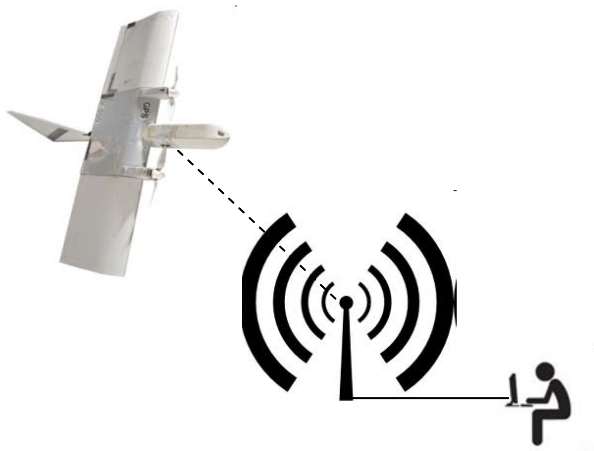
Wireless Datalink for Unmanned Aircraft Systems: Requirements, Challenges and Design Ideas



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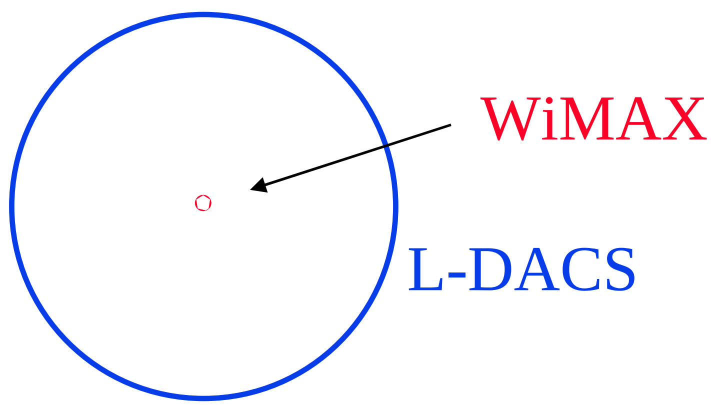
AIAA InfoTech Conference, Saint Louis, MO, March 29, 2011

These slides and audio/video recording of this talk are at:
http://www.cse.wustl.edu/~jain/talks/uas_dlt.htm

1. Challenges: Distance, Velocity, Spectrum
2. L-DACS1 vs. L-DACS2
3. Design Issues: Availability, Preemption, Chaining
4. Interference Mitigation

Aeronautical Datalinks: Challenges

- Very long distances:
  - WiFi covers 100 m
  - WiMAX cells are 1km in urban and 3 km in suburban areas
  - L-DACS needs to cover 360 km (200 nautical miles)
    - Limited Power ⇒ High bit error rate or very low data rate ⇒ Low Spectral efficiency (2 bps/Hz is a challenge)
    - Long turn-around times ⇒ Large guard times (360 km = 1.2 ms one-way at speed of light)



Datalinks Challenges (Cont)

- Very High Mobility:
  - WiFi isn't designed for mobility
    (200m at 60km/h = 12s between handovers)
  - WiMAX is optimized for 0-10 km/h, operates up to 120 km/h
  - L-DACS has to operate up to 600 nm/h (1080

Issue 1: Spectrum

- 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 more bandwidth and higher data rate
  $\Rightarrow$ Trend: Move up in Frequency
- Effect of Frequency on signal:

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2$$

- Attenuation $\propto$ (frequency)^2(distance)^2
  $\Rightarrow$ Lower Frequencies have lower attenuation,
  e.g., 100 MHz has 20 dB less attenuation than 1GHz
  $\Rightarrow$ Lower frequencies propagate farther
  $\Rightarrow$ Cover longer distances

Spectrum (Cont)

- Doppler Shift = velocity/wavelength
  $\Rightarrow$ Lower frequencies have lower Doppler shift
  Higher Frequencies not good for high-speed mobility
  Mobility $\Rightarrow$ Below 10 GHz
- Higher frequencies need smaller antenna
  Antenna $\geq$ Wavelength/2, 800 MHz $\Rightarrow$ 6”
- Higher frequencies are affected more by weather
  Higher than 10 GHz affected by rainfall
  60 GHz affected by absorption of oxygen molecules

L-DACS: Common Features

- 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/h = 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

- OFDMA: Similar to WiMAX
- Multi-carrier: 50 carriers 9.76 kHz apart
- Use two channels of 498 kHz each

L-DACS2

- Based on GSM
- GSM PHY, AMACS MAC, UAT Frame Structure
- Uses Gaussian Minimum Shift Keying (GMSK) modulation as in GSM
- GSM works at 900, 1800, 1900 MHz
  ⇒ 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.

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

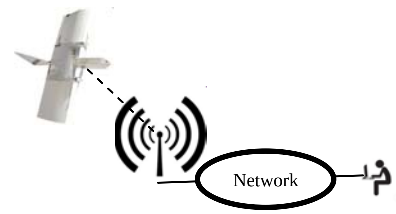
L-DACS1 vs. L-DACS2

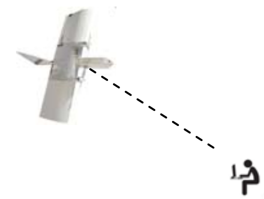
1. L-DACS1 with OFDM is more scalable than L-DACS2 with single carrier modulation.
2. L-DACS1 also has better spectral efficiency because it can use adaptive modulation and coding (QPSK through 64 QAM).
3. Multi-carrier design of L-DACS1 is also more flexible in terms of spectrum placement.
4. Multi-carrier design of L-DACS1 is also more suitable for interference avoidance and co-existence than L-DACS2.
5. The TDD design of L-DACS2 is better suited for asymmetric data traffic than FDD design of L-DACS1.
6. The cyclic prefix and subcarrier spacing of L-DACS1 need to be analyzed to check if it will work at aircraft speeds.
7. GSM900 stations may cause significant interference with the L-DACS systems. Again L-DACS2 is more susceptible to such interference.

Ref: See Related paper.

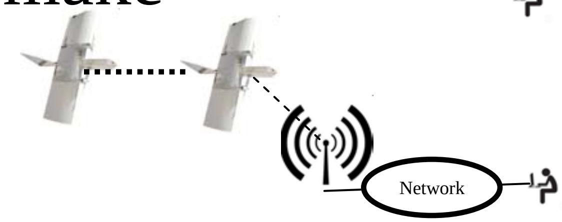
UAS Datalink Design Issues

1. Availability
2. Networked or non-networked (Defense): Support both





3. Preemption: Preempt non-critical to make room for critical
4. Chaining: Aircraft-to-Aircraft



5. Compatibility with manned aircrafts: Sharing the same airspace

Availability: Traditional Definition

- Availability = P(System being up) = $\frac{\text{Up Time}}{\text{Total Time}}$
- Problems:

A. --------- --------- --------- --------- --------- --------- --------- --------

B. --   ---------

C. --- --- --- --- --- --- --- --- --- --

- All of the above are 90% availability
- No distinction for large downtime or small uptime
- Revised Definition: Ignore small uptime
- Availability2=P(System being up >Ta)

$$= \frac{\Sigma\ (\text{Uptime}|\text{Uptime}>\text{Ta})}{\text{Total Time}}$$

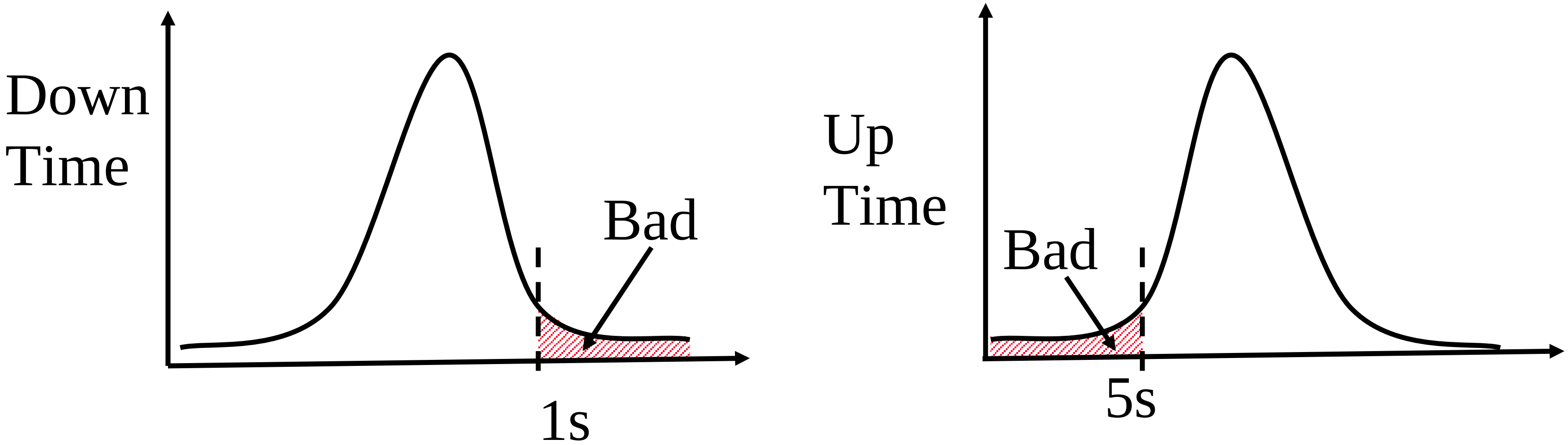
Continuity: Definition 1

- Continuity = P(Transaction completion)
  Transaction Time = Tc

$$=P(\text{Uptime}>T_c) = \frac{\Sigma\,(\text{Uptime}|\text{Uptime} > T_c)}{\text{Total Time}}$$

- This is the current definition of continuity.
- This is same as Availability2 with Ta replaced by Tc.
- Problems:
  - Ignores large downtimes
  - It is really not the probability of transaction completion

Percentiles

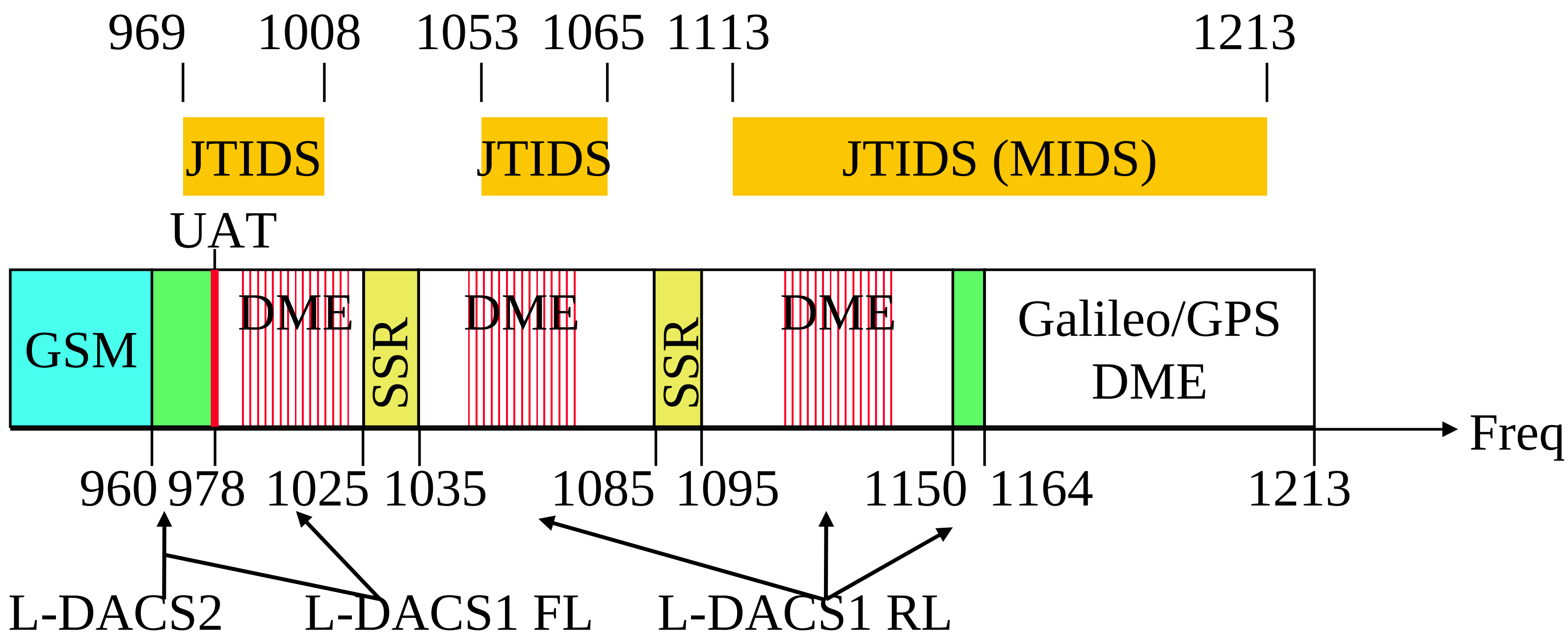


- 99.9-percentile downtime and 0.1-percentile uptime are more meaningful than any metric based on total uptime or downtime
- Alternately:
  - Probability of downtime > Tc = 0.999
    Probability of Uptime <Ta = 0.001

Availability Summary

- For time critical services, sums are meaningless (Difficult to assess risk)
- Statistics related to individual downtime or uptime are more meaningful
- Percentiles of downtime are meaningful in risk assessment.

L-Band Spectrum Usage



- 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

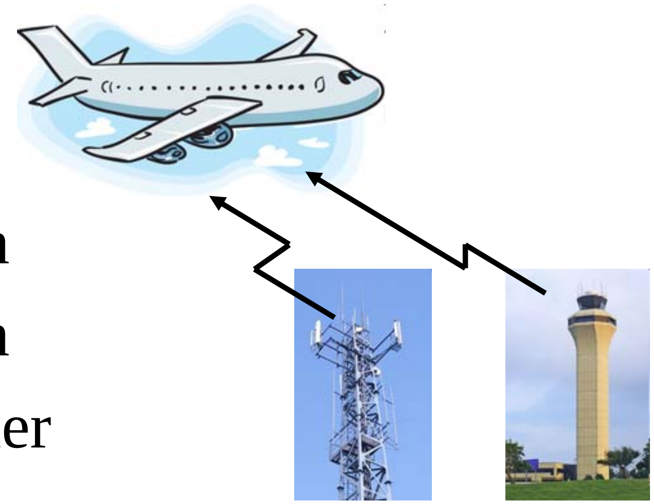
DME=Distance Measuring Equipment
JTIDS=Joint Tactical Information Distribution System
MIDS=Multifunction Information Distribution System
SSR=Secondary Surveillance Radar
GSM=Global System for Mobile Communications

Issue 4: Interference

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

GSM900 Interference



- Maximum allowed EIRP 62 dBm
  - 43 dB power + 19 dBi Antenna gain
  - 37 dB power + 25 dBi Antenna gain
- -80 dBc power at 6 MHz from the carrier
- GSM900 Interference:
  - L-DACS1 = -22dBm
  - L-DACS2= -10.8 dBm
    (L-DACS2 uses a band close to GSM)

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

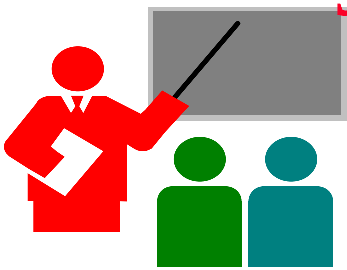
Collaborative Coexistence Strategies

- 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



1. Designing UAS wireless datalink is challenging because of long distances, high-velocity, and spectrum availability issues
2. L-DACS1 vs. L-DACS2: L-DACS1 uses √ OFDM with × FDD while L-DACS2 uses × TDM with √ TDD
3. Traditional definitions of availability/continuity are not suitable for sense and avoid high-risk systems. Percentiles are better.
4. Other UAS datalink design issues include networked/non-networked scenario, pre-emption, aircraft-to-aircraft chaining, and compatibility with manned systems
5. Interference with GSM and other systems can be avoided using collaborative and non-collaborative approaches.

Related Paper

- Raj Jain, Fred L. Templin, Kwong-Sang Yin, "**Analysis of L-Band Digital Aeronautical Communication Systems: L-DACS1 and L-DACS2**," IEEE Aerospace Conference, Big Sky, Montana, March 5-12, 2011, http://www1.cse.wustl.edu/~jain/papers/ldacs.htm