L-DACS1/2 Data Link Analysis Part I: Functional Analysis

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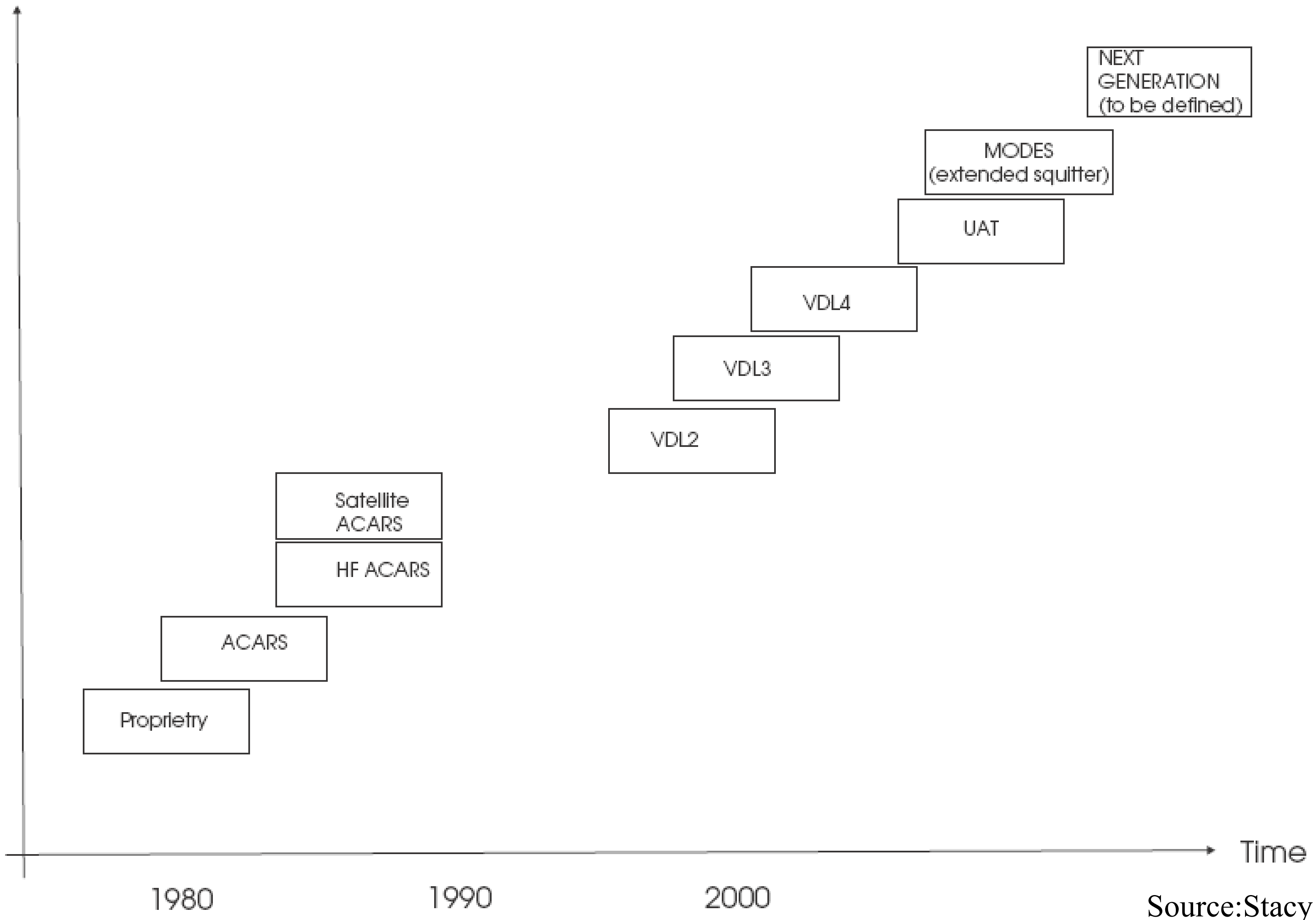
- Application
- Aeronautical Datalink Evolution
- Spectrum
- Implications of Channel Access Disciplines:
  TDD vs FDD, OFDM vs TDM, Spectral efficiency
- Link Layer Framing
- Protocol Stack
- Link Layer Reliability Mechanisms

Application

- L-DACS = L-band Digital Aeronautical Communications System Type 1 and Type 2
- Both designed for Airplane-to-ground station communications
- Airplane-to-airplane in future extensions
- 3C: **C**overage, **C**apacity, **C**wality
- Range: 200 nautical miles (nm)
  (1 nm =1 min latitude along meridian = 1.852 km =1.15 mile)
- Motion: 600 knots = 600 nm/hr = Mach 1 at 25000 ft
- Capacity: 200 aircrafts
- Workload: 4.8 kbps Voice+Data
- All safety-related services
- Data=Departure clearance, digital airport terminal information, Oceanic clearance datalink service

Aeronautical Datalink Evolution

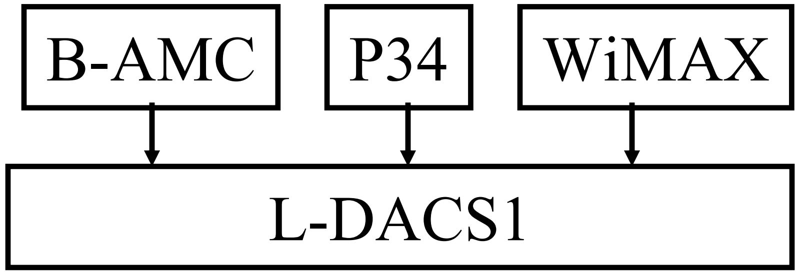


Source:Stacy 2008

Datalink Evolution

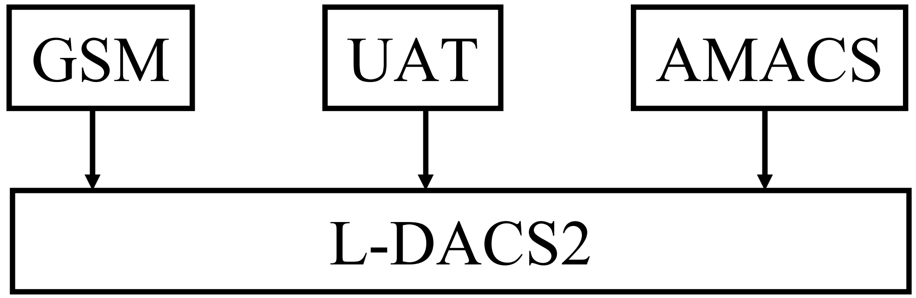
- Aeronautical radio systems ⇒ Voice
- Digital data by modem over analog wireless
- VDL4 = VHF Datalink 4 in 2001
- 19.2 kbps over 25 kHz in VDL4
- 1 minute slotted frame ⇒ 4 minute advance reservation
- B-VHF = Overlay in VHF band ⇒ Costly
  ⇒ Change Band
- B-AMC = Broadband Aeronautical Multicarrier Systems in L-Band

L-DACS1 Evolution



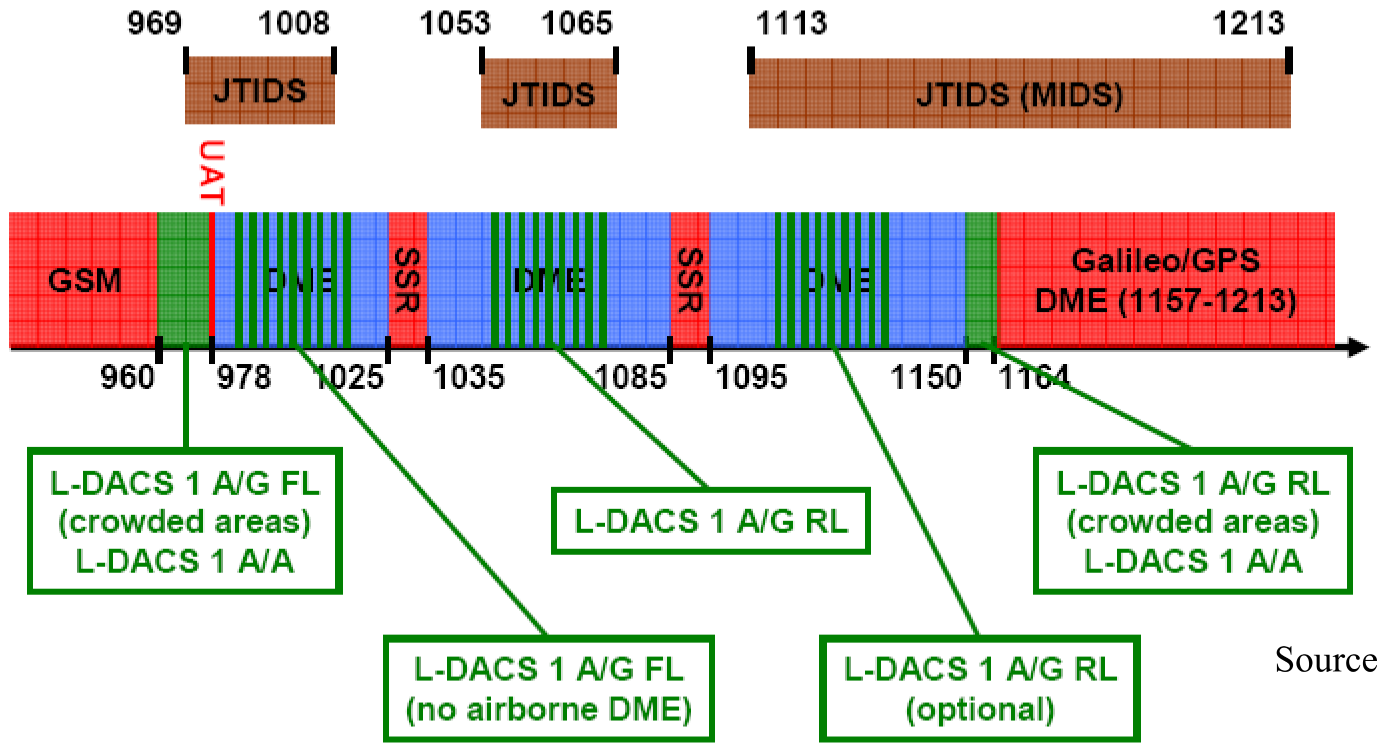
- B-AMC
  - Overall protocol stack
  - Medium access control cycle
  - Data link service protocol
- P34
  - AGC preamble concept (RL), PAPR reduction technique,
  - MAC layer states, primitives for data transfer, …
  - Control message formats
  - Addressing scheme
- WiMAX
  - Tiles and chunks in the physical layer
  - FL and RL allocation map
  - Approach to QoS (request, scheduling, grant)

L-DACS2 Evolution



- Based on GSM, UAT (Universal Access Transceiver), AMACS (All-purpose multi-carrier aviation communication system)
- GSM PHY, AMACS MAC, UAT Frame Structure
- Both UAT and GSM use GMSK
- GSM works at 900, 1800, 1900 MHz
  $\Rightarrow$ L-DACS2 is in lower L-band close to 900MHz
- Tested concept
- Price benefit of GSM components
- Uses basic GSM not, later enhanced versions like EDGE, GPRS, …
  These can be added later.

Spectrum



Source: Schnell 2008

- L-Band 960-1164 MHz
- L-DACS1 ⇒ 2x498.5 kHz FL in 985.5-1008.5MHz, RL in 1048.5-1071.5MHz, Duplex spacing 63 MHz

DME=Distance Measuring Equipment
JTIDS=Joint Tactical Information Distribution System
MIDS=Multifunction Information Distribution System
SSR=Secondary Surveillance Radar
GSM=Global System for Mobile Communications

Spectrum (Cont)

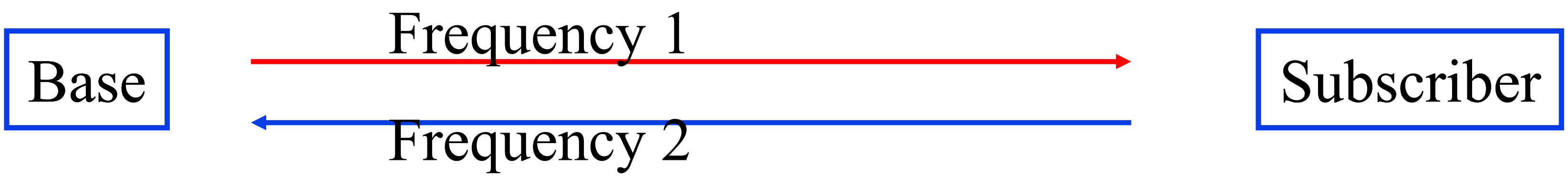
- L-DACS2 ⇒ One 200 kHz channel in lower L-Band 960-975 MHz
- WiFi: 20 MHz channels in 2.4 or 5.8 GHz
- WiMAX uses 1.25, 2.5, 5, 10, 20 MHz in 2.3, 3.5,… GHz
- Very early aeronautical networks used HF (3-30 MHz)
- Later aeronautical networks used VHF (30 MHz-300MHz)
- IEEE L-Band is 950-1450 MHz.
  It is part of UHF (300 MHz-3GHz)
  Down conversion of satellite signals by low-noise blocker (LNB) results in a signal in this band.
- Other L-bands are:
  - NATO L-Band: 40-60 GHz
  - Optical L-Band: 1565-1625 nm
  - Infrared Astronomy L-Band: 3.5um

Effect of Frequency

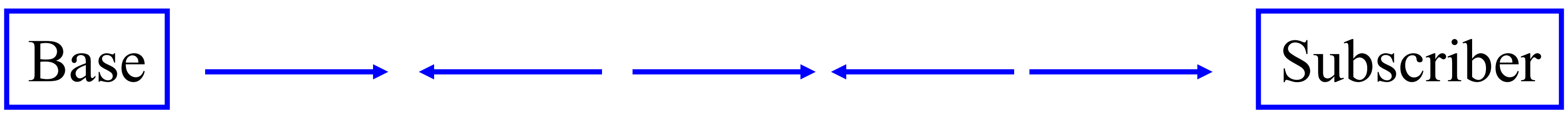
- Lower frequencies propagate farther ⇒ Need larger cell sizes
- Lower frequencies are more crowded.
  HF (3-30MHz) is more crowded than VHF (30-300MHz).
  VHF is more crowded than L-band.
- Higher Frequencies have higher attenuation,
  e.g., 18 GHz has 20 dB/m more than 1.8 GHz
- Higher frequencies need smaller antenna
  Antenna ≥ Wavelength/2, 800 MHz ⇒ 6”
- Higher frequencies are affected more by weather
  Higher than 10 GHz affected by rainfall
  60 GHz affected by absorption of oxygen molecules
- Higher frequencies have more bandwidth and higher data rate
- Higher frequencies allow more frequency reuse
  They attenuate close to cell boundaries.
- Mobility ⇒ Below 10 GHz

TDD vs FDD

- L-DACS1 is FDD, L-DACS2 is TDD.
- Duplex = Bi-Directional Communication
- Frequency division duplexing (FDD) (Full-Duplex)



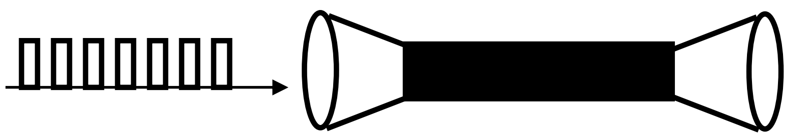
- Time division duplex (TDD): Half-duplex

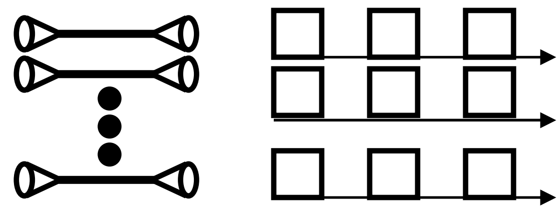


- Most WiMAX/LTE deployments will use TDD.
  - Allows more flexible sharing of DL/UL data rate
    Good for data
  - Does not require paired spectrum
  - Easy channel estimation $\Rightarrow$ Simpler transceiver design
  - Con: All neighboring BS should time synchronize

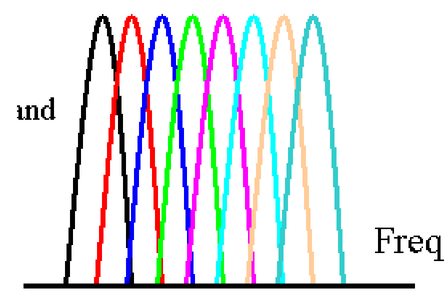
OFDM

- Orthogonal Frequency Division Multiplexing
- Ten 100 kHz channels are better than one 1 MHz Channel
  $\Rightarrow$ Multi-carrier modulation





- Frequency band is divided into 256 or more sub-bands. Orthogonal $\Rightarrow$ Peak of one at null of others
- Each carrier is modulated with a BPSK, QPSK, 16-QAM, 64-QAM etc depending on the noise (Frequency selective fading)
- Used in 802.11a/g, 802.16, Digital Video Broadcast handheld (DVB-H)
- Easy to implement using FFT/IFFT



L-DACS1 Main System Parameters

Parameter	Value
Channel bandwidth B	498 kHz
Length of FFT Nc	64
Used sub-carriers	50
Sub-carrier spacing (498/51 kHz) f	9.76 kHz
OFDM symbol duration with guard Tog	120 μs
OFDM symbol duration w/o guard To	102.4 μs
Overall guard time duration Tg	17.6 μs
OFDM symbols per data frame Ns	54

- Large number of carriers ⇒ Smaller data rate per carrier ⇒ Larger symbol duration ⇒ Less inter-symbol interference
- Reduced subcarrier spacing ⇒ Increased inter-carrier interference due to Doppler spread in mobile applications

Modulation

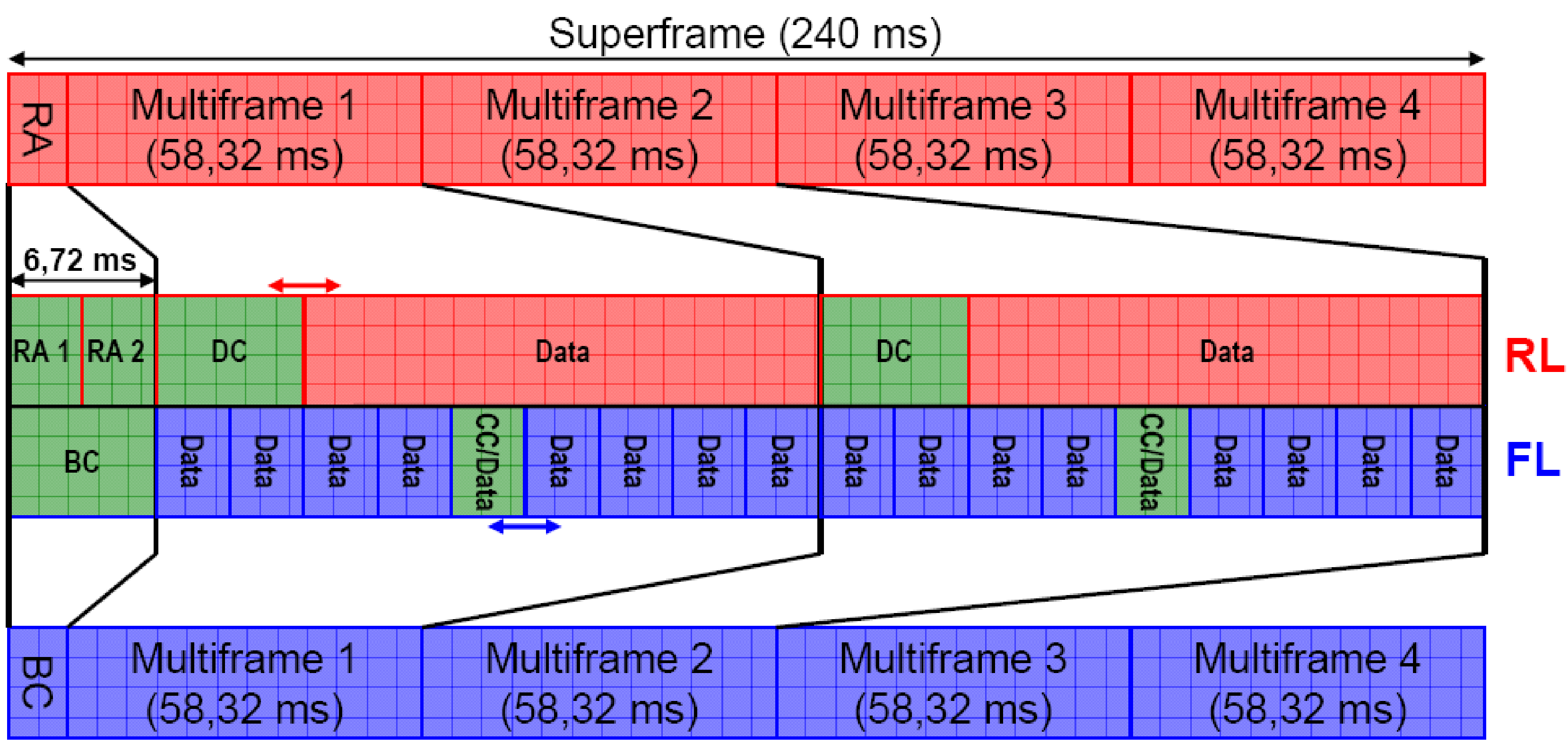
- L-DACS1: OFDM, Adaptive Coding and Modulation (ACM)
- L-DACS2: Single carrier, Continuous Phase Frequency Shift Keying (CPFSK)/Gaussian Minimum Shift Keying (GMSK)
- GSM uses GMSK
- WiMAX, 11a/g/n use OFDM
- Advantages of OFDM:
  - Graceful degradation if excess delay
  - Robustness against frequency selective burst errors
  - Allows adaptive modulation and coding of subcarriers
  - Robust against narrowband interference (affecting only some subcarriers)
  - Allows pilot subcarriers for channel estimation

Ref: http://en.wikipedia.org/wiki/Gaussian_Minimum_Shift_Keying#Gaussian_minimum-shift_keying

Data Rate

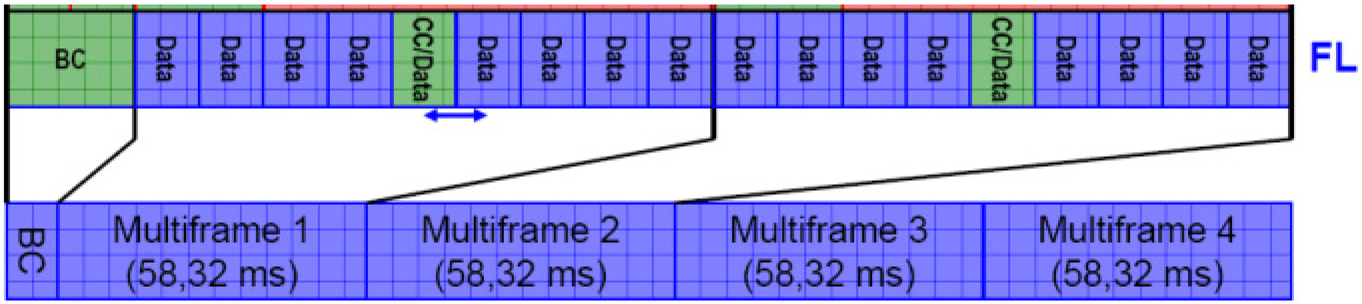
- L-DACS1: QPSK1/2 - 64-QAM 3/4
  - ⇒ FL (303-1373 Kbps)+ RL (220-1038 Kbps) using 1 MHz
  - ⇒ Spectral efficiency = 0.5 to 2.4 bps/Hz
- L-DACS2: 270.833 kbps (FL+RL) using 200 kHz
  - ⇒ Spectral efficiency = 1.3 bps/Hz

L-DACS1 PHY Framing



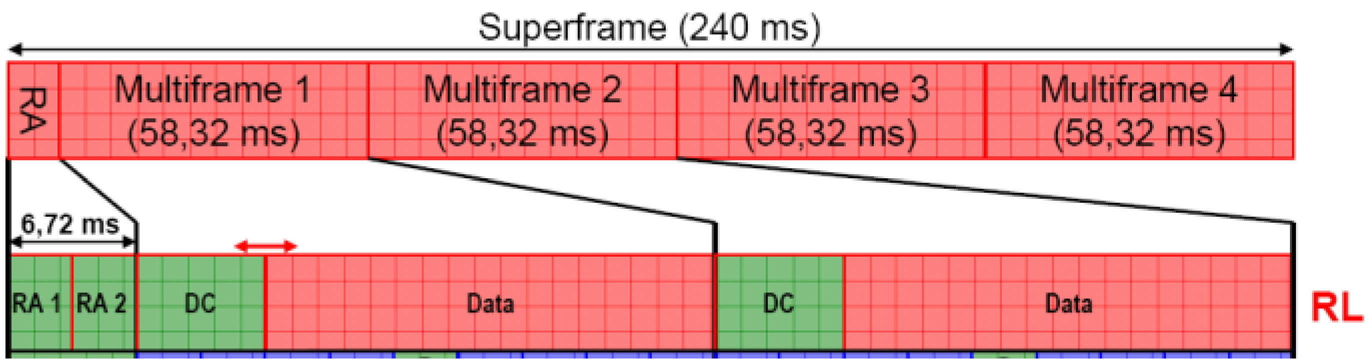
RA=Random Access
DC=Dedicated Control
CC=Common Control
BC=Broadcast Control

L-DACS1 Forward Link



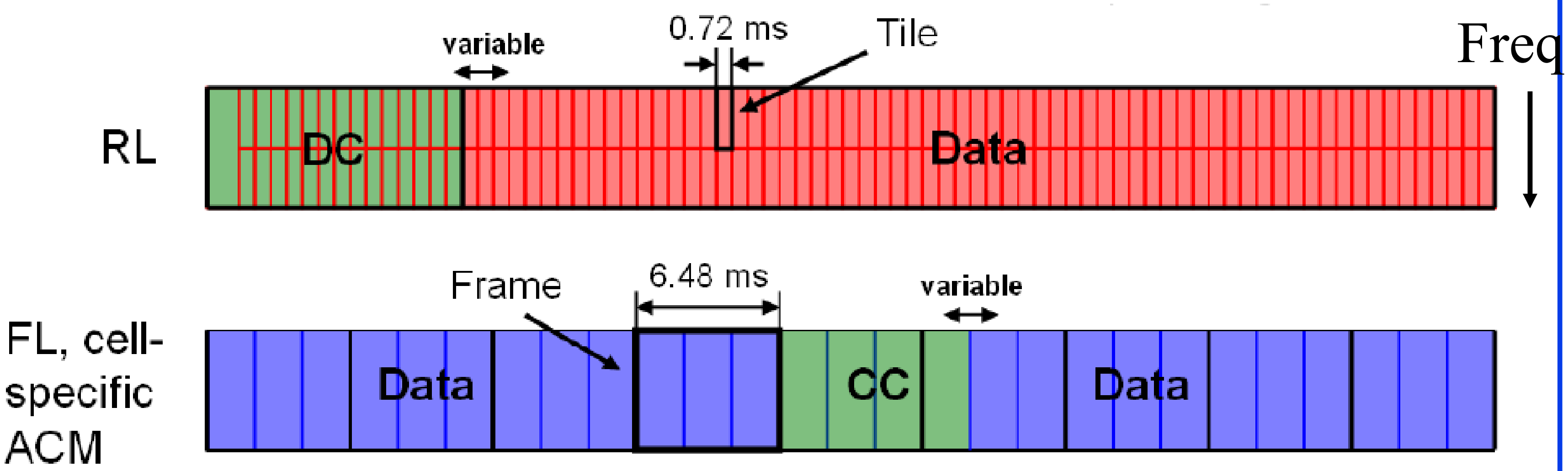
- Super Frame (SF) = 240ms = 2000 OFDM symbols
- Super Frame = Broadcast Control + 4 Multi-Frame (in FL)
- Multi-Frame (MF) = 58.32ms = 486 OFDM symbols
- Broadcast Control (BC)= 6.72ms = 54 OFDM symbols
- Payload Data/Common Control = 6.48 ms
- Data = 3 PHY PDUs
- Common Control (CC) = 1-14 PHY PDUs
- 1 Multi-Frame = 4 Data + 1 CC + 4 Data

L-DACS1 Reverse Link



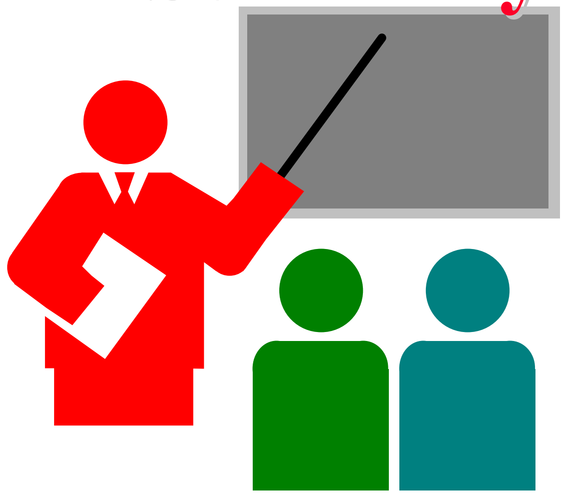
- Super Frame = 2 Random Access + 4 Multi Frame
- Random Access (RA) = 6.72/2 s
- Dedicated Control (DC)
  = 1 AGC + 5 OFDM Sync + 1 PDU (6 Symbols)
  = 12 Symbols (min)
- Each AS has one dedicated RL PHY-PDU for its "dedicated control channel" DCCH.

L-DACS1 Reverse Link (Cont)



- Each AS is allocated some number of tiles
- Tile = 25 contiguous subcarriers over 6 contiguous OFDM symbols
- TDMA component in RL ensures low duty cycle
  ⇒ Each AS finishes fast.
- TDMA component reduces co-site interference impact
  Co-site=Multiple antennas close to each other

Summary



	L-DACS1	L-DACS2
Modulation	√OFDM	Single Carrier
Spectral efficiency	√0.5-2.3 bps/Hz	1.3 bps/Hz
Spectrum Flexibility	√Entire L-Band	Lower L-Band
Duplexing	FDD	√TDD

L-DACS1 References

- EUROCONTROL, "L-DACS1 System Definition Proposal: Deliverable D2," Feb 13, 2009, 175 pp.
- EUROCONTROL, "L-DACS1 System Definition Proposal: Deliverable D3 - Design Specifications for L-DACS1 Prototype,", April 1, 2009, 122 pp.
- T. Graupl, "L-DACS 1 Data Link Layer Design and Performance," Presentation slides, ICNS Conference, 13-15 May 2009, 31 pp.
- M. Schnell, "L-DACS 1 Development - Status and Preliminary Specification," Presentation Slides, 7th EUROCONTROL Innovative Research Workshops and Exhibition, Dec 2-4, 2008, 23 pp.

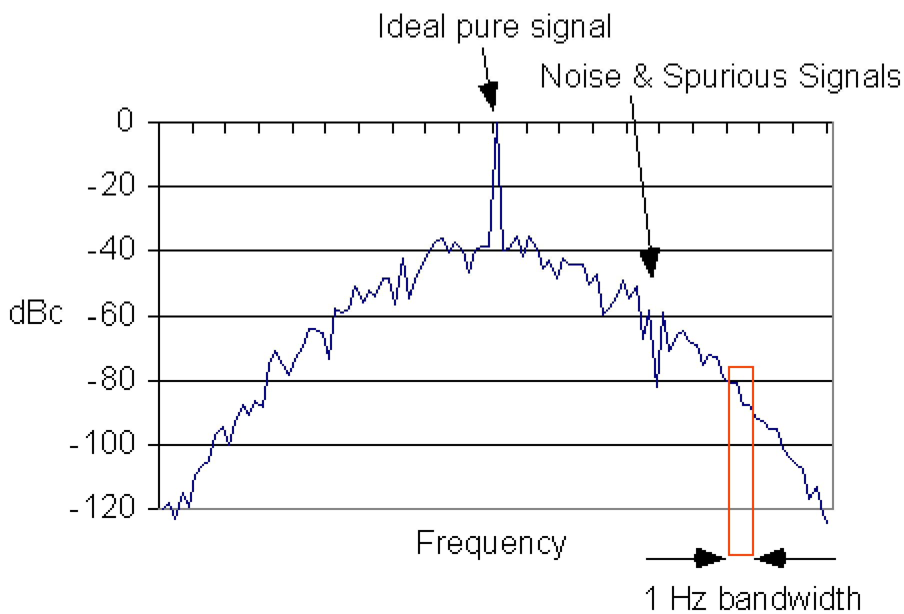
L-DACS2 References

- EUROCONTROL, "L-DACS2 System Definition Proposal: Deliverable D1," Mar 11, 2009, 116 pp.
- EUROCONTROL, "L-DACS2 System Definition Proposal: Deliverable D2," May 11, 2009, 121 pp.
- EUROCONTOROL, "L-DACS2 Transmitter and Receiver prototype equipment specifications: Deliverable D3," June 18, 2009, 47 pp.
- L. Deneufchâtel, "LDACS 2," Presentation slides, March 25, 2009, 9 pp.
- L. Deneufchâtel, "LDACS 2 Development Status and preliminary specifications," Presentation slides, Mar 12, 2008, 22 pp.

L-DACS2 Power Budget

	Uplink		Downlink	
Tx	55	350 W	47	50 W
Tx EIRP	61	5,5 dB	44	"- 3 dB"
Loss	143	200 Nm	143	200 Nm
Rx	-83	3 dB	-92	2,5 dB
Thermal noise	-108		-111	
Rx sensitivity	-97		-100	
Minimum C/N	11	11,32	11	11,32
C/N	25		20	
Margin	8		3	

Source: Deneufchâtel, 2009


Ideal pure signal
Noise & Spurious Signals
0
-20
-40
dBc -60
-80
-100
-120
Frequency
1 Hz bandwidth