0.1 Data Link layer functions and services

0.1.1 Main functions

- Provide service interface to the network layer.
- Eliminate/reduce transmission errors.
- Regulate data flow: Slow receivers not swamped by fast senders.

0.1.2 Services provided

Principal service: Transfer data from the network layer on the source machine to the network layer on the destination machine.

There are three reasonable possibilities that we will consider:

- **Unacknowledged connectionless service:**
  - No logical connection is established beforehand or released afterwards.
  - Transmitter sends independent frames without having the destination machine acknowledge them.
  - If a frame is lost due to noise on the line, no attempt is made to detect or recover from that loss.
  - Appropriate when the error rate is very low and for real-time traffic.
- **Acknowledged connectionless service:**
  - No logical connections used.
  - Each frame sent is individually acknowledged so the sender knows if a frame arrived correctly or has been lost.
  - If it has not arrived within a specified time interval, it can be sent again.
  - This service is useful over unreliable channels, such as wireless systems.(i.e. Wi-Fi).
- **Acknowledged connection-oriented service:**
  - The source and destination machines establish a connection before any data are transferred.
  - Each frame is numbered, and the data link layer guarantees that each frame sent is indeed received.
  - Guarantees that each frame is received exactly once and that all frames are received in the right order.
  - Appropriate over long, unreliable links (satellite channel, long-distance telephone circuit).

- Divided in 3 phases:
  * **First phase:** The connection is established (initialize variables and counters needed to keep track of which frames have been received and which ones have not).
  * **Second phase:** One or more frames are actually transmitted.
  * **Third phase:** The connection is released (free the variables, buffers, and other resources used to maintain the connection).

0.2 Framing

Breaking up the bit stream into discrete frames, computing a short token called a checksum for each frame, and including the checksum in the frame when it is transmitted. When a frame arrives at the destination,the checksum is recomputed. If it is different from the one contained in the frame, the data link layer knows that an error occurred.

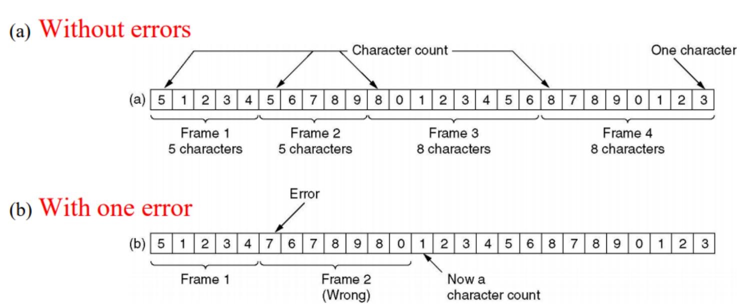
A good design must make it easy for a receiver to find the start of new frames while using little of the channel bandwidth. We will look at three methods:

0.2.1 Byte count

Uses a field in the header to specify the number of bytes in the frame. When the data link layer at the destination sees the byte count, it knows how many bytes follow and hence where the end of the frame is.

Issues

- The count can be garbled by a transmission error.
- A single bit flip, may trigger the destination to get out of synchronization.
- If an out-of-sync occurs it is unable to locate the correct start of the next frame.



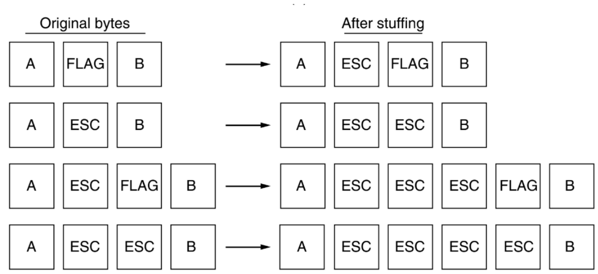
0.2.2 Flag bytes with byte stuffing

This method gets around the problem of resynchronization by having each frame start and end with special bytes (flag bytes).

However, this flag may occur in the middle of the data and induce the receiver in error by thinking the end of the frame was reached. This issue can be solved using **byte stuffing**.

Byte Stuffing

- Inserting a special escape byte (ESC) before each flag byte in the data.
- Makes framing flag bytes distinguishable from the ones in the data.
- Escape bytes present in the data also need to be escaped.



0.2.3 Flag bits with bit stuffing

- Each frame begins and ends with a special bit pattern (01111110 / 0x7E).
- When the sender finds five consecutive 1 bits in the data, it stuffs a 0 bit into the outgoing bit stream.
- When the receiver finds five consecutive incoming 1 bits, followed by a 0 bit, it destuffs the 0 bit.

Advantages:

- The boundary between two frames is unambiguously recognized by the flag pattern (flag sequences can only occur at frame boundaries and never within the data).
- Frames can contain an arbitrary number of bits made up of units of any size.
- Ensures a minimum density of transitions that help the physical layer maintain synchronization.

Figure 5. Bit stuffing. (a) The original data. (b) The data as they appear on the line. (c) The data as they are stored in the receiver's memory after destuffing.

Both byte and bit stuffing:

- Are completely transparent to the network layer in both computers.
- Have a frame length that depends on the contents of the data.

Many data link protocols use a combination of these three methods for safety.

0.3 Error detection

0.3.1 Types of Errors

- **Simple Error:** Random and independent from previous error.
- **Errors in burst:**
  - Not independent.
  - Affect neighbour bits.
  - Burst lenght defined by the first and last bits in error.

0.3.2 Counting Errors

Frame Error Probability(FER):

$$FER = 1 - (1 - BER)^n \quad (1)$$

BER = Bit Error Ratio
n = frame length

No Error Probability: $P = (1-p)^n$
Error Probability: $P = 1 - (1-p)^n$
i Error Probability: $P = \binom{n}{i} p^i (1-p)^{n-i}$

p = bit error probability
n = frame length

0.3.3 Error Detection Techniques

Used by the receiver to determine if a packet contains errors. If a packet is found to contain errors, the receiver may request the transmitter to re-send the packet.

0.3.4 Parity Check

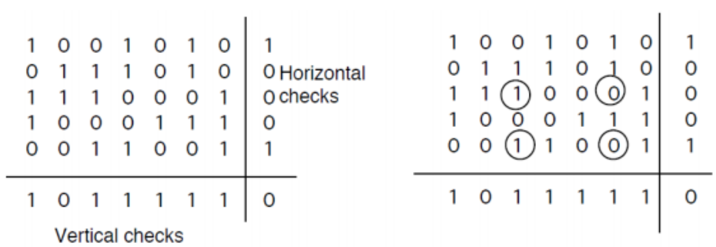
Simple Parity Check: One parity bit added to every k information bits so that:

- The total number of bits 1 even (even parity).
- The total number of bits 1 odd (odd parity).

Allows the detection of simple errors and any number of odd errors in a block of k + 1 bits. However, does not detect even number of errors in a block of k + 1 bits.

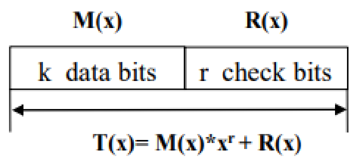
Bi-dimensional Parity

- Parity per row.
- Parity per column.
- Minimum code distance = 4.



0.3.5 Cyclic Redundancy Check (CRC)

A fixed number of check bits are appended to the message to be transmitted. Data receivers check on the check value attached by finding the remainder of the polynomial division of the contents transmitted. If it seems that an error has occurred, a negative acknowledgement is transmitted asking for data retransmission.



The bit string is represented as a polynomium (i.e. $110011 \Rightarrow x^5+x^4+x+1$)

How to compute the check bits: R(x)?

- Choose a generator string G(x) of length r+1 bits.
- Choose R(x) such that T(x) is a multiple of $G(x) : T(x) = A \times G(x)$.

Generating R(x):

$$R(x) = M(x)x^r \textbf{ mod } G(x) \tag{2}$$

Choice of G(x) is very important! ($G(x) = x^r + \ldots + 1$)

Generating R(x) example:

Assume for example:

- r=3.
- $G(x) = x^3 + 1 \Rightarrow 1001$.
- $M(x) = x^5 + x^4 + x^2 + 1 \Rightarrow 110101$.

Then:

- $x^r = x^3$.
- $M(x) \times x^3 = x^8 + x^7 + x^5 + x^3 \Rightarrow 110101000$.
- $R(x) = M(x)x^3 \textbf{ mod } G(x) = 110101000 \textbf{ mod } 1001 = 011 = x^1 + 1$

Checking at the Receiver

- Divide T(x) by G(x):
  - If the remainder $R(x) = 0 \Rightarrow$ no errors.
  - If the remainder $R(x)! = 0 \Rightarrow$ errors have occurred.

Performance:

For r check bits per frame the following can be detected

- All patterns of 1, 2, or 3 errors ($d > 3$).
- All bursts of errors of r or fewer bits.
- All errors consisting of an odd number of inverted bits.

0.4 Automatic Repeat reQuest (ARQ)

An error-control method for data transmission that uses acknowledgements (messages indicating whether or not the message has been correctly received) and timeouts to achieve reliable data transmission over an unreliable service. This mechanisms automatically request the retransmission of:

- Missing packets.
- Packets with errors.

There are three common ARQ schemes:

0.4.1 Stop and Wait

- Sender transmits information frame I and waits for positive confirmation ACK from receiver.
- Receiver receives I frame:
  - If I frame has no error sends ACK.
  - If I frame has error sends NACK.
- Sender receives I frame:
  - If ACK, proceeds and transmits new frame.
  - If NACK, retransmits frame I.
- If I, ACK or NACK is lost a timeout is required!

Issue: If the transmitter times-out and sends a packet twice, the receiver cannot tell whether the second frame is a retransmission or a new frame transmission.

Solution: Define a 1 bit sequence number in the header of the frame.

This sequence number alternates (from 0 to 1) in subsequent frames. The transmitter sends a frame with a sequence number attached to it so the receiver can check if it matches the expected. When the receiver sends an ACK, it includes the sequence number of the next packet it expects. This way, the receiver can detect duplicated frames by checking if the frame sequence numbers alternate.

Efficiency(S):

$$S = \frac{T_f}{T_f + 2 \times T_{prop}} = \frac{1}{1+2a} \tag{3}$$

where:

T_f = Data transmission time
T_{prop} = Propagation Delay

Probability of k Attempts required to transmit a frame with success

$$P[A = k] = {p_e}^{k-1}(1 - p_e) \tag{4}$$

where:

p_e = frame error probability(FER)

Expected number of Attempts to transmit a frame with success

$$E[A] = \frac{1}{1 - p_e} \tag{5}$$

where:

p_e = frame error probability(FER)

Efficiency with Errors

$$S = \frac{T_f}{E[A](T_f + 2 \times T_{prop})} = \frac{1 - p_e}{1+2a} \tag{6}$$

where:

p_e = frame error probability(FER)

0.4.2 Go Back N

Allows the transmission of new packets before earlier ones are acknowledged.

Sender:

- May transmit up to W frames without receiving RR(Receiver Ready = ACK).
- I frames are numbered sequentially I(NS): I(0), I(1), I(2), etc.
- Cannot send I(NS=i+W) until it has received the RR(NR=i).

Receiver:

- Does not accept frames out of sequence.
- Sends RR(NR) to sender indicating:
  - That all the packets up to NR-1 have been received in sequence.
  - The sequence number, NR, of the next expected frame.

Behaviour under Errors

- Frames with errors are silently discarded by the Receiver.
- If Receiver receives Data frame out of sequence:
  - First out-of-sequence-frame: Receiver sends REJ(NR) where NR = next in-sequence frame expected.
  - Following out-of sequence-frames: Receiver discards them; no REJ sent.
- When Sender receives REJ(NR=x), the Sender:
  - Goes-Back and retransmits I(x), I(x+1), etc.
  - Continues using Sliding Window mechanism.
- If timeout occurs, the Sender:
  - Requests the Receiver to send a RR message.
  - Sends a special message (RR command message).

Maximum Window Size(W):

$$W = M - 1 = 2^k - 1 \tag{7}$$

where:

M = Number of sequence numbers
k = Number of bits used to code sequence numbers

Efficiency:

- If $W \geq 1 + 2a \Rightarrow S = 1$.
- If $W < 1 + 2a \Rightarrow S = \frac{W}{1+2a}$.

Efficiency with Errors:

$$S = \begin{cases} \dfrac{1-p_e}{1+2ap_e} & ,W \geq 1+2a \\ \dfrac{W(1-p_e)}{(1+2a)(1-p_e+Wp_e)} & ,W < 1+2a \end{cases}$$

Figura 1: pe - frame error probability (ratio, FER)

0.4.3 Selective Repeat

Similar to **Go Back N**, however it does not discard successful frames when errors occur.

Receiver:

- Accepts out of sequence frames.
- Confirms negatively, SREJ, a frame not arrived.
- Uses RR to confirm blocks of frames arrived in sequence.

Sender: Retransmits only the frames signaled by SREJ.

Maximum window size(W):

$$W = \frac{M}{2} = 2^{k-1} \tag{8}$$

where:

M = Number of sequence numbers
k = Number of bits used to code sequence numbers

Efficiency:

$$S = \begin{cases} 1-p_e & ,W \geq 1+2a \\ \dfrac{W(1-p_e)}{1+2a} & ,W < 1+2a \end{cases}$$

Figura 2: pe - frame error probability (ratio, FER)

0.4.4 Useful Formulas for All Methods

Data transmission time (T_f):

$$T_f = \frac{L}{R} \tag{9}$$

where:

L = Frame Size
R = Data Rate

Propagation Delay(T_{prop}):

$$T_{prop} = \frac{d}{V} \tag{10}$$

where:

d = Distance between sender and receiver
V = Propagation Velocity

SUMETHIN(a)

$$a = \frac{T_{prop}}{T_f} \tag{11}$$

where:

T_{prop} = Propagation Delay
T_f = Data transmission time

Maximum Rate(R_{max}):

$$R_{max} = S \times R \tag{12}$$

where:

S = Efficiency
R = Data rate

Round Trip Time(RTT - Time of transmission and acknowledgement of a frame):

$$RTT = 2 \times T_{prop} + T_f \tag{13}$$

where:

T_{prop} = Propagation Delay
T_f = Data transmission time

0.5 Framing, Error detection and ARQ in common networks

0.5.1 Ethernet

- **Framing:**
  - Start of Frame - preamble + SFD.
  - End of Frame - end of signal transitions(Manchester code).
- **Error Detection:** CRC using ITU-32 (common polynomial for G(x)).
- **No ARQ:**
  - Bit Error ratio (BER) very low.
  - Frame Error Ratio (FER) low.
  - CRC/FCS strong: good detection of error frames.

0.5.2 Point to Point Protocol

- **Framing:** FLAGS - 0x7E; Byte Stuffing - 0x7D.
- **Error Detection:** Can be negotiated.
- **No ARQ.**

0.5.3 Wireless LAN

- **Framing:**
  - Synchronization.
  - Start Frame Delimiter.
  - Length: Payload length in us.
- **Error Detection:** CRC (Header Error Check) using ITU-16 (common polynomial for G(x)).
- **ARQ:** Modified version of Stop and Wait .

0.5.4 High-Level Data Link Control

- **Framing:** FLAGS and bit stuffing.
- **Error Detection:** CRC using ITU-16 (common polynomial for G(x)).
- **ARQ:** Selective Repeat.
- Used as basis for many telecom networks.

0.6 Reliability in the TCP/IP Reference Model

The TCP/IP reference model assumes:

- Every data link layer offers an error free service to the upper layer.
- Service Data Units are:
  - Delivered to upper layer without error.
  - Discarded.

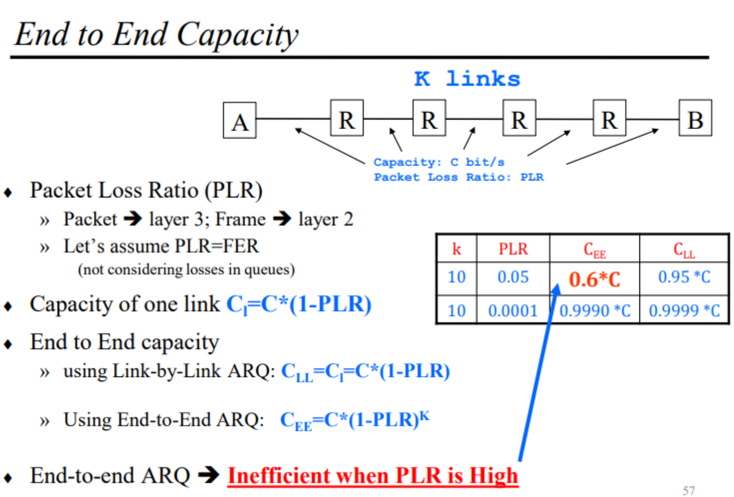
The layered model transforms bit error in packet losses. Therefore, packet losses must be repaired. Two strategies can be used:

0.6.1 Link-by-Link ARQ

- Repairs losses link by link.
- Requires network elements to
  - Remember information about packet flows ⇒ High processing per frame/packet.
  - Store packets in case they have to be retransmitted ⇒ Memory required.

0.6.2 End-to-End ARQ

- Low complexity : Intermediate network elements (switches, routers) become simple.
- Packets may follow different end to end paths.
- Not acceptable when Packet Loss Ratio is high



0.6.3 ARQ in the TCP/IP Reference Model

The TCP/IP architecture assumes that:

- The Data Link layer provides error-free packets to the network layer.
- Data link layer provides a service with very low FER.
- End-to-End ARQ is used, implemented at Transport or Application Layers.

In the TCP/IP reference model, packet losses are repaired:

- At the Data Link layer on lossy channels (e.g. wireless data links).
- At the end systems (transport layer or application layer).

0.7 Data Link Layer Some Exam Exercises - Part 2 Only

Note: In some exams, some question may need information given in previous questions.

0.7.1 2017/18 Exam

Efficiency and Maximum Rate

1. Duas estações comunicam usando uma ligação de dados baseada num mecanismo ARQ do tipo ***Go-Back-N***. O tempo de transmissão de uma trama de dados é de 8 ms, o atraso de propagação entre estações é de 160 ms e os pacotes têm um tamanho típico de 600 bytes. Assuma duas situações de erro distintas: $BER_1=0$ e $BER_2=10^{-4}$.
   a) (*1,5 valor*) Considere inicialmente que as tramas são numeradas **módulo 16**. Calcule a eficiência máxima do protocolo e o débito máximo para as duas situações de erro.

Go-Back-N ARQ	$BER_1=0$	$BER_2=10^{-4}$	
Eficiência máxima (%)	36,6	3,6	3 3
Débito máximo (kbit/s)	220	21,6	2 2

$T_f = 8$ ms, $T_p = 160$ ms, $L = 600 \times 8 = 4800$ bit, $N = 16 \to a = \frac{T_p}{T_f} = \frac{160}{8} = 20$

$1+2a = 41$ GBN $\to W = N-1 = 15$ $W < 1+2a$

BER = 0 $\to$ FER = 0

$S_{max} = \frac{W}{1+2a} = \frac{15}{41} = 36,6\%$

$Deb_{max} = C \times S_{max} = 600 \times 10^3 \times 36,6\% = 220$ kbit/s

$T_f = \frac{L}{C} \to C = \frac{L}{T_f} = \frac{4800}{8 \times 10^{-3}} = 600$ kbit/s

BER $= 10^{-4}$

FER $= 1 - (1-10^{-4})^{4800} = 0,38$

$S_{max} = \frac{15(1-0,38)}{(1+2a)(1-0,38+15 \times 0,38)} = 3,6\%$

$Deb_{max} = S_{max} \times C = 3,6\% \times 600 \times 10^3 = 21,6$ kbit/s

Window Maximum Size, Module (M) and Efficiency

b) (*1 valor*) Determine o tamanho crítico da janela de transmissão (e o módulo de numeração correspondente) que permitiria teoricamente a eficiência máxima do canal para as duas situações de erro indicadas. Calcule a eficiência máxima obtida para os módulos de numeração identificados nas duas situações de erro.

Go-Back-N ARQ	$BER_1=0$	$BER_2=10^{-4}$
Tamanho crítico da janela de transmissão	41	41
Módulo de numeração para a janela crítica de transmissão	64	64
Eficiência máxima (%)	100	3,8

2 1
2 1
2 2

$W \geq 1+2a \rightarrow S_{max} = \frac{1-FER}{1+2aFER}$

$W \geq 1+2a$

$W \geq 41 \Rightarrow N = 64 \Rightarrow W = N-1 = 63$

$BER = 0 \Rightarrow FER = 0$

$S_{max} = 1$

$BER = 10^{-4} \Rightarrow FER = 1 - (1-10^{-4})^{4800} = 0{,}38$

$S_{max} = \frac{1-FER}{1+2aFER} = \frac{1-0{,}38}{1+40 \times 0{,}38} = 3{,}8\%$ //

Selective Repeat Efficiency; Frame Size(L) and Module(M) to double that Efficiency

c) (*1,5 valor*) Na situação em que $BER_2=10^{-4}$ e nas condições da alínea anterior calcule a eficiência máxima para o mecanismo *ARQ Selective Repeat* (se não resolveu a alínea b) considere o módulo de numeração 64). Admitindo que tinha a liberdade de controlar o comprimento das tramas (L) e o módulo de numeração (M), o que faria para duplicar o valor da eficiência desta ligação usando o mecanismo *ARQ Selective Repeat*? Quais os valores das variáveis L e M nesta situação?

Eficiência máxima (%)	*Situação de eficiência dupla*	
	L (bit)	*M*
48,4	325	2048

4 3 3

$BER = 10^{-4}$, $FER = 0{,}38$, $N = 64$; $W = \frac{N}{2} = 32$; $1+2a = 41 \rightarrow W < 1+2a$

$S_{max} = \frac{W(1-FER)}{1+2a} = \frac{32(1-0{,}38)}{41} = 48{,}4\%$

Se $W \geq 1+2a \rightarrow S = 1-FER$. Se $L \searrow \rightarrow FER \searrow$, mas se $L \searrow$ $T_f = \frac{L}{c} \searrow$ $a = \frac{T_p}{T_f} \nearrow$

$S_{max} = 2 \times 48{,}4\% = 96{,}8\%$. Se $W \geq 1+2a$, $S = 1-FER$, $FER = 1-S = 1-96{,}8\% = 0{,}032$

$0{,}032 = 1-(1-10^{-4})^L \rightarrow L = \frac{\log(1-0{,}032)}{\log(1-10^{-4})} = \frac{-0{,}0141}{-4{,}3432} = 325$

0,03

0,032

$T_f = \frac{L}{c} = \frac{325}{600 \times 10^3} = 0{,}54$ ms; $a = \frac{T_p}{T_f} = \frac{160}{0{,}54} = 296$ | $W > 1+2a$; $W > 593$

$SR \rightarrow W = \frac{N}{2}$ $N > 593 \times 2 = 1186$

$M = 2048$

2. Através de uma porta de saída de um comutador de tramas é encaminhado tráfego recebido em 24 portas de

0.7.2 2016/17 Exam

Minimum and Maximum Distances between two machines, having an efficiency above X

1. Dois equipamentos comunicam usando uma ligação de dados que usa mecanismos ARQ. Assuma que a capacidade do canal (em cada sentido) é de 1 Mbit/s, que o comprimento das tramas de informação é de 100 Bytes, que informação se propaga à velocidade da luz ($3*10^8$ m/s) e que queremos usar no máximo 2 bits de para numerar as tramas que informação.

a) (*1,5 valor*) Para as variantes *Stop and Wait*, *Go Back N* e *Selective Repeat*, calcule a distância mínima e máxima entre os dois equipamentos por forma a obtermos uma eficiência da ligação superior a 80%.

	Stop and Wait	*Go Back N*	*Selective Repeat*
Distância mínima (km)	0	0	0
Distância máxima (km)	30	336	180

$\begin{pmatrix} 1 & 1 & 1 \\ 3 & 2 & 2 \end{pmatrix}$

$C = 1$ Mbit/s, $L = 100 \times 8 = 800$ bit, $v = 3 \times 10^8$ m/s, $k = 2$

$T_f = \frac{L}{C} = \frac{800}{10^6} = 0,8$ ms $\quad T_p = \frac{d}{v} = \frac{d}{3 \cdot 10^8} = \frac{d}{3} \times 10^{-8}$; $a = \frac{T_p}{T_f} = \frac{d \cdot 10^{-8} \cdot 10^6}{3 \cdot 800} = \frac{d}{24} \cdot 10^{-4}$

SW: $S_{max} = \frac{1}{1+2a} \geq 0,8$

$\frac{1}{1+2a} \geq 0,8$; $a \leq \frac{1}{8}$

$\frac{d}{24} \cdot 10^{-4} \leq \frac{1}{8}$ $\quad \boxed{d \leq 30 \text{ km}}$

GBN: $k=2$, $N = 2^2 = 4$, $W = N-1 = 3$

$S_{max} = \frac{W}{1+2a} \geq \frac{8}{10}$; $\frac{3}{1+2a} \geq \frac{8}{10}$

$a \leq 1,4$ $\quad \frac{d}{24} \cdot 10^{-4} \leq 1,4$

$\boxed{d \leq 336 \text{ km}}$

SR: $k=2$; $N = 2^2 = 4$; $W = \frac{N}{2} = 2$

$S_{max} = \frac{W}{1+2a} \geq \frac{8}{10}$

$\frac{2}{1+2a} \geq \frac{8}{10}$ $\quad a \leq \frac{3}{4}$

$\frac{d}{24} \cdot 10^{-4} \leq \frac{3}{4}$ $\quad \boxed{d \leq 180 \text{ km}}$

Block of Data Send Time and Observed Rate

b) (*1 valor*) Suponha que os dois equipamentos distam de 30 km e que emissor tem um bloco de 100 kBytes de dados para transmitir. Desprezando os *overheads* introduzidos pelo protocolo de ligação lógica, calcule para as duas variantes ARQ indicadas o tempo necessário para o envio do bloco de dados (até ser recebida a última confirmação pelo emissor) e o débito observado pela camada superior. Se necessário recorra a diagramas temporais.

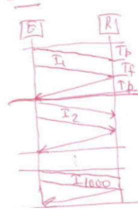
	Stop and Wait	*Selective Repeat*
Tempo de envio do bloco (ms)	1000	800
Débito observado (kbit/s)	800	1000

$\begin{pmatrix} 3 & 3 \\ 2 & 2 \end{pmatrix}$

$d = 30$ km ; Bloco $= 100$ kByte, $L = 100$ Bytes $\rightarrow$ 1000 tramas a serem enviadas

$T_f = 0,8$ ms $\quad T_p = \frac{d}{3 \cdot 10^8} = \frac{3 \times 10^3}{3 \cdot 10^8} = 0,1$ ms $\quad a = \frac{T_p}{T_f} = \frac{0,1}{0,8} = \frac{1}{8}$

SW



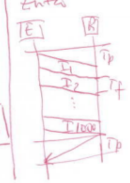
$T_f + 2T_p = 1$ ms

$T_{Bloco} = 1000 \times 1$ ms $= \boxed{1 s}$

Débito $= \frac{8 \times 100 \times 10^3}{1 s} = \boxed{800 \text{ kbit/s}}$

SR: $W > 1+2a$? $\quad 2 \geq 1 + \frac{2}{8}$ ✓ $\rightarrow S_{max} = 1$

Então



$T_{Bloco} = 2T_p + 1000\,T_f$

$= 0,2$ ms $+ 800$ ms

$\simeq 800$ ms

$Deb_{max} = \frac{8 \times 100 \times 10^3}{800 \times 10^{-3}} = \boxed{1 \text{ Mbit/s}}$

1

Choose Block of Data Size and calculate Efficiency and Maximum Rate

c) (*1,5 valor*) Admita que, para a mesma distância de 30 km, a ligação se efetua sob condições de transmissão que conduzem a uma situação de erro caracterizada por um **BER=10^{-3}**. Considere que é utilizado o mecanismo ARQ ***Stop and Wait***. Assumindo que o tamanho de trama (L) pode variar entre 100 e 1000 Bytes, que tamanho escolheria por forma a obter a eficiência máxima (S_{max})? Qual o valor essa eficiência? Qual é o débito máximo (Deb_{max}) obtido nessa situação?

L	S_{max} *(%)*	Deb_{max} *(kbit/s)*
100	36	360

(4 3 3)

SW: $S_{max} = \frac{1-PER}{1+2a}$ $\quad$ se $L \searrow$ PER $\searrow$ S $\nearrow$ $\rightarrow L = 100$ Byte $= 800$ bits (apesar de a depender também de L)

$BER = 10^{-3}$ $\quad PER = 1 - (1-BER)^L = 1 - (1-10^{-3})^{800} = 0,55$

$S = \frac{1-0,55}{1+2 \cdot \frac{1}{8}} = \frac{0,45}{1,25} = 36\%$ $\quad Deb_{max} = 0,36 \times 10^6 = 360$ kbit/s

0.7.3 2015/16 Exam

Window Size, Efficiency and Maximum Rate

1. Duas estações separadas por uma distância de 2000 km comunicam usando um protocolo de ligação de dados do tipo ARQ. O atraso de propagação da informação é de 5 µs/km e a capacidade do canal é 1024 kbit/s (em cada sentido). Admita que as tramas de Informação usam 3 bits para numeração, têm um tamanho típico de 2048 bits e são imediatamente confirmadas por tramas de Supervisão em sentido oposto. Despreze o tamanho das tramas de Supervisão.

a) *(1,5 valor)* Para as variantes *Go-Back-N* e *Selective Repeat*, calcule a janela de transmissão, a eficiência máxima do protocolo e os débitos máximos.

	Go-Back-N	*Selective Repeat*
Janela de transmissão, W	7	4
Eficiência máxima, S (%)	63,6	36,1
Débito Máximo (kbit/s)	651	370

$$\begin{pmatrix} 2 & 2 \\ 2 & 2 \\ 1 & 1 \end{pmatrix}$$

$d = 2000\,km$; $T_p = 5\frac{\mu s}{km} \times 2000\,km = 10\,ms$; $T_f = \frac{L}{C} = \frac{2048\,bit}{1024 \times 10^3\,bit/s} = 2\,ms$

$a = T_p / T_f = \frac{10}{2} = 5$; $1+2a = 11$; $M = 2^k = 2^3 = 8$

GBN: $W = M-1 = 8-1 = 7$

$W < 1+2a \Rightarrow S_{GBN} = \frac{W}{1+2a} = \frac{7}{11} = 63{,}6\%$

$Deb_{max} = S_{GBN} \times C = 0{,}636 \times 1024 = 651\,kbit/s$

SR: $W = \frac{M}{2} = \frac{8}{2} = 4$

$S_{SR} = \frac{W}{1+2a} = \frac{4}{11} = 36{,}1\%$

$Deb_{max} = S_{SR} \times 1024 = 370\,kbit/s$

Efficiency using two different frame sizes

b) *(1 valor)* Pretende-se analisar o efeito dos erros de transmissão e do tamanho das tramas de Informação. Considere tramas com tamanhos 1024 e 2048 bits e uma situação de ruído caracterizada por **BER=10^{-3}**. Calcule a eficiência máxima dos dois mecanismos para estes 2 casos e discuta o comportamento destes mecanismos em relação ao tamanho das tramas

S_{max} (%)	*Go-Back-N*	*Selective Repeat*
L=2048	1,3	4,7
L=1024	2,5	6,9

$$\begin{pmatrix} 3 & 2 \\ 2 & 3 \end{pmatrix}$$

$L_1 = 2048$: $FER_1 = 1-(1-BER)^{L} = 1-(1-10^{-3})^{2048} = 0{,}87$; $1-FER_1 = 0{,}13$

GBN: $7 < 11 \Rightarrow S = \frac{W(1-FER)}{(1+2a)(1-FER+W\,FER)} = \frac{7 \times 0{,}13}{11 \times (0{,}13 + 7 \times 0{,}87)} = \frac{0{,}91}{68{,}42} = 1{,}3\%$

SR: $4 < 11 \Rightarrow S = \frac{W(1-FER)}{1+2a} = \frac{4 \times 0{,}13}{11} = 4{,}7\%$

$L_2 = 1024$; $T_f = \frac{L}{C} = \frac{1024}{1024 \times 10^3} = 1\,ms$; $a = \frac{T_p}{T_f} = \frac{10}{1} = 10$; $1+2a = 21$

$FER_2 = 1-(1-BER)^{L_2} = 1-(1-10^{-3})^{1024} = 0{,}64$; $1-FER_2 = 0{,}36$

GBN: $7 < 21 \Rightarrow S = \frac{W(1-FER)}{(1+2a)(1-FER+W\,FER)} = \frac{7 \times 0{,}36}{21\,(0.36 + 7 \times 0{,}64)} = \frac{2{,}56}{101{,}64} = 2{,}5\%$

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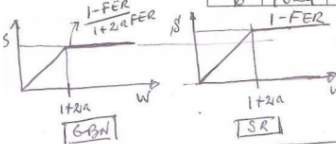
SR: $4 < 21 \Rightarrow S = \frac{W(1-FER)}{1+2a} = \frac{4 \times 0{,}36}{21} = 6{,}9\%$

Number of bits for sequence number, Frame Size, Mechanism ARQ, Efficiency

c) *(1,5 valor)* Admita que, para esta situação de erro, tinha a liberdade de escolher o número de bits de numeração (k), um dos dois tamanhos de trama indicados (L=1024 ou L=2048 bits) e um dos dois mecanismos ARQ (*Go-back-N* ou *Selective Repeat*). Que solução escolheria? Qual o valor da eficiência máxima nessa situação. Justifique.

k bits	*L*	*Mecanismo ARQ*	*Smax (%)*
6	1024	SR	36

(3 2 3 2)



1

Para $W > 1+2a$

$S_{SR} > S_{GBN}$ porque $1+2aFER > 1$ logo

$1-FER > \frac{1-FER}{1+2aFER} \rightarrow ARQ = SR$

2

$L_2 < L_1 \Rightarrow FER_2 < FER_1 \Rightarrow 1-FER_2 > 1-FER_1$

Logo L_2 é melhor $\rightarrow L = L_2 = 1024$ bit

3

Para que S seja máximo $W > 1+2a \rightarrow W > 21$

$k=4;\ 2^4=16;\ W=8<21$

$k=5;\ 2^5=32;\ W=16<21$

$k=6;\ 2^6=64;\ W=32>21 \rightarrow k=6$

4

$S_{max} = S_{SR} = 1-FER_2 = 0,36$