2001-06-26

Questions for any and all VDL Mode 2 proponents

Comparisons between VDL Mode 2, 4 (and 3).

1. Introduction

During the last five years it has become obvious that we need to make a choice of data link technology. The selection should be made on the operational and technical merits of the different technologies. A general assessment has been made based on available data for the two technologies plus the FAA proposed VDL Mode 3. The selection should be made on the total systems impact on spectrum, networking, etc..

In the following data from various measurements and studies are presented in order to facilitate the discussions and decision making process.

2. Characteristics of Mobile VHF data link systems in ICAO.

	VHF-digital link systems		
Characteristics/ Required capability	**VDL Mode 2 (CSMA)**	**VDL Mode 3 (TDMA)**	**VDL Mode 4 (STDMA)**
Data Rate/Modulation	31,5 kbps D8PSK	31,5 kbps D8PSK	19,2 kbps GFSK
Global standard	All technologies are currently global standards through ICAO		
Operation from block to block	No, can be used only where ground infrastructure is available (see Note 1)	No, ground master stations may be required so it does not cover remote areas	Yes, can be used anywhere (see Note 1)
High availability	No, unpredictable delay (see Note 5)	Yes	Yes
High integrity	All technologies have high integrity achieved through proper implementation		
Low cost	Yes	Yes	Yes
Robust and with graceful degradation	No, rapid and catastrophic failure characteristic under high traffic loads (see Note 5)	Potentially not robust due to the selected modulation scheme (D8PSK) (see Note 3)	Yes (see Note 2)
Maximise spectrum efficiency	No, contention access; wastes available spectrum (CCI values ~26 dB) (see Note 5 and 4)	No, voice and data are integrated together, but D8PSK modulation wastes available spectrum (CCI values ~26 dB)	Yes, data from many users is efficiently multiplexed. GFSK has good CCI values (~12dB)
Capacity for 2020 traffic and beyond	Not likely; depends availability of spectrum (see Note 6)	Not likely; depends on availability of spectrum (see Note 6)	Four 25 kHz channels plus one or two for AOC will be required for 2020 traffic volumes; capacity is approx. 15 times greater than VDL's Mode 2 (see Note 6)
Include flexibility to support new procedures	VDL Mode 2 is not suitable for ADS-B and ATM applications (see Note 5)	Flexibility may be limited (see Note 7)	Yes
Support easy transition	Yes, assuming availability of spectrum	Potential transition problems (see Note 7)	Yes

Notes:

1. In remote areas where there are no ground stations, VDL Mode 2 does not support air-air communications. However, VDL Mode 4 will be used for air-air communication. In continental areas, both can provide air-ground communications.
2. VDL Mode 4 incorporates the use of two global signalling channels plus local channels as required and it can also re-use the timeslots of distant users under high traffic loads. This gives redundancy and graceful degradation. VDL Mode 4 is also robust to the failure of the standard network time source (i.e. GLONASS or

GPS). If primary timing is lost, timing can be obtained from an internal oscillator, another user, from a clock in the ground network or from another satellite (e.g. television satellites) connected to the ground network.

3 A potential weakness of VDL Mode 3 is the shared voice and data spectrum A stuck transmitter could prevent both voice and data communications. This could be overcome with suitable implementation. Also, both voice and data communications are lost if the ground station fails. (Note that both air-air and air-ground communications are lost in this circumstance.) Doubts have also been raised over robustness of the proposed modulation scheme (D8PSK) for VDL Mode 2 and 3.[1]

4 The available channel time is wasted during simultaneous transmissions and in the time loss in the gaps between random messages.

5 VDL Mode 2 uses a 'contention access' protocol with similar behaviour to the Ethernet LAN protocol. This means low capacity of channel bandwidth and fails catastrophically if overloaded, although VDL Mode 2 includes some measures to try and prevent catastrophic failure. At high capacity loading the access delay becomes very long and unpredictable. A CSMA protocol is therefore fundamentally unsuited for delivery of time-critical data, e.g. differential corrections, CPDLC, TIS-B or ADS-B data, except in very low traffic densities.

6 VDL Mode 2 and 3 capacity will have lower capacity than VDL Mode 4.[2] VDL Mode 2 capacity is lower because is based on a 'contention access' protocol that is inefficient under heavy traffic loads. Both VDL Mode 2 and 3 capacities are lower because it does not re-use spectrum as efficiently. D8PSK offers a CCI value of approx. ~26 dB. (VDL Mode 4 uses GFSK with a CCI value of approx. ~5-9 dB (MOPS requires 10 dB or better), and it automatically re-uses timeslots in case of high load). Over a wide geographic area, VDL Mode 4 will have a significantly more efficient use of spectrum, particularly for ADS-B, TIS-B, CPDLC, DGNSS and also for AOC applications.

7 There are concerns[3] about the flexibility of voice/data channel allocations in VDL Mode 3. VDL Mode 3 may be unable to re-distribute channels between voice and data to adopt to requirements changes as data becomes more frequently used. This could cause particular problems during transition as data link traffic grows. Another problem is how to transition from analogue voice to digital voice given the spectrum constraints.

3. Typical message transfer requirements for an European en-route traffic scenario

(Source: EU's STF 109 Report – recalculated to current traffic volumes; 800 a/c within 300 nmi from Brussels and 100% data link equipage is assumed)

Message length	Quality of Service	Priority	Message Frequency (messages per hour)	Message type
Short	Low	Routine	1,350	Point-to-point
	Medium	Routine	2,700	Point-to-point
	High	Critical	16,200	Broadcast
		Routine	10,800	Point-to-point
	Very high	Critical	577,000	Broadcast
Medium	Low	Routine	10,800	Point-to-point
	High	Critical	1,350	Point-to-point
	Very high	Critical	31,400	Broadcast
Long	Low	Routine	6,750	Point-to-point
	High	Routine	8,100	Point-to-point
Very long	High	Routine	1,350	Point-to-point
		Total	667,800 of which critical msg ~626,000	

As can be noted from the above table the time-critical messages represents 93,7 % of the forecasted total number of messages.

[1] 'Discrimination of weaker signals using STDMA/GMSK', CARD report, 15 November 1995.

[2] Presentation 'Status of STDMA', Project Management Enterprises Inc.

[3] ICAO AMCP WG/D-meeting, San Francisco, 11-22 September 1995.

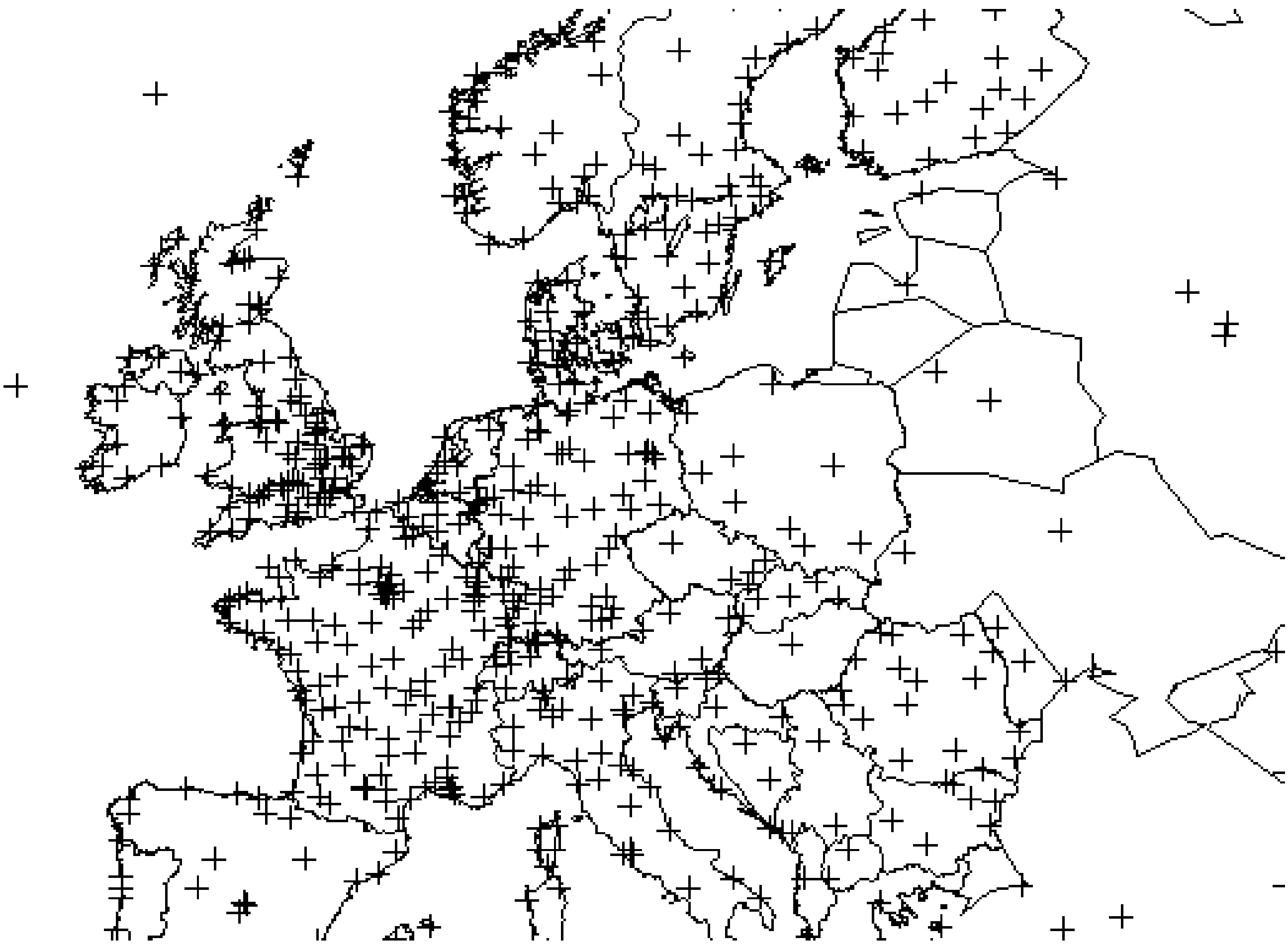
4. Traffic Growth

Eurocontrol's forecast of the total number of aircraft within a radius of 300 nmi from Brussels in the year 2015 is presented in the following table.

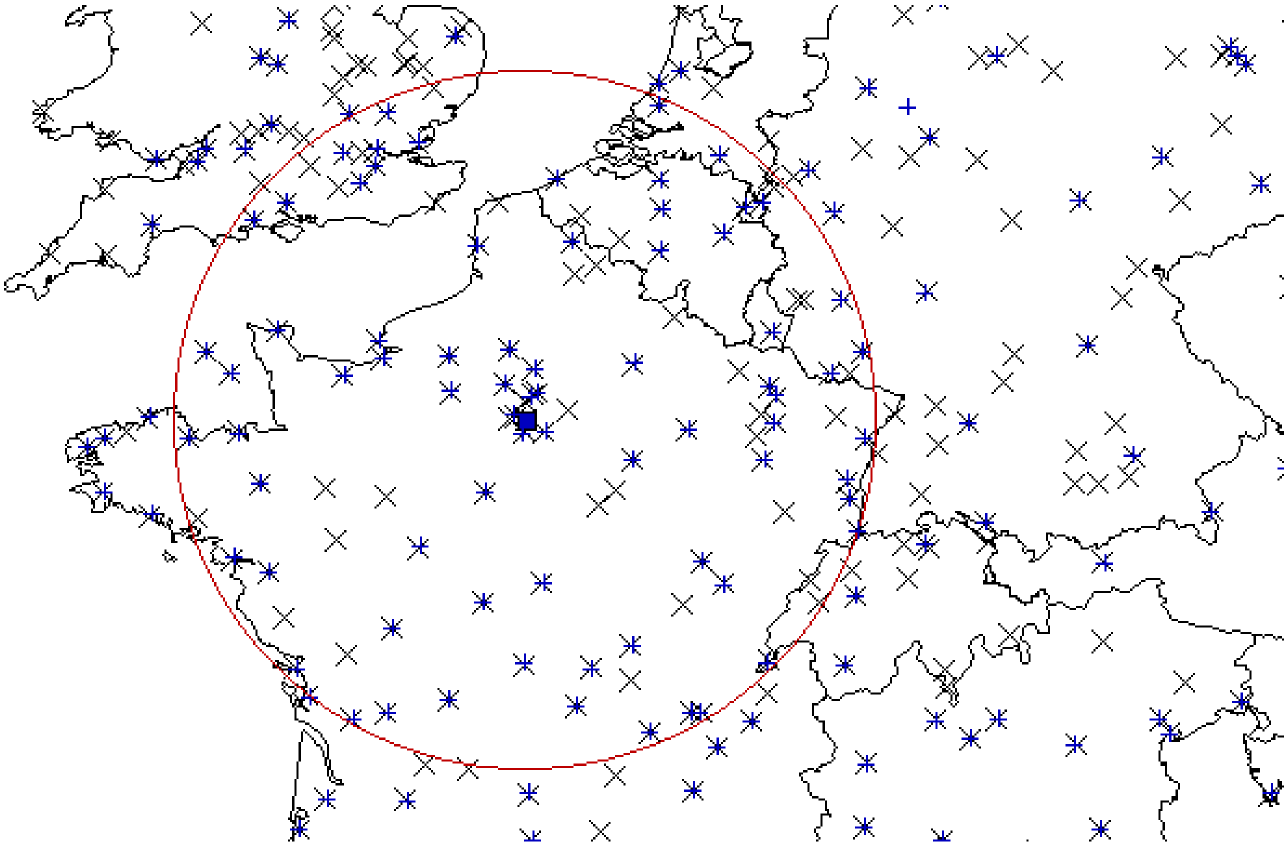
Scenario	Total Aircraft	Scenario Area
Core Europe 2015 (XCE)	2091 aircraft (73 percent increase over 1999 traffic levels) (including 150 on the ground)	300 nmi radius

5. Number of airports with schedule services

5.1. Present CAT I, II and III Airports in Western Europe



A 400 km frequency protection area around Paris



Note: For information, data from both the ICAO Air Navigation Plan (indicated as “x”) and from the Swissair database (indicated as “+”) are shown. The ICAO database includes civil and military airports, whilst the Swissair database includes only civil airports. As traffic is growing and few more runways can be expected over the next 15 years, new airports will have to be made available in order to accommodate forecasted growth.

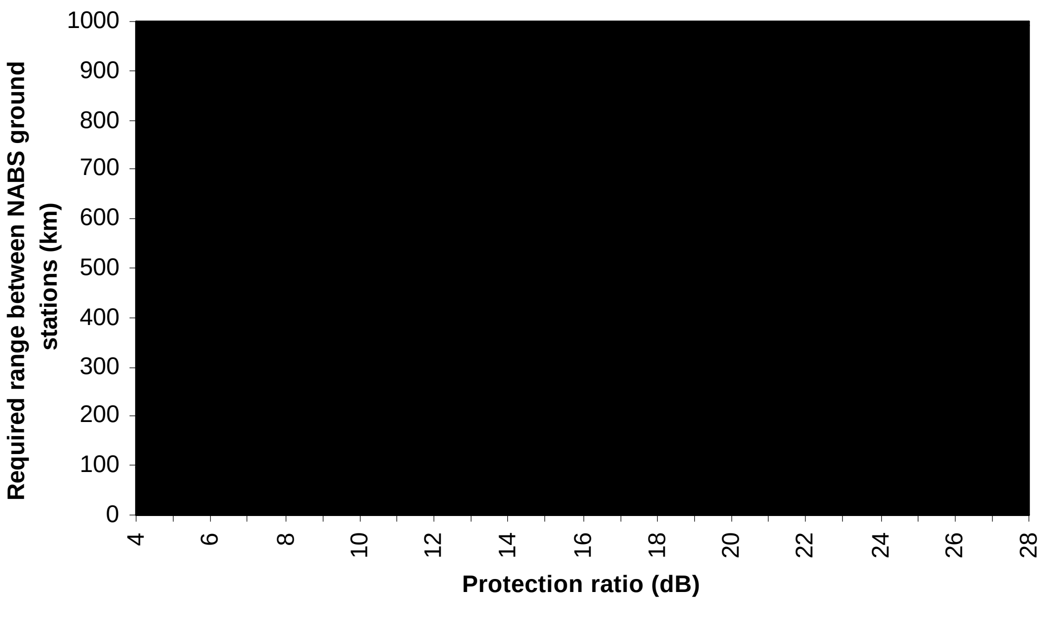
Approximately 450 – 500 airports in western and central Europe is a reasonable estimate number of airports equipped to serve schedule services under IFR conditions. Each of those will ultimately need a data link ground station.

5. Required range between ground stations

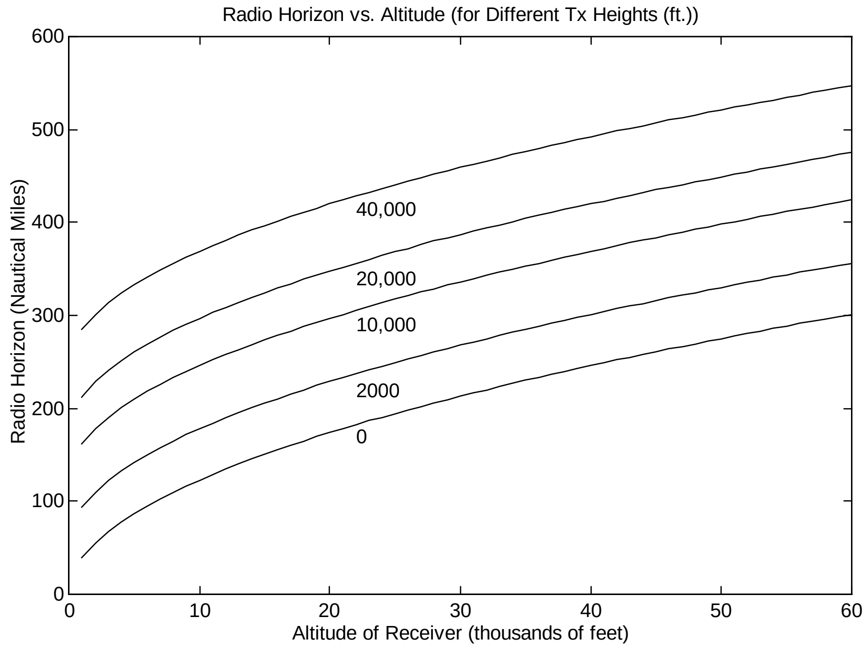
?? *Radio horizon***.** Using a 4/3 radio propagation model, the configuration of transmitter height and service volume defined above, results in a radio horizon of 380 km. Beyond this horizon, radio signal strength quickly decays. Given the approximations of the 4/3 model, and to reflect local changes in terrain, the effective radio horizon is taken to be 400 km.

?? *Desired/undesired signal ratio (D/UR).* A channel can be re-used by another ground station, even if the old signal can still be received, as long as the desired signal is sufficiently stronger than the undesired signal and the background noise. The amount by which the signal strengths must differ (the “desired/undesired signal ratio”, D/UR) depends on the discrimination properties of the modulation scheme used and the degree of additional fading safety margin required for spectrum planning. The safety margin must be set according to the level of fading experienced, but there appears to be some quantitative data available to help to decide on suitable fade margins for digital systems (with various modulation schemes) for new CNS applications. The fade margins used for existing analogue AM systems (14 dB) may not be appropriate for digital systems. This is an area that the Swedish CAA (SCAA) has investigated in its airborne trials with VDL Mode 4. US manufacturers have measured D/UR’s for VDL Mode 2 of 26-27 dB. German DFS have also made measurements but the final results are not available yet. However, for illustration, a fade safety margin of 7dB (corresponding to a difference between desired and undesired signals of about a factor of 5) is added. Results from recent SCAA flight trials using GFSK modulation at 19.2 kbps and measure by German DFS indicate that this is a safe assumption. For GFSK modulation, operating at 19.2 bps, the D/UR is taken as 14 dB, consisting of 7 dB for signal discrimination and 7 dB as a safety margin. If a similar margin were added to the D8PSK modulated VDL Mode 2 it would require a D/UR of ~33-34 dB, consisting of 26-27 dB for signal discrimination and 7 dB safety margin. D8PSK is more sensitive to noise and interference than GFSK and therefore would require a higher safety margin, but for the sake of this paper that has been disregarded. However, aircraft at high altitudes will cause interference to other aircraft en-route well beyond the radio horizon.

The figure below shows the required range between ground stations for a range of D/UR as well as the radio horizon. The radio horizon is such that the maximum required separation between ground stations is about 400km. On the edge of the radio horizon, the D/UR is about 19 dB. Since D8PSK need a greater D/UR, then the minimum required range will be determined by radio horizon, ie the D8PSK channels can be re-used after 400 km. GFSK 19.2 kbps channels can be re-used after 230 km, as determined by the D/UR of 14 dB.



Source: Swedish CAA paper to the ICAO GNSSP, 1997.



Radio horizon versus different Tx altitudes

Source: Ohio University, USA

6. Questions to and tasks for the VDL Mode 2 proponents.

In order to facilitate the selection process it is of vital importance to get data and simulation results that can help clarifying the possibility to further consider VDL Mode 2 as a candidate for implementation. Therefore any VDL Mode 2 proponent is urgently requested to provide information that could clarify:

?? VHF spectrum consequences of a full VDL Mode 2 implementation. How many 25kHz channels will be needed for a full deployment scenario taking into account traffic growth, so-called “guard-bands”[4], ground stations at each of the 450-500 European airports, etc.?
?? Concept for networking of ground stations?
?? Handling of time-critical messages such as ATC messages?

The increasing and escalating shortage of VHF spectrum in the aeronautical band requires an answer to the above questions and whether aviation needs several data link systems?

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[4] According to Eurocontrol two “guard-channels” is required for the airborne scenario and four for the ground scenarios.