



Communication
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Layer

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Data link
Layer

Frame
delimitation

Error
Detection and
Correction

Flow control

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management
procedures

MAC sublayer

Communication Networks course

Data Link Layer

Pr A. DJEFFAL

2nd licence year

2025-2026

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Data Link Layer

Data Link Layer

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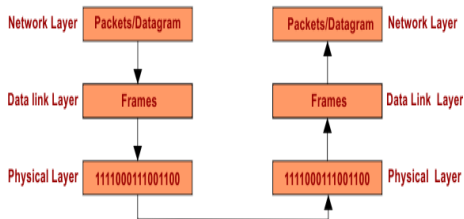
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MAC sublayer

- Physical layer : transmission of bits.
- The data link layer (layer n° 2) : ensure the correction of transmitted bits.
- The data link layer (layer n° 2) : retrieves data packets from the network layer, wraps them in frames, sends them one by one to the physical layer.





Data Link Layer

Link Layer

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The link layer must ensure :

- The delimitation of the exchanged data blocks ;
- Checking the integrity of received data ;
- The organization and control of the exchange.
- Shared channel access control



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Link Layer

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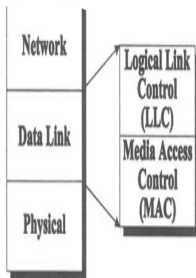
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MAC sublayer

The link layer consists of two sub-layers : LLC (Logical Link Control) and MAC (Media Access Control)





Frame delimitation

Frame delimitation

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MAC sublayer

- Asynchronous transmissions : start bits and stop bits frame the information bits
- Synchronous transmission : special information added for start and end of data
- Two methods :
 - 1 Character count
 - 2 Using Flags



Frame delimitation

Character counting

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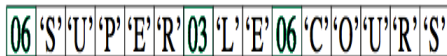
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A field in the frame header is used to indicate the number of characters in the frame.





Frame delimitation

Character counting

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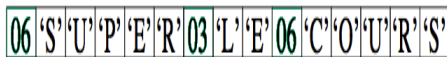
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MAC sublayer

A field in the frame header is used to indicate the number of characters in the frame.



Problem : if the value of the added field is modified during transmission !!



Frame delimitation

Use of Flags

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The frame is delimited by a particular sequence of bits called flag.





Frame delimitation

Use of Flags

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The frame is delimited by a particular sequence of bits called flag.



Problem : if the value of the flag appears in the data !!



Frame delimitation

Use of Flags

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The frame is delimited by a particular sequence of bits called flag.



Problem : if the value of the flag appears in the data !!

Solution : Binary Transparency (**bit stuffing**)



Frame delimitation

Using bit stuffing

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Need for transparency bits ; For example, if the flag is byte 01111110, a "0" Transparency Bit is inserted after any sequence of five successive 1s in the frame.

(a) 0 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0

(b) 0 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0

Stuffed bits

(c) 0 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0

Advantages : Synchronization always + frames of any size.



Error Detection and Correction

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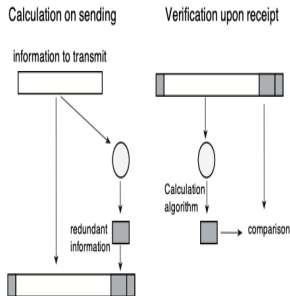
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MAC sublayer

- Ensure that received data has not been altered during transmission
- Due to interference and distortion
- Exploit redundancy : Add control bits





Error Detection and Correction

Duplicate data

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- Double message : difference : error ; equality : OK
- Problem : if the same error on both messages
- Message Triple : Correct by taking two identical copies ;
- Problem : if two different errors on two copies ;
- Problem : If the same error on two copies



Error Detection and Correction

Parity check code

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- This is a code in which a bit (the parity bit) is added to the initial word to ensure parity.
- **Example** : Transmission of characters using a representation code (the 7-bit ASCII code).

7 bits of data	(count of 1-bits)	8 bits including parity	
		even	odd
0000000	0	00000000	00000001
(Q) 1010001	3	10100011	10100010
(I) 1101001	4	11010010	11010011
1111111	7	11111111	11111110



Error Detection and Correction

Parity check code

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- This code is able to detect all errors in odd number
- But it does not detect even number errors.
- It detects a parity error, but does not locate it.



Error Detection and Correction

Parity Check Code (Vertical Parity)

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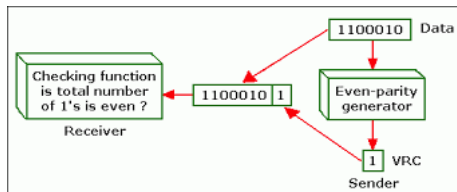
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To each character we add a bit (vertical redundancy bit or parity bit, VRC : Vertical Redundancy Check)





Error Detection and Correction

Parity Check Code (Longitudinal Parity)

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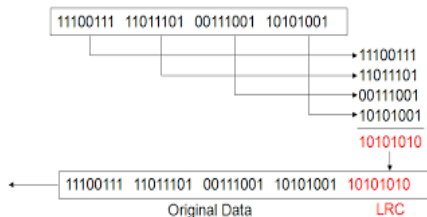
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MAC sublayer

To each block of characters, we add an additional check field
(LRC : Longitudinal Redundancy Check)





Error Detection and Correction

Parity Check Code (Longitudinal and Vertical Parity)

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The data block is laid out in a matrix form ($k = a \bullet b$). Parity is applied to each row and each column. We get a matrix $(a + 1, b + 1)$.

	H	E	L	L	O	LRC →
bit 0	0	1	0	0	1	0
bit 1	0	0	0	0	1	1
bit 2	0	1	1	1	1	0
bit 3	1	0	1	1	1	0
bit 4	0	0	0	0	0	0
bit 5	0	0	0	0	0	0
bit 6	1	1	1	1	1	1
VRC ↓	0	1	1	1	1	0

1001000	0	1000101	1	1001100	1	1001100	1	1001111	1	1000010	0
H		E		L		L		O		LRC	



Error Detection and Correction

Polynomial codes (CRC : Cyclic redundancy check)

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MAC sublayer

- Most commonly used method for detecting group errors.
- Before transmission, control bits are added.
- If errors are detected on receive, retransmit.
- n bits \rightarrow polynomial of degree $n - 1$.
 - $1101 \rightarrow x^3 + x^2 + 1$
 - $110001 \rightarrow x^5 + x^4 + 1$
 - $11001011 \rightarrow x^7 + x^6 + x^3 + x + 1$



Error Detection and Correction

Polynomial codes (CRC) - Principle

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Use modulo 2 addition and subtraction (XOR)

$$\begin{array}{r} 1\ 0\ 0\ 1\ 1\ 0\ 1\ 1 \\ +\ 1\ 1\ 0\ 0\ 1\ 0\ 1\ 0 \\ \hline =\ 0\ 1\ 0\ 1\ 0\ 0\ 0\ 1 \end{array}$$

$$\begin{array}{r} 1\ 1\ 1\ 1\ 0\ 0\ 0\ 0 \\ -\ 1\ 0\ 1\ 0\ 0\ 1\ 1\ 0 \\ \hline =\ 0\ 1\ 0\ 1\ 0\ 1\ 1\ 0 \end{array}$$



Error Detection and Correction

Polynomial codes (CRC) - Principle

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- The source and the destination choose the same generator polynomial $G(x)$ of degree r .
- $M(x)$ polynomial corresponding to the original message.
- Multiply $M(x)$ by x^r , which is equivalent to adding r zeros to the end of the original message
- Perform the following division modulo 2 :

$$\frac{M(x)x^r}{G(x)} = Q(x) + R(x)$$

- The quotient $Q(x)$ is ignored. The remainder $R(x)$ (Checksum) contains r bits (degree of remainder $r - 1$). We then perform the subtraction modulo 2 :

$$M(x).x^r - R(x) = T(x)$$

- $T(x)$ message ready to send



Error Detection and Correction

Polynomial codes (CRC) - Principle

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On reception, the following division is carried out :

$$\frac{T(x)}{G(x)}$$

- If the remainder = 0, there is no error
- If the remainder $\neq 0$, there is an error, so we must retransmit

By carefully choosing $G(x)$, we can detect any error on 1 bit, 2 consecutive bits, a sequence of n bits and beyond n bits with a very high probability.



Error Detection and Correction

Polynomial Codes (CRC) - Example

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MAC sublayer

- 1 Transmit the message 1011011 using the generator polynomial $G(x) = x^4 + x + 1$.
- 2 original message = 1011011 \Rightarrow
 $M(x) = x^6 + x^4 + x^3 + x^1 + 1$
- 3 $G(x) = x^4 + x + 1$
- 4 $M(x).x^4 = x^{10} + x^8 + x^7 + x^5 + x^4$
- 5 Compute $R(x)$ by Polynomial division



Error Detection and Correction

Polynomial Codes (CRC) - Example

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Polynomial division

$$\begin{array}{r} x^{10} + x^8 + x^7 + x^5 + x^4 \\ x^{10} + x^7 + x^6 \\ \hline x^8 + x^6 + x^5 + x^4 \\ x^8 + x^5 + x^4 \\ \hline x^6 \\ x^6 + x^3 + x^2 \\ \hline x^3 + x^2 \end{array} \quad \left| \quad \begin{array}{r} x^4 + x + 1 \\ x^6 + x^4 + x^2 \end{array}$$



Error Detection and Correction

Polynomial Codes (CRC) - Example

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$$R(x) = x^3 + x^2 = (1100)_2$$

The message to send $T(x) = M(x).x^r - R(x)$

$$T(x) = x^{10} + x^8 + x^7 + x^5 + x^4 - x^3 - x^2 = (10110111100)_2$$

On reception, a similar calculation is performed on the received word, but here the remainder must be zero.

Otherwise, an error has occurred along the way.



Error Detection and Correction

Polynomial Codes (CRC) - Polynomial codes used

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MAC sublayer

- LRCC-8 : $x^8 + 1$
- LRCC-16 : $x^{16} + 1$
- CRC 12 : $x^{12} + x^{11} + x^3 + x^2 + x + 1$
- CRC 16 Forward : $x^{16} + x^{15} + x^2 + 1$
- CRC 16 Backward : $x^{16} + x^{14} + x + 1$
- CRC CITT Forward : $x^{16} + x^{12} + x^5 + 1$
- CRC CITT Backward : $x^{16} + x^{11} + x^4 + 1$



Flow control

Objective

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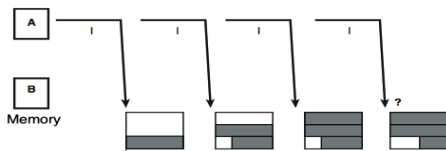
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MAC sublayer

- A : sender, B : receiver,
- If A produces faster than B consumes \Rightarrow B will be congested (saturated or overloaded)
- Flow control : send rhythm control
- Solution : Provide B with memory



\forall memory size, it may be full



Flow control

Sent and Wait

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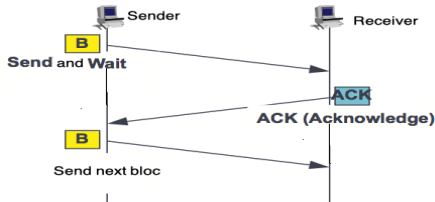
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MAC sublayer

- A sends an information block and stops waiting for an acknowledgment.
- Upon receipt of the acknowledgment (ACK for Acknowledge), A sends the next block.





Flow control

Sent and Wait

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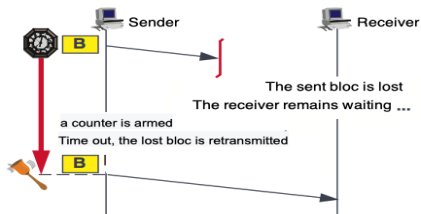
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MAC sublayer

- In the event of an error, the received block is rejected by B (lost) and is not acknowledged.
- A then remains pending !?
- Solution : Armed a timer.
- At Time Out, if no ACK, A retransmits.





Flow control

Sent and Wait

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MAC sublayer

- What if ACK is lost !!!?
- A retransmits, B receives twice.
- Solution : A uses an N_s counter (Number sent) and B an N_r counter (Number to receive)
- N_s , N_r initialized to 0,



Flow control

Sent and Wait

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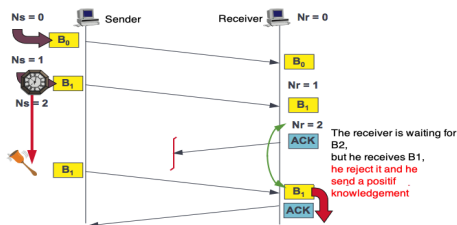
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MAC sublayer

- A transmits N_s with the block,
- B compares with N_r .
- If $=$, valid block. If \neq ,
- Block rejected and acknowledged if it matches a block already received.





Flow control

Sent and Wait

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If the consumption times are longer :

- A transmits B0,
- B treats B0 heavily then acknowledges,
- A retransmits B0 then receives the acknowledgement, and transmits B1,
- B receives the 2nd B0 and acknowledges
- B1 lost
- A receives the acknowledgment of B0, it considers it of B1 and transmits B2
- B1 is not resent



Flow control

Sent and Wait

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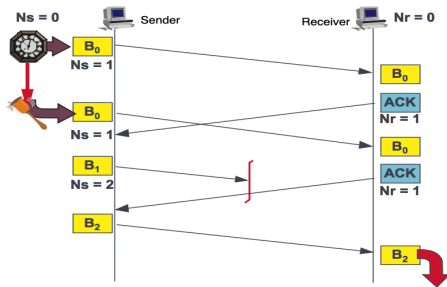
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- Solution : number the acknowledgments,

The waiting time for acknowledgments makes the send and wait method inefficient.



Flow control

Anticipation window

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- Reduces waiting time for acknowledgments
- Anticipation : emit multiple blocks without waiting for ACKs
- Window of size W : ACK acknowledges W frames
- $r \leq Ns \leq r + W - 1$, r :the number of the next expected frame
- $W = 1$ in the case of a Send-and-Wait procedure.



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Anticipation window

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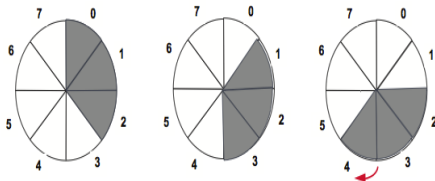
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MAC sublayer

To be able to retransmit erroneous frames :

- Transmitter : save unacknowledged frames in buffers
- Acknowledged frame : free the corresponding buffer
- Window "*sliding*"
- Example : frames numbered from 0 to 7, $W = 3$





Flow control

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- If receiver wants to suspend the exchange for a period,
- It sends a particular frame (Receiver not ready)
- Transmitter suspends until received (Receiver Ready)



Data management procedures

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MAC sublayer

- Link Layer Protocols,
- Implement previous techniques (frame delimitation, error correction and flow control)



Data management procedures

HDLC Procedure (overview)

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MAC sublayer

- HDLC (High-level Data Link Control) developed by IBM and standardized by the ITU in 1976
- point-to-point and multipoint in full duplex,
- frames separated by flags of value 01111110 (7E)
- Three modes :
 - ① Normal Response Mode (NRM) : secondary waits for an order from the primary to transmit.
 - ② The secondary Asynchronous Response Mode (ARM) : sends without being prompted by the primary. Known as LAP (Link Access Protocol).
 - ③ The Asynchronous Balanced Mode (ABM) response mode : point-to-point link ; LAP-B (Link Access Protocol-Balanced). Currently the only mode used.



Data management procedures

HDLC Procedure (Frame Types)

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MAC sublayer

- 1 Information frames or **I** frames : ensure data transfer ;
- 2 Supervision frames or **S** (Supervisor) frames : ensure the transmission of supervision commands (acknowledgment of receipt, etc.),
- 3 Unnumbered frames or **U** (Unnumbered) frames : supervise the link (connection, disconnection).



Data management procedures

HDLC Procedure (Frame Structure)

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8 bit	8 bit	8 bit	n bit	16 bit	8 bit
flag	address	control	information	FCS	flag



Data management procedures

HDLC Procedure (Frame Structure)

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MAC sublayer

- Pennant (flag) : 01111110
 - delimits frames.
 - frame synchronization : constantly search for the flag ;
 - a flag : closing and opening ;
 - transparency inserts a 0 after every five consecutive 1's other than the flags appear.



Data management procedures

HDLC Procedure (Frame Structure)

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MAC sublayer

- Address field : command or response frame. For ABM, preset values : 11000000, 10000000, 11110000 1110000).
- Control field : frame type + parameters.
- FCS (Frame Check Sequence) : CRC16 V.41 ($x^{16} + x^{12} + x^5 + 1$).



Data management procedures

HDLC Procedure (Frame Structure)

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MAC sublayer

	1	2	3	4	5	6	7	8
Information	0	Ns			P/F	Nr		
Supervision	1	0	S	S	P/F	Nr		
Unnumbered	1	1	M	M	P/F	M	M	M

- Ns : transmitted frame number,
- Nr : next frame number expected (acknowledgment in the data),
- P/F (Poll/Final) := 1 \Rightarrow immediate response solicits.



Data management procedures

HDLC Procedure (Frame Structure)

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S-frame :

S	S	Command	Meaning
0	0	RR (Receiver Ready)	Station is ready to receive frame Nr number and accuse positively reception frames up to (Nr - 1)
0	1	RNR (Receiver not Ready)	Station is not ready to receive frames but and positively acknowledges t reception of frames until (Nr - 1)



Data management procedures

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S-frame :

S	S	Command	Meaning
1	0	REJ (Reject)	Station rejects frames from number Nr. The issuer is obliged retransmit ($P/F = 1$)
1	1	SREJ (Reject)	=REJ but only for frame number Nr.



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HDLC Procedure (Frame Structure)

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U frame :

Frame	Command	Meaning
11111100	SABM	Set ABM request establishment in ABM mode
11110000	DM	Disconnect Mode indicates that the station is located at offline
11001010	DISC	Disconnect release link
11000110	UA	Unnumbered Acknowledge indicates the reception and acceptance of a unnumbered order



Data management procedures

HDLC procedure (example of exchanges)

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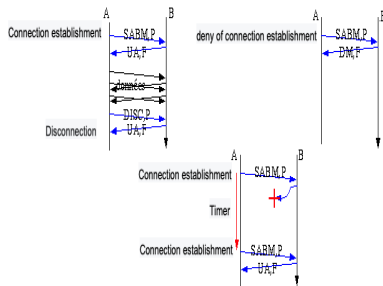
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Data management procedures

HDLC procedure (example of exchanges)

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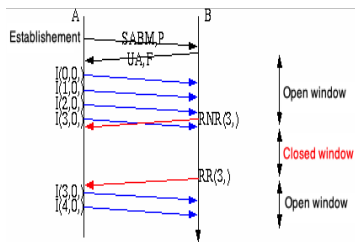
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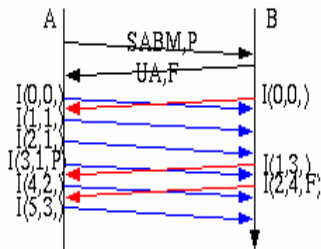
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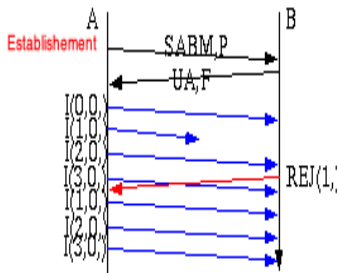
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MAC sublayer Addressing

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MAC sublayer

- Physical address (hard level) (MAC address)
- Format defined by IEEE : 48 bits
- Universal device addressing 24-bit
- : constructor, 24-bit serial number



Adresse MAC (6 octets)



MAC sublayer

Support Access Techniques

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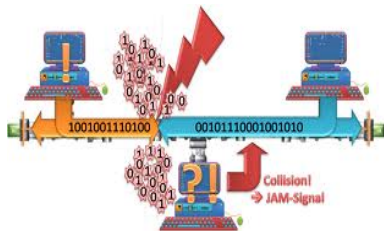
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MAC sublayer

- LAN : machines share the same bandwidth
- Arbitration needed : access method
- CSMA/CD, Token ring





MAC sublayer

Media Access Techniques (CSMA/CD)

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MAC sublayer

- Carrier Sense Multiple Access with Collision Detection (often referred to as Ethernet)
- Random method,
- Broadcast Network
- Listen before sending,
- If busy : wait for release
- If free : send and continue listening (duration min)
- If no problem : continue sending the frame
- If problem (collision) : wait random time then return
- [Video](#)



MAC sublayer

Media Access Techniques (CSMA/CD)

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