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L-band Digital Aeronautical Communications System (LDACS)
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Abstract

   This document provides an overview of the architecture of the L-band
   Digital Aeronautical Communications System (LDACS), which provides a
   secure, scalable and spectrum efficient terrestrial data link for
   civil aviation. LDACS is a scheduled, reliable multi-application
   cellular broadband system with support for IPv6.

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   This Internet-Draft will expire on 3 October 2020.

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1. Introduction

    One of the main pillars of the modern Air Traffic Management (ATM)
    system is the existence of a communication infrastructure that
    enables efficient aircraft control and safe separation in all phases
    of flight. Current systems are technically mature but suffering from
    the VHF band's increasing saturation in high-density areas and the
    limitations posed by analogue radio communications. Therefore,
    aviation globally and the European Union (EU) in particular, strives
    for a sustainable modernization of the aeronautical communication
    infrastructure.

   In the long-term, ATM communication shall transition from analogue
   VHF voice and VDL2 communication to more spectrum efficient digital
   data communication. The European ATM Master Plan foresees this
   transition to be realized for terrestrial communications by the
   development (and potential implementation) of the L-band Digital
   Aeronautical Communications System (LDACS). LDACS shall enable IPv6
   based air- ground communication related to the aviation safety and
   regularity of flight. The particular challenge is that no additional
   spectrum can be made available for terrestrial aeronautical
   communication. It was thus necessary to develop co-existence
   mechanism/procedures to enable the interference free operation of
   LDACS in parallel with other aeronautical services/systems in the
   same frequency band.

2. Terminology

2.1. Terms used in this document

   The following terms are used in the context of RAW in this document:

   A/A Air-To-Air
   AeroMACS Aeronautical Mobile Airport Communication System
   A/G Air-To-Ground
   AM(R)S Aeronautical Mobile (Route) Service
   ANSP Air traffic Network Service Provider
   AOC Aeronautical Operational Control
   AS Aircraft Station
   ATC Air-Traffic Control
   ATM Air-Traffic Management
   ATN Aeronautical Telecommunication Network
   ATS Air Traffic Service
   CCCH Common Control Channel
   DCCH Dedicated Control Channel
   DCH Data Channel
   DLL Data Link Layer
   DLS Data Link Service
   DME Distance Measuring Equipment
   DSB-AM Double Side-Band Amplitude Modulation
   FAA Federal Aviation Administration
   FCI Future Communication Infrastructure
   FDD Frequency Division Duplex
   FL Forward Link
   GANP Global Air Navigation Plan
   GNSS Global Navigation Satellite System
   GS Ground Station
   GSC Ground-Station Controller
   HF High Frequency
   ICAO International Civil Aviation Organization

```
kbit/s  kilobit per second
LDACS  L-band Digital Aeronautical Communications System
LLC  Logical Link Layer
LME  LDACS Management Entity
MAC  Medium Access Layer
MF  Multi Frame
OFDM  Orthogonal Frequency-Division Multiplexing
OFDMA  Orthogonal Frequency-Division Multiplexing Access
PDU  Protocol Data Units
PHY  Physical Layer
QoS  Quality of Service
RL  Reverse Link
SARPs  Standards And Recommended Practices
SESAR  Single European Sky ATM Research
SF  Super-Frame
SNP  Sub-Network Protocol
SSB-AM  Single Side-Band Amplitude Modulation
TBO  Trajectory-Based Operations
TDM  Time Division Multiplexing
TDMA  Time-Division Multiplexing-Access
VDL2  VHF Data Link mode 2
VHF  Very High Frequency
VI  Voice Interface
```

3. Motivation and Use Cases

   Aircraft are currently connected to Air-Traffic Control (ATC) and
   Airline Operational Control (AOC) via voice and data communications
   systems through all phases of a flight. Within the airport terminal,
   connectivity is focused on high bandwidth communications, while
   during en-route high reliability, robustness, and range is the main
   focus. Voice communications may use the same or different equipment
   as data communications systems. In the following the main
   differences between voice and data communications capabilities are
   summarized. The assumed use cases for LDACS completes the list of
   use cases stated in [RAW-USE-CASES] and the list of reliable and
   available wireless technologies presented in [RAW-TECHNOS].

3.1. Voice Communications Today

   Voice links are used for Air-To-Ground (A/G) and Air-To-Air (A/A)
   communications. The communication equipment is either ground-based
   working in the High Frequency (HF) or Very High Frequency (VHF)
   frequency band or satellite-based. All VHF and HF voice
   communications is operated via open broadcast channels without any
   authentication, encryption or other protective measures. The use of
   well-proven communication procedures via broadcast channels helps to

enhance the safety of communications by taking into account that
other users may encounter communication problems and may be
supported, if required. The main voice communications media is still
the analogue VHF Double Side-Band Amplitude Modulation (DSB-AM)
communications technique, supplemented by HF Single Side-Band
Amplitude Modulation (SSB-AM) and satellite communications for remote
and oceanic areas. DSB-AM has been in use since 1948, works reliably
and safely, and uses low-cost communication equipment. These are the
main reasons why VHF DSB-AM communications is still in use, and it is
likely that this technology will remain in service for many more
years. This however results in current operational limitations and
becomes impediments in deploying new Air-Traffic Management (ATM)
applications, such as flight-centric operation with point-to-point
communications.

3.2. Data Communications Today

   Like for voice, data communications into the cockpit is currently
   provided by ground-based equipment operating either on HF or VHF
   radio bands or by legacy satellite systems. All these communication
   systems are using narrowband radio channels with a data throughput
   capacity of some kilobits per second. While the aircraft is on
   ground some additional communications systems are available, like
   Aeronautical Mobile Airport Communication System (AeroMACS; as of now
   not widely used) or public cellular networks, operating in the
   Airport (APT) domain and able to deliver broadband communication
   capability.

   The data communication networks used for the transmission of data
   relating to the safety and regularity of the flight must be strictly
   isolated from those providing entertainment services to passengers.
   This leads to a situation that the flight crews are supported by
   narrowband services during flight while passengers have access to
   inflight broadband services. The current HF and VHF data links
   cannot provide broadband services now or in the future, due to the
   lack of available spectrum. This technical shortcoming is becoming a
   limitation to enhanced ATM operations, such as Trajectory-Based
   Operations (TBO) and 4D trajectory negotiations.

   Satellite-based communications are currently under investigation and
   enhanced capabilities are under development which will be able to
   provide inflight broadband services and communications supporting the
   safety and regularity of flight. In parallel, the ground-based
   broadband data link technology LDACS is being standardized by ICAO
   and has recently shown its maturity during flight tests [SCH191].
   The LDACS technology is scalable, secure and spectrum efficient and
   provides significant advantages to the users and service providers.
   It is expected that both - satellite systems and LDACS - will be

deployed to support the future aeronautical communication needs as
envisaged by the ICAO Global Air Navigation Plan (GANP).

4. Provenance and Documents

The development of LDACS has already made substantial progress in the
Single European Sky ATM Research (SESAR) framework, and is currently
being continued in the follow-up program, SESAR2020 [RIH18]. A key
objective of the SESAR activities is to develop, implement and
validate a modern aeronautical data link able to evolve with aviation
needs over long-term. To this end, an LDACS specification has been
produced [GRA19] and is continuously updated; transmitter
demonstrators were developed to test the spectrum compatibility of
LDACS with legacy systems operating in the L-band [SAJ14]; and the
overall system performance was analyzed by computer simulations,
indicating that LDACS can fulfil the identified requirements [GRA11].

LDACS standardization within the framework of the ICAO started in
December 2016. The ICAO standardization group has produced an
initial Standards and Recommended Practices (SARPs) document
[ICAO18]. The SARPs document defines the general characteristics of
LDACS. The ICAO standardization group plans to produce an ICAO
technical manual - the ICAO equivalent to a technical standard -
within the next years. Generally, the group is open to input from
all sources and develops LDACS in the open.

Up to now the LDACS standardization has been focused on the
development of the physical layer and the data link layer, only
recently have higher layers come into the focus of the LDACS
development activities. There is currently no "IPv6 over LDACS"
specification publicly available; however, SESAR2020 has started the
testing of IPv6-based LDACS testbeds.

The IPv6 architecture for the aeronautical telecommunication network
is called the Future Communications Infrastructure (FCI). FCI shall
support quality of service, diversity, and mobility under the
umbrella of the "multi-link concept". This work is conducted by ICAO
Communication Panel working group WG-I.

In addition to standardization activities several industrial LDACS
prototypes have been built. One set of LDACS prototypes has been
evaluated in flight trials confirming the theoretical results
predicting the system performance [GRA18] [SCH191].

5. Characteristics

   LDACS will become one of several wireless access networks connecting
   aircraft to both Aeronautical Telecommunications Network (ATN, IPS as
   well as OSI) and ACARS/FANS networks [FAN19].

5.1. LDACS Sub-Network

   An LDACS sub-network contains an Access Router (AR), a Ground-Station
   Controller (GSC), and several Ground-Stations (GS), each of them
   providing one LDACS radio cell serving up to 512 aircraft stations
   (AS). User plane interconnection to the ATN is facilitated by the
   Access Router (AR) peering with an Air/Ground Router (A/G Router)
   connected to the ATN. It is up to implementer's choice to keep
   Access Router and Air-Ground Router functions separated, or to merge
   them. The internal control plane of an LDACS sub-network is managed
   by the Ground-Station Controller (GSC). An LDACS sub-network is
   illustrated in Figure 1.

```
   wireless        user
   link            plane
     A-------------G-------------Access---A/G-----ATN
     S..............S             Router   Router
                    . control       . |
                    . plane         . |
                    .               . |
                    GSC..............|
                    .                 |
                    .                 |
                    GS--------------+
```
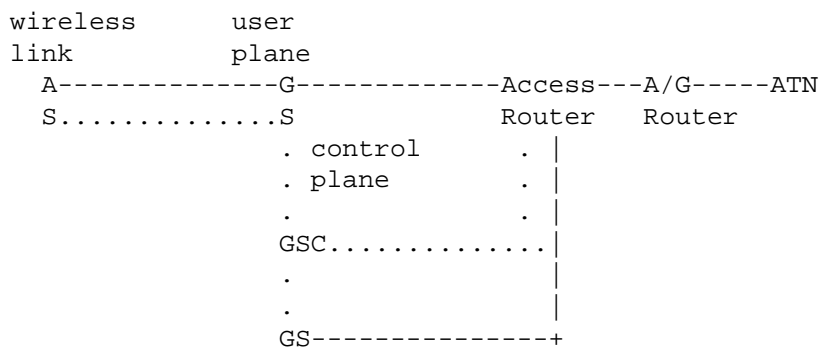
               Figure 1: LDACS sub-network with two GSs and one AS

   The LDACS wireless link protocol stack defines two layers, the
   physical layer and the data link layer.

5.2. LDACS Physical Layer

   The physical layer provides the means to transfer data over the radio
   channel. The LDACS GS supports bi-directional links to multiple
   aircraft under its control. The forward link direction (FL; ground-
   to-air) and the reverse link direction (RL; air-to-ground) are
   separated by frequency division duplex. Forward link and reverse

link use a 500 kHz channel each. The ground-station transmits a
continuous stream of Orthogonal Frequency-Division Multiplexing
(OFDM) symbols on the forward link. In the reverse link different
aircraft are separated in time and frequency using a combination of
Orthogonal Frequency-Division Multiple-Access (OFDMA) and Time-
Division Multiple-Access (TDMA). Aircraft thus transmit
discontinuously on the reverse link with radio bursts sent in
precisely defined transmission opportunities allocated by the ground-
station.

5.3. LDACS Data Link Layer

The data-link layer provides the necessary protocols to facilitate
concurrent and reliable data transfer for multiple users. The LDACS
data link layer is organized in two sub-layers: The medium access
sub-layer and the logical link control sub-layer. The medium access
sub-layer manages the organization of transmission opportunities in
slots of time and frequency. The logical link control sub-layer
provides acknowledged point-to-point logical channels between the
aircraft and the ground-station using an automatic repeat request
protocol. LDACS supports also unacknowledged point-to-point channels
and ground-to-air broadcast.

5.4. LDACS Data Rates

The user data rate of LDACS is 315 kbit/s to 1428 kbit/s on the
forward link, and 294 kbit/s to 1390 kbit/s on the reverse link,
depending on coding and modulation.

5.5. Reliability and Availability

LDACS has been designed with applications related to the safety and
regularity of flight in mind. It has therefore been designed as a
deterministic wireless data link (as far as possible).

5.5.1. LDACS Medium Access

LDACS medium access is always under the control of the ground-station
of a radio cell. Any medium access for the transmission of user data
has to be requested with a resource request message stating the
requested amount of resources and class of service. The ground-
station performs resource scheduling on the basis of these requests
and grants resources with resource allocation messages. Resource
request and allocation messages are exchanged over dedicated
contention-free control channels.

LDACS has two mechanisms to request resources from the scheduler in
the ground-station.

Resources can either be requested "on demand" with a given class of
service. On the forward link, this is done locally in the ground-
station, on the reverse link a dedicated contention-free control
channel is used called Dedicated Control Channel (DCCH; roughly 83
bit every 60 ms). A resource allocation is always announced in the
control channel of the forward link (Common Control Channel (CCCH);
variable sized). Due to the spacing of the reverse link control
channels every 60 ms, a medium access delay in the same order of
magnitude is to be expected.

Resources can also be requested "permanently". The permanent
resource request mechanism supports requesting recurring resources in
given time intervals. A permanent resource request has to be
canceled by the user (or by the ground-station, which is always in
control).

User data transmissions over LDACS are therefore always scheduled by
the ground-station, while control data uses statically (i.e. at cell
entry) allocated recurring resources (DCCH and CCCH). The current
specification documents specify no scheduling algorithm. However
performance evaluations so far have used strict priority scheduling
and round robin for equal priorities for simplicity. In the current
prototype implementations LDACS classes of service are thus realized
as priorities of medium access and not as flows. Note that this can
starve out low priority flows. However, this is not seen as a big
problem since safety related message always go first in any case.
Scheduling of reverse link resources is done in physical Protocol
Data Units (PDU) of 112 bit (or larger if more aggressive coding and
modulation is used). Scheduling on the forward link is done Byte-
wise since the forward link is transmitted continuously by the
ground-station.

The LDACS data link layer protocol running on top of the medium
access sub-layer uses ARQ to provide reliable data transmission.

5.5.2. LDACS Mobility

The LDACS mobility service manages in the GSC and LME cell entry,
cell exit and handover between cells.

LDACS supports internal handovers to different RF channels.
Handovers may be initiated by the aircraft (break-before-make) or by
the ground- station (make-before-break). Make-before-break handovers
are only supported for ground-stations connected to the same ground-
station controller.

External handovers between non-connected LDACS deployments or

different aeronautical data links shall be handled by the FCI multi-
link concept.

5.5.3. LDACS Incremental Deployment

The LDACS data link provides enhanced capabilities to the future IPv6
based ATN enabling it to better support user needs and new
applications. The deployment scalability of LDACS allows its
implementation to start in areas where most needed to improve
immediately the performance of already fielded infrastructure. Later
the deployment is extended based on operational demand.

6. Protocol Stack

The protocol stack of LDACS is implemented in the AS, GS, and GSC: It
consists of the Physical Layer (PHY) with five major functional
blocks above it. Four are placed in the Data Link Layer (DLL) of the
AS and GS: (1) Medium Access Layer (MAC), (2) Voice Interface (VI),
(3) Data Link Service (DLS), (4) LDACS Management Entity (LME). The
last entity resides within the sub-network layer: Sub-Network
Protocol (SNP). The LDACS network is externally connected to voice
units, radio control units, and the ATN network layer.

Figure 2 shows the protocol stack of LDACS as implemented in the AS
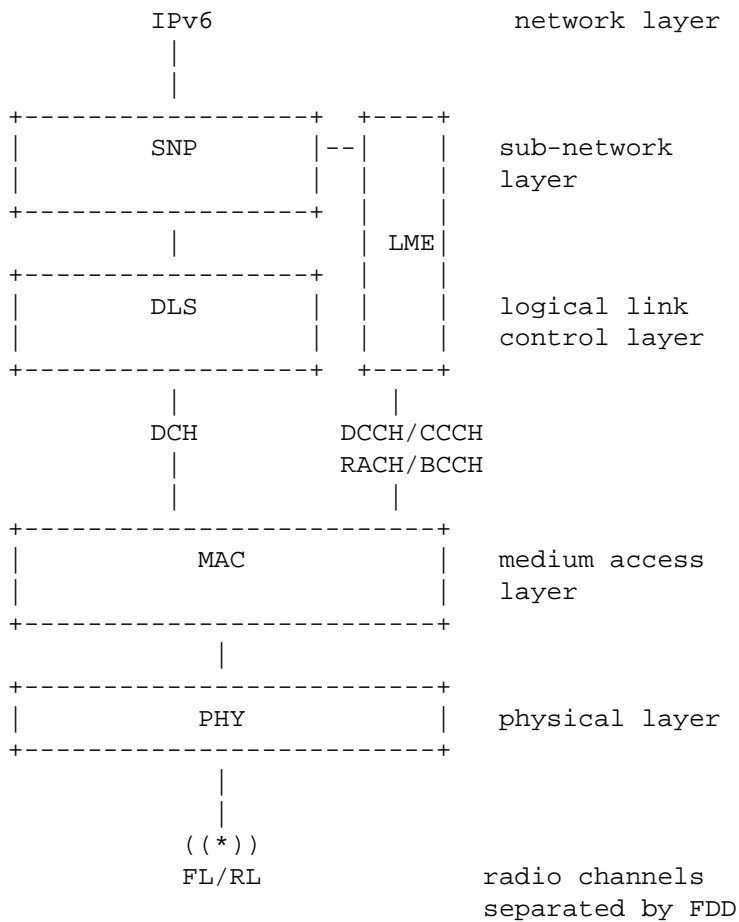and GS.

```
          IPv6                      network layer
           |
           |
           |
  +-----------------+  +----+
  |      SNP        |--|    |       sub-network
  |                 |  |    |       layer
  +-----------------+  |    |
          |            | LME|
  +-----------------+  |    |
  |      DLS        |  |    |       logical link
  |                 |  |    |       control layer
  +-----------------+  +----+
          |            |
         DCH       DCCH/CCCH
          |        RACH/BCCH
          |            |
  +-------------------------+
  |         MAC             |       medium access
  |                         |       layer
  +-------------------------+
            |
  +-------------------------+
  |         PHY             |       physical layer
  +-------------------------+
            |
            |
         ((*))
         FL/RL              radio channels
                            separated by FDD
```

Figure 2: LDACS protocol stack in AS and GS

6.1. Medium Access Control (MAC) Entity Services

   The MAC time framing service provides the frame structure necessary
   to realize slot-based Time Division Multiplex (TDM) access on the
   physical link. It provides the functions for the synchronization of
   the MAC framing structure and the PHY layer framing. The MAC time
   framing provides a dedicated time slot for each logical channel.

   The MAC sub-layer offers access to the physical channel to its
   service users. Channel access is provided through transparent
   logical channels. The MAC sub-layer maps logical channels onto the
   appropriate slots and manages the access to these channels. Logical
   channels are used as interface between the MAC and LLC sub-layers.

The LDACS framing structure for FL and RL is based on Super-Frames
(SF) of 240 ms duration. Each SF corresponds to 2000 OFDM symbols.
The FL and RL SF boundaries are aligned in time (from the view of the
GS).

In the FL, an SF contains a Broadcast Frame of duration 6.72 ms (56
OFDM symbols) for the Broadcast Control Channel (BCCH), and four
Multi-Frames (MF), each of duration 58.32 ms (486 OFDM symbols).

In the RL, each SF starts with a Random Access (RA) slot of length
6.72 ms with two opportunities for sending reverse link random access
frames for the Random Access Channel (RACH), followed by four MFs.
These MFs have the same fixed duration of 58.32 ms as in the FL, but
a different internal structure

Figure 3 and Figure 4 illustrates the LDACS frame structure.

```
^
|     +------+-----------+-----------+-----------+-----------+
|  FL | BCCH |    MF     |    MF     |    MF     |    MF     |
F     +------+-----------+-----------+-----------+-----------+
r     <--------------- Super-Frame (SF) - 240ms ---------------->
e
q     +------+-----------+-----------+-----------+-----------+
u  RL | RACH |    MF     |    MF     |    MF     |    MF     |
e     +------+-----------+-----------+-----------+-----------+
n     <--------------- Super-Frame (SF) - 240ms ---------------->
c
y
|
--------------------------- Time ------------------------------>
|
```
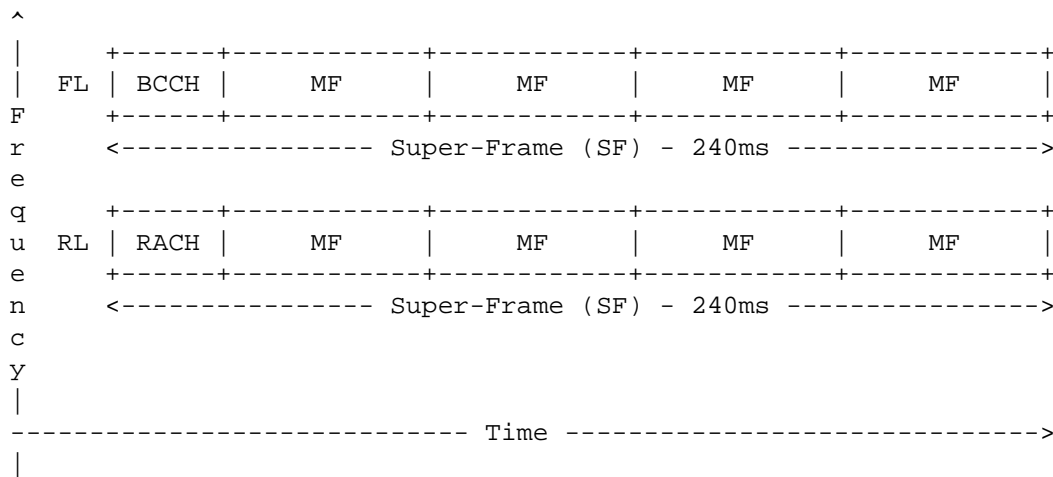
Figure 3: LDACS super-frame structure

```
 ^
 |       +-------------+------+-------------+
 |  FL | |      DCH    | CCCH |     DCH     |
 F       +-------------+------+-------------+
 r       <---- Multi-Frame (MF) - 58.32ms -->
 e
 q       +------+-------------------------+
 u  RL | | DCCH |          DCH            |
 e       +------+-------------------------+
 n       <---- Multi-Frame (MF) - 58.32ms -->
 c
 y
 |
 --------------------------- Time ------------------------------>
 |
```

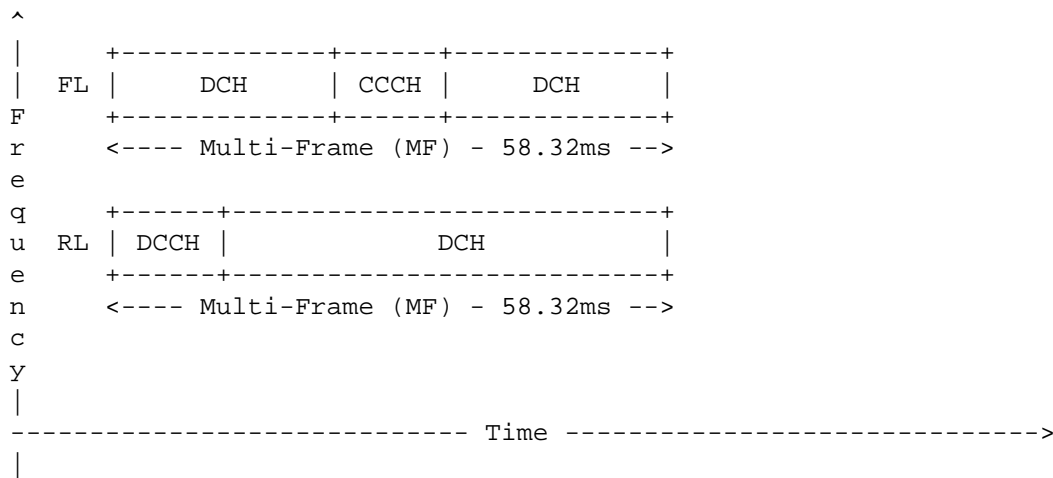   Figure 4: LDACS multi-frame (MF) structure

6.2. Data Link Service (DLS) Entity Services

   The DLS provides acknowledged and unacknowledged (including broadcast
   and packet mode voice) bi-directional exchange of user data. If user
   data is transmitted using the acknowledged data link service, the
   sending DLS entity will wait for an acknowledgement from the
   receiver. If no acknowledgement is received within a specified time
   frame, the sender may automatically try to retransmit its data.
   However, after a certain number of failed retries, the sender will
   suspend further retransmission attempts and inform its client of the
   failure.

   The data link service uses the logical channels provided by the MAC:

   1. A ground-stations announces its existence and access parameters
       in the Broadcast Channel (BC).
   2. The Random Access Channel (RA) enables AS to request access to an
       LDACS cell.
   3. In the Forward Link (FL) the Common Control Channel (CCCH) is
       used by the GS to grant access to data channel resources.
   4. The reverse direction is covered by the Reverse Link (RL), where
       aircraft-stations need to request resources before sending. This
       happens via the Dedicated Common Control Channel (DCCH).
   5. User data itself is communicated in the Data Channel (DCH) on the
       FL and RL.

6.3. Voice Interface (VI) Services

The VI provides support for virtual voice circuits. Voice circuits
may either be set-up permanently by the GS (e.g., to emulate voice
party line) or may be created on demand. The creation and selection
of voice circuits is performed in the LME. The VI provides only the
transmission services.

6.4. LDACS Management Entity (LME) Services

The mobility management service in the LME provides support for
registration and de-registration (cell entry and cell exit), scanning
RF channels of neighboring cells and handover between cells. In
addition, it manages the addressing of aircraft/ ASs within cells.
It is controlled by the network management service in the GSC.

The resource management service provides link maintenance (power,
frequency and time adjustments), support for adaptive coding and
modulation (ACM), and resource allocation.

6.5. Sub-Network Protocol (SNP) Services

The data link service provides functions required for the transfer of
user plane data and control plane data over the LDACS sub-network.

The security service provides functions for secure communication over
the LDACS sub-network. Note that the SNP security service applies
cryptographic measures as configured by the ground station
controller.

7. Security Considerations

Aviation will require secure exchanges of data and voice messages for
managing the air-traffic flow safely through the airspaces all over
the world. The main communication method for ATC today is still an
open analogue voice broadcast within the aeronautical VHF band.
Currently, the information security is purely procedural based by
using well-trained personnel and proven communications procedures.
This communication method has been in service since 1948. Future
digital communications waveforms will need additional embedded
security features to fulfill modern information security requirements
like authentication and integrity. These security features require
sufficient bandwidth which is beyond the capabilities of a VHF
narrowband communications system. For voice and data communications,
sufficient data throughput capability is needed to support the
security functions while not degrading performance. LDACS is a
mature data link technology with sufficient bandwidth to support
security.

Security considerations for LDACS are defined by the official ICAO SARPS [ICAO18]:

1. LDACS shall provide a capability to protect the availability and continuity of the system.
2. LDACS shall provide a capability including cryptographic mechanisms to protect the integrity of messages in transit.
3. LDACS shall provide a capability to ensure the authenticity of messages in transit.
4. LDACS should provide a capability for nonrepudiation of origin for messages in transit.
5. LDACS should provide a capability to protect the confidentiality of messages in transit.
6. LDACS shall provide an authentication capability.
7. LDACS shall provide a capability to authorize the permitted actions of users of the system and to deny actions that are not explicitly authorized.
8. If LDACS provides interfaces to multiple domains, LDACS shall provide capability to prevent the propagation of intrusions within LDACS domains and towards external domains.

The cybersecurity architecture of LDACS [ICAO18], [MAE18] and its extensions [MAE191], [MAE192] regard all of the aforementioned requirements, since LDACS has been mainly designed for air traffic management communication. Thus it supports mutual entity authentication, integrity and confidentiality capabilities of user data messages and some control channel protection capabilities [MAE192].

8. Privacy Considerations

LDACS provides a Quality of Service (QoS), and the generic considerations for such mechanisms apply.

9. IANA Considerations

This memo includes no request to IANA.

10. Acknowledgements

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Thanks to SBA Research Vienna for fruitful discussions on

aeronautical communications concerning security incentives for
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