Integrations of Airborne Radio Communications into Global Aeronautical Distress and Safety System (GADSS) Network

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Abstract: In this paper are introduced integrations of current and new airborne radio communications as a subsegment of the Global Aeronautical Distress and Safety System (GADSS). The traditional aircraft radio communications are based on analog voice on either a Very High Frequency (VHF) or High Frequency (HF) radio waves. However, in the mid 1980s the use of airborne data communications via VHF and HF radio became a reality. In addition, the airspace management system is transferring into computer technology and innovations, so in such a way new requirements evolve and the choice of radio communications systems expand, regulating the world's air traffic flow can safely become more automated and efficient. Besides, aircraft are currently being equipped with communications systems that transport data via satellite plus while they are on the ground and in some cases broadband networks can receive or broadcast strategic information regarding aircraft situation and even maintenance trends. A range of aeronautical radio communication technologies for implementation via VHF-band; radio VHF ACARS network; radio VDL communication network; radio ADS-B CNS network; radio communications via HF-band, integration of Satellite, LDACS and AeroMACS Networks; integration of Satellite, LDACS and VDL Networks; and radio LDACS1 topology are discussed in this paper.

Key Words: GADSS, VHF, HF, ACARS, LDACS, VDL, FMS, CDU, CCP, MFD, LOS, ARS, GRS

1. Introduction

The basic radio communication installations onboard aircraft include two VHF-band and two HF-band radio communication transceivers. In addition, recently was developed new type 1 and 2 airborne radio system known as L-band Digital Aeronautical Communications System (LDACS). These systems are automatically powered when electrical power is applied to the aircraft. However, due to safety and emergency situation, when it comes to a loss of main aircraft power, it would be desirable for key radio devices to have additional battery power supply. Thus, the selection of radio unit and tuning can be carried out using the Flight Management System (FMS), Control Display Unit (CDU) or the Cursor Control Panel (CCP) and the Multifunction Display (MFD).

2. Short Range VHF Radio Communication System

Voice and data radio communication on VHF-band is used for rapid transmissions in range of direct visibility or Line of Sight (LOS) up to 350 km, which scenario is illustrated in **Figure 1.** Airborne VHF radio communication links between ARS and GRS terminals or ATC stations remains an essential part of routine and emergency air-to-air, air-to-ground and ground-to-air transmissions. Namely, the main purpose of voice (verbal) VHF radio communication is providing bilateral (two-way) communication between aircraft and air traffic controller and also communication with other aircraft in vicinity.

In emergency operations, voice tone and nuance provide valuable information. Many pilots have spoken of the reassuring effect of hearing a calm controller's voice. However, VHF can transmit information only as fast as a person can speak coherently, and it cannot handle multiple transmissions on the same frequency. In fact, technology such as CPDLC can significantly reduce the demand for bandwidth and time. Increasingly, routine ATM air-to-ground radio transmission services will use data communications, with voice for real-time, critical communication.

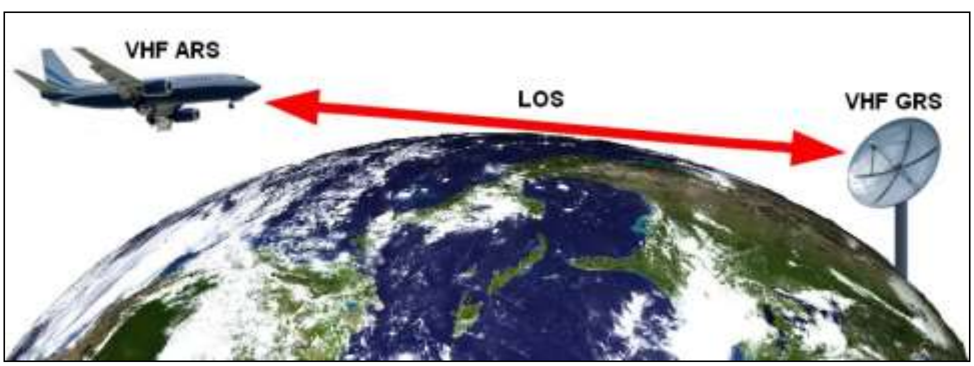

Figure 1. Radio Communications via VHF-band – Courtesy of Manual: by Ostroumov

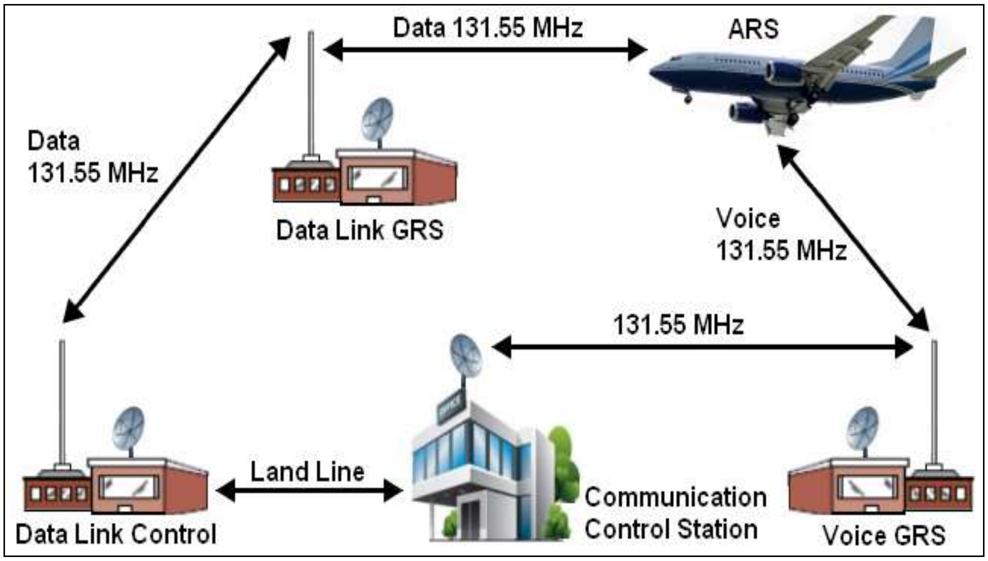

Figure 2. Radio VHF ACARS Network – Courtesy of Manual: by Ilcev

Thus, an aircraft can reply to ATC system with a standard format message or in free text and messages from a controller normally follow a standard format, with response required to most messages. The advantages of CPDLC include: (1) Reduced congestion of voice channels; (2) Fewer communication errors; and (3) Lower workload for pilots and controllers.

Frequency range that is used in aviation for VHF is between 118 and 135.975 MHz and distance between channels is equal to 25 kHz. However, the need for using a larger number of digital radio channels for VHF data transmission is lead to narrow of distance between channels up to 8.33 kHz. The significance in such type of communication is that channel can be organized only in LOS of receiver and transmitter antennas, which linesign of radio VHF communication are depicted in **Figure 1**.

Control of available radio communication facilities onboard of aircraft executes with the help of control panel. High reliability of organizational communication channel on VHF frequencies is allowed to use his for information transmission in digital form. Thus, for organization of digital data transmission in VHF-band range is used two systems, such as ACARS and VDL modes.

In modern aero navigation systems the biggest role is intended for digital channel data link between aviation facilities and ground infrastructure. Digital data exchange on VHF-band data link is most desirable in case of communication implementation in small distances. In the past, ICAO intended special standards on building of digital data link:

(1) VDL mode 1 (VDL1) is based on protocol of data exchange ACARS, which allows implement speed of data exchange equal to 2.4 Kb/s. This mode was deleted in 1994.

(2) VDL mode 2 (VDL2) ensures data exchange with speed is equal to 31.5 Kb/s. This protocol is more effective than ACARS and support data exchange from pilot of aircraft till air traffic controller (CPDLC).

(3) VDL mode 3 (VDL3) is realized procedure of multiple accesses with Time Division Multiple Access (TDMA) channel for digital and verbal building.

(4) VDL mode 4 (VDL4) is self-organized protocol data transmission that allows intending digital data exchange between aircraft and ground station or other aircraft. Consider like a base for organization of data exchange in concept of RADS-B.

2.1. Radio VHF ACARS Communication Network

The radio VHF Aircraft Communications Addressing and Reporting System (ACARS) is a special aviation network of addressing digital data exchange between Aircraft Radio Station (ARS) and Ground Radio Station (GRS), which radio voice and data network is illustrated in **Figure 2.**

The ACARS network was proposed and developed in 1978 by ARINC Company involved in developments of aeronautical radio. Speed of data transmission in ACARS is not great than 2400 bauds, but provide high reliability of data transmission. In fact, airborne equipment of ACARS system consist from control panel and interactive display. Pilot enters information or automatically obtains it from other aircraft system and transmits to the ground center. Besides, this system allows monitoring the serviceability of the aircraft systems by malfunction signals sending in automatic regime.

Otherwise, domestic and international airlines use ACARS VHF and HF ground stations as well as satellite communications to send and receive billions of ATC and AOC messages every year. The ASARS VHF radio network is the air-to-ground data communications infrastructure that hundreds of airlines around the world use to communicate with ATC, national aviation authorities and their own operations centers. Thus, for functional service ACARS needs an extensive ground infrastructure, which consist from large amount of the receiver-transmission centers and wiring points. The ACARS VHF network provides duplex or bilateral communication between airlines and their aircrafts while are in flight. Depending on where the aircraft is and its equipage, ACARS messages are routed through a global network of thousands of ground stations or satellite constellations that cover the Earth. When the aircraft is over land a network of VHF stations, including VDL2 that is 10x the speed of traditional VHF, route and deliver ACARS messages.

Over the ocean a message can be delivered via High Frequency HDL ground stations, Inmarsat satellite communications or Iridium satellite communications. If the aircraft is over either of the poles it can use HDL radio or Iridium satellite network. In this way, AOC messages include take-off and landing confirmation, weather information, gate information, and engine reports. Thus, ATC messages include navigation information, aircraft positional reporting, departure clearances, oceanic clearances, runway conditions, and weather data. Currently AOC messages take up 80% of ACARS network traffic versus 20% for ATC, but the FAA Next Generation (NextGen) new program will shift more and more voice communications to data in the near future.

The airborne onboard equipage varies depending on the age and chief use of the aircraft. Typically domestic aircraft have only traditional ACARS (VHF) capabilities and one long-range option. Nearly all aircraft produced before 2000, domestic or longhaul, have only traditional ACARS. Aircraft produced today however are equipped to support traditional VHF and VDL2. Most all are equipped for either Inmarsat or Iridium, but not both. The Main functions of ACARS network are as follows:

(1) Duplex information message exchange between aircrafts and ground station. Messages can be sending automatically or by pilot.

(2) Establishment of voice data link in function of Selective Calling (SELCAL). Pilot can send message on voice communication organization. On ground after obtained decision about organization of communication, message is formed and sends on board of the aircraft with information for pilots with the frequency for coherent airborne equipment setup and with commands of automatic transition to voice mode.

(3) If airborne equipment of ACARS doesn’t transmit messages, system monitors digital messages, which sends from ground station. Each radio message contains encoded unique aircraft address. With the help of address airborne equipment receives only those messages that addressed for particular aircraft. However, the main function of ACARS network is giving information about stage of flight and technical state of aircraft facilities. Besides, pilot can use a big amount of information services which available in digital networks of ground telecommunication. For example, it is available to load data about condition of Meteorological Aerodrome Report (METAR) or Terminal Aeronautical Forecasts (TAF) reports for any place on the Earth surface.

The data exchange with the help of ACARS mode during route flight airborne equipment of ACARS forms and periodically emits some radio messages. For example, during flight airborne equipment forms messages, which contain information about aircraft position in airspace. These signals in VHF range taken by receiver, and this receiver are a part of the radio receiver center. Received signals decode and final messages from board of aircraft saved in special database.

Access to the ACARS messages, saved in database, provided through an air digital ground network data exchange and Internet technology. Security of information is provided by facilities for restricted access. Depends on privacy configuration of service equipment access to data can be free or with user authentication. In general case any user through an Internet network can obtain access to the data with the help of special clients software. The ACARS ClientNG software gives opportunities for direct interaction with the ACARS database. It allows view all ACARS messages for the any time and creates a local database messages. After data storage in local base, it can be used for users representation or for statistical processing.

In ACARS messages transmits information of different type and formats of messages are different too, because majority of airlines use own formats for information transmission. But message structure about location of aircraft is standard. This give opportunity to create software for ACARS decoder messages selection, which is associated with location of the aircraft, and display them for the purposes of monitoring air traffic. Typical ACARS decoder message about aircraft location contains the following information: (1) Message type; (2) Geographic latitude and longitude; and (3) Flight level.

With the help of special software ACARS decodes with further selection about location and after conversion of coordinates defined aircraft location view on map of the Earth surface. Namely, the source cartographic information can be cartographic servers via Web pages of Google or Russian Yandex, which provide complimentary access.

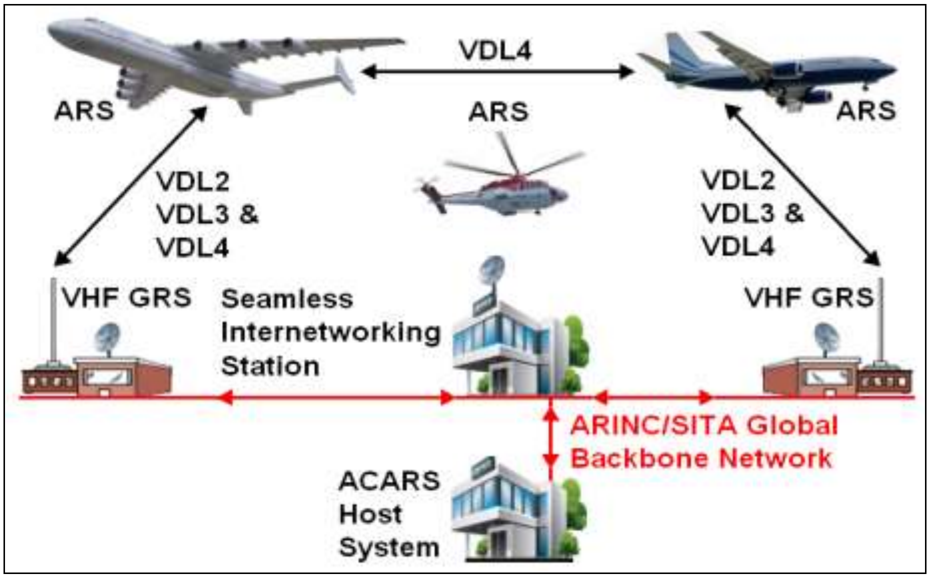

Figure 3. Radio VDL Communication Network – Courtesy of Manual: by Ilcev

Thus, for tracking of individual aircraft a piece of map defined automatically with the aim that chosen aircraft always be in the center and does not exceed the specified range or convenience and clarity every aircraft designated with special sign handed down with a form that displays registration number and the number of occupied flight level. Information about location on map updates every time, when new message coming, herewith aircraft trajectory of flight is saved on map with point representation of its previous location.

2.2. Radio VDL Communication Network

The radio VDL communication network connects ARS terminals via VDL2, VDL3 and VDL4 links, GRS terminals and Seamless Internetworking Station (SIS), ARINC/SITA global backbone network with ARINC Host System, which is shown in **Figure 3.**

A performance comparison between VHF ACARS and VDL2 is that VHF ACARS is the most popular VHF aeronautical datalink. This system is used for such applications as airline operation and ATC, which has only a 2400 bit/s transmission rate air-ground link. While the VDL2 system has a thirteen times higher transmission rate air-ground link than VHF ACARS, is very similar to VHF ACARS. Both systems can deal with messages in ACARS format. In this segment will be introduced VDL2, VDL3 and VDL4 schemes.

1. VHF Digital Link Mode 2 (VDLM2) – The VDL2 as the main version of VDL type of an air-ground data link specified in the ICAO documents “Annex 10 Volume III - Communication Systems” and “Manual on VHF Digital Link Mode 2”. The CPDLC system was advanced with implementation of VDL2 in approximately 2000 aircraft to transport ACARS messages simplifying the addition of CPDLC. Networks of ground stations providing VDL2 service has been deployed by ARINC and SITA companies with varying levels of coverage.

The ICAO standard for the VDL2 specifies three layers, such as the subnetwork, service links and physical layers. The subnetwork layer complies with the requirements of the ICAO ATN standard that specifies an end-to-end data protocol to be used over multiple air-ground and ground subnetworks including VDL. The VDL2 Link Layer is made up of two sublayers, a data link service and a Media Access Control (MAC) sublayer. The data link VDL protocol is based on the ISO standards used for dialup HDLC access to X.25 networks. This protocol provides aircraft with a positive link establishment to a ground station (GRS) and defines an addressing scheme for ground stations. The MAC protocol is a version of Carrier Sense Multiple Access (CSMA).

The VDL2 Physical Layer specifies the use in a 25 kHz wide VHF channel of a modulation scheme called Digital 8-Phase Shift Keying providing a data rate of 31.5 Kb./s. This is the highest data rate that can be achieved in a 25 kHz channel with a maximum range of 200 nautical miles. This required the implementation of VHF digital radios. This mode is using Differentially Encoded 8-Phase Shift Keying (D8PSK) modulation scheme operating at a bit rate of 31.5 kbps in a 25 kHz frequency band. In fact, the data is transmitted in the form of short bursts. The maximum number of data bits at a single packet is 217 -1 bits, which corresponds to a packet length of approximately 4 seconds. Each packet carries a header field, which contains a 48 bits synchronization sequence and a packet length field.

The packet length field is protected with a (25, 20) block code, and the remaining data bits are protected with a systematic fixed-length Reed Solomon (255,249) 28-ary code. Channel access is achieved using the carrier sense multiple access (CSMA) algorithm and the data link service sublayer uses the Aviation VHF Link Control (AVLC) protocol. AVLC is an extension of the HDLC standard that is specified by the following ISO documents: ISO 3309, ISO 4335, ISO 7809 and ISO 8885. The AVLC packets start and end with a special flag byte (0x7E) and include a 9 bytes long AVLC header after the start flag and 2 bytes long Cyclic Redundancy Check (CRC) field before the end flag. The header contains the 24-bit ICAO aircraft/ground station addresses of the sending and receiving terminals and one byte link control field indicating the type of the packet, e.g. INFO, Receive Ready (RR), Exchange Identity (XID), TEST, and Selective Reject (SREJ). In HEX output mode the whole AVLC packet is printed bytewise as hex. In ITA5-US mode the AVLC frame types and 24-bit ICAO aircraft/ground station addresses are decoded and printed. For INFO frames, the data field is decoded correspondingly if it is an ACARS packet, and is printed in hex format (0xXX) if it is an ATN packet. For XID frames, the parameters IDs are mapped to their names, and corresponding values are printed as hex. For other frame types, the whole data field is printed as hex. It is recommended to decrease the "Gain" manually until locating the bursts first visually in FFT Direct view with a 48 kHz bandwidth. The polarity should be set also correctly according to the output polarity of the receiver.

Data link technology is the standard in routine communications between flight crews and air traffic service providers. In addition, flight-operations applications such as graphical weather descriptions, electronic charts, and engine/aircraft health monitoring programs are commonly used to enhance flight efficiency and safety. Namely, both of these factors have precipitated a strong need for far greater digital bandwidth than is provided by ARINC's existing GLOBALink/VHF service, which uses the character-oriented ACARS technology.

In response to the additional bandwidth that these technologies require, as is stated ARINC developed VDL2 (VDLM2), a bit-oriented, air-to-ground and ground-to-ground data link technology that delivers information at 31.5 Kb/s over 10 times the rate used by ACARS, the existing character-oriented technology. Aside from its much greater bandwidth, VDL2 offers significant advantages over ACARS. Its internationally approved standards-based architecture provides tremendous user flexibility, including complete freedom of choice in aircraft and ground display systems, avionics and applications. Because it offers a common infrastructure that can be shared by the entire aviation industry, its cost can be distributed over a large pool of users. The VDL2 mode expanded bandwidth has allowed ARINC to offer a whole new range of flight information, aeronautical operational control, and air traffic control applications and services. Soon after VDL2 mode is officially implemented many airlines worldwide made the transition from legacy ACARS to ACARS utilizing the VDL2 air-to-ground data link. This new service is supported by over 200 ground stations currently deployed throughout the contiguous 48 US states and is expanding worldwide into Europe and Asia. Besides, ACARS ground stations are being replaced with integrated ground stations that support both ACARS and VDL2, and ARINC has also deployed an operational VDL2 network in Japan for AVICOM. For existing aircraft, ARINC is providing ACARS over AVLC (AOA) service, as well as ATN VDL2 service. Because operators can continue to use ACARS applications over the VDLM2 infrastructure when using the AOA service, they're only required to make avionics changes; the host systems and existing data link applications require no modification. Operators can transparently support their mixed avionics fleet and preserve much of their investment.

2. VHF Digital Link Mode 3 (VDLM3) – The special ICAO standard for VDL3 defines a protocol providing aircraft with both data and digitized voice communications that was defined by the US FAA with support from Mitre Company. The digitized voice support made the Mode 3 protocol much more complex than VDL2. The data and digitized voice packets go in Time Division Multiple Access (TDMA) slots assigned by ground stations. The FAA implemented a prototype system around 2003 but did not manage to convince airlines to install VDL3 avionics and in 2004 abandoned its implementation. The specific features of this standard are as follows: deploys TDMA modulation with Differential 8 Phase Shift Keying (D8PSK), 31,500 bits/s, acknowledged connection-less and supports Priority (4 levels).

2. VHF Digital Link Mode 4 (VDLM4) – This technology standardized by ICAO and ETSI provides digital communication between mobile stations (aircraft and airport surface vehicles) and between mobile units and fixed ground stations. The data link is designed to support CNS/ATM digital communication services, including time and safety-critical broadcast applications as well as point-to-point communication. It is characterized by very high delivery probability from the unique Self Organizing TDMA (SOTDMA) function. The data link transmits digital data in a standard 25 kHz VHF communications channel and divides the communication channel into a large number of time slots. The start of each slot is an opportunity for a station to transmit. As a result of this 'self-organizing' protocol, VDL Mode 4 is capable of operating outside the coverage of a ground infrastructure and can therefore support air-air as well as ground-air data communications and applications.

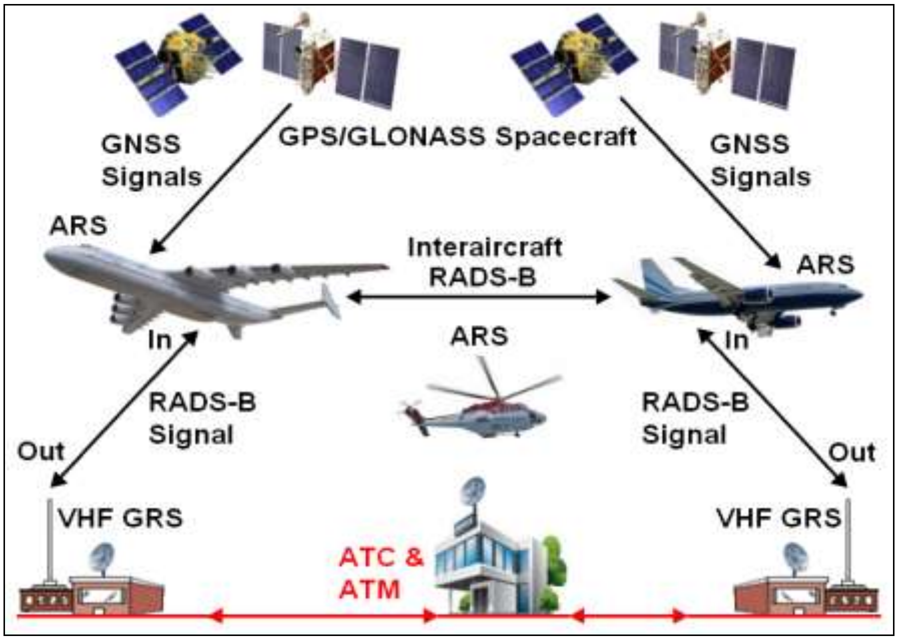

Figure 4. Radio ADS-B CNS Network – Courtesy of Manual: by Ilcev

2.3. Radio ADS-B Communication, Navigation and Surveillance (CNS) Network

The new ADS-B is intended to transform ATC facilities by providing transmission of more accurate and reliable tracking of airplanes in flight and on the ground. This CNS technique and technology is moving toward airspace and flight operations to enable greater flexibility and adaptability along with assuring improved traffic flow, capacity, efficiency and safety. A key part is the transition from radar surveillance to new Radio Automatic Dependent Surveillance-Broadcast (RADS-B) is to track airplanes in flight and on the ground more accurately and reliably. In fact, the changes will require new equipage on Boeing airplanes in production as well as those already in service. Thus, the RADS-B system is the core service of the CNS transmission network. This CNS radio network is officially known as Automatic Dependent Surveillance-Broadcast (ADS-B), but since the new satellite ADS-B is implemented on the avionic scene, it would be more convenient suited for both systems to be called RADS-B and Satellite ADS-B (SADS-B).

The RADS-B service enables all units in operation to automatically send periodic reports with information about their PVT with 3-dimensional position, aircraft ID, altitude, intent and other pertinent data, which infrastructure is depicted in **Figure 4.** In addition, the ADS-B Messages also include parameters required for the data link synchronization and slot allocation and ADS-B messages are received and processed by all VDL Mode 4 units within radio range:

1. ADS-B Out – This mode will be required beginning 1 January 2020, in airspace where transponders are mandatory today to broadcasts GPS position to ground stations (GRS) and directly to equipped aircraft (ARS). Namely, airborne radio station (ARS) receives GNSS signals from GPS or GLONASS satellites, processes them and sends to the ground station (AGS) as ADS-B Out. Ground station (AGS) receives ADS-B Out messages and translates them into ASTERIX Category 21 format for transmission to the ATC and ATM ground network. This data provides surveillance information about all VDL Mode 4-equipped mobile units (aircraft and vehicles) within radio range of the AGS;

2. ADS-B In – The ground station (AGS), as optional service, generally refers to radio transmission of weather and air traffic information from ground stations into the cockpit (ARS), where it can be displayed on panel-mounted avionics or a tablet, like an iPad. In addition, mobile unit (aircraft or vehicles on the airport surface) receives ADS-B messages from all VDL Mode 4-equipped mobile units including ATC stations within radio range for collision avoidance. Thus, by connecting a CDTI/display to the data link, the pilot/driver can display ADS-B surveillance information. Finally, all aircraft flying in certain area can have interaircarft RADS-B transmissions for collision avoidance.

Therefore, the RADS-B network is radio and GNSS-bases surveillance system designed to replace the traditional radar-based technology ATC has relied on for decades to detect and manage aircraft traffic and management. It provides constant transmission of PVT, ID and other data radar-like surveillance through Mode S Extended Squitter (1090 MHz). The features of Mode S 1090 ES are use of single channel at 1090 MHz with random and fixed ADS-B reporting rate.

Besides, VDL4 uses multi-channel at 108 to 137 MHz with timeslot access and variable ADS-B reporting rate, while Universal Access Transceiver (UAT) uses single channel at 978 MHz with timeslot access and variable ADS-B reporting rate. The Majority of the aircraft nowadays are broadcasting ADS-B messages constantly. There are many ways you can set up you own receiver and antenna to start tapping into those signals (DVB-T USB stick, Mode-S Beast, Raspberry Pi, RadarScape, etc).

As stated, the ADS-B system relies on an aircraft's GNSS receiver to determine highly accurate position and groundspeed information, which it is calculating by receiving radio signals from a network of GPS satellites and comparing the time stamp of when those signals were sent with the time stamp of when they are received. After taking GPS data and along with identification and flight-status information, RADS-B system transmits it to ground-station receivers using a datalink transmitter in the form of either a Mode S 1090 ES transponder or a universal access transceiver. This occurs automatically a minimum of once every second, compared with the existing radar-based system, which scans for data once every five to 12 seconds, thus providing a much more accurate picture of the traffic landscape at any given time to ATC. Accordingly this change will allow ATC to reduce separation between aircraft and implement more efficient routing.

The RADS-B information is not just transmitted to ATC and ATM, but it is also shared among aircraft flying in the same flight area. In such a way, aircraft fitted with ADS-B In capabilities can receive this information either directly from other aircraft or via the ground stations, which re-broadcast it along with position data for non-RADS-B-equipped aircraft that have a transponder and are within radar coverage. Besides, UAT-equipped aircraft can also receive subscription-free weather.

The Mode-S Enhanced Surveillance (EHS) provides ATC more information than what is included in the Mode-S Elementary Surveillance (ELS). The GNSS Augmentation Service – Broadcast (GNS-B) is an uplink service intended to support a range of applications such as airport surface surveillance, terminal area, and en-route operations. Each ground station provides uplink broadcast of GNS-B messages generated in the ground station. The GNS-B infrastructure provides increased position accuracy complying with the Advanced - Surface Movement Guidance and Control (A-SMGC) concept and supports increased position accuracy of ADS-B reports. Thus, mobile VDL Mode 4 unit that receives GNS-B data will use it to enhance its own position accuracy. The GNS-B data is also available for external use in the aircraft/vehicle. Flight Information Service-Broadcast (FIS-B) is an uplink service that provides local terminal area information to the mobile user. Traffic Information Service-Broadcast (TIS-B) is an uplink service that provides surveillance information from other surveillance sources to VDL Mode 4-equipped aircraft and ground vehicles.

3. Long Range HF Radio Communication System

The basic principles of airborne HF radio communications system in range of 2 and 30 MHz carriers for transmission purposes that greatly extends the range at which ARS terminal can establish contact with ground terminals. The interval between channels is 1 kHz. Before the advent of aeronautical satellite communication systems, long distance communication with aircraft over the oceans and other remote regions was solely carried out using HF radio, sometimes called shortwave, which can operate over the horizon.

The transmission of HF radio system has some propagation problems. Namely, the air in the ionosphere strongly rarefied and under the influence of solar radiation in the ionosphere of atomic gases released many free electrons, which is resulting the appearance of positive ions. Ionization of the upper layer of the atmosphere is being. Ionized layer is able to absorb radio waves and distort their way. During the day, depending on the intensity of solar radiation the number of free electrons in the ionized layer, its thickness and elevation change and this change and electrical properties of this layer, respectively, and the ability rereflect radio waves. Therefore, if ionospheric propagation conditions are unfavourable it is often impossible to contact aircraft on big distances. However, if propagation conditions are good there is often considerable congestion due to interference by transmissions from other regions of the world on the same channel. Even on flights transiting long distances it is not uncommon to have periods where no useful contact can be made, because there is either no propagation or serious congestion due to interference or atmospheric effects. In **Figure 5** is shown HF radio link between HF ARS and HF GRS with the ability range of the HF radio waves rereflected from the ionosphere and radio communication over long distances is provided.

In parallel to technological advances and the development of a VHF radio datalink, there was the same requirement to pass data between aircraft and the ground (or other aircraft) for new applications (for improving the navigation, surveillance and communication functions) for long-range flights. Thus some kind of HF Data Link (HDL) was required. Unlike the ACARS over VHF, the ACARS for HF has followed the ICAO standardization process, and in 1999, HF ACARS was incorporated in Annex 10 (Amendment 74). Provisions for this new HF datalink service were approved by the ITU in July 1998.

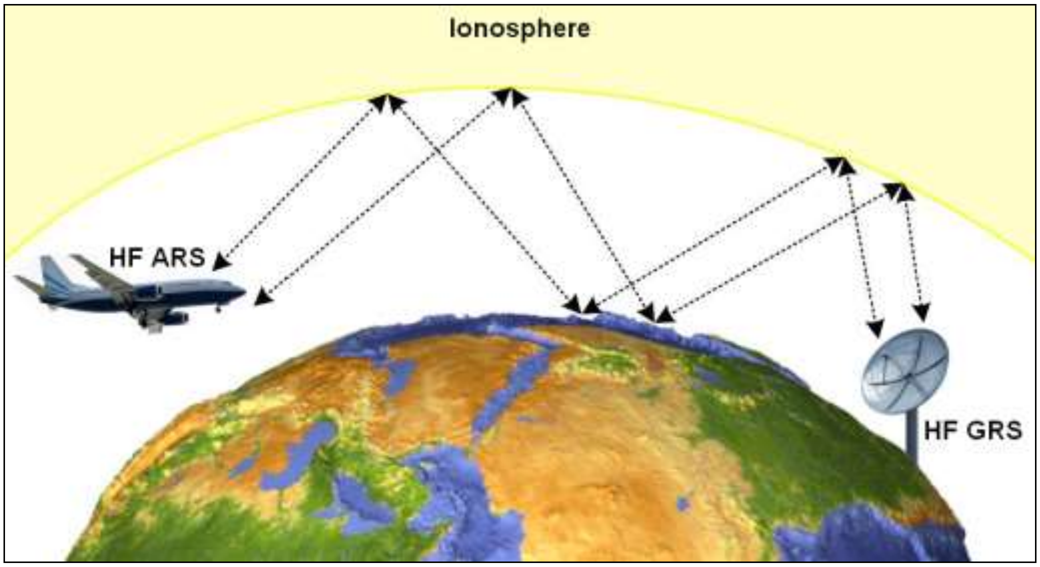

Figure 5. Radio Communications via HF-band – Courtesy of Manual: by Ilcev

The usual way of using airborne HF radio is voice communication shown in **Figure 5** for decades has been the main mode of transmissions between aircraft (ARS) and ground terminals (GRS). As stated, in HF voice communications for exchanging ARINC has developed a global HDL system of digital data exchange. The HDL system consists of 14 GRS terminals for receiving and transmitting information, connected to a central server, which provides access to onboard equipment ground data network (AviNet) to obtain the necessary information. Data exchange is at 300, 600, 1200 or 1800 bit/s speeds.

The HF radio system still used in aviation is very inefficient and difficult for pilots to use, especially during times of high workload or stress due to emergency situations. The fact that communications with air traffic controllers have to be made through radio operators on the ground also slows things down considerably. The availability of HF communications is a lot poorer than the official statistics suggest because very often pilots expect it to be poor and do not report problems. On the other hand, satellite communications do not suffer from these difficulties.

The aeronautical HF-band can be operated in two different ways, such as:

(1) Open channels shared between multiple users in broadcast mode enable a channel to be used in simplex (one-way radio links); and

(2) Selective Calling (SECAL) channels are used bidirectionally in half-duplex radio mode between an aeronautical station and a ground station. In fact, the two parties identify each other via a unique station number (much like a telephone DTMF Code).

With the selective calling system known as SELCAL, the voice call is replaced by the transmission of coded tones to the aircraft over the radiotelephony channels. Thus, a single selective call consists of a combination of four pre-selected audio tones whose transmission requires approximately two seconds. The tones are generated in the aeronautical station coder and are received by a decoder connected to the audio output of the airborne receiver. Receipt of the assigned tone code activates a cockpit call system in the form of light and/or chime signals.

To permit the SELCAL of individual aircraft over radiotelephone channels linking the ground station (or other aircraft) with the aircraft, the individual stations must be allocated a calling code. There are 16,300 codes available in the world, and than, the SELCAL mode is accomplished by the coder of the ground transmitter sending a simple group of coded tone pulses to the aircraft receiver and decoder. It uses multi-frequency dual tones exactly like the more modern telephone exchanges. When using HF radio system, there can be a small delay compared to the perceived instantaneous nature of VHF. This is because the propagation time delay is a function of distance. So for a long path (say 9000 km), this can get up to as much as 30 ms. This is just noticeable but not as severe as satellite systems.

Civil aviation mainly uses HF-band for long-distance en route over water or remote regions where no VHF coverage exists. In some instances it can act as an emergency backup to the VHF system or to the Inmarsat satellite communications system to cover polar flights. In such a way, it is cheap to operate, as ground infrastructure is minimal for the vast areas of coverage provided. For oceanic flights, carriage of HF avionics is usually mandated by the regulatory authorities involved. Thus, availability of a channel is rarely due to it not having enough power to reach through but is more often a function of a radio channel being open or closed at a given time and adverse and random propagation conditions.

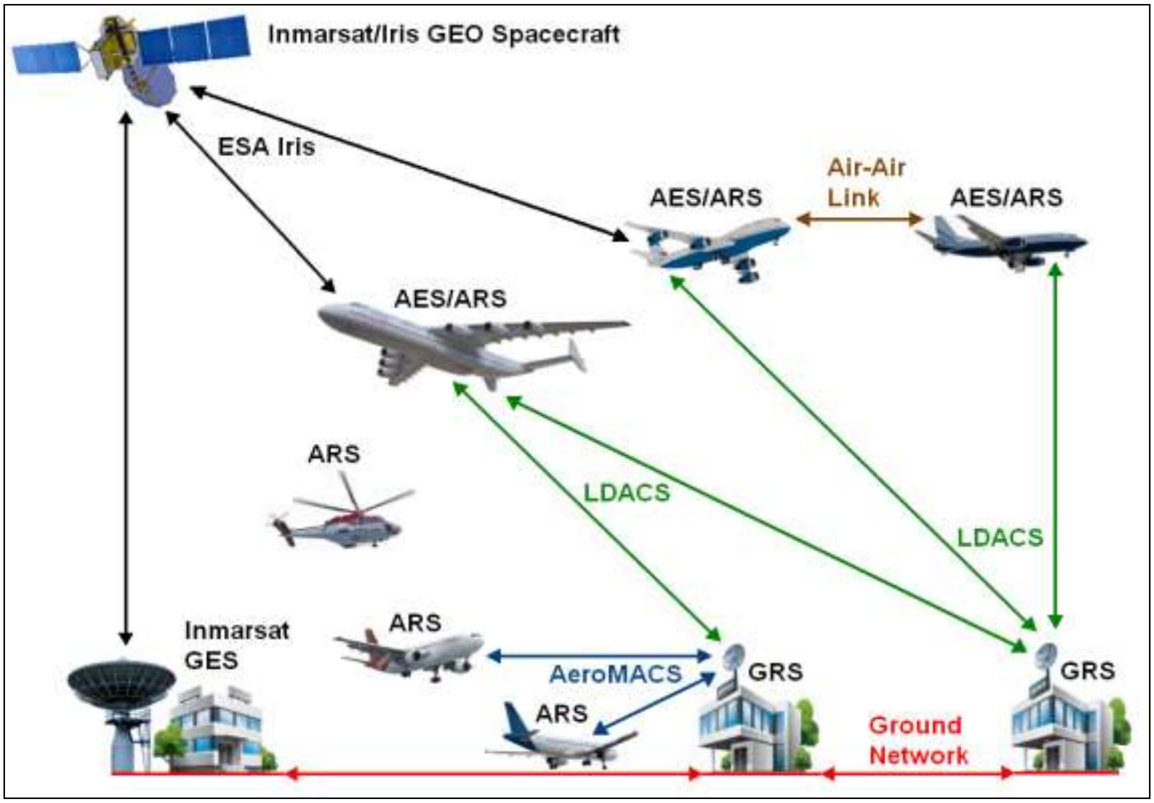

Figure 6. Integration of Satellite, LDACS and AeroMACS Networks – Courtesy of Manual: by Ilcev

The semi-random element to availability (reliability and integrity) makes HF engineering sometimes more of a black art than a science. Different countries and airlines use or do not use HF to different extents. There are now sophisticated automated systems available to minimize pilot/user interface. They can take the pain out of establishing a link. They use a combination of sophisticated software and ionosphere sounding techniques to optimize this.

4. L-band Digital Aeronautical Communication System (LDACS)

The analog voice-based ATM air-to-ground communication system for aircraft guidance is suffering from increasing saturation of the VHF band in high-density traffic areas. Thus, the tendency in Europe is to organize transition from analog VHF voice communication to more spectrum efficient digital data communication technique. Therefore, this transition shall be realized, among others, by the development and implementation of the L-band Digital Aeronautical Communications System (LDACS) radio broadband system, which integration with Inmarsat ESA Iris and AeroMACS network is depicted in **Figure 6.**

The Inmarsat satellite ESA Iris system is a key to a successful European Union (EU) implementation of Satellite Data Link (SDL) for ATC/ATM and could underpin a global solution. This GEO satellite system is funded and promoted by the European Space Agency (ESA) and based on Inmarsat SwiftBroadband-Safety (SW-S) technology that is already certified for oceanic use, it will be extended for use in continental airspace for the provision of advanced VDL (referred to as ATN B1 and B2), as well as advanced AOC service. Developed for ESA by a world-class industrial consortium led by Inmarsat, Iris is already contributing to the EC’s Aviation Strategy and the aeronautical community. However, additional steps are needed for the adoption of satellite into the ATM network and the provision of current and future VDL with the required performance.

The second integration infrastructure with radio LDACS network is Aeronautical Mobile Airport Communications System (AeroMACS). It is a wireless broadband technology that supports the increasing need for airport data communications and moreover it also supports the information sharing on the airport surface for both fixed and mobile applications. Thus,

based on the WiMAX standard (IEEE 802.16e), AeroMACS operates in the protected and licensed aviation spectrum band from 5091 MHz to 5150 MHz, which has been designated on a worldwide basis by ITU at WRC/2007.

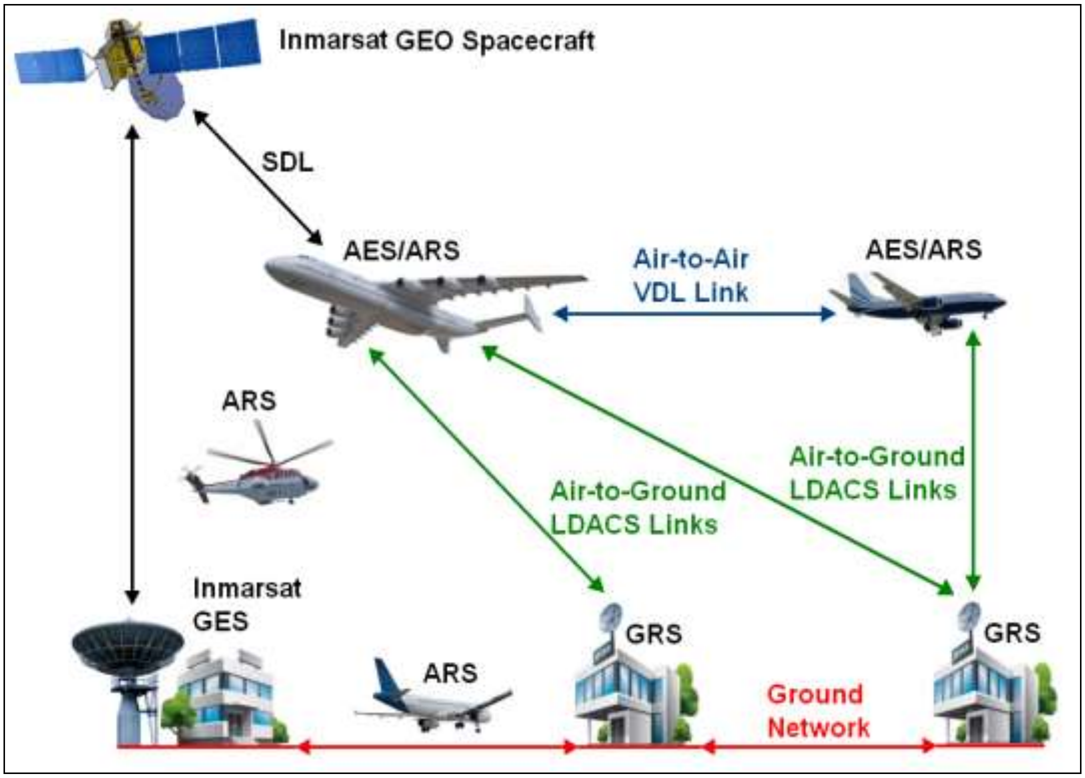

Figure 7. Integration of Satellite, LDACS and VDL Networks – Courtesy of Manual: by Ilcev

The AeroMACS Tech Manual was approved at the ICAO CP meeting in October 2016, published in ICAO Annex 10 Volume III at the end of 2016. Besides, AeroMACS is internationally standardized and globally harmonized. It is the only wireless technology that has been validated by Eurocontrol, FAA and ICAO to support the safety and regularity of flight. The existing LDACS system consists of two subsystems: LDACS1 and LDACS2. Thus, LDACS has not yet been demonstrated outside of the laboratory. In order to verify the suitability of the LDACS system for both communications and navigation, a flight trial campaign will be performed within the nationally funded German project MICONAV (Migration towards Integrated COM/NAV Avionics).

The evolution of the LDACS system as a part of Air-to-Ground Communication (A2GC) infrastructure is shown in **Figure 7.** In 1940, the first A2GC link was deployed using the analog modulation based communication system. However to improve the robustness and throughout, A2GC link was digitized in 1990's and deployed in the 19 MHz VHF band at 118 to137 MHz, which is referred to as VHF Data Link (VDL). In the following years the air traffic volume has increased dramatically, which implied that the aeronautical communication system operated in the VHF-band suffered from severe congestion in some regions of the world. With an increase in the air-traffic and the need to support futuristic delay sensitive multimedia services which demand wider bandwidths, such as L-band at 960 to 1164 MHz LDACS has been recently proposed.

Though L-band is being used by other legacy avionic systems such as DME system, joint tactical information distribution system, different radars etc., spectrum measurement studies show that major portion of the L-band is underutilized. This lead to an inlay approach based LDACS where transceivers can exploit frequency bands between adjacent legacy signals. Then in 2009, LDACS specifications were finalized and the first prototype was demonstrated in 2014. Till today, there is an active research on the design of robust and low complex LDACS transceivers.

4.1. Radio LDACS1 Network

The VHF-band (118–136.975 MHz) currently used for A2GC links is becoming congested, and the future ATM concepts will require much greater use of data communications than today. Seeking to define a Future Communication System (FCS) suitable for planned ATM operations, the Federal Aviation Administration (FAA) and Eurocontrol initiated a joint study in the frame of Action Plan 17 (AP17), with support from the National Aeronautics and Space Administration (NASA) and the US and European contractors, to investigate suitable technologies and provide recommendations to the ICAO ACP Working Group T.

One of the considered technologies in the first phase of AP17 activities was the Broadband – Very High Frequency (B-VHF) system designed to be operated in the VHF-band range. This technology was developed within the research project B-VHF and was co-funded by the EC's Sixth Framework Programme. The B-VHF project completed a substantial work in developing and designing the Orthogonal Frequency Division Multiplexing (OFDM) system for operation in the VHF-band. The "overlay" implementation option for B-VHF was considered as feasible within the B-VHF project, but it would require high effort. Considering the high congestion of the VHF-band, especially in the Europe - European Commission (EC) context, including propagation characteristics of the candidate aviation bands (VHF, L and C bands), the joint Eurocontrol - FAA Action Plan 17 activities identified the L-band as the target band for the new terrestrial data link system for the year 2020 and beyond.

In 2007, Eurocontrol launched research of a technology similar to B-VHF, but operating in the aeronautical L-band (960–1164 MHz) that has recently been made potentially available for the Aeronautical Mobile Route Service (AMRS). The related B-VHF system re-design work was conducted within a specific Eurocontrol study. The generic name given to the new L-band system is Broadband - Aeronautical Multicarrier Communication (B-AMC). The objective of the B-AMC study was to re-use the B-VHF system design up to maximum possible extent when designing the B-AMC system in the L-band. Moreover, the B-AMC communicat6ion system has been designed according to the Communications Operating Concept and Requirements document. Due to the specific nature of the interference in the L-band, significant modifications were required compared to the basic B-VHF design, in particular affecting the design of the B-AMC Physical Layer (PHY).

The LDACS1 Broadband multicarrier system is based on OFDM multi-carrier scheme and it is similar to IEEE 802.16 standard and employs inlay approach between incumbent DME signals. For the next-generation Air-to-Ground Communication (A2GC) system, LDACS1 seems to be a better choice due to the capability to support high-speed delay-sensitive multimedia services and compatibility with the cellular mobile standards. Hence, the work presented in this report will focus on LDACS1 that will refer to it as LDACS hereafter.

Thus, AP17 activities have identified desirable features the future L-band network system should fulfill. Based on these features, two options of LDACS were proposed. The first option of LDACS1 system is based on Frequency Division Duplex (FDD), utilizing OFDM modulation. The LDACS1 system has been derived from B-AMC, Telecommunication Industry Association (TIA-902) or P34 Network (Wideband System), and WiMAX (IEEE 802.16e) technologies. The second option (LDACS2) uses Time Division Duplex (TDD) combined with GMSK modulation. Moreover, it is a derivative of Land Digital Link (LDL) and All-purpose Multichannel Aviation Communication System (AMACS) technologies. The ongoing Eurocontrol task aims at developing an initial set of system specifications for the LDACS1, and a set of initial specifications for LDACS1 prototype equipment. A similar parallel task has been initiated with respect to the LDACS2 option.

The Future Communications Infrastructure (FCI) system full functionality comprises either Air-to-Ground (A/G) or Ground-to-Air (G/A) and Air-to-Air (A/A) radio data links. On fact, the prime objective of the LDACS1 concept is to provide both required functionalities based on the common technology, having two modes of operation. Therefore, the LDACS1 network offers two modes of operation, one for A/G communications and another one A/A communications. These two modes use different radio channels with different physical layer and data link layer approaches.

The ground LDACS1 is only required for A/G communications, however, if a ground user should participate in (e.g. monitor) A/A communications, a ground radio station similar to these installed onboard aircraft platforms would be required. In both modes, LDACS1 has to co-operate with the existing L-band systems (DME, UAT and SSR/Mode S). The radio LDACS1 network has been designed to minimize propagation interference to and from these other systems. The specific interference situation has influenced decisions related to the LDACS1 network high-level system design. The physical LDACS1 cell coverage is effectively de-coupled from the operational coverage required for a particular service. Services requiring wide-area coverage (e.g. A/G data link) are installed at several adjacent LDACS1 cells. From the wide-area coverage service point of view, the handover between the involved LDACS1 cells is seamless, automatic, and transparent to the user. Therefore, the LDACS1 A/G radio communications concept is open to the future dynamic airspace management concept.

The common features of LDACS are as follows:

1. L-band Digital radio communication system, TYPE 1 AND Type 2, both designed for airplane-to-ground station communications;
2. Airplane-to-airplane in future extension;
3. Range of 200 nautical miles (nm) and motion of 600 knots – 600 nm/h – 1 march at 25000 ft;
4. Capacity of 200 aircraft in area with workload of 4.8 kb/s for voice and data;
5. All safety related services; and
6. Data-departure clearance, digital airport terminal information, ocean clearance datalink service.

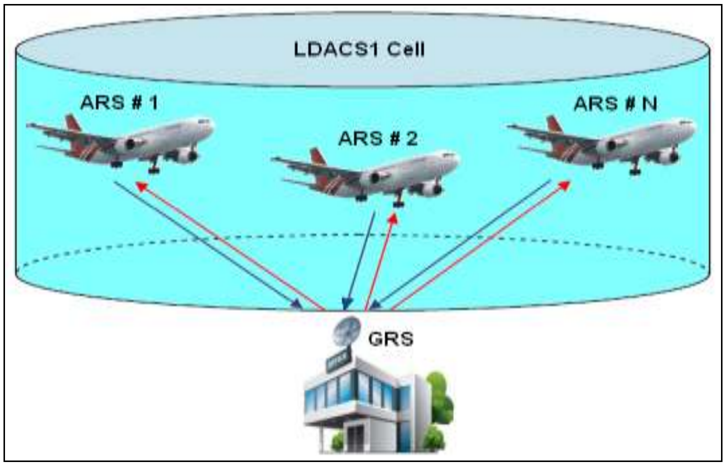

Figure 8. Radio LDACS1 Topology – Courtesy of Manual: by Ilcev

The LDACS1 network operating in the A/G mode is a cellular point-to-multipoint system. The A/G mode assumes a star-topology is shown in **Figure 8**, where ARS belonging to aircraft within a certain volume of space LDACS1 cell are connected to the controlling GRS terminals. The LDACS1 GRS is a centralized instance that controls the LDACS1 A/G communications. In fact, the LDACS1 GRS terminal can simultaneously support several bi-directional links to the ARS terminals under its control. Prior to utilizing the system an AS has to register at the controlling GRS in order to establish dedicated logical channels for user and control data. Control channels have statically allocated resources, while avionic user channels have dynamically assigned resources according to the current demand. On such a way, logical channels exist only between the GRS and the ARS. Direct voice and data transmissions between ARS of the same cell cannot be performed without a relay function operating at the GRS terminals.

4.2. Radio LDACS2 Network

As early stated, the LDACS1 solution is broadband radio system based on OFDM scheme combining B-AMC and P34, while the LDACS2 solution is narrowband system based on single-carrier technology of Gaussian Minimum Shift Keying (GMSK) scheme combining LDL and AMACS. In **Table 1** are presented common LDACS1 and LDACS2 features.

Table 1. Common LDACS1and LDACS2 Features

LDACS1	LDACS2
B-AMC → L-DACS1; P34 → L-DACS1; WiMAX → L-DACS1	GSM → L-DACS2; UAT → L-DACS2; AMACS → L-DACS2
OFDMA: Similar to WiMAX	Based on GSM
Multi-carrier: 50 carriers 9.76 kHz apart	GSM PHY, AMACS MAC, UAT Frame Structure
Use two channels of 498 kHz each	Uses GMSK modulation as in GSM
B-AMC, P34 and WiMAX	L-DACS2 is in lower L-band close to 900MHz

The deliverables of the LDACS1 network specification study (as well as the ones from the separate LDACS2 specification study) will be proposed by Eurocontrol agency as a starting point for further activities within the Single European Sky ATM Research (SESAR) Joint Undertaking (JU) framework (WP15, project P15.2.4). The LDACS2 network is flexible multipurpose communication system is supporting air/ground point-to-point, and it also supports of air/air point-to-point data communications using specific system configuration and specific channels.

The second LDACS radio option LDACS2 is an TDD configuration utilizing a binary modulation derivative family of the Continuous Phase Frequency Shift Keying (CPFSK) and of the already implemented UAT system. In addition, the LDACS2 is similar to the existing commercial cellular communication infrastructure of the Global System for Mobile (GSM), which operational usage in the low part of the DME frequency between 960 and 975 MHz. This radio solution is a derivative of the LDL and AMACS technologies and also uses Gaussian minimum shift keying modulation scheme, as well as custom protocols for lower layers, providing high GoS management capability.

5. Conclusion

The Global Aeronautical Distress and Safety System (GADSS) was proposed by author of this paper in 1999 and since than we are still in the development phase of this very important future avionic infrastructure. The GADSS network has to integrate radio and satellite subsystems, which both have to be implemented under an GADSS umbrella. In GADSS network has to integrate radio and satellite elements capable of being operated by and an individual onboard aircraft with minimum communication knowledge, even they are crew staff, and yet enable alerting with Search and Rescue (SAR) services to be reliably coordinated.

The GADSS has to be an international system that uses radio and satellite technology to ensure rapid, automated alerting of ground-based communication and rescue authorities, in addition to ships in the immediate vicinity of aircraft in distress at sea, and in the event of an aircraft distress on the ground. The basic concept is that search and rescue authorities ashore, as well as shipping in the immediate vicinity of the aircraft in distress at sea, will be rapidly alerted through radio and satellite communication techniques so that they can assist in a co-ordinated search and rescue operation with the minimum of delay.

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