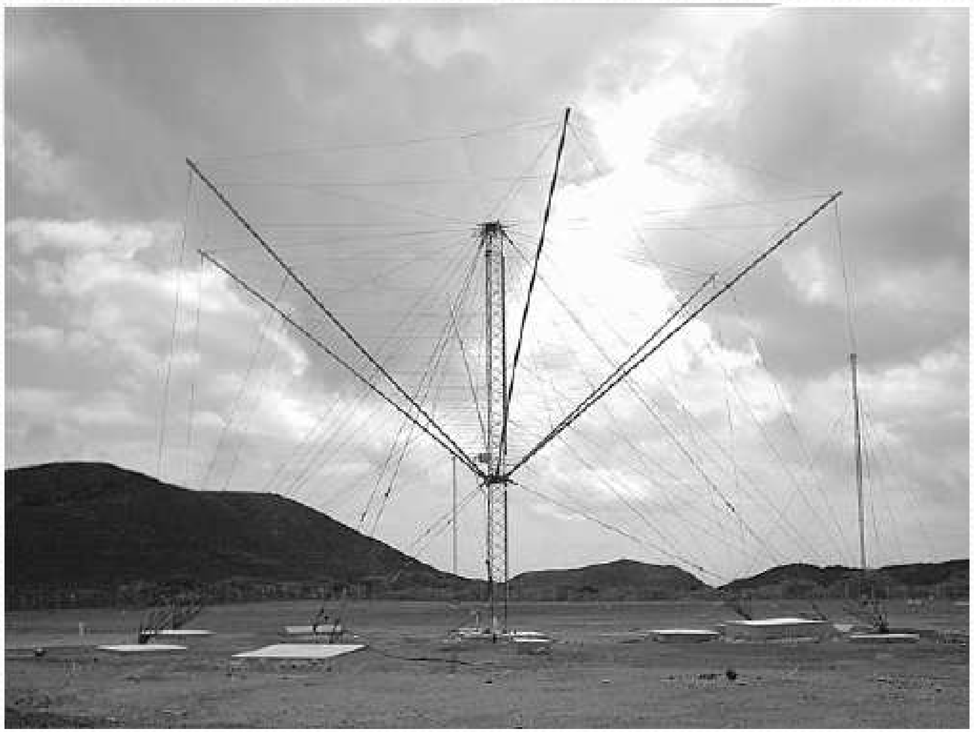
# HFDL

Presented by
Na TAO
ALTRAN on behalf of ENAC

# Objectives

- List the principles of HFDL



# Outlines

- Introduction
- Characteristic
  - Physical layer
  - Link layer
  - Network layer
- Implementation

# Introduction

- High Frequency range : 3 - 30 MHz
- Traditional way for voice
- HFDL : implement data links in the HF band
- Wide coverage
  - SATCOM backup
- Available on the whole planet
  - Low cost (vs. SATCOM)
  - No coverage hole at the poles
- Allows covering non dense areas at low cost (vs. VDL)

# Introduction

- HF used for ATC when VHF is not available
- HF specs for civil aviation: ICAO annex 10
  - Frequency range : 2.8 – 22 MHz
  - Voice signal bandwidth : 300-2700 Hz
  - Channel access : simplex communication
  - Maximum power :
    - 6 kW for ground stations
    - 400 W for aircrafts

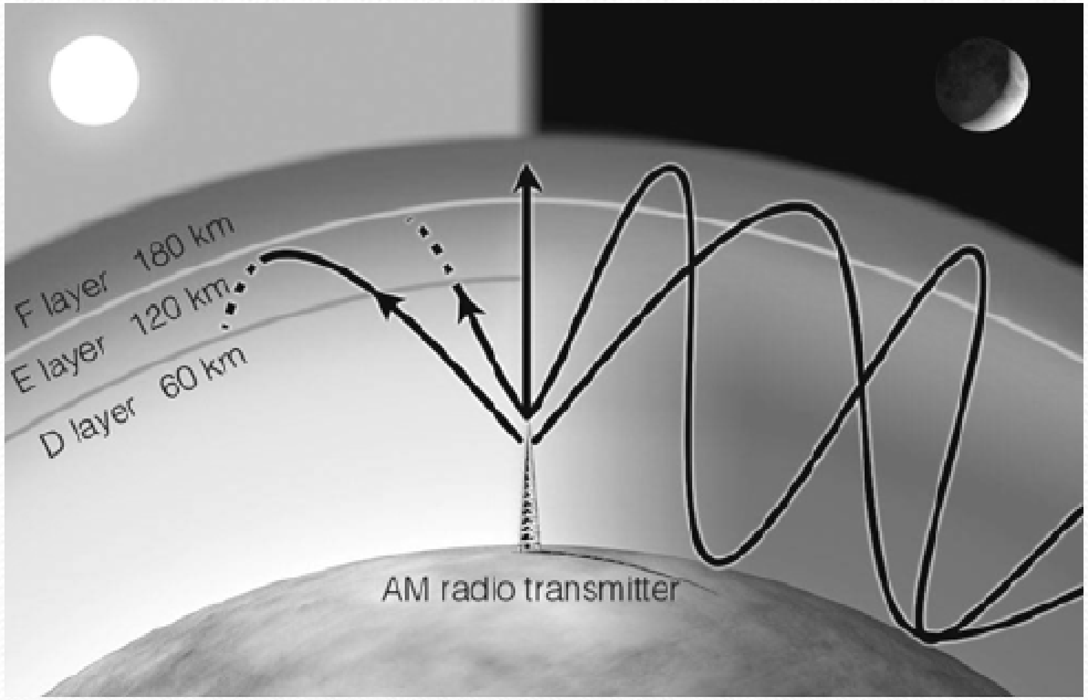
# Introduction

- ATM availability requirements
  - For many ATM applications, system availability requirement : 0.999
    - Single AMSS : 0.98
    - Single HFDL : 0.99

  →Single AMSS + Single HFDL : 0.9998
- Operated by 17 ground stations spread all over the world. Each stations operates a subset of available HFDL channels

# HF Propagation

- Ionosphere reflection allows long range



# HF Propagation

- Low atmospheric influence
- High ionospheric influences
- Band : 2,85 – 22 MHz

# HF usage

- Voice
  - 1 station per FIR : 1 primary and one backup frequency
  - Ionosphere perturbations = loss
  - Manual tuning
- Data
  - No limit of connectivity
  - Dynamic frequency management
  - Digital Signal Processing

# Technical Choices

- The aircraft shall declare themselves
  - LOG ON procedure
- Automatic frequency management
  - Aircraft scan for available frequencies
- Ground stations are synchronized
  - Aircraft can connect to a new station transparently
- Reliable communication service (RLS)
  - Segmentation is allowed
- “Normal” communication service (DLS)
  - No segmentation

# Performances

- Integrity : same as VDL2
  - Checksum
- Residual error ratio
  - 10-6 per 128 bytes packets
- Transit delay
  - Uplink: 45s (Less than 90s in 95% of transf.)
  - Downlink: 60s (less than 90s in 95% of transf.)

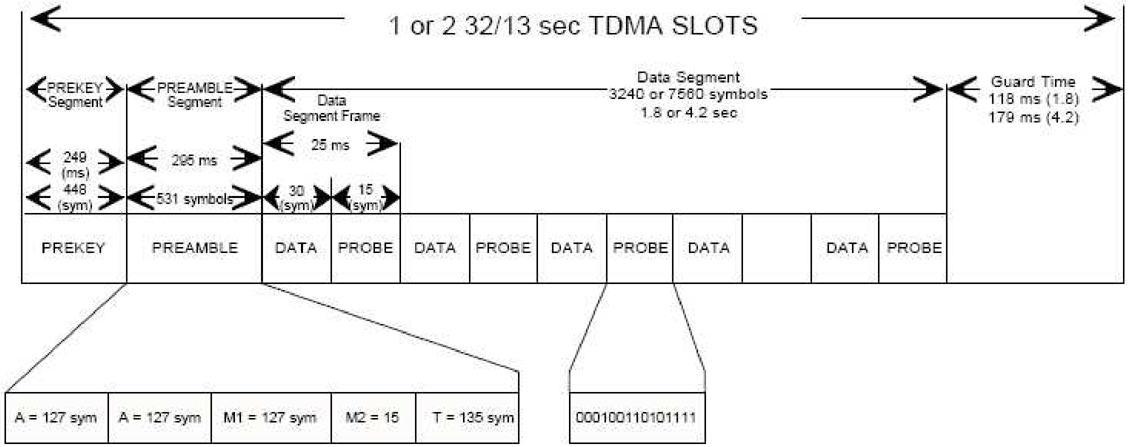
# Physical layer

- Phase Shift Keying (BPSK, QPSK and 8PSK)
- Symbol rate: 1800 bauds (symbols /second)
- Uses FEC, Interleaving and scrambling
- Normal bit coding ratio: ½
- Bit rate:
  - BPSK: 300/600 bits/s
  - QPSK : 1200 bits/s
  - 8PSK : 1800 bits/s

# Access

- TDMA (Time Division Multiple Access ) controlled by the ground station
- 13 time slots in a 32 seconds long frame
- 1 slot (2,46 s) : 1 burst
  - Prekey: 249 ms
  - Preamble: 531 symbols BPSK (295 ms)
  - Transmission: 1.8 sec (single slot) or 4.2 sec (double slot)
  - Guard delay: 118 ms

# Burst HFDL




A = 010 1101 1101 1110 0011 1010 0010 1011 1000 0001 1110 1100 1100 0100 1001 1100 1111 1001 0000 0100 0110 1010 1001 1011 0100 1010 0001 0110 0001 1001 0111 1111

M1 = 1 OF 10 SHIFTS OF FOLLOWING SEQUENCE: 011 1011 0111 1010 0010 1100 1011 1110 0010 0000 0110 0110 1100 0111 0011 1010 1110 0001 0011 0000 0101 0101 1010 0111 1001 00001 1010 1000 0111 1111

M2 = first 15 symbols of shifted M1 sequence

T = 000 100 110 101 111 repeated 9 times

NOTE = Left most bit of each sequence is transmitted first

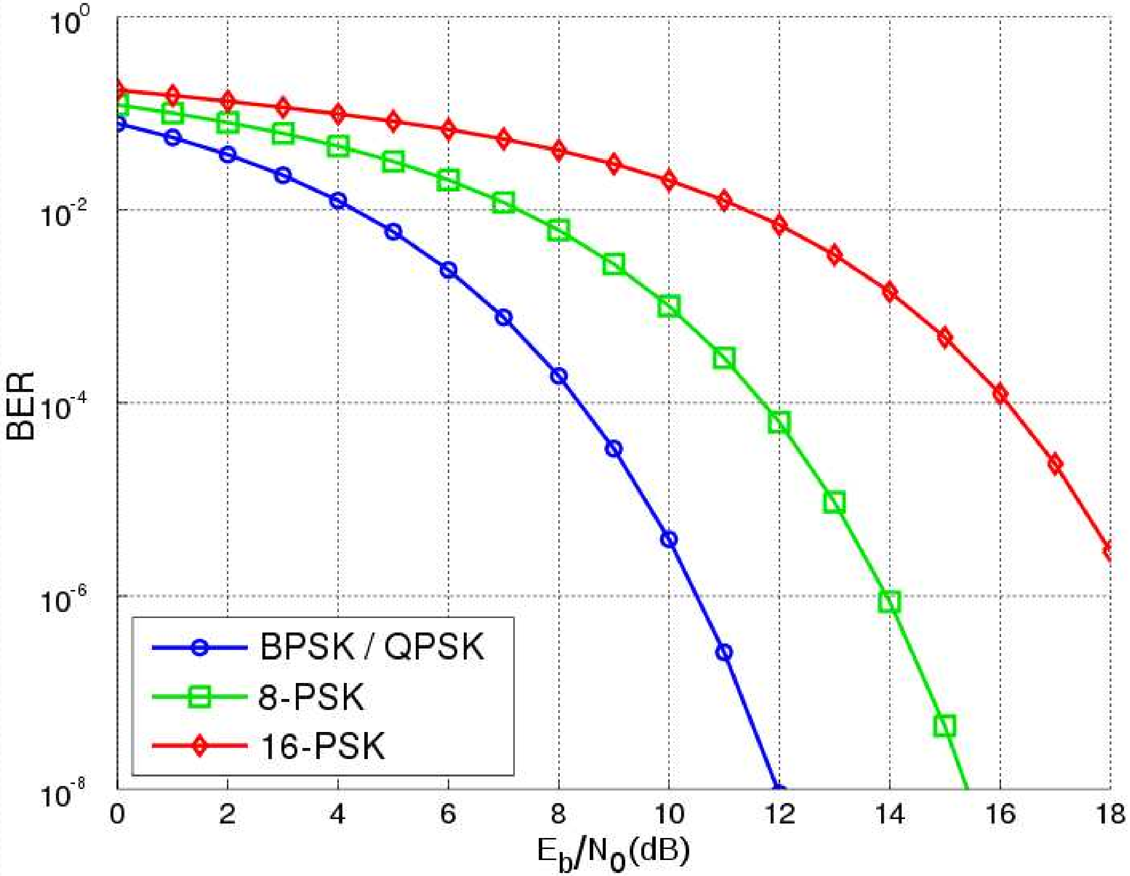
| DATA RATE | INTERLEAVER | M1 SHIFT |
|---|---|---|
| 300 bits/s | 1.8 s | 72 sym |
| 600 bits/s | 1.8 s | 82 sym |
| 1 200 bits/s | 1.8 s | 113 sym |
| 1 800 bits/s | 1.8 s | 123 sym |
| 300 bits/s | 4.2 s | 61 sym |
| 600 bits/s | 4.2 s | 103 sym |
| 1 200 bits/s | 4.2 s | 93 sym |
| 1 800 bits/s | 4.2 s | 9 sym |

Figure A.1 TDMA slot definition

# Data rate management

- Receivers impose the max data rate
  - Aircraft provide max uplink
  - Ground station provide max downlink
- BER increases with symbol’s size (SNR)
  - Minimizing symbol’s size minimizes BER
  - Choose the lowest required data rate

# BER vs M-PSK

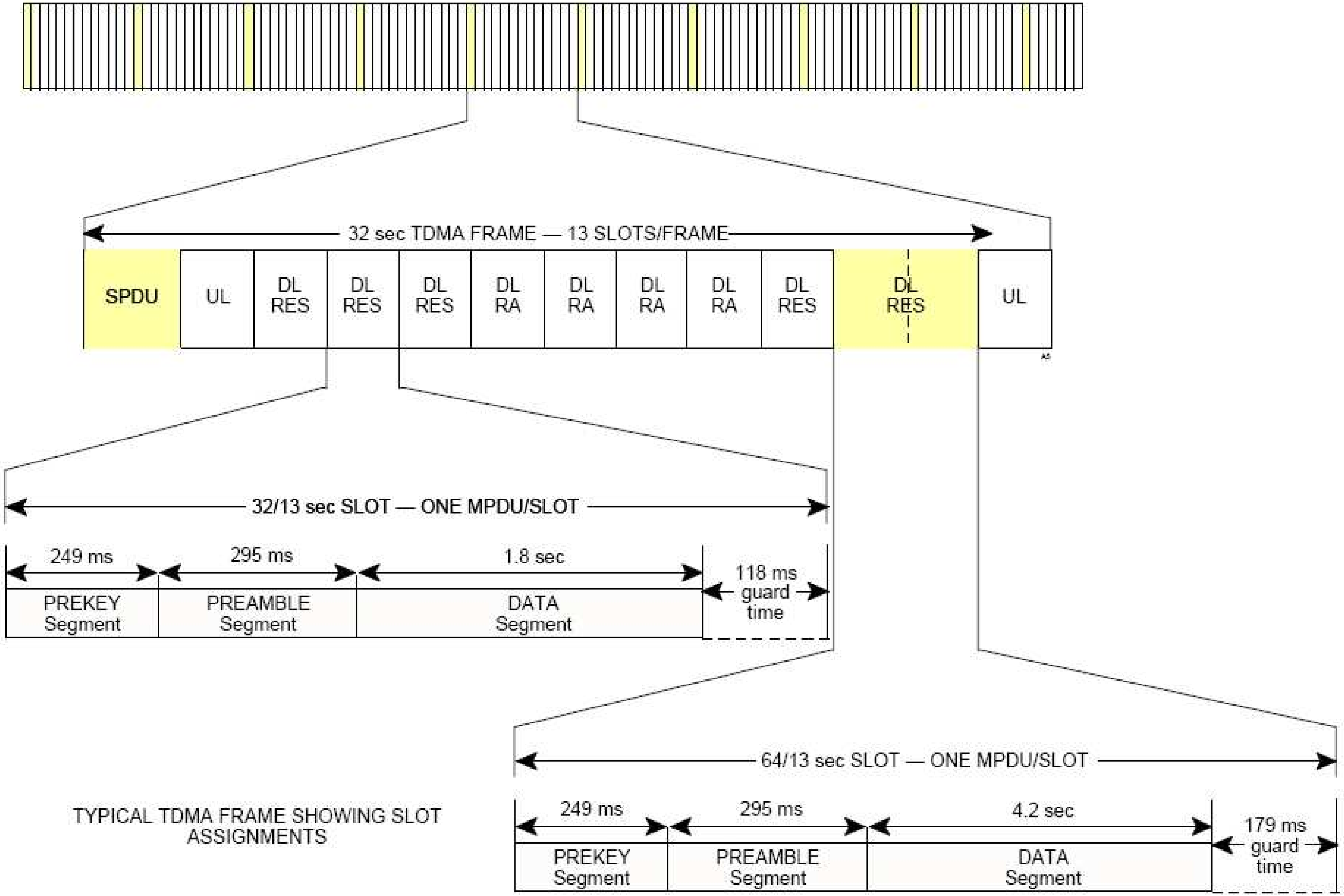


BER
$10^0$
$10^{-2}$
$10^{-4}$
$10^{-6}$
$10^{-8}$
0
2
4
6
8
10
12
14
16
18
$E_b/N_0$(dB)
BPSK / QPSK
8-PSK
16-PSK

# Channel Access

- TDMA
  - Managed by the Ground station
  - A frame contains 13 slots
    - 1st slot reserved for the GS (called squitter)
    - Slots may be reserved for
      - Uplink or Downlink
      - Random access DL
      - 2 consecutive slots may be grouped

# Format de la trame

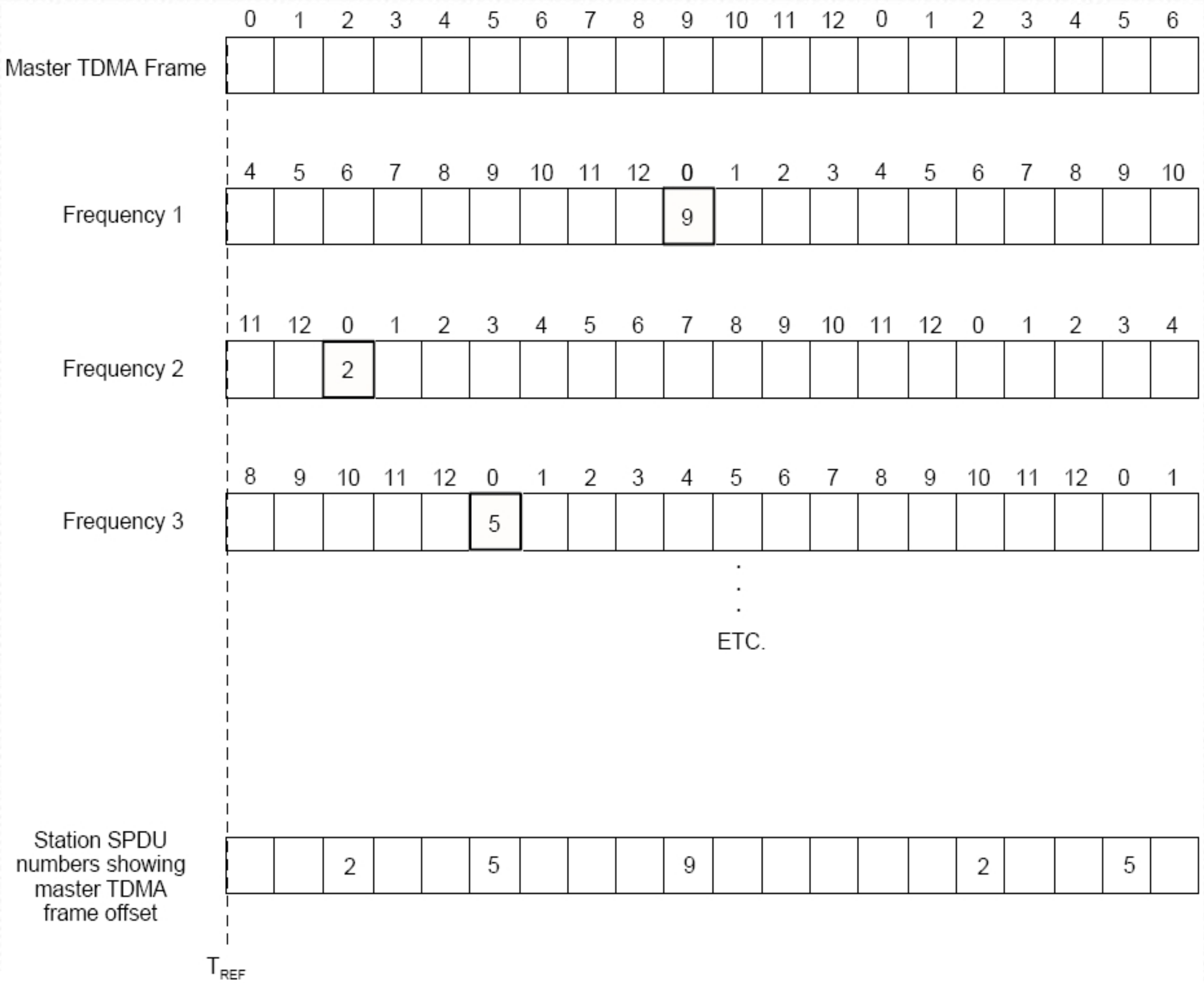



TYPICAL TDMA FRAME SHOWING SLOT ASSIGNMENTS

# SPDU (Squitter Protocol Data Unit )

- Fixed size: 67 bytes (throughput ?)
- Position of the SPDU in the Master frame varies
- Acknowledges DL transmissions
- Slot management/allocations:
  - Slots 3 to 12 of the current frame
  - Slots 1 and 2 of the next frame
- Provides ground station’s list of frequencies
  - Informs aircraft of frequency changes
- Provide 2 other ground stations’ list of freq and ID

# SPDU position vs. Master Frame



# Other MPDU

- Size depends on:
  - Maximum allowed data rate
  - Number of allocated slots (0, 1 or 2)
  - The size of the data to be transmitted
- Encapsulate LPDU frames (Link PDU)
  - DL: 0 to 15 LPDU
  - UL: 0 to 64 LPDU

# MPDU

<table>
<tr><th>8</th><th>7</th><th>6</th><th>5</th><th>4</th><th>3</th><th>2</th><th>1</th><th></th></tr>
<tr><td>P</td><td>0</td><td colspan="4">NLP (1 in this example)</td><td>T</td><td>1</td><td>1</td></tr>
<tr><td>UTC SYNC</td><td colspan="7">GROUND STATION ID</td><td>2</td></tr>
<tr><td colspan="8">AIRCRAFT ID</td><td>3</td></tr>
<tr><td rowspan="2">SLOT SEL</td><td>H</td><td colspan="3">N2</td><td colspan="3">N1</td><td rowspan="2">4</td></tr>
<tr><td colspan="7">NF</td></tr>
<tr><td colspan="5">U(R)</td><td colspan="3">UDR</td><td>5</td></tr>
<tr><td colspan="8">U(R) vect</td><td>6</td></tr>
<tr><td colspan="8">LPDU SIZE (one octet per LPDU)</td><td>7</td></tr>
<tr><td colspan="8">MPDU HEADER FCS</td><td>. .</td></tr>
<tr><td colspan="8">. .</td><td>. . . .</td></tr>
<tr><td colspan="8">FLUSH FIELD</td><td rowspan="2">N</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>

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<tr><th>8</th><th>7</th><th>6</th><th>5</th><th>4</th><th>3</th><th>2</th><th>1</th><th></th></tr>
<tr><td>P</td><td colspan="3">NAC (1 in this example)</td><td>0</td><td>0</td><td>T</td><td>1</td><td>1</td></tr>
<tr><td>UTC SYNC</td><td colspan="7">GROUND STATION ID</td><td>2</td></tr>
<tr><td colspan="8">AIRCRAFT ID</td><td>3</td></tr>
<tr><td colspan="4">NLP (1 in this example)</td><td colspan="3">DDR</td><td>P</td><td>4</td></tr>
<tr><td colspan="8">LPDU SIZE (one octet per PLDU)</td><td>5</td></tr>
<tr><td colspan="8">MPDU HEADER FCS</td><td>. .</td></tr>
<tr><td colspan="8">. .<br>. .</td><td>. . . . . .</td></tr>
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<tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>

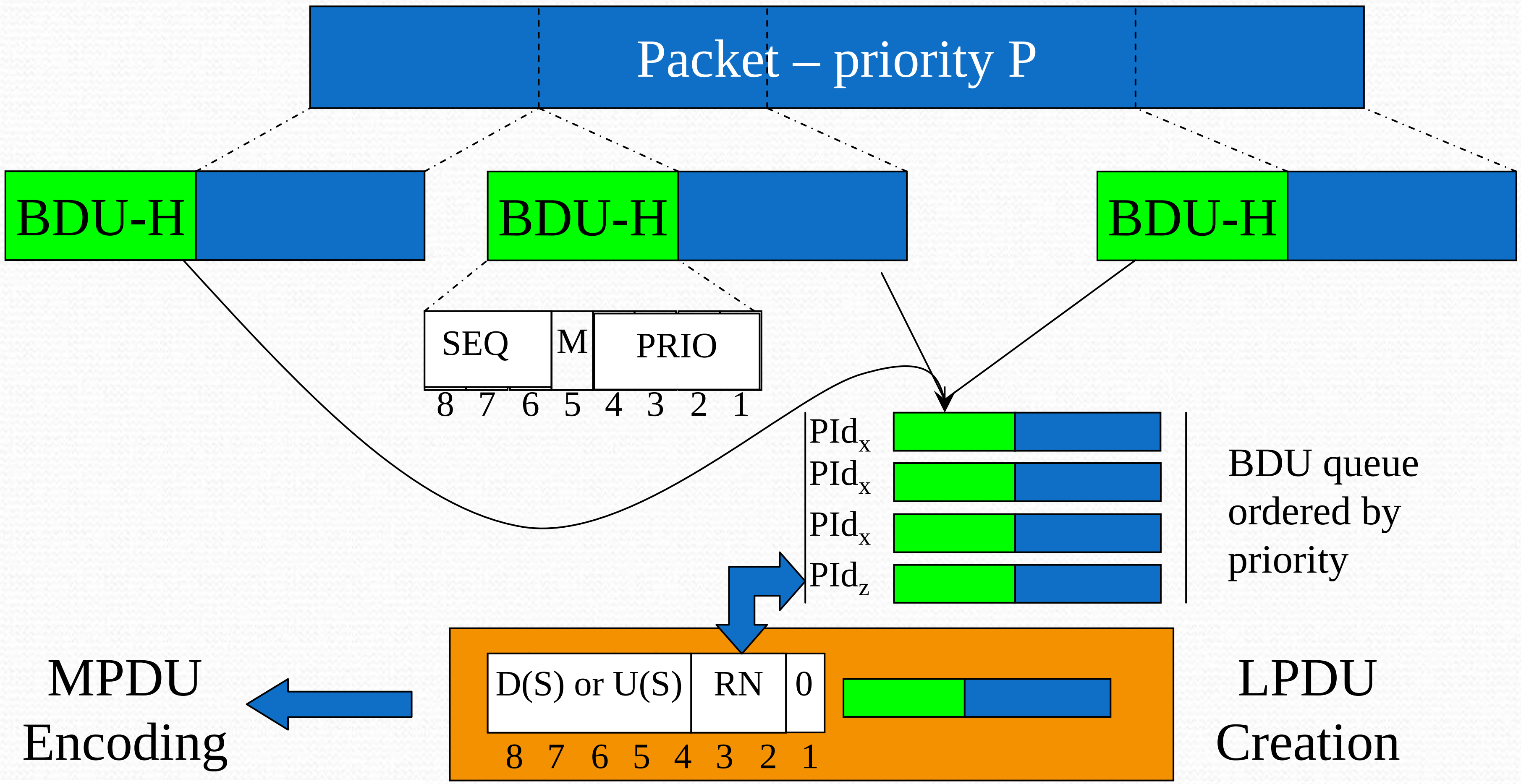
# Acknowledgment

- Each LPDU shall be acknowledged
  - UL: by U(R) + $U(R)_{vect}$
  - DL: by the SPDU
    - Slot acknowledgment on 4 bits (4 LPDU)
    - If more than 4 LPDU to acknowledge, group by 2 (LPDU 1+2, LPDU 3+4 …)

# LPDU Format – 1 byte + payload

- LSB = 1
  - Unnumbered frames
    - Log on procedure
    - Data acknowledgment
    - Unnumbered frame (performances)
- LSB = 0
  - Data frame
  - Bit 2 and 3: segment numbering (RLS)
  - Bit 4 to 8: LPDU number

# Data LPDU/RLS



# Transmission algorithm

- If A/C has one or more allocated slots
  - Queued LPDU: Only transmit in allocated slots
  - No LPDU: shall transmit a zero filled LPDU or performance data
- If no allocated slots
  - Look for Random Access (RA) slots
  - Select one or more slots randomly for transmission
  - Wait for the acknowledgments in next SPDU

# Log on procedure

- Aircraft scans the frequencies
- On SPDU reception
  - Request a Log on (specific LPDU)
    - Address: ICAO 24 bits
    - Data can be conveyed in the Log on LPDU
- On Log on LPDU reception
  - Acknowledge the slot with Aircraft Id FFh
  - Send a log on confirm LPDU, with allocated Aircraft Id

# Log off

- Silently
  - When A/C logs on another GS
  - When the station does not respond to UL
- Explicitly
  - Transmitting a DL outside the limits of a slot
  - DL sent on an UL allocated slot
  - Protocol error (e.g. wrong LPDU number)
  - Invalid Aircraft Id

# Error recovery

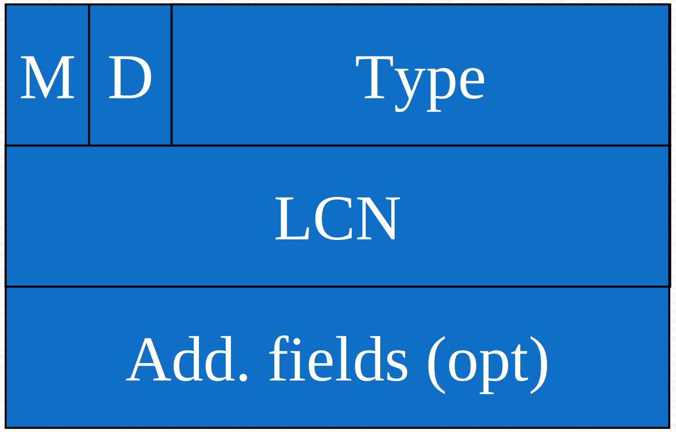
- Look for a new frequency
  - The GS announce (SPDU)
    - A frequency change
    - A connectivity error or a system halt
  - Loss of 2 consecutive SPDU
  - No acknowledgment for 3 consecutive DL
  - 5 out of 10 consecutive SPDU are erroneous (CRC)
- Log on resume procedure (handover)

# Qualification of layer 2 services

- Acknowledged or unacknowledged?
- Connected or connectionless?
  - Log on phase
  - Transfer phase
  - Log off phase

# Network layer (RLS)

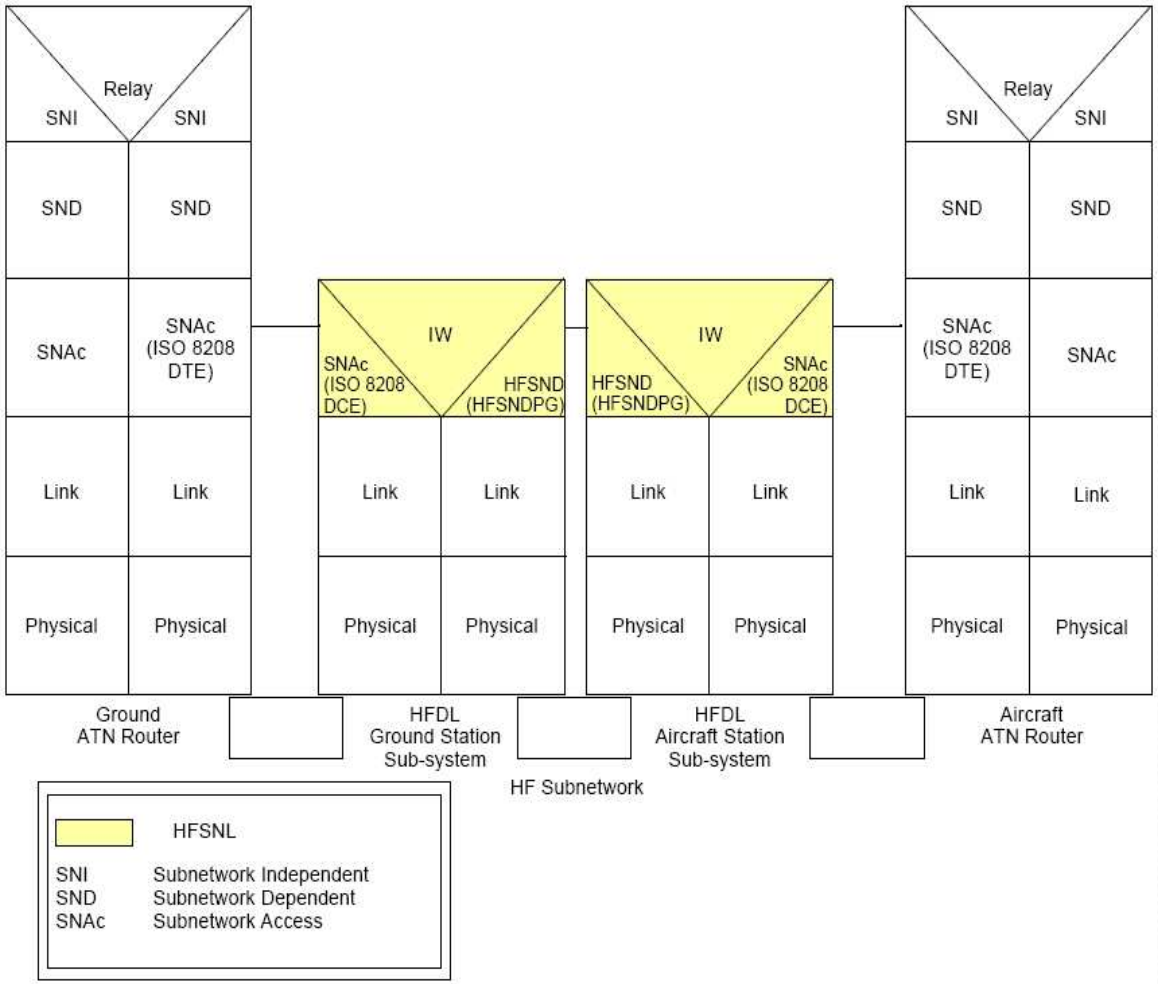
- Similar to ISO 8208
  - Logical channel (on 1 byte – 255 channels)
  - Header slightly different



# Network layer (RLS)

- Role
  - Provide a connection oriented service
  - Multiplexing on top of layer 2
    - Use of priority for each logical channel
  - Packet encoding identical to SATCOM
  - Same procedures at layer 3

# Network

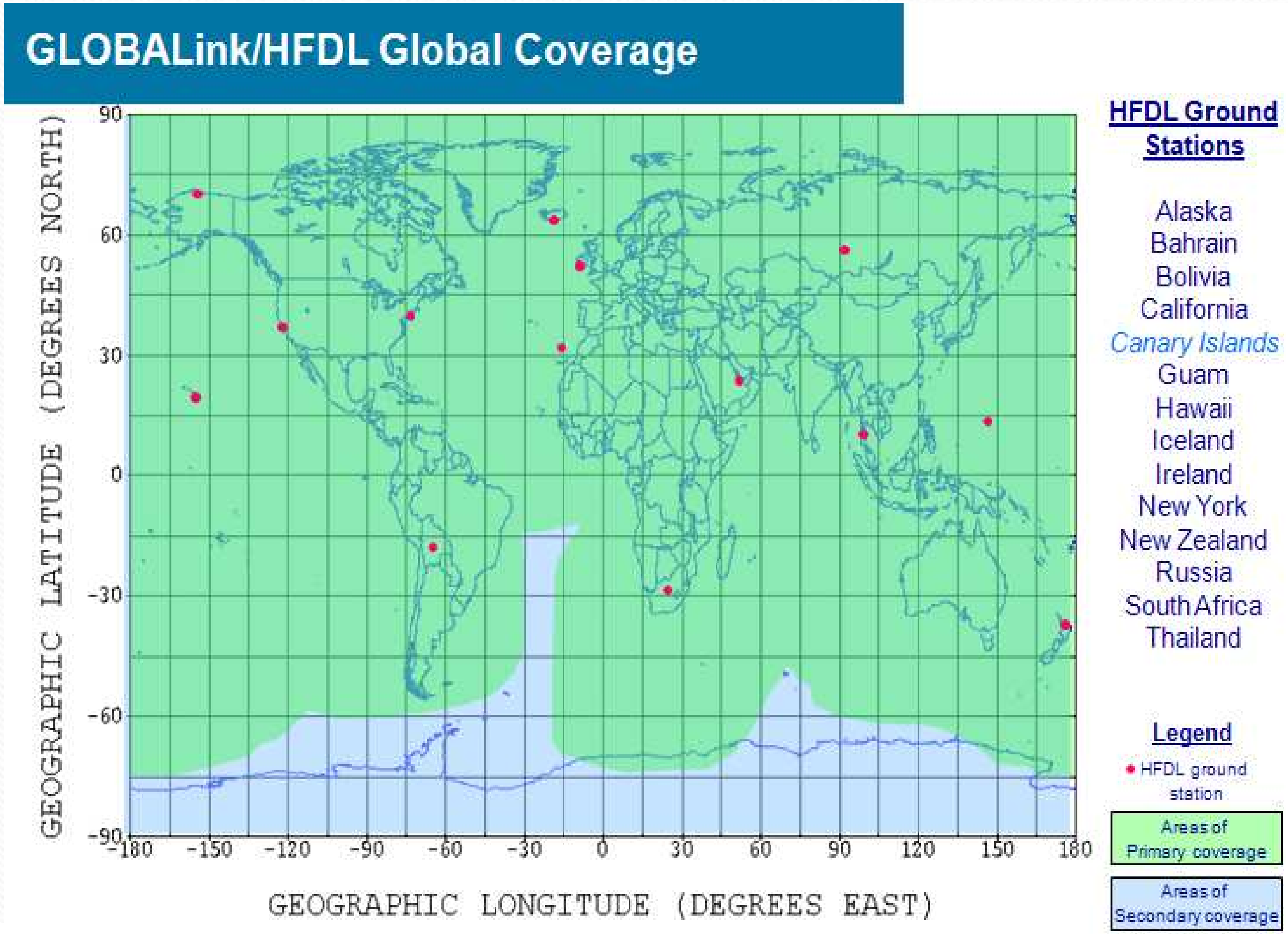


Relay
SNI
SNI
SND
SND
SNAc
SNAc (ISO 8208 DTE)
Link
Link
Physical
Physical
Ground ATN Router
IW
SNAc (ISO 8208 DCE)
HFSND (HFSNDPG)
Link
Link
Physical
Physical
HFDL Ground Station Sub-system
IW
HFSND (HFSNDPG)
SNAc (ISO 8208 DCE)
Link
Link
Physical
Physical
HFDL Aircraft Station Sub-system
HF Subnetwork
Relay
SNI
SNI
SND
SND
SNAc (ISO 8208 DTE)
SNAc
Link
Link
Physical
Physical
Aircraft ATN Router
HFSNL
SNI Subnetwork Independent
SND Subnetwork Dependent
SNAc Subnetwork Access

# Implementation

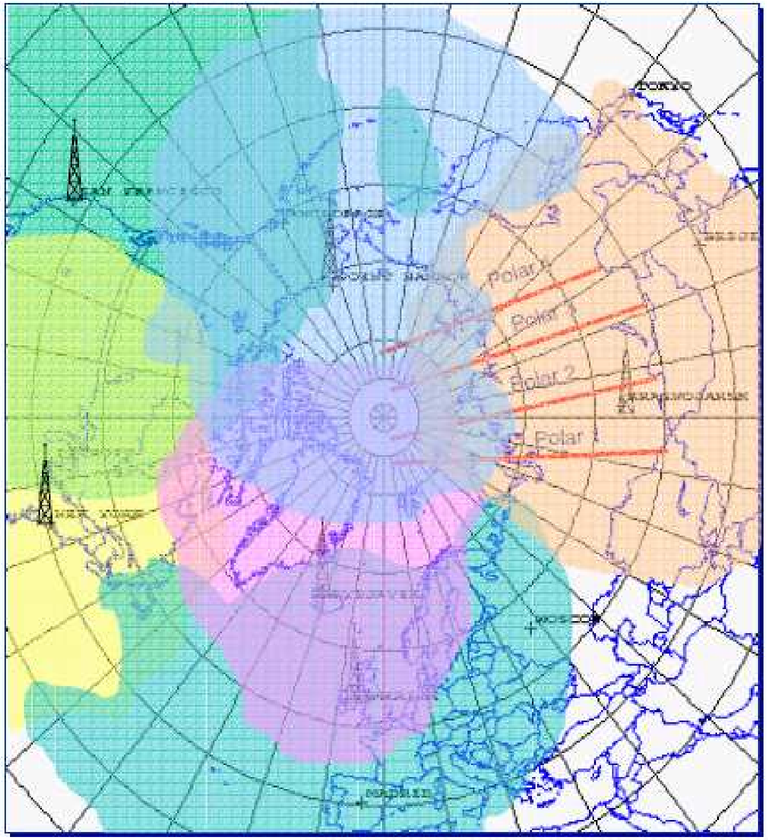
- 76 airlines, 2000+ aircraft currently use HFDL
- A single service provider
  - ARINC – more than 4.7 million messages per month
  - GLOBALink/HF Data Link
  - 15 active ground stations
- Specs
  - ICAO SARPs and Manual
  - ARINC 635
  - RTCA MASPS et MOPS

# HFDL Coverage



# HFDL Coverage

## HFDL North Polar Coverage



HFDL Stations

- San Francisco, California
- Riverhead, New York
- Shannon, Ireland
- Reykjavik, Iceland
- Krasnoyarsk, Russia
- Barrow, Alaska

Polar Routes (1 - 4)

**HFDL is the world's only North Polar data link communications capability**

# HF Frequencies for ACARS

| GROUND STATIONS | | Frequencies in kHz | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 01 | San Francisco | 21934 | 17919 | 13276 | 112378 | 10081 | 8927 | 6559 | 5508 | 4672 | 2947 | | | | | | | | | | |
| 02 | Molokai, | 21937 | 21928 | 17934 | 17919 | 13276 | 11348 | 11312 | 10081 | 8936 | 8912 | 6559 | 5538 | 5529 | 5508 | 5463 | 3434 | 3019 | 3001 | 2947 | 2878 |
| 03 | Reykjavik, | 17985 | 15025 | 11184 | 8977 | 6712 | 5720 | 3900 | 3116 | | | | | | | | | | | | |
| 04 | Riverhead, | 21934 | 21931 | 17934 | 17919 | 13276 | 11315 | 8912 | 6652 | 5523 | 3428 | | | | | | | | | | |
| 05 | Auckland, | 21949 | 17916 | 13351 | 11327 | 10084 | 8921 | 6535 | 5583 | 3404 | 3016 | | | | | | | | | | |
| 06 | Hat Yai, | 21949 | 17928 | 13270 | 10066 | 8825 | 6535 | 5655 | 4687 | 3470 | | | | | | | | | | | |
| 07 | Shannon, | 11384 | 10081 | 8942 | 8843 | 6532 | 5547 | 3455 | 2998 | | | | | | | | | | | | |
| 08 | Johannesburg, | 21949 | 13321 | 8834 | 4681 | 3016 | | | | | | | | | | | | | | | |
| 09 | Barrow, | 21937 | 21928 | 17934 | 17919 | 11354 | 10093 | 10027 | 8936 | 8928 | 6646 | 5544 | 5529 | 4687 | 4654 | 3497 | 3007 | 2992 | 2944 | | |
| 13 | Santa Cruz, | 21997 | 21988 | 21973 | 21946 | 17916 | 13315 | 11318 | 8957 | 6628 | 5660 | 3467 | 2983 | | | | | | | | |
| 14 | Krasnoyarsk, S | 13321 | 10087 | 2905 | 2878 | | | | | | | | | | | | | | | | |
| 15 | Al Muharraq, | 21982 | 17967 | 13354 | 11312 | 10075 | 8885 | 5544 | 2986 | | | | | | | | | | | | |
| 16 | Agana, | 17934 | 17919 | 13339 | 13312 | 13276 | 11306 | 11288 | 8936 | 8927 | 8912 | 6661 | 6652 | 6634 | 6550 | | | | | | |
| 17 | Telde, Canaries | 21955 | 17928 | 13303 | 11348 | 8948 | 6529 | 5589 | 2905 | | | | | | | | | | | | |

Black: active frequencies
Red: reserved frequencies

# Frequencies management

- Several frequencies per Ground Station
  - from 4 to 8 MHz : night frequencies
  - from 8 to 12 MHz : dawn frequencies
  - from 12 to 18 MHz : day frequencies

# Conclusion

- Global coverage
- TDMA based
- Lower performances compared to VHF
- HF will be used for a long time

# Bibliography


- Annex 10 – Volume 3 – Chapter 11
- Manual on HF Data Link (ICAO – Doc 9741)