VDL Mode 2

VHF Datalink mode 2

Presented by

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ALTRAN on behalf of ENAC

ENAC

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Objectives

- List the principles of VDL Mode 2

Contents

- Introduction
- System Architecture
- Physical layer
- Link layer
- Sub-network layer

Introduction

- One of the air-ground sub network
- VDL mode 2 : selected for the first implementation of data link in Europe following the European LINK 2000 + Project

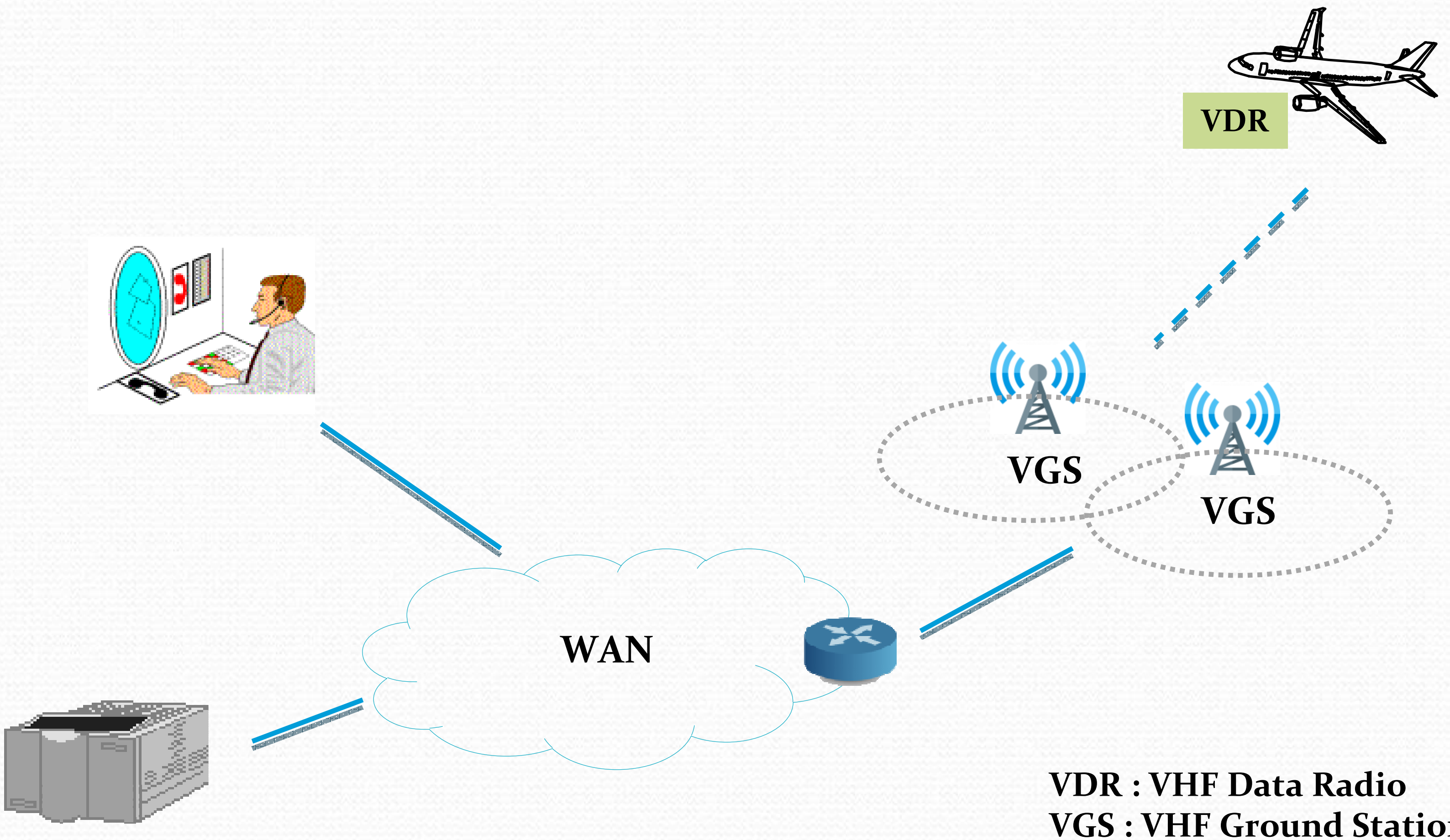
Introduction

- VDL: Four modes have been specified
  - Mode 1
    - uses ACARS analog radios
  - Mode 2
    - improved radios and data encoding (D8PSK), CSMA, 31.5 Kbit/s
    - Operational deployment by ARINC & SITA
  - Mode 3
    - integrates voice and data, TDMA
    - No deployment
  - Mode 4
    - based on STDMA, air-air communications
    - May be used for surveillance (ADS-B)

Some dates

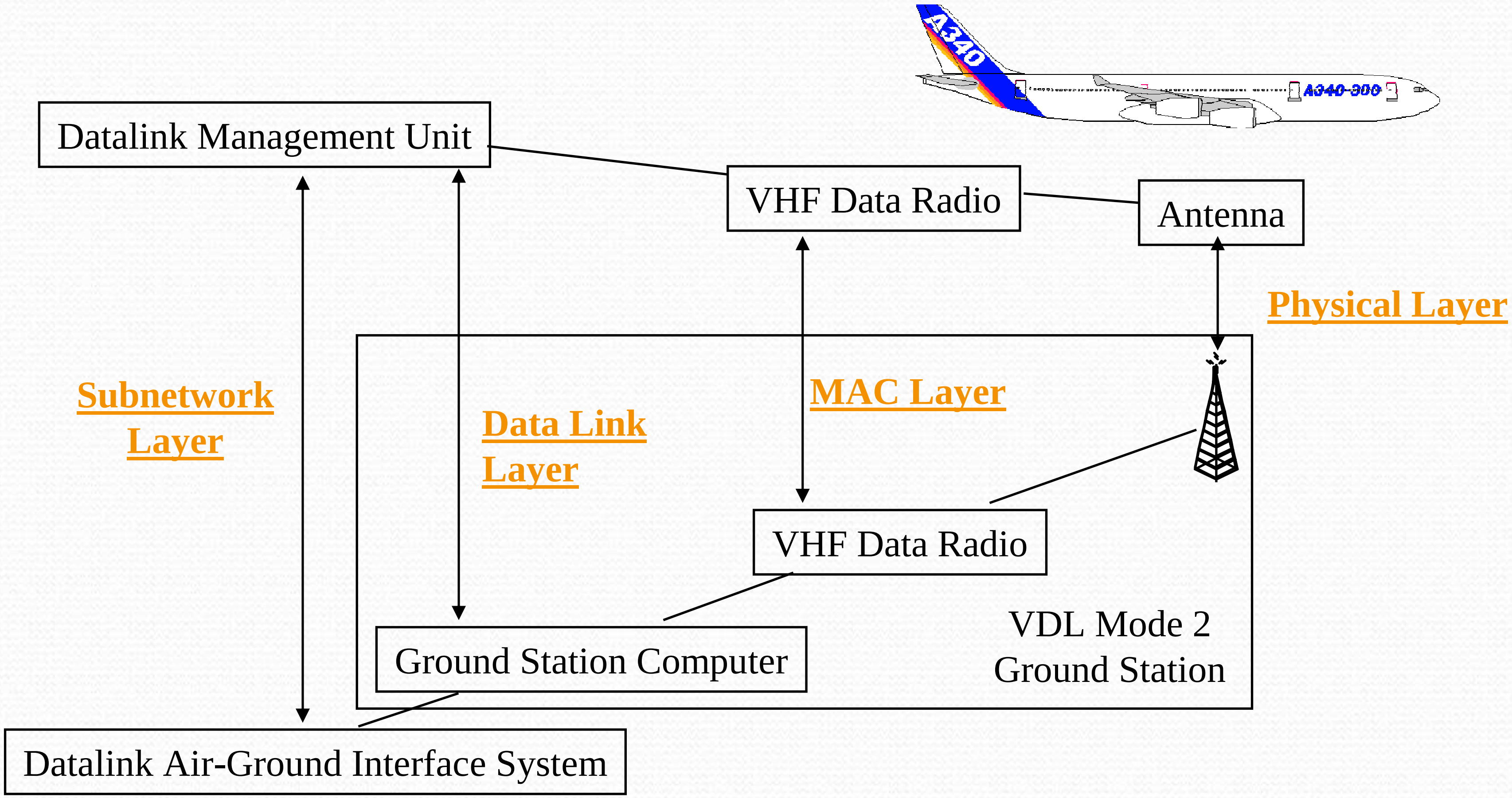
- 1988 : starting of the first work on the ATN by ICAO
- 1990 : decision to use VHF to support air-ground segment
- 1991 : starting of work on VDL standard
- 1996 : the VDLm2 SARPs are approved
- 1997 : the SARPs are applicable
- 2009 : European regulation to provide VDLM2

System Architecture - Overview

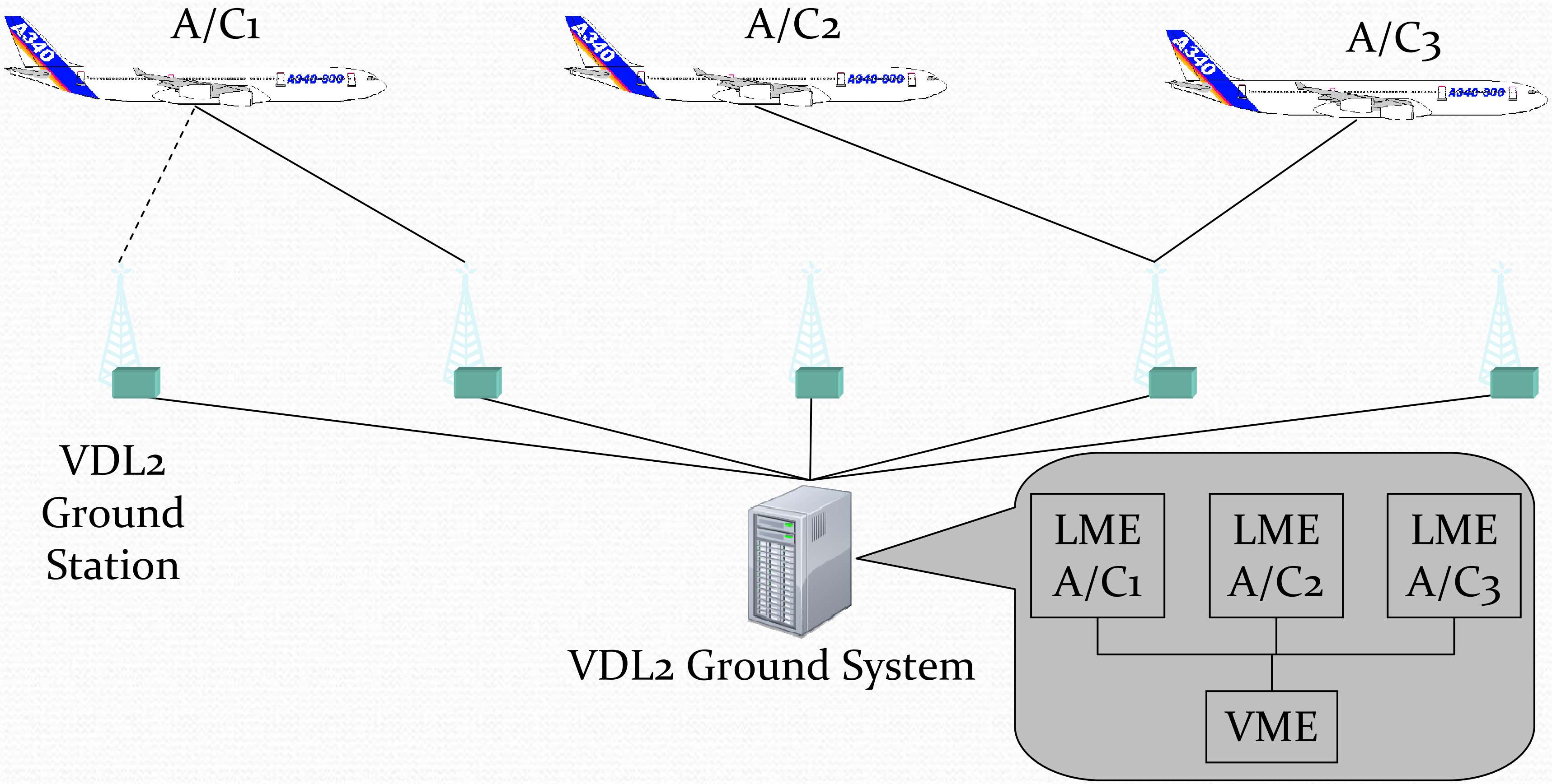


VDR : VHF Data Radio
VGS : VHF Ground Station

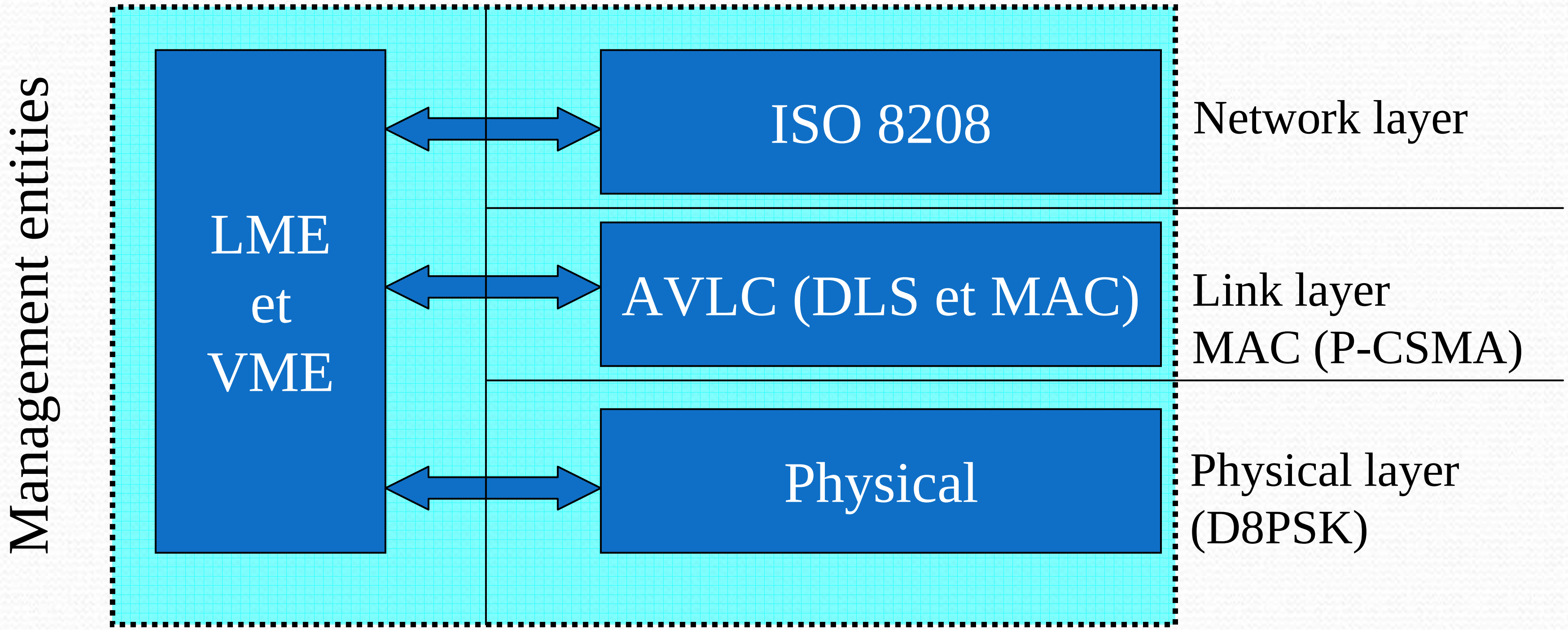
System Architecture - Data plane



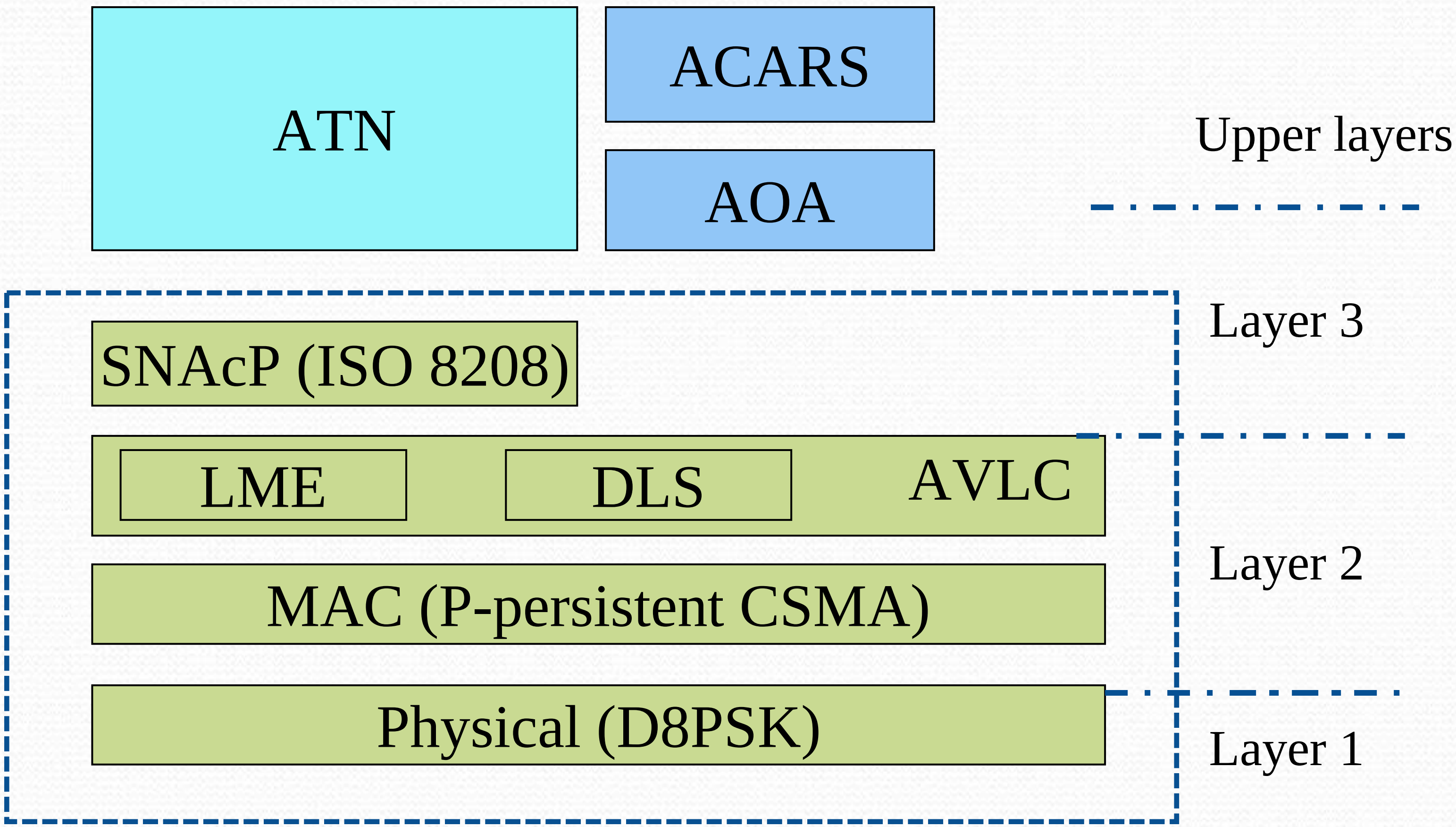
System Architecture – Control plane



System Architecture



VDL mode 2 protocol stack



Physical Layer

Modulation

FEC

Interleaving & Scrambling

Physical layer

- Voice channels: 25 kHz
- VHF band (118 - 137 MHz)
- CSC (Common Signaling Channel) for initial link establishment : 136.975 MHz worldwide
- Multi-frequency
- Supplied functions
  - Transmission channel activation
  - Bit synchronization
  - Data transmission/reception
  - Channel signalization status (SQP : Signal Quality Parameter)

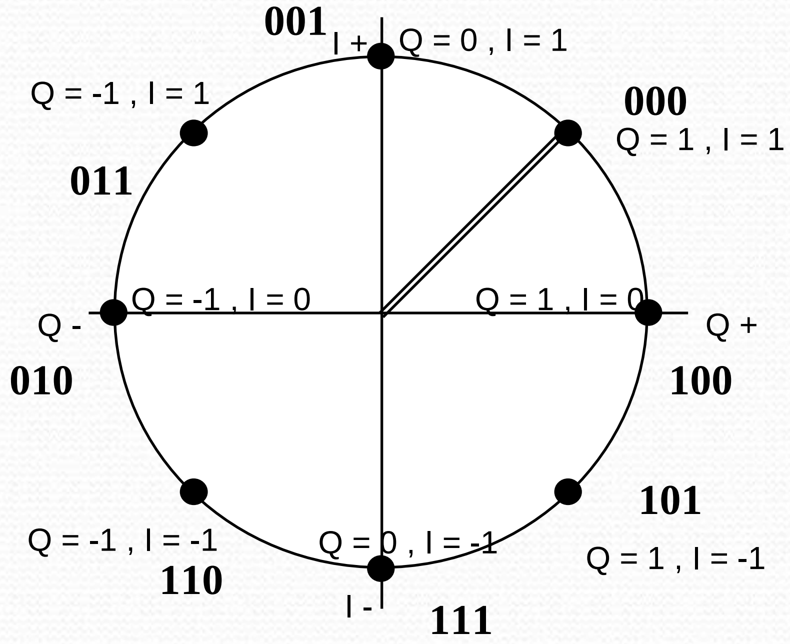
Modulation

- D8PSK : Differential 8 Phase Shift Keying
- Modulation speed : 10500 symbols per second
- Throughput : 10500 * 3 = 31,5 Kbit/s
- Three bits symbols
- Use of Gray code
  - Reduces noise sensitivity

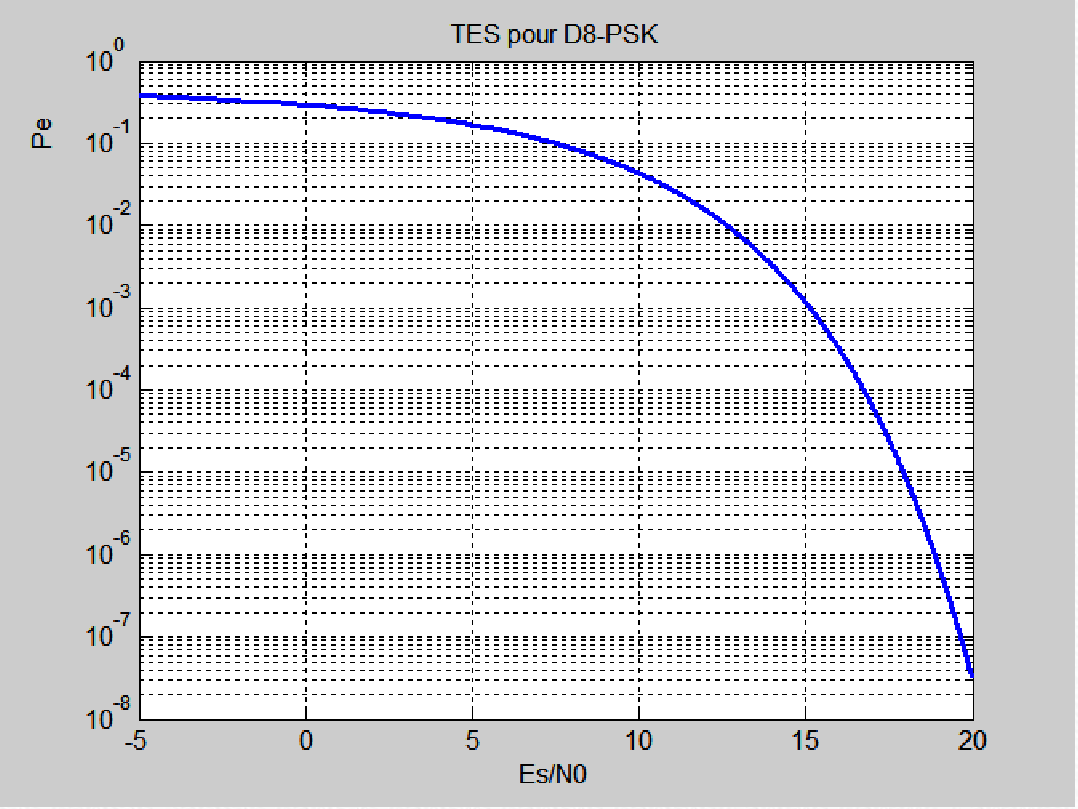
Tribit	Δφ
000	0*π/4
001	1*π/4
011	2*π/4
010	3*π/4
110	4*π/4
111	5*π/4
101	6*π/4
100	7*π/4

Modulation

- D8PSK
  - Differential
  - On phase change
- Coding = Δφ
  - NOT coding on φ
- Using a Nyquist filter



Symbol Error Rate



Physical frame

transmitter ramp-up	synchronisation word	reserved	length	header FEC (error code)	Data
15 bits	48 bits	3 bits	17 bits	5 bits	

Total burst header
88 bits

Maximum frame length: $2^{17} - 1 = 131\ 071$ bits

Header FEC

- Controls the HEADER
  - limited to
    - The “Reserved” segment
    - The length field
- Matrix based
  - $[P1,\ldots P5]=[R1,..R3,L1,\ldots L17]*H^T$

FEC (Forward Error Correction)

- Use of forward error correction for the data
  - Reed Solomon type
    - If X symbols are added
    - Able to correct up to X/2 symbols errors
  - For the VDL 2 : RS (255,249)
    - 255 bytes per blocks
    - 249 bytes of data
  - 6 bytes of RS code
    - Corrects up to 3 erroneous bytes
    - Detect up to 6 erroneous bytes

Additional information

- The maximum size of a bloc using Reed Solomon coding is given by the expression 2^m -1, where m is the number of elements of the symbol.
  - In the case of VDL2, the symbol is the byte which contains 8 elements. The maximum size of a Reed Solomon block is then 255 bytes (FEC code included).
- In the case : size of the date < 249 bytes
  - the last bloc is padded with 0 for the RS code computation. However, these padding bytes are not transmitted
  - If there are less than 67 bytes (but at least 31 bytes) in the last bloc, the RS code contains 4 bytes (up to 2 bytes can be corrected)
  - If there are less than 31 bytes in the last bloc, the RS code contains only 2 bytes (one byte may be corrected).

After Reed Solomon

249 bytes data blocks

+ 6 bytes of RS code

D1	**D2**	**D3**		**D249**	**RS1**	**RS2**	**RS3**	**RS4**	**RS5**	**RS6**
D250	**D251**	**D252**		**D498**	**RS7**	**RS8**	**RS9**	**RS10**	**RS11**	**RS12**
D499	**D500**			**D747**	**RS13**	**RS14**	**RS15**	**RS16**	**RS17**	**RS18**

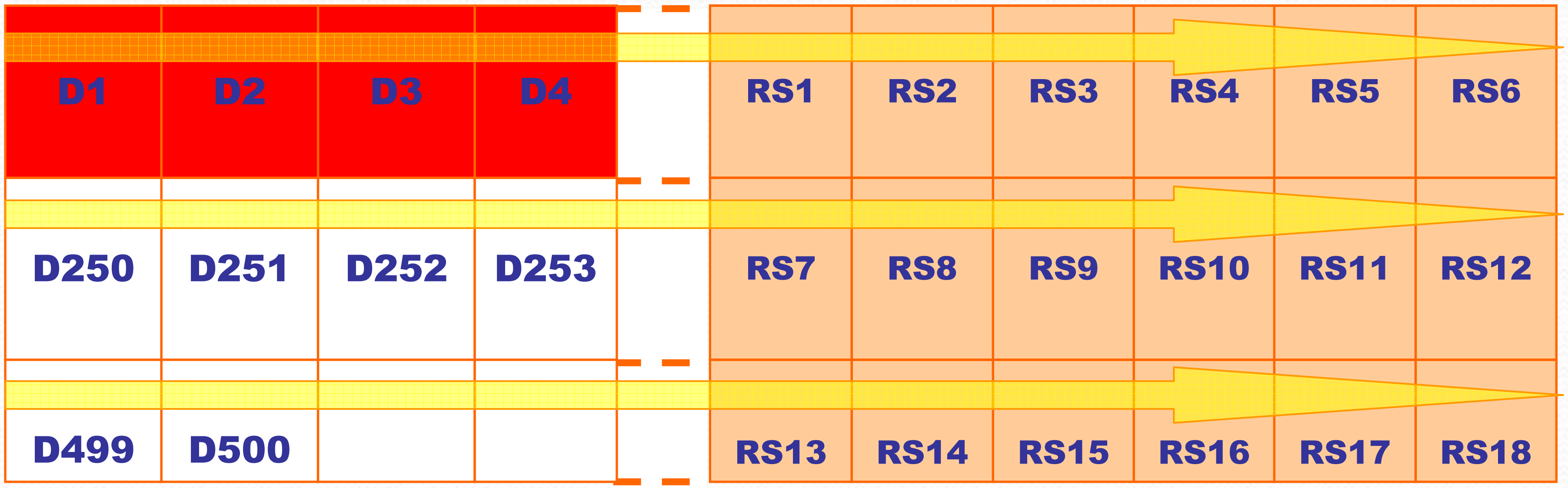
Interleaving

- The errors
  - Per packet
  - Grouped Corruptions
- Principle
  - Organize data in 2 dimensions :
    - Each Reed Solomon block is a row
    - Send data column by column

  → Spreads errors among the blocks

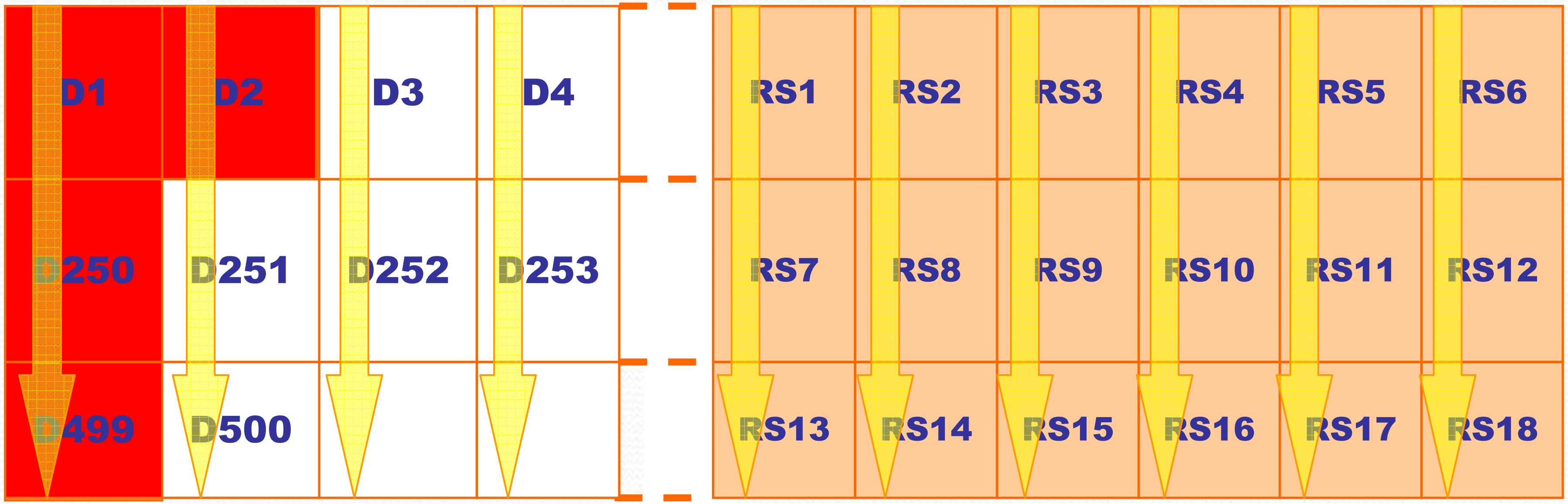
Without interleaving

Row-by-row sending method: If 4 bytes are corrupted, they most probably will belong to the same RS block, and the RS will not be able to correct the data. → The block is lost !



With interleaving

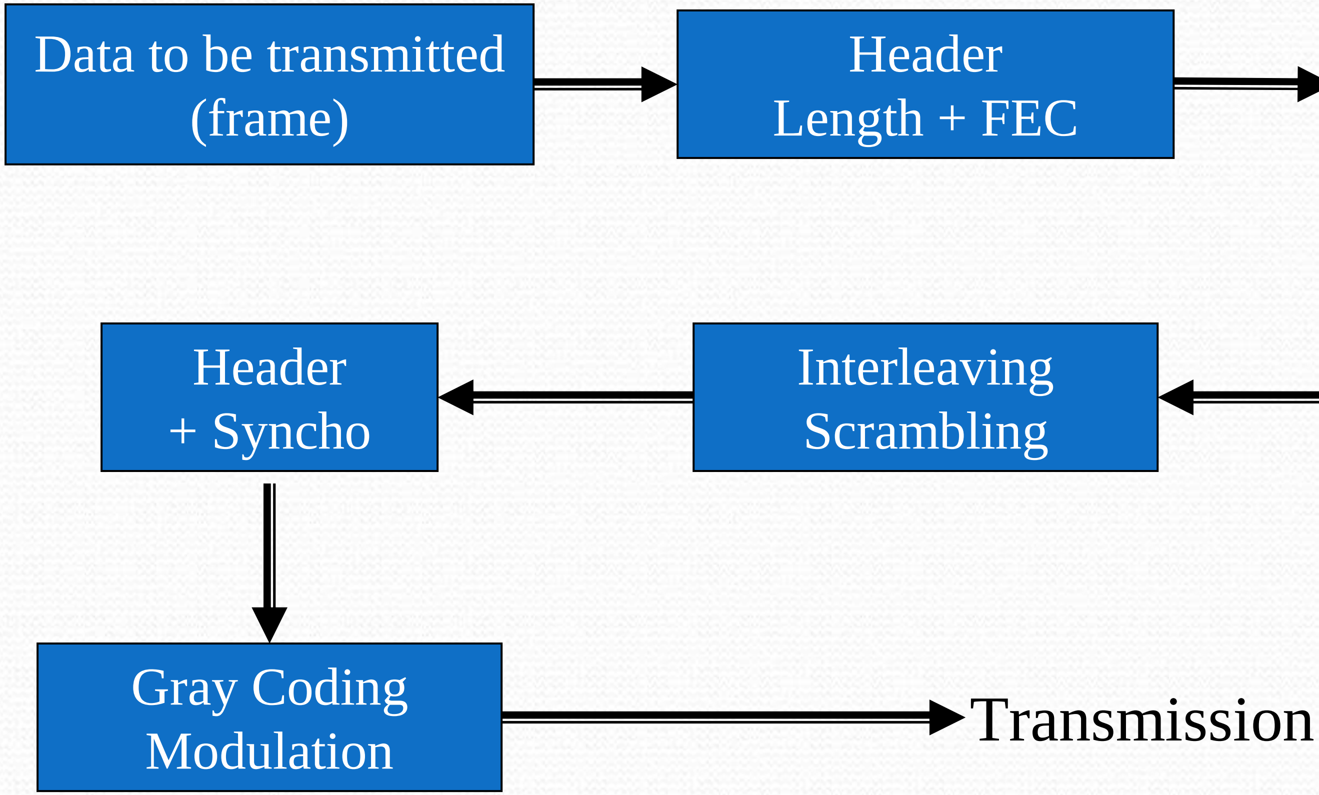
Column-by-column sending method: the same corruption will be spread over several RS blocks. It is more likely that the power of the RS correction will not be exceeded in this case.



Bit Scrambling

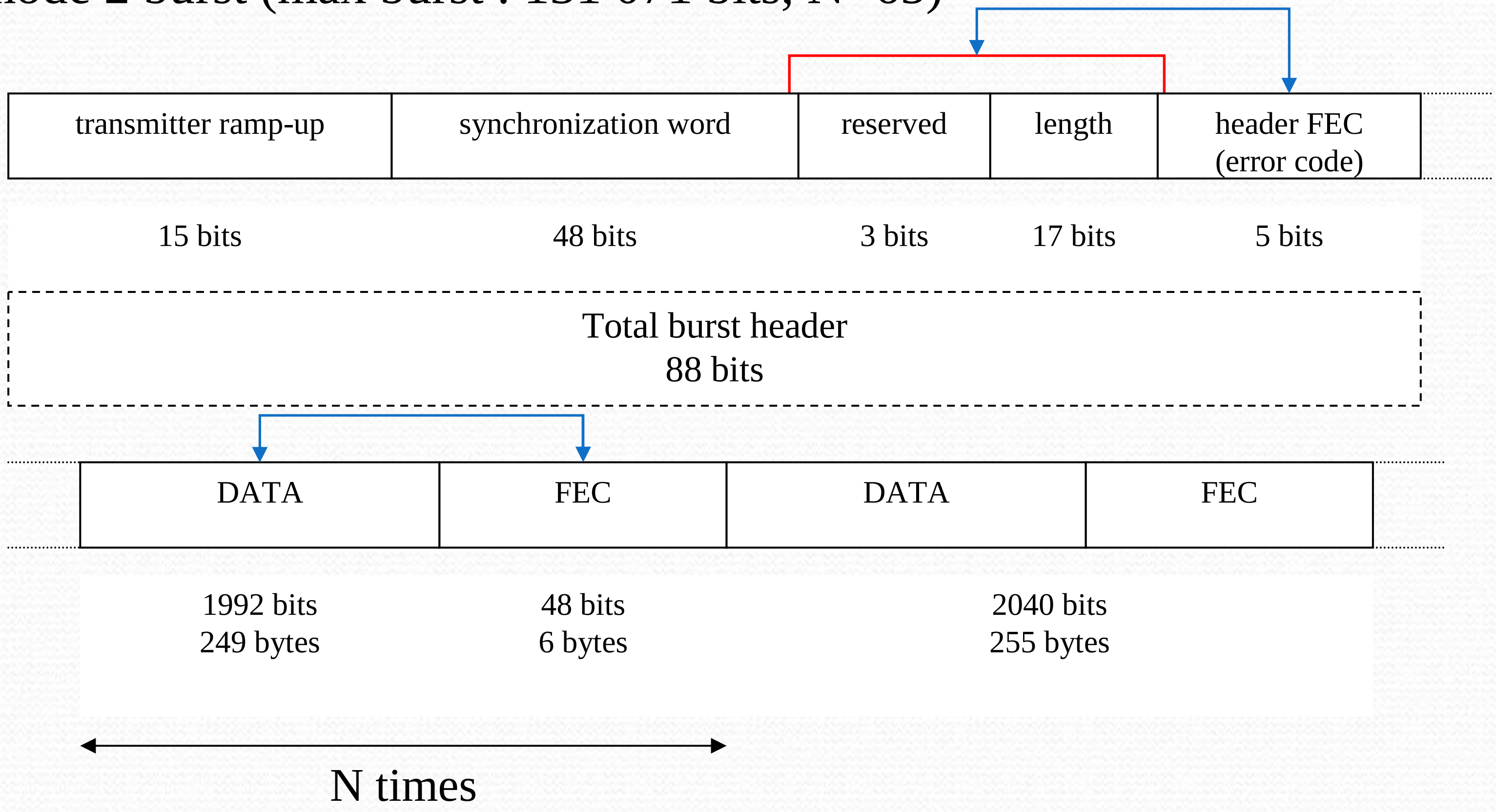
- Bit synchronization
  - It is the aim of the preamble
- Keeping the bit synchronization
  - Problem of having series of identical symbols
  - Risk of clock drift
  - Break series with a polynomial code
    - For the VDL 2 : $X^{15} + X + 1$

Processing description



Physical frame

VDL mode 2 burst (max burst : 131 071 bits, N=65)



Some remarks (Physical Layer)

- Integrity requirement at output : P= 10^{-4}
- Thoughput (Practice VS Theory)
  - Hidden transmitters issue
  - Signal reflection/propagation issues
  - Protocol overhead
  - ...

  → The actual throughput will be < 31,5 Kbits/s
    - Simulation results give 5% to 40% of usable throughput (1575 to 12600 bits/s)
    - Real measures will tell the truth…

Link Layer

MAC (Medium Access Control)
DLS (Data Link Service)
Link Management

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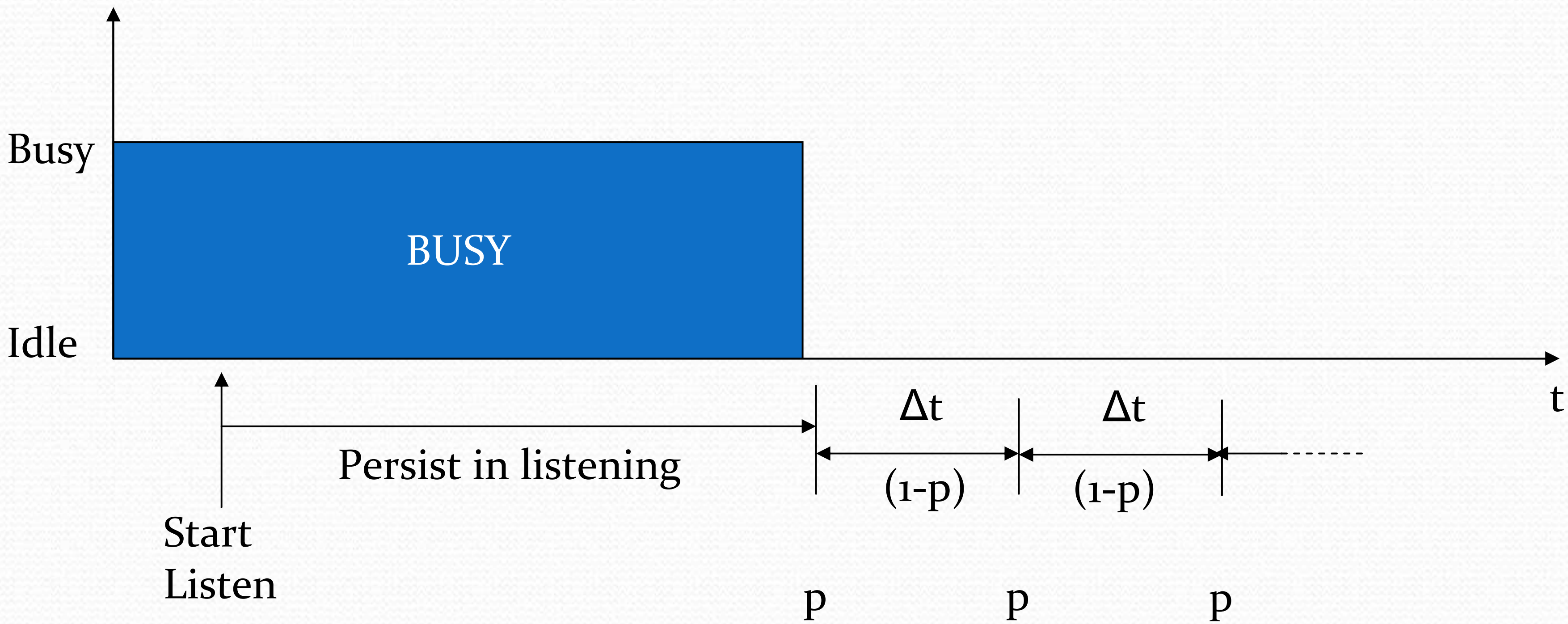
Link layer

- The MAC (Medium Access Control) entity
  - Shared channel access
- The DLS (Data Link Service) entity
  - Provides a connected service
    - Between two DLE (Data Link Entity)
  - Also provides connectionless service
    - Currently not used
- The VME(VDL Management Entity)/LME (Link Management Entity)

MAC

- P-CSMA (P-persistent Carrier Sense Multiple Access)



MAC

- P-CSMA with following tuning:
  - TM1 : minimum delay between access attempts
    - min : 0,5 ms – max : 125 ms – default : 4,5 ms
  - TM2 : maximum delay for a transmission
    - min : 6 s – max : 120 s – default : 60 s
  - M1 : maximum number of attempts
    - min : 1 – max : 65535 – default : 135
  - p : probability of sending
    - min : 1/256 – max : 1 – default : 13/256

DLS (Data Link Service)

- Bit interface
  - can convey any data
- **AVLC** (Aviation VHF Link Control) protocol derived from ISO **HDLC** (High-Level Data Link Control)
  - Frame numbering
  - Frame error detection
  - Addressing

AVLC

- Frame Format :
  - Frame delimiter flag : 7E (Hexadecimal Code)
  - Address
  - Control
  - Data
  - Frame Check Sequence (FCS)
- Format of an AVLC frame

7Eh	Address block	Control	Data	FCS	7Eh
	8 bytes	1 byte		2 bytes	

Bit Stuffing

- Series of 1s will be interpreted as a flag
- Use of « bit stuffing »
  - Inserting a “0” after 5 consecutive “1” bits
  - Except for the Flag
- Example : 1F – 22 : 0001/1111- 0010/0010
  - LSB : 1111/1000 – 0100/0100
  - Stuffing : 1111/1**0**00 – 0010/0010 – 0….
  - Lecture : 00**0**1/1111 – 0100/0100 – 0 : 1F – 44

FCS (Frame Check Sequence)

- Based on CRC (Cyclic Redundancy Check)
- 2 bytes (16 bits)
  - Probability of non detection $< 2^{-16} = 1{,}53.10^{-5}$
  - CCITT polynomial: $X^{16} + X^{12} + X^{5} + 1$
- Overall probability of non detection
  - BER : 10^{-4} maximum (output of physical layer)
  - Probability of error $< 10^{-4} * 1{,}53.10^{-5} = 1{,}53.10^{-9}$

7Eh	Address block	Control	Data	FCS	7Eh
	8 bytes	1 byte		2 bytes	

System Architecture

Undetected error rate?

AVLC

FCS

Bit error rate < 10^{-4}

Physical

Reed-Solomon

BER (Bit error rate) < 10^{-3}

Integrity requirement for VDLm2

- At the output of the MAC sub layer
  - Average packet length of 128 bytes
- RER (Residual Error Rate):
  - $< 10^{-6}$ uplink (to the A/C)
  - $< 10^{-5}$ downlink (from the A/C)
- Application :

$$RER < (128 \times 8) \times 10^{-4} \times 2^{-16} = 1{,}56 \cdot 10^{-6}$$

- Integrity checking also at transport layer

Address Format

- 4 bytes long – LSB first
- LSB of each byte shall be 0, except for the last one (HDLC compatible format)
- The first usable bits are used for:
  - Air/Ground bit in the destination address part
    - 0 only for aircraft (If VDL subsystem is able to detect take off)
    - 1 for aircraft and ground station
  - C/R (Command/Response) bit in the source address part
    - 0 for a command ; 1 for a response

7Eh	Address block	Control	Data	FCS	7Eh
	8 bytes	1 byte		2 bytes	

Address Format

- Aircraft : use the ICAO 24 bits address
  - 3 remaining bits code the type of address (always 001)
- Ground station :
  - ICAO administered address
  - ICAO delegated address
- Types of address (bits 27/26/25)
  - Aircraft : 0/0/1
  - Ground station
    - ICAO : 1/0/0
    - Other : 1/0/1
  - Broadcast : 1/1/1

Broadcast et multicast

- Global Broadcast :
  - Type: 111
  - All the address bits to “1”
- Broadcast for one type of addresses
  - Type as requested
  - All the address bits to “1”
  - Broadcasting all Planes : ____________

Ground Station & Ground System

- Ground System
  - Bound to physical limits of the ground net
- Ground Station
  - Has an address
  - Has a Ground System mask
- Address $\&_{\text{bitwise}}$ mask => Ground System Number
- Stations have the same Ground System Number means
  - Stations belong to the same Ground System

AVLC Control Field

- The control field :
  - XID (Exchange Identity)
  - INFO
  - RR (Receive Ready)
  - SREJ (Selective reject)
  - FRMR (Frame reject)
  - UI/UA (Unnumbered Info/Acknowledgment)
  - DISC/DM (Disconnect Mode)

7Eh	Address block	Control	Data	FCS	7Eh
	8 bytes	1 byte		2 bytes	

AVLC T1 Parameter

- Retransmission timer: T1
  - Delay while waiting for the ACK (acknowledgement)
  - Adaptive
  - $T1 = T1_{min} + 2TD_{99} + \min(U(x), T1_{max})$
    - TD_{99} : transmit delay for 99 % of the transmissions
    - Random part: U(x)
- $T1_{min}$ = 1s (default)
- $T1_{max}$ = 15s (default)
    - At least about 3s
    - Depends on Idle/Busy ratio
    - Depends on number of retransmissions

AVLC T2 Parameter

- T2 : maximum delay before sending the ACK
  - Used to group acknowledgements
  - Aims at reducing channel occupancy

  →Do not acknowledge immediately

- By default: T2 = 500 ms

AVLC T3 Parameter

- T3 : link establishment delay
  - Similar to T1 (but longer)
  - Between a link establishment request and its response
  - By default $T3_{min}$ is 6s

Other AVLC parameters

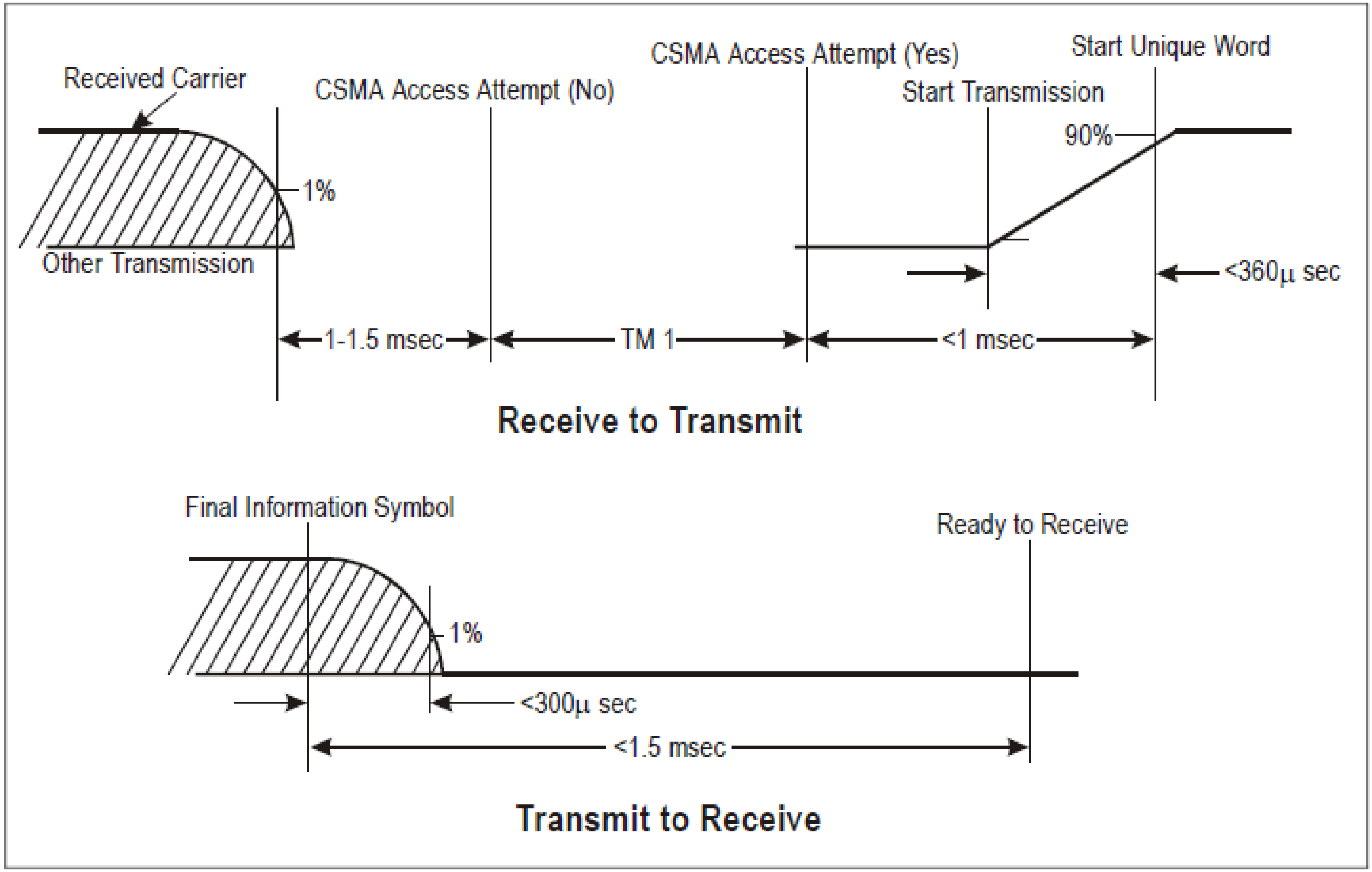
- k : window size, by default : 4
- N1 : max number of bits in a frame
  - Without flags and bit stuffing
  - default : 8312 bits – max : 16504 bits
- N2 : max number of transmission
  - Incr. if no response to a frame (T1 expired)
  - default : N2 = 6
- T4 : maximum delay between transmissions
  - Send a RR(Receive Ready) command P=1 if T4 expires
  - default : 20 minutes

What about…

- What do you think about N1 compared to the length of the physical burst?

- What is the useful/real throughput ratio at the AVLC service interface?
  - Use next diagram for physical layer,
  - Assume p=1,
  - No bit stuffing at link layer,
  - Continuously send 128 bytes INFO frames
  - No frame grouping

What about…

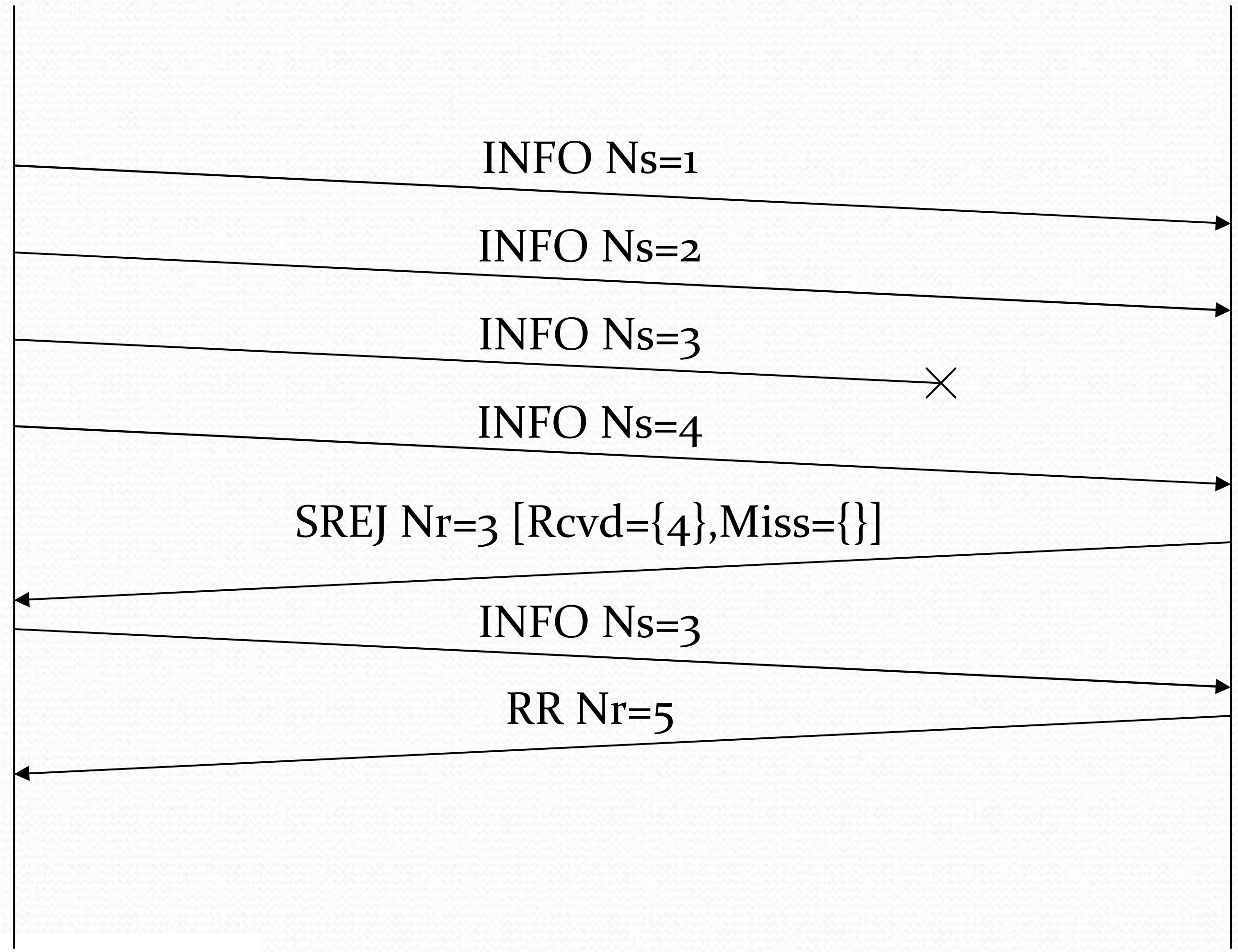


Received Carrier
CSMA Access Attempt (No)
CSMA Access Attempt (Yes)
Start Unique Word
Start Transmission
90%
1%
Other Transmission
<360µ sec
1-1.5 msec
TM 1
<1 msec
Receive to Transmit
Final Information Symbol
Ready to Receive
1%
<300µ sec
<1.5 msec
Transmit to Receive

SREJ (Selective Reject)

- Ask for retransmission of one or several frames
  - I receive frames 1;2;4 : frame 3 is missing
  - SREJ(3) asks for the retransmission of frame 3 and acknowledges frames 1 & 2
    - AVLC specific: I may also ACK frame 4 here
  - I receive frame 3 – I acknowledge up to 4 : RR(5)
- Advantage ?

SREJ (Selective Reject)



XID (Exchange Identification)

- One AVLC control field value
- Several significations, depending on the data contained in the Information field:
  - XID_CMD or XID_RSP
  - XID_CMD_LE
  - XID_CMD_GSIF

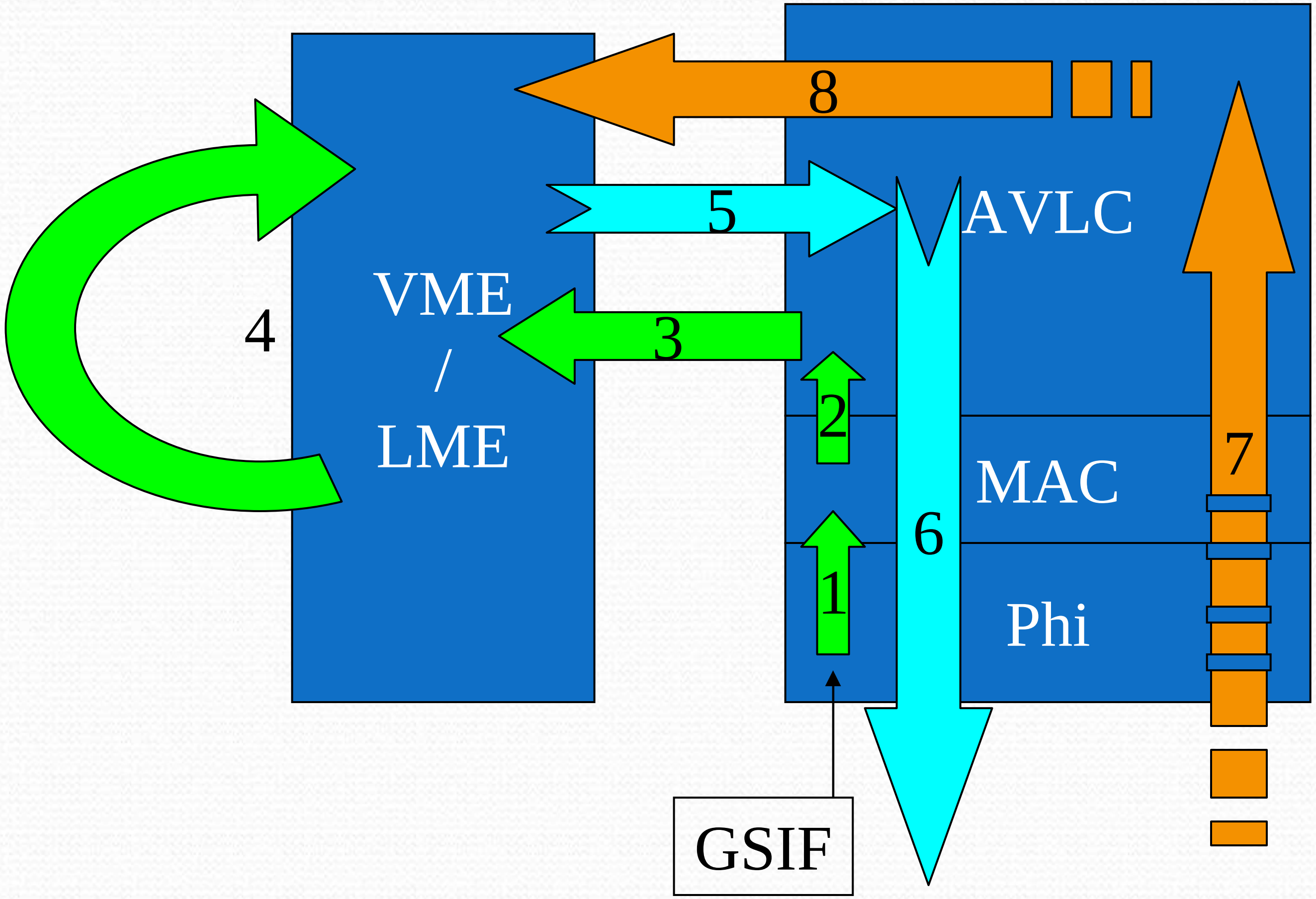
Link establishment

- Ground station transmission
  - The ground stations SHALL regularly send an identification frame on the CSC
    - Common Signaling Channel = 136.975MHz
- GSIF : Ground Station Information Frame
  - XID_CMD frame
  - May contain alternate frequencies
  - Max delay between transmissions (TG3 : 100 to 120s)
  - Max delay between GSIF (TG4 : 100 to 120 s)

Link establishment

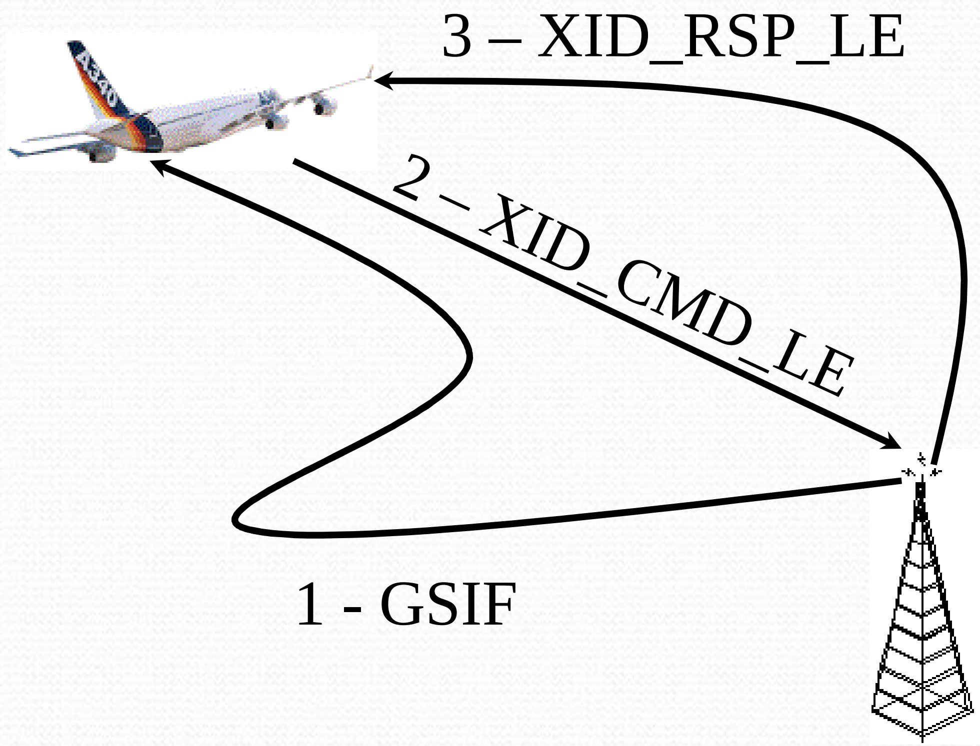
- The GSIF are sent by the ground to the LME
- Choice to establish the connection
  - Based on received GSIF
- If OK
  - XID_CMD_LE : Link Establishment request
    - XID_RSP_LE : ground accepts
    - XID_RSP_LCR : ground refuses (exceptional)

Link establishment



1 - Signal decoding
2 - FCS validation
3 - @$_{DST}$ validation
XID decoding
GSIF – forward to LME
4 – LE decision
5 – LE request
6 – XID_CMD_LE
7 – XID_RSP_LE
8 – Forward to LME

Link establishment summary



Link validity

- TG3 and TG4 already presented before
- TG1 : frequency scanning time
  - Maximum time to stay on a “silent” frequency
- TG2 : maximum idle activity time
  - Maximum time to keep data on an inactive distant Station
  - Detects out-of-coverage with no com
- TG5 : maximum link overlap time (used during a handoff)

Mobility management

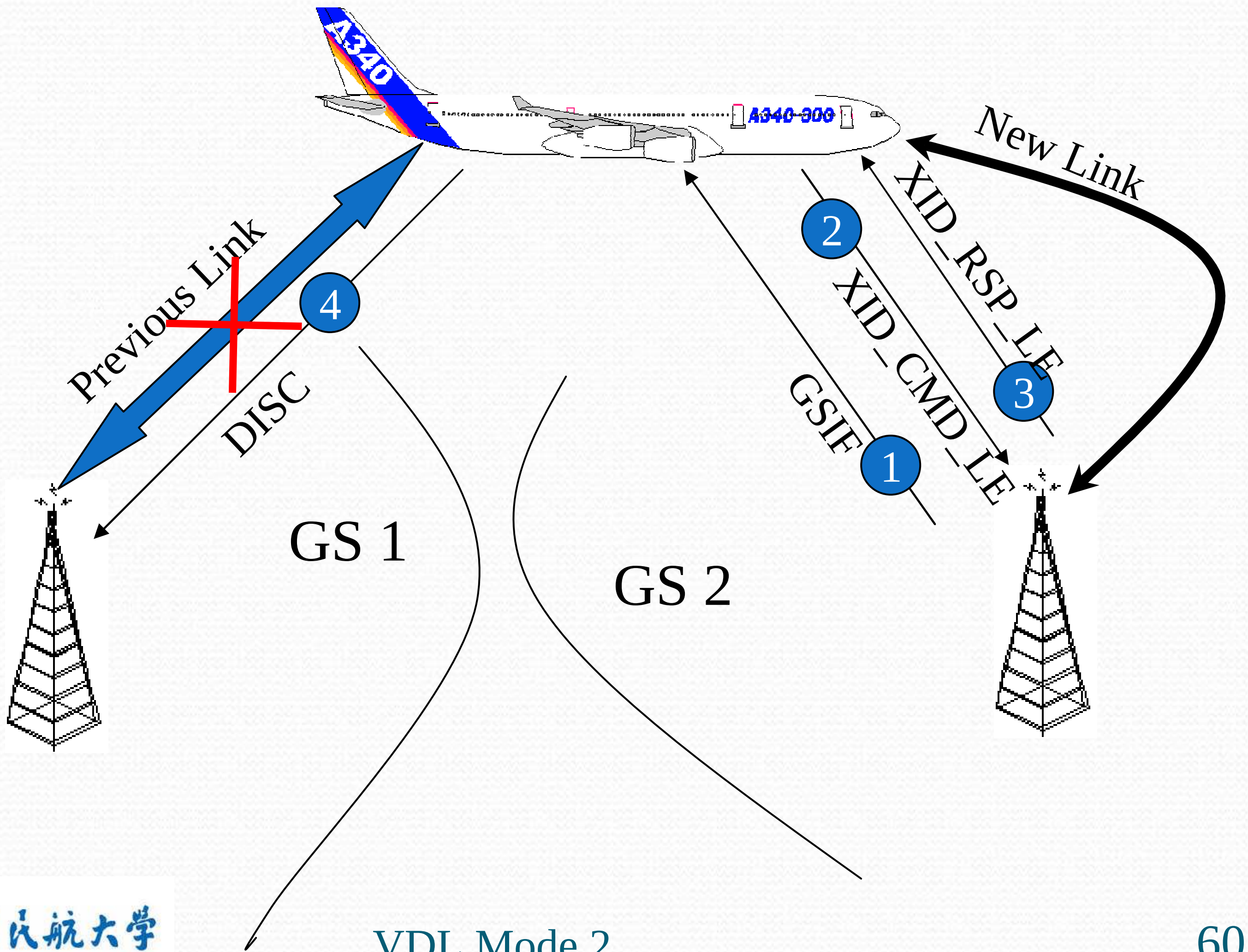
- A Ground System contains several Ground Stations
- LME (Link Management Entity)
  - Manages the link between a Ground System and an Aircraft
  - Shared among the Ground Stations of a Ground System
- Passing the connection from one Ground Station to another is called the Handoff

Handoff between Ground Systems

- Can only be initiated by the Aircraft
- Procedure:
  - New link with the new Ground System
  - Through one of its Ground Stations
  - DISC with the previous Ground System

- Link Establishment = Login into ground system

Air Initiated Handoff



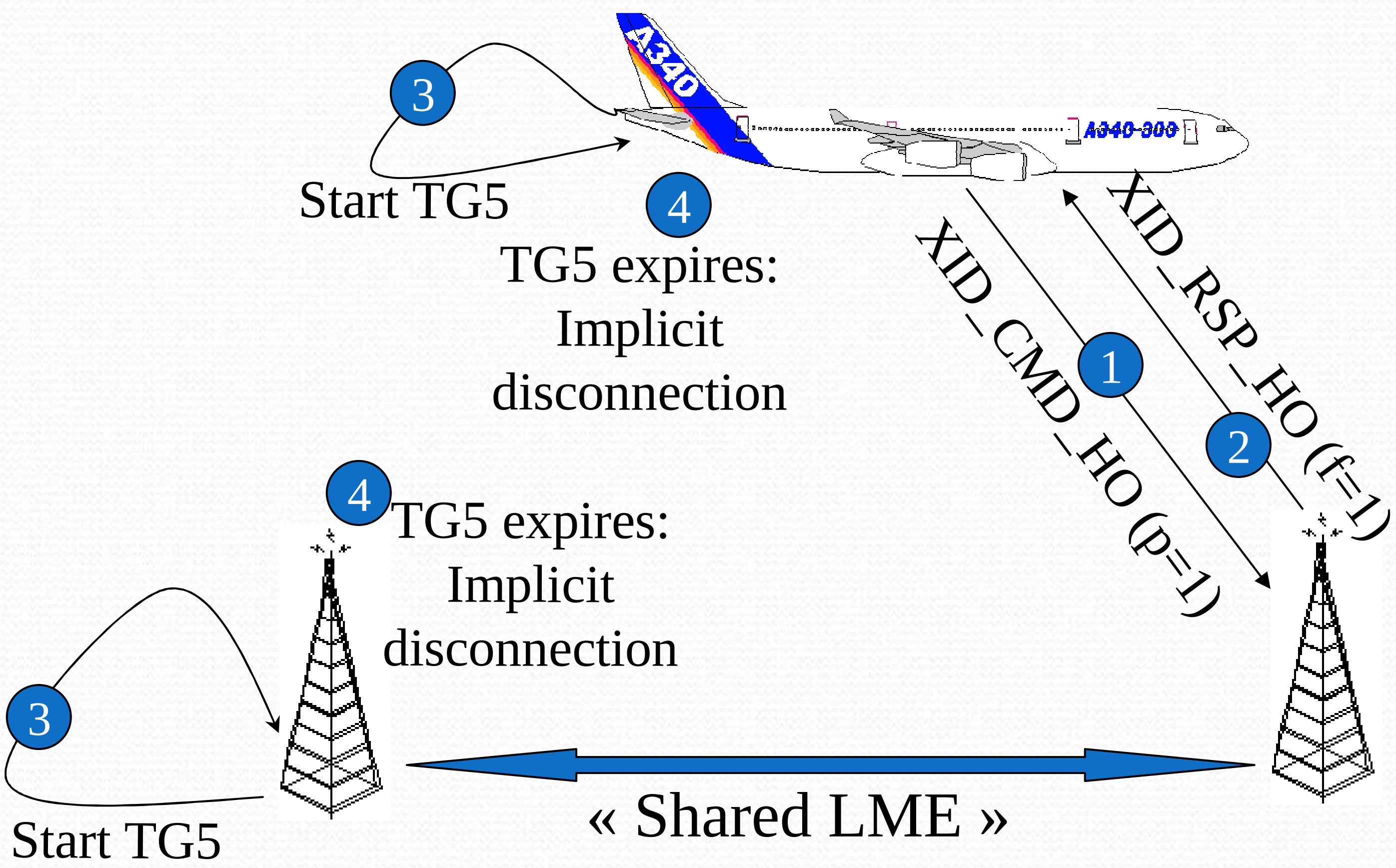
Handoff inside Ground System

- 4 Possibilities :
  - Aircraft initiated Handoff
  - Ground initiated Handoff
  - Aircraft requested Ground initiated Handoff
    - Only if supported by the Ground System
    - The A/C requests the handoff from the Ground System
  - Ground requested Aircraft Initiated Handoff
    - Only if supported by the A/C
    - The Ground System requests the handoff from the A/C
    - Used for Multifrquency management (load balancing)

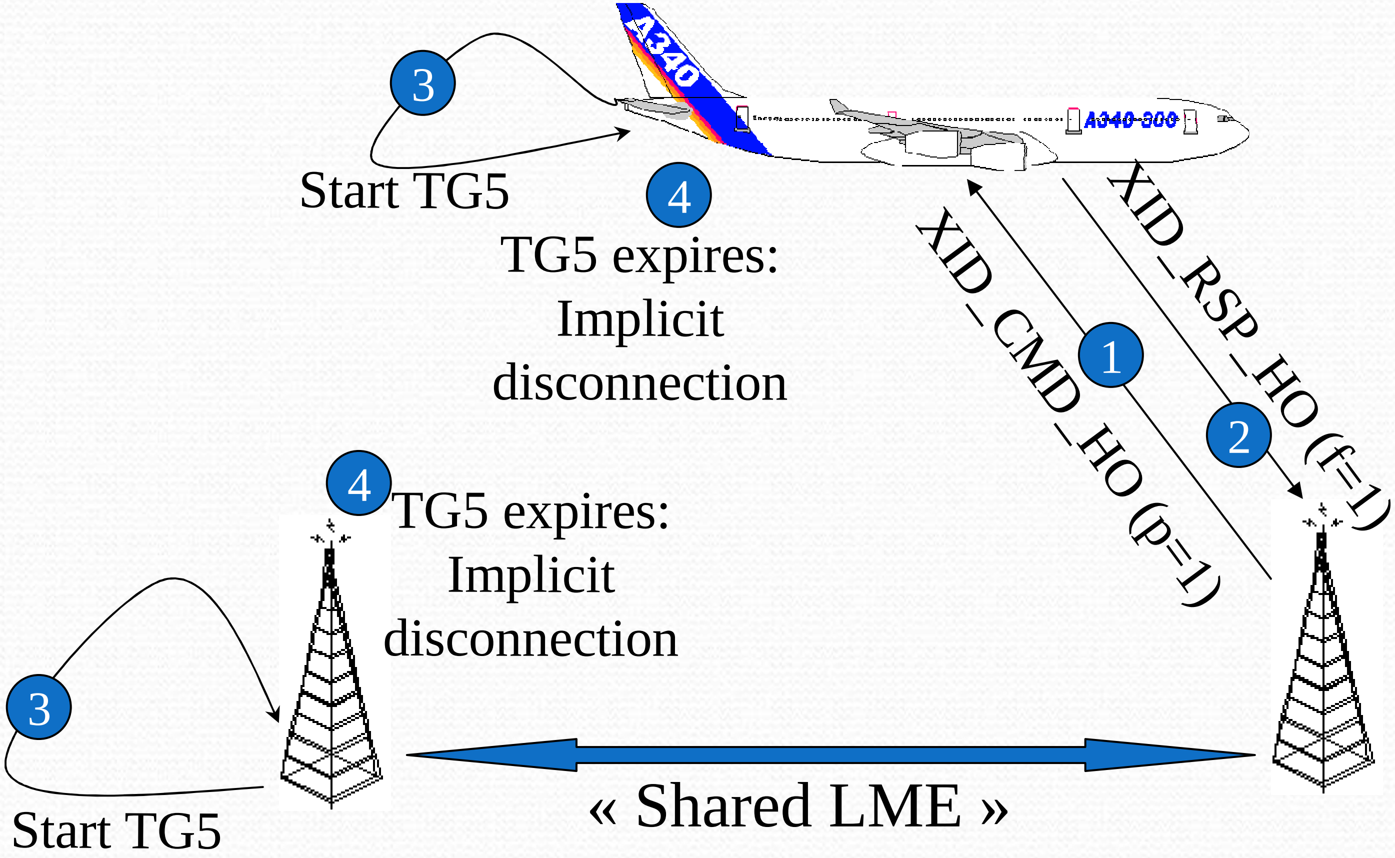
Aircraft initiated Handoff

- Required if
  - SQP (Signal Quality Parameter) of the new station >> SQP current station
  - N2 retransmission (AVLC layer)
  - TG2 expires = inactive station
  - TM2 expires (MAC layer) = congestion

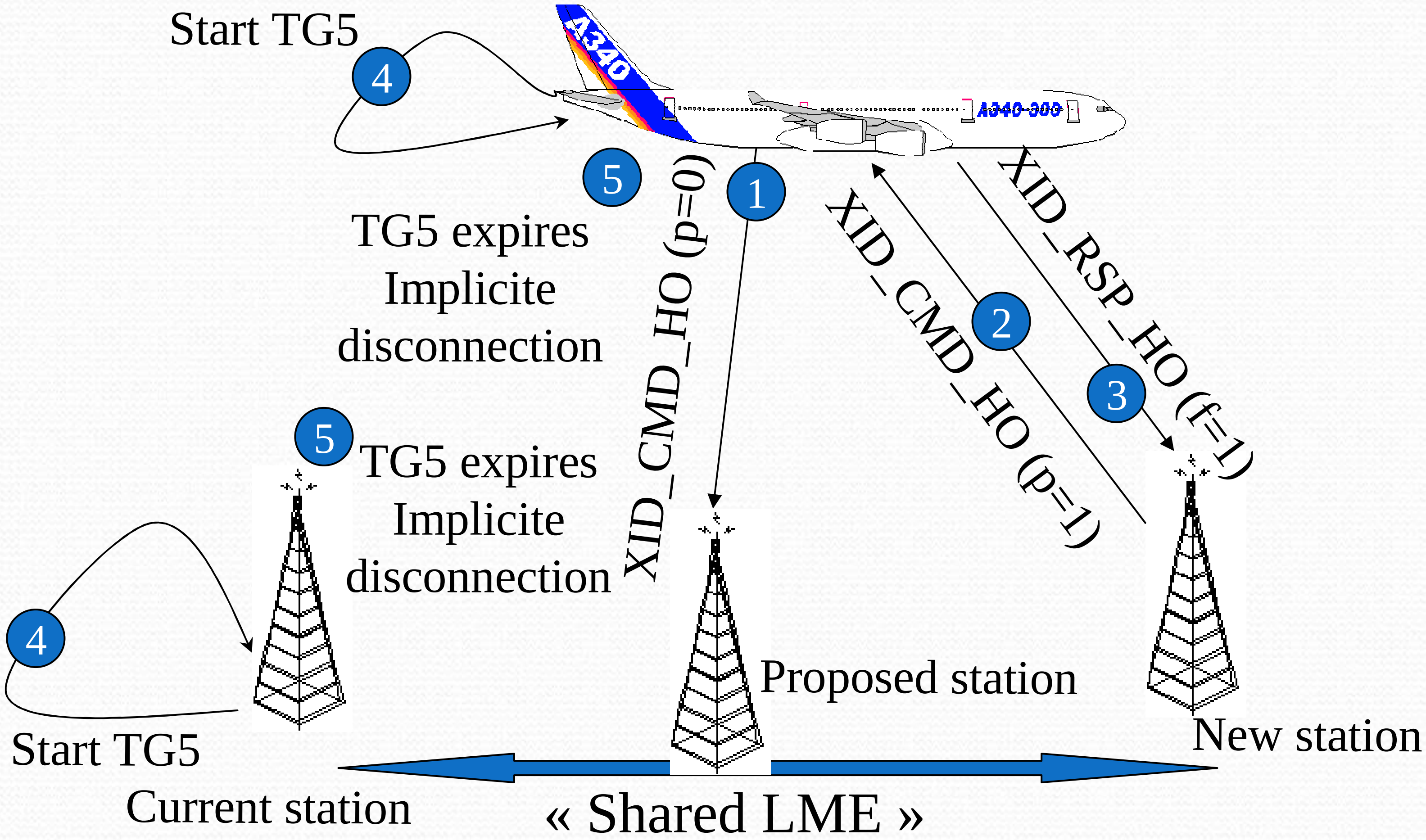
Aircraft initiated Handoff



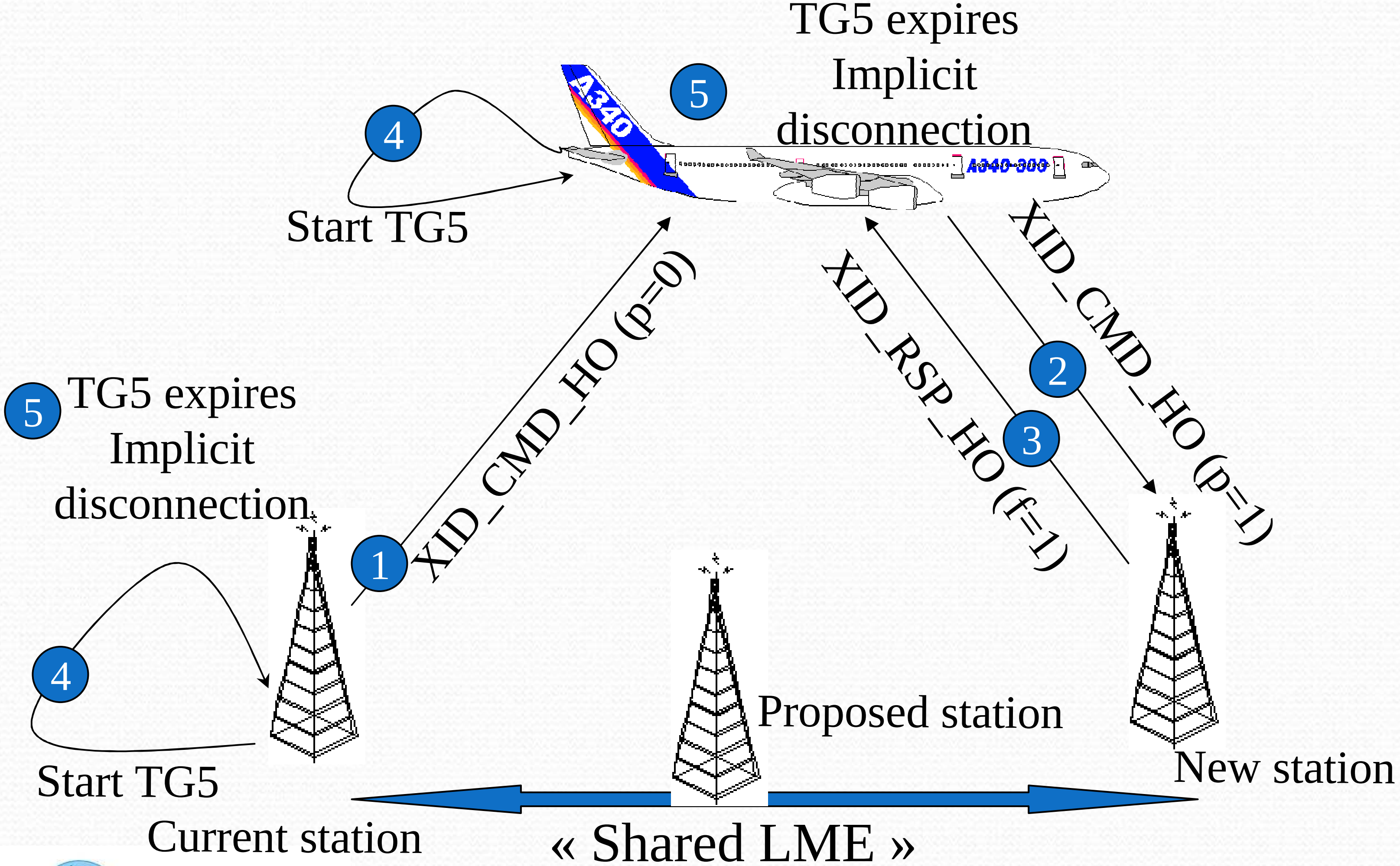
Ground Initiated Handoff



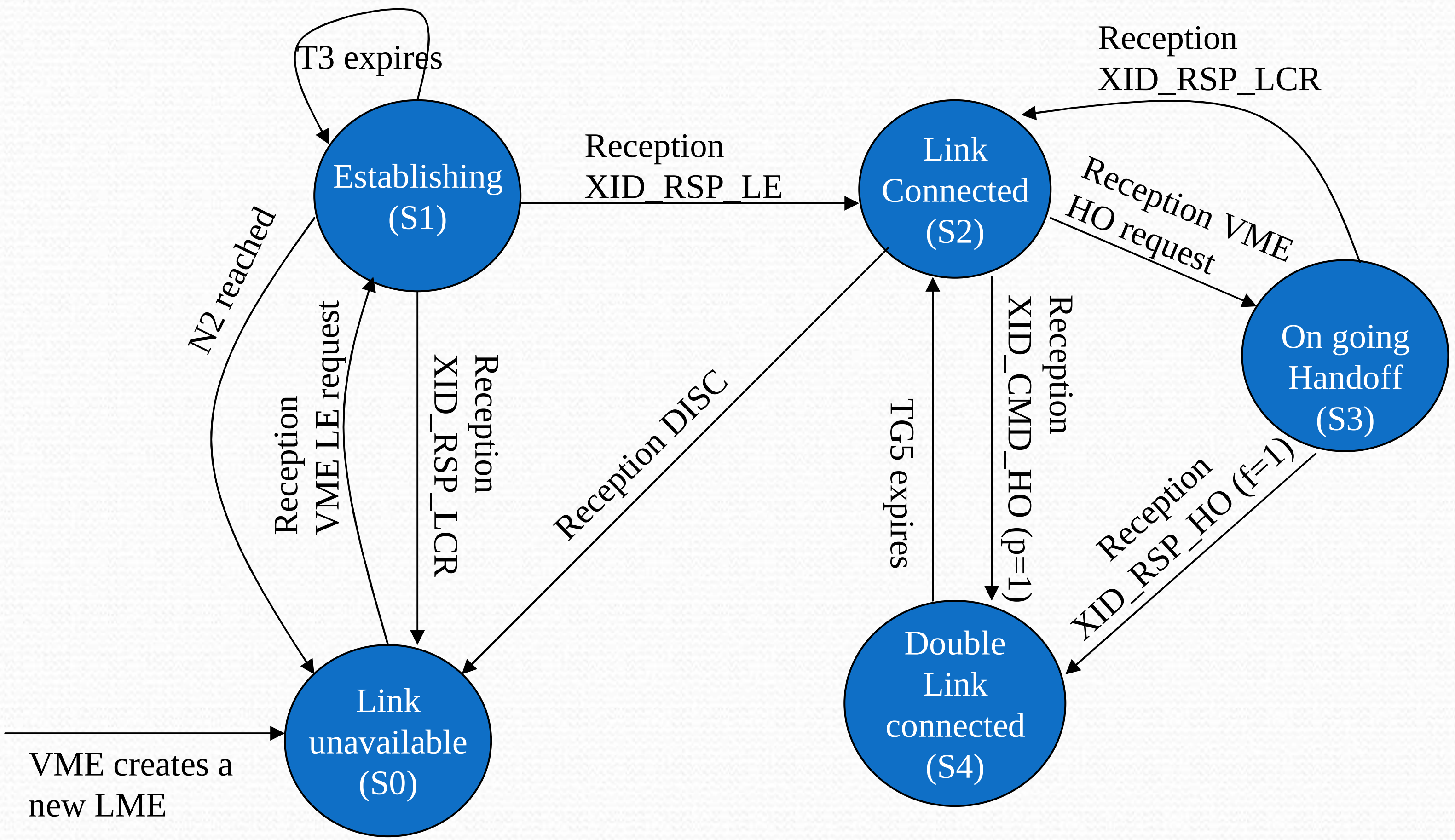
Aircraft requested Ground initiated Handoff



Ground requested Aircraft Initiated Handoff



LME : state machine (aircraft)



Summary

- The air-ground communication is established
- We are able to manage the mobility
- The link is reliable
- Parameters are tuned to limit the channel occupancy

Link loss detection issue

The asymmetry

- For the <u>A/C</u>:
- – An A/C flying out of the station's coverage
    - Without transmission
        - Detection in: TG2 seconds (4 minutes)
    - With transmission
        - Detection in N2*T1 seconds
- – If the A/C is in the coverage of another station
    - Air initiated handoff

Link loss detection issue

- For the <u>Ground</u>:
  - Without transmission
    - Detection in: TG2 seconds (60 minutes)
  - With transmission
    - Detection in N2*T1 seconds

Subnetwork layer

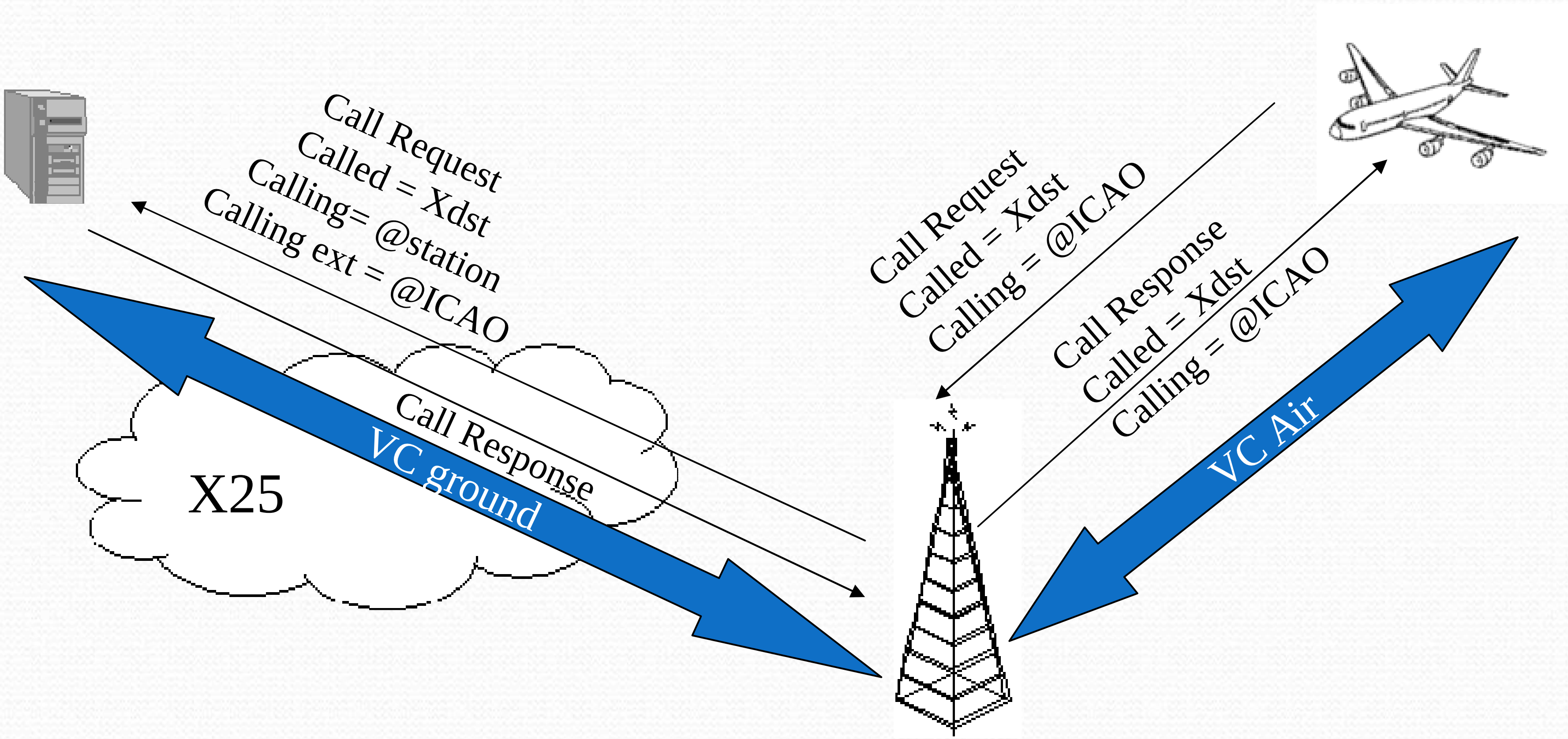
3a sub-layer

- Functions
  - Segmentation
  - Establish VC (Virtual Circuits) between airborne router and ground router
- Between the A/C and the Ground Station
  - X25 like Layer 3
  - Only defines an interface
  - No description of ground network

Addresses

- A network level address is required
  - Aircraft:
    - ICAO 24 bits address (8 symbols) binary coded
  - Ground:
    - X121 address (option)
    - Also called VSDA : VDL Specific DTE Addressing
- Use of the X25 address extension option

VC establishment in X25



Questions ?

- How to provide the X121 @ or the VSDA to the A/C ?
  - The ground station provides it in the GSIF
- And then?
  - X25 like
  - Ground station “binds” the two ends transparently

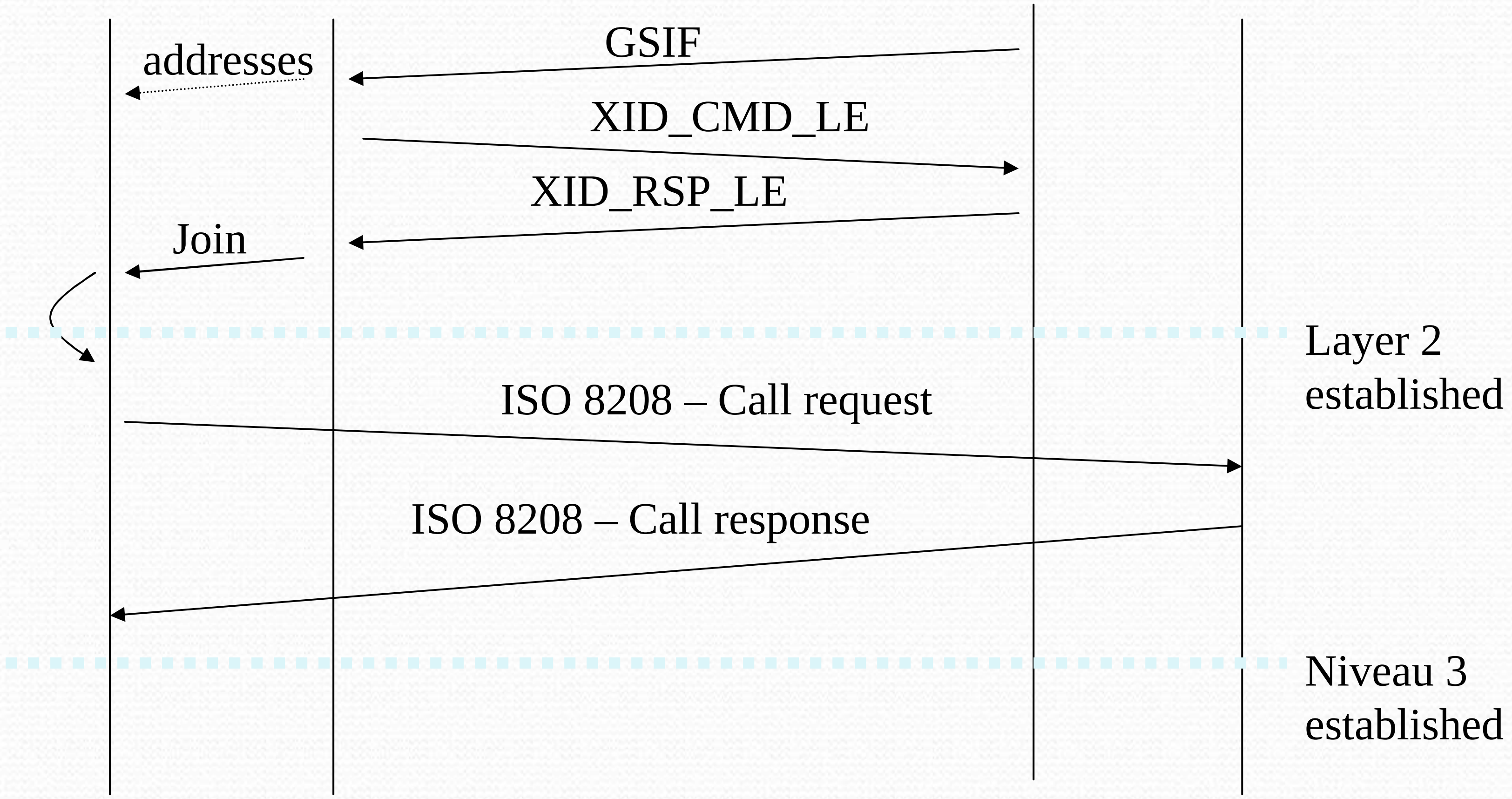
ISO 8208 air tuning

- Sending window W (default is 7)
  - Acknowledgement window A (default is 4)
- Flow management
  - Stop sending RR to stop the transmissions
  - If no loss on layer 2, no problem
    - Optional protection T24/T25 : forces transmission of RR after 180 seconds

ISO 8208 air tuning

- Reset :
  - On reception of a RESET on the ground
    - Only a ground-ground problem
    - Not propagated to the air
- Most options are prohibited
- Fast Select authorized
  - To transmit up to 128 bytes of data during the establishment

Global view

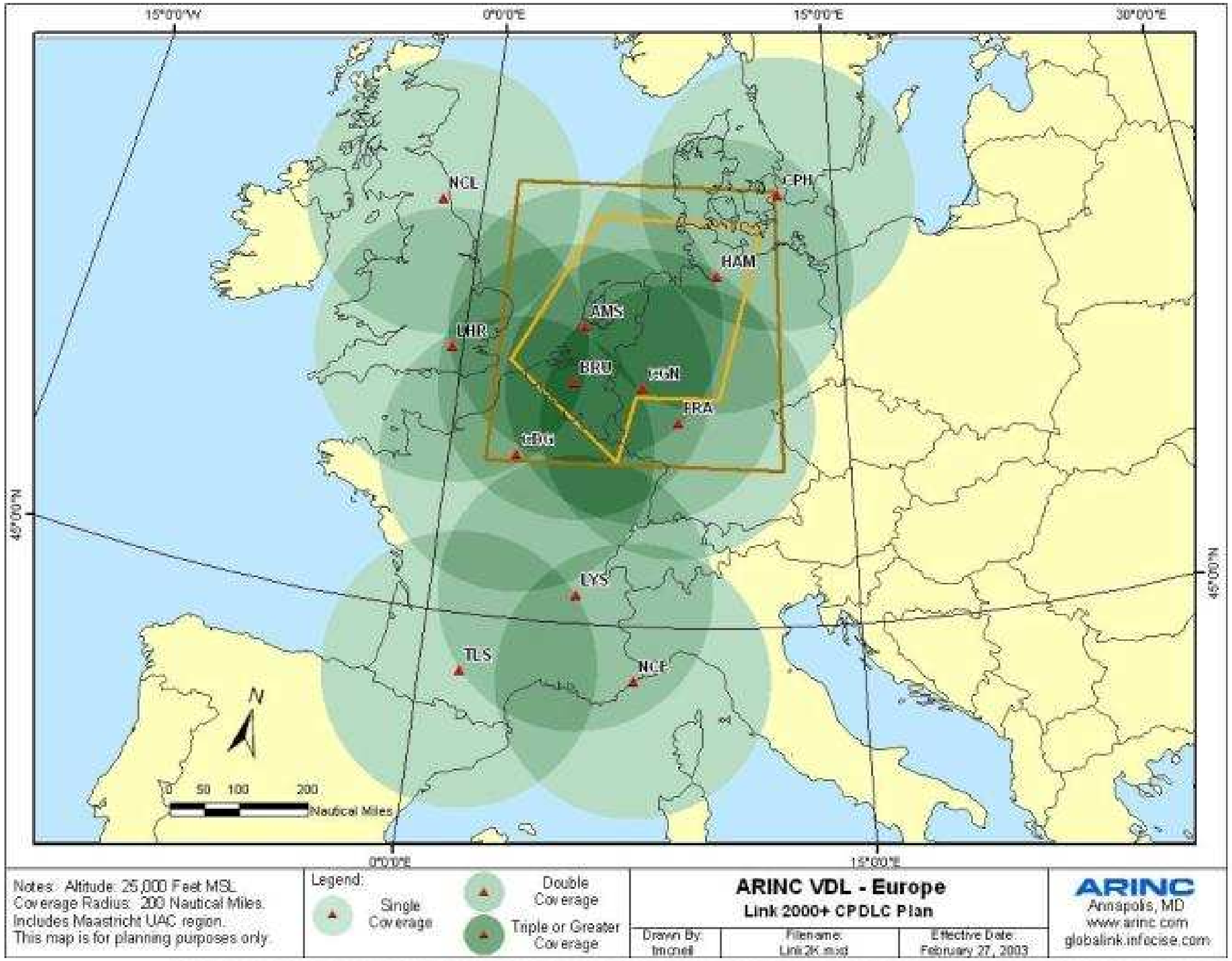


GSIF
addresses
XID_CMD_LE
XID_RSP_LE
Join
Layer 2
established
ISO 8208 – Call request
ISO 8208 – Call response
Niveau 3
established

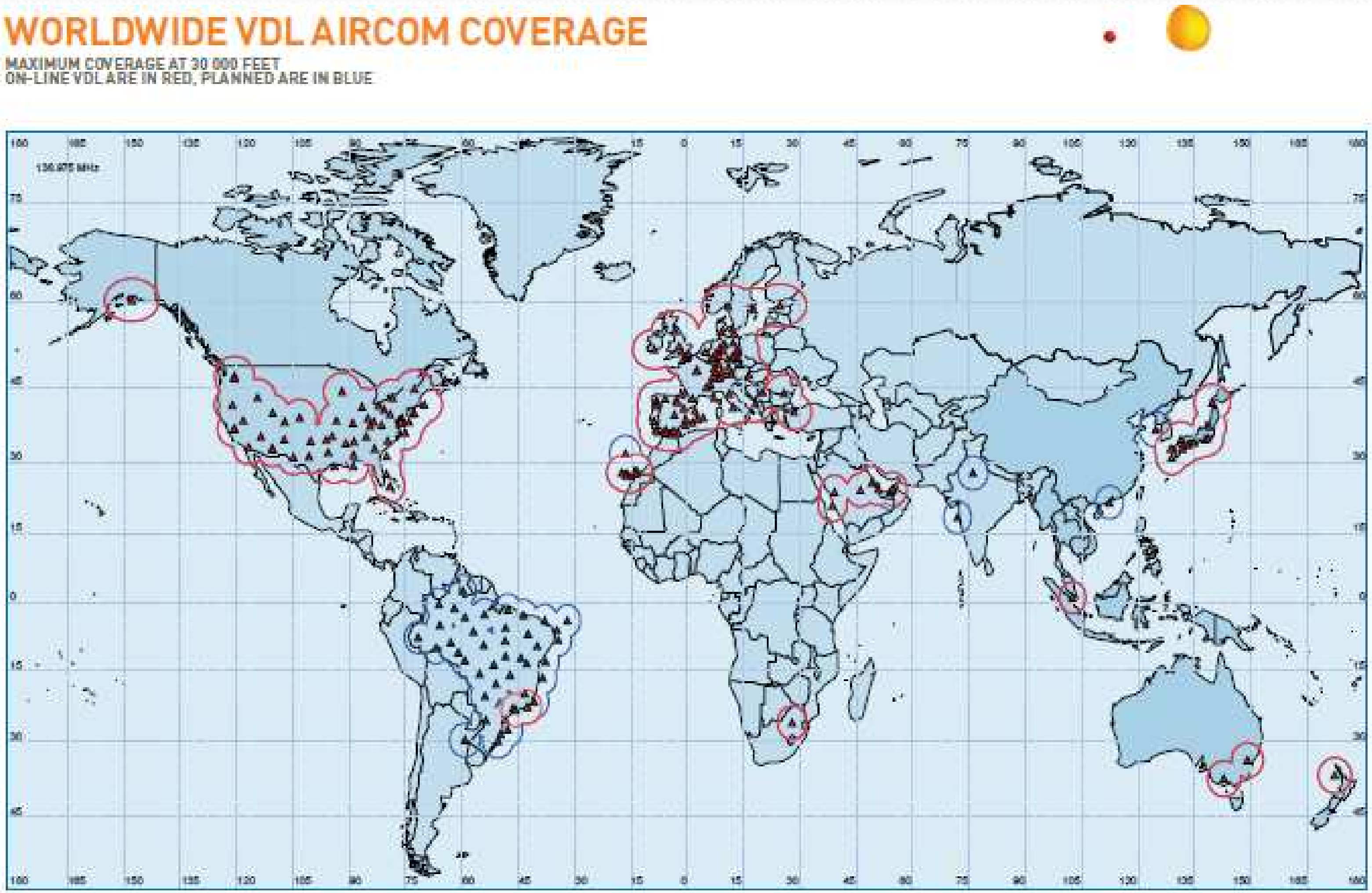
The requirements

- Availability :
  - 99,9 %
  - Single failure tolerance
- Integrity : 10^{-6}
- Delay : 5 major components –95 % limit
  - Transmission/reception switching delay: 1 ms
  - Packet transmission delay: 250 ms
  - Propagation delay: 1,3 ms
  - Process delay: 100 ms
  - Access delay: 3000 ms

ARINC coverage



SITA coverage



Conclusion

- The main characteristics of VDL mode 2:
  - Physical layer
  - MAC layer
  - Link layer
  - Sub-network layer

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