Technical details of VDL Mode 2

Project report for TSKS03 spring 2016

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Abbreviations

ACARS	Aeronautical Communication And Reporting System
ADS-B	Automatic Dependent Surveillance – Broadcast
AOA	ACARS Over AVLC
AOC	Aeronautical Administrative Communications
ARINC	Aeronautical Radio Incorporated
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Service
AVLC	Aviation VHF Link Control
BS	Base Station
CPDLC	Controller Pilot Data Link Communications
CSC	Common Signalling Channel
CSMA	Carrier Sense Multiple Access
D8PSK	Differentially encoded 8 Phase Shift Keying
DLE	Data Link Entity
DSP	Data link Service provider
FANS	Future Air Navigation System
FEC	Forward Error Correction
FMS	Flight Management System
HDLC	High-level Data Link Control
HFDL	HF Data Link
ICAO	International Civil Aviation Organization
L-DACS	L-band Digital Aeronautical Communications System
LLC	Logical Link Control
LME	Link Management Entity
MAC	Medium Access Control
OSI	Open Systems Interconnection
PDU	Protocol Data Unit
SARPS	Standards And Recommended PracticeS
SITA	Societe Internationale de Telecommunications Aeronautiques
SNAcP	SubNetwork Access Protocol
VDL	VHF Data Link
QoS	Quality of Service

1 Abstract

This report is about the digital radio link known as VHF Data Link (VDL) mode 2. It will give an overview of what it is used for and some of the properties of the radio link such as modulation and channel coding,

2 Introduction

The aeronautical community is very conservative, with one of the reasons being the very long lifetime of airframes, typically more than 30 years [5]. Aircraft still uses AM VHF radios for voice communication with ground when most other users have switched to FM or digital voice.

However, congestion in the aeronautical radio bands led to the need for more efficient communication between civil aircraft and ground controllers. The first data link was known as Aeronautical Communication And Reporting System (ACARS), which was introduced by the company Aeronautical Radio Incorporated (ARINC) in 1978 [5]. The data rate (2.4 kbps) was sufficient for the time and it could easily be added to existing aircraft since it used the same analog VHF radios that was already used for voice communication. The increase in air traffic, particularly in the USA and mainland Europe, meant that higher data rates would be needed. Starting in the 1990:s, several digital data links were tested for suitability. The overarching name for these links is VHF Data Link. The method finally chosen for digital data communication (and especially for Controller Pilot Data Link Communications (CPDLC)) is VDL mode 2.

There was a total of 4 versions of VDL, where mode 1 was an early version using analog radios; mode 3 was an attempt to add digital voice to the link (which was unsuccessful when airlines failed to adopt the technology); and finally mode 4, which was initially intended as the physical layer for Automatic Dependent Surveillance – Broadcast (ADS-B), but was overtaken by the Mode S data link in 2003.

VDL mode 2 is the only VDL data link in operation, the others are no longer in use even though they are still in the standard documents. Therefore, “VDL” will be used as abbreviation for “VDL mode 2” henceforth in this document.

3 Overview

VDL is a digital radio link used for communication between aircraft and ground stations. More specifically it is used as the primary physical channel for the VHF ground/air subsystem that is used for Aeronautical Telecommunication Network (ATN).

It is defined by the International Civil Aviation Organization (ICAO) and is operated almost exclusively by the commercial service providers ARINC and Societe Internationale de Telecommunications Aeronautiques (SITA).

VDL specifies Open Systems Interconnection (OSI) Layer 1-2 and partly 3 (subnet, link and physical) for communication between civil aircraft and ground stations. [2]

It is meant to be used primarily for CPDLC, which is mandatory for all aircraft flying over Europe over flightlevel 285 (28500 feet at standard surface pressure) from 5 February 2015 [1], but as a generic data link it can be used for other things too.

Data in VDL typically consists of messages to/from pilots from/to Air Traffic Service (ATS) or Aeronautical Administrative Communications (AOC). Examples of messages are route clearances to/from Air Traffic Control (ATC) and information between the aircraft and airline.

In very busy areas, especially mainland Europe, route and area clearances are the main reason for congestion in the aeronautical bands since voice communication is used between aircraft and ground controllers. The offloading of these types of messages to a comparatively much more efficient method, in this case VDL, should enable an even higher aircraft density in these areas. Also, it will reduce the risk of mishearing a clearance, for example the flightlevel the aircraft is supposed to be at.

VDL is a data link only. There are no provisions to transmit audio information on a real-time basis (this was one of the purposes of VDL Mode 3, which has been cancelled). It is instead intended to replace a lot of voice communication, thus freeing up much needed radio spectrum.

The link management layer can also transmit information about the aircrafts position and destination airport, making it easier for the ground system to select which ground stations and frequencies to use in order to maintain a reliable link to the aircraft.

One of the other uses is to transmit ACARS messages which are otherwise transmitted over existing VHF analog voice radios using an audio minimum shift keying (MSK) modem (ACARS Over AVLC - AOA). Since ACARS is meant to be phased out, VDL will probably replace it, but currently both AOA and “Plain Old ACARS” or POA is used in many commercial aircraft.

As an access method, it uses Carrier Sense Multiple Access (CSMA), which is in principle “listen before you talk”. This method is also used for example in WiFi.

VDL is half-duplex, which means that only one station transmits at a time and the same frequency is used for all transmissions.

The communication range is approximately 400km for an aircraft at normal cruising altitudes of 30000-40000 feet.

4 Technical description

ATN is specified using the OSI model. VDL specifies the lower three layers of the ATN protocol architecture.

These three layers are the physical, data link and the lowest part of the network layer (the latter is also called the subnetwork layer).

Figure 1 shows where VDL is located within the ATN architecture according to the OSI model.

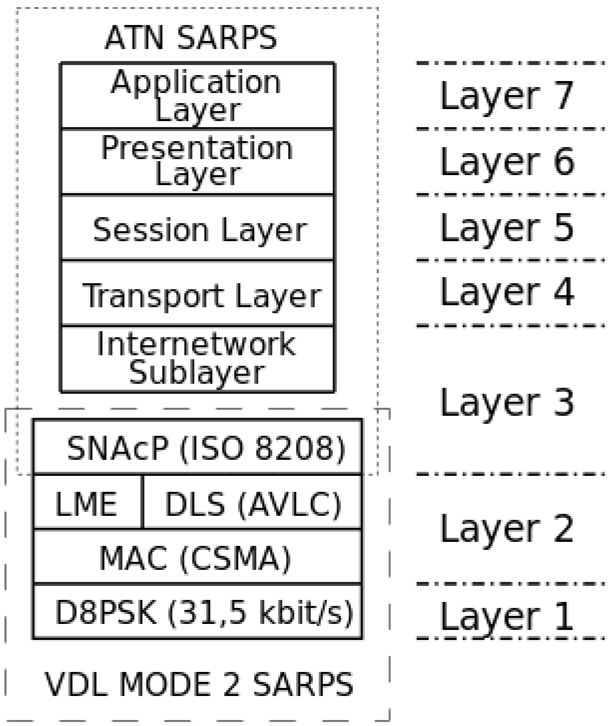

Figure 1: VDL in ATN architecture

VDL is one of several links that can be used for ATN, there are satellite and HF links that can be used as well.

This report is supposed to focus mainly on the radio parts of the data link, therefore the higher layers will only be discussed briefly.

4.1 Physical layer

VDL uses the aeronautical VHF band between 117.975 and 137.000 MHz with 25 kHz channel spacing. The common signaling channel (CSC) used for initial link establishment is 136.975 MHz worldwide. The physical layer can be described as half-duplex, as the same frequency is used for both up-link and down-link, and the channel can only be used by one radio transmitter at a time (also known as time division duplex or TDD).

After initial link establishment, the ground stations can assign a different frequency channel for an aircraft, but this is only done in very high usage areas like central Europe. For most areas, the CSC is shared with all users.

4.1.1 Modulation

VDL uses D8PSK modulation, using a raised cosine filter with α=0.6 (where α is the excess bandwidth).

The data rate is 31500 bits per second, which using D8PSK translates to 10500 symbols per second.

The input data stream is divided into groups of 3 consecutive bits with LSB first and zeros are padded at the end if it is needed for the final channel symbol.

The bits are Gray coded into the D8PSK constellation as shown in Figure 2.

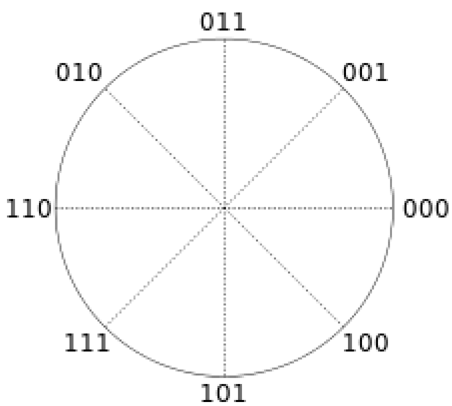

Figure 2: D8PSK constellation diagram

4.1.2 Frame format

A full frame consists of a training sequence followed immediately by an Aviation VHF Link Control (AVLC) data frame as shown in Figure 3.

Figure 3: AVLC frame format

4.1.3 Channel coding

For a data link, it is good for data reception if the data looks random. Long sequences of 0:s or 1:s can make it hard for bit synchronization, especially if the data packages are long. Therefore bit scrambling is introduced in the channel coding step. It is reversed in the receiver using the exact same pattern.

Bit scrambling is done on all data bits after the synchronization pattern using a pseudo random (PN) sequence. The PN sequence is generated using a 15-stage generator initiated with the bit pattern 1101 0010 1011 001 and using the characteristic polynomial $X^{15}+X+1$ as can be seen in Figure 4.

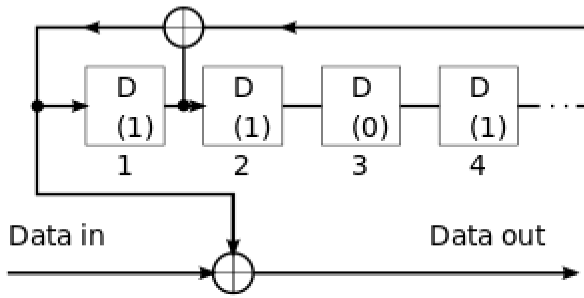

Figure 4: PN generator for channel coding

4.1.4 Training sequence

The training sequence consists of 5 symbols of transmitter ramp-up, a 16 symbol synchronization pattern, a single reserved symbol, 17 bits of transmission length and header Forward Error Correction (FEC). The FEC is a kind of checksum that enables the receiver to detect and correct some bit errors in a transmitted data packet.

The transmitter ramp-up consists of five symbols of 000.

The synchronization pattern consists of the unique word:

000 010 011 110 000 001 101 110 001 100 011 111 101 111 100 010

The synchronization pattern is there to provide a well known bit sequence at the beginning of the data burst to enable the receiver to do bit time synchronization and channel estimation.

The reserved symbol consists of three zeros.

The transmission length tells the total number of bits that follow the header FEC, not including Reed Solomon (RS) FEC and padded bits in the AVLC frame. It is transmitted LSB first. Since the transmission length consists of 17 bits, the maximum length of any transmission is 131071 bits, not including RS FEC.

The header FEC is a (25,20) convolutional block code computed over reserved symbol and transmission length. The generator matrix is shown below.

$$H=\begin{bmatrix}0&0&0&0&0&0&0&0&1&1&1&1&1&1&1&1&1&1&1&1\\0&0&1&1&1&1&1&1&0&0&0&0&1&1&1&1&1&1&1&1\\1&1&0&0&0&1&1&1&0&0&1&1&0&0&0&0&1&1&1&1\\1&1&0&1&1&0&1&1&0&1&0&1&0&0&1&1&0&0&1&1\\0&1&1&0&1&0&0&1&1&1&1&0&0&1&0&1&0&1&0&1\end{bmatrix}$$

The parity bits are calculated using the following equation:

$$[P_1, \ldots, P_5] = [R_1, \ldots, R_3, TL_1, \ldots, TL_{17}] H^T$$

This block code is able to correct all 1-bit errors and detect, but not correct, about 25% of all possible 2-bit errors [4].

The structure of the whole training sequence is shown in Figure 5.

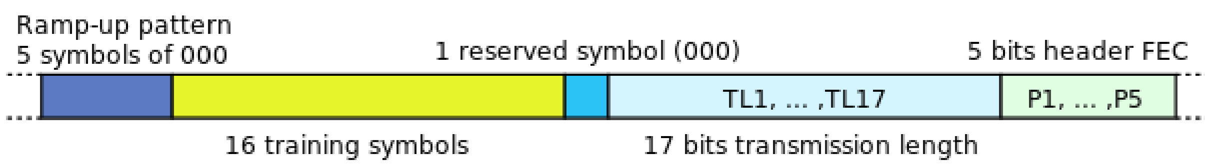

Figure 5: Training sequence structure

4.1.5 Message data and FEC

Message data to be transmitted is received from the data link layer and is then encoded as described in chapter 4.1.5.1.

Received data is decoded using the same process steps but backwards. If errors are detected, these are corrected if possible, otherwise the received frame is rejected. Only error free frames are forwarded to upper layers.

4.1.5.1 AVLC data frame message encoding

AVLC data is protected by a systematic fixed-length RS(255,249) 2^8-ary code.

In a VDL data burst, the data is always sent in 249 octet (1992 bit) blocks with FEC appended to each block.

If the data to be sent is less than 249 octets, the block is padded with zeros to fill an entire block. The padded zeros are only used to generate the correction codes and shall not be transmitted.

If there is more than 249 octets to send, the data is split up into blocks of 249 octets.

This code is byte oriented, so each data block of 249 octets are used to generate up to six RS-check octets. These octets are appended to the end of the data for a total block size of 255 octets or 2040 bits.

For data consisting of ≤ 2 octets, no error correction is used.

For data consisting of 3 to 30 octets, all six RS-octets are generated, but only the first two are transmitted. The remaining four RS-octets will be treated as erasures at the decoder.

For data consisting of 31 to 67 octets, all six RS-octets are generated, but only the first four are transmitted. The remaining two RS-octets will be treated as erasures at the decoder.

For data consisting of more than 67 octets, all six RS-octets are generated and transmitted.

The primitive polynomial of the RS code is:

$$p(x) = x^8 + x^7 + x^2 + x + 1$$

and the generator polynomial is:

$$\prod_{i=20}^{125} (x - \alpha^i)$$

where:

α is a primitive element of GF(256)

GF(256) is a Galois field of size 256.

Interleaving is used to enhance the performance of the FEC.

Interleaving is done block wise. A bit matrix is generated, with the octets from each block (including FEC) in each row. The octets are added to the matrix MSB first. The data is then sent to the physical layer taking the data column-wise, starting from the top left and first going down then right, but skipping any octet that contains padding bits or RS FEC erasures.

4.2 Data link layer

The data link layer houses the media access control, link management, frame assembly and disassembly, frame synchronization and RF channel selection.

4.2.1 Media Access Control

The MAC uses a variant of Carrier Sense Multiple Access (CSMA) called “P-Persistent CSMA”.

How this works is that when there is a request for transmission from the upper layers, the radio first senses if the channel is busy. If it is busy, the radio waits until the channel is idle. When the channel goes idle, the radio starts the transmission with the probability *p*. If the transmission is not started (which will happen with a probability of *1-p)*, a timer (called TM1) is instead started and the radio waits for that timer to expire. After that, if the channel is idle, the radio again starts the transmission with probability *p* and so on. This goes on until the message is transmitted or a predefined maximum wait time is reached.

If the maximum wait time is reached, the transmission attempt is canceled and congestion algorithms in the higher layers are called to decide how to deal with the situation.

The default value of TM1 is 4.5 ms, the default value of the maximum wait time is 60 s and the default value for *p* is 13/256.

4.2.2 Link management

Link management consists of three main entities, data link entity (DLE), logical link control (LLC) and link management entity (LME).

The DLE is the entity that provides connection-oriented or connection-less point-to-point links with the peer DLE on the other end and is implemented using AVLC, which is an adaptation of High-Level Data Link Control (HDLC), which is itself specified in [8]. This is the entity that relays data messages to and from higher layers.

The LME entity handles acquisition, establishment, disconnection and maintenance of the link itself, including physical radio channel selection. Among other things, it broadcasts information about the aircrafts position and destination airport to the ground stations. This is used by the ground system to select appropriate ground stations and frequencies for the aircraft to use to maintain reliable links between itself and the aircraft.

The LLC entity maps LME information into AVLC frames for transmission.

A more thorough explanation of this part of VDL is out of the scope of this report.

4.2.3 AVLC frame format

The AVLC frame format is adapted from HDLC and is shown in Figure 6.

FLAG (1)	Dest. addr. (4)	Source. addr. (4)	Control (1)	Information (N)	FCS (2)	FLAG (1)

Figure 6: AVLC frame structure

When assembling data for the physical layer, if there is more than one AVLC frame waiting to be transmitted, they can be assembled in the same transmit entity with only one flag octet between them. Likewise, the frames received from the physical layer may contain more than one AVLC frame, which then needs to be split apart.

AVLC is only slightly modified from HDLC. The differences are in [3] and [4]. A more detailed description of HDLC is out of the scope of this report, but can be found in [8].

4.3 Network subnet Layer

This layer is also called SubNetwork Access Protocol (SNAcP) and is based on ISO 8208 (also called X.25) [9] with some adaptations. This layer is a pure data layer with no impact on the subject of radio communication, so no further explanation of this layer is presented in this report.

4.4 VDL frame structure

Using all the information gathered so far, the following transmission scheme appears:

First, a data block from the upper layers is put into an 8208 frame and prepended with an 8208 header. Then that 8208 frame is inserted into an AVLC frame, where start and stop flags, an AVLC header and a Frame Check Sequence FCS is added. Then one or more AVLC frames are assembled and interleaved, the interleaved data blocks have their RS FEC appended, and are put into a data block that is appended to a training sequence.

The resulting data sequence is then sent to the physical layer, where it is transformed into symbols and transmitted according to the MAC rules.

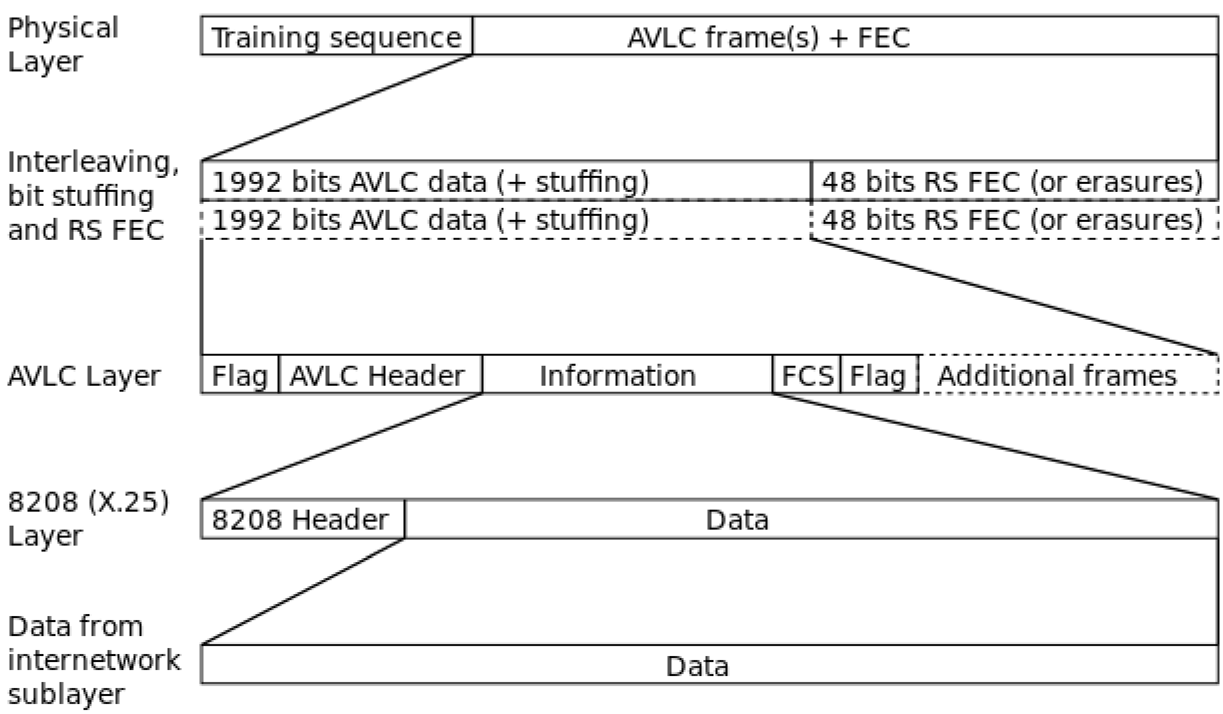

Figure 7: Complete VDL frame structure

5 Conclusion

This report has been a basic overview of VDL mode 2, a radio communication link used between aircraft and ground stations.

While VDL is a needed addition to the aeronautical radio community, there have been criticism of the use of outdated data link methods. [5] brings up several issues, specifically the legitimacy of OSI based data communication in light of modern IP-based networks and security issues that were not considered when the link was designed. A new IPv6-based protocol suite called ATN/IPS has been developed, but it is still in draft version [5][10].

6 References

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