Short Presentation of
VDL MODE 4 and some European projects

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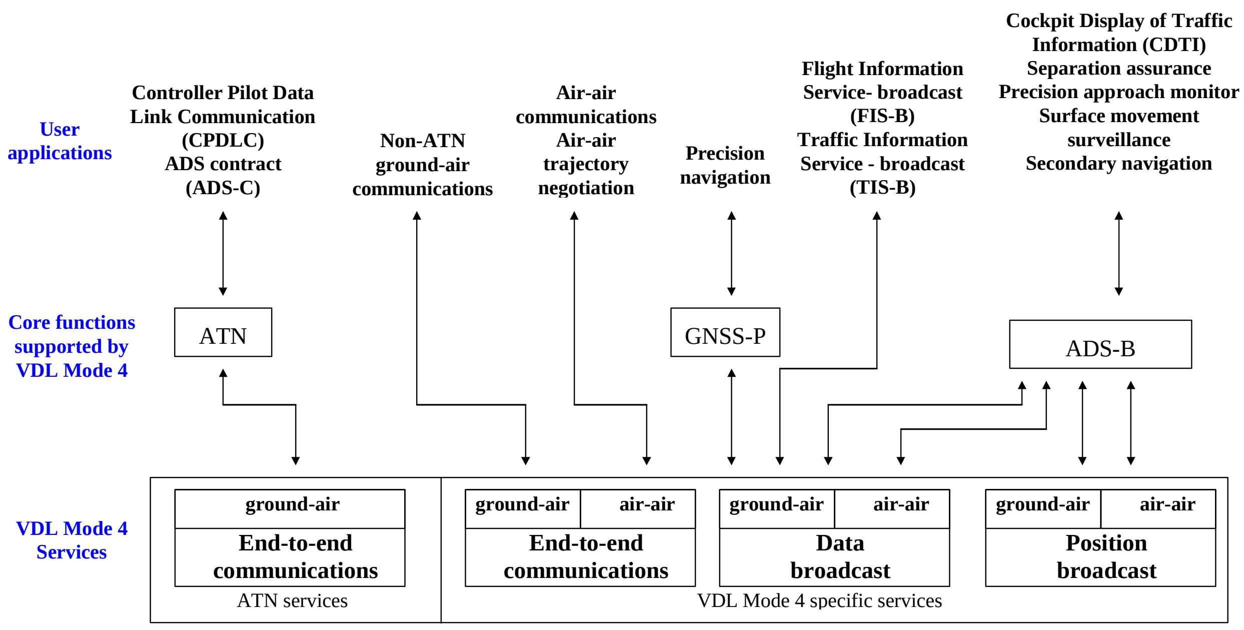
1. Introduction to VDL MODE 4/STDMA

The VDL Mode 4 system is the heart of future CNS/ATM systems. VDL Mode 4 is the International Civil Aviation Organisation's (ICAO) acronym for VHF Digital Link and is essentially a generic digital communications system that is capable of supporting virtually all kinds of air, sea and land mobile applications. VDL Mode 4 are based on the Self-organising Time Division Multiple Access Technology known as STDMA. **Further information can also be found on the following web addresses:** www.lfv.se/ans/card**,** www.vm4.com**,** www.nup.nu **and** www.gpc.se Some of the applications for aviation that are supported by VDL Mode 4 are shown below. These applications and their relation to VDL Mode 4/STDMA services are illustrated in Figure 1.

Figure 1. VDL Mode 4/STDMA communications services and example applications



1.1. VDL Mode 4 communication services

VDL Mode 4 supports two different communications services:

- VDL Mode 4 specific services;
- VDL Mode 4 ATN services.

The VDL Mode 4 specific services include broadcast and point-to-point communications with a minimum of overhead information for time critical data exchange and low-end users. The VDL Mode 4 ATN service is fully ATN compliant. Together these services support a range of broadcast and end-to-end communications services.

1.2. Broadcast communication services

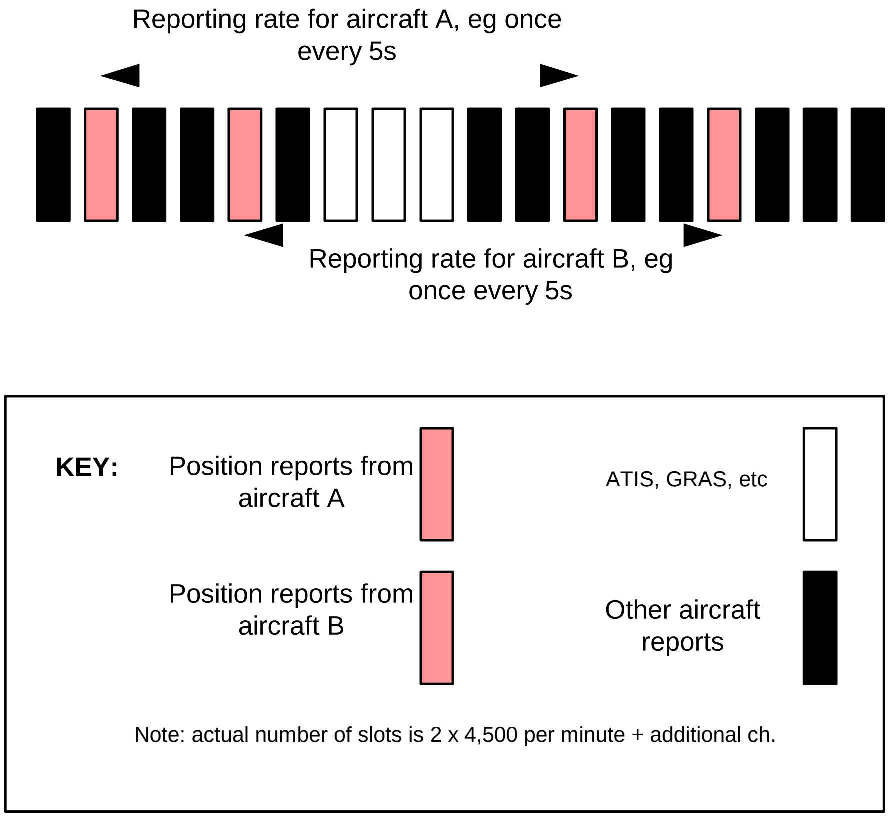
ATN does not support broadcast transmissions. Such services are defined as "specific services" in the ATN concept. VDL Mode 4 specific services support broadcast data applications. Broadcast transmissions are used in many different CNS/ATM applications. Depending on the application the broadcast transmission can be sent both from ground sites and from mobile units.

1.3. End-to-end communication services

In VDL Mode 4, end-to-end communications can be realised as a VDL Mode 4 specific service or using the full ATN protocol stack. Most ATN communications will use another frequency than short position reports as for Automatic Dependent Surveillance-Broadcast (ADS-B). The selection of service may depend on the aircraft equipage, type of ground infrastructure, time criticality, economical aspects, channel loads, etc.

When using VDL Mode 4 for ADS-B, aircraft reports of navigation data are transmitted in the time-slots available on the data link. An example of the use of the data link is shown in Figure 1.1.

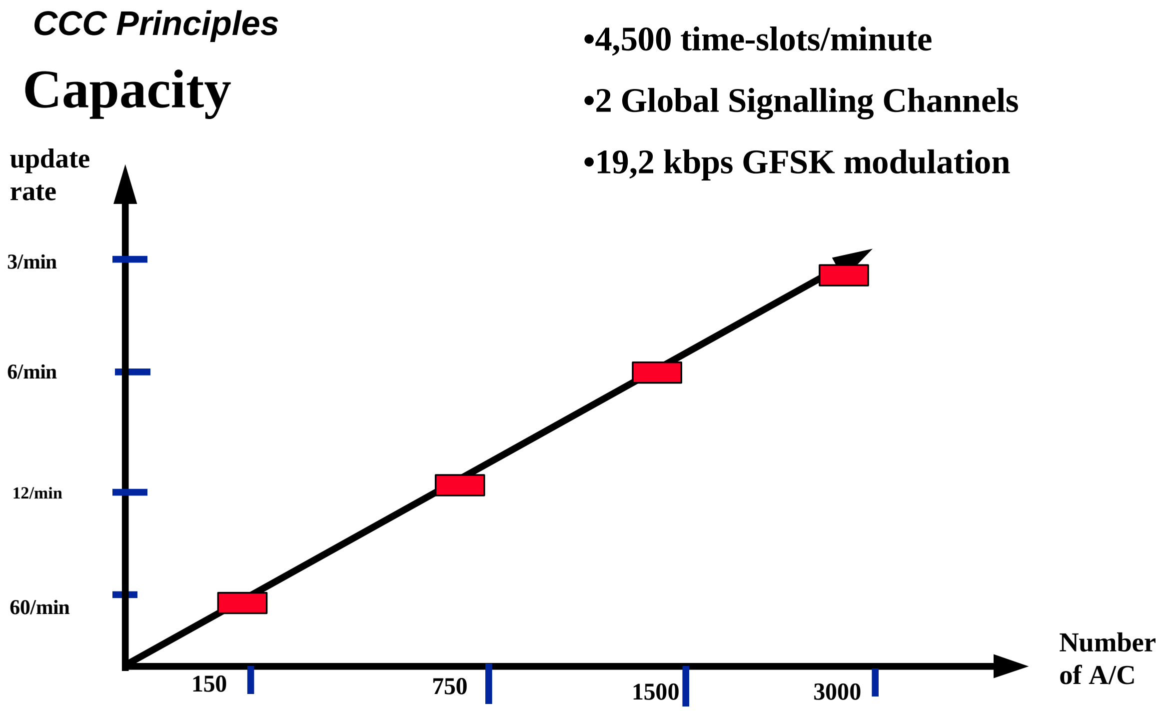
Figure 1.1. Time-slot usage in VDL Mode 4



1.4. VDL Mode 4 Capacity.

Some of the key-features of VDL Mode 4 is that it is a multi-channel narrow band system that operates *with or without* a ground infrastructure, it is a *distributed* communications system, and it provides *higher capacity* per bandwidth than any other known wireless communications technology. *Compared with, for instance, the ICAO VDL Mode 2 data link system the capacity offered by VDL Mode 4 is estimated to be about 15 times higher despite a lower bit rate*. This is due to the better spectrum mask and a CCI value of ~10 dB for VDL Mode 4 compared with ~26 dB for VDL Mode 2. The spectrum efficiency is thereby significantly improved. This is illustrated in figure 2 below.

Figure 2. VDL Mode 4 Capacity.



In order to make capacity and spectrum efficiency comparisons with other competing technologies it is important to seek an answer to the question: “How many position reports or other types of 256-bit messages can be transmitted per minute or second per kHz bandwidth“?

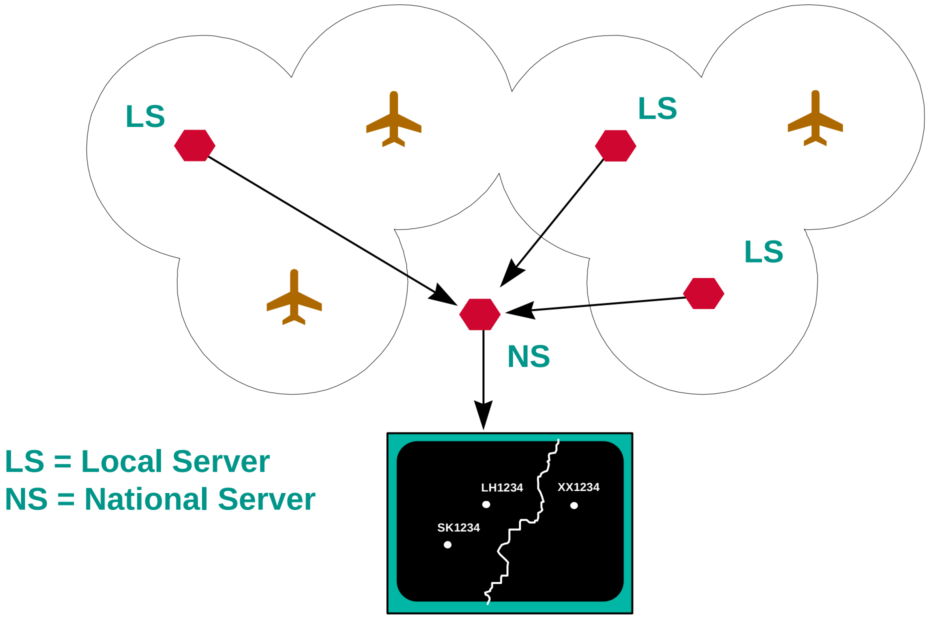
Additional capacity, if and as needed, is provided by adding more regionally or locally assigned 25 kHz channels.

2. Automatic Dependent Surveillance - Broadcast (ADS-B).

Although the development started in Europe in the 1980’s ADS-B is a relatively new aviation surveillance concept whereby aircraft transmit their positions (usually derived from a GNSS receiver on-board the aircraft) over a radio data link. Position information is transmitted and received by every aircraft in the vicinity so that all users have knowledge of their own location and the locations of all other surrounding aircraft or vehicles. The position information may be displayed in the cockpits of suitably equipped aircraft to give new situation awareness capabilities. Also, ground vehicles and fixed ground stations can also be equipped to transmit and receive position data, allowing surveillance of all types of traffic and a two-way data link capability.

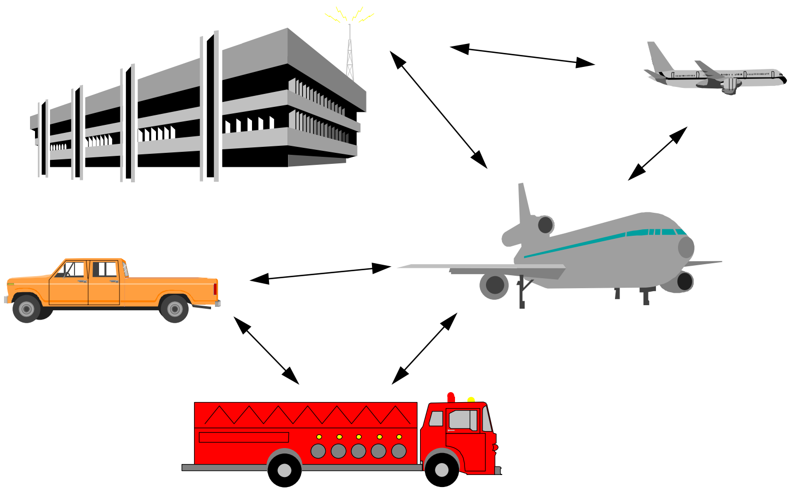
When using VDL Mode 4 for ADS-B, all aircraft and vehicles within range will receive reports of navigation data. With a VDL Mode 4 infrastructure in place such as the North European ADS Network (NEAN) and the Italian FARAWAY system position information and GNSS Augmentation and other information is provided for a large areas for use e.g. by aircraft for precision navigation, ATC for Surveillance and Communication, by airlines for Fleet Management, and for Search and Rescue, etc. An example of such an infrastructure is shown in Figure 2.

Figure 2. VDL Mode 4 Ground infrastructure



With ADS-B, the position information is constantly being shared amongst all users, as illustrated in Figure 3. This is a unique surveillance capability since traffic information is made available to all users - not just the ground ATC system.

Figure 3. ADS-B aviation participants.



In addition to position information, other data is also broadcast on the data link. Most importantly, this includes the aircraft identity (so that all the users know the identity of other users) and velocity of the aircraft or vehicle, usually derived from the GNSS receiver. With a VDL Mode 4 ground infrastructure GNSS Augmentations is also available to the users within radio range.

ADS-B should not be confused with Satellite ADS (also known as ADS-Contract or ADS-C).

With ADS-B, an aircraft periodically and frequently transmits its ID and position data to all surrounding users, whether they are ground based or airborne. However, with ADS-C the aircraft only transmits its position to a single ground control centre with lower frequency and as often as required by that ground centre.

The Swedish CAA and Swedavia AB has been working with the VDL Mode 4 technology since 1991 and in particular different ADS-B applications provided by VDL Mode 4. ADS-B offers benefits to many different types of air and ground users. Some of the groups using VDL Mode 4 operationally or for trials are:

- commercial aircraft operators, such as Air Valle, Alitalia, Lufthansa, SAS, OLT, Golden Air, and Maersk Air.
- general aviation users;
- ground vehicle operators, for example snow clearing vehicles at Stockholm's Arlanda International Airport use VDL Mode 4 to operate in poor visibility and to shorten the time for snow clearing;
- helicopter operators, such as Maersk Air who operate in the North Sea.
- Air Traffic Control such as Eurocontrol Maastricht, Stockholm-Arlanda Tower, and Brindisi, Ciampino and Padua ACC's, Italy.

3. ADS-B in the cockpit

ADS-B will have a major impact on the cockpit environment because it will provide the pilot with full situation awareness of all surrounding traffic (the aircraft flight number is automatically shown on the screen). Figure 4 shows a cockpit display that is used to show the positions and intent of all the aircraft within 200 NM. The cockpit display is also known as a Cockpit Display Traffic Information (CDTI) or a Traffic Situation Display (TSD) and is already installed in several commercial and some military aircraft (Lufthansa, SAS, OLT, Golden Air, USAF C-5 Galaxy, etc.). In order to assure that the future onboard systems can support flight critical functions such as e.g. future Airborne Separation Assurance System (ASAS) a need for two (2) 25 kHz frequencies have been identified through the work completed by the Airborne Architecture Group. This requirement has also been recognised in the context of the standardisation work completed by ICAO and EUROCAE in March/April 2001.

In contrast to e.g. ACAS/TCAS (Mode S Squitter) VDL Mode 4 is a low power system that allows dual installations in the aircraft, thus meeting the availability requirements for on-board surveillance applications in non-radar airspace.

Figure 4. Cockpit Display for all CNS applications

Pilots can use the cockpit display to monitor the traffic around them and to keep abreast of the traffic distribution. They can easily monitor essential traffic and for the first time the crew will have the same surveillance picture as the controller.

The cockpit displays will support new manoeuvres such as station keeping in which a pilot is asked to follow another aircraft maintaining a particular separation. This does not relieve the ground controller of his responsibilities for separation maintenance, but it does allow the controller to share some of his workload with the pilot. Station keeping can be used, for example, to efficiently sequence aircraft during departure operations.

Another application may be to allow passing manoeuvres. Currently, manoeuvres such as in-trail climbs are made using TCAS to provide separation assurance. This is not desirable because it involves the pilot specifically ignoring TCAS advisories during the manoeuvre, potentially causing confusion to the pilot and reducing the value of other TCAS warnings.

One of the benefits of the cockpit display is that it can replace the ‘party-line’, which refers to the way in which pilots listen to VHF radio to hear the exchanges between other pilots and the ground controller. By listening to the radio, the pilot builds up a mental picture of traffic close to himself. The cockpit display gives a much more complete and accurate picture of essential traffic to the pilot. Pilots are worried that introducing CPDLC (controller-pilot data link communications) will remove the party line and they will therefore lose their present situation awareness; ADS-B, with an appropriate cockpit display, gives a much better situation awareness to help overcome this concern. The Cockpit Display shown in Figure 4 is - in addition to navigation and surveillance- providing a range of other functions including Flight Plan Management and CPDLC. Airborne Conflict Detection and Conflict Resolution using the VDL Mode 4 prototype system and CDTI has been tested by Eurocontrol and others (DFS, Lufthansa, Luftfartsverket and SAS) within the FREER 3 programme.

4. ADS-B on the ground

On the ground, ADS-B will provide new surveillance capabilities to ATC at a fraction of the cost of conventional SSR/MSSR, Mode S and PSR. It offers 10 times more capabilities at about 10-20 % of the cost for a radar based system. An ADS-B ground station is a transmitting/receiving station without the expensive and complex rotating antennas of radar systems. Also, unlike radar systems an ADS-B ground station is not required to make high precision measurements of aircraft position, so the cost of ground electronics, maintenance and operation is much less.

ADS-B will therefore offer an advanced and low-cost surveillance system to those states that have areas not covered by radar with the following benefits:

- **High quality surveillance data with unambiguous identity and gate-to-gate coverage**: rather than a variable quality of surveillance cover depending on the phase of flight and ground station siting.
- **Low cost**: since there would be no separate surveillance system (it would be part of the communication infrastructure already in place).
- **Flexibility**: surveillance reporting rates can be varied according to the requirement, e.g. PRM monitoring can have a higher reporting rate than en-route applications.
- **More accurate navigation data**: GNSS position data has an accuracy of about a metre if differential corrections (DGNSS) are available to the GNSS receiver. This is a much higher accuracy than radar systems. Also, the velocity information given by a GNSS receiver is more accurate than velocity derived from consecutive radar tracks.
- **More advanced surveillance information**: for example, additional data from the FMS or other airborne computers may be transmitted over the data link to other users.
- **Support for new applications**: a general purpose data link such as VDL Mode 4 can be used to pass additional surveillance information or support new applications.
- **Identical surveillance information available to all users**: including airborne and ground-based users. In remote areas, aircraft could use this surveillance data for autonomous control.
- **Suitable for all phases of flight**: including airborne, surface movement surveillance and precision surface navigation.

5. VDL Mode 4 - The solution for ADS-B

VDL Mode 4/STDMA provides a real-time two-way data link, for all types of aviation applications, as well as ADS-B functionality. VDL Mode 4 has been standardised by the ICAO Aeronautical Mobile Communication Panel (AMCP). The SARPs have been extensively validated and was approved by ICAO in March 2001. SARPs will be published in Annex 10, November 2001.

In addition, EUROCAE WG-51 has developed MOPS standards for VDL Mode 4 airborne equipment and ETSI has standardized Mode 4 Ground Stations. ITU and IMO have adopted the same basic system (for maritime applications called Automatic Identification System-AIS) to become mandatory equipment (starting 1 July 2002) on-board ships under SOLAS Chapter V and on all other passenger ships.

There are many projects ongoing around the world that are using prototype VDL Mode 4/STDMA equipment. Most of the projects involve the Swedish Civil Aviation Administration, and most European ones are sponsored by the European Commission (EC) and Eurocontrol.

There is insufficient space in this paper to describe all the projects using VDL Mode 4/STDMA here, but some of them are listed below:

- **NEAN** ***(Sponsored by EC DG VII)*** The largest European activity is known as the North European ADS-B Network (NEAN). Under NEAN, an ADS-B capability is being created through a network of ground stations and mobile VDL Mode 4 equipment that is installed in commercial aircraft and airport vehicles. The network spans Germany, Denmark and Sweden, and once position reports are received by a ground station they are then distributed throughout the network to air traffic control and other users. There are 15 ground stations in the NEAN project and 16 aircraft equipped including six 747s, two DC9s, two F28s, one SAAB 340 and a helicopter involved in North Sea operations. Around 30 ground-vehicles have also been equipped. NEAN is a collaborative venture between the German, Danish and Swedish Civil Aviation Administrations and the following aircraft operators: Lufthansa, SAS, OLT, Maersk Helicopters and Golden Air. The UK CAA has been looking at the certification and validation parts of the project. The NEAN ground network was completed in May 1997 and all airborne installations during the first half of 1998. In June 1997, Flight International Magazine gave an Aerospace Industry Award to Luftfartsverket (the Swedish CAA) and SAS. The award was for pioneering work within the NEAN project to demonstrate the potential of ADS-B, GNSS Augmentation, CDTI, etc.
- **NEAP (*****Sponsored by EC DGVII)*** The North European CNS/ATM Applications Project (NEAP) is a sister project to the NEAN, with the same participants. Using the infrastructure implemented in the NEAN, the NEAP has developed and demonstrated end-to-end (airborne and ground based) applications using the VDL Mode 4/STDMA data link. The applications investigated in NEAP include enhanced ATC surveillance (both while airborne and on the ground); uplinked support information for pilots, e.g. ATIS data; uplinked GNSS corrections and integrity data for approach and landing. The NEAN/NEAP projects were successfully completed in February 1999 with a flight demonstration during which some 80 guests from various parts of the world were onboard two of the SAS Fokker F-28 that participated in the demonstration (See also appendix 1).
- **North European Update Programme/NUP** ***(Sponsored by EC DG VII).*** The objective of NUP is to further enhance the NEAN/NEAP -projects by developing and deploy SARPs compliant VDL Mode 4 air and ground systems and to further improve the network and the network management technologies within NEAN, FARAWAY II, etc. The overall objective of the project is to implement a system that can be put into operational use. The project was formally approved in July 1998 and will continue until 2001.
- **FARAWAY (*****Sponsored by EC DG XIII)*** The objective of FARAWAY was to investigate the enhanced operational performance of ground surveillance and aircraft navigation made possible through fusion of radar and ADS-B data. The Faraway project was co-ordinated by Alenia Spa, Italy and involved ATM service providers and airlines in Germany, Italy and Sweden. Initially three Alitalia MD-82 were equipped with VDL Mode 4/STDMA and Cockpit Display equipment. Ground stations have also been

installed at Brindisi, Ciampino and Padua ACCs, in Italy. The FARAWAY trials have been going on from October 1997 and was successfully completed June 1998. The trials were testing a variety of applications such as enhanced navigation by Augmented GNSS, ADS-B, Traffic Information Services-Broadcast (TIS-B), and fusion of ADS-B and radar data in controller working positions at the new Rome ACC, located near Ciampino Airport. Data from more than 2,000 flights was collected and analysed. The air-ground range of the ADS-B and DGNSS was more than 200 NM, and the tracking performance was significantly improved by ADS-B.

FARAWAY II (*Sponsored by EC DG XIII)* The objective of FARAWAY II was to extend the coverage of the ICAO VHF Mode 4/STDMA two way datalink into the NEAN airspace and down to Brindisi in southern Italy**;** provide co-ordination with selected ADS trials conducted under National or European Projects, such as the Eurocontrol ADS Mediterranean Trials, PETAL II, NEAN/NEAP, SUPRA, Regional ADS projects by ENAV and others supported by the European Commission; secure Interoperability of systems and Flight Management functions through the constitution of a pre-operational scenario adopting compatible technologies, provide inputs to on-going standardisation and certification initiatives, and develop a set of advanced Validation Tools as part of a certification process. The project was successfully completed November 2000, and has been nominated as a finalist for the Aerospace Industry Awards 2001.

SUPRA (*Sponsored by EC DG XIII)* This project was co-ordinated by Indra of Spain and focused on the use of ADS-B and cockpit displays for general aviation (GA) aircraft and airport ground vehicles. Within the project two GA aircraft and one ground vehicle were equipped at El Robledillo airport outside of Madrid. A VDL Mode 4/STDMA ground station was also installed for uplinking of DGNSS messages and ATIS reports. Successful demonstrations of the SUPRA installations were completed in April 1997. The project received the 1998 Aerospace Industry Award.

- **MAGNET B (*Sponsored by EC DG XIII*)** The objectives of Magnet B was to develop GNSS1 user segments, to assess their capability to meet the most demanding aviation requirements and to evaluate the benefits that users can achieve from the integration of GNSS1 with a two-way data link. The Magnet B project was co-ordinated by Dassault Electronique, France and included participants from Germany, UK, Norway, the Netherlands and Sweden. Installations were made early January 1999 at Amsterdam Schiphol Airport. The project was successfully completed by the end of 1999.
- **PETAL II *(Sponsored by EUROCONTROL)*** PETAL-II is an Eurocontrol project to investigate use of air-ground data link to perform real-time Controller Pilot Data Link Communications (CPDLC). Petal II is using the two-way data link capability of VDL Mode 4/STDMA to provide this application. VDL Mode 4/STDMA ground stations were installed at the Maastricht Centre and at the Eurocontrol Experimental Centre during March/April 1997. PETAL II was a finalist for the Aerospace Industry Awards 2000.
- **Offshore helicopter operations** Companies in Denmark and Norway are installing VDL Mode 4/STDMA equipment on helicopters flying personnel and supplies to oil rigs in the North Sea. The first installation onboard a Super Puma helicopter was completed in February 1997.

In addition, there are many activities underway in the rest of the world. For example, the FAA has performed a test program at the Atlanta Hartsfield Airport, USA, to evaluate VDL Mode 4/STDMA for ADS-B; GNSS ground augmentation and uplink of traffic information (TIS-B) and to compare the performance capabilities of different ADS-B systems.

6. Conclusions and Future plans

ADS-B is a technology that can provide pilots with accurate information about surrounding air traffic, and offers important operational benefits. In addition ADS-B, will bring other benefits including possibilities optimise the flow of air traffic, to further automate the ground systems, to enhance safety and last but not least reduced Communications and surveillance costs and provide greater capability and flexibility.

The Swedish CAA has concluded that VDL Mode 4 is the only technology that can deliver the benefits of ADS-B and provide CNS/ATM functions in line with the Eurocontrol "Gate-to-Gate" policy. The Association of European Airlines that include all major European airlines of which Lufthansa and SAS are actively involved in VDL Mode 4 development supports this view.

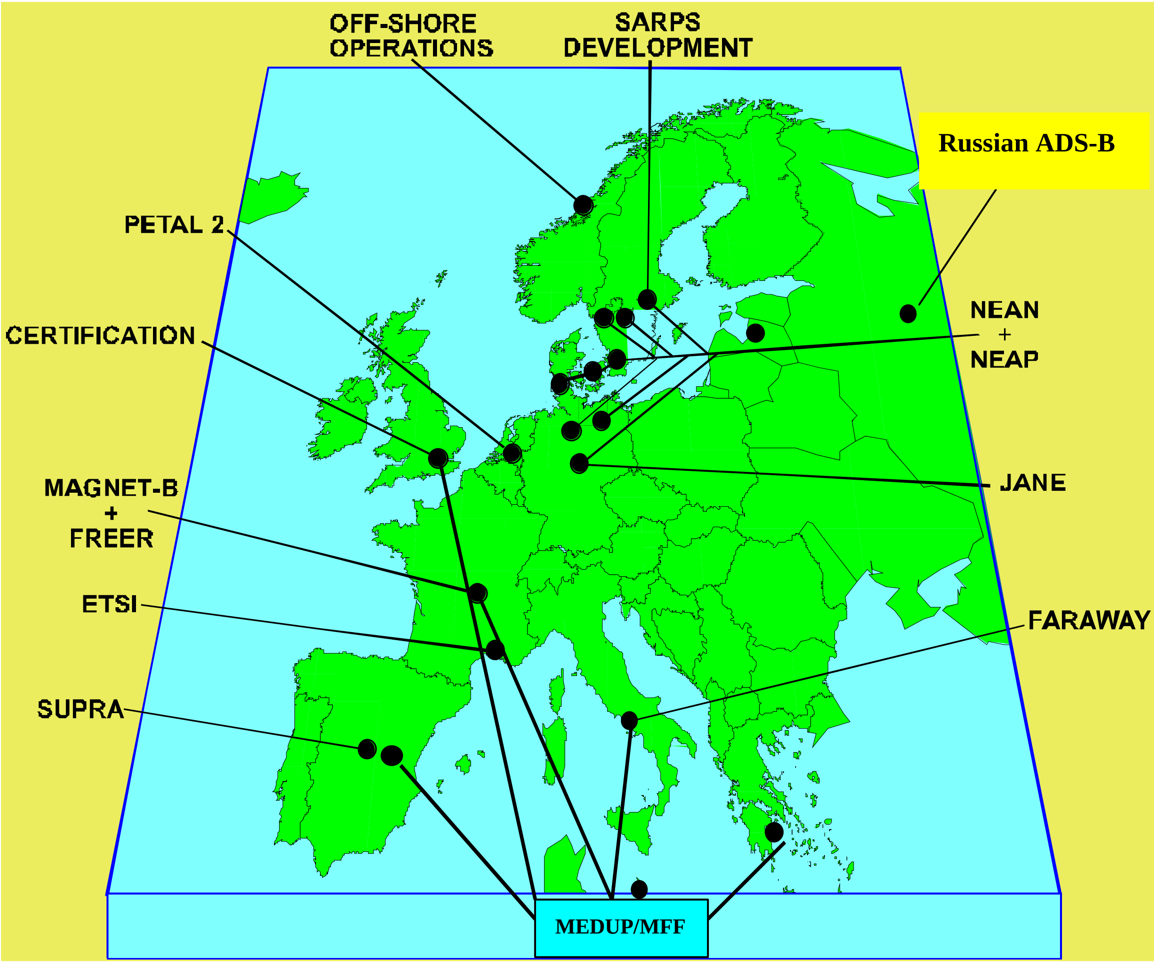
Future plans are to progress with VDL Mode 4 pre-operational trials aiming at deployment of fully operational systems. The Swedish CAA is planning to deliver new services based on the principles of early delivery of benefits to airlines and the incremental introduction of services, starting with low-criticality applications that have the lowest certification requirements. These applications will be used to gain operational experience and confidence. The pre-operational experience gained in the NEAN/NEAP and FARAWAY-projects and the other projects described above will assist in a fast transition to the new services and benefits offered by VDL Mode 4 such as ADS-B, CDTI, TIS-B, FIS-B, DGNSS Augmentation, CPDLC, etc.

Two other major projects are currently going on in the Mediterranean area – the Mediterranean Update Program **(MEDUP)** and the Mediterranean Free Flight **(MFF).** The objective of the MEDUP is to upgrade current prototype VDL Mode 4 to SARPs compliant equipment and to deploy additional infrastructure in Greece, France, Malta and Spain. The MFF is aiming at an evaluation of different operational procedures related to Free Routing and Flight in the Mediterranean airspace.

The MFF-program, is based on the utilisation of the latest CNS technologies including VDL Mode 4, and will last about 3 more years. The program and is subdivided into two Phases. Phase I will last until the end of 2002 and will define and carry out the free routing and free flight scenarios, operational procedures, separation assurance management, ATM systems, avionics and the related safety issues and includes the use of both model based and real time simulations. Phase II will start 2003 and continue until the end of 2004. Phase II will test and verify the overall operational procedures, for both pilots and controllers through flight trials. Large scale validation activities and the development of a methodology for the Free Flight operational safety assessment will be completed during Phase II.

After a series of successful tests and trials **Russia** has declared its intention to implement ADS-B/VDL Mode 4 and start operational use of the technology from late 2005.

The figure below shows some of the European VLD Mode 4/STDMA ADS-B projects.


OFF-SHORE
OPERATIONS
SARPS
DEVELOPMENT
Russian ADS-B
PETAL 2
CERTIFICATION
NEAN
+
NEAP
JANE
MAGNET-B
+
FREER
ETSI
FARAWAY
SUPRA
MEDUP/MFF