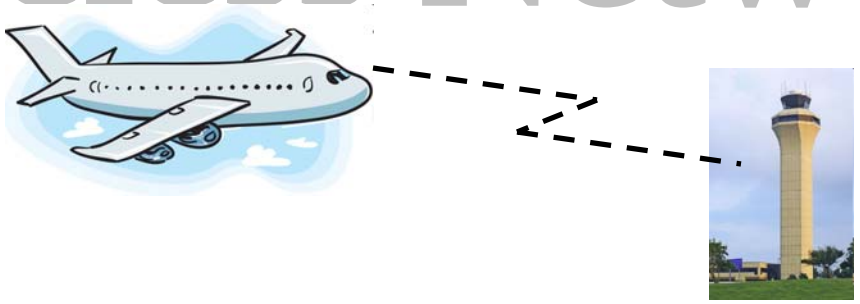
# Aeronautical Wireless Networks



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Audio/Video recordings of this lecture are available at:

http://www.cse.wustl.edu/~jain/cse574-10/

# Overview

- Aeronautical Wireless Applications
- Aeronautical Datalink Evolution
- L-DACS
- Interfering Technologies
- Coexistence Strategies

# Frequency Bands

- High Frequency (HF): 3-30 MHz
- Very High Frequency (VHF): 30-300 MHz
- L-Band: 950-1450 MHz - results from down conversion of satellite signals by LNB (Low noise block converters)

| | |
|---|---|
| L band | 1 to 2 GHz |
| S band | 2 to 4 GHz |
| C band | 4 to 8 GHz |
| X band | 8 to 12 GHz |
| Ku band | 12 to 18 GHz |
| K band | 18 to 26.5 GHz |
| Ka band | 26.5 to 40 GHz |

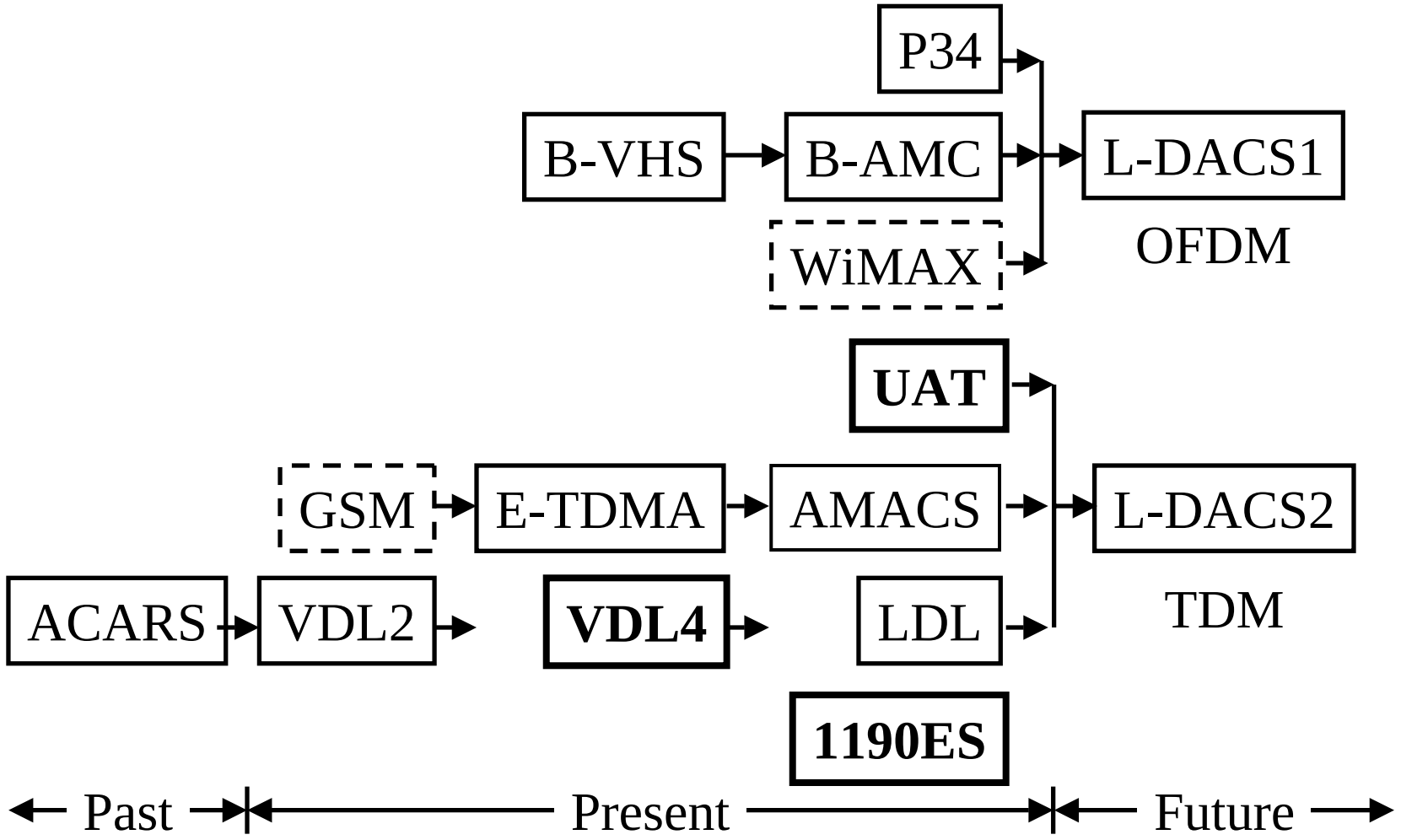
Ref: http://en.wikipedia.org/wiki/Ka_band

# Aeronautical Wireless Applications

- Distance measuring equipment (DME)
- Passenger telephones
- Aeronautical Operation Control (AOC)
- Automatic Dependent Surveillance Broadcast (ADS-B)
- Airline administrative control
- Controller-Pilot Datalink Communication (CPDLC)
  - Voice communication between pilot and controller
  - Data communication between plane and the tower

This lecture is limited to recent developments in voice/data communication

# Aeronautical Datalinks



# Aeronautical Datalink Evolution (Cont)

- ACARS (Aircraft Communications Addressing and Reporting System):
  - Short telex-like messages between plane and ground.
  - Uses VHF (117.975 - 137 MHz) and Satellites
  - Uses HF in the polar region (HF ACARS)
  - Developed by ARINC in 1978. Analog radio.
- VDL (VHS Digital Link):
  - Four modes - 1, 2, 3, 4. Mode 1 was deleted in 1994.
  - VDL2 required in all aircrafts flying in Europe.
    8-PSK over 25 kHz $\Rightarrow$ 31.5 kbps
    Widely Implemented since 1994

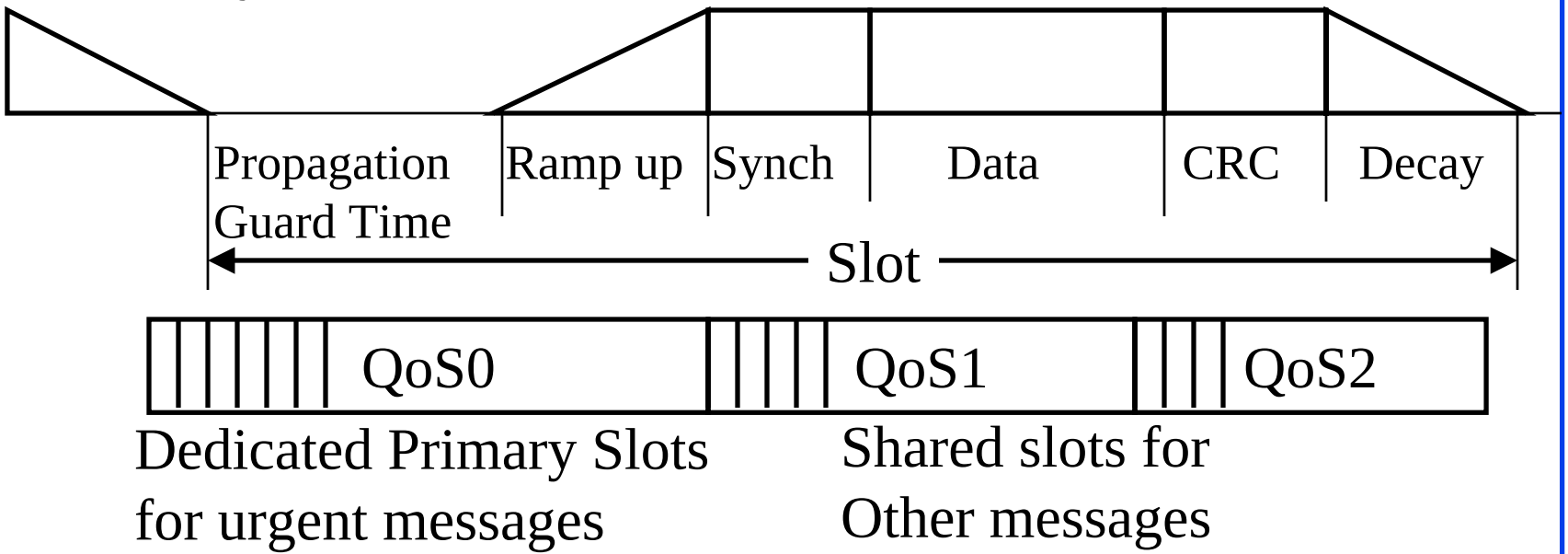
# Aeronautical Datalink Evolution (Cont)

- VDL3 – Added digital voice to VDL2. Abandoned in 2004
- VDL4 – Added aircraft-to-aircraft communication. No master ground station required. Developed in 2001. Limited deployment.

- UAT (Universal Access Transceiver):
  - 981 MHz
  - 1 Mbps channel rate using 3 MHz
  - Each aircraft allowed to transmit one 16 or 32B message every second
  - Developed 2002
- 1090ES (1090 MHz Extended Squitter): Secondary surveillance radar (aka Mode S) with a "extended squitter" message that periodically announces position, velocity, time, and intent

# E-TDMA

- Extended Time Division Multiple Access
- Developed by Hughes Network Systems. 1998-2001.
- Statistical Self Synchronization: Aircrafts measure guard times arrivals from other devices and adjust their clocks
- TDMA system like GSM. Slotted Structure and Multi-QoS




**Ref:** "The E-TDMA Concept: Towards a new VDL strategy - Some key issues & possible way forward," AMCP-WG/C2-WP26 7-11 May 2001, http://www.icao.int/anb/panels/acp/WG/C/wgc2/wgc2_wp26.ppt

# LDL

- L-Band Digital Link
- VDL3 shifted to L-Band
- TDMA frame structure with 120 ms frames and 5 slots/frame (like GSM)
- Some of the slots can be allocated for voice. Others are used for data.

# AMACS

- All Purpose Multichannel Aviation Communications System (AMACS). Completed October 2007
- Based on E-TDMA slots and QoS. xDL4 broadcast. GSM/UAT coding (GMSK)
- Flexible 100 kHz, 200kHz, or 400 kHz spectrum in 960-975 MHz band
- 0.1 ms ramp up
- 0.9ms guard time ⇒ 150 nm cell radius


**Ref**: L. Deneufchatel and L. Johnsson, "All-purpose Multi-channel Aviation Communication System (AMACS)," AGC FG/4 meeting, 13 September 2007, http://www.eurocontrol.int/nexsat/gallery/content/public/Steering%20Group/Meeting9/DAY1/AI2_3_2_2_1AMACS.pdf

# B-VHF

- Funded by European Commission 6th Framework Program
- 118-137 MHz VHF band
- Multi-Carrier Code-Division Multiple Access (MC-CDMA) = OFDM + CDMA
- Each bit is encoded as multiple chips and these chips use separate subcarriers of OFDM
- Excessive noise in one subcarrier ⇒ loss of one chip ⇒ Symbol can still be decoded
- Time division duplexing (TDD)
- 2 kHz subcarrier spacing

Ref: http://www.b-vhf.org

# B-AMC

- Broadband Aeronautical Multicarrier Systems in L-Band
- B-VHF extended to L-Band
- Air-to-Ground mode: OFDM and FDD
- Frequency division duplexing ⇒ Two smaller (500 kHz) bands rather than on one (1 MHz) band
- 10 kHz subcarrier spacing ⇒ Increased Doppler spread required for higher frequency
- OFDMA rather than MC-CDMA
- 240 ms super frame = 4 multi-frames of 58.32 ms + 6.72 ms management frame
- Ground station uses management frame for broadcasts
  Aircraft uses management frames for "random access"
- Air-to-Air mode would require a common control channel and a global time reference ⇒ could not be designed.

Ref: http://www.eurocontrol.int/communications/public/standard_page/LBANDLIB.html

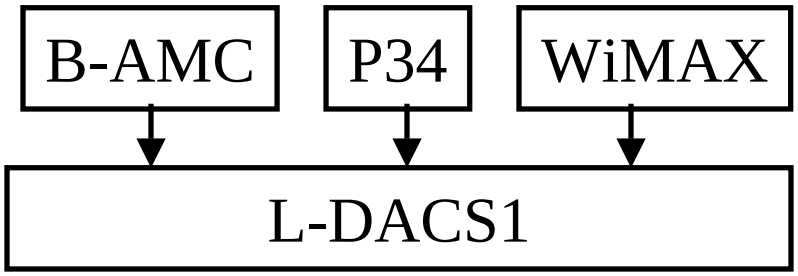
# P34

- Project 34 of Electronic Industries Association (EIA)
- Public safety radio system connecting mobile radios and fixed network and direct radio to radio communication
- 187.5 km sectors
- 50, 100, 150 kHz channels in 960-1164 MHz band

# L-DACS

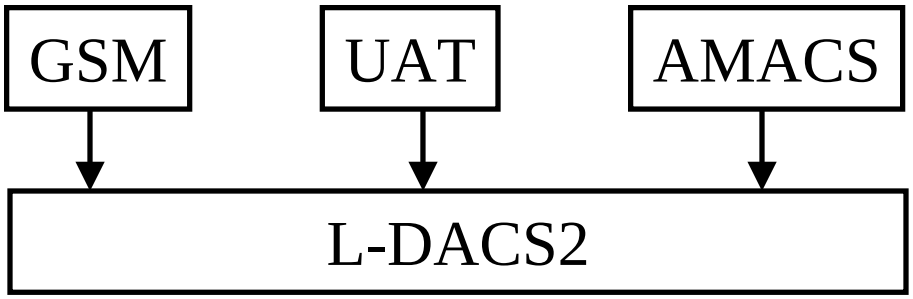
- L-band Digital Aeronautical Communications System
- Type 1 and Type 2
- Both designed for Airplane-to-ground station communications
- Airplane-to-airplane in future extensions
- Range: 200 nautical miles (nm)
  (1 nm =1 min latitude along meridian = 1.852 km =1.15 mile)
- Motion: 600 knots = 600 nm/hr = 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

# L-DACS1 Evolution



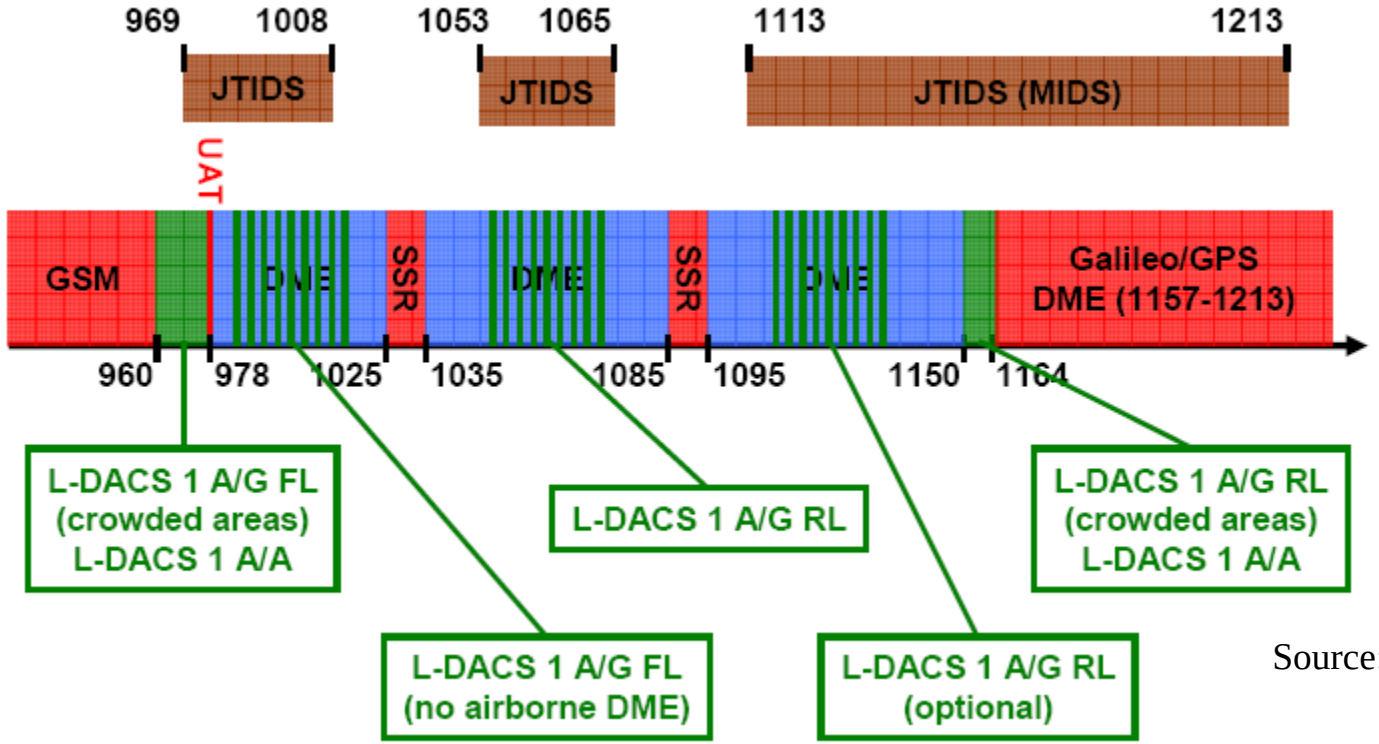

- B-AMC
  - Overall protocol stack
  - Medium access control cycle
  - Data link service protocol
- P34
  - AGC preamble concept (RL), PAPR reduction technique,
  - MAC layer states, primitives for data transfer, …
  - Control message formats
  - Addressing scheme
- WiMAX
  - Tiles and chunks in the 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-DACS1 ⇒ 2x498.5 kHz
  FL in 985.5-1008.5MHz,
  RL in 1048.5-1071.5MHz,
  Duplex spacing 63 MHz
- L-DACS2 ⇒ One 200 kHz channel in lower L-Band 960-975 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

# 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

# Interfering Technologies

1. Distance Measurement Equipment (DME)
2. Universal Access Transceiver (UAT)
3. 1090 Extended Squitter (ES)
4. Secondary Surveillance Radar (SSR)
5. Joint Tactical Information Distribution System (JTIDS)

Missing:

6. Groupe Speciale Mobile (GSM)
7. Geostationary Navigation Satellite System (GNSS)

# DME

- Distance Measuring Equipment
- Ground DME markers transmit 1kW to 10 kW EIRP.
- Aircraft DME transmits 700W = 58.5 dBm
- Worst case is Aircraft DME to Aircraft L-DACS

| | L-DACS |
|---|---|
| AS DME XMTR Power | 58.5 dBm |
| Path loss | -35 dB |
| Net Interference | 23.5 dBm |

- Same side of the aircraft or small aircrafts
  $\Rightarrow$ Even 35 dB isolation results in +23.5 dBm
- Need to design coordination

# Bluetooth and WiFi Coexistence

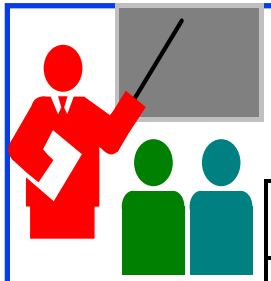
- Bluetooth frequency hops in 1 MHz carriers over 2402 - 2480 MHz (79 MHz total)
- WiFi uses OFDM with 52 subcarriers in 20 MHz channels in 2402-2480 MHz (3 non-overlapping channels)
- Most computers have both Bluetooth and WiFi
- Collaborative Strategies: Two networks on the same device
- Non-Collaborative Strategies: No common device

# Collaborative Coexistence Strategies

- Both networks on the same equipment (Laptop or IPhone):
  1. Time Division: Bluetooth skips slots when WiFi is busy, WiFi reserves time for Bluetooth between Beacons
  2. Packet Traffic Arbitration: Packets are prioritized and queued on a common queue for transmission
  3. Notch Filter: WiFi OFDM does not use subcarriers to which Bluetooth hops

# Non-Collaborative Coexistence Strategies

- Measure noise level and error rate:
  Random bit errors $\Rightarrow$ Noise
  1. Adaptive Packet Selection: Bluetooth uses coding (FEC and Modulation) depending upon interference. Use FEC only if noise. No FEC if interference.
  2. Master Delay Policy: Bluetooth keeps track of error rates on various frequencies. Refrains from transmission on frequencies where interference is high
  3. Adaptive frequency hoping: Hop over only good frequencies
  4. Adaptive Notch Filter on WiFi



# 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 |

1. SS Radar, DME, UAT, and L-DACS from the same plane will require some co-ordination technique to be developed
2. GSM base stations located near the airport can seriously interfere with L-DACS
3. L-DACS1 has better chances of coexistence because of OFDM
4. Need to extend known coexistence strategies to L-DACS

# Related Wikipedia Articles

- http://en.wikipedia.org/wiki/Next_Generation_Air_Transportation_System
- http://en.wikipedia.org/wiki/Automatic_dependent_surveillance-broadcast
- http://en.wikipedia.org/wiki/Air_traffic_control_radar_beacon_system#Mode_S
- http://en.wikipedia.org/wiki/CPDLC
- http://en.wikipedia.org/wiki/VHF_Data_Link
- http://en.wikipedia.org/wiki/Aircraft_Communications_Addressing_and_Reporting_System

# References


- Dale Stacey, "Aeronautical Radio Communication Systems and Networks," April 2008, 372 pp., ISBN:978-0-470-01859-0
- Eurocontrol L-band Communications Library, http://www.eurocontrol.int/communications/public/standard_page/LBANDLIB.html
  - EUROCONTROL, "L-DACS1 System Definition Proposal: Deliverable D2," Feb 13, 2009, 175 pp.
  - EUROCONTROL, "L-DACS2 System Definition Proposal: Deliverable D2," May 11, 2009, 121 pp.
  - "Future Communications Infrastructure – Step 2: Technology Assessment Results," http://www.eurocontrol.int/communications/gallery/content/public/documents/FCI_Step%202%20Report_V10.pdf

# References (Cont)


- Helios, "FCI Technology Investigations: L-Band Compatibility Criteria and Interference Scenarios Study, Deliverables S1-S7: L-Band Interference Scenarios," Eurocontrol, Report, 25 August 2009, 49 pp.

# List of Acronyms

- 1090ES 1090 Extended Squitter
- 8-PSK 8 Phase Shift Keying
- ACARS Aircraft Communications Addressing and Reporting System
- ADS-B Automatic Dependent Surveillance Broadcast
- AGC Automatic Gain Control
- AMACS All Purpose Multichannel Aviation Communications System
- AOC Aeronautical Operation Control
- ARINC Aeronautical Radio, Inc.
- AS Aircraft Station
- ATS Aeronautical Traffic Services
- B-AMC Broadband Aeronautical Multicarrier Systems
- B-VHF Broadband Very High Frequency System
- BC Broadcast Control
- CC Common Control
- CDMA Code Division Multiple Access

# List of Acronyms (Cont)

- CPDLC Controller-Pilot Datalink Communication
- DCH Data Channel
- DME Distance Measurement Equipment
- E-TDMA Extended Time Division Multiple Access
- EIA Electronic Industries Association
- FCI Future Communications Infrastructure
- FDD Frequency Division Duplexing
- FEC Forward Error Correction
- FL Forward Link (Ground to Airplane)
- GHz GHz
- GMSK Gaussian Minimum Shift Keying
- GS Ground Station
- GSM Groupe Speciale Mobile
- HF High Frequency
- JTIDS Joint Tactical Information Distribution System
- L-DACS L-band Digital Aeronautical Communications System

# List of Acronyms (Cont)

- LDL L-band Digital Link
- MC-CDMA Multi-carrier Code Division Multiple Access
- MHz Mega Hertz
- OFDM Orthogonal Frequency Division Multiplexing
- OFDMA Orthogonal Frequency Division Multiple Access
- P34 Project 34
- PAPR Peak-to-Average Power Ratio
- PHY Physical Layer
- RA Random Access
- SS Secondary Surveillance
- SSR Secondary Surveillance Radar
- TDD Time division duplexing
- TDMA Time Division Multiple Access
- UAT Universal Access Transceiver
- VDL VHS Digital Link
- VHF Very High Frequency