VDL2 monitoring flights report

Analysis of the 2022 EUROCONTROL flight monitoring campaigns

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1 Summary

EUROCONTROL is performing regular monitoring flights over core of Europe to assess VDL2 performance and interference as observed from the airborne side. This report presents the analysis of the results obtained from the two monitoring flights performed in 2022 (March and August).

Data collection is done over the full flight duration by collecting IQ data samples over the whole VHF VDL2 band (136.700-137.000 MHz), permitting hence a complete analysis of the band.

The evolution of the use of VDL2 and measured performance is presented in comparison with the previous monitoring flights since 2015.

Some highlights of the analysis are summarised below.

The traffic exchange on the VDL2 frequencies in 2022 has reached levels equivalent to or above the pre-pandemic levels (2019). The ATN traffic exchanged airborne represents 50% of the overall VDL2 traffic, while AOA represents 35% and the remaining 15% is related to AVLC protocol (i.e. GSIF, hand-over, …). **The VDL2 traffic volume from ACARS messages where engine reports are expected to be found represents around 45% of the airborne AOA traffic volume.**

The Common Signalling Channel (CSC) is still the most used frequency. The hidden terminal phenomenon associated to the high number of VGSs observed from en-route is the major factor affecting performance. Keeping en-route traffic on the CSC negatively impacts the global network performance and should be avoided. **The removal of en-route traffic off the CSC would improve global performance for the whole network**. The analysis of the traffic exchanged on the ground for the top 5 busiest airports in Europe shows that one single frequency would be sufficient to handle ground traffic at airports for both ACSPs. A VDL2 coverage analysis highlighted the impact of multi-coverage on the uplink packet loss, which is further increased with multipath impacting negatively signal-to-interference ratio, even close to the VGS where the received level is expected to be comfortable. **VDL2 performance could be improved with a more optimised use of the frequencies available today.**

Finally, as observed during previous monitoring campaigns, **interferences (voice as well as industrial noise) continue to bel observed in the VDL2 frequencies**. This report focuses on the analysis of the most important interference cases observed during the two flights with an impact on VDL2 demodulation and decoding.

2 Introduction

The purpose of this document is to report the findings on data link performance from the two 2022 monitoring flight campaigns above core Europe (on 31/03/2022 and 09/08/2022). This report also presents the evolution and trends of the measured parameters from the previous flights (since August 2015) as well as dedicated analyses.

As the monitoring flights are intended to analyse VHF Data Link at the airborne side, some effort has been made, when needed, to distinguish between airborne traffic (ENR) and ground traffic (Terminal) which is expected to be different in nature. However, except where stated otherwise, the traffic values presented in this report consider all monitored frequencies as they are part of the monitoring flight results.

Frequency assignments have been set according to AIR and GND categories (see ICAO Doc11 [2]). The designation of the frequencies in this report is then based on these two categories[1]. The terminology "alternate" frequency used in this document refers to any frequency other than the CSC. In line with FMG/28 amendment to ICAO Doc.011, no more dedicated ACSP frequency allocation is provided. However, the following table summarises the current use of the frequencies by the ACSPs.

Frequency	ACSP (use)
136.975	Common Signalling Channel (CSC)
136.875	SITA (GND), ENAV (MIXED)
136.825	Collins (MIXED)
136.775	SITA (ENR), ENAV (MIXED)
136.725	Collins (MIXED)

In 2022, the flight route has been extended from previous years to cover the north of the Italian airspace extending hence the monitoring flight to a duration of nearly 5 hours.

The August 2022 monitoring flight suffered from a data acquisition problem of about 45 minutes while flying above France, during which no data was available.

In order to enhance analysis, data from ground logs (VGS) were provided by Collins and SITA for the flight held on the 9th of August 2022.

2.1 Outline of the report

Chapter 3 covers the measurement setup and the analysis methodology.

Chapter 4 presents the monitoring flight results.

Finally, chapter 5 provides conclusions and recommendations.

[1] The denomination "MIXED" frequency denotes a use for both GND and AIR.

3 Measurement setup and method of analysis

Measurements were performed using NLR[2]'s Cessna Citation II flying in core of Europe at FL370 using a R&S EM100XT monitoring receiver.

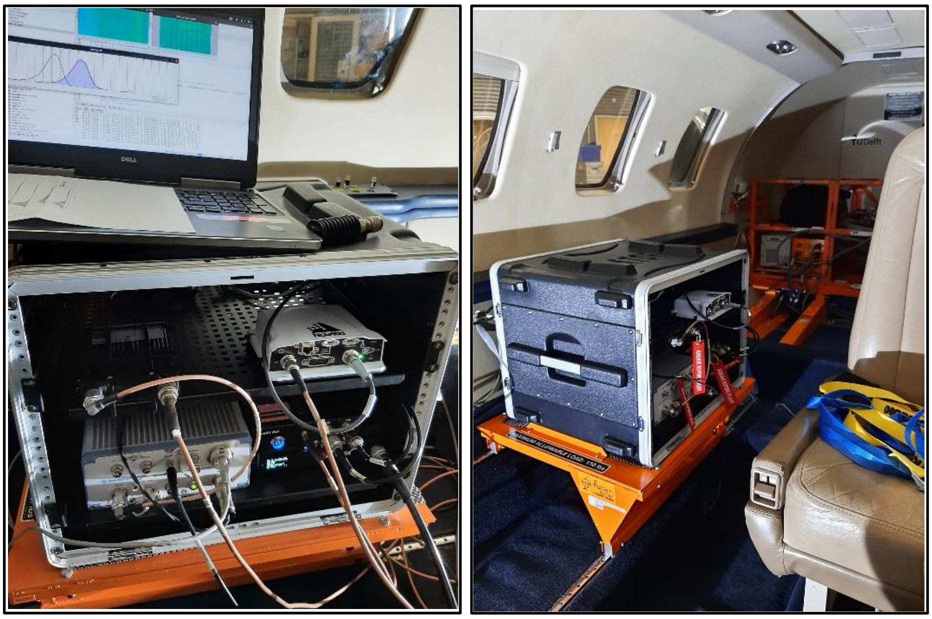


Figure 3-1: Monitoring equipment setup.

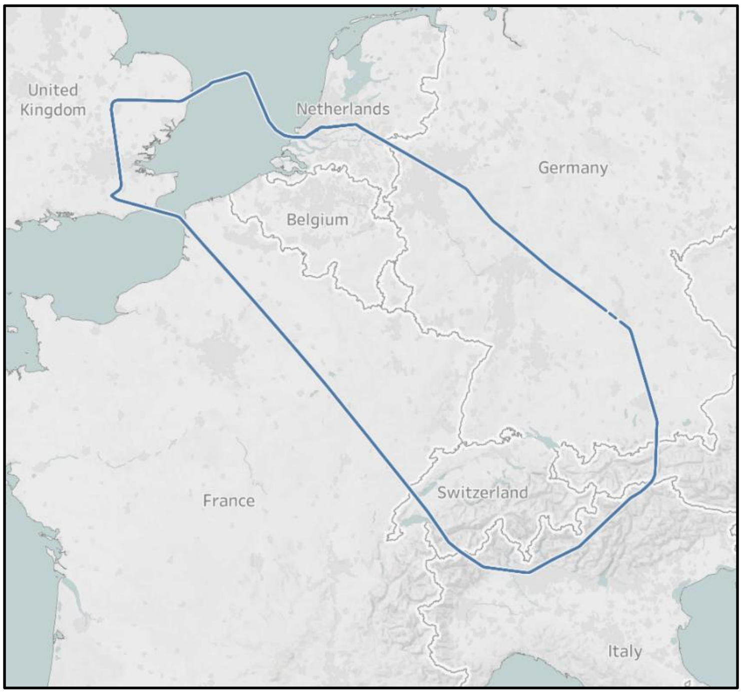


Figure 3-2: Monitoring flight route.

[2] Nationaal Lucht-en Ruimtevaarlaboratorium (NLR).

3.1 Data processing

The R&S EM100XT is used to record 500kHz of IQ data[3] centred on the VDL2 band (136.700 – 137.000 MHz) and 5MHz of IP-PAN (spectrum) data during the whole duration of the flight. The receiver connected to the DM C50-17 antenna located at the bottom rear of the fuselage (RH side), through a band pass filter. Acquisition is performed using a laptop connected to the receiver and consist on IQ data recordings over a bandwidth of 500 kHz centred on 136.8375 MHz[4].

The settings of the receiver are as follow:

Centre Frequency	**136.8375 MHz**
IQ bandwidth	500 kHz
Sampling rate	640 kS/s
AGC	OFF
Reference level	50 dBµV
Attenuation	OFF

The location of the monitoring aircraft is recorded independently in the aircraft and used to enhance RF data recordings.

Dedicated tools are used to analysis the recordings.

IF-PAN (spectrum) data are converted into "spectrum tiles" to display the recorded spectrum to perform interference analysis. It is also used to list all the voice transmissions generated by the aircraft and overloading the receiver – the latter events being excluded from the following analysis.

The recorded IQ data (500 kHz) is first channelized to the desired 25 kHz channels and saved into separate IQ files.

Each channel is then processed to detect and demodulate VDL2 bursts. Demodulated AVLC frames are saved into text files in a hexadecimal format with additional RF information (timestamp, level, duration).

Airborne channel occupancy and other RF statistics (levels distribution) are also processed channel by channel and the results saved in text files.

AVLC frame analysis is performed for each generated channel log file providing various statistics for the ACSPs, AVLC frame types, time stamps or plane location. Only correctly demodulated and valid AVLC frames (correct CRC) are used for the analysis.

When needed IQ data is also used to demodulate other type of signals (i.e., voice, ACARS (POA)).

[3] In-phase and Quadrature-phase (IQ) describe a complex signal that can be transformed to or can be derived from a corresponding real valued RF signal. Complex representation of signal (IQ) is extensively used in many signal processing contexts.
[4] This is the centre frequency of the VDL band.

4 Results

4.1 Occupancy measurements

Channel occupancy is a RF characteristic defined as the proportion of time during which a channel is sensed “occupied” (received level above a specified threshold). It is measured without any demodulation nor signal analysis and computed over raw channelized IQ data using 64 kSamples/s.

As occupancy values depends on the level threshold used, power level Probability Density Function (PDF) graphs are provided hereafter for each frequency and each monitoring flight of the 2022 campaign.

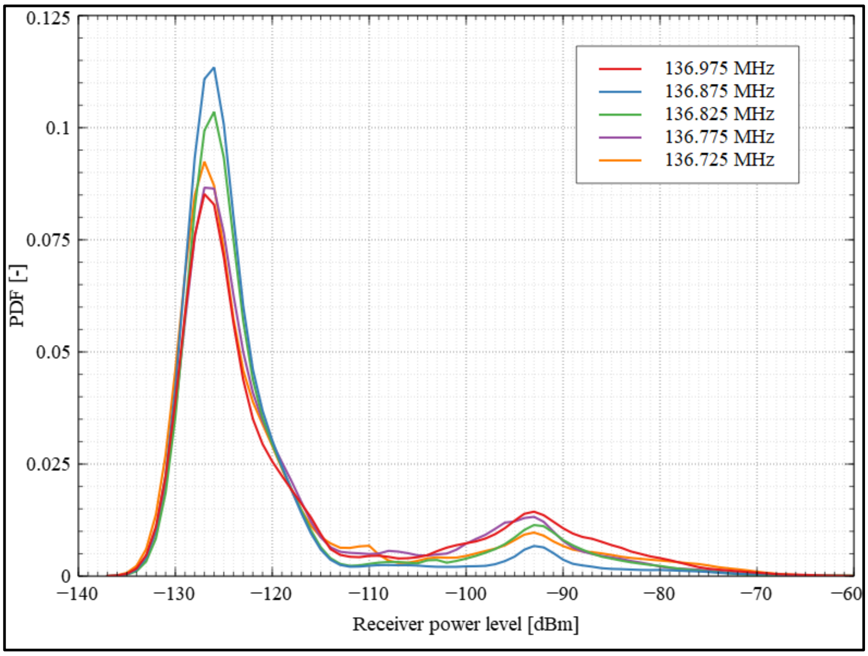


Figure 4-1: PDF of received power level form the 31/03/2022 flight.

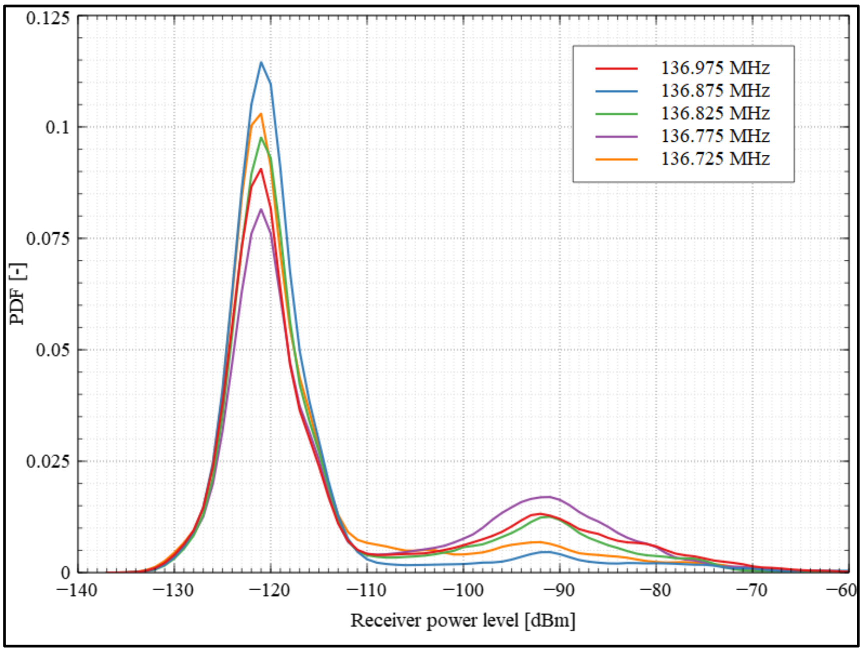


Figure 4-2: PDF of received power level from the 09/08/2022 flight.

The main peak level in the above PDF curves represent the RF noise power of the receiver (around -125 dBm to -120 dBm), while the small ones (around -90 dBm) represent VDL2 traffic.

Using a -90 dBm threshold at the antenna ("idle to busy" threshold defined in ICAO annex 10) and a one-minute time widow, the following occupancy figures are obtained.

Figure 4-3 shows the distribution of occupancy values measured during the various monitoring flights since 2015. Box plots are used to display the distribution of the one-minute occupancy values for each flight. The reader is invited to refer to Appendix A for further information on how to interpret them.

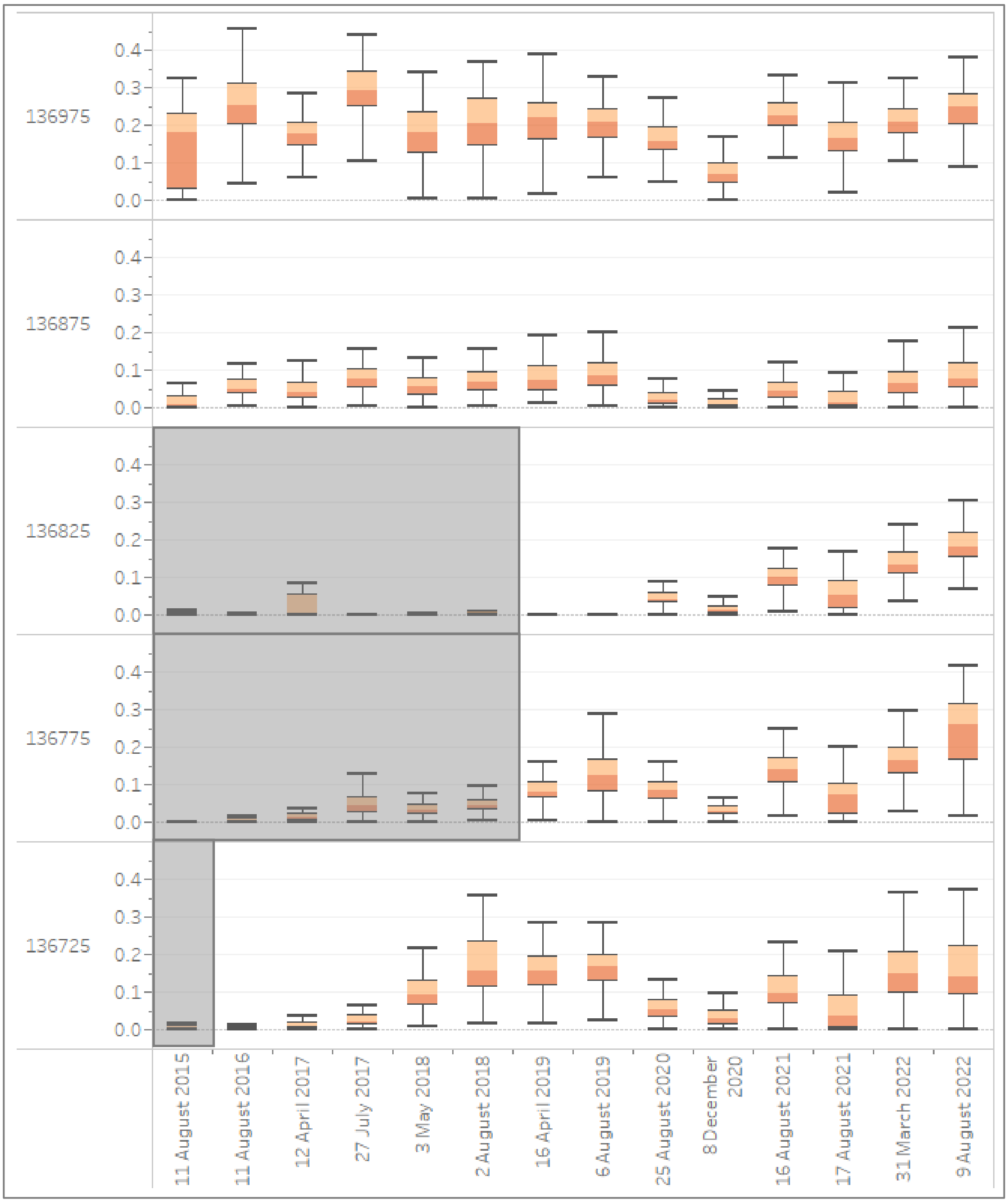


Figure 4-3 : One-minute occupancy distribution.

Note: The greyed areas are measurements periods during which VDL2 was not deployed yet. The occupancy values are then referred to other transmissions observed on the frequency (i.e. voice communications or ACARS) in line with the frequency band planning (ICAO Doc. 011) at the time of monitoring.

Figure 4-3 highlight the drop of occupancy during the COVID-19 period as well as the recovery period until today. It also shows that occupancy values have already reached pre-pandemic values even if the global flight traffic has not.

Figure 4-4 focuses on the 2022 monitoring campaign. Except for 136.775 MHz in August, the CSC remains the most occupied channel. The less occupied frequency is 136.875MHz.

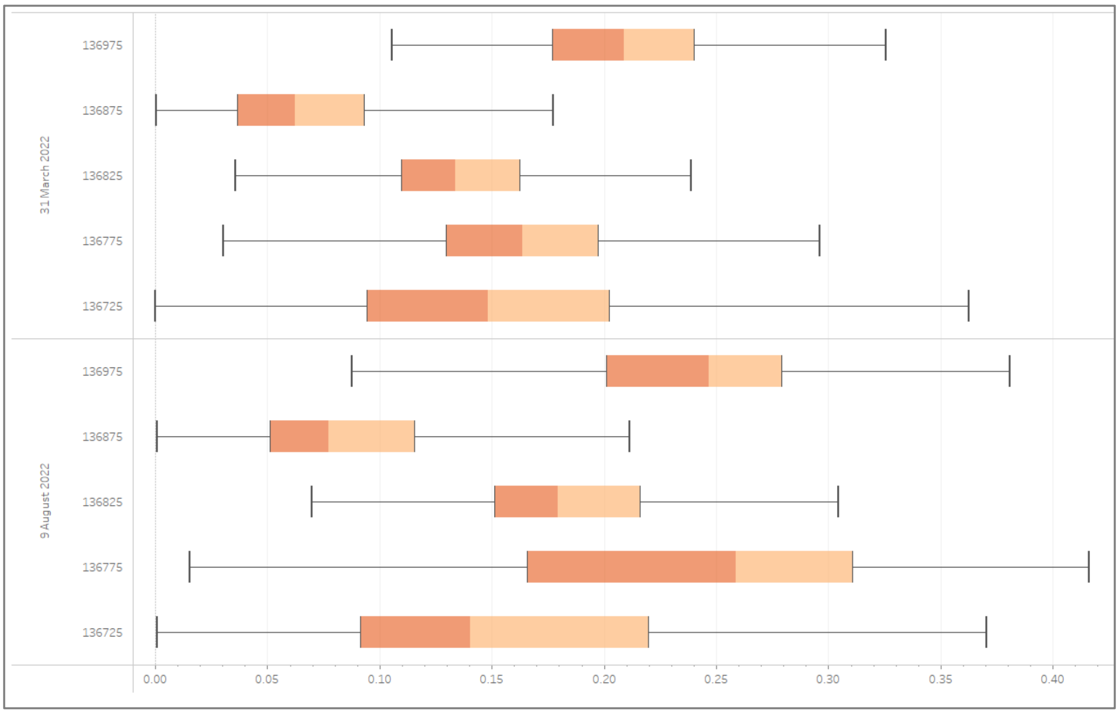


Figure 4-4 : One-minute occupancy distribution for the 2022 monitoring campaign.

4.2 Channel use

Figure 4-5 shows the evolution of AVLC traffic volume monitored over time and its proportion over the different frequencies.

Even if the traffic volume on the CSC has decreased in proportion of the total traffic volume monitored from 88% in 2015 down to 26% in 2022, the absolute traffic volume hasn't changed much since 2015 – at the except of the COVID-19 period.

The global traffic volume exchanged during the monitoring period has now reached pre-COVID levels.

As already highlighted above, the CSC remains the most used frequency.

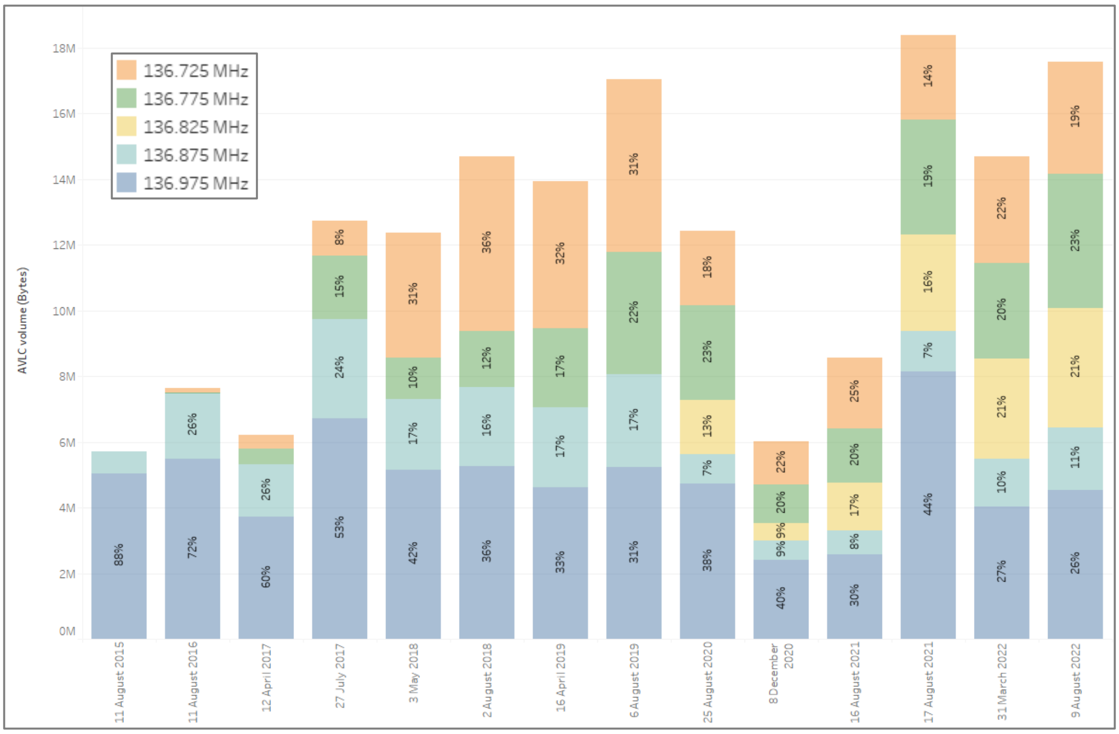


Figure 4-5 : Traffic volume proportion per frequency.

Note: The monitoring flight of the 17 August 2021 was a two legs flight, 4hrs each, down to Malta. The traffic volume for that day is thus twice the traffic volume expected compared to previous flights.

4.2.1 Use of dedicated GND frequency

136.875MHz is used by SITA as a dedicated GND frequency. Mainly GND traffic is thus exchanged on this frequency and airborne monitoring is not appropriate to analyse this frequency. VGS logs provided by ACSPs are used to assess its use.

The efficiency of a dedicated single CSP frequency for ground exchange has been challenged in various fora's (DPMG, DSG, RAFT, FMG).

From the EUROCONTROL/NM datalink monthly performance report "VDL2 daily average traffic volume" metric, it can be seen that the traffic volume on 136.875MHz represents around 23% of the daily average traffic volume exchange on SITA's network (8.5% of the overall daily average traffic volume). To make a fair comparison between "en-route" and "ground" frequencies, we need to look at the "service volume" they provide service to. For a "ground" frequency, the "service volume" covered is around the airport and thus the traffic volume needs to be analysed on a per airport basis. Because of the physics of propagation, a frequency used at an airport can be fully re-used at another one which is not the case of an en-route frequency. In terms of channel capacity, each airport has access to the full capacity of the channel, while en-route channels need to share the capacity among a much larger service volume.

In August 2022, 27 airports were covered by 136.875MHz, leading to a proportion of 0.85% of the daily average traffic volume on SITA's network (0.3% of the overall daily average traffic volume).

The use of a dedicated ground frequency for a single CSP is not efficient.

4.2.2 Airborne Vs ground channel use.

In the light of the above analysis, further assessment on the amount of traffic exchanged on the ground compared to the amount of traffic exchanged with airborne aircraft is needed.

VGS data provided by ACSPs on the 9th of August 2022 is used to perform an analysis of the traffic volume exchanged with both airborne and grounded aircraft.

On the 9th of August 2022, around 33% (225MB over 674MB) of the overall (airborne and ground) traffic volume is exchange on the ground. Considering coverage at +- 180 airports, the daily average traffic volume per airport would be around 1.4MB, representing hence less than 0.3% of the daily average traffic volume exchanged with airborne aircraft.

Figure 4-6 displays, using a one-minute interval window, the average traffic rate (bits/s) exchanged on the ground (for both ACSPs) on the 9th of August 2022 for 5 of the busiest airports in Europe (LHR, CDG, AMS, MAD, FRA). The curve refers to the one-minute traffic rate over time while the box plot in the middle of the graph represents the statistical distribution of the traffic rate over the whole day (see annex A on how to understand box plots).

The highest traffic rate exchange don the ground is observed for LHR. The distribution characteristics is compared with the distributions observed on the alternate frequencies (see section on traffic rate) is provided in the following table. "Q" refers to the quartiles of the traffic rate distribution (Q1=25%, Q2=50%, Q3=75%).

Traffic rate [kbits/s]				
	LHR	**136.825 MHz**	**136.775MHz**	**136.725MHz**
Q1	0.51	2.59	2.86	1.60
Q2 (median)	1.86	3.28	3.81	2.49
Q3	2.80	4.15	4.62	4.00

The table above shows that the traffic rate observed at LHR on the 9th of August is around 60% of what is observed on alternate frequencies providing ENR service.

The traffic rate exchange on the ground at airports is less than the traffic rate observed on frequencies covering ENR in core of Europe.

Today, only one single frequency[5] would be sufficient to handle all ground traffic at airports.

Figure 4-7 further split the traffic rate per ACSP showing the low traffic rate on 136.875MHz (20% of what is observed on ENR) and consolidating the statement made in the previous section on dedicated ground frequency for single ACSP.

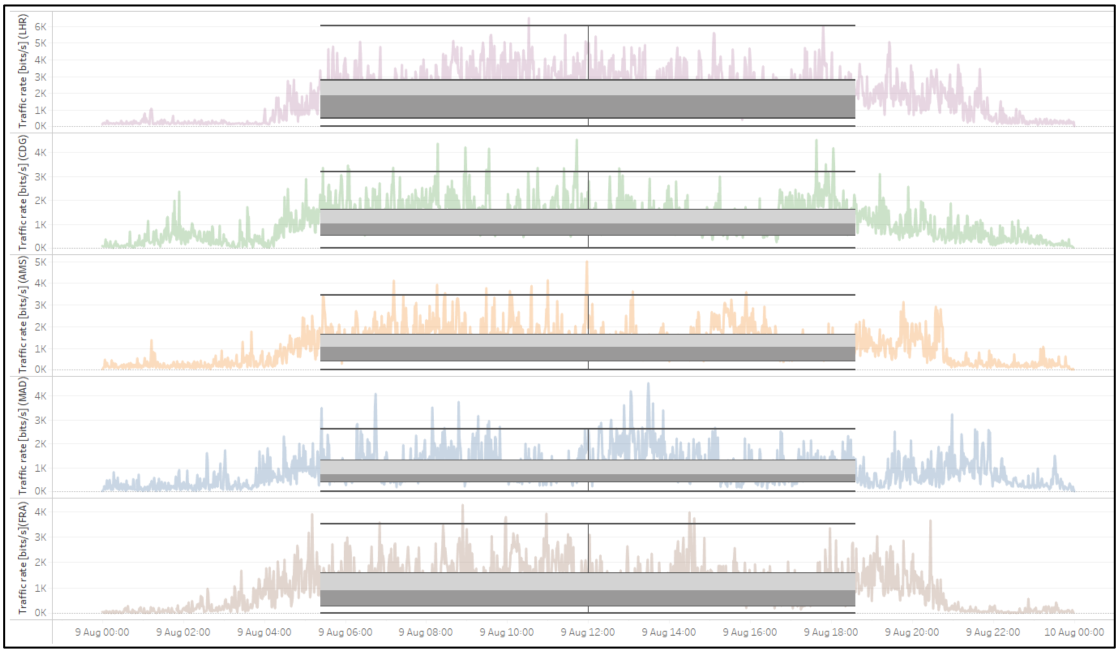


Figure 4-6 : Traffic rate exchanged on ground per airport.

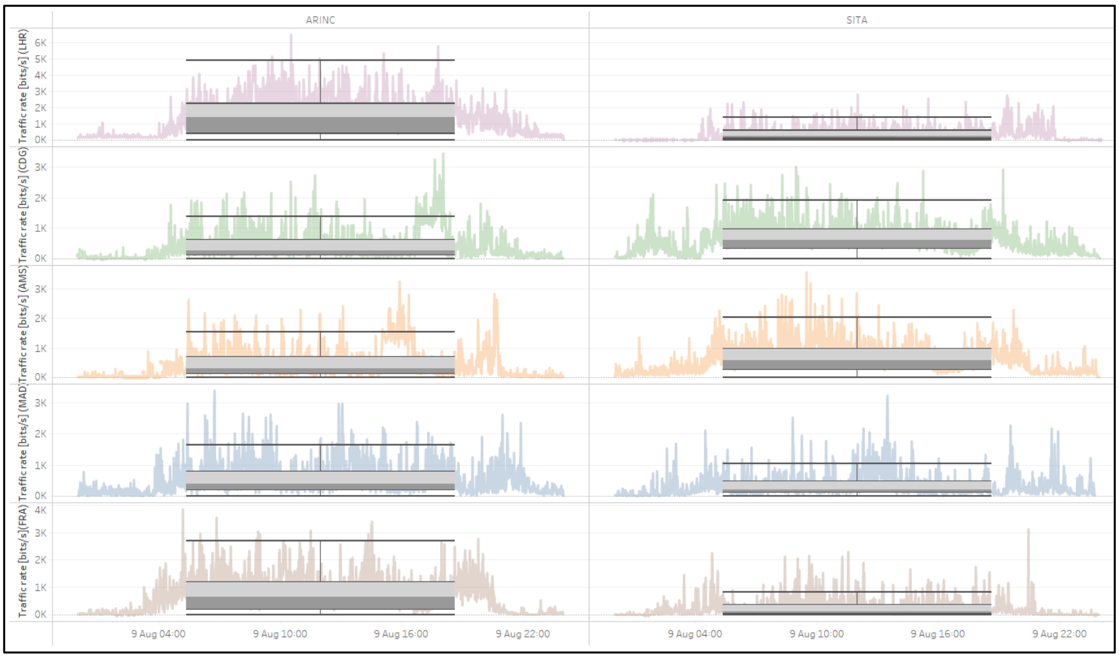


Figure 4-7 : Traffic rate exchanged on ground per airport and per CSP.

[5] It was proposed at the FMG to use the CSC to convey ground traffic, assuming no more ENR traffic would be exchanged.

4.3 VDL2 traffic analysis

The following graphs show VDL2 traffic statistics. The focus is made on the exchange of traffic between airborne aircraft and the ground stations.

Figure 4-8 displays the traffic volume partition in function of the AVLC frame payload[6].

In 2022 the ATN traffic volume exchanged with airborne aircraft represented around 50% of the VDL2 traffic volume, while 35% for AOA.

The remaining 15% represented the AVLC protocol exchange. Considering the monitored ground traffic, both ATN and AOA exchanged the same amount of traffic volume (42%), showing that more AOA traffic than ATN is exchanged on the ground while the contrary is observed with airborne aircraft.

	11 August 2015	11 August 2016	12 April 2017	27 July 2017	3 May 2018	2 August 2018	16 April 2019	6 August 2019	25 August 2020	8 December 2020	16 August 2021	17 August 2021	31 March 2022	9 August 2022
ISO8327	0.4%	2.2%	5.0%	4.9%	7.3%	5.9%	7.4%	7.7%	12.9%	7.4%	12.0%	10.2%	11.1%	11.6%
TP4	1.0%	3.3%	7.1%	7.1%	10.4%	8.7%	10.6%	11.2%	18.0%	10.8%	18.2%	15.0%	15.9%	16.5%
IDRP	27.2%	23.0%	20.6%	19.6%	15.4%	13.7%	12.8%	13.5%	12.5%	10.0%	13.4%	17.7%	12.1%	13.6%
CLNP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.3%	0.1%	0.1%	0.2%	0.2%	0.2%
ES-IS	4.3%	3.0%	1.9%	2.2%	0.9%	1.0%	0.7%	0.8%	0.3%	0.3%	0.6%	1.0%	0.4%	0.6%
ISO8208	9.3%	9.4%	7.3%	7.9%	6.8%	6.7%	6.3%	6.6%	6.7%	5.0%	6.6%	6.6%	6.3%	6.8%
AVLC protocol	8.8%	7.7%	9.6%	9.6%	7.8%	8.5%	8.2%	7.0%	8.3%	14.4%	10.1%	7.6%	8.5%	8.1%
XID	14.9%	12.0%	9.5%	10.4%	8.2%	7.9%	8.1%	8.8%	5.6%	5.6%	6.7%	6.9%	7.5%	7.5%
ACARS Link test	3.8%	3.6%	2.7%	3.2%	2.9%	2.8%	2.7%	2.6%	2.0%	1.6%	1.7%	2.2%	2.0%	2.2%
H1	4.4%	4.5%	4.4%	4.7%	5.3%	5.3%	6.8%	6.6%	5.7%	8.5%	3.7%	3.6%	6.2%	5.3%
H1/DF-EI	6.3%	9.2%	10.5%	9.5%	14.7%	19.2%	15.8%	13.6%	12.2%	17.8%	9.8%	16.5%	12.6%	12.7%
FIS	3.4%	4.6%	3.8%	3.9%	3.4%	2.7%	3.6%	3.4%	2.7%	1.8%	2.3%	2.1%	3.1%	2.1%
ACARS Protocol	6.2%	6.8%	6.6%	6.5%	7.0%	7.2%	7.0%	8.1%	5.7%	6.7%	7.4%	4.9%	6.4%	5.8%
ACARS misc.	10.0%	10.8%	10.9%	10.6%	9.7%	10.5%	9.9%	10.1%	7.1%	9.9%	7.3%	5.6%	7.8%	7.0%

Figure 4-8 : Traffic volume partition per AVLC frame content.

4.3.1 ATN traffic

Figure 4-9 focuses on ATN traffic volume exchanged with airborne aircraft. It shows the increase, in proportion, of ATN end-user data (CPDLC session and messages) that needs to be correlated with the decrease, in proportion, of the ATN "overhead" (i.e IDRP).

	August 2015	August 2016	April 2017	July 2017	May 2018	August 2018	April 2019	August 2019	August 2020	December 2020	August 2021	March 2022	August 2022
ISO8327	1.0%	5.5%	11.9%	11.7%	17.9%	16.4%	19.6%	19.4%	25.4%	22.1%	21.1%	24.1%	23.5%
TP4	2.5%	8.1%	16.9%	17.1%	25.5%	24.3%	28.0%	28.1%	35.5%	32.1%	31.3%	34.6%	33.5%
IDRP	64.4%	56.2%	49.2%	46.9%	37.7%	38.0%	33.8%	33.8%	24.6%	29.8%	32.5%	26.3%	27.6%
CLNP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.6%	0.4%	0.4%	0.4%	0.4%
ES-IS	10.2%	7.2%	4.5%	5.3%	2.3%	2.7%	1.9%	2.1%	0.6%	0.8%	1.8%	0.8%	1.3%
ISO8208	22.0%	23.0%	17.5%	19.0%	16.6%	18.6%	16.6%	16.5%	13.3%	14.7%	13.0%	13.8%	13.7%

Figure 4-9 : ATN traffic volume partition.

[6] The AVLC traffic volume (size of AVLC frame) is split among categories depending on the "highest" level protocol observed in its payload. There is no dissection of the AVLC frames to extract the number of bits/bytes of the protocol encapsulation. As an example, and AVLC frame conveying only ISO8208 packet protocol (without any CLNP data) is categorized ISO8208.

To understand this behaviour, one needs to remind that when an aircraft is VDL2/ATN capable, it will automatically connect to the ATN (and thus exchanging IDRP traffic over the ATN) even if no CPDLC session is established (no connection to an ANSP). In 2015, few aircraft were observed to use CPDLC (as seen in Figure 4-10) and more than 95% of the traffic volume was only ATN traffic (overhead). Today, after the DLS-IR implementation date (Feb. 2020), more and more aircraft are using CPDLC, increasing hence the traffic volume related to end-users.

August 2015	August 2016	April 2017	July 2017	May 2018	August 2018	April 2019	August 2019	August 2020	December 2020	August 2021	March 2022	August 2022
26%	21%	35%	37%	43%	41%	48%	52%	66%	57%	75%	70%	71%

Figure 4-10 : Proportion of ATN capable aircraft observed to have at least a CPDLC session.

The traffic volume related to the ATN (overhead) has dropped down to 43% and will continue to decrease, in proportion, as the use of CPDLC will increase.

4.3.2 AOA traffic

Figure 4-11 focuses on AOA traffic volume exchanged with airborne aircraft. It is further split between uplink and downlink.

		August 2015	August 2016	April 2017	July 2017	May 2018	August 2018	April 2019	August 2019	August 2020	December 2020	August 2021	March 2022	August 2022
D	FIS	8.7%	8.6%	5.9%	7.3%	5.3%	4.1%	5.1%	4.6%	5.5%	2.7%	4.7%	4.8%	4.0%
	H1	14.4%	13.9%	10.6%	13.7%	13.2%	11.3%	16.4%	17.0%	17.9%	19.6%	10.7%	17.5%	15.8%
	H1/DF-EI	26.4%	31.5%	40.8%	34.3%	44.9%	51.7%	44.2%	40.7%	43.6%	46.4%	54.2%	43.0%	46.2%
	Link test	16.0%	12.3%	10.6%	11.7%	9.0%	7.5%	7.7%	7.9%	7.0%	4.3%	7.6%	7.0%	8.0%
	Other	24.1%	23.5%	22.3%	22.2%	16.9%	16.2%	17.1%	16.6%	16.7%	19.3%	14.5%	16.7%	16.2%
	Protocol	10.5%	10.3%	9.8%	10.8%	10.7%	9.1%	9.4%	13.2%	9.3%	7.8%	8.4%	11.0%	9.8%
U	FIS	13.1%	20.0%	17.2%	17.1%	16.0%	10.8%	17.1%	16.5%	15.7%	9.3%	12.1%	19.2%	13.0%
	H1	10.0%	4.8%	12.9%	8.5%	9.9%	10.8%	9.2%	8.8%	10.0%	12.9%	10.3%	12.2%	12.1%
	H1/DF-EI	0.2%	0.8%	0.7%	0.5%	0.2%	0.4%	1.1%	2.2%	0.6%	1.9%	0.5%	0.5%	0.5%
	Other	41.2%	37.7%	38.8%	41.5%	40.2%	42.2%	37.1%	40.4%	32.5%	31.2%	30.5%	32.4%	33.2%
	Protocol	35.5%	36.7%	30.4%	32.4%	33.7%	35.8%	35.4%	32.2%	41.2%	44.7%	46.6%	35.7%	41.3%

Figure 4-11 : AOA traffic volume partition.

The H1/DF H1/EI are ACARS label messages where "engine reports" are expected to be found. It represents in 2022 around 45% of the AOA traffic volume downlinked by airborne aircraft.

The "protocol" category contains mainly (99%) ACARS acknowledgments. ACARS acknowledgement on top of the AVLC acknowledgement (known as the double acknowledgement) is responsible for 16% of the AOA traffic volume exchanged.

4.3.3 AVLC size analysis

Figure 4-12 display the AVLC frame size distribution (in Bytes) split between ATN and AOA payload and per ACSP. It shows the significant differences in frame size on the AOA side between the two ACSPs. It is known that the probability of failure on the uplink due to the hidden terminal phenomenon is greater for large frame than smaller ones. This could explain some difference in performance between the two ACSPs as usually observed (see DPMF monthly report).

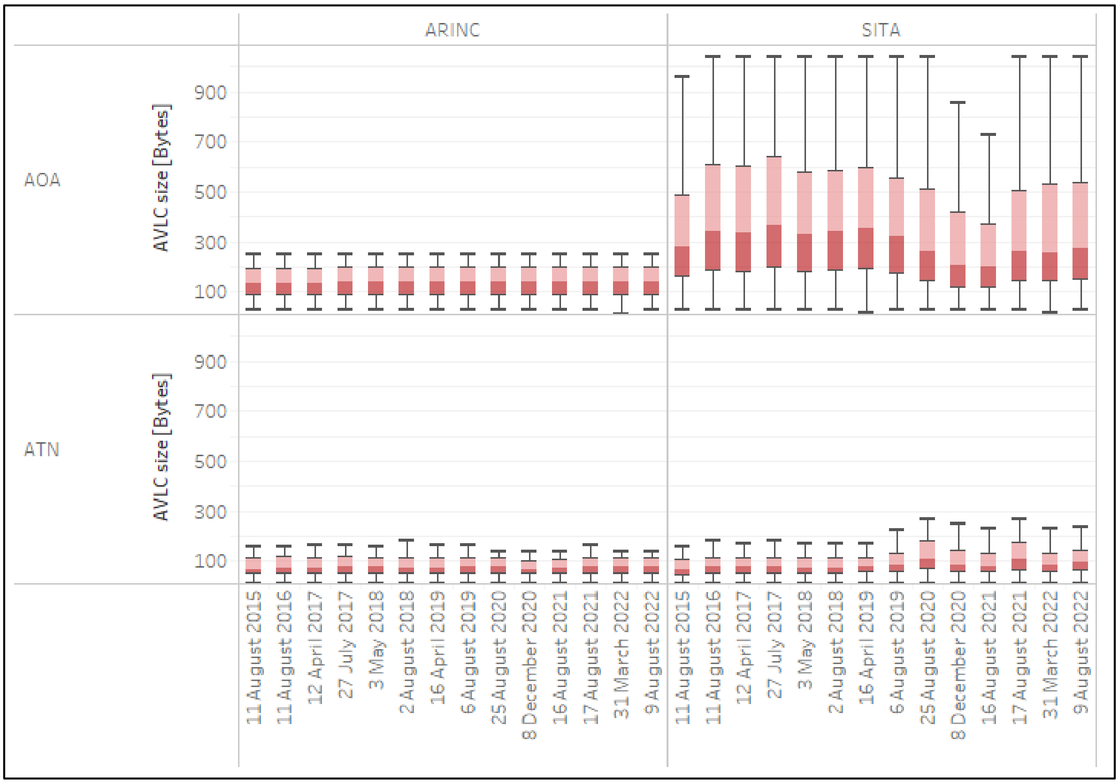


Figure 4-12 : AVLC size for ATN and AOA payload per ACSP.

Figure 4-13 focuses on the split of AVLC frame size conveying AOA traffic between uplink and downlink on SITA's network, showing that both uplink and downlink convey large AOA frames.

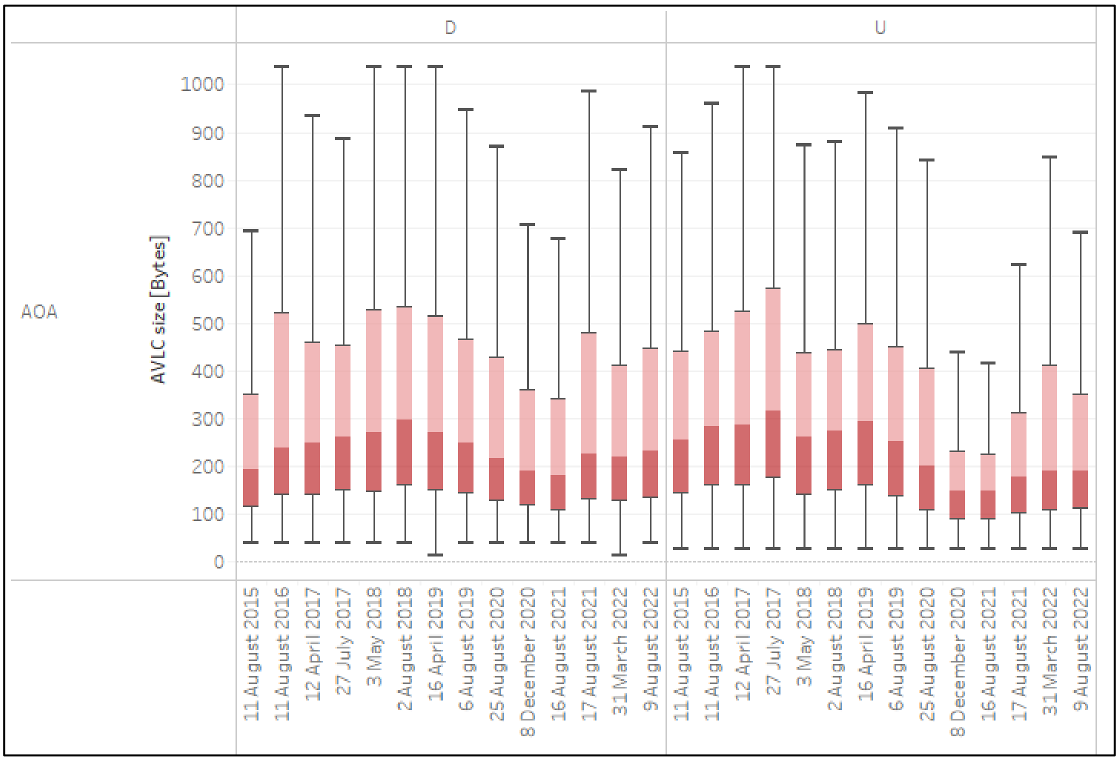


Figure 4-13 : AVLC frame size distribution conveying AOA traffic on SITA's network.

4.4 VDL2 traffic rate and throughput

Channel capacity is an important parameter in radio network design. It gives you the maximum amount of traffic you can exchange over a radio propagation channel within the specified performance limits.

The channel capacity, expressed as a rate, is defined in the literature as the maximum throughput, the latter being defined as the amount of traffic volume per unit of time (kbits/s) that was successfully transmitted over the radio channel (and thus correctly received and acknowledged by the destination station). The maximum measured throughput, relative to the offered load[7], is often used to characterise the efficiency of the radio propagation channel.

The estimation of the throughput from the monitoring flight requires the analysis of the AVLC link to identify AVLC frames being acknowledged or not. It is observed that the monitoring aircraft does not receive all the AVCL frames and acknowledgement needed to make proper AVLC link analysis because of the monitored aircraft moving in and out of the radio coverage volume continuously, making the AVLC link analysis very difficult from AVLC frame received from the monitoring aircraft.

In order to make a proper estimate of the maximum throughput, VGS logs provided by Collins and SITA during the August monitoring flight are used to analyse the AVLC link and identify if a frame was acknowledged or not, estimating hence properly the throughput within the monitored radio coverage volume.

The rate, defined as the amount of traffic per unit of time correctly received by the monitoring aircraft is provided in the following subsection. It is an important measure as it is identifying the traffic that is really exchanged over the radio channel.

The throughput analysis, as introduced above, is then presented at the end of the analysis.

4.4.1 Traffic rate

Figure 4-14 displays the VDL2 traffic rate distributions for each frequency over time since 2015, while Figure 4-15 focuses on 2022. Like for the occupancy, the traffic rate (kbits/s) is estimated using a one-minute time window. The graphs below use box plots (see annex A) to display the distributions of traffic rates for each monitoring flight. The left axis displays the traffic rate in kbits/s while the right one to the proportion (in %) of the modulation rate of VDL2 (31.5 kbits/s).

The maximum rate observed in 2022 is 7.6 kbits/s on 136.725MHz.

While flying above ENAV (where both Collins and SITA's customers are on the same frequencies) the maximum rate observed in August 2022 is 7.1 kbits/s on 136.775MHz

[7] The offered load (G) is the amount of traffic volume, expressed as a rate, that is sent on the radio channel to achieve a throughput (S). It is the sum of S with all the retransmissions needed to succeed transmission within the maximum number of attempts. As, in VDL2, the number of retransmissions is finite, the throughput is often less than the expected amount of traffic that is expected to be sent to the destination stations.

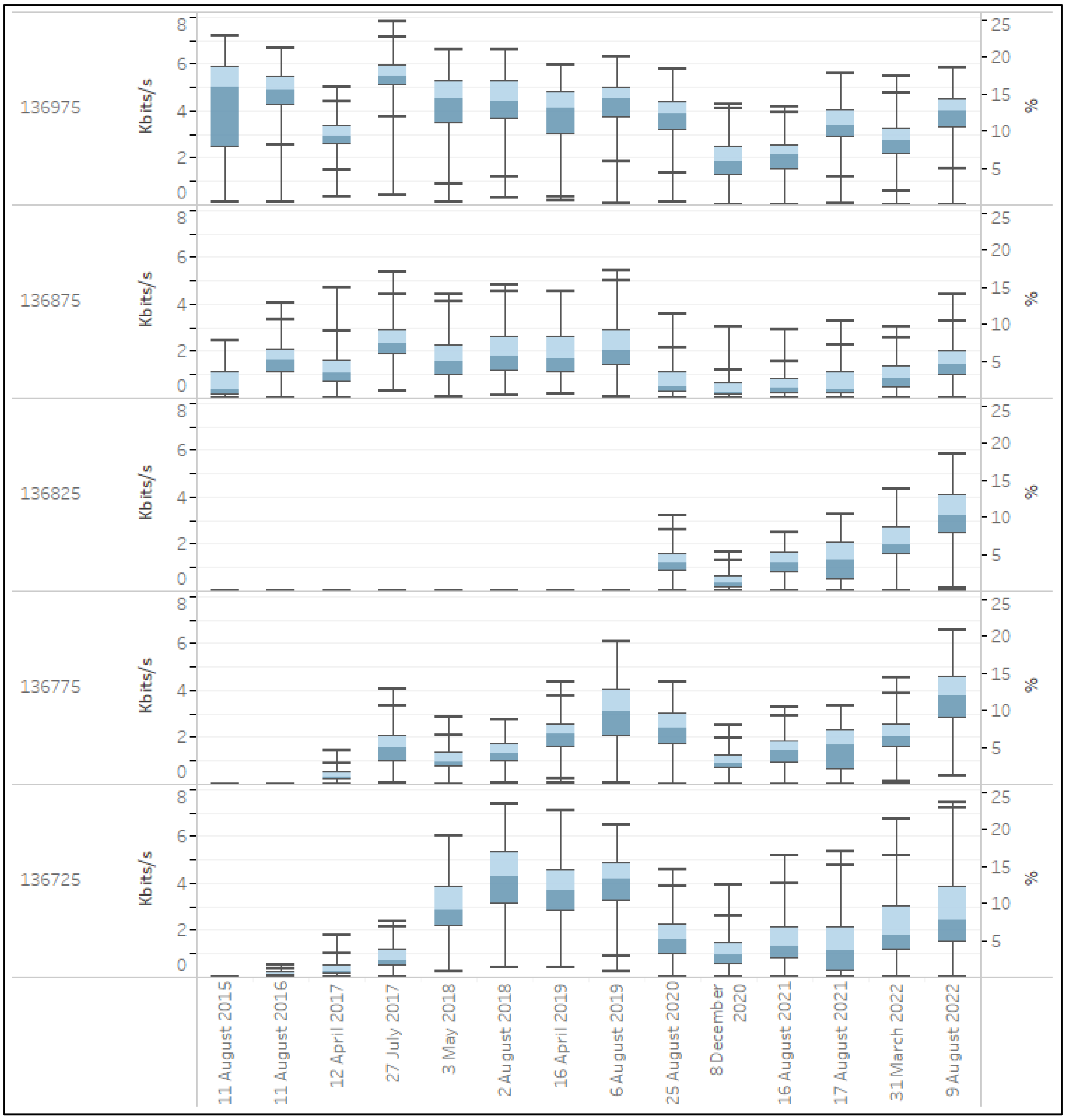


Figure 4-14 : VDL2 traffic rate.

<u>Note</u>: The traffic rate observed on 136.875MHz is not representative of what is really happening in the "service volume" (airport) as it represents the aggregated data from multiple airports at the same time as observed from ENR.

Figure 4-15 shows the same information focussing on year 2022. It highlights the heavy use of the CSC. Knowing that the performance of this frequency, due to the high number of VGSs transmitting on this frequency[8] (mainly due to the "hidden transmitter" phenomenon), is less than dedicated ENR frequencies, the amount of traffic on this frequency affects global performance of the network.

The removal of ENR traffic off the CSC would improve performance of the whole network.

[8] The CSC needs to be deployed and available in all airspace and ground

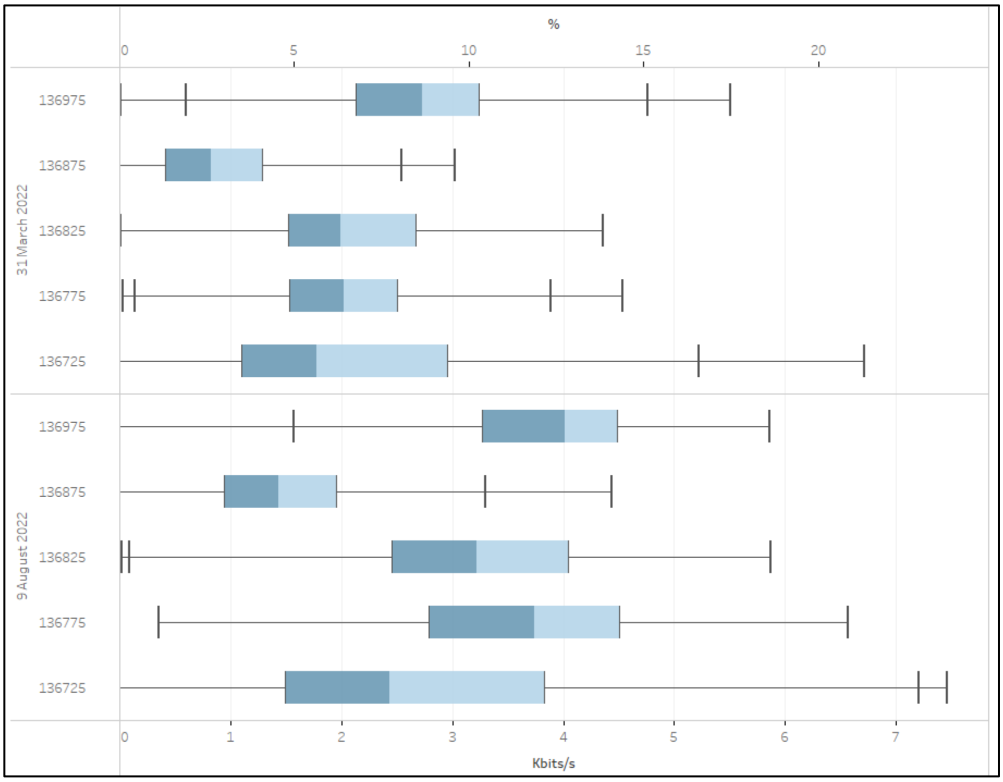


Figure 4-15 : VDL2 traffic rate for 2022.

4.4.2 Throughput

The following analysis uses both flight and VGS monitoring data to correctly assess performance of the radio channel. It is based on the followings:

a) The monitoring flight data is used to identify, over one-minute time windows, the aircraft-VGS pairs heard within the radio coverage volume of the monitoring aircraft.
b) VGS logs are used to extract the AVLC traffic exchanged over the specified one-minute time widow and compute the throughput and offered load. As the VGS logs contain the complete AVCL exchange, each AVLC frame exchanged during the specified time window is correctly assessed (acknowledged or not).
c) The throughput is split between uplink and downlink.
d) The downlink estimated throughput is computed using correctly received downlink AVLC frames by the VGSs.
e) The uplink estimated throughput is computed using uplink acknowledge AVLC frames by the destination aircraft.
f) Only AVLC INFO frames are being considered in order not to overestimate throughput with AVLC protocol frames (GSIF, XID, …) not being correctly received by the destination station.

Figure 4-16 displays the estimated VDL2 throughput distributions for each frequency during the monitoring flight of the 9th of August 2022 using box plots (see annex A). The maximum throughput estimated is 8.2 kbits/s on 136.725MHz.

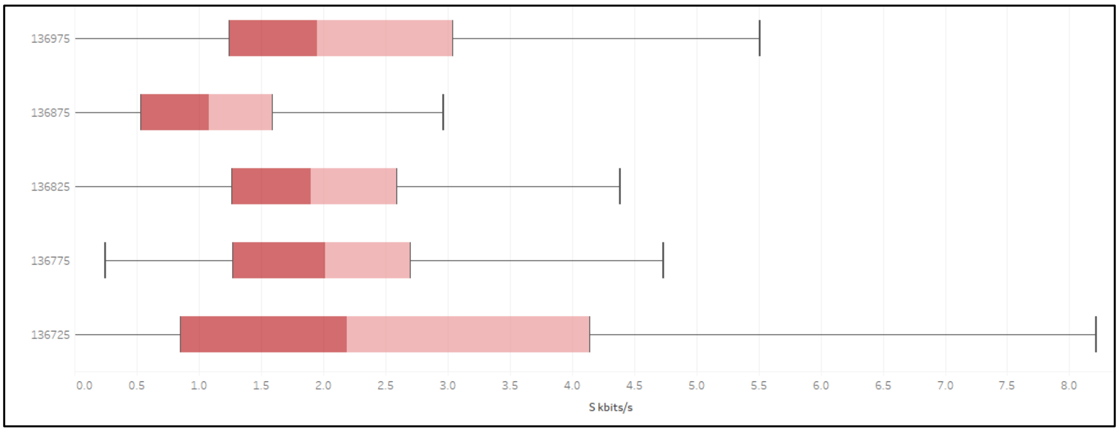


Figure 4-16: August 2022 throughput

In the exercise above, the offered load (G) is computed together with the throughput (S) which makes possible to display throughput graphs (throughput in function of the offered load), well known from radio network design engineers and helpful to assess radio channel performance.

Figure 4-17 display the throughput graph for each frequency providing en-route service on the 9th of August 2022 together with some known theoretical throughput curves. Each circle represents a one-minute time window data. Colour refers to frequency.

Figure 4-17 needs to be analysed in comparison with the occupancy, traffic volume and traffic rate observed for each frequency.

The less efficient channel is the CSC. It can be observed that, with its high traffic (as observed on Figure 4-15), the CSC cannot reach high throughput, as compared with 136.725MHz with less traffic. The high occupancy measured on the CSC reveals the higher number of failures and retransmissions needed to successfully send an AVLC frame to the destination station. As we already know, most of the failures occurs on the uplink due to the hidden terminal phenomenon and its behaviour is expected to be in the same order of magnitude as a pure ALOHA channel.

Similar behaviour is observed on 136.825MHz and 136.775MHz. However, for the same offered load above G=0.2, 136.825MHz generally achieves a better throughput than 136.775MHz

The most efficient channel observed is 136.725MHz, where the measured maximum throughput is 26% (8.2 kbits/s). However, it is achieved with less traffic than on the other frequencies.

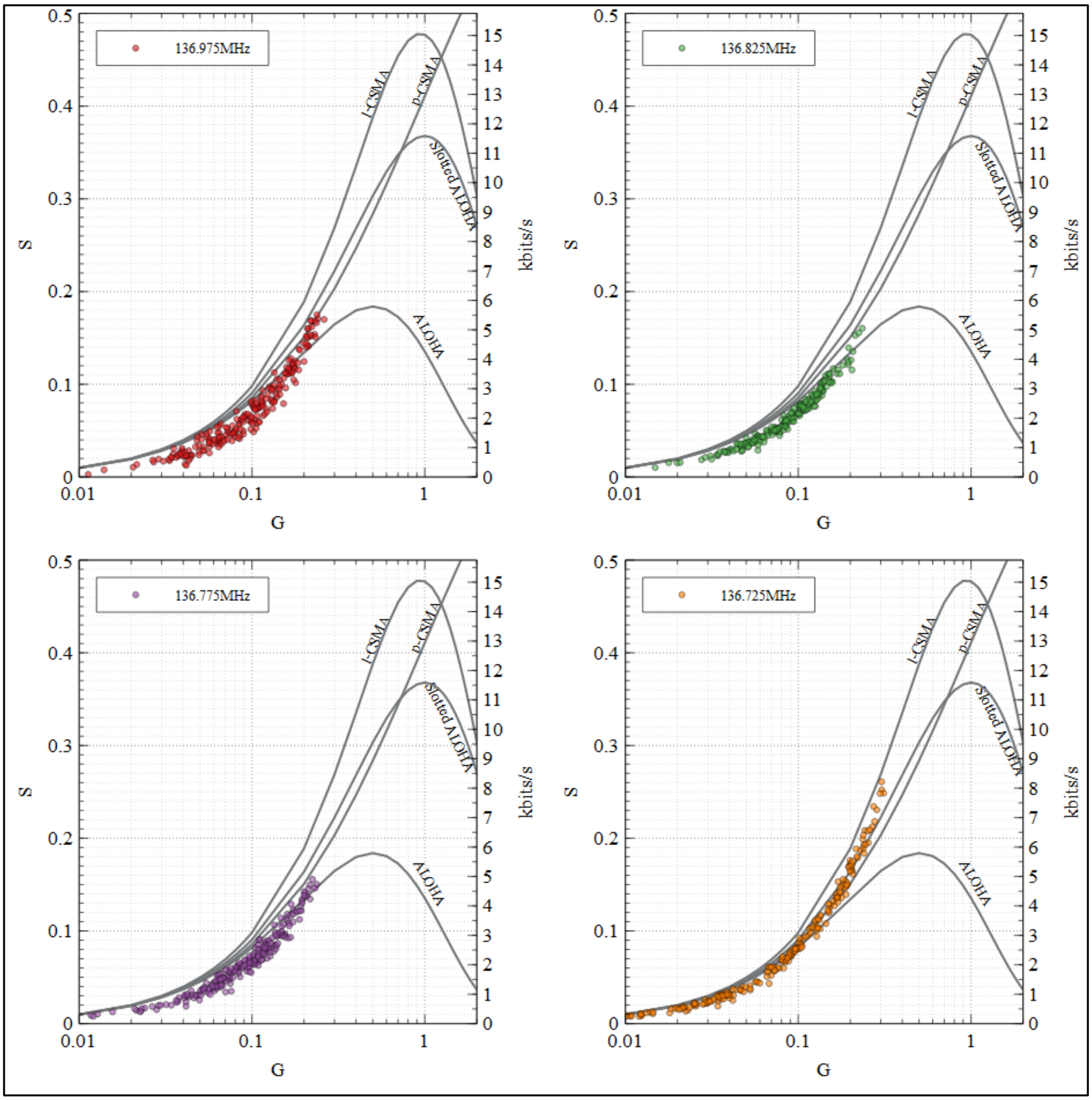


Figure 4-17: Throughput (S) in function of the offered load (G).

4.5 Interference analysis

The same kind of interferences, as observed during previous monitoring flights, were observed, main of which are voice communications and industrial noise signals.

The following sections report the most important ones for illustration purposes with an assessment of plausible impact on VDLm2 as observed from the monitoring aircraft. The reader is invited to keep in mind that these interferences might be observed anywhere in the European datalink airspace and not only located where the monitoring flights flown.

The impact of interference on VDL2 signals is assessed by trying to demodulate the VDL2 signal in the presence of the interference (see examples below).

The VDL2 burst is manually selected (vertical red bars in Figure 4-19) from which the demodulation and decoding of the burst is performed. Correct demodulation of the VDL2 burst is assessed using the Bit Error Rate (BER) on the synchronisation word while the correct decoding of the VDL2 bursts and AVLC frame is assessed using the outcome of the Reed-Solomon Forward Error Correction (FEC) decoder and the AVLC Cyclic Redundancy Check (CRC).

Figure 4-19 displays an example of a VDL2 burst that failed demodulation and decoding due to a collision (left) and of a VDL2 burst correctly demodulated and decoded (right).

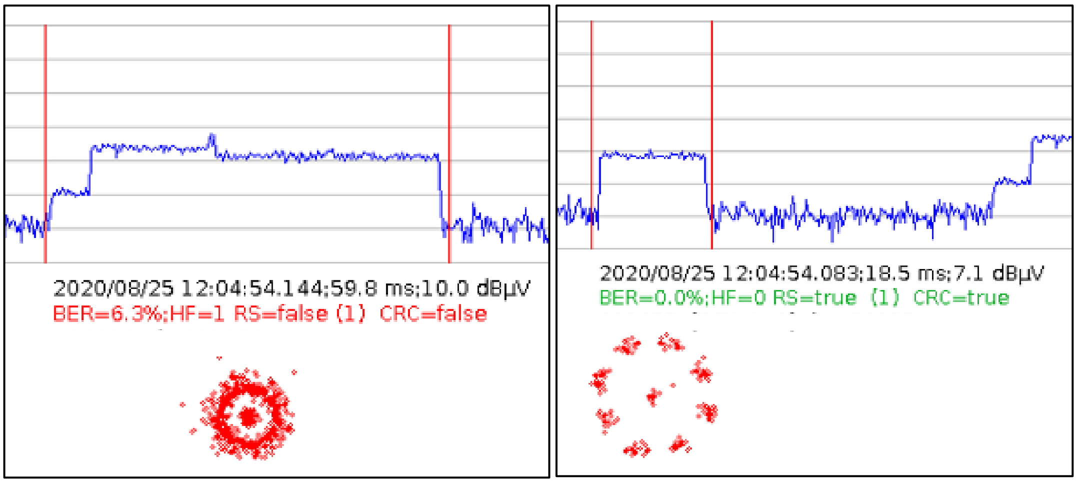


Figure 4-18

Figure 4-19 : Example of a failed (left) and successful (right) decoding of a VDL2 burst in the presence of interference.

Th red dots in the above figures displays the VDL2 demodulated symbols (IQ) in a polar representation. When the burst is correctly demodulated, the typical D8PSK pattern can be clearly identified.

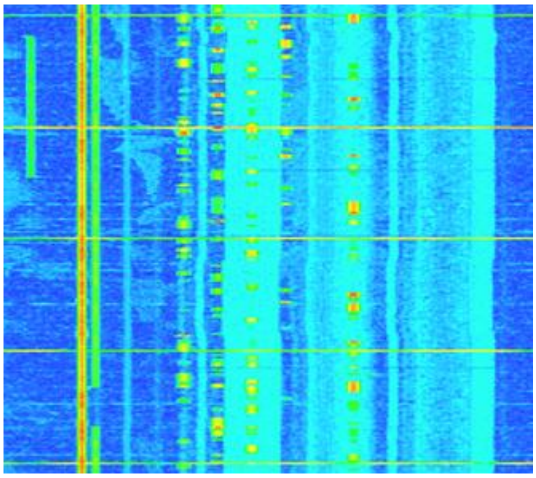
The failure of the demodulation and decoding is due to the bad signal-to-interference plus noise ratio (SNIR) that should be on average above 20dB.

4.5.1 Industrial noise interferences

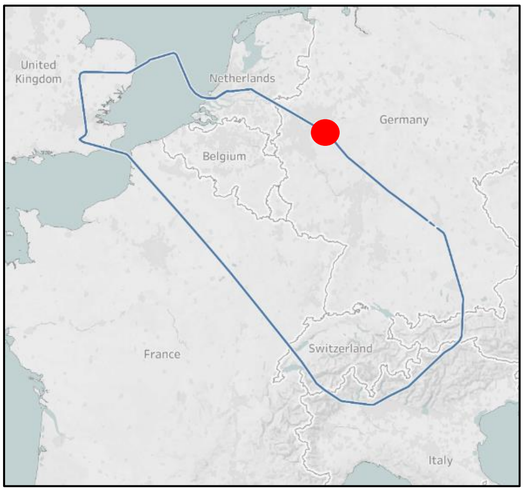
Date: 31st March 2022

Time: 10:45 – 10:50 UTC

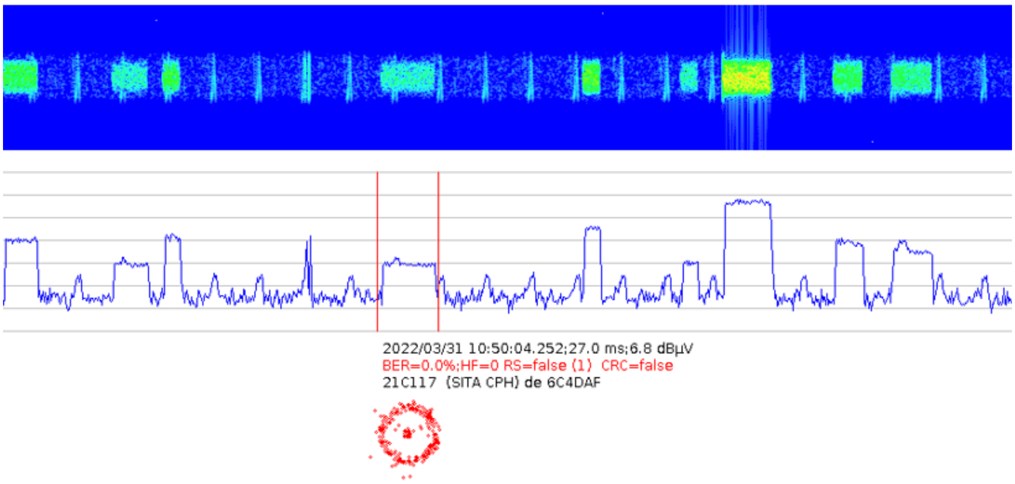
Description: Wideband complex signal 10dB above noise level



Location: Germany



Impact on VDLm2: Decoding failure of low level VDL2 bursts

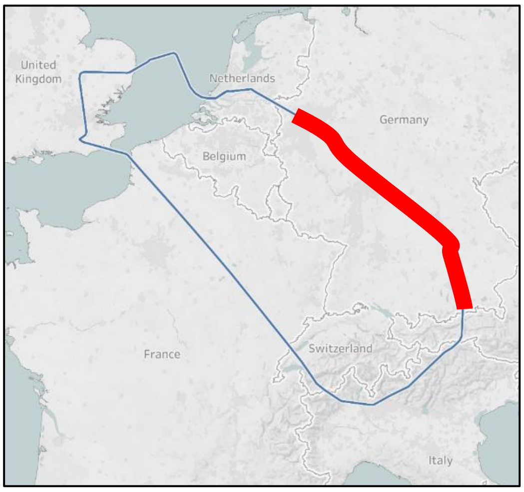


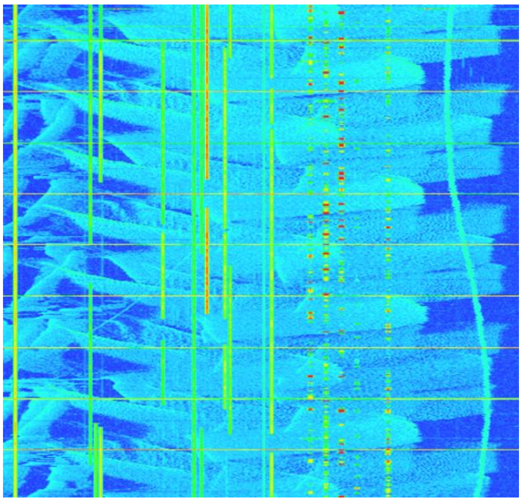
Date: 31st March and 9th August 2022

Time: 10:45 – 11:47 UTC

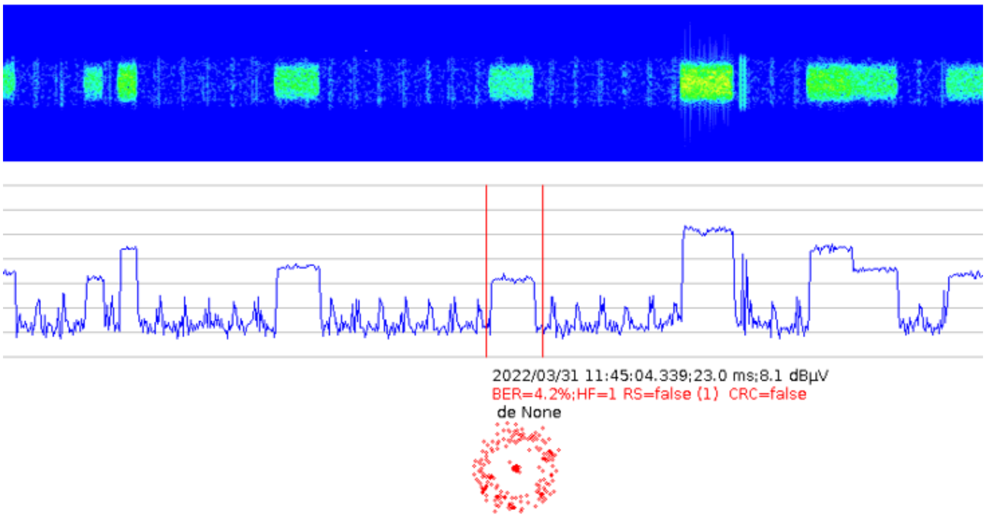
Description: Wideband complex sweeping signal 8-10dB above noise level

Location: Germany





Impact on VDLm2: Decoding failure of low level VDL2 bursts

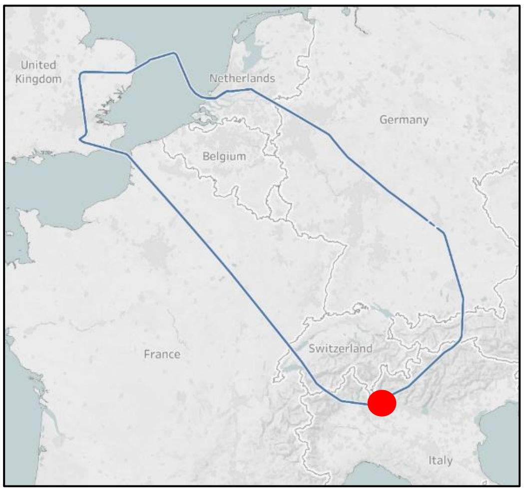


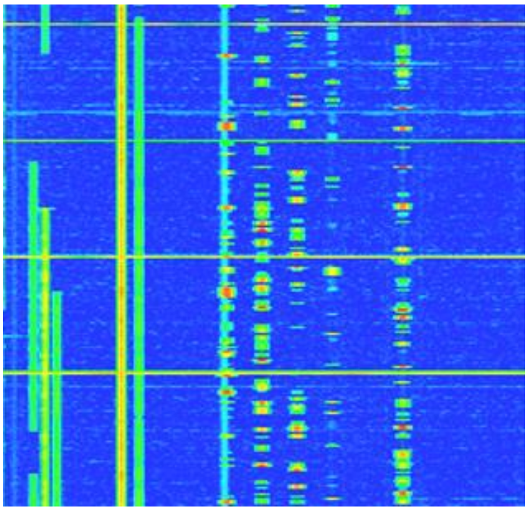
Date: 31st March

Time: 11:14 – 11:21 UTC

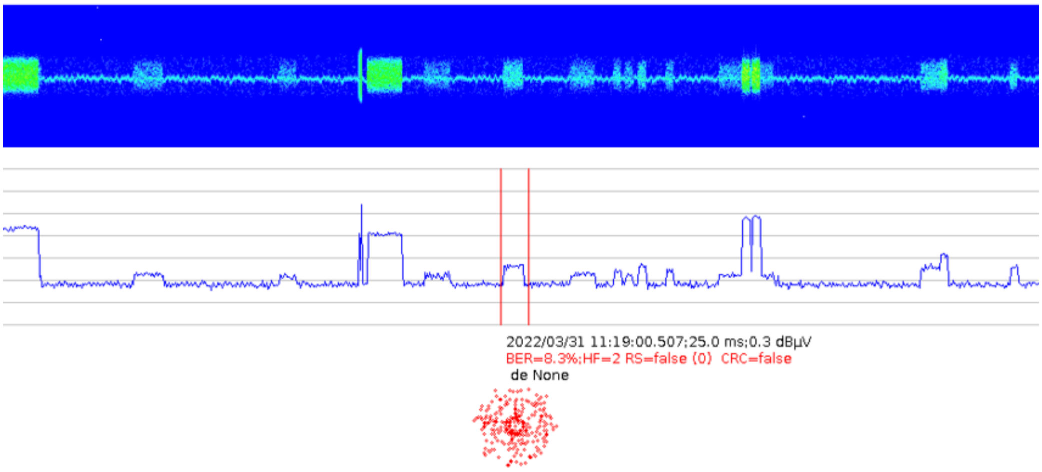
Description: Unstable Carrier near 136.725MHz

Location: Italy





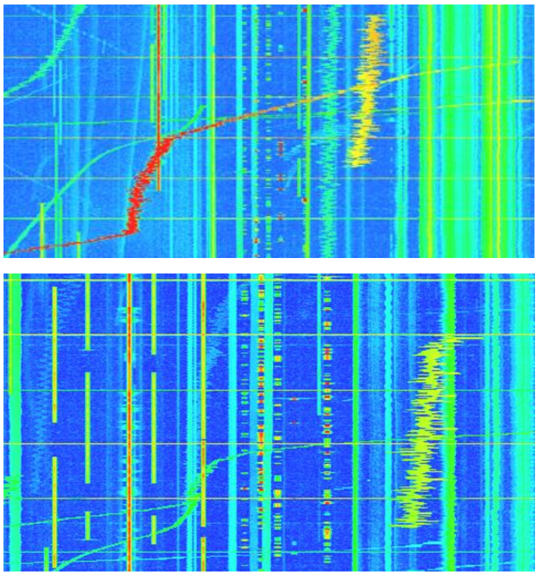
Impact on VDLm2: Decoding failure of low level VDL2 bursts



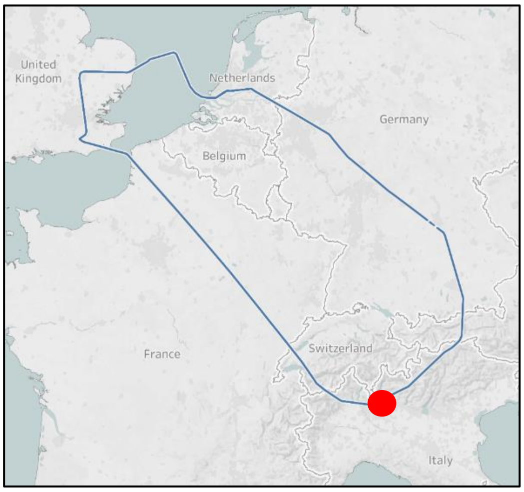
Date: 31st March and 9th August 2022

Time: 12:25 – 12:35 UTC

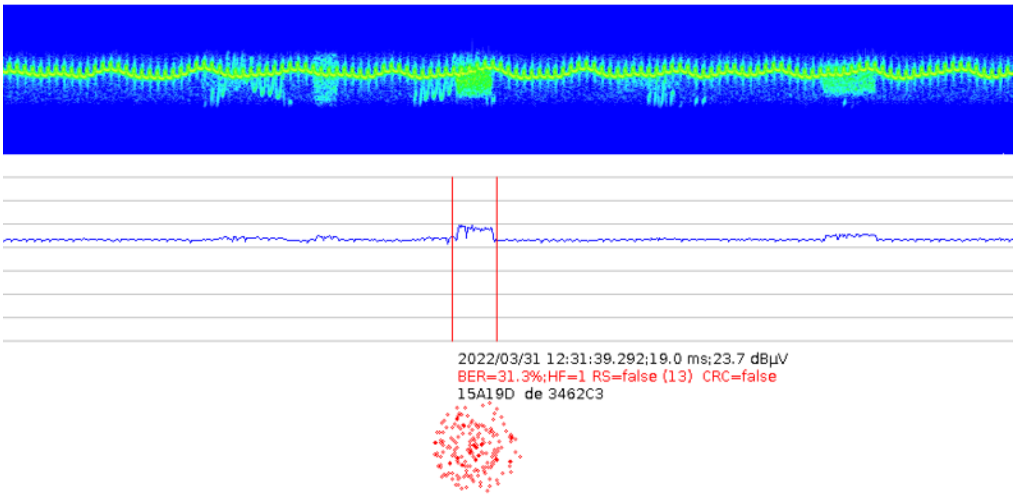
Description: Various sweeping signal up to 50dB above noise level



Location: Italy



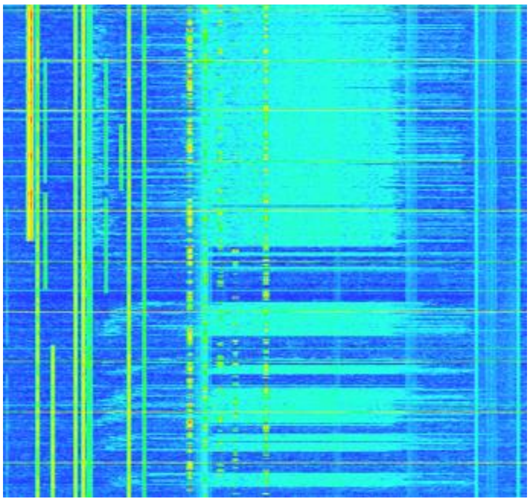
Impact on VDLm2: Decoding failure of all VDL2 bursts



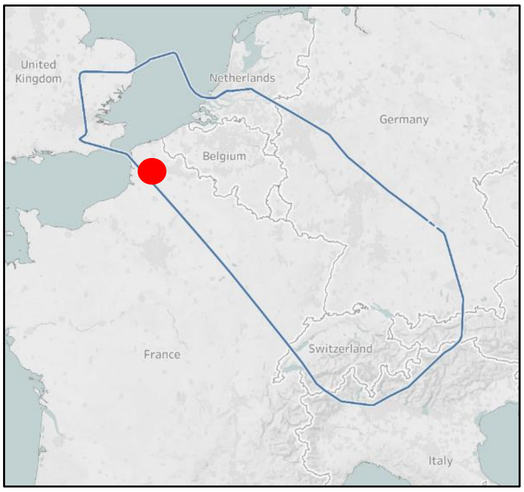
Date: 31st March 2022

Time: 13:50 – 14:00 UTC

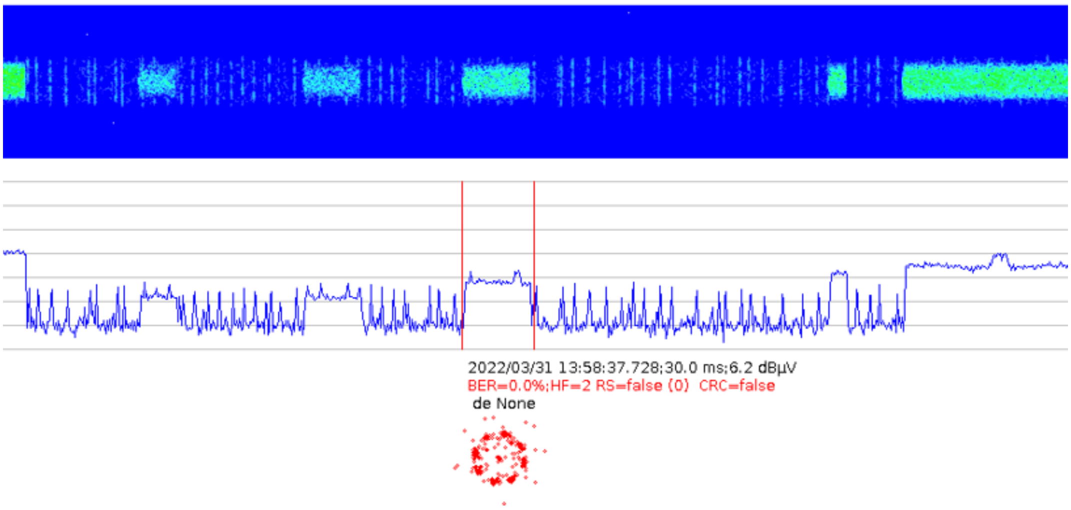
Description: Wideband signal up to 16dB above noise level



Location: France



Impact on VDLm2: Decoding failure of low level VDL2 bursts

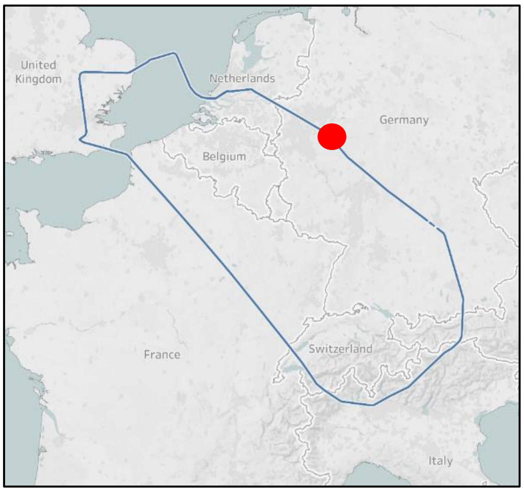


4.5.2 Voice communication interferences

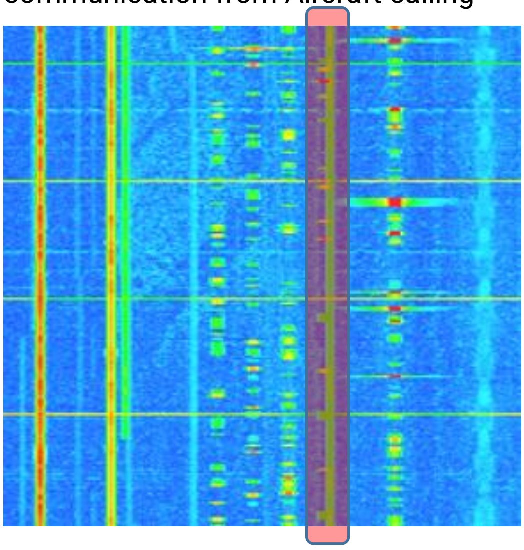
Date: 31st March 2022

Time: 10:53 UTC (duration 7s)

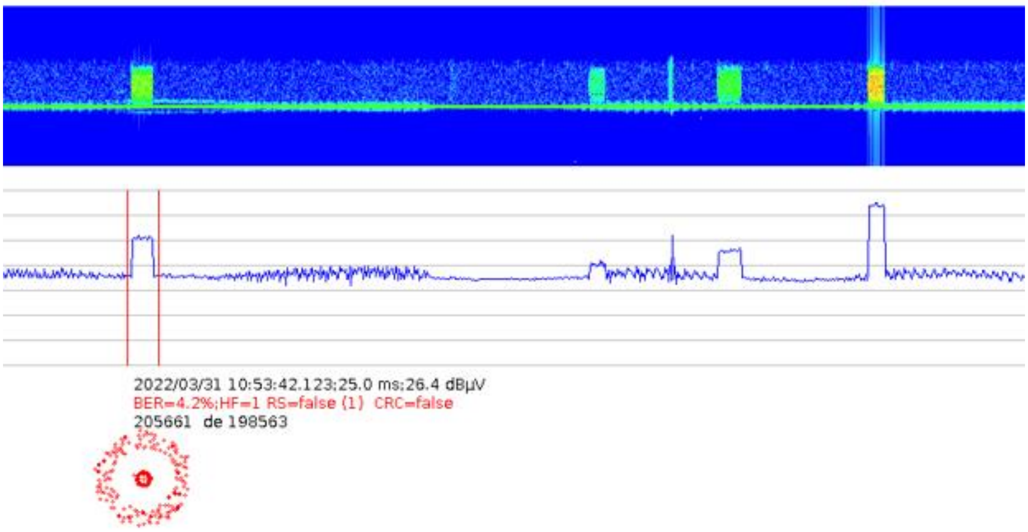
Location: Germany



Description: 8.33 kHz AM voice communication from Aircraft calling



Impact on VDLm2: Decoding failure of all VDL2 bursts on 136.875 MHz



4.6 VDL2 coverage analysis

4.6.1 VGS density

The number of VGSs an aircraft can hear is a key factor affecting performance, due to the hidden terminal phenomenon. The higher the number of hidden transmitters (VGS) the higher the probability of uplink collisions.

Using a one-minute time window, Figure 4-20 shows, using box plots (see annex A), the distribution of the number of VGS heard from the monitoring aircraft on the different frequencies.

Due to the need of wide coverage (airport and en-route), the number of VGS observed on the CSC is, as expected, high. The peak number of VGS observed over a one-minute time window for August 2022 is 42. This is to be correlated to the worse performance of the CSC compared to alternate frequencies (see NM/DPM monthly reports of VDL2 performance).

On alternate frequencies (providing ENR coverage), a peak of 12 VGSs is observed on 136.775MHz, 9 on 136.725MHz and 7 on 136.825MHz.

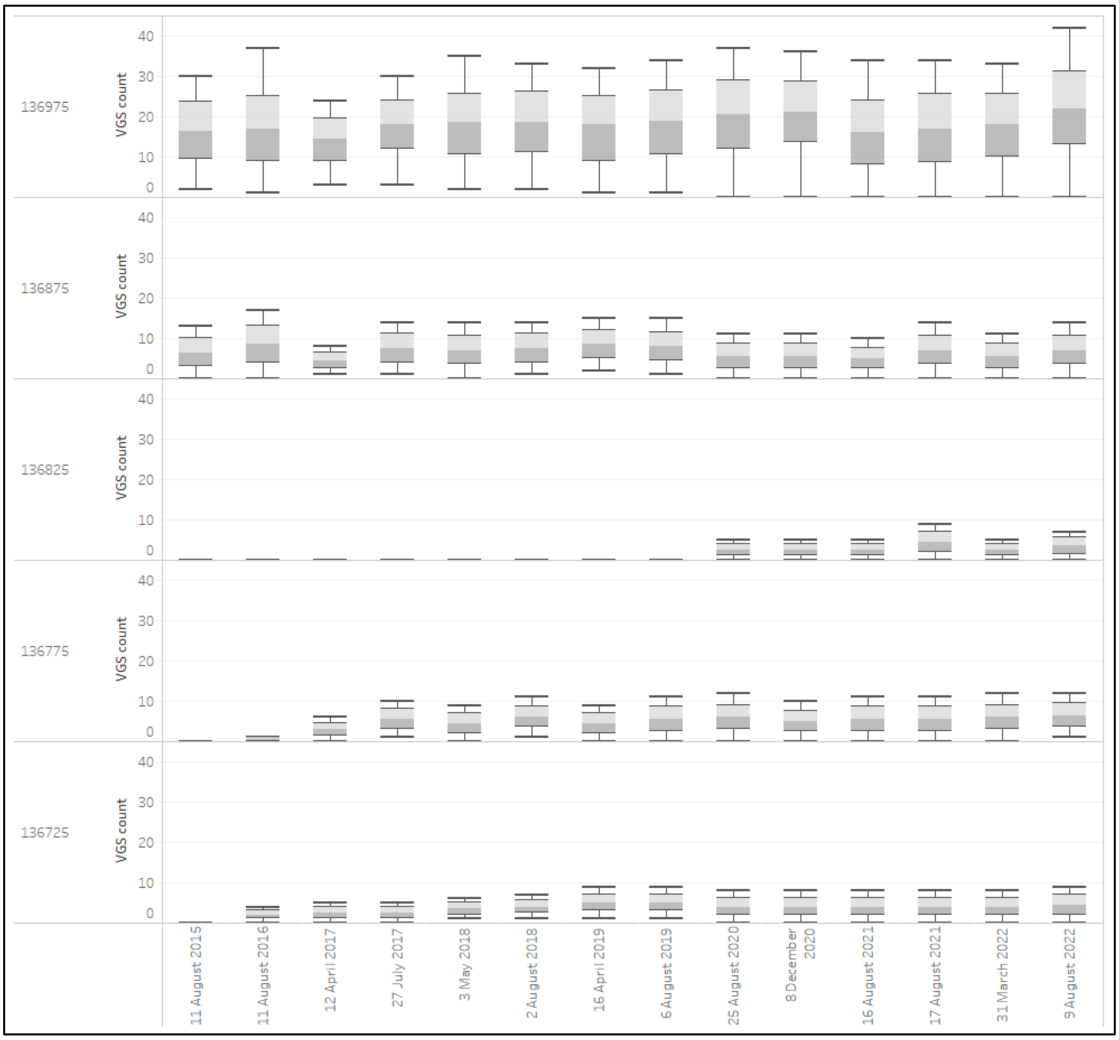


Figure 4-20 : Distribution of the number of VGS heard from the monitoring aircraft.

Figure 4-21 displays the number of VGS (unique 24-bits address) identified during each monitoring flight for each frequency. VGSs are further split according the ACSP.

As the monitoring aircraft is flying near or within ENAV's airspace, we can observe VGSs advertising ARINC network on 136.775MHz and 136.875MHz.

It is observed that the number of VGSs on 136.775MHz and 136.725MHz, to cover the same airspace, is significantly different. Correlation with the performance on these frequencies can easily be made[9] (see NM/DPM monthly reports of VDL2 performance), highlighting again the dependency of the number of hidden transmitters (VGSs) on VDL2 performance.

Frequency	CSP	11 August 2015	11 August 2016	12 April 2017	27 July 2017	3 May 2018	2 August 2018	16 April 2019	6 August 2019	25 August 2020	8 December 2020	16 August 2021	17 August 2021	31 March 2022	9 August 2022
136.975 MHz	ARINC	26	32	29	32	39	42	42	47	51	55	58	70	63	68
	SITA	45	54	50	56	59	65	60	60	60	58	56	66	56	59
136.875 MHz	ARINC	6	2						1	1	1		1	1	1
	SITA	13	28	24	28	25	26	25	28	21	22	23	23	26	27
136.825 MHz	ARINC									11	12	15	12	16	21
	SITA												18		
136.775 MHz	ARINC								2	2	2	2	3	4	1
	SITA		1	11	16	17	20	17	20	21	19	19	24	22	25
136.725 MHz	ARINC		5	7	7	11	13	16	17	16	16	17	17	17	17

Figure 4-21 : Number of VGSs observed during each monitoring flight for each frequency.

To realise what any aircraft flying in the European Datalink airspace will typically experience, Figure 4-22 displays the measured VGS coverage using the VGS receiver's level (in dBm) on each frequency (covering ENR) for the first part of the 9th of August monitoring flight. Each dot represents the received level of VDL2 burst. Colour refers to different VGSs.

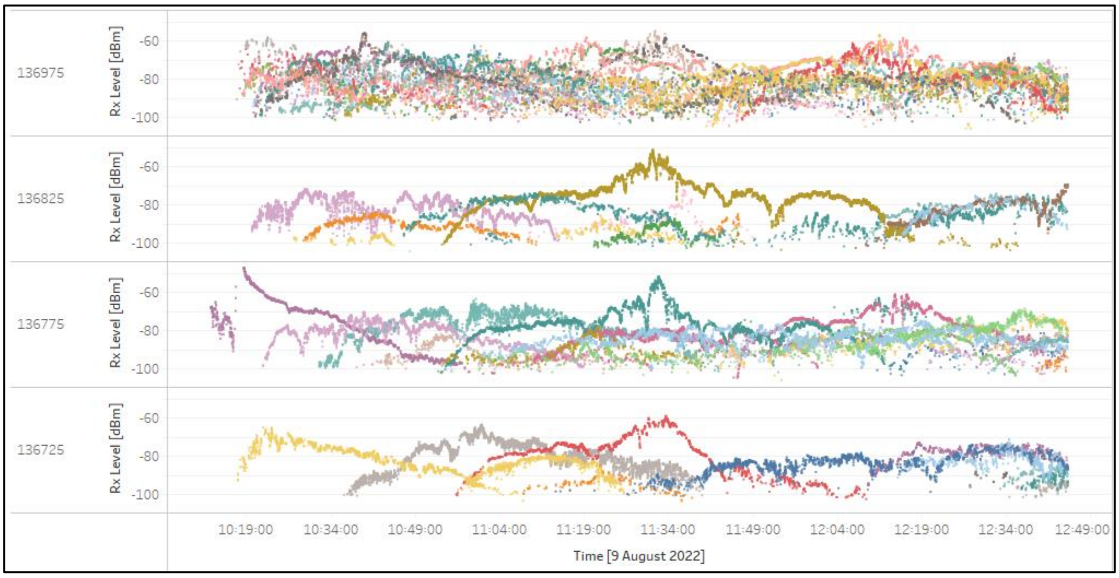


Figure 4-22 : Received VGS level in function of time for the 9th of August 2022 monitoring flight around Munich.

While the reader could easily identify the typical coverage pattern of VGSs located at Munich on alternate frequencies (at the centre of Figure 4-22 and displayed

[9] Performance on 136.775MHz is generally worse than on 136.725MHz and 136.825MHz for comparable amount of traffic. See NM/DPM monthly reports on VDL2 performance.

independently in Figure 4-23), it remains very difficult to do so on the CSS due to the very high number of VGS observed.

Figure 4-23 displays the received level for some VGSs located at Munich. Multipath patterns can easily be identified as well as variations in the number received VDL2 bursts per unit of time (dots density).

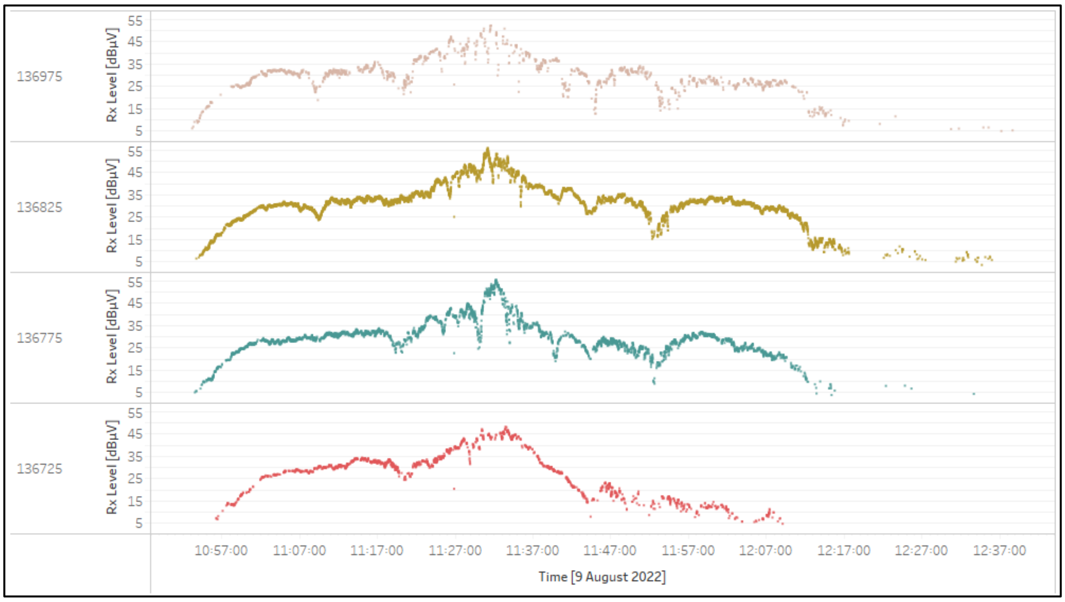


Figure 4-23 : Example of VGS coverage from VGSs located at Munich highlighting multipath.

4.6.2 Uplink packet loss

VGS and monitoring flight data are used together to analyse uplink packet loss, multiple coverage, multipath and their respective impacts. Over the same period, the number of uplinked AVLC frames sent from the VGS is compared with the number of uplinked AVLC frames received from the monitoring aircraft.

The analysis is performed from the point of view of the monitoring aircraft, but the findings are applicable to any aircraft flying in the European datalink airspace.

On the following graphs, the received level (dBµV at the receiver) of VDL2 bursts conveying AVLC frames is displayed (each dot represents the received level of a VDL2 burst) together with the proportion of uplinked AVLC frames missed/loss from the monitoring aircraft over the same period of time compared to what was really sent by the VGS. A missing/loss rate of "0" means that all the frames uplinked by the VGS are correctly received by the monitoring aircraft. On the contrary, a missing/loss rate of "1" means that all the frames uplinked by the VGS are not received by the monitoring aircraft. In order to differentiate between AVLC frames loss and moments during which the VGS is not transmitting on the received level graphs, the moment at which a VGS is transmitting is displayed with a frame set at 0dBµV and below.

Figure 4-24 displays the received level for 4 VGSs as received from the monitoring flight over its route. The focus is made on the "red" VGS over which the route is flying. The maximum received level is when the monitoring aircraft is the closest to the VGS.

Figure 4-25 displays the received level and the missing frame rate for the "red" VGS. The high loss frame rate before 11:30 is due to the presence of the "green" VGS. As the monitoring aircraft get closer to the "red" VGS and moves out of the coverage of the "green" and "yellow" VGSs, the probability of receiving uplinks increases.

As the signal to interference ratio increases (above 20 dB) the probability to successfully receive an uplinked AVLC frame increase.

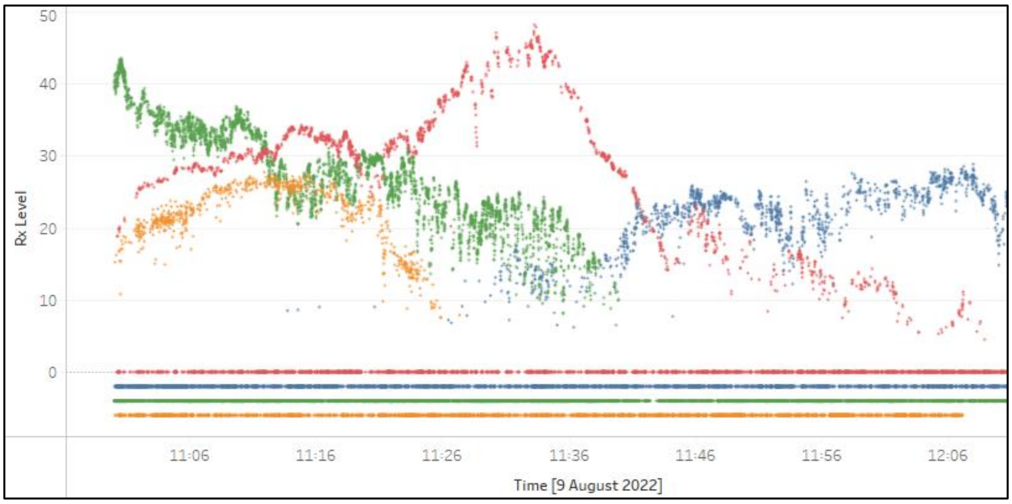


Figure 4-24 : Received level of 4 VGSs along the monitoring route.

After 11:46, while entering the coverage of the "blue" VGS, the received signal of the "red" VGS experiences multipath during which a higher number of uplinked frames are lost. As the monitoring aircraft is leaving the coverage of the "red" VGS, the probability of uplinked frame loss increases. However, due to the multipath, the probability of uplinked frame loss is also "modulated" with the multipath pattern. The correlation between multipath and the missing frame rate is well observed on Figure 4-25.

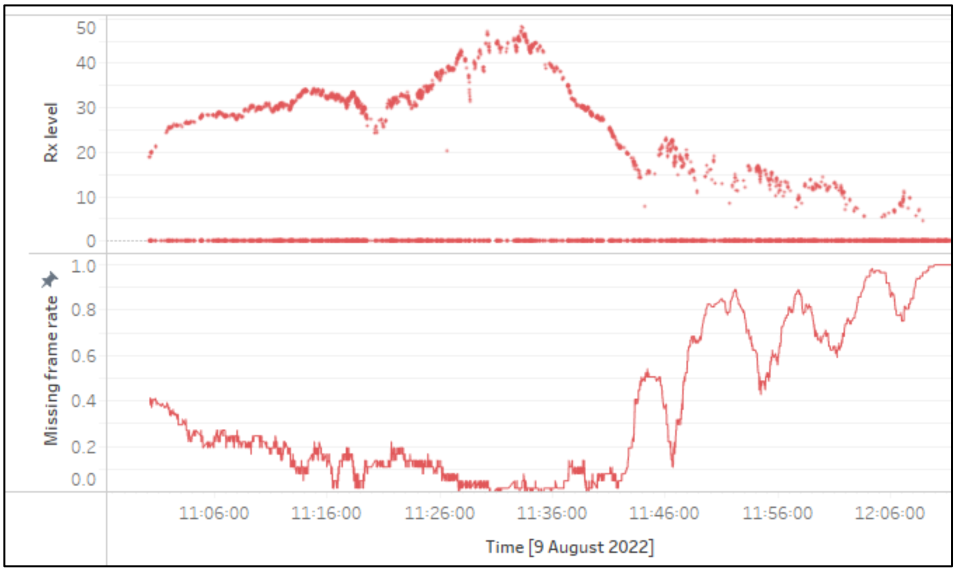


Figure 4-25 : Received level and missing frame rate for the "red" VGS.

In the case of multiple coverage, multipath affects signal to interference ratio and thus also the probability to successfully receive uplinked AVLC frames.

This finding is also observed when the monitoring aircraft is close to the VGS (and thus received it with stronger signal) and not only at the edge of the coverage of a VGS.

Figure 4-24 and Figure 4-25 also highlight that only a small number of VGSs (multi-coverage) is sufficient to increase the probability of uplink packet loss. Between 11:00

and 11:20, the received level of the 3 VGSs (red, yellow, and green) is sufficiently comfortable to conclude that:

The uplink packet loss is not due to loss of coverage but due to collisions from to the hidden transmitter phenomenon.

5 Conclusions and recommendations

Monitoring flights were held on the 31st of March and 9th of August 2022. While the amount of the recorded data is only covering these two instances, the conclusions and recommendations below consider in addition to the recorded data in these monitoring flights, the trends and data form the previous monitoring flights and are also taking into consideration other available information for the VDL2 network and performance.

VDL2 channel use

The use of the VDL2 frequencies has reached levels equivalent or above to pre-pandemic (2019).

The Common Signalling Channel (CSC) is still the most used frequency. The bad performance of the CSC compared to alternate frequencies is well known (see regular monthly performance reports from NM). The hidden terminal phenomenon associated to the high number of VGS observed from en-route is the major factor of performance issue. Keeping en-route traffic on the CSC negatively impacts the global network performance and should be avoided. The CSC should not be used for en-route traffic.

The dedicated ground frequency 136.875MHz is underused compared to frequencies providing en-route service. The analysis of the traffic exchanged on the ground for the top 5 busiest airports in Europe is showing that one single frequency would be sufficient to handle ground traffic at airports for both ACSPs.

Recommendations

- All en-route traffic should be removed from the CSC and moved on the alternate frequencies where performance is expected to be better.
- The CSC should not be used for en-route traffic.
- The use of frequencies on which ground traffic is exchanged should be optimised to increase VDL2 spectrum efficiency.

VDL2 traffic analysis

For airborne aircraft, the recorded ATN traffic volume exchanged represents 50% of the overall VDL2 traffic, while AOA represents 35%, and the remaining 15% is related to AVLC protocol (i.e. GSIF, hand-over, …).

The VDL2 traffic volume related to the ATN (overhead), in proportion to the overall traffic volume observed, has dropped to 43% since 2015, and will continue to decrease, in proportion, as the use of CPDLC will increase.

The VDL2 traffic volume from ACARS messages where engine reports are expected to be found represents around 45% of the airborne AOA traffic volume.

A significant difference on the size of AVLC frames conveying AOA is observed between the two ACSPs. This could explain some observed differences in performance, knowing that the probability of uplink collisions increases with the size of the frames.

An estimation of the VDL2 throughput have been made. The less efficient channel is found to be the CSC, while the most efficient is found to be 136.725MHz, where a maximum throughput of 26% (8.2 kbits/s) was observed.

Recommendation

- SITA is invited to consider decreasing the maximum size of AOA frames to increase VDL2 performance on their network.

Interferences

As observed during pervious monitoring campaigns, interferences are still observed. This report focuses on the analysis of the most important ones observed during the two flights with an impact assessment on VDL2 demodulation and decoding.

Recommendation

- Administrations are invited to apply Article 15.2 §8 from ITU-RR Chapter IV [10].

VDL2 coverage

An analysis of the VDL2 coverage has been presented. It was shown that the overlapping -coverage of multiple VGSs increases the uplink packet loss due to the hidden terminal phenomenon. It is also highlighted that multi-path affects signal-to-interference ratio, also leading to an increase of uplink packet loss. The latter phenomenon is also observed at the vicinity of the VGS where the signal received by the ground station is expected higher.

Recommendations

- The VGS coverage should be optimised to decrease multi-coverage (number of VGSs seen by aircraft) and decrease multi-path in order to improve uplink packet loss and increase global performance.

Further analysis and monitoring flights

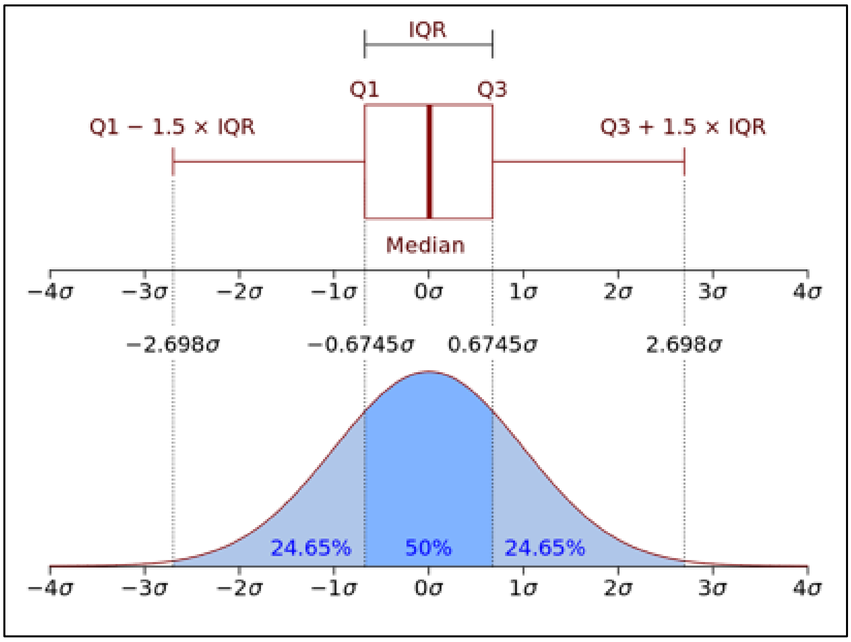
The analysis of the recording will continue, and further flights will be planned in 2023.

[10] ITU Radio Regulation (RR) Chapter IV "Interferences", Section II "Interference from electrical apparatus and installations of any kind except equipment used for industrial, scientific and medical applications", Article 15.2 §8: "*Administrations shall take all practicable and necessary steps to ensure that the operation of electrical apparatus or installations of any kind, including power and telecommunication distribution networks, but excluding equipment used for industrial, scientific and medical applications, does not cause harmful interference to a radiocommunication service and, in particular, to a radionavigation or any other safety service operating in accordance with the provisions of these Regulations*".

Appendix

A. Box plot

Box plot is a useful tool to display basic information about the distribution of a dataset. The following graph shows the relation between a box plot and the distribution it represents. Q1 and Q3 are respectively the first and third quartiles (25% and 75%) forming the Inter Quartile Range (IQR). 50% of the data lays between Q1 and Q3 while 99.3% of the data between "Q1-1.5 x IQR" and "Q3+1.5 x IQR"



References

[1] Data link Network Operational Status Report, August 2022.

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