after that).

- When an out-of-sequence frame is received, reject the frame:
  - Discard that frame and all subsequent (out-of-sequence) frames, may send negative acknowledgment indicating the expected frame.
  - Transmitter must go back and retransmit the expected frame and all subsequent frames in the window.

Go-Back-N ARQ



Example: Frame 3 is lost.

After A exhausts its transmit window, retransmit frames 3, 4, 5, 6.

Selective Repeat (Reject) ARQ

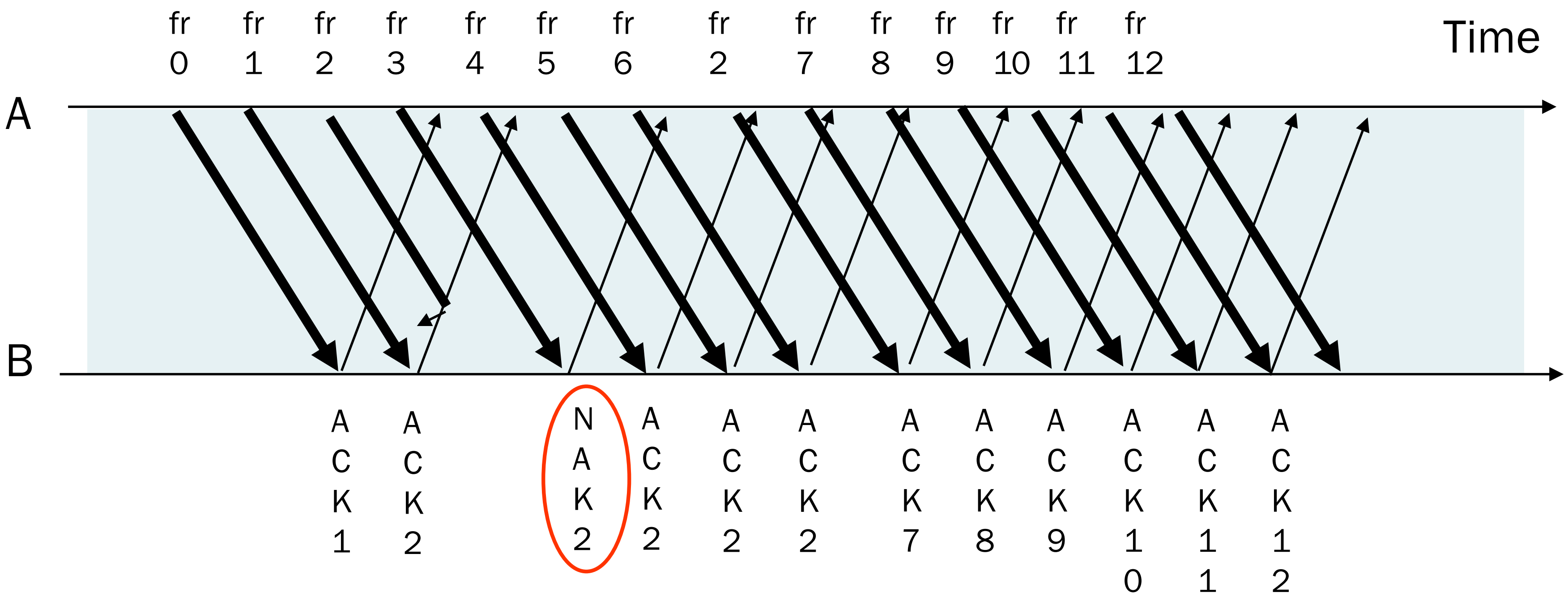
- Go-Back-N ARQ is inefficient because multiple frames are resent when errors or losses occur.

- Selective Repeat retransmits only an individual frame.
  - Timeout causes individual corresponding frame to be resent.
  - NAK causes retransmission of oldest un-acked frame.

- Minimises retransmission.

- More complex logic in transmitter and receiver.
  - The receiver must contain storage to save post-NAK frames until the frame in error is retransmitted and must contain logic for reinserting that frame in the proper sequence.
  - The transmitter also requires buffers to store copies of unacknowledged packets and requires complex logic to be able to send frames out of sequence.

Selective Repeat ARQ



- Retransmit only the frame in error.
- Store other frames in the buffer of the receiver.
- Wait for the error frame to be received correctly.

Window Size

Supplementary Notes

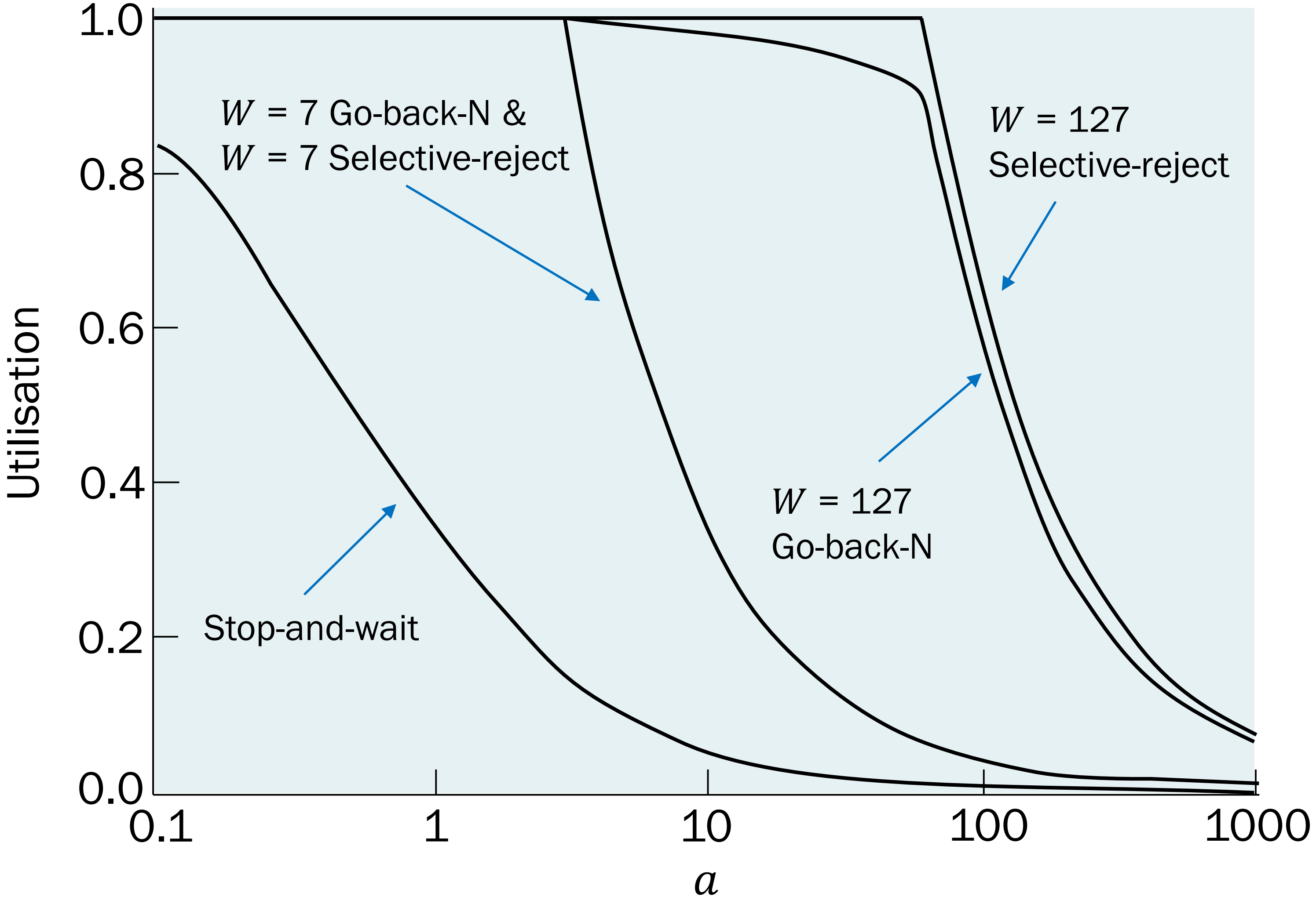
Maximum sending window size for Go-Back-N ARQ with k-bit sequence number field:

$$W_{\text{Go-back-N}}(\max) = 2^k - 1$$

Maximum sending window size for Selective–Repeat ARQ with k-bit sequence number field:

$$W_{\text{Selective-Repeat}}(\max) = 2^{k-1}$$

Performance of ARQ Schemes



ARQ Utilisation as a Function of a = (p = 10^{-3})

Applications

Stop-and-Wait ARQ

E.g. Trivial File Transfer Protocol (RFC 1350):
Simple protocol for file transfer over UDP.

Go-back-N ARQ

E.g. HDLC (High-Level Data Link Control)

Selective-Repeat ARQ

E.g. TCP: Transport layer protocol uses variation of selective repeat to provide reliable stream service.

Summary

Summary

Key points discussed in this topic:

- The purpose of the ARQ is to ensure a sequence of information packets is delivered in order and without errors or duplications despite transmission errors and losses.

- The types of ARQ schemes include S&W, Go-back-N and Selective-Repeat.

- In the S&W ARQ,
  - After transmitting a single frame, the source sets a timer (stop-and-wait).
  - If (data) frame is damaged, receiver discards it – A retransmission at the transmitter is resulted.
  - If the data frame is intact but ACK is damaged, transmitter will not recognise – A retransmission at the transmitter is resulted.