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EECNS

PJ14 EECNS (ESSENTIAL AND EFFICIENT COMMUNICATION NAVIGATION AND SURVEILLANCE INTEGRATED SYSTEM)

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Abstract

This report represents deliverable D3.3.010 developed in WP3 of PJ14 EECNS, providing an update of the already existing LDACS specification produced in SESAR1 P15.02.04 with modified wording and additional clarifications in some areas. The updated specification shall serve as a solid and stable baseline for further LDACS testing and technical verification activities. Current maturity level of LDACS A/G data communication (i.e., enabler CTE-C02e — New A/G datalink using ATN/IPS over L-band) is TRL4.

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1 Executive Summary

This document represents deliverable D3.3.030 developed in WP3 of PJ14 EECNS. It provides an update of the L-Band Digital Aeronautical Communications System A/G link (originally called LDACS1, but referred to as LDACS in this document), which was originally produced in Project P15.02.04 of the SESAR1 Programme.

The specification presented herein focuses on elements of the system design for the LDACS A/G link that are relevant for the subsequent development of the related ICAO standard.

The updated LDACS A/G specification is based on the initial LDACS specification [LDACS1_D2] and on the Updated LDACS System Specification (EWA04-1-T2-D1) [LDACS1_Spec]. It corrects all errors identified so far in [LDACS1_Spec]. Additionally, improved wording and clarifications are provided in some areas. Minor modifications that will further improve the LDACS A/G specification have been implemented.

When reviewing the Updated LDACS specification [LDACS1_Spec], some major modifications have been proposed in order to further improve the LDACS design. After having them validated up to the possible extent, such items are now also captured in this report.

The LDACS A/G specification update is performed in Task 1 of WP3 of PJ14 (also referred to as PJ-14.02.01). The outcome of this task shall serve as input when producing the material required for progressing with the LDACS standardization at ICAO.

2 Introduction

2.1 Purpose of the Document

This document represents deliverable D3.3.010 developed in WP3 of PJ14 EECNS. It provides an update of the L-Band Digital Aeronautical Communications System A/G link (originally called LDACS1, but referred to as LDACS in this document), which was originally produced in Project P15.02.04 of the SESAR1 Programme.

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2.1.1 Organisation of the Document

In order to preserve the traceability to the Updated LDACS specification [LDACS1_Spec][LDACS1_D2], this report follows the same structure that was used in the original [LDACS1_Spec] document.

This report is structured as follows:

- Introductory part, comprising:
    - Chapter 2 (this chapter) – general information about the purpose of this document, its organisation, intended readership and background. It also captures abbreviations used in the report and explains LDACS-specific terms.
    - Chapter 3 – LDACS overview, summarising the main characteristics for the A/G mode. The A/A mode is addressed in a separate document.
- The main body of the LDACS A/G specification, comprises:
    - Chapter 4 – characteristics and capabilities that apply to the entire LDACS.
    - Chapter 5 – the specification of the ground LDACS installation (transmitter, receiver, timing/frequency requirements shared between the ground transmitter and receiver),

  - Chapter 6 – the specification of the airborne LDACS (transmitter, receiver, timing/frequency requirements shared between the airborne transmitter and receiver),
  - Chapter 7 – the description of the LDACS protocol architecture,
  - Chapter 8 – the specification of the LDACS Physical Layer (PHY) layer.
  - Chapter 9 – the specification of the LDACS Medium Access Layer (MAC) sub-layer,
  - Chapter 10 – the specification of the LDACS Management Entity (LME),
  - Chapter 11 – the specification of the LDACS Data Link Service (DLS) entity,
  - Chapter 12 – the specification of the LDACS Voice Interface (VI),
  - Chapter 13 – the specification of the LDACS Sub-Network Dependent Convergence Protocol (SNDCP),

- Appendices, providing supplementary information:

  - Appendix A- LDACS Link Budget
  - Appendix B - Brief overview of Extended LDACS System Capabilities (A/G voice)
  - Appendix C- Interference Reduction at LDACS RX
  - Appendix D - Tracking of Comments and Changes

- List of references used for producing this report.

2.1.2 Conventions

For the purposes of this specification the following conventions are used in Chapters 3-13 to emphasize the strength of a particular requirement:

- The word SHALL has the same meaning as the phrase "REQUIRED" and means that the definition is a mandatory requirement of the specification.
- The word SHOULD or the adjective "RECOMMENDED", means that there may exist valid reasons in particular circumstances to ignore a particular item, but the full implications must be understood and carefully weighted before choosing a different course.
- The word MAY or the adjective "OPTIONAL" means that an item is truly optional.

The requirements themselves are formatted as normal text.

Explanatory items (e.g. rationales, references) are formatted as italics or inserted as NOTEs.

2.2 Intended Readership

This LDACS A/G Specification is addressed mainly to the SJU Partners that are involved with tasks related to mobile air-ground data link communications in the long-time frame (beyond 2020) and shall serve as input for developing the required material (SARPS and Manual) for standardizing LDACS.

Partners involved with Multi-link (ML) operational concept as well Partners involved with other mobile technologies (AeroMACS, new AMSS link) may also benefit from understanding the features, constraints and limitations of LDACS.

Finally, final versions of updated LDACS system specifications will help in achieving the necessary acceptance for this new system within the world-wide aeronautical community.

2.3 Acronyms and Terminology

Term	Definition
%	Prefix for binary numbers
A/A	Air-to-Air
A/C	Aircraft
A/G	Air-to-Ground
ACB	Adjacent Cell Broadcast
ACK	Acknowledgement
ACK_CUM	Cumulative Acknowledgement
ACK_FRAG	Fragment Acknowledgement.
ACK_SEL	Selective Acknowledgement
ACM	Adaptive Coding and Modulation
AGC	Automatic Gain Control
AMACS	All-purpose Multi-channel Aviation Communication System
AS	Aircraft Station
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
AWGN	Additive White Gaussian Noise
BCCH	Broadcast Control Channel used to announce the properties of the cell to newly arrived users (FL).
BER	Bit Error Ratio
BW	Bandwidth
CCCH	Common Control Channel used by the Ground Station to announce control information for all users (FL).
CE	Channel Estimation
CP	Cyclic Prefix
CELL_EXIT	Cell exit
CELL_RQST	Cell entry request
CELL_RESP	Cell Entry Response
CMS_FL	CMS FL Map
CRC	Cyclic Redundancy Check
dBr	Relative difference (in dB) to some reference value that is made apparent in the context

Term	Definition
DC sub-carrier	Direct Current sub-carrier ("middle" sub-carrier in the spectrum of an OFDM signal, not being transmitted)
DC tile	Dedicated Control tile within the RL DC segment
DC slot	RL slot carrying Dedicated Control Channel (DCCH) information
DCCH	Dedicated Control Channel used for LLC signalling information (RL).
DCH	Logical channel used on FL/RL for the transmission of data DLL-PDUs.
DLL	Data Link Layer
DLS	Data Link Services Entity of the logical link control sub-layer (LLC).
DME	Distance Measuring Equipment
E-ATMS	European Air Traffic Management System
EIRP	Effective Isotropically Radiated Power
FCS	Frame Check Sequence
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FFT	Fast Fourier Transformation
FL	Forward Link (from the GS to the AS)
FL_ALLOC	FL Allocation
FL BC frame	FL Broadcast OFDM frame - control information is broadcast to all users
FL frame	FL frame containing either broadcast control information for all users or addressed data or control information for multiple users, together with pilot symbols, prefixed by synchronisation symbols.
FL/BC slot	MAC slot occupied by FL broadcast (BC) frame (comprising BC1+BC2+BC3 sub-frames)
FL/CC slot	MAC slot occupied by the FL Common Control (CC) frame
FL/DATA slot	MAC slot used for the transmission of Data Frame (DF)
FL PHY-PDU	Forward Link Physical Layer Protocol Data Unit (PDU)
GF	Galois Field
GLONASS	Global Orbiting Navigation Satellite System
GMSK	Gaussian Minimum-Shift Keying
GNSS	Global Navigation Satellite Systems
GS	Ground Station
GSM	Global System for Mobile Communications
HO_COM	Handover Command
ISI	Inter Symbol Interference
JTIDS	Joint Tactical Information Distribution System

Term	Definition
KEEP_ALIVE	Keep alive
LDACS	L-band Digital Aeronautical Communication System
LLC	Logical Link Control sub-layer of the data link layer
LM_DATA	Link Management Data
Logical channel	Logical channels are defined by WHAT TYPE of information is transferred and can be classified into control channels (BCCH, RACH, DCCH, CCCH) for control plane data and traffic channels (DCH, VCH) for user data.
LSB	Least Significant Bit
MAC	Medium Access sub-layer of the data link layer.
MAC slot	Reserved space in time controlled by the MAC comprising a set of PHY-SDUs used to convey a logical channel. Each PHY-SDU must be contained within exactly one MAC slot.
MACK_SEQ	Multiple Acknowledgements
ME	Medium Access Entity (within MAC sub-layer) that assigns transport channels to physical channels.
MF	Multi-frame. This item has two equivalent meanings in the LDACS context. At the PHY layer it denotes a repeating pattern of OFDM CC/Data frames of 58.32 ms length, at the MAC sub-layer it denotes repeating pattern of MAC slots of 58.32 ms length carrying payload for the corresponding OFDM frames
MIDS	Multi-Function Information Distribution System
MNWG	Multi-National Working Group
NF	Noise Figure
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OFDM Frame	Fixed length combination of contiguous OFDM symbols, comprising AGC symbols, synchronization symbols, pilot symbols and symbols carrying payload data.
OFDM Symbol	Combination of modulated data symbols transmitted on several OFDM sub-carriers.
OFDM Tile	The constellation of 150 symbols, spanning 25 contiguous symbols in frequency- and 6 contiguous symbols in time direction. A tile comprises 4 PAPR reduction symbols, 12 pilot symbols and 134 data symbols. NOTE: Tiles are only used on the RL.
OOB	Out-Of-Band
OSI	Open System Interconnect
P34	Denotes TIA-902 standard (public safety communications)
PAPR	Peak-to-Average Power Ratio
PDU	Protocol Data Unit
PHY-PDU	Physical Layer Protocol Data Unit. A PHY-PDU represents a constellation of modulated data symbols within the OFDM frame, sub-frame or tile that carry the actual payload. The PHY-PDU size (number of modulated data symbols) and the number of FL PHY-PDUs within a particular frame depend on the OFDM frame type. On the RL each PHY-PDU corresponds to

Term	Definition
	the data symbols of one RA frame, one DC tile or one Data tile. The PHY-PDU, by definition, excludes any non-data symbols like AGC symbols, synchronization symbols, symbols for PAPR reduction, pilot symbols or unmodulated DC symbols.
PHY-SDU	Physical Layer Service Data Unit. PHY-SDUs are exchanged between PHY layer and its local MAC sub-layer, containing the payload exchanged between PHY-SDUs. The size of PHY-SDU is expressed in uncoded data bits.
PID	Packet Identifier
POW_REP	Power report
ppm	Parts per million
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RACH	Logical Random Access Channel used during cell-entry and hand-over to acquire the time advance value (RL) for an unsynchronised user.
Radio burst	Time-limited transmission event, containing a (number of-) physical OFDM frames with optional radio overhead (ramp-up/ramp-down times, AGC provisions), but excluding propagation guard times
RC	Raised-Cosine (window)
RF	Radio Frequency
RL	Reverse Link (from the AS to the GS)
RL_ALLOC	RL Allocation
RL RA frame	RL Random Access frame, containing users' cell entry requests.
RL DATA slot	MAC slot providing a transmission opportunity for RL data segment.
RL DC slot	MAC slot providing a transmission opportunity for RL Dedicated Control (DC) segment.
RL RA slot	MAC slot providing two transmission opportunities for RL Random Access (RA) frames.
RL PHY-PDU	Reverse Link Physical Layer Protocol Data Unit (PDU)
RMS	Root-Mean-Square
RS	Reed-Solomon (coding)
RSBN	Радиотехническая система ближней навигации (Short-range radio-navigation system)
RSC_CANCEL	Resource Cancellation
RX	Receiver
SAC	Sub-net Access Code
SAP	Service Access Point
SDU	Service Data Unit
SESAR	Single European Sky ATM Research Programme
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.

Term	Definition
SF	Super-frame. This item has two equivalent meanings in the LDACS context. At the PHY layer it denotes a high-order repeating pattern of 240 ms length comprising OFDM frames/Multi-Frames, at the MAC sub-layer it denotes high-order repeating pattern of 240 ms length, comprising MAC slots/Multi-Frames.
SIB	System Identification Broadcast
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SLOT_DESC	Slot Descriptor
SSR	Secondary Surveillance Radar
SRC_RQST	Single resource request
STB	Scanning Table Broadcast
Symbol	In the LDACS context, one sub-carrier of one OFDM symbol
SYNC_POLL	SYNC signalling
TAV	Timing Advance Value
TBC	FL Transport channel carrying logical BCCH channel.
TDMA	Time Division Multiple Access
TX	Transmitter
UAT	Universal Access Transceiver
UMTS	Universal Mobile Telecommunications System
VCH	Logical channel used on FL/RL for the transmission of voice DLL-PDUs.
VDL	VHF Digital Link
VI-Entity	Voice Interface Entity of the logical link control sub-layer.
VoIP	Voice over IP
VSB	Voice Service Broadcast
Wide-area service	Aeronautical service with an operational range that exceeds the coverage range of a single LDACS cell. Such service must be installed at multiple LDACS cells, with seamless service handover between the cells.
WSSUS	Wide Sense Stationary Uncorrelated Scattering

3 LDACS Overview

This section gives an overview of the past activities that have led to the LDACS technology development and briefly explains the LDACS concept. Documents providing in-depth information are listed in section 14.1.

3.1 Background

The VHF COM band (118–136.975 MHz) currently used for air–ground communications is becoming congested, and the future Air Traffic Management (ATM) concepts will require much greater use of data communications than today. Seeking to define a Future Communication Infrastructure (FCI) 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 United States (U.S.) and European contractors, to investigate suitable technologies and provide recommendations to the ICAO ACP Working Group T (formerly called WG-C).

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 COM range. This technology was developed within the research project Broadband VHF (B-VHF) and was co-funded by the European Commission's Sixth Framework Programme.

The B-VHF project completed a substantial amount of work in developing and designing the OFDM-based multi-carrier system for operation in the VHF band. The "overlay" implementation option for B-VHF was considered feasible, but it would require high effort. Taking into account the high congestion of the VHF band (especially in the European context) as well as the 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 investigations of a technology similar to B-VHF, but operating in the aeronautical L-band (960–1164 MHz). This band has been made potentially available for the Aeronautical Mobile (Route) Service (AM(R)S). The related B-VHF system re-design work was conducted in a separate EUROCONTROL study. The generic name that was given to the proposed L-band system was Broadband - Aeronautical Multi-Carrier 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.

The final outcome of AP17 activities was that no single technology could be recommended for further consideration, primarily due to concerns about the operational compatibility (interference between the new system and different already deployed L-band systems). However, AP17 activities have identified desirable features the future L-band system should fulfil. Based on these features, two options for the L-band Digital Aeronautical Communication System (LDACS) were proposed.

One option (LDACS1) is based on Frequency Division Duplex (FDD), utilizing OFDM modulation. The LDACS system has been derived from B-AMC, TIA-902 (P34), and WiMAX (IEEE 802.16e) technologies.

Another option (LDACS2) uses Time Division Duplex (TDD) combined with GMSK modulation. It is a derivative of LDL and AMACS technologies.

In 2008, EUROCONTROL funded the first specification of the L-band Digital Aeronautical Communication System. The specific EUROCONTROL task has produced an initial set of system specifications for LDACS1 [LDACS_D2], as well as a set of initial specifications for LDACS1 prototype equipment [LDACS_D3]. A similar parallel task has been executed with respect to the LDACS2 option.

In 2011 the LDACS1 specification was updated in Project P15.02.04 of the SESAR1 Programme [LDACS_Spec]. During SESAR1 it became evident that only LDACS1 will be further enhanced to increase the system's maturity level. Therefore, in the following LDACS1 will always be referred as LDACS.

This document is an update of the LDACS specification based on the initial LDACS specification [LDACS1_D2] and on the Updated LDACS System Specification (EWA04-1-T2-D1) [LDACS1_Spec].

3.2 LDACS Description

The FCI comprises both A/G and A/A data links. LDACS concept is designed to support both modes of operation.

The LDACS design shall therefore offer two modes of operation, one for air-ground communications and another one for air-air communications. These two modes use different radio channels with different physical layer and data link layer approaches.

In both modes, LDACS has to co-operate with the existing aeronautical L-band systems (DME, JTIDS/MIDS, UAT, GNSS, RSBN and SSR/Mode S), as well as with systems close to the aeronautical L-band (e.g. GSM/UMTS). LDACS has been designed to minimize interference to and from these systems. The specific interference situation in the L-band has influenced decisions related to the LDACS system design.

This document contains the specification of the LDACS air/ground mode.

This document does NOT specify the LDACS air/air mode.

Note: The air/air mode will not reach the same maturity level the end of wave 1 as the air/ground mode. Therefore, in SESAR2020 wave 1 just an FRD for the air/air functionality will be developed and reviewed (V1 Gate at the end of wave 1).

3.2.1 Main Capabilities

LDACS is a multi-application cellular broadband system capable of simultaneously providing various kinds of Air Traffic Services (including ATS-B3) and Aeronautical Operational Control (AOC) communications services from deployed Ground Stations (GS). The LDACS A/G sub-system physical layer and data link layer are optimised for data link communications, but the system also supports air-ground voice communications[1].

LDACS supports communication in all airspaces (airport, TMA, and en-route), and on the airport surface.

The physical LDACS cell coverage is effectively de-coupled from the operational coverage required for a particular service. Services requiring wide-area coverage are installed at several adjacent LDACS cells. The handover between the involved LDACS cells is seamless, automatic, and transparent to the user. Therefore, the LDACS A/G communications concept is open to the future dynamic airspace management concept.

The LDACS A/G sub-system provides a bi-directional point-to-point addressed data link comprising Forward Link (FL) and Reverse Link (RL) as well as optional broadcast capabilities (FL only). The LDACS data link sub-system (AS and GS) can be integrated as a sub-network into the Aeronautical Telecommunication Network ATN via an access router. It is controlled by a ground-station controller (GSC) as illustrated in Figure 1.

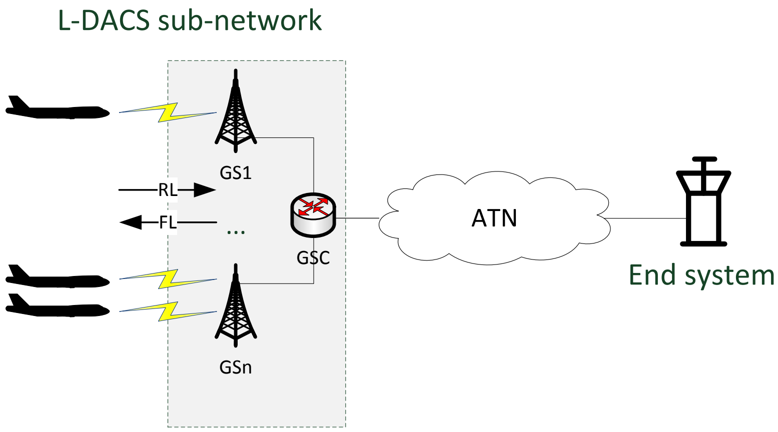

Figure 1: LDACS sub-network (highlighted) connected to the ATN.

In addition to communication the LDACS system can also be used for ranging. The LDACS ranging capability may provide input to Alternative Positioning and Timing (A-PNT) solution.

3.2.2 Interfaces and Scope of this Document

[1] LDACS voice functionality is not addressed in depth within this specification. Some further information about LDACS voice capability is provided in Section 12 - Voice Interface (VI) Specification and Appendix B- Extended LDACS System Capabilities.

The LDACS architectural design is described in [PJ14 TS/IRS], however, a high-level overview is provided in Figure 2. According to the LDACS architecture the scope of this document is the air/ground interface R1.

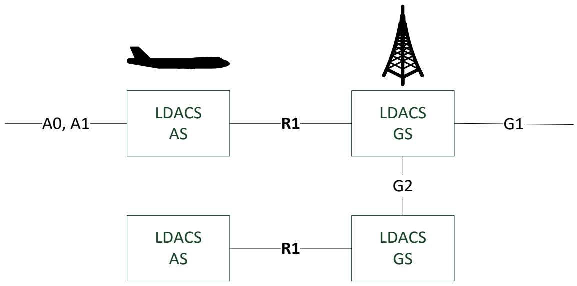

Figure 2: LDACS sub-network architecture and interfaces.

3.2.3 Topology

The LDACS A/G mode implements the R1 interfaces shown in Figure 2.

LDACS operating in the A/G mode is a cellular point-to-multipoint system. The A/G mode assumes a star-topology (Figure 3) in each cell where Airborne Stations (AS) belonging to aircraft within a certain volume of space (the LDACS cell) are connected to the controlling GS. The LDACS GS is a centralised instance that controls LDACS A/G communications within its cell. The LDACS GS can simultaneously support multiple bi-directional communication to the ASs under its control. LDACS ground stations themselves are connected to a ground station controller (GSC) controlling the LDACS sub-network.

Prior to utilizing the system an AS has to register at the controlling GS to establish dedicated logical channels for user and control data. Control channels have statically allocated resources, while user channels have dynamically assigned resources according to the current demand. Logical channels exist only between the GS and the AS.

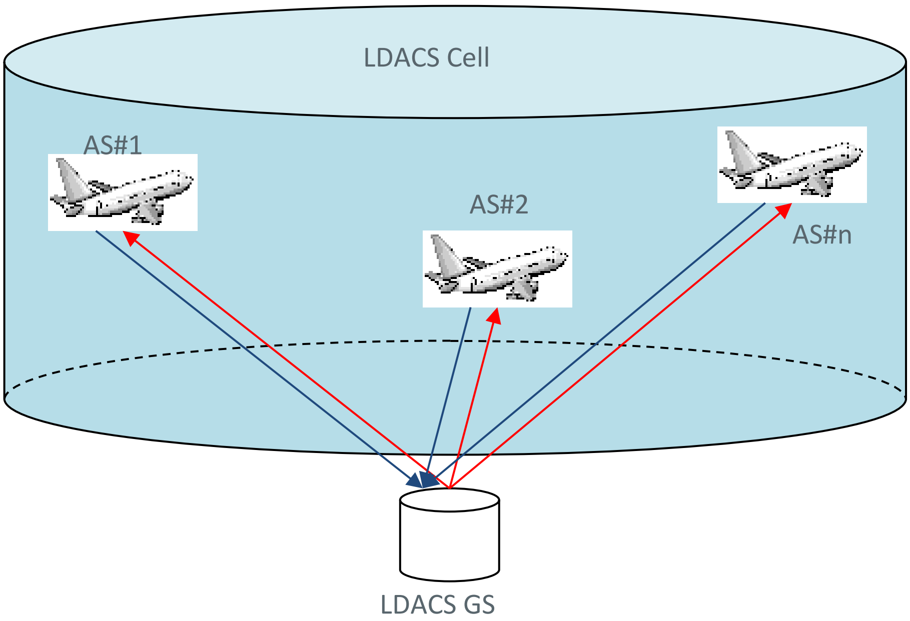

Figure 3: LDACS topology within one cell.

3.2.4 L-band Specifics

LDACS is intended to operate in the lower part of the L-band (960-1164 MHz) without causing interference towards or being influenced by the interference from existing L-band systems. Currently, several other systems are already operating in the L-band, as shown in Figure 4.

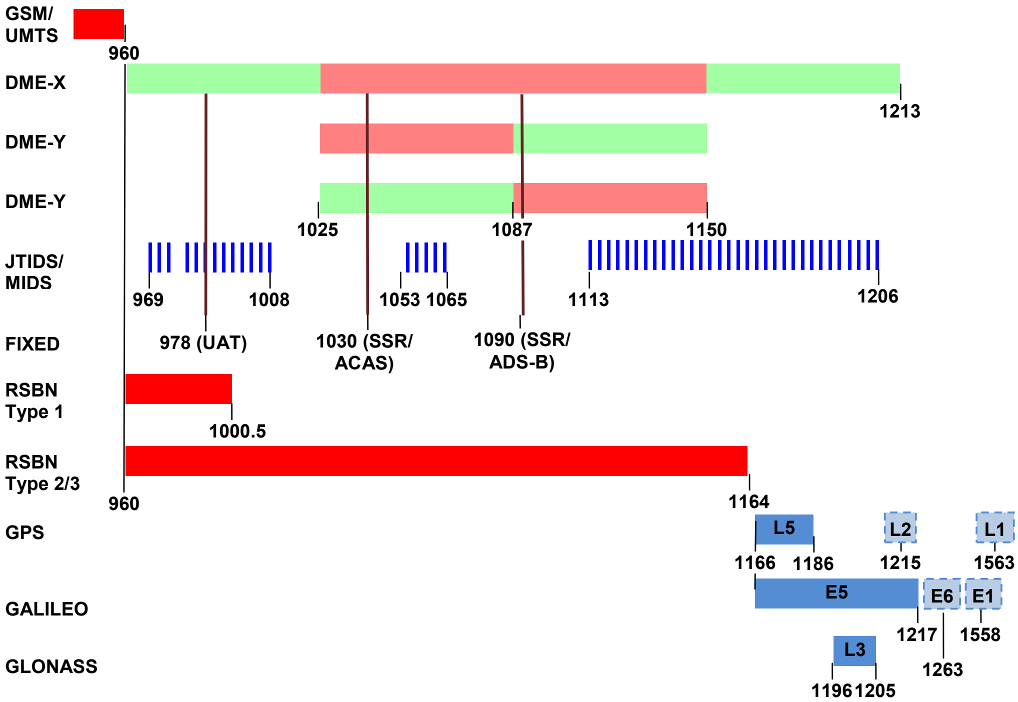

Figure 4: Current L-band Usage

Distance Measuring Equipment (DME) operating as a Frequency Division Duplex (FDD) system on the 1 MHz channel grid is a major user of the L-band. Parts of this band are used in some countries by the military Multifunctional Information Distribution System (MIDS). Several fixed channels are allocated for the Universal Access Transceiver (UAT) and for Secondary Surveillance Radar (SSR)/Airborne Collision Avoidance System (ACAS) systems. Fixed allocations have been made in the upper part of the L-band for Global Position System (GPS), Global Orbiting Navigation Satellite System (GLONASS) and GALILEO channels. Universal Mobile Telecommunications System (UMTS) and Global System for Mobile Communications (GSM) commercial systems are operating immediately below the lower boundary of the aeronautical L-band (960 MHz). Additionally, different types of RSBN (Радиотехническая система ближней навигации) radio navigation systems may be found in some parts of the world, operating on channels between 960 MHz and 1164 MHz.

3.2.5 Physical Layer Design

In order to maximise the capacity per channel and to optimally use the available spectrum, LDACS is defined as an OFDM-based FDD system, supporting simultaneous transmission in Forward Link (FL) and Reverse Link (RL) channels, each with an occupied bandwidth of 498.05 kHz[2]. Within that bandwidth, 50 OFDM sub-carriers are placed, separated by 9.765625 kHz. Each sub-carrier is separately modulated, the total duration of each modulated OFDM symbol is T_s= 120 µs. The OFDM parameters have been selected taking into account specifics of an aeronautical mobile L-band channel.

LDACS FL PHY is a continuous OFDM transmission. Broadcast and addressed user data are transmitted on a (logical) data channel, while dedicated control and signalling information are transmitted on (logical) control channels.

LDACS RL transmission is based on OFDMA-TDMA bursts, with silence phases between such bursts. The RL resources are assigned to different users (ASs) on demand by the ground station (GS).

LDACS A/G design includes propagation guard times sufficient for the operation at a maximum distance of 200 nautical miles (nm) from the GS. At this distance, one-way propagation delay is 1.26 ms, roughly corresponding to the duration of 10 LDACS OFDM symbols. In a practical deployment, LDACS can be designed for any range up to this maximum range.

3.2.6 Framing Structure

The LDACS framing structure (Figure 5) 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).

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[2] The occupied bandwidth comprises an unmodulated DC carrier and 25 OFDM carriers on each side of the DC carrier. The LDACS RF bandwidth has been selected as a trade-off between the achievable capacity and the restrictions of the inlay deployment concept (bandwidths larger than 500 kHz would lead to increased required separation distances between LDACS radios and other L band radio stations).

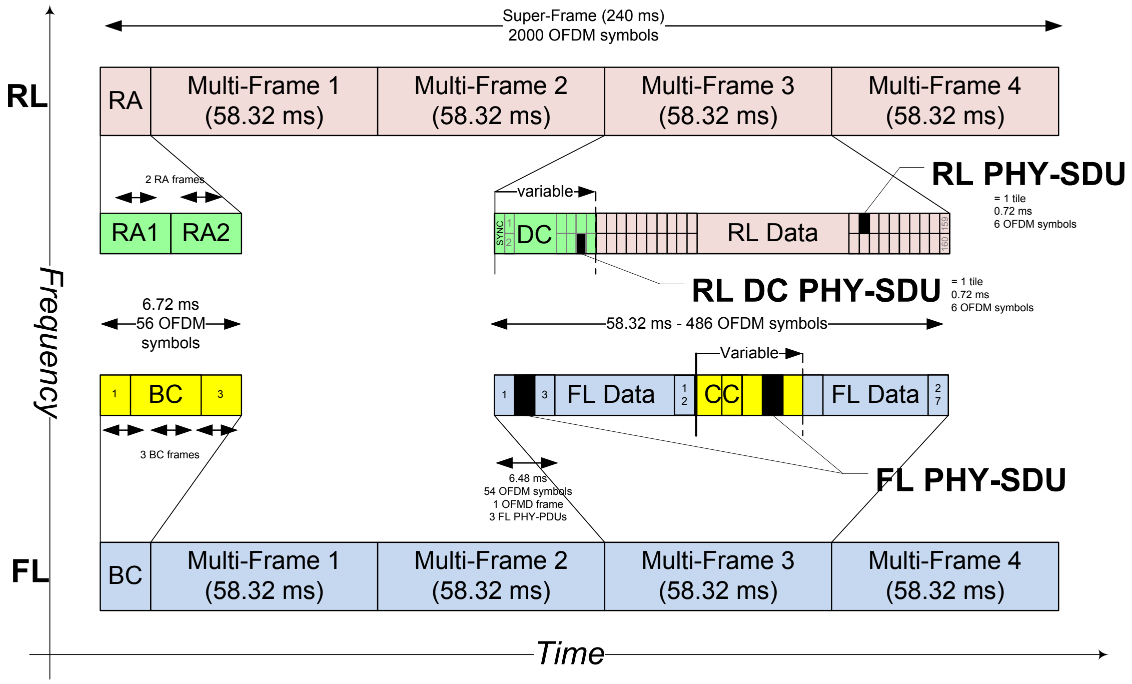

Figure 5: LDACS Framing Structure

In the FL, an SF contains a Broadcast frame (BC) of duration T_{BC} = 6.72 ms (56 OFDM symbols), and four Multi-Frames (MF), each of duration T_{MF} = 58.32 ms (486 OFDM symbols).

Each FL MF contains 9 OFDM frames with a frame duration of $T_{DF/CC}$ = 6.48 ms (54 OFDM symbols). Each OFDM frame has a total data capacity of 2442 symbols[3] and comprises exactly three FL PHY-PDUs that are used for transmitting either the common control (CC) information or payload data. The size of the CC slot and thus also the size of the data slot is variable. Within each MF, FL PHY-PDUs 1 to 12 contain user payload data. The slot with CC information starts with the beginning of the 13th FL PHY-PDU. The CC slot has variable length between 1 and 8 FL PHY-PDUs (i.e. the maximum CC slot is from the 13th to the 20th FL-PHY-PDU). The remaining FL PHY-PDUs in the MF again contain user payload data.

In the RL, each SF starts with a time slot of length T_{RA} = 6.72 ms with two opportunities for sending Reverse Link Random Access (RL RA) frames, followed by four MFs. These MFs have the same fixed duration of T_{MF} = 58.32 ms as in the FL, but a different internal structure.

Each RL MF is constructed from RL PHY-PDUs equivalent to OFDMA tiles. RL PHY-PDUs are used for dedicated control information (DC) or payload data by different AS. The size of the DC slot and thus also the size of the data slot is variable. An OFDMA tile spans a specified number of contiguous symbols, both in frequency and time direction. The size of an RL Data PHY-PDU and an RL DC PHY-

[3] The indicated data capacity is related to modulated data symbols, excluding the DC carrier and pilot symbols.

PDU correspond to the number of modulated data symbols of a corresponding DC/Data tile. DC tiles are stronger protected than Data tiles and have therefore less capacity. Synchronisation tiles do not contain any user data. The minimum size of the DC slot is 12 OFDM symbols, corresponding to one synchronisation tile, occupying 5 OFDM symbols followed by the single-symbol AGC preamble and six OFDM symbols carrying the dedicated control (DC) information for one or two users, which leads to a minimum DC segment duration of $T_{DC,min}$ = 1.44 ms. The maximum DC slot duration is 108 OFDM symbols, corresponding to $T_{DC,max}$ = 12.96 ms. The duration of the data segment in the RL is variable, equal to $T_{DF} = T_{MF} – T_{DC}$, resulting in $T_{DF,min}$ = 45.36 ms and $T_{DF,max}$ = 56.88 ms.

3.2.7 Protocol Design

The LDACS protocol architecture (Figure 6) defines five major functional blocks above the PHY layer.

Four are placed in the Data Link Layer (DLL) of the AS and GS:

- LDACS Management Entity (LME)
- Data Link Service (DLS)
- Voice Interface (VI)
- Medium Access Control (MAC)

One 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 through a Sub-Network Dependent Convergence Function (SNDCF; OSI network layers), Convergence Sub-layer (CS; other network layers), or Interworking Function (IWF; legacy networks) not discussed in this specification.

The SNP connects the AS and GS DLL providing end-to-end user plane connectivity between the LDACS AS and GS.

The DLL provides Quality of Service (QoS) assurance according to [COCRv2] requirements. Multiplexing of different service classes is possible. Except for the initial aircraft cell-entry and the situation after Type 1 handover, medium access is deterministic, with predictable performance. Optional support for adaptive coding and modulation is provided as well. The four functional blocks of the LDACS DLL are organised into two sub-layers, the Medium Access Control (MAC) sub-layer and the Logical Link Control (LLC) sub-layer discussed in the next sections.

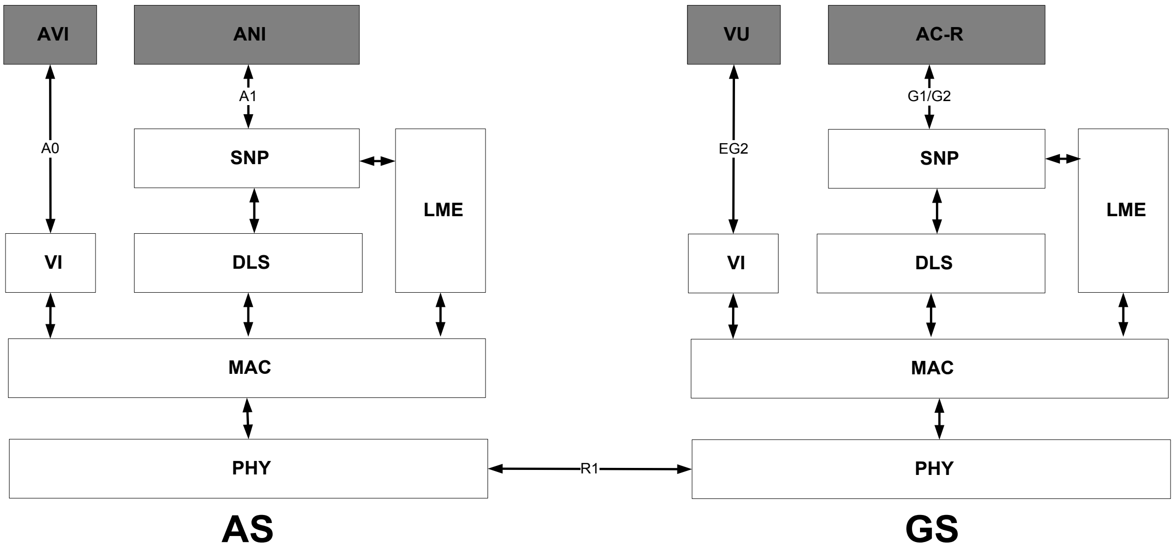

Figure 6: LDACS Protocol Suite in the AS and GS.

The AS is connected to the Airborne Voice Interface (AVI) and the Airborne Network Interface (ANI). The GS is connected to a Voice Unit (VU) for interconnection with external voice services, and the Access-Router (AC-R) and Ground-Station Controller (GSC).

3.2.8 MAC Sub-layer Design

The Medium Access Control sub-layer comprises the Medium Access Control (MAC) entity. MAC entities are present in the AS and the GS. The MAC entity maps logical channels that run between peer DLL entities (Figure 7) to PHY layer resources.

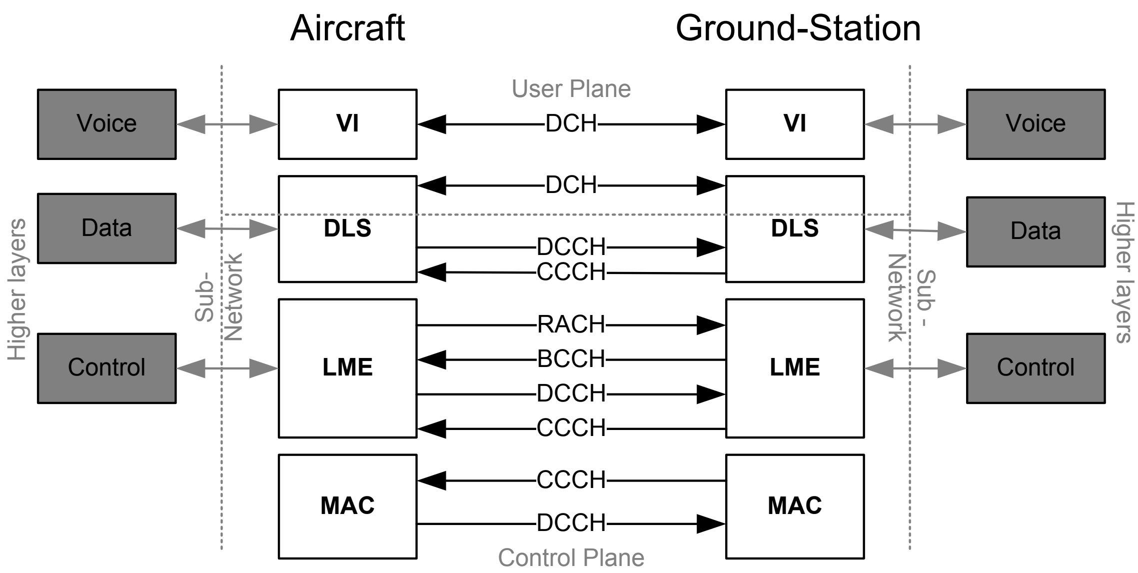

Figure 7: LDACS DLL Logical Channel Structure in the AS and GS

The DCH, CCCH, and DCCH logical channels are point-to-point channels and require at the GS one DLS instance per each controlled AS.

The access to the PHY layer is organised by the MAC entity in a slot structure constructed from PHY-PDUs. MAC slots provide opportunities for conveying different logical channels (Figure 8). Note that the FL slot structure is shifted versus the multi-frame structure. Slots are constructed from FL and RL PHY-PDUs, respectively. Every fourth FL data slot is interrupted by a BC slot.

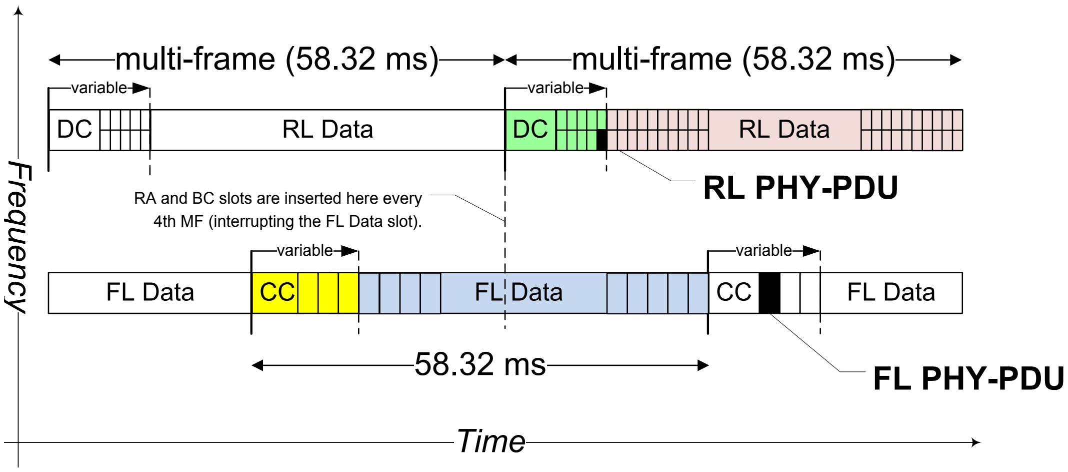

Figure 8: LDACS Slot Structure.

There are three types of FL MAC slots:

- BC slot, carrying the Broadcast Control Channel (BCCH) for all airborne users
- CC slot, carrying the Common Control Channels (CCCH) for airborne users
- Data slot, carrying the FL data payload (DCH)

Note: The FL DATA slot is not aligned with the multi-frame boundary, but between two consecutive CC slots!

There are also three types of RL MAC slots:

- RA slot, carrying the Random Access Channel (RACH) available to all airborne users
- DC slot, carrying the Dedicated Control Channels (DCCH) of airborne users
- Data slot, carrying the RL data payload (DCH)

The size of FL CC slots and RL DC slots can be dynamically adjusted (in PHY-PDU steps), allowing for an optimum accommodation of varying levels of signalling traffic.

3.2.9 LLC Sub-layer Design

The LLC sub-layer of the DLL manages the radio link and offers to the sub-network layer a bearer service with different classes of service. It contains the LME, DLS, and VI entities. The DLS and VI may be present in multiple instances.

There is one LME in each AS and one LME in the GS. The GS LME performs link maintenance and manages AS registration (cell-entry) and deregistration (cell-exit) at a particular GS as well as handovers between GSs (mobility) under the control of the NME. During cell-entry the identity and authorization of an AS is verified. This is conducted over BCCH (GS to AS) and RACH (AS to GS) logical channels. These two channels are special in the sense that they are available to AS before registration. Otherwise, excluding registration, the LME uses the CCCH and the DCCH for exchanging control information.

The dynamic assignment of physical layer resources to logical data channels is provided by the GS LME. For ground-to-air transmissions this assignment is performed locally in the GS. However, air-to-ground transmission resources have to be requested by the AS LME and are assigned by the GS LME. The air-to-ground resource allocation mechanism uses DCCH (AS to GS) and CCCH (GS to AS) logical channels for the exchange of resource request and resource allocations.

Bi-directional exchange of user data between the GS and the AS is performed by the DLS entities. There is one DLS entity in each AS and one peer DLS entity for each AS in the GS. All DLS entities use the DCH logical channel for DLS user plane transmissions and the DCCH and CCCH channels for DLS control plane transmissions.

LDACS offers a built-in support for the transmission of digital voice. This service is provided by the VI entity. A voice stream is transmitted over the DCH logical channel. The channel may be shared by several users to emulate party-line voice communication. If several voice channels should be simultaneously available on a single LDACS radio channel, LME selects the logical voice channel to be used via the VI (in this case LME is controlled from an external system).

3.2.10 Sub-Network Protocol Design

The Sub-Network Protocol (SNP) provides the basis for the A1, G1, G2, G3, G4, G5, G7, and G8 interfaces described in [PJ14 TS/IRS] and shown in Figure 2. It provides end-to-end user plane and control connectivity between the AS and GS as indicated in Figure 9.The Ground-Station Controller (GSC) controlling the LDACS sub-network is not part of this specification.

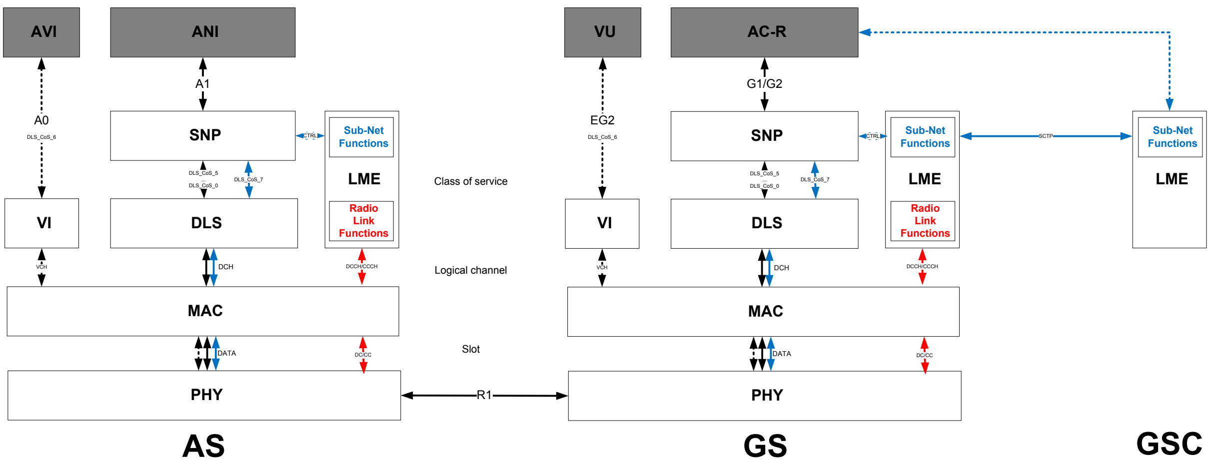

Figure 9: LDACS sub-network protocol architecture.

4 LDACS Characteristics

This section describes radio aspects, characteristics and capabilities of LDACS that affect both AS and GS, considering the LDACS A/G mode of operation[4].

4.1 Polarization of LDACS Emissions

The design polarization of LDACS emissions shall be vertical.

4.2 LDACS Designed Coverage

The maximum designed coverage range of LDACS is 200 nm. The designed coverage range is determined by the propagation guard time considered during the system design. Dependent on the interference situation, real operational coverage may be chosen to be smaller than 200 nm.

Note: An extended range mode for ranges beyond 200 nm will be defined in a later update of this specification.

4.3 LDACS Radio Frequency Range

LDACS shall operate in the 960 –1164 MHz range.

The LDACS frequency bands for the A/G link are the following:

- Forward Link: 1110-1156 MHz
- Reverse Link: 964 – 1010 MHz

Note: The reverse link is proposed to operate in the lower part of the DME, which does not have an international allocation (and as result there are not international DMEs operating in this band). The complete Reverse Link frequency band also surrounds the UAT frequency at 978 MHz for regions were UAT is deployed parts of the reverse link frequency band cannot be used and means must be defined to allow a parallel operation of LDACS and UAT.

4.4 LDACS FL/RL Duplex Spacing

The duplex spacing between LDACS A/G FL and RL is 146 MHz.

Note.— There is no fixed assignment between the forward link channels and the revers link channels. This allows a dynamic allocation of FL and RL channels, which gives more flexibility for deploying LDACS.

[4] In this LDACS specification no detailed information is provided for the A/A mode of operation.

4.5 LDACS RF Channel Grid

4.5.1 FL/RL Channel Grid

The nominal frequency of FL/RL channels for LDACS within the respective transmission/reception range shall lie on the 0.5 MHz grid. All FL and RL channels shall have a unique channel number starting with the first allocated frequency. The first LDACS channel LC#1 shall operate at a centre frequency (DC subcarrier) of 964 MHz. Table 1 shows an excerpt of the mapping of LDACS channels to the frequencies.

LDACS shall operate without guard bands between adjacent LDACS channels.

LDACS co-channel interference rejection shall be at least 14 dB.

Note 1: This corresponds to a frequency reuse factor of 7.

Note 2: The figure for co-channel interference rejection ensures that at least all adaptive coding and modulation types involving QPSK modulation fulfil the required bit-error ratio (BER).

Table 1: LDACS channel assignment

LDACS channel	Center Frequency
LC#0	960.0 MHz
LC#1	960.5 MHz
LC#2	961.0 MHz
…	…
LC#8	964.0 MHz
…	…
LC#100	1010 MHz
…	…
LC#330	1125 MHz
…	…
LC#392	1156 MHz
…	…
LC#408	1164.0 MHz

Note: Only channels within the LDACS radio frequency bands shall be used.

The LDACS channel number (LC#nb) shall be calculate by the following equation:

LC#nb = (Assigned Frequency [MHz] – Reference Frequency [MHz])*2

The Reference Frequency is 960 MHz.

4.5.2 LDACS RF Channel Bandwidth

The occupied bandwidth of the LDACS signal is B_{occ} = 498.05 kHz (Section 8.4.2).

*Note 1.— LDACS in its basic profile occupies a transmit bandwidth of 498.05 kHz (51*9.765625 kHz).* LDACS RF bandwidth has been selected as a trade-off between the system capacity and the capability of operating between DME channels without mutual influence (inlay concept).

Note 2.— It is foreseen that additional LDACS profiles are defined at a later stage which might use more than 51 subcarriers and with that occupy a larger bandwidth.

5 System Characteristics of the Ground Installation

This section comprises items that are specific to the implementation of the LDACS GS operating in the A/G mode. The GS comprises the transmitter (TX), receiver (RX) and some common functions, e.g. common timing/frequency reference. RF duplexer and RF filtering equipment may appear within the GS architecture but are considered as optional.

5.1 GS Radio Frequency Range

The GS radio frequency range shall be as specified in Section 4.3.

5.2 GS Duplexer

LDACS duplexer shall be of passband type.

5.3 GS Transmitting Function

Unless explicitly differently stated, all requirements upon the GS transmitter apply to the RF output connector of the transmitter.

5.3.1 GS Operational Coverage

The effective radiated power of the LDACS GS transmitter (TX) should be such as that it provides on the basis of free-space propagation the minimum required spatial power density at the AS antenna as specified in *Section 6.4.6.*

LDACS GS will provide communications service to airborne users within service volumes characterised via Designated Operational Coverage (DOC). The GS operational coverage may be less than or at most equal to the LDACS system designed coverage of 200 nm (Section 4.2).

The requirement specifies the required GS TX power, but is indirectly dependent upon the selected AS RX operating point (minimum required operating signal power) S1 (dBm) under interference conditions that in turn is firmly coupled with a spatial received power density Pd (dBW/m2), assuming the reference antenna/cabling configuration. The AS RX parameters S1 and Pd are proposed in Section 6.4.6. These parameters are selected based on satisfactory interference performance, considering also safety and banking margins.

5.3.2 Ground TX Maximum Transmitting Power

LDACS GS equipment shall be able to generate a transmit power of 42 dBm averaged over continuous FL transmissions and measured directly at the transmitter output.

The maximum EIRP of an LDACS GS in regular range mode averaged over continuous FL transmissions shall be 52 dBm.

Note 1: In defining the maximum EIRP, 42 dBm transmit power, 2 dB cable loss as well as 12 dBi antenna gain is assumed.

Note 2: The actual EIRP used of an LDACS GS in regular range mode might be smaller depending on the coverage area of the LDACS GS.

5.3.3 Ground TX Maximum PAPR

LDACS GS PAPR shall not exceed 11 dB measured directly at the transmitter output.

5.3.4 Ground TX Transmitter Spectral Flatness

When transmitting on all usable sub-carriers N_u (N_u is the maximum number of OFDM sub-carriers available on FL specified in Section 5.3.5), the following shall apply:

- Absolute average power difference between adjacent sub-carriers: ≤ 0.1 dB (If "n_{B_FL}" dB pilot boosting is applied," n_{B_FL}" dB allowance should be added for pilot sub-carriers).
- Deviation of average power in each sub-carrier (Figure 10) from the measured sub-carrier power averaged over all N_u active sub-carriers:
- Sub-carriers from [-12 to -1] and [1 to 12]: ≤ ±2 dB
- Sub-carriers from [-25 to -13] and [13 to 25]: ≤ +2/–4 dB
- The average power transmitted at spectral line 0 shall not exceed –15 dB relative to total average GS transmitted power (excluding the sub-carriers intentionally power-boosted or suppressed).

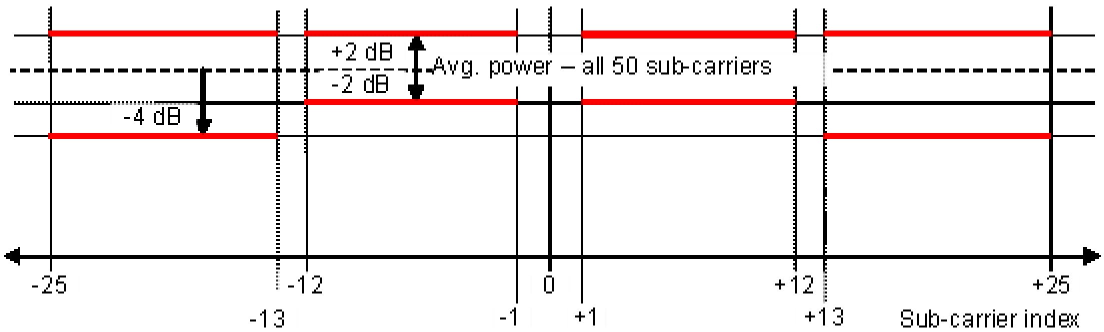

Figure 10: TX Spectral Flatness

The boosting level n_{B_FL} shall be adjustable (Section 8.7.1).

All above requirements apply to the RF output connector of the equipment.

Under ideal conditions, all OFDM sub-carriers would be transmitted with nearly equal "per sub-carrier" power, so the OFDM signal spectrum would be flat. Under real conditions, the degree of spectral flatness must be specified for the OFDM transmitter in order to reduce implementation efforts at the receiver side.

The postulated spectral flatness is only achievable in the mean, i.e. after long averaging, since within each OFDM symbol significant differences from sub-carrier to sub-carrier might occur. This holds especially for 16- and 64-QAM but also for QPSK.

5.3.5 Ground TX Maximum Number of Used Sub-carriers

Except for the synchronisation symbols where some sub-carriers are not transmitted, the ground LDACS TX uses in all FL frames the maximum number of OFDM sub-carriers: $N_{used} = N_u = 50$ sub-carriers.

Note: The Nu figure above does not include the DC sub-carrier at zero offset.

5.3.6 Ground TX Relative Constellation Error

To ensure that the receiver SNR does not degrade more than 0.5 dB due to the ground transmitter SNR, the relative constellation Root Mean Square (RMS) error of a ground TX, averaged over all sub-carriers, OFDM frames and packets, shall not exceed an ACM mode dependent value according to Table 2.

Table 2: Allowed Relative Constellation Error for Ground TX

ACM mode	Relative constellation error [dB]
QPSK, 1/2	-15,0
QPSK, 2/3	-17,0
QPSK, 3/4	-18,5
16QAM, 1/2	-21,5
16QAM, 2/3	-23,0
64QAM, 1/2	-25,0
64QAM, 2/3	-28,5
64QAM, 3/4	-31,0

The relative constellation RMS error is calculated as

$$Error_{RMS} = \frac{1}{M}\sum_{i=1}^{N_f}\sum_{j=1}^{L_p}\sum_{k\in S}\sqrt{\frac{[I(i,j,k)-I_0(i,j,k)]^2+[Q(i,j,k)-Q_0(i,j,k)]^2}{I_0(i,j,k)^2+Q_0(i,j,k)^2}}$$

where

- M denotes the total number of measurements
- L_p denotes the number of OFDM symbols used in a measurement (length of the OFDM frame with data relevant to the measurement),
- N_f denotes the number of OFDM frames containing data used in the measurement,

- *$[I_0(I,j,k), Q_0(I,j,k)]$* denotes the ideal symbol point in the complex plane (in the constellation diagram) of the i-th OFDM frame, j-th OFDM symbol of the OFDM frame, k-th sub-carrier of the OFDM symbol modulated with data relevant to this measurement,
- *$[I(I,j,k), Q(I,j,k)]$* denotes the observed symbol point in the complex plane (in the constellation diagram) of the i-th OFDM frame, j-th OFDM symbol of the OFDM frame, k-th sub-carrier of the OFDM symbol modulated with data relevant to this measurement,
- *S* denotes the group of modulated data sub-carriers where the measurement is performed.

5.3.7 Ground Transmit Filter

LDACS transmit filter insertion loss should be less than 1 dB. LDACS transmit filter shall provide a rejection to ensure a sufficient protection of other relevant systems.

5.3.8 Ground TX Noise and Spurious Emissions

The level of any spurious signal measured in an active mode at the GS TX output terminated in a matched impedance load shall not exceed -36 dBm.

The broadband noise power density measured across the spurious domain (Figure 11) at the GS TX output, when the TX terminated in a matched impedance load operates at the maximum power (Section 5.3.2) shall not exceed -133 dBc/Hz.

5.3.9 Ground TX Spectrum Mask

Within the out-of-band domain, the spectral density of the transmitted LDACS signal shall fall within the spectral mask shown in Figure 11 and Table 3. The measurements shall be made by using a 10 kHz resolution bandwidth and a 30 kHz video bandwidth. The 0 dBr level is the average LDACS TX in-band power density.

Note 1.— Δf is the frequency offset in [kHz] measured from the LDACS center frequency.

Note 2.— a is the attenuation in [dBr] relative to the LDACS passband power level.

Note 3.— The frequency coordinates of the points A,…,G are derived from the half channel bandwidth of an LDACS transmit signal, which is 250 kHz:

- Frequency coordinate for point A [kHz]: 250*1
- Frequency coordinate for point B[kHz]: 250*1.35
- Frequency coordinate for point C[kHz]: 250*2.5
- Frequency coordinate for point D[kHz]: 250*3.1
- Frequency coordinate for point E[kHz]: 250*5
- Frequency coordinate for point F[kHz]: 250*8
- Frequency coordinate for point G[kHz]: 250*16

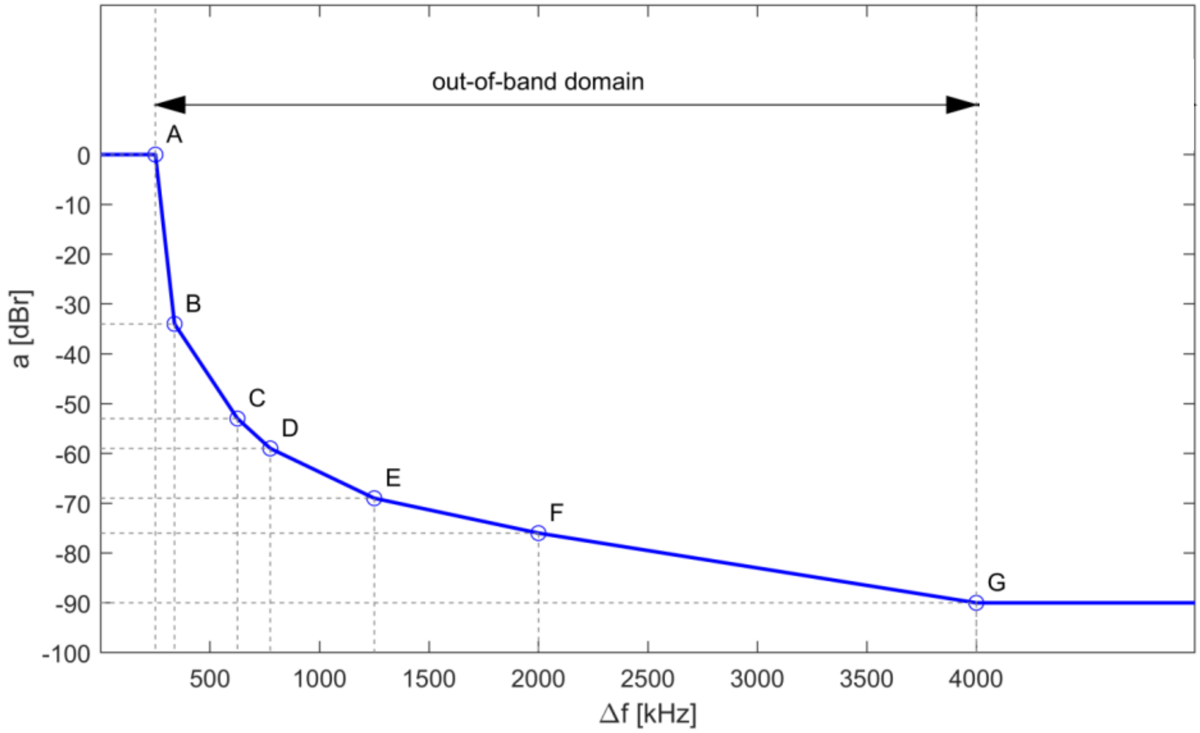

Figure 11: LDACS Ground TX Spectral Mask

Table 3: LDACS Ground TX Spectral Mask

	A(Δ*f*,*a*)	B(Δ*f*,*a*)	C(Δ*f*,*a*)	D(Δ*f*,*a*)	E(Δ*f*,*a*)	F(Δ*f*,*a*)	G(Δ*f*,*a*)	Spur
Frequency Offset Δ*f*	250.0	337.5	625.0	775.0	1250	2000	4000	>4000
Attenuation *a*	0	34	53	59	69	76	90	90

5.3.10 Ground TX Time/Amplitude Profile

LDACS ground transmissions are continuous, without ramp-up or ramp-down phases.

5.4 GS Receiving Function

5.4.1 Ground RX Reference Bit Error Ratio

For the LDACS receiver, the reference corrected BER (after FEC) shall be 10^{-6}.

The BER measured after FEC is an appropriate measure of the receiver's ability of receiving and properly decoding incoming data messages. It is equally suitable for measurements with and without external interference.

5.4.2 Ground RX Sensitivity

LDACS minimum receiver sensitivity depends on the chosen coding and modulation scheme and shall comply with Table 4.

Note: The sensitivity level is defined as the power level measured at the receiver input when the bit error ratio (BER) is equal to 1 × 10-6 and all active sub-carriers are transmitted in the channel. In general, the requisite input power depends on the number of active sub-carriers of the transmission.

Table 4: LDACS minimum receiver sensitivity values

Modulation	Coding Rate of Convolutional Code (CC)	GS Receiver Sensitivity
QPSK	1/2	-103 dBm
QPSK	2/3	-101 dBm
QPSK	3/4	-100 dBm
16QAM	1/2	-97 dBm
16QAM	2/3	-94 dBm
64QAM	1/2	-92 dBm
64QAM	2/3	-89 dBm
64QAM	3/4	-88 dBm

Note: The sensitivity values in Table 4 assume a receiver noise figure of 6 dB.

Note: The sensitivity values in Table 4 assume absence of any source of interference except for thermal and receiver noise.

5.4.3 Ground RX Filter

LDACS receive filter insertion loss should be less than 1 dB.

LDACS receive filter shall provide a rejection to ensure a sufficient protection from other relevant systems.

5.4.4 Ground RX Selectivity

LDACS receiver selectivity shall comply with Table 5 and Figure 12.

Note: The receiver selectivity values comprise the complete LDACS receiver chain after the duplexer, i.e. the duplexer is not included.

Table 5: LDACS receiver selectivity values

Passband Ripple (±250 kHz)	within ± 1 dB
Attenuation @ ±300 kHz	> 6 dB

Attenuation @ ±400 kHz	> 40 dB
Attenuation @ ±500 kHz	> 70 dB
Attenuation @ ±750 kHz	> 80 dB
Attenuation @ ±1500 kHz	> 90 dB

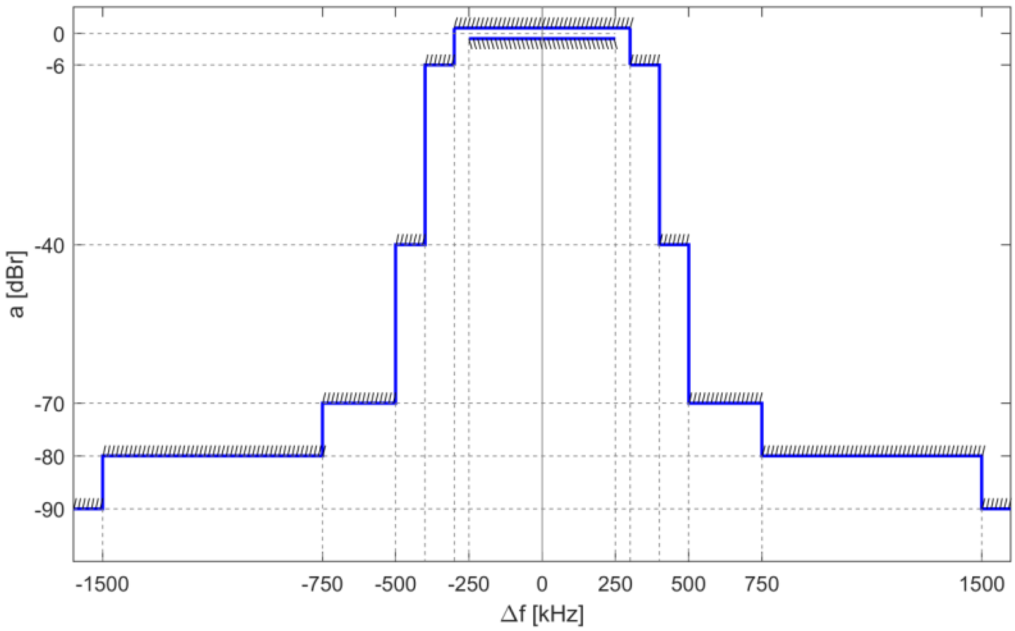

Figure 12: LDACS receiver selectivity.

5.4.5 Ground RX Operating Point

When using all RL sub-carriers ($N_{used} = N_u$) with QPSK modulation, convolutional coding with r_{cc} = ½, interleaving over 6 tiles and Reed-Solomon RS (98, 84, 7) coding, using RL Data tiles where AS uses full RL bandwidth, the ground LDACS RX shall fulfil the BER specified under 5.4.1 when the signal S1[5] as defined in Table 6 or greater is present at the RX input.

S1 defines the RX operating point – a minimum required RX input signal power at the RX input under real interference conditions (cumulative L-band interference), considering an appropriate aeronautical channel and applicable banking margin.

Table 6: GS RX Operating Point S1 and Power Density Pd

[5] The S1 value has been derived from the LDACS link budget in Appendix A - LDACS Link Budget and may have to be further adjusted.

Antenna Conversion	Unit	ENR	TMA	APT	Equation
Tx-Rx Distance	nm	120	40	10	d
Speed of Light	m/s	3E+08	3E+08	3E+08	c
Transmit mid-band frequency	MHz	987	987	987	f
Wavelength	m	0.30	0.30	0.30	$\lambda = c / f$
Correction Factor	dB	-21.34	-21.336	-21.336	$CF = 10 * \log_{10} \frac{\lambda^2}{4 * \pi}$
Rx operating point (S1)	dBm	-95.83	-93.03	-85.43	S1
RX cable loss	dB	2	2	2	Lca
Duplexer loss	dB	0	0	0	Lda
Minimum RX Antenna gain	dBi	12	12	12	Lra
Required power at RX antenna	dBm	-105.83	-103.03	-95.43	Pa=S1+Lca-Lra
Required power at RX antenna	dBW	-135.83	-133.03	-125.43	Pa1=Pa-30
Spatial power density at RX antenna	dBW/m^2	-114.49	-111.69	-104.09	Pd=Pa1-CF

Assuming fixed antenna gain and cable losses, the GS RX operating point S1 for particular LDACS designed operational coverage (environment) is related to the minimum required signal power density Pd (dBW/m2) in front of the GS receive antenna.

Under above conditions, the GS RX shall provide the BER specified under 5.4.1 when the spatial power density at the GS RX antenna is equal to or greater than the Pd value specified in the last row of Table 6.

*When calculating Pd, the conversion formula from ICAO Annex 10, Volume I, Attachment C, Section 7.2.1 has been used: Pd = Pa – 10*log10(λ2/(4*π)), where Pd is the spatial power density (dBW/m2), Pa is the isotropic received power at the receiving point (dBW) and λ is the wavelength (m).*

When calculating the relation between Pd and the corresponding required signal power level S1 at the GS receiver input, the mid-range GS receiving frequency and the minimum available GS antenna gain towards the concerned AS at the coverage boundary have been assumed. The worst-case AS-GS antenna misalignment occurs in the TMA/APT environment (peak GS antenna gain of + 8 dBi has been reduced by 2 dB in these environments). This reduction is the ground contribution to the total GS-AS antenna misalignment loss (7 dB) that was used in TMA/APT link budget calculations.

5.4.6 Ground RX Interference Immunity Performance

The LDACS receiver shall be able to receive the desired LDACS signal in the presence of undesired signals received from other L-band sources at power levels that may exceed the power of the desired signal. This receiver feature is highly dependent on the frequency offset between the desired and undesired signal channels.

The interference immunity performance cannot be stated based on the currently available LDACS parameters. Instead, it should be measured in the laboratory on LDACS GS RX prototype.

It is expected that the interference immunity will be assessed as Interference Rejection (IR) dependent on the frequency spacing between involved systems.

The Interference Rejection (IR) represents the power difference (in dB) between the interfering undesired signal (U) at specified frequency offset from the LDACS channel and the on-channel desired LDACS signal, for specified desired signal level (D) and specified reference BER (Section 5.4.1).

IR shall be measured by setting the desired LDACS signal's power to the level "D" (dBm) equal to the operating point S1 that is 6 dB above the rate dependent receiver sensitivity S0 (as specified in 5.4.2) and raising the power level "U" (dBm) of the interfering signal until the target BER (as specified in 5.4.1) is obtained.

IR shall be separately assessed and declared for each applicable type of interfering signal (e.g. DME, SSR, UAT, GSM/UMTS, RSBN, JTIDS/MIDS). Each interfering signal must be specified in terms of its operating frequency (or frequency offset to the LDACS channel), peak power, and duty-cycle. Table 7 illustrates one example of stating IR for a particular interfering L-band system "X". IR is frequency-dependent and shall be stated for different frequency offsets between the desired LDACS signal and undesired interference signal.

Table 7: Interference Rejection (IR) Requirements for GS RX (System "X")

Desired signal power D (dBm)	D = S0 + 6dB				
Frequency offset Δf (MHz)	Δf_1	Δf_2	Δf_3	Δf_4	Δf_n
Tolerable undesired signal power U_x (dBm)	U_1	U_2	U_3	U_4	U_n
IR=U/D (System „X", dB)	U_1/D	U_2/D	U_3/D	U_4/D	U_n/D

The Δf values in Table 7 should be selected as appropriate for the System "X". In particular, for tests with DME equipment, the appropriate Δf values may be ± 0.5 MHz, ±1 MHz, ± 1.5 MHz, ±2 MHz, ± 2.5 MHz etc. The IR values will be determined during the laboratory measurements.

5.4.7 Ground RX Maximum Desired Signal

The GS receiver shall be capable of decoding on-channel desired LDACS signal (D) with the peak instantaneous power of –10 dBm (measured at the RX input).

Due to internal implementation choices and constraints, e.g. clipping in the input stage, an aeronautical receiver is generally able to decode desired incoming signals only up to some specified maximum power level. If this level is exceeded, receiver operation may fail.

An AS TX on the ground operating with +42 dBm average AS TX power at 100 m distance to the GS antenna would produce -28.5 dBm average power at the GS RX input, assuming 0 dBi gain airborne antenna, 3.5 dB airborne cable and duplexer losses, free-space propagation, 8 dBi ground antenna gain and 2 dB ground cable losses, Assuming 17 dB provision for TX PAPR[6], the peak received LDACS signal power becomes -11.5 dBm (rounded-up to -10 dBm).

This requirement represents the best current guess and may require further refinement (e.g. free-space propagation model may not be applicable to airport surface, or the minimum required distance to GS may be increased above 100 m).

5.4.8 Ground RX Maximum Tolerable Input Signal Power

The ground LDACS receiver shall tolerate at its input a pulsed interference signal with peak power of up to +30 dBm without damage.

Receiver implementation imposes constraints on the maximum (desired or undesired) signal power at the receiver input such that it still does not cause permanent damage of the receiver input circuit. The proposed value is the best current guess and may have to be further adjusted.

Due to the possible co-location with GSs of other aeronautical systems, the same (stringent) value has been proposed for the GS RX as for an AS RX (see Section 6.4.9). The implementation can be made easier by using radio frequency (RF) filters between the GS antenna and the receiver input; however, the usage of such filters is optional.

5.4.9 Ground RX Measurement of RL Power Error

The GS RX shall be able to measure – separately for each RL user – the difference between the signal power of the incoming RL frames/tiles and the local reference (optimum) power setting at the GS with an accuracy of ± 0.5 dB.

LDACS GS applies closed-loop power management to maintain the power level of airborne transmitters at the minimum power level that is still sufficient for successful decoding of RL messages by the GS receiver. In order to issue power correction commands on FL, LDACS GS receiver must be able to accurately measure received signal power levels – respective to its internal reference – separately for each RL user. For that purpose, each RL RA frame contains two OFDM synchronisation symbols. If

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[6] In the practical implementation it should be able to reduce the maximum possible PAPR value with 50 OFDM sub-carriers (17 dB) by using PAPR reducing techniques (Section 8.7.2).

required, the GS can request the AS to transmit a synchronisation tile within the RL DC segment.

5.4.10 Ground RX S/N Measurement

GS RX shall continuously measure S/N for RL frames/tiles received from the controlled ASs. The S/N value shall be separately derived for each AS under control of the GS, permanently updated and averaged after each new RL frame/tile has been received from the controlled AS.

5.5 GS Frequency/Timing Requirements

5.5.1 Network Synchronisation

In order to support hand-over procedures between GSs, all LDACS GSs from a particular LDACS network shall be synchronised to a common timing reference.

The external synchronising references may be e.g. a 1 pulse-per-second (PPS) timing pulse and a 10 MHz frequency reference. In case of loss of the network timing signal, GSs shall continue to operate and shall automatically re-synchronise to the network timing signal when it is recovered.

A single GS shall be able to operate without a network timing signal. In such a situation registered AS will not be able to conduct a Type 2 handover and will not be able to scan adjacent cells without losing synchronisation to (and having to re-enter) the current cell. Type 2 handover is also not available between GSs of different LDACS networks that are not using common timing reference.

The frequency- and symbol clock accuracy of a "free running" GS is specified in Section 5.5.4.

5.5.2 GS Transmitter Synchronisation to Network Time Reference

At the GS, the start of the first transmitted symbol in an FL super-frame shall be time-synchronous with the external timing reference.

Time-synchronous in this context means that there is a fixed, time-invariant relation between the reference timing point of the transmitted FL SF, and therefore also between the reference timing points for all FL frames within the SF, relative to the reference timing point of the external time reference.

The timing of the transmitted symbols shall be tracked at the GS TX antenna.

5.5.3 GS Synchronisation Accuracy to Network Time Reference

The FL SFs transmitted by the serving GS shall be synchronised with the Network Time Reference to a level of at least ±1/11 cyclic prefix length.

*The duration of the cyclic prefix is 11*Tsa, where Tsa = 1.6 µs represents the selected sampling time (Section 8.4.1).*

For ranging the GS clocks shall be synchronized with an error of 50 ns or less

5.5.4 GS Centre Frequency and Symbol Clock Frequency Accuracy

At the GS, the transmit centre frequency, receive centre frequency, and the symbol clock frequency shall be derived from the same reference oscillator.

At the GS, the reference frequency accuracy shall be better than ± 0.1 ppm.

This requirement is valid independently of whether the GS is synchronised to the network reference or not (Section 5.5.1).

5.5.5 GS to AS Frequency Synchronisation

The GS shall be able to individually synchronise to-, receive, and decode RL RA frames.

The GS frequency synchronisation to RL RA frames should be based on observing the synchronisation symbol pairs that occur at the start of RL RA frames and/or RL synchronisation tiles.

Detailed methods for frequency acquisition and tracking are an implementation issue. The GS RX frequency synchronisation to RL RA frames is expected to be based on synchronisation sequences. Additionally, pilot tones from the RA frame may be used.

When receiving RA frames, the GS RX shall acquire frequency synchronisation on RL within the tolerance[7] that is sufficient for satisfactory reception on the RL (sensitivity requirement, as specified in Section 5.4.2).

The initial GS RX frequency capture range shall be sufficient for accommodating both imperfect AS TX - GS RX reference frequency accuracy (Sections 6.5.1 and 5.5.4) and the maximum applicable GS - AS Doppler shift (1.7 kHz at 850 knots and 1156.5 MHz).

When an LDACS AS contacts the new GS for the first time, it may transmit its RL RA frame/synchronisation tile with a significant offset from the GS receiving frequency due to a non-compensated TX-RX frequency error and/or Doppler shift.

At this time, AS RL transmissions occur in the "Receive-only mode" based on FL-derived estimates, where an AS has not yet received from the GS any absolute correction value for its RL power-, timing- and frequency settings.

As RL RA frames/synchronisation tiles are relatively short, no frequency tracking is required.

The GS shall be able to individually synchronise to RL synchronisation tiles received from different ASs at the beginning of RL DC segments.

After initial contact, the AS is synchronised with the GS, but for the synchronisation maintenance it may be required that the AS selected by the GS sends a special synchronisation tile at the beginning of the RL DC segment.

[7] This tolerance needs not to be exactly specified – like AGC, synchronisation is just an enabler for the normal operation of the AS RX. Synchronisation performance will be indirectly confirmed via AS RX sensitivity check.

5.5.6 GS to AS Time Synchronisation

The GS shall be able to individually lock onto, receive, and decode RL RA frames received with different power-, frequency-, and timing settings, relative to the GS reference values.

Detailed methods for timing acquisition and tracking are an implementation issue. The GS RX time synchronisation to RL RA frames is expected to be based on synchronisation sequences. Additionally, pilot tones from the RA frame may be used.

When receiving RA frames, the GS RX shall acquire time synchronisation on RL within the tolerance[8] that is sufficient for satisfactory reception on the RL (sensitivity requirement, as specified in Section 5.4.2).

In order to be able to demodulate the RL RA frame, the GS RX must first acquire time synchronisation with the AS RA frame.

The reception of RA frames is supported by the large propagation guard times that are defined in Section 8.5.2.3 and by the synchronisation symbol pairs that occur at the start of RL RA frames.

5.5.7 GS Measurement of RL Frequency Error

The GS RX shall be able to measure frequency offset between the incoming RL centre frequency and the local frequency reference applicable to RL. The measurement tolerance shall be better than 1% of the sub-carrier spacing.

5.5.8 GS Measurement of RL Timing Error

The GS RX shall be able to measure the time offset between the incoming RL frames / tiles and the local reference frame timing to an accuracy of ± 1/6 of the guard time T_g or better.

[8] This tolerance needs not to be exactly specified – it will be indirectly confirmed via AS RX sensitivity check.

6 System Characteristics of the Aircraft Installation

This section comprises specification items that are specific to the implementation of the LDACS Airborne Station (AS) operating in the A/G mode. The AS comprises the transmitter (TX), receiver (RX), duplexer and some common functions, e.g. common timing/frequency reference.

6.1 AS Radio Frequency Range

The AS radio frequency range shall be as specified in Section 4.3.

6.2 AS Duplexer

LDACS duplexer shall be of passband type.

Recommendation: The in-band insertion loss of the LDACS AS duplexer should be less than 1 dB.

The minimum attenuation of the LDACS AS duplexer from the transmit port to the receiver port at the assigned LDACS FL frequency band shall be at least 69 dB.

6.3 AS Transmitting Function

6.3.1 AS Operational Coverage

The effective radiated power of the LDACS AS transmitter (TX) should be such as that it provides on the basis of free-space propagation the minimum required spatial power density at the GS antenna as specified in *Section 5.4.5*. The requirement applies to ranges and altitudes appropriate to the operational conditions applicable to the areas in which the aircraft is operated.

> *The requirement specifies the AS TX power, but is indirectly dependent upon the GS RX operating point (minimum required operating signal power) S1 (dBm) under interference conditions that in turn is firmly coupled with a spatial received power density Pd (dBW/m2), assuming the reference antenna/cabling configuration. The GS RX parameters S1 and Pd are proposed in Section 5.4.5 based on satisfactory interference performance, considering also safety and banking margins. The requirement may need to be separately stated for large cells with 200 nm radius.*

6.3.2 Airborne TX Maximum Transmitting Power

LDACS AS equipment shall be able to generate a transmit power of 42 dBm averaged over continuous RL transmissions and measured directly at the transmitter output.

The maximum EIRP of an LDACS AS averaged over continuous RL transmissions shall be 41 dBm.

Note 1: In defining the maximum EIRP, 42 dBm transmit power, 3 dB cable loss,1 dB duplexer loss as well as 3 dBi antenna gain is assumed.

Note 2: The maximum EIRP is required to support communications up to the maximum coverage.

The AS TX shall transmit with declared nominal average power P_{AS}. Declared average power P_{AS} is measured (must be maintained-) over the duration of any continuous RL transmission that uses all N_u OFDM sub-carriers.

Dependent on the AS capability, some ASs may be configured to use less than +42 dBm in some airspace types, but once selected, declared AS average power level P_{AS} does not change during operation.

When the AS TX transmits OFDM data symbols with less than N_u sub-carriers (data symbols in RA frames, DC and Data tiles), it shall maintain the same per-sub-carrier power (for all sub-carriers except for boosted pilot tones) as in the case where all N_u sub-carriers are used.

When transmitting AGC preambles and synchronisation sequences that do not use all RL carriers, the AS TX shall adjust the average per-symbol transmitting power such that it becomes equal to the average per-symbol transmitting power for RL OFDM data symbols that use Nu sub-carriers.

If the number of active sub-carriers allocated to a user by the GS is reduced or increased, the total transmitted power shall be proportionally reduced or increased by the AS alone, without additional GS power control messages. The total average power P_{AS} must always remain below +42 dBm.

In order to assure interference-free operation towards other L-band receivers the maximum EIRP (antenna main lobe) for an AS should be limited.

6.3.3 Airborne TX Maximum PAPR

LDACS AS peak-to-average power ratio (PAPR) shall not exceed 11 dB measured directly at the transmitter output.

6.3.4 Airborne TX Power Dynamic Range

The AS TX shall be able to transmit with declared nominal power level that shall not exceed the maximum specified power (Section 6.3.2).

Airborne LDACS transmitter shall support monotonic AS TX power level reduction below the declared nominal AS TX power within a control range not less than 50 dB.

TX power shall be adjustable in steps that are at maximum 1 dB.

TX power level minimum relative step accuracy shall be ± 0.5 dB or better.

6.3.5 Airborne TX Transmitter Spectral Flatness

When transmitting on all usable sub-carriers N_u (N_u is the maximum number of OFDM sub-carriers that are available on RL), the following shall apply:

- Absolute power difference between adjacent sub-carriers: ≤ 0.1 dB (if “n_{B_RL}” dB pilot boosting is applied,” n_{B_RL}” dB should be added for pilot carriers)
- Deviation of average power in each sub-carrier (Figure 10) from the measured per sub-carrier power averaged over all N_u active sub-carriers:
    - Sub-carriers from [-12 to -1] and [1 to 12]: ≤ ±2dB
    - Sub-carriers from [-25 to -13] and [13 to 25]: ≤ +2/–4 dB
- The average power transmitted at spectral line 0 shall not exceed –15 dB relative to total average AS transmitted power (excluding the sub-carriers intentionally power-boosted or suppressed).

The boosting level n_{B_RL} shall be adjustable (Section 8.7.1).

All requirements on the AS transmitter apply to the RF output connector of the equipment.

6.3.6 Airborne TX Maximum Number of Used Sub-carriers

AS TX shall be configurable to use N_{used} = N_u OFDM sub-carriers, where N_u = 50 is the maximum possible number of sub-carriers), except for the RL RA frames where a fixed pre-defined number of sub-carriers is used in OFDM symbols carrying data (Section 8.5.2.3).

6.3.7 Airborne TX Relative Constellation Error

To ensure that the receiver SNR does not degrade more than 0.5 dB due to the airborne transmitter SNR, the relative constellation RMS error of an airborne TX, averaged over all sub-carriers, OFDM frames and packets, shall not exceed an ACM mode dependent value according to Table 2 (Section 5.3.6).

The relative constellation RMS error is calculated as described in Section 5.3.6.

6.3.8 Airborne Transmit Filter

LDACS transmit filter insertion loss should be less than 1 dB. LDACS transmit filter shall provide a rejection to ensure a sufficient protection of other relevant systems.

6.3.9 Airborne TX Noise and Spurious Emissions

The level of any spurious signal measured in an active mode at the AS TX output terminated in a matched impedance load shall not exceed -36 dBm.

Above 1 GHz, the level of any spurious signal measured in an active mode at the properly terminated AS TX output shall not exceed -60 dBm.

This second requirement is based on [V4 MOPS]/Section 3.2.3.5 and may be further revised to be brought in line with related requirements for other L-band systems. In particular, it should be clarified whether it should be valid for all frequencies above 1 GHz or just over special sub-bands, e.g. around SSR/GPS/GALILEO channels. For the measurement method, please refer to Section 5.3.8.The broadband noise power density measured across the spurious domain (Figure 11) at the AS TX output when the TX terminated in a matched impedance load operates at full power (Section 6.3.2) shall not exceed -133 dBc/Hz.

6.3.10 Airborne TX Spectrum Mask

In the out-of-band domain, the spectral density of the LDACS signal transmitted by an AS TX shall fall within the spectral mask defined in Section 5.3.7 (Figure 11 and Table 3).

For further details, including the measurement method, please refer to Section 5.3.7.

The preliminary LDACS TX spectral mask as specified in this specification may have to be adjusted, based on the laboratory measurements using real radio equipment.

6.3.11 Airborne TX Time-Amplitude Profile

The ramp-up/ramp-down behaviour of the RL RF burst is determined by the RC windowing function (Section 8.8.1). Therefore, the ramp-up/ramp-down time roughly corresponds to the window time T_W (12.8 µs) as defined in Section 8.4.1.

The RF RL burst duration is variable. The minimum RF burst duration corresponds to the length of a single synchronisation tile sent in the DC segment. Otherwise, dependent on the type of the RL transmission, the burst duration is determined by the duration of the RL RA frame, duration of the DC tile or the number/total duration of successive (in time) Data tiles allocated to that AS.

6.3.12 Airborne TX Closed-loop Power Control

To maintain at the GS a spectral power density consistent with the modulation and FEC rate used by each AS, the GS shall change the AS TX power through power correction messages (see Section 10.3.2.2).

This requirement applies as long as per sub-carrier power received on RL from a particular AS is above the threshold adjusted at the GS. Optionally, the GS may also change the AS assigned modulation and FEC rate, see Section 10.3.3.

An airborne TX shall accept GS power adjusting commands received by the AS on FL and correspondingly adjust the AS's RL transmit power when sending RL DC tiles, Data tiles and synchronisation tiles.

6.3.13 Airborne TX Open-loop Power Control

An airborne TX sending RL RA frames to the controlling GS should – whenever applicable – reduce its RL transmitting power below the declared maximum value (Section 6.3.3) by applying open-loop power correction.

The correction factor for increasing/decreasing AS TX power shall be derived according to the estimated RL link budget that in turn shall be calculated from the known GS EIRP and the FL S/N value provided by the airborne RX.

6.3.14 Airborne TX Switch-over Time

When commanded to switch the RL RF channel, an airborne LDACS TX synthesizer shall achieve the required frequency accuracy on the new channel within ≤ 0.5 ms referred to the moment when the switching command has been given.

6.4 AS Receiving Function

6.4.1 Airborne RX Reference Bit Error Rate

For the LDACS AS receiver, the reference corrected BER is 10^{-6}.

6.4.2 Maximal Tolerable Input Interference Power

LDACS AS receiver shall tolerate at its input a peak pulsed interference signal power of up to +30 dBm without damage.

Note: Such a high interference power level may cause signal interruptions or any other performance degradation within the receiver.

6.4.3 Airborne RX Sensitivity

LDACS minimum receiver sensitivity depends on the chosen coding and modulation scheme and shall comply with Table 8.

Note: The sensitivity level is defined as the power level measured at the receiver input when the bit error ratio (BER) is equal to 1×10^{-6} and all active sub-carriers are transmitted in the channel. In general, the requisite input power depends on the number of active sub-carriers of the transmission.

Table 8: LDACS minimum receiver sensitivity values

Modulation	Coding Rate of Convolutional Code (CC)	AS Receiver Sensitivity
QPSK	1/2	-104 dBm
QPSK	2/3	-102 dBm
QPSK	3/4	-101 dBm
16QAM	1/2	-98 dBm
16QAM	2/3	-95 dBm
64QAM	1/2	-93 dBm
64QAM	2/3	-90 dBm
64QAM	3/4	-89 dBm

Note: The sensitivity values in Table 8 assume a receiver noise figure of 6 dB.

Note: The sensitivity values in Table 8 assume absence of any source of interference except for thermal and receiver noise.

6.4.4 Airborne RX Filter

LDACS receive filter insertion loss should be less than 1 dB.

LDACS receive filter shall provide a rejection to ensure a sufficient protection from other relevant systems.

6.4.5 Airborne RX Selectivity

LDACS receiver selectivity shall comply with Table 9 and Figure 13.

Note: The receiver selectivity values comprise the complete LDACS receiver chain after the duplexer, i.e. the duplexer is not included.

Table 9: LDACS receiver selectivity values

Passband Ripple (±250 kHz)	within ± 1 dB
Attenuation @ ±300 kHz	> 6 dB
Attenuation @ ±400 kHz	> 40 dB
Attenuation @ ±500 kHz	> 70 dB
Attenuation @ ±750 kHz	> 80 dB
Attenuation @ ±1500 kHz	> 90 dB

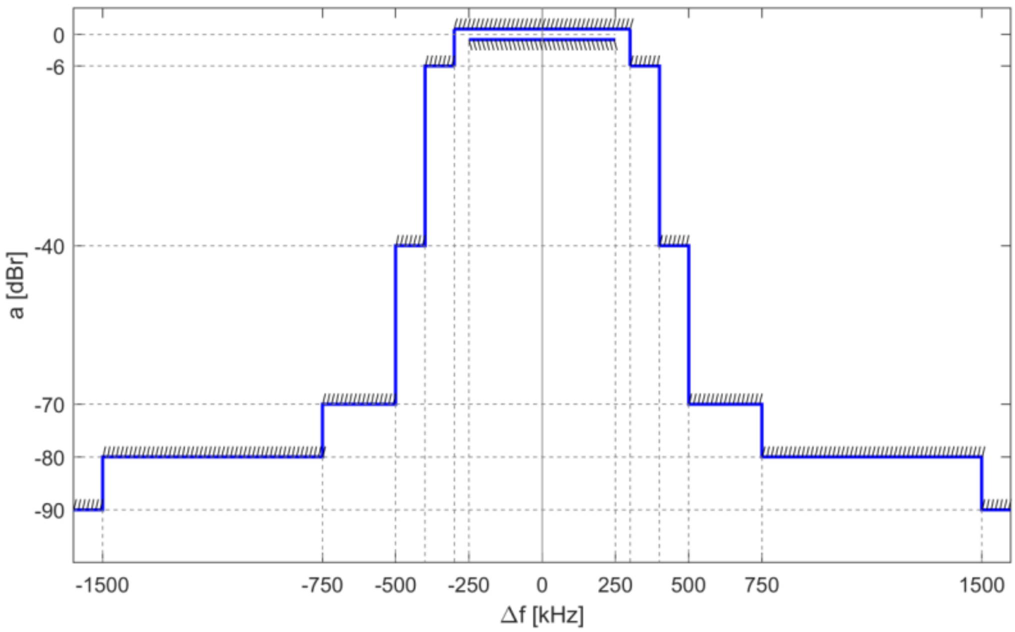

Figure 13: LDACS receiver selectivity.

6.4.6 Airborne RX Operating Point

When using all FL sub-carriers (N_{used} = N_u) with QPSK modulation, convolutional coding with r_{cc} = ½,interleaving and Reed-Solomon RS (101,91,5) coding in FL CC/Data frames, the airborne LDACS RX shall fulfil the BER specified under 6.4.1 when the signal S1[9] as defined in Table 10 is present at the RX input.

S1 defines the RX operating point – a minimum required RX input signal power under real interference conditions (cumulative L-band interference), considering an appropriate aeronautical channel and including safety margin and applicable banking margin.

Table 10: AS RX Operating Point S1 and Power Density Pd

Antenna Conversion	Unit	ENR	TMA	APT	Equation
Tx-Rx Distance	nm	120	40	10	d
Speed of Light	m/s	3E+08	3E+08	3E+08	c
Transmit mid-band frequency	MHz	1133	1133	1133	f
Wavelength	m	0.26	0.26	0.26	$\lambda = c / f$
Correction Factor	dB	-22.53	-22.53	-22.53	$CF = 10 * \log_{10} \frac{\lambda^2}{4 * \pi}$
Rx operating point (S1)	dBm	-98.03	-95.43	-92.73	S1
RX cable loss	dB	3	3	3	Lc_a
Duplexer loss	dB	1	1	1	Ld_a
Minimum RX Antenna gain	dBi	3	3	3	Lr_a
Required power at RX antenna	dBm	-98.03	-95.43	-92.73	$Pa=S_1+Lc_a-Lr_a$
Required power at RX antenna	dBW	-128.03	-125.43	-122.73	$Pa_1=Pa-30$
Spatial power density at RX antenna	dBW/m^2	-105.50	-102.90	-100.20	$Pd=Pa_1-CF$

Assuming fixed antenna gain and cable/duplexer losses, the AS RX operating point S1 for particular LDACS designed operational coverage (environment), is related to the minimum required signal power density Pd (dBW/m2) in front of the AS receive antenna.

[9] The S_1 value has been derived from the LDACS link budget in Appendix A - LDACS Link Budget and may have to be further adjusted.

Under above conditions, the AS RX operating in a corresponding environment shall provide the BER specified under 6.4.1 when the spatial power density at the AS RX antenna is equal to or greater than the Pd value specified in the last row of Table 10.

When calculating Pd, the conversion formula from ICAO Annex 10, Volume I, Attachment C, Section 7.2.1 has been used: Pd = Pa – 10$\log_{10}$(λ2/(4*π)), where Pd is the spatial power density (dBW/m2), Pa is the isotropic received power at the receiving point (dBW) and λ is the wavelength (m).*

When calculating the relation between Pd and the corresponding required signal power level S1 at the AS receiver input, the mid-range AS receiving frequency and the minimum available AS antenna gain towards the concerned GS have been assumed. The worst-case AS-GS antenna misalignment occurs in the TMA/APT environment (peak AS antenna gain of 0 dBi has been reduced by 5 dB in these environments). This reduction is the airborne contribution to the total GS-AS antenna misalignment loss (7 dB) that was used in TMA/APT link budget calculations.

6.4.7 Airborne RX Interference Immunity Performance

The LDACS receiver shall be able to receive the desired LDACS signal in the presence of undesired signals received from other L-band sources at power levels that may exceed the power of the desired signal. This receiver feature is highly dependent on the frequency offset between the desired and undesired signal channels.

The interference immunity performance cannot be stated based on the currently available LDACS parameters. Instead, it should be measured in the laboratory on LDACS AS RX prototype.

It is expected that the interference immunity will be assessed as Interference Rejection (IR) dependent on the frequency spacing between involved systems.

The Interference Rejection (IR) represents the power difference (in dB) between the interfering undesired signal (U) at specified frequency offset from the LDACS channel and the on-channel desired LDACS signal, for specified desired signal level (D) and specified reference BER (Section 6.4.1).

IR shall be measured by setting the desired LDACS signal's power to the level "D" (dBm) equal to the operating point S1 that is 6 dB above the rate dependent receiver sensitivity S0 (as specified in 6.4.3) and raising the power level "U" (dBm) of the interfering signal until the target BER (as specified in 6.4.1) is obtained.

IR shall be separately assessed and declared for each applicable type of interfering signal (e.g. DME, SSR, UAT, GSM/UMTS, RSBN, JTIDS/MIDS). Each interfering signal must be specified in terms of its operating frequency (or frequency offset to the LDACS channel), peak power, and duty-cycle.

Table 7 illustrates one example of stating IR for a particular interfering L-band system "X". IR is frequency-dependent and shall be stated for different frequency offsets between the desired LDACS signal and undesired interference signal.

IR shall be measured by setting the desired LDACS signal's power to the level "D" (dBm) that is "m" dB (e.g. 6 dB) above the rate dependent receiver sensitivity S0 (as specified in 6.4.3) and raising the power level "U" (dBm) of the interfering signal until the error rate (as specified in 6.4.1) is obtained.

IR should be separately assessed and declared for all applicable types of interfering signals (e.g. DME, SSR, UAT, GSM/UMTS, RSBN, JTIDS/MIDS). Each interfering signal must be specified in terms of its operating frequency (or frequency offset to the LDACS signal), peak power, and duty-cycle.

6.4.8 Airborne RX Maximum Desired Signal

The AS receiver shall be capable of decoding on-channel desired LDACS signal with a peak instantaneous power of –10 dBm (measured at the RX input).

A GS operating with +41 dBm average TX power would produce -29.5 dBm average power at the RX input of an AS being on the ground at 100 m distance to the GS antenna, assuming 8 dBi ground antenna gain, 2 dB ground cable losses, free-space propagation, 3.5 dB airborne cable and duplexer losses as well as an 0 dBi gain airborne antenna. Assuming 17 dB provision for TX PAPR[10], the peak received LDACS signal power becomes -12.5 dBm (rounded-up to -10 dBm).

However, this preliminary value has been estimated by assuming free-space propagation model that does not necessarily apply to the airport environment and will need to be validated and confirmed.

6.4.9 Airborne RX Maximum Tolerable Input Signal Power

The airborne LDACS receiver shall tolerate at its input a peak pulsed interference signal power of +30 dBm without damage.

The strongest interference comes from an on-board DME interrogator. Assuming +63 dBm peak DME TX power, 3 dB DME cable losses, 3.5 dB LDACS RX airborne cable and duplexer losses as well as 35 dB antenna isolation (antennas on the same side of an aircraft), peak DME power at the LDACS RX input becomes +21.5 dBm. Additional 3.5 dB margin have been added to that value. The proposed value may have to be further adjusted.

Maximum safe RX input power has been stated at the RX input, without considering any RF filtering (or duplexer) between the antenna and the RX input. By using such filtering, the requirement upon the RX input robustness can be significantly relaxed.

6.4.10 Airborne RX Switchover Time

[10] In the practical implementation it should be able to reduce the maximum possible PAPR value with 50 OFDM sub-carriers (17 dB) by using PAPR reducing techniques (Section 8.7.2).

An airborne radio is requested by the controlling GS to regular scan FL broadcast frames (BC2 sub-frames, see Section 8.5.1.2) of adjacent non-controlling GSs operating on different RF channels.

When commanded to switch the FL RF channel, an airborne LDACS RX synthesizer shall achieve the required frequency accuracy on the new channel within ≤ 0.5 ms referred to the moment when the switching command has been given.

*This value has been specified based on current LDACS framing structure. During scanning the AS may be very close to its controlling GS and be instructed to scan BC2 frame of another GS that is up to 200 nm away. In this case the frames of such distant GS will arrive up to Tg = 1.23466 ms later than the frames of the controlling GS that determines the AS timing point. However, if the AS is at 200 nm distance from its controlling GS and is flying over adjacent GS, the BC2 frames of a close GS will arrive up to Tg = 1.23466 ms earlier than the frames of the controlling GS. The duration of the scanned BC2 frame itself is 3.12 ms. By considering 2*Tg = 2.4693 ms around the BC2 frame and the total duration of the BC frame of 6.72 ms, total time available for switching the channel frequency back and forth becomes 6.72 – 3.12 – 2.4693 = 1.1307 ms. Roughly one half of this time has been allocated for one-way frequency switching time.*

6.4.11 Airborne RX S/N Measurement

An airborne RX shall continuously measure and report S/N for FL frames received from the controlling GS. The S/N value shall be permanently updated and averaged after each new FL frame has been received from the controlling GS.

An airborne RX shall measure and report S/N over parts of FL BC2 frames received from the non-controlling GSs.

6.5 AS Frequency/Timing Requirements

6.5.1 AS Centre Frequency and Symbol Clock Accuracy

At the AS, the transmit centre frequency, the receive centre frequency and the sampling frequency shall be derived from the same reference oscillator.

The accuracy of the AS reference oscillator shall be ± 1 ppm or better.

6.5.2 AS to GS Frequency Synchronisation

Except when transmitting RL RA frames, the AS RL TX shall pre-adjust its centre frequency such that the deviation between the AS TX centre frequency and the GS RX centre frequency shall be less than 1% of the sub-carrier spacing[11].

This requirement has been taken-over from the WiMAX specification [802.16e].

During the synchronisation period, the AS shall acquire frequency synchronisation on FL within the tolerance[12] that is sufficient for satisfactory reception on the FL (sensitivity requirement, as specified in Section 6.4.3) before attempting any RL transmission.

The initial AS RX frequency synchronisation should be achieved via pairs of synchronisation symbols that repetitively occur within the FL stream of the controlling GS (marking the start of BC1/2/3 and Data/CC FL frames).

Detailed methods for frequency acquisition and tracking are an implementation issue. AS RX frequency tracking on FL is expected to be based on synchronisation sequences, but the AS RX may apply supplementary mechanisms for enhancing the FL frequency synchronisation performance, like pilot tones.

The initial AS RX frequency capture range shall be sufficient for accommodating both imperfect GS-AS reference frequency accuracy (Sections 5.5.4 and 6.5.1) and the maximum applicable GS-AS Doppler shift (1.7 kHz at 850 knots and 1156.5 MHz).

After an initial AS RL frequency correction by the GS, the AS shall track and correct for the changes of the FL centre frequency.

The AS frequency synchronisation maintenance should be based on observing the synchronisation symbol pairs that repetitively occur within the FL stream and are sent by the controlling GS. The AS RX may apply supplementary mechanisms to enhance the FL synchronisation maintenance.

When determining the AS TX centre transmit frequency, the AS shall consider the frequency offset corrections received from the GS.

If the AS is capable of estimating the RL frequency offset based on tracking the GS FL signal, it may add it to the frequency correction indicated by the GS.

If FL synchronisation is lost, the AS TX shall after configurable time defer any RL transmission.

6.5.3 AS to GS Time Tracking

Initial AS time synchronisation and time synchronisation maintenance should be based on observing the synchronisation symbol pairs that repetitively occur within the FL stream, being sent by the controlling GS.

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[11] The requirement as a whole would be supported via frequency corrections issued by the GS to the AS after an initial contact has been established.

[12] This tolerance needs not to be exactly specified – it will be indirectly confirmed via AS RX sensitivity check.

Detailed methods for time acquisition and tracking are an implementation issue. AS RX time tracking on FL is expected to be based on synchronisation sequences, but the AS RX may apply supplementary mechanisms for enhancing the FL frequency synchronisation performance, like pilot tones.

During the synchronisation period, the AS shall acquire time synchronisation on FL within the tolerance[13] that is sufficient for satisfactory reception on the FL (sensitivity requirement, as specified in Section 6.4.3) before attempting any RL transmission.

During the initial RL RA access, the AS TX shall directly apply its current FL SF timing for its RL RA transmission, without any timing pre-compensation.

After the timing correction has been received from the GS, the AS shall apply it for its subsequent RL transmissions. An AS shall maintain its RL SF timing such that all non-RA RL OFDMA symbols arrive at the GS time coincident with the local GS SF timing to an accuracy of ± 1/3 of the OFDM guard time T_g or better.

OFDM guard time T_g = 4.8 µs that is three times the sampling time T_{sa} = 1.6 µs (Section 7.4.1).

At zero timing advance and retard setting (without GS closed-loop timing control), the start of the first RL data symbol in a SF, when measured at the AS antenna port, shall be aligned in time with the nominal start of the GS SF to an accuracy of ± 1/3 of the OFDM guard time T_g or better.

After an initial timing correction, an AS shall track the differential changes of the GS FL and shall fine adjust its own RL timing to compensate for these changes. This tracking should be based on observing the earliest arrival path of the FL synchronisation symbols.

[13] This tolerance needs not to be exactly specified – it will be indirectly confirmed via AS RX sensitivity check.

7 LDACS Protocol Services and Interfaces

This chapter deals with services of LDACS functional blocks above the PHY layer as well as with interfaces between these functional blocks. The description provided here is based on the LDACS protocol architecture as provided in Section 3.2.7. For better clarity, the LDACS protocol stack representation (Figure 6) from Section 3.2.7 is replicated in this section as well (Figure 14).

The description is covering the LDACS A/G mode of operation.

The LDACS PHY layer is described in detail in CHAPTER 7. Details about LDACS MAC, LME, DLS, VI, and SNP entities are provided in CHAPTER 8, CHAPTER 9, CHAPTER 11, CHAPTER 12, and CHAPTER 12 respectively.

NOTE: In the following, the term "Aircraft" has the same meaning as "Aircraft Station" or "AS".

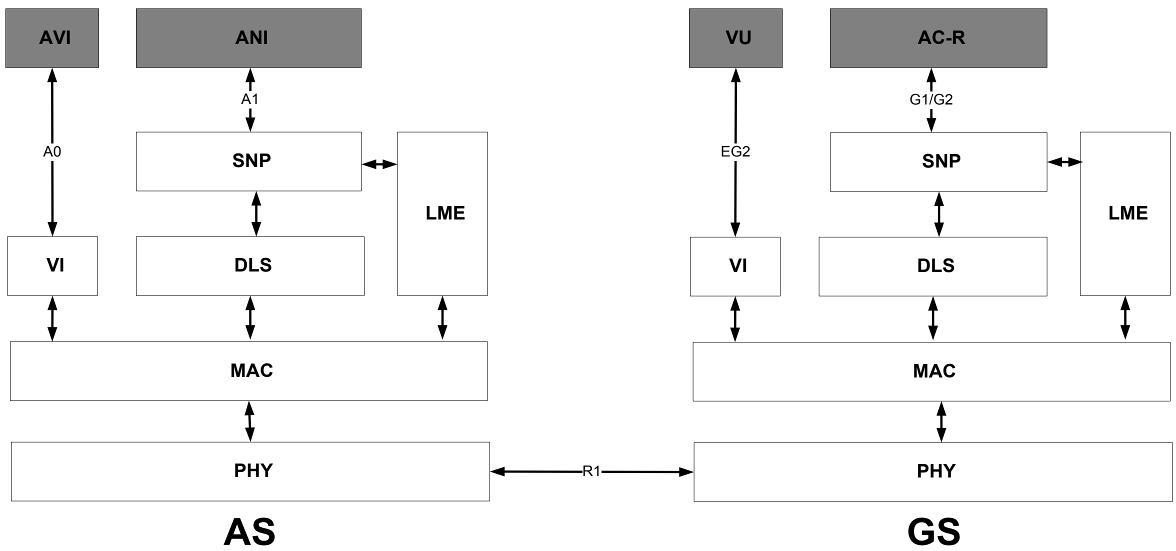

Figure 14: LDACS Protocol Suite in the AS and GS

7.1 Services of the Data Link Layer and Sub-Network Protocol

7.1.1 Medium Access Control (MAC) Entity Services

7.1.1.1 MAC Time Framing Service

The MAC time framing service provides the frame structure necessary to realise slot-based time division multiplex (TDM) access on the physical link. It provides the functions for the synchronisation of the MAC framing structure and the PHY layer framing. The MAC time framing provides a dedicated time slot for each logical channel.

7.1.1.2 Medium Access Service

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.

7.1.2 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.

7.1.3 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.

7.1.4 LDACS Management Entity (LME) Services

7.1.4.1 Mobility Management Service

The mobility management service provides support for registration and de-registration (cell entry and cell exit), scanning RF channels of neighbouring 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.

7.1.4.2 Resource Management Service

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

7.1.5 Sub-Network Protocol (SNP) Services

7.1.5.1 Data Link Service

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

7.1.5.2 Security Service

The security service shall provide 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.

7.2 LDACS Internal Interfaces

The interface between the functional blocks of the LDACS system shall be realised via service primitives.

There are three types of interface service primitives: Requests, responses, and indications. Requests may have responses reporting the result of the request (similar to a blocking function call). Indications may be raised without a request (similar to asynchronous events).

7.2.1 PHY Service Primitives

The interface of the PHY layer towards the DLL shall be realised by the primitives shown in Table 11.

Table 11: Physical Layer Interface

Primitive	SAP	Request/Response	Indication
PHY_FSCAN	P_SAPC	X	
PHY_GSCAN	P_SAPC	X	
PHY_CONF	P_SAPC	X	X
PHY_RDY_TO_SCAN	P_SAPC		X
PHY_BC	P_SAPD	X	X
PHY_RA	P_SAPD	X	X
PHY_CC	P_SAPD	X	X
PHY_DC	P_SAPD	X	X
PHY_DATA	P_SAPD	X	X
PHY_RTX_BC	P_SAPT		X
PHY_RTX_RA	P_SAPT		X
PHY_RTX_CC	P_SAPT		X
PHY_RTX_DC	P_SAPT		X
PHY_RTX_DATA	P_SAPT		X
PHY_FLSYNC	P_SAPS		X
PHY_SYNC	P_SAPS	X	X

7.2.1.1 PHY Time Framing Service (PHY_RTX)

The time framing for the PHY data transmission service is offered via the physical layer service access point T (P_SAPT).

The PHY_RTX_* primitives shall be used to indicate that the PHY layer is ready to transmit in the given slot (BC, RA, CC, DC, and FL/RL DATA). The PHY_RTX primitives shall be used to indicate the PHY layer framing and timing to the MAC time framing service.

7.2.1.2 Medium Access (PHY_BC, PHY_RA, PHY_CC, PHY_DC, and PHY_DATA)

The PHY data transmission service is offered via the physical layer service access point D (P_SAPD).

The PHY_BC, PHY_RA, PHY_CC, PHY_DC, and PHY_DATA primitives shall be used to request to send data via the given physical layer slot. The result of the sending operation is reported in the appropriate response.

When data is received in the given slot the received information shall be indicated via the PHY_BC, PHY_RA, PHY_CC, PHY_DC, and PHY_DATA primitives.

7.2.1.3 Aircraft Synchronisation (PHY_SYNC, PHY_FLSYNC)

The PHY time and frequency synchronization service is offered via the physical layer service access point S (P_SAPS).

The PHY_SYNC primitives shall be used by the AS to request the transmission of a physical layer synchronisation sequence in the DC slot. The result of the sending operation is reported in the appropriate response. When a synchronization sequence is received in the GS, this shall be indicated by the same primitive.

The PHY_FLSYNC primitive shall indicate the PHY layer synchronisation status to the AS.

7.2.1.4 Aircraft PHY Configuration (PHY_CONF)

The PHY configuration service is offered via the physical layer service access point C (P_SAPC).

The PHY_CONF.req primitives shall be used to select the RF channel, adjust the time advance, the frequency offset and the transmit power in the AS.

The PHY_CONF.ind primitive shall be used to indicate a change of PHY parameters (e.g., measured received power).

7.2.1.5 Ground-Station PHY Configuration (PHY_CONF)

The PHY_CONF.req primitive shall be used to set PHY parameters.

The PHY_CONF.ind primitive shall be used to indicate a change of PHY parameters (e.g., measured received power).

7.2.1.6 Aircraft Fast Scanning of Neighbour Cells (PHY_FSCAN)

The PHY_FSCAN primitives shall be used by the AS MAC to initiate the fast scanning procedure in the AS PHY.

7.2.1.7 GS Controlled Scanning of Neighbour Cells (PHY_GSCAN)

The PHY_GSCAN primitive shall be used by the AS MAC to request the GS controlled scanning of a given LDACS frequency for the preparation of a handover. It shall indicate the received power on FL and the first fully decoded FL BC PHY-PDU.

7.2.1.8 Receiving the FL in the Aircraft

When the PHY layer has decoded a BC frame, CC frame or DATA frame, it shall indicate this to the MAC sub-layer using the PHY_BC, PHY_CC or PHY_DATA primitives.

In the cell-specific ACM mode, the FL PHY layer is configured by the MAC sub-layer to use the cell-specific coding and modulation scheme of the received data.

In the user-specific ACM mode, the FL PHY layer shall be configured according to the CMS FL MAP. The CMS FL MAP contains information on the used coding and modulation schemes. The physical layer shall use this information to decode the received data and transfer it to the MAC sub-layer as described above.

The decoded CC packets shall be delivered to the MAC sub-layer prior to the start of the next DC slot, since the information in this DC slot depends on the information conveyed in the CC slot.

7.2.1.9 Transmitting on the RL in the Aircraft

Before transmitting an RA frame, a DC frame or a data frame, the PHY layer shall indicate the transmission opportunity to the MAC sub-layer using the PHY_RTX_RA, PHY_RTX_DC, and PHY_RTX_DATA indications.

In the case that not all RL PHY-PDUs are used by the same AS, the MAC sub-layer shall provide RL PHY-SDU numbers. In the user-specific ACM mode the MAC sub-layer shall also signal the used coding and modulation scheme to the PHY.

7.2.1.10 Receiving the RL in the Ground-Station

When the PHY layer has decoded an RA frame, DC frame or DATA frame, it shall indicate this to the MAC sub-layer using the PHY_RA, PHY_DC, and PHY_DATA primitives.

In the user-specific ACM mode, the PHY layer shall be configured in advance by the MAC sub-layer for the decoding and demodulation scheme of the users' RL PHY-PDUs.

7.2.1.11 Transmitting on the FL in the GS

Before transmitting a BC frame, a CC frame or a DATA frame, the PHY layer shall indicate the transmission opportunity to the MAC sub-layer using the PHY_RTX_BC, PHY_RTX_CC, and PHY_RTX_DATA primitives.

In the cell-specific ACM mode, the MAC sub-layer shall configure the PHY layer for the cell-specific coding and modulation.

In user-specific ACM mode, the MAC sub-layer shall configure the coding and modulation parameters of the individual coding blocks.

7.2.1.12 Ready to Scan Indication (PHY_RDY_TO_SCAN)

The PHY_RDY_TO_SCAN primitive shall inform the AS MAC about the beginning of the BC slot. This primitive is needed for invoking the GS controlled scanning procedure.

7.2.2 MAC Service Primitives

The MAC sub-layer offers services to the LME through the service access point M_SAPR for RACH data, the service access point M_SAPB for BCCH data, the service access point M_SAPC for CCCH data and DCCH data, and the service access point M_SAPI for configuration procedures.

The MAC sub-layer offers services to the DLS through the service access point M_SAPC for CCCH data and DCCH data, and the M_SAPD for user and control plane data on the DCH.

The interface of the MAC entity towards its service users shall be realised by the primitives shown in Table 12.

Table 12: Medium Access Control Entity Interface

Primitive	SAP	Request/Response	Indication
MAC_CONNECT	M_SAPI	X	
MAC_FSCAN	M_SAPI	X	
MAC_CSCAN	M_SAPI	X	
MAC_GSCAN	M_SAPI	X	
MAC_CC_STATUS	M_SAPI	X	
MAC_SYNC	M_SAPI		X
MAC_OPEN	M_SAPI	X	
MAC_HO2	M_SAPI	X	
MAC_BCCH	M_SAPB	X	X
MAC_RACH	M_SAPR	X	X
MAC_DCCH	M_SAPC	X	X
MAC_CCCH	M_SAPC	X	X
MAC_DCH	M_SAPD	X	X

7.2.2.1 MAC Control (MAC_CONNECT, MAC_OPEN and MAC_HO2)

The MAC time framing service is managed via the medium access service access point I (M_SAPI).

The MAC_CONNECT primitives shall be used to configure the MAC sub-layer for a given physical channel. Configuration information for the AS is announced by the GS on the broadcast control channel (BCCH). If the MAC has successfully opened a connection to a GS, the MAC logical channels are established.

The MAC_OPEN primitive shall be used by the AS LME to transit its MAC into the OPEN state.

The MAC_HO2 primitive shall be used by the AS LME to transit its MAC into the HO 2 state.

7.2.2.2 Aircraft Fast Scanning of Neighbour Cells (MAC_FSCAN)

The MAC_FSCAN primitive shall be used by the AS LME to request the AS MAC to fast scan the LDACS radio channels. In FSCAN state the MAC will fast scan all known LDACS frequencies and indicate the received power to the LME.

7.2.2.3 AS Controlled Scanning of Neighbour Cells (MAC_CSCAN)

The MAC_CSCAN primitive shall be used by the AS LME to request the AS MAC to scan a given active frequency for a valid LDACS signal and the GS properties.

7.2.2.4 GS Controlled Scanning of Neighbour Cells (MAC_GSCAN)

The MAC_GSCAN primitive shall be used by the AS LME to request the AS MAC to scan the indicated frequency for the preparation of a handover. After scanning, the physical layer is restored to its previous configuration to retain connectivity with the current GS.

7.2.2.5 Aircraft Synchronization (MAC_SYNC)

The MAC_SYNC.req primitive shall be used by the AS LME to request the transmission of a synchronisation tile from the AS MAC.

The MAC_SYNC.ind primitive shall be used by the GS MAC to inform the GS LME that a RL synchronisation tile has been received. RL synchronisation tiles are used for link maintenance and the MAC_SYNC.ind shall report the time offset and frequency offset of the AS – as measured by the GS PHY - to the GS LME.

7.2.2.6 CC Status Report (MAC_CC_STATUS)

The MAC_CC_STATUS primitive shall be used by the GS LME to request the current size of the CC transmission buffer.

7.2.2.7 Access to Logical Channels

The MAC medium access service is offered via the medium access service access points B, R, C, and D (M_SAPB, M_SAPR, M_SAPC, and M_SAPD).

The MAC_BCCH, MAC_RACH, MAC_DCCH, MAC_DCH, MAC_VCH and MAC_CCCH primitives shall be used to request and indicate transmissions on the according logical channel.

NOTE: The voice samples shall be transmitted in the FL or RL DATA slot of the PHY layer. So, they shall be transferred from the VI entity to its MAC entity by issuing the MAC_DCH primitives.

7.2.3 DLS Service Primitives

The interface of the DLS entity towards LME shall be realised by the primitives shown in Table 13.

The DLS_DATA and DLS_UDATA primitives shall also be offered as an Interface of the DLS towards the SNDCP.

Table 13: Data Link Service Interface

Primitive	SAP	Request/Response	Indication
DLS_DATA	D_SAPD	X	X
DLS_UDATA	D_SAPD	X	X
DLS_OPEN	D_SAPC	X	

DLS_CLOSE	D_SAPC	X	

7.2.3.1 Acknowledged Data Link Service (DLS_DATA)

The DLS data link service shall be offered via the DLS service access point D (D_SAPD).

The DLS_DATA primitives shall be used by the DLS to request and indicate an acknowledged data transfer.

7.2.3.2 Unacknowledged Data Link Service (DLS_UDATA)

The DLS_UDATA primitives shall be used by the DLS to request and indicate an unacknowledged user data transfer.

The DLS broadcast data link service shall only be available in the GS. It shall use the DLS_UDATA primitives in combination with the AS Sub-net Access Code (AS SAC) broadcast address.

The DLS_UDATA primitives shall be also used for the transfer of packet voice Service Data Units (SDUs) (VoIP). The packet mode voice service shall use the DLS_UDATA primitives in combination with the DLS_CoS_6 service class (which is reserved for this service).

7.2.3.3 Data Link Service Control (DLS_OPEN and DLS_CLOSE)

DLS data link service control shall be offered via the DLS service access point C (D_SAPC).

The DLS_OPEN and DLS_CLOSE primitives shall be used by the LME to control the state of the data link service. When in closed state, the DLS shall ignore all service requests.

7.2.4 LME Service Primitives

The interface of the LME towards its service users shall be realised by the primitives shown in Table 14.

Table 14: LDACS Management Entity Interface

Primitive	SAP	Request/Response	Indication
LME_VC_CONF	L_SAPV	X	
LME_OPEN	L_SAPC	X	
LME_CONF	L_SAPC	X	
LME_STATE	L_SAPC		X
LME_R	L_SAPR	X	

NOTE: The LME_R primitive shall also be used to indicate the permanent resource allocation to the VI entity.

7.2.4.1 Link Configuration (LME_CONF)

The LME configuration shall be offered via the LME service access point C (L_SAPC).

The LME_CONF primitives shall be used to configure LDACS (data link layer and physical layer).

7.2.4.2 Link Control (LME_OPEN)

The LME_OPEN primitive shall be used to activate LDACS AS radio.

7.2.4.3 Link State (LME_STATE)

The LME_STATE primitive shall be used to indicate the LDACS A/G link state to the higher layers.

Note: LME_STATE shall enable the higher layers to identify when an AS has left or joined an LDACS cell or get indications of the current link quality.

7.2.4.4 Voice Service Configuration (LME_VC_CONF)

The LME voice configuration shall be offered via the LME service access point V (L_SAPV).

The LME_VC_CONF primitives shall be used to request the configuration of new circuit voice channels (dedicated and on-demand channels).

7.2.4.5 Radio Resource Management (LME_R)

The LME resource management service shall be offered via the LME service access point R (L_SAPR).

The LME_R primitives shall be used within the GS for the resource requests of the FL.

7.2.4.6 External Users of LME Service

Both airborne and ground LME are controlled by external Radio Control Units (RCU), therefore, above primitives are exchanged between the LME and its local RCU.

7.2.5 VI Service Primitives

The interface of the VI towards its service users shall be realised by the primitives shown in Table 15.

Table 15: VI Interface

Primitive	SAP	Request/Response	Indication
VI_VOICE	V_SAPV	X	X
VI_OVERRULE	V_SAPV		X
VI_OPEN	V_SAPC	X	
VI_CLOSE	V_SAPC	X	

7.2.5.1 Dedicated Circuit Voice Service (VI_VOICE and VI_OVERRULE)

The VI voice service shall be offered via the VI service access point V (V_SAPV).

The VI_VOICE primitives shall be used to request and indicate the transfer of an AMBE ATC 10B vocoder voice sample on the selected voice channel.

The VI_OVERRULE primitives shall be used in the AS to indicate that the GS has pre-empted the AS for a higher prioritized ground voice user on the selected dedicated voice channel.

7.2.5.2 Demand Assigned Circuit Voice Service (VI_VOICE)

The VI_VOICE primitives shall be used to request and indicate the transfer of AMBE ATC10B vocoder voice samples on the selected voice channel.

7.2.5.3 Voice Interface Control (VI_OPEN and VI_CLOSE)

The VI configuration shall be offered via the VI service access point C (V_SAPC).

The VI_OPEN and VI_CLOSE primitives shall be used to control the state of the voice interface. When in closed state, the VI shall ignore all service requests.

7.2.5.4 External Users of VI Service

Both airborne and ground VIs are attached to external Voice Units (VU), therefore, above primitives are exchanged between the VI and its local VU.

The VI_VOICE primitive shall be used to request the transfer of voice samples. If an airborne transmission is pre-empted, this is reported by the VI_OVERRULE primitive to the airborne VU.

7.2.6 SNP Service Primitives

The interface of the SNP towards its service users shall be realised by the primitives shown in Table 16.

Table 16: Sub-Network Protocol Interface

Primitive	SAP	Request/Response	Indication
SN_DATA	SN_SAPD	X	X
SN_UDATA	SN_SAPD	X	X
SN_CONF	SN_SAPC	X	

7.2.6.1 Acknowledged Data Link Service (SN_DATA)

The SN data link service shall be offered via the SN service access point D (SN_SAPD).

The SN_DATA primitives shall be used to request and indicate an acknowledged user data transfer.

7.2.6.2 Unacknowledged Data Link Service (SN_UDATA)

The SN_UDATA primitives shall be used to request and indicate and unacknowledged user data transfer.

7.2.6.3 Sub-Network Configuration (SN_CONF)

The SN configuration shall be offered via the SN service access point C (SN_SAPC).

The SN_CONF primitives shall be used to request the configuration of the SN data link and security services.

7.2.7 Aircraft Interface

Figure 15 shows LDACS protocol entities applicable to an LDACS AS, together with service primitives and Service Access Points (SAPs).

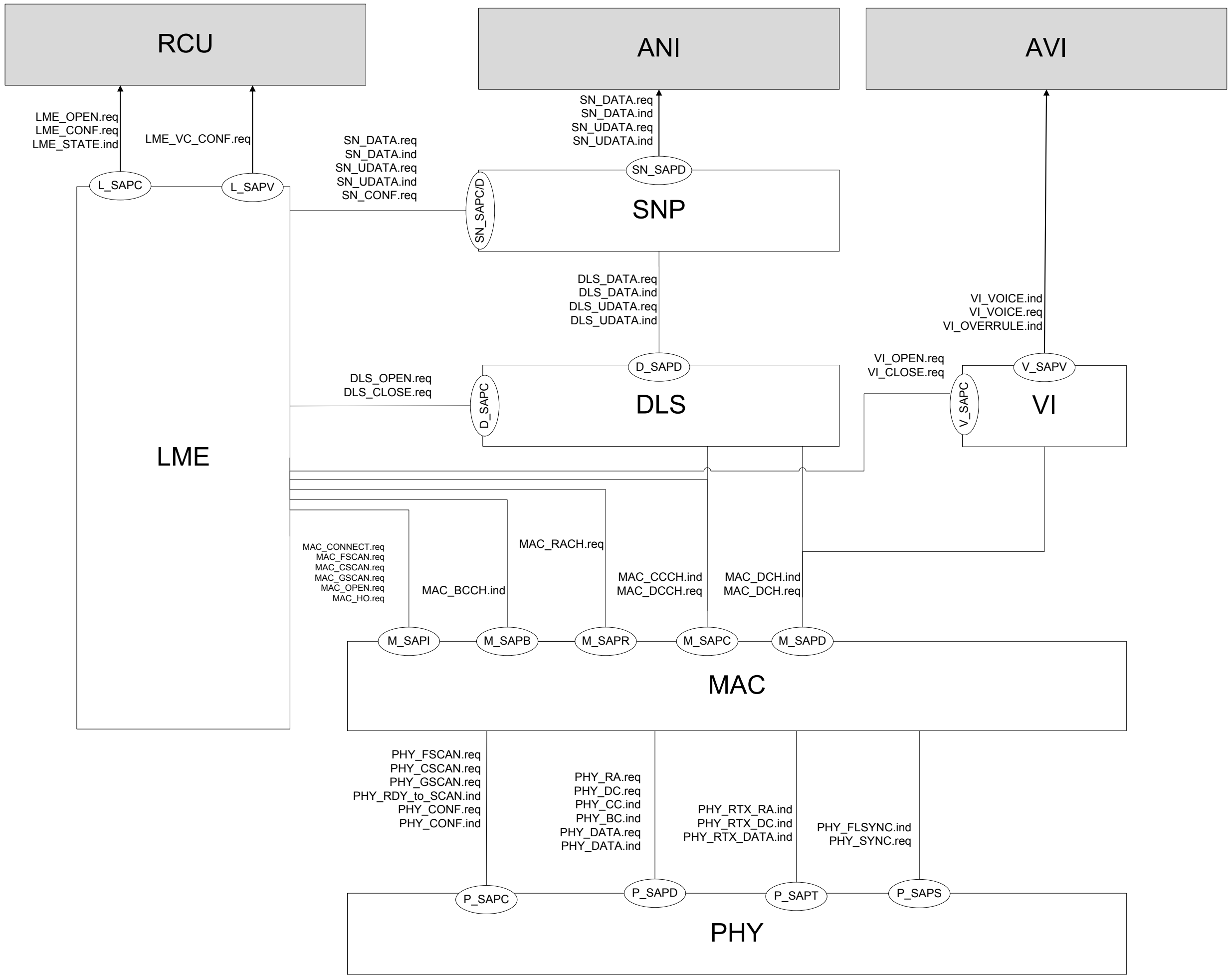

Figure 15: LDACS Interfaces in the Aircraft Station

7.2.8 Ground-Station Interface

Figure 16 shows LDACS protocol entities applicable to an LDACS GS, together with service primitives and SAPs.

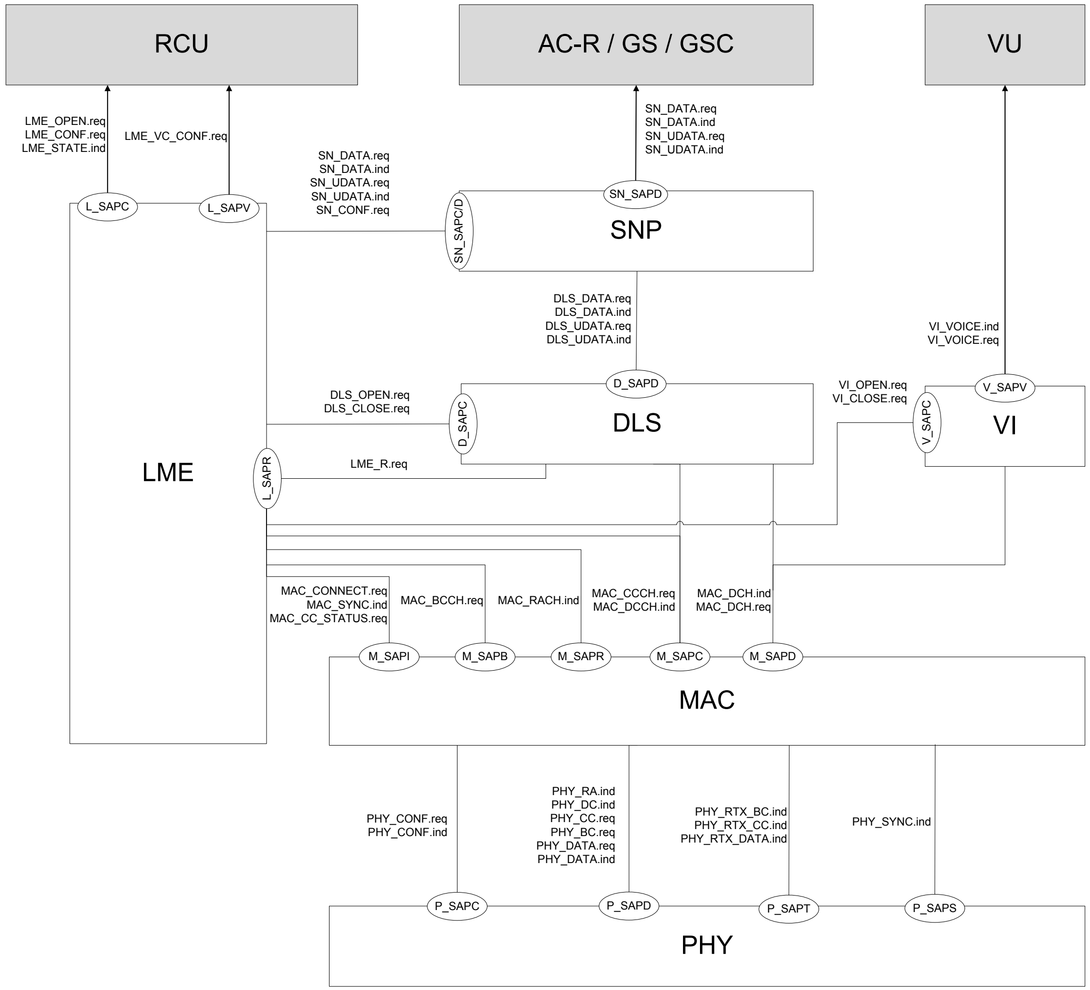

Figure 16: LDACS Interfaces in the GS

8 Physical Layer Protocols and Services

8.1 Physical Layer Characteristics

The LDACS physical layer (PHY) is based on OFDM modulation and designed for operation in the aeronautical L-band (960 –1164 MHz). In order to maximise the capacity per channel and optimally use available spectrum, LDACS is defined as a FDD system supporting simultaneous transmission in the Forward Link (FL) and the Reverse Link (RL) channels, each with an occupied bandwidth of 498.05 kHz.

LDACS FL PHY is a continuous OFDM transmission. Broadcast and addressed user data are transmitted on a (logical) data channel, dedicated control and signalling information is transmitted on (logical) control channels. The capacity/size of the data and the control channel changes according to system loading and service requirements. Message based adaptive transmission data profiling with adjustable modulation and coding parameters is supported only for the data channel.

LDACS RL transmission is based on OFDMA-TDMA bursts assigned to different users on demand. In particular, the data and the control segments are divided into tiles, enabling the MAC sub-layer of the Data Link Layer the optimisation of the resource assignments as well as the bandwidth and duty cycle reduction, according to the interference conditions.

8.2 FL – OFDM Transmission

8.2.1 Frequency Domain Description

The typical structure of an FL OFDM symbol in the frequency domain is depicted in Figure 17.

An FL OFDM symbol consists of N_{FFT} sub-carriers, which can be occupied by:

- Null symbols i.e. unmodulated sub-carriers in guard bands, the DC sub-carrier, and inactive sub-carriers,
- Data symbols, used for transmission of user data,
- Pilot symbols, used for channel estimation purposes,
- Synchronisation symbols, occupied by synchronisation sequences.

As guard bands, $N_{g,left}$ sub-carriers on the left and $N_{g,right}$ sub-carriers on the right side of the signal spectrum are used. Taking one DC sub-carrier into account, this results in N_u sub-carriers used for data symbols, pilot symbols and synchronisation sequences.

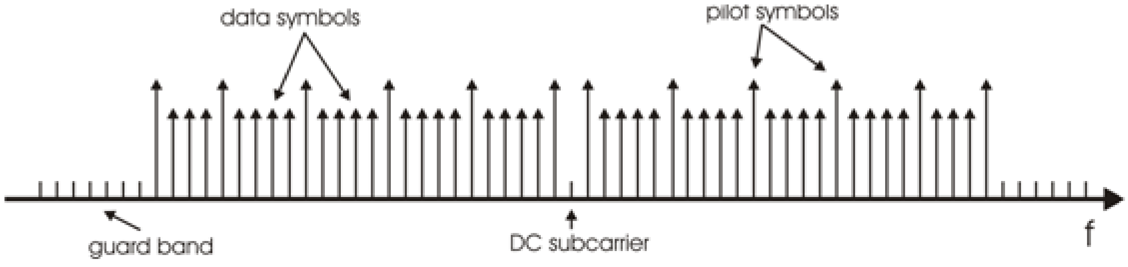

Figure 17: OFDM Symbol, Frequency Domain Structure

8.2.2 Time Domain Description

The inverse Fourier transform of a frequency domain OFDM symbol creates the OFDM time domain waveform. The duration of this signal is referred to as the useful symbol time T_u. A copy of the last T_{cp} of the useful symbol period, termed cyclic prefix (CP), is added in front of the useful symbol period. A T_w part of this CP is used for windowing; a T_g part provides a tolerance for symbol time synchronisation errors and resistance to intersymbol interference (ISI). In addition to the cyclic prefix, a cyclic postfix of length T_w is added. For applying windowing, the cyclic postfix and a T_w part of the cyclic prefix are multiplied with a decaying window. Finally, the OFDM symbols are stringed together, whereby the postfix of an OFDM symbol overlaps with a T_w part of the CP of the subsequent OFDM symbol. Figure 18: shows this procedure in two steps. The windowing method is addressed in Section 8.8.1.

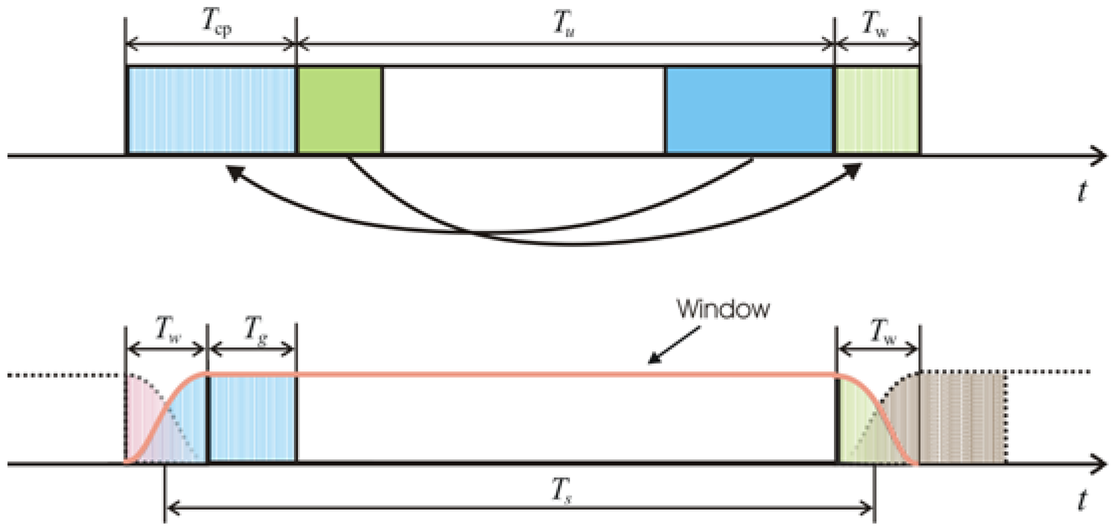

Figure 18: OFDM Symbol, Time Domain Structure

8.3 RL – OFDMA-TDMA Transmission

8.3.1 Frequency Domain Description

Except for RL RA frames, the time-frequency domain is segmented into tiles assigned to different ASs.

A tile carries data, pilot, and PAPR reduction symbols and spans a half of the total number of sub-carriers available in the RL (25 contiguous sub-carriers) and six contiguous OFDM symbols. This structure allows two users to share the effective LDACS RL bandwidth in an OFDMA transmission. The OFDMA structure in the RL is clarified in Figure 19. The tile structure is further defined in Section 8.5.2.1.

Tiles as defined above are the main building block for RL DC segments and are also used to build up RL data segments. In addition to these tiles, the RL DC segment also comprises a special synchronisation tile and an AGC preamble (Section 8.5.2.2).

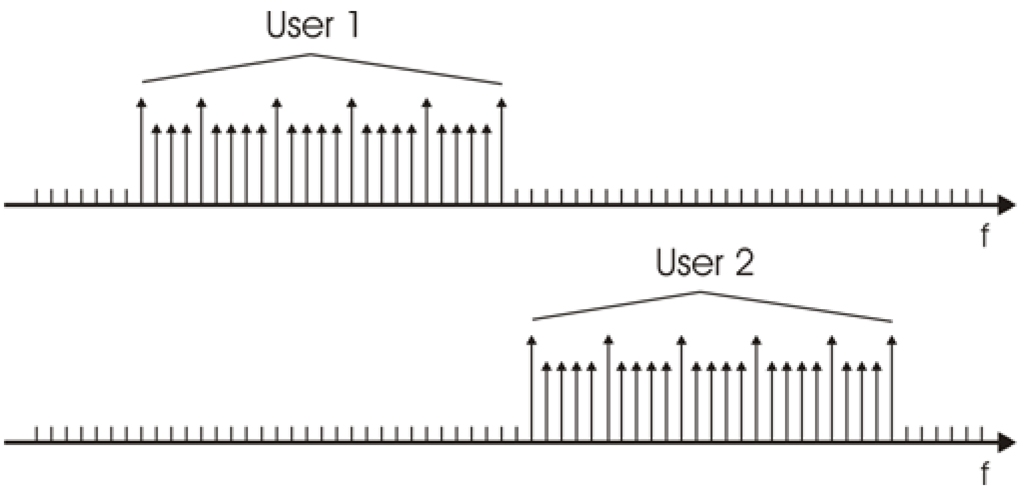

Figure 19: OFDMA Structure in the RL

In addition to tiles, RL RA frames and DC segments comprise also AGC preambles and synchronization sequences.

8.3.2 Time Domain Description

In the RL, each involved AS creates separately its time domain OFDM symbol as described in Section 8.2.2. In an OFDMA transmission, the GS receives a superposition of two separate time domain signals, requiring a synchronous reception of symbols of these two ASs in time and frequency, as well as power alignment between these two ASs.

One tile is assigned to only one AS, but the following tile in the time direction may already be used by another AS. Thus, subsequent received OFDM symbols belonging to different tiles can carry data from different ASs.

8.4 PHY Layer Parameters

8.4.1 OFDM Parameters

The parameters summarised in Table 17 are valid both in the FL and in the RL.

Table 17: OFDM Parameters

FFT size: N_{FFT}	64
Sampling time: T_{sa}	1.6 µs
Sub-carrier spacing: Δf	9.765625 kHz
Useful symbol time: T_u	102.4 µs
Cyclic prefix ratio: G	11/64
Cyclic prefix time: T_{cp}	17.6 µs
OFDM symbol time: T_s	120 µs

Guard time: T_g	4.8 µs[14]
Windowing time: T_w	12.8 µs
Number of used sub-carriers: N_u	50
Number of lower frequency guard sub-carriers: $N_{g,left}$	7
Number of higher frequency guard sub-carriers: $N_{g,right}$	6
Sub-carrier indices of guard sub-carriers	-32, -31, …, -26 26, 27, …, 31
Sub-carrier indices of pilot sub-carriers	Defined in Table 18, Table 19 and Table 20 for the FL and in Table 21, Table 22, Table 23 and Table 24 for the RL
Sub-carrier indices of PAPR sub-carriers	-24, 23, only in the RL tiles

8.4.2 LDACS RF Channel Bandwidth

The total FFT bandwidth is $B_0 = N_{FFT} \cdot \Delta f = 625.0$ kHz. Due to the guard bands, an effective RF bandwidth of $B_{occ} = (N_u+1) \cdot \Delta f = 498.05$ kHz is obtained, that includes the DC sub-carrier. B_{occ} represents the occupied RF channel bandwidth on both the FL and the RL.

8.5 Physical Frame Characteristics

OFDM symbols are organised into OFDM frames. Depending on the data to be transmitted different types of OFDM frames are defined, as described in the following sections. All frame types can be figuratively represented with symbols in a time-frequency plane.

Symbol positions are noted with (t, f) indices, where the time index t takes the values between 1 and N_{OFDM}, with N_{OFDM} being the total number of OFDM symbols within one frame. The frequency index f takes values between -32 and 31 with f = 0 representing the DC sub-carrier. The numbering starts with the guard symbol in the upper left corner with the symbol position (1,-32) as illustrated in Figure 20:.

[14] This value must be confirmed with realistic tests representing the most critical real environments.

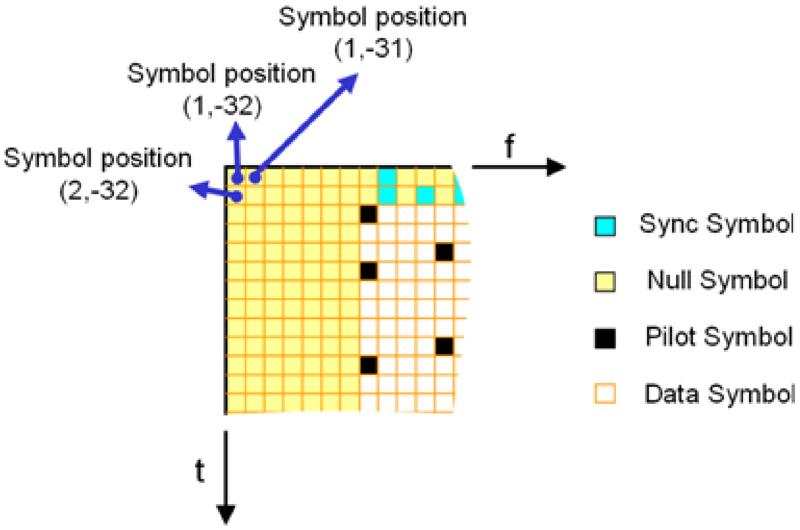

Figure 20: Numbering of the Symbols in the Time-Frequency Plane

8.5.1 Forward Link Frame Types

8.5.1.1 FL Frame

The structure of an FL frame is depicted in Figure 21: It contains 54 OFDM symbols resulting in a frame duration of $T_{DF/CC}$ = 6.48 ms.

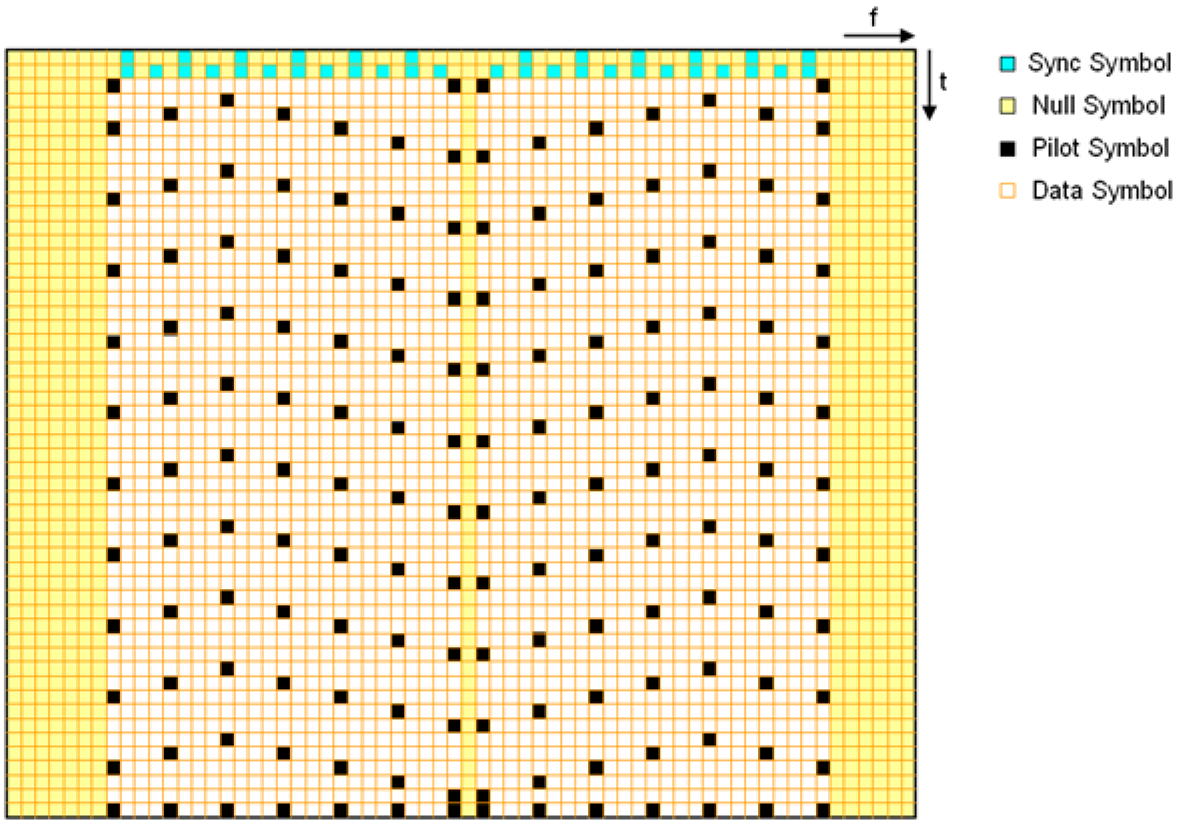

Figure 21: Structure of an FL Frame

The first two OFDM symbols contain synchronisation sequences. The remaining 52 OFDM symbols contain data symbols as well as pilot symbols. The assignment of either user data or CC information onto the provided symbols is described in Section 8.5.3.1.

The pilot pattern is depicted in Figure 21: and described in Table 18. Apart from the first and last OFDM symbol in the frame, the pilot pattern repeats every 5 OFDM symbols. The total number of 158 pilot symbols leads to a total data capacity of (52*50 – 158) = 2442 symbols per FL frame.

Table 18: Pilot Symbol Positions for FL Frame

OFDM symbol position n		Pilot symbol positions
n = 3		-25, -1, 1, 25
n = 3+5·p + i, p = 0, .., 9	i = 1	-17, 17
	i = 2	-21, -13, 13, 21
	i = 3	-25, -9, 9, 25
	i = 4	-5, 5
	i = 5	-1, 1
n = 54		-25, -21, -17, -13, -9, -5, -1, 1, 5, 9, 13, 17, 21, 25

8.5.1.2 FL Broadcast Frame

A FL broadcast (BC) frame consists of three consecutive sub-frames (BC1/BC2/BC3), in which the GS broadcasts signalling information to all active ASs within its coverage range. Figure 22 shows the structure of these sub-frames.

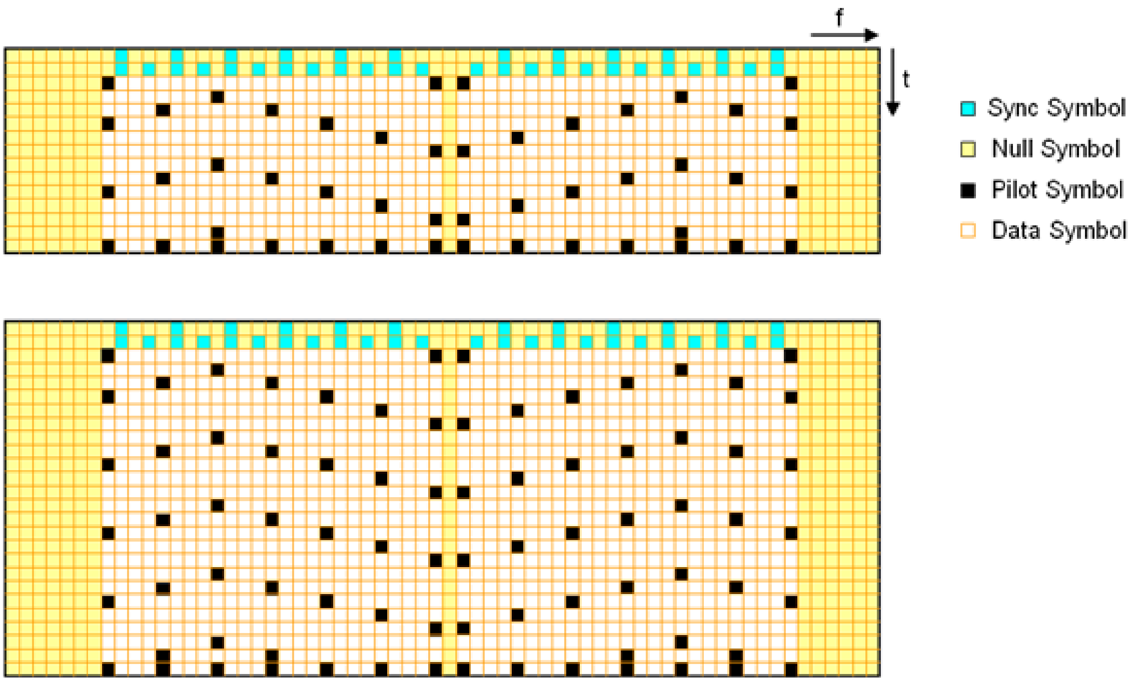

Figure 22: Structure of BC1 and BC3 Sub-frames (above) and BC2 Sub-frame (below)

All sub-frames start with the same synchronisation sequence (two consecutive synchronisation symbols), followed by 13 OFDM symbols in the BC1 and the BC3 sub-frame and by 24 OFDM symbols in the BC2 sub-frame. The frame duration is T_{BC1} = T_{BC3} =1.8 ms for the BC1 and the BC3 sub-frame and T_{BC2} = 3.12 ms for the BC2 sub-frame, resulting in an overall duration of the broadcast frame of T_{BC} = 6.72 ms. Pilot symbols follow the patterns given in Table 19 and Table 20. The number of pilot symbols is 48 for the BC1 and the BC3 sub-frame and 80 for the BC2 sub-frame, resulting in a data capacity of (13*50 – 48) = 602 symbols for the BC1 and the BC3 sub-frame, and (24*50 – 80) = 1120 symbols for the BC2 sub-frame. The total data capacity of the FL BC frame is 2*602 + 1120 = 2324 symbols.

Table 19: Pilot Symbol Positions for BC1 and BC3 Sub-frame

<table>
<tr><th colspan="2">OFDM symbol position n</th><th>Pilot symbol positions</th></tr>
<tr><td colspan="2">n = 3</td><td>-25, -1, 1, 25</td></tr>
<tr><td rowspan="5">n = 3+5·p + i, p = 0, 1</td><td>i = 1</td><td>-17, 17</td></tr>
<tr><td>i = 2</td><td>-21, -13, 13, 21</td></tr>
<tr><td>i = 3</td><td>-25, -9, 9, 25</td></tr>
<tr><td>i = 4</td><td>-5, 5</td></tr>
<tr><td>i = 5</td><td>-1, 1</td></tr>
<tr><td colspan="2">n = 14</td><td>-17, 17</td></tr>
<tr><td colspan="2">n = 15</td><td>-25, -21, -17, -13, -9, -5, -1, 1, 5, 9, 13, 17, 21, 25</td></tr>
</table>

Table 20: Pilot Symbol Positions for BC2 Sub-frame

<table>
<tr><th colspan="2">OFDM symbol position n</th><th>Pilot symbol positions</th></tr>
<tr><td colspan="2">n = 3</td><td>-25, -1, 1 25</td></tr>
<tr><td rowspan="5">n = 3+5·p + i, p = 0, .., 3</td><td>i = 1</td><td>-17, 17</td></tr>
<tr><td>i = 2</td><td>-21, -13, 13, 21</td></tr>
<tr><td>i = 3</td><td>-25, -9, 9, 25</td></tr>
<tr><td>i = 4</td><td>-5, 5</td></tr>
<tr><td>i = 5</td><td>-1,1</td></tr>
<tr><td colspan="2">n = 24</td><td>-17, 17</td></tr>
<tr><td colspan="2">n = 25</td><td>-21, -13, 13, 21</td></tr>
<tr><td colspan="2">n = 26</td><td>-25, -21, -17, -13, -9, -5, -1, 1, 5, 9, 13, 17, 21, 25</td></tr>
</table>

8.5.2 Reverse Link Frame Types

To realise multiple access via OFDMA-TDMA in the RL, except for the RA frame, the transmission is organised in slots containing tiles, rather than in OFDM frames and sub-frames as in the FL.

8.5.2.1 RL Data Slot

In the RL, Data slot consists of tiles. One tile spans 25 symbols in frequency and 6 symbols in time direction and is illustrated in Figure 23. It comprises 4 PAPR reduction symbols and 12 pilot symbols. This leads to a data capacity of 134 symbols per tile, representing the smallest allocation block in the RL. The pilot pattern and position of the PAPR reduction symbols within a tile are given in Table 21 for a tile on the left side of the DC sub-carrier and in Table 22 for a tile on the right side of the DC sub-carrier.

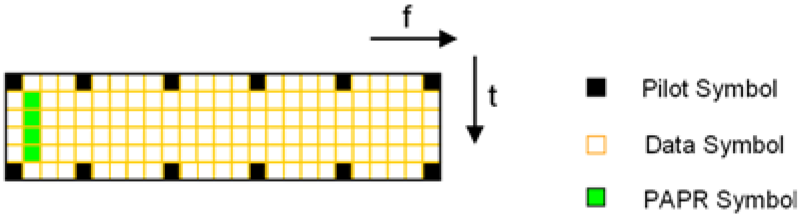

Figure 23: Structure of a tile in the RL

Table 21: Pilot and PAPR Reduction Symbol Positions in a Left Tile

Table 22: Pilot and PAPR Reduction Symbol Positions in a Right Tile

OFDM symbol position n	Pilot symbol positions	OFDM symbol position n	Pilot symbol positions
n = 1, 6	-25, -21, -16, -11, -6, -1	n = 1, 6	1, 6, 11, 16, 21, 25
	PAPR reduction symbol positions		**PAPR reduction symbol positions**
n = 2, 3, 4, 5	-24	n = 2, 3, 4, 5	23

An RL data slot, comprising 8 tiles, is depicted in Figure 24.

The length of an RL data slot is variable and is described in Section 8.5.3.2.

Note that PAPR reduction symbols are located on different subcarriers in left and right tiles.

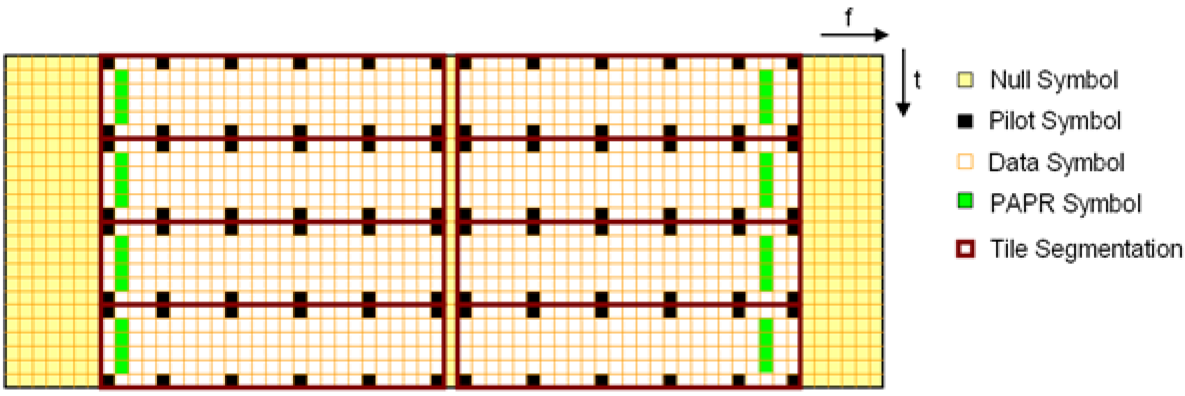

Figure 24: Structure of an RL data slot

8.5.2.2 RL Dedicated Control Slot

A dedicated control (DC) slot has the same tile structure as the RL data slot (see Figure 23).

However, the DC slot starts with a synchronisation tile, spanning 5 OFDM symbols in time direction and 51 sub-carriers, including the DC sub-carrier in frequency direction and is illustrated in Figure 25. The synchronisation tile starts with an AGC preamble, followed by two OFDM synchronisation symbols. The 4th and 5th OFDM symbol consist of pilot symbols. The total duration of the synchronisation tile is T_{SYNC} = 0.6 ms. Pilot positions are given in Table 23. The synchronisation tile provides a possibility for an AS to execute a Handover Type 2.

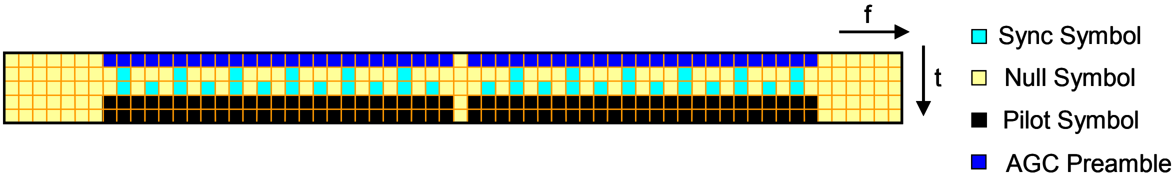

Figure 25: Structure of a Synchronisation Tile

Table 23: Pilot Symbol Positions in a Synchronisation Tile

OFDM symbol position n	Pilot symbol positions
n = 4, 5	-25, -24, …, -1, 1, 2, …, 25

The synchronisation tile is followed by an AGC preamble (single OFDM symbol) with a duration of T_{AGC} = 120 µs.

Within the remainder of the DC slot, exactly one tile is assigned to one AS. The length of a DC slot is variable and is described in Section 8.5.3.2. Therefore, the number of OFDM symbols in the DC slot is also variable (N_{dc}). As an example, one DC slot comprising the (mandatory) synchronisation tile, the (mandatory) single AGC preamble and six tiles is depicted in Figure 26.

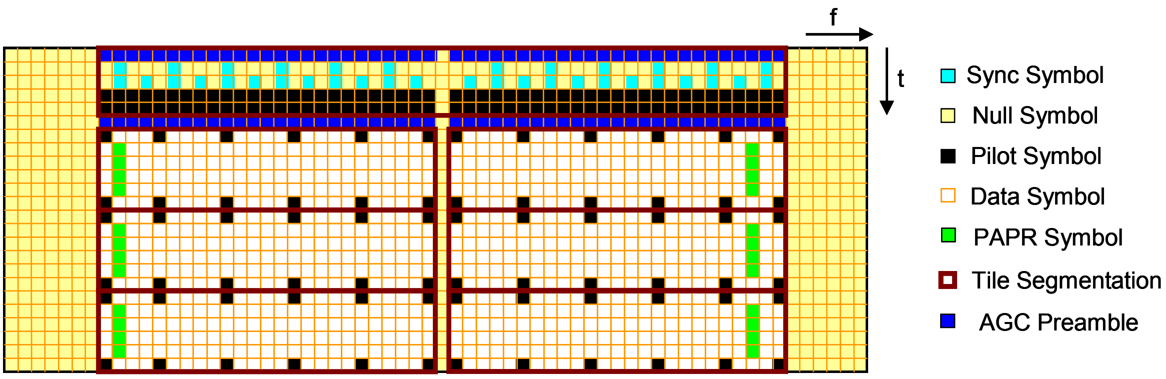

Figure 26: Structure of an RL DC slot

8.5.2.3 RL Random Access Frame

NOTE: Since in the RL Random Access (RA) frame no OFDMA-TDMA is utilised, the wording 'frame' as in the FL is used.

An RL RA frame provides an opportunity for AS to send its cell entry request to the GS (Figure 27). Within each SF there are two opportunities for sending RA frames. Each RA frame can be preceded and followed by propagation guard times of length $T_{g,RA}$ = 1.26 ms, respectively.

This propagation guard time of 1.26 ms corresponds to a maximal AS-GS distance of 200 nm. When transmitting an RA frame, an AS is not yet synchronised to the GS. Under such conditions, an AS sends the first RA frame directly after the start of an RL SF that in turn has been determined from the GS FL signal that needs 1.26 ms to reach an AS at the maximum distance from the GS. From the GS point of view, such an AS starts the transmission of the first RL RA frame with 1.26 ms delay relative to the GS local timing. Another propagation guard time of 1.26 ms is required for the RL RA frame to reach the GS. Thus, from the GS point of view, an RA frame in this case appears to be surrounded by two propagation guard times (Figure 27). Similar considerations are valid for the RA frame sent in the second opportunity that lags in time by 3.36 ms relative to the first one.

Figure 27: RA Access Opportunities

The RA frame contains seven OFDM symbols, resulting in a duration of $T_{sub,RA}$ = 840 µs. The structure of an RA frame is given in Figure 28.

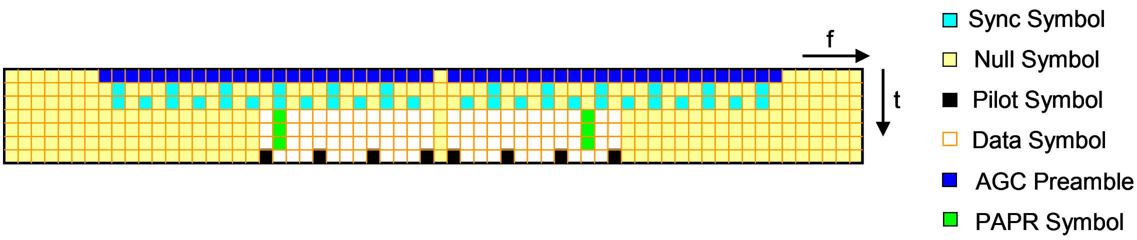

Figure 28: Structure of an RA Frame

The first OFDM symbol represents the AGC preamble, the following two OFDM symbols contain synchronisation sequences, while the remaining four OFDM symbols carry data, PAPR reduction symbols and pilot symbols. These four OFDM symbols use only 27 sub-carriers (including the DC sub-carrier), which leads to guard bands with $N_{g,left}$ = 19 and $N_{g,right}$ = 18 sub-carriers. The arrangement of the pilot symbols and PAPR reduction symbols follows the pattern given in Table 24. The number of 8 pilot symbols and 6 PAPR reduction symbols leads to a data capacity of (26·4 - 8 - 6) = 90 symbols per RA frame.

Table 24: Pilot and PAPR Reduction Symbol Positions for RL RA Frame

OFDM symbol position n	Pilot symbol positions
n = 7	-13, -12, …, -1, 1, 2, …, 13

	PAPR reduction symbol positions
n = 4, 5, 6	-12, 11

8.5.3 Framing

The LDACS physical layer framing is hierarchically arranged. In Figure 29 and Figure 30, this framing structure is summarised graphically, from the Super-Frame (SF) down to the OFDM frames. One SF has duration of T_{SF} = 240 ms. From the view of the GS, the SF transmission on the FL and the RL is synchronous.

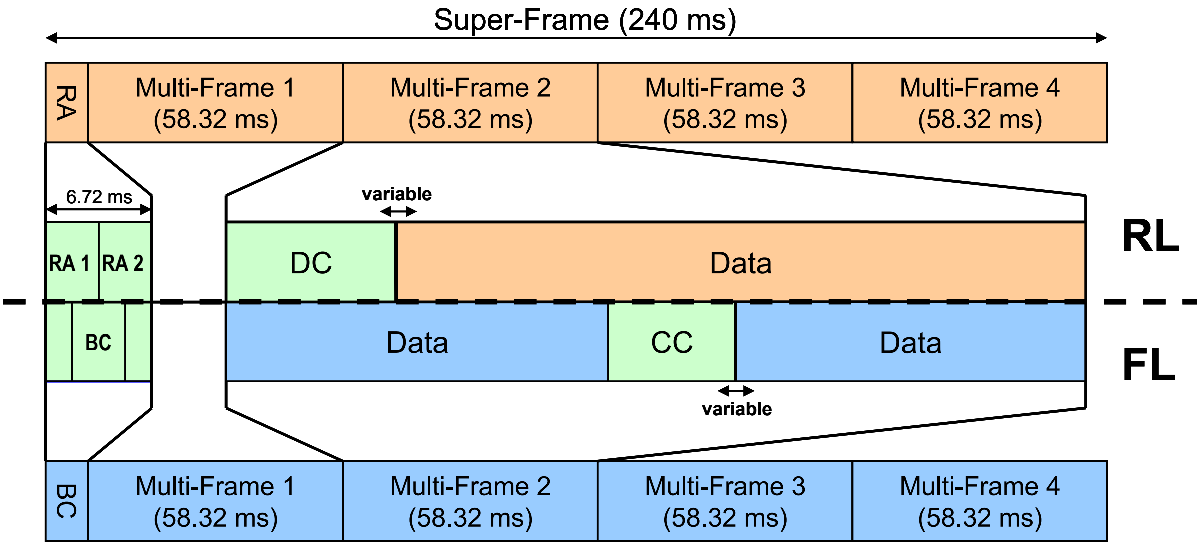

Figure 29: Super-Frame Structure

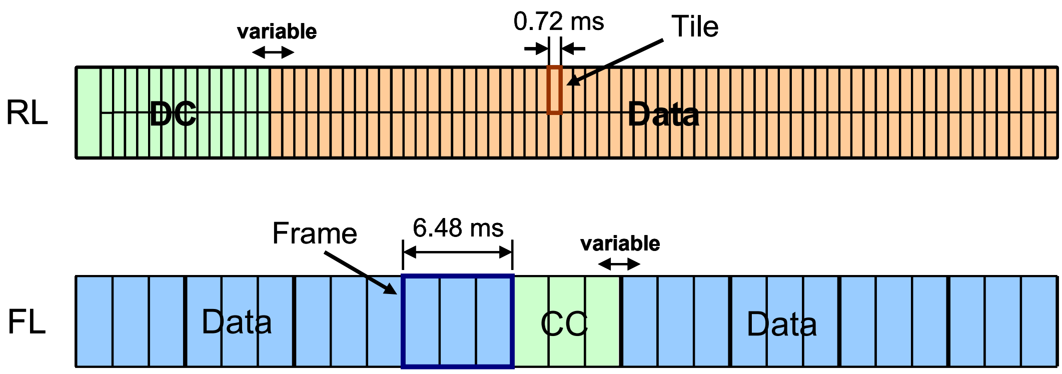

Figure 30: Multi-Frame Structure

The data to be transmitted on FL and RL are provided by the MAC sub-layer in the form of FL PHY-SDUs and RL PHY-SDUs, respectively. The size of the FL/RL PHY-SDUs corresponds to the capacity of the PHY-PDUs in different types of frames and tiles. A PHY-PDU represents a constellation of modulated data symbols within the OFDM frame, sub-frame or tile that carry the actual payload –

PHY-SDUs. The PHY-PDU, by definition, excludes any non-data symbols like AGC symbols, synchronization symbols, symbols for PAPR reduction, pilot symbols or unmodulated DC symbols.

8.5.3.1 Forward Link Framing

In the FL, an SF contains a broadcast frame (BC) of duration T_{BC} = 6.72 ms, and four Multi-Frames (MF), each of duration T_{MF} = 58.32 ms. One FL BC1/BC3 PHY-PDU is mapped onto one BC1/ BC3 sub-frame, respectively. One FL BC2 PHY-PDU is mapped onto one BC2 sub-frame. The number of modulated data symbols in the BC sub-frames corresponds to the size of the FL BC PHY-PDUs. One MF is subdivided into 9 FL frames. Onto these frames, FL PHY-PDUs are mapped. The size of an FL PHY-PDUs is 814 symbols, i.e. 1/3 of an FL frame. Within the MF, starting from the frame number 5, N_{CC} = 1, …, 8 FL PHY-PDUs are mapped onto the subsequent frames for the CC slot. The remainder of the MF shall be filled with FL PHY-PDUs for data. The numbering of the FL PHY-PDUs shall start at the beginning of the MF.

Note: The FL DATA slot carrying FL PHY-PDUs for data is not aligned with the multi-frame boundary, but between two consecutive CC slots as illustrated in Figure 45*!*

8.5.3.2 Reverse Link Framing

In the RL, each SF starts with an RA frame of length T_{RA} = 6.72 ms followed by four MFs. One RL RA PHY-PDU is mapped onto one RA frame. The number of modulated data symbols in an RA frame corresponds to the size of an RL RA PHY-PDU. The duration of an MF is T_{MF} = 58.32 ms as in the FL. Each MF in the RL starts with an RL DC slot, followed by an RL data slot. RL DC and Data slots are sub-divided in tiles. Within one MF, the DC slot size and thus also the size of the data slot is variable. One RL DC PHY-PDU or RL PHY-PDU is mapped onto one tile in the DC slot or data slot, respectively. The size of an RL PHY-PDU and an RL DC PHY-PDU corresponds to the number of data symbols of a tile.

The minimal size of the DC slot is 12 OFDM symbols, corresponding to a synchronisation tile followed by an AGC preamble and two allocated RL DC PHY-PDUs (one in a left and one in a right tile), which leads to a minimum RL DC segment duration of $T_{DC,min}$ = 1.44 ms. The maximal duration is $T_{DC,max}$ = 12.96 ms.

The duration of the data segment in the RL is $T_{DF} = T_{MF} – T_{DC}$, resulting in $T_{DF,min}$ = 45.36 ms and $T_{DF,max}$ = 56.88 ms.

NOTE: In this context, the size of a PHY-PDU is given in complex symbols. The corresponding number of uncoded bits (PHY-SDU size) and coded bits in the PHY-PDUs is given in Section 8.6.2.5 and 8.6.2.6.

8.6 Coding and Modulation

8.6.1 Randomizer

Prior to the channel coding, data randomization is applied to each PHY-SDU separately in the FL and the RL. The structure of the randomizer is depicted in Figure 31, comprising 2 XOR operations and 15 memory elements. The uncoded bits of each PHY-SDU enter the randomizer serially. For each PHY-SDU, the randomizer shall be used independently, which means that prior to each PHY-SDU, the memory elements shall be set to the begin-state, which is defined by the initial sequence

$$\{p_0, p_1, p_2, ..., p_{14}\} = \{0,0,0,0,0,0,0,0,1,0,1,0,1,0,0,1\}.$$

The output bits of the randomizer enter the channel coding.

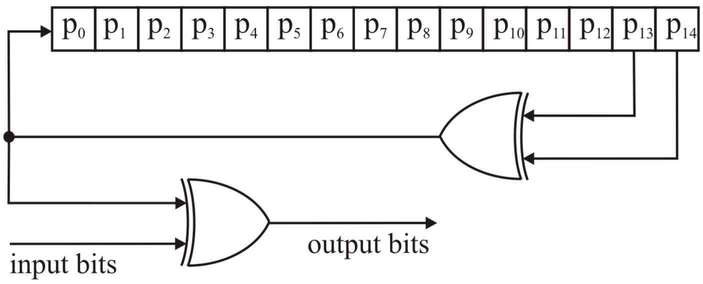

Figure 31: Randomizer Structure

A reverse operation of the randomization has to be applied after the channel decoding at the RX side.

8.6.2 Channel Coding

As FEC scheme, LDACS uses a concatenation of an outer Reed-Solomon (RS) code and an inner variable-rate convolutional code. The coding and interleaving procedure is illustrated in Figure 32.

At the TX side, the information bits after randomization first enter the RS encoder, followed by a block interleaver. Afterwards, zero-terminating convolutional coding is applied. In a last step, the coded bits are interleaved, using a helical interleaver.

The complementary operation is applied in reverse order at the RX side.

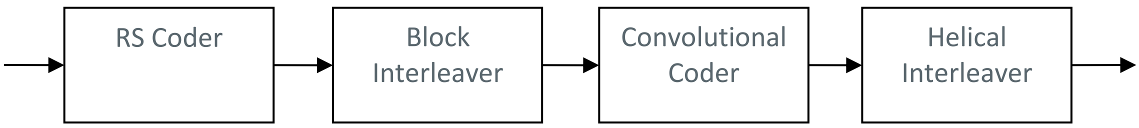

Figure 32: Channel Coding and Interleaving

For the termination of the inner convolutional code, six zero bits are added to the end of the data block before convolutional encoding. These bits are discarded at the RX side after decoding the convolutional code.

If the number of bits to be coded and modulated does not exactly fit to the size of one PHY-PDU, a corresponding number of zero pad bits shall be added after the convolutional coder. These bits are discarded at the RX side before decoding the convolutional code.

8.6.2.1 Outer Coding

An RS code obtained by shortening a systematic RS ($N = 2^8$-1, K, F) code using Galois field GF (2^8), the primitive polynomial

$$p(x) = x^8 + x^4 + x^3 + x^2 + 1$$

and the generator polynomial

$$g(x) = \prod_{i=1}^{2F}\left(x+\lambda^i\right), \quad \lambda = 02_{HEX}$$

shall be applied for outer encoding. The shortening shall be done by padding zeros in front of the uncoded bytes. The RS parameters are as follows:

- K: number of uncoded bytes,
- N: number of coded bytes,
- $F = floor\left(\frac{N-K}{2}\right)$ is the number of bytes that can be corrected

8.6.2.2 Inner Coding

Each output data block of the block interleaver is encoded by a non-recursive binary convolutional coder. Zero-termination of each data block is applied. The generator polynomials of the coder are given by:

- $G_1 = 171_{OCT}$, for the first output
- $G_2 = 133_{OCT}$, for the second output.

The native coding rate is r_{cc} = ½, the constraint length is equal to 7. The block diagram of the coder is given in Figure 33. The coded bits streams $X^{(1)}$ and $X^{(2)}$ are combined by alternately taking bits from $X^{(1)}$ and $X^{(2)}$, i.e. $X^{(1)}_1$, $X^{(2)}_1$, $X^{(1)}_2$, $X^{(2)}_2$,… . Other coding rates can be derived by puncturing the native code. The puncturing patterns for the provided coding rates are given in Table 25, a “1” means a transmitted bit and a “0” denotes a removed bit, whereas $X^{(1)}$ and $X^{(2)}$ are in accordance to Figure 33.

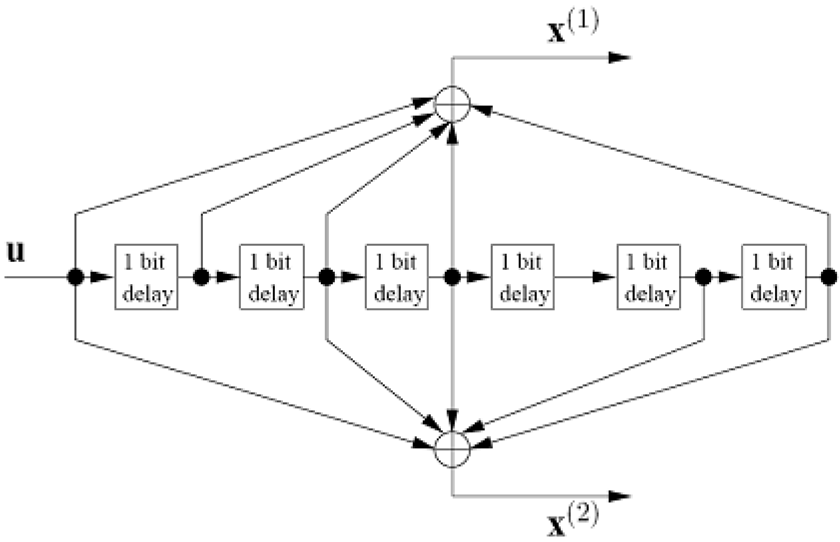

Figure 33: Block Diagram of Convolutional Coder (171, 133, 7)

Table 25: Puncturing Pattern for Convolutional Coder (171, 133, 7)

Coding rate	1/2	2/3	3/4
$X^{(1)}$	1	10	101
$X^{(2)}$	1	11	110
$X^{(1)}\ X^{(2)}$	$X^{(1)}{}_1X^{(2)}{}_1$	$X^{(1)}{}_1X^{(2)}{}_1\ X^{(2)}{}_2$	$X^{(1)}{}_1X^{(2)}{}_1\ X^{(2)}{}_2X^{(1)}{}_3$

For the RL RA PHY-SDUs and the RL DC PHY-SDUs, a r_{cc} = 1/3 convolutional coder with a constraint length equal to 7 is used. In this case, no RS encoding and block interleaving is performed. The block diagram of the coder is given in Figure 34: The coded bits streams $X^{(1)}$, $X^{(2)}$ and $X^{(3)}$ are combined by alternately taking bits from $X^{(1)}$, $X^{(2)}$ and $X^{(3)}$, i.e. $X^{(1)}{}_1$, $X^{(2)}{}_1$, $X^{(3)}{}_1$,$X^{(1)}{}_2$, $X^{(2)}{}_2$,…

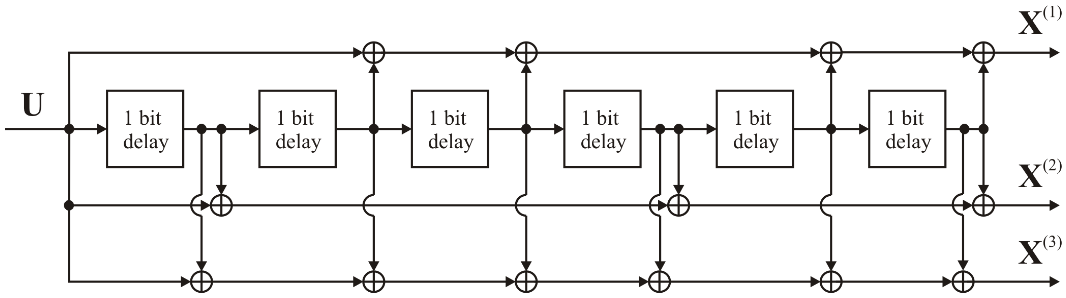

Figure 34: Block Diagram of Convolutional Coder (133, 145, 177, 7)

8.6.2.3 Block Interleaver

The output bytes of the RS encoder are interleaved by a block interleaver. The block interleaver is defined by a matrix. The number of rows is given by the number of RS codewords which are interleaved together. The number of columns is defined by the number of coded bytes per RS codeword. For the interleaving, the bytes are written row-wise into the matrix and read out column-wise. These parameters are defined in the tables provided in Section 8.6.2.5 and 8.6.2.6.

8.6.2.4 Helical Interleaver

The interleaving of the output of the convolutional encoder is done by a helical interleaver. This ensures that the coded bits are evenly spread across the time-frequency plane. The block size of the interleaver $N_{I2} = a \cdot b$ complies with the coding block sizes. These are equivalent to the number of coded bits in the tables provided in Section 8.6.2.5 and 8.6.2.6. The following calculation specifies the pattern of the interleaver:

for l = 0:a-1

for n = 0:b-1

$$k = l \cdot b + n + 1,$$
$$m_k = b \cdot (3 \cdot n + l)_{\mathrm{mod}\, a} + n + 1$$

end

end

Here, k is the index of an encoded data bit before the helical interleaver and m_k is the index of the encoded data bit after the helical interleaver.

The de-interleaving operation at RX side is the inverse of the interleaving operation.

8.6.2.5 FL Coding

The combination of QPSK modulation, a fixed RS code and a convolutional code with r_{cc} = ½ is mandatory for the FL BC PHY-SDUs. Each FL BC PHY-SDU is separately RS encoded, convolutional coded and helical interleaved. Table 26 gives the modulation schemes, channel coding parameters, interleaver parameters and block sizes for these FL PHY-SDUs.

The modulation schemes are described in Section 8.6.3.

For the FL MF two modes of coding and modulation are defined:

- Cell-specific ACM mode, which means that all FL MFs within the cell are encoded and modulated with a fixed scheme, and
- User-specific ACM mode, which means, that separated coding and modulation schemes are applied to data of different ACM parameter sets within one MF.

In case of cell-specific ACM, the information about the chosen coding and modulation scheme is transmitted via the System Identification Broadcast (see Section 10.5.2.2). In case of user-specific ACM the GS transmits the information about the coding and modulation schemes for the different ASs via the CMS FL MAP (see Section 9.3.2.2).

The selection of the ACM mode and the coding and modulation schemes is beyond the scope of this specification.

Due to the fixed size of FL PHY-PDUs of 814 modulated symbols, always $N_D = 27 - N_{CC} = \{19, 20, 21, 22, 23, 24, 25, 26\}$ FL PHY-PDUs are mapped onto the FL data slot of the MF, for both ACM modes. The RS encoding is performed separately for each FL PHY-SDU.

In the case of cell-specific ACM, all RS codewords within either 2 frames or 3 frames are jointly block interleaved, convolutional coded and helical interleaved as indicated in red in Figure 35. In each MF FL PHY-PDUs 1 to 6, 7 to 12, 13 to 21 (regardless how many of these FL PHY-PDUs are used for the CC slot or FL data slot), and 22 to 27 are jointly interleaved.

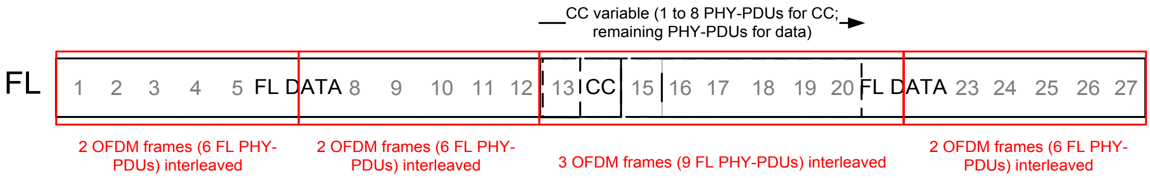

Figure 35: Joint interleaving in the FL MF in cell specific ACM mode

In the case of user-specific ACM, the block interleaving, convolutional coding and helical interleaving is performed jointly for all users, having the same ACM parameter set. The allowed sizes for an ACM parameter set are 3 and 6 FL PHY-SDUs according to Figure 36, which may be assigned arbitrarily to different users. The parameter set of the interleaving block containing the CC slot cannot change. It is modulated and coded as announced in the SIB. The resulting parameters are shown in Table 27.

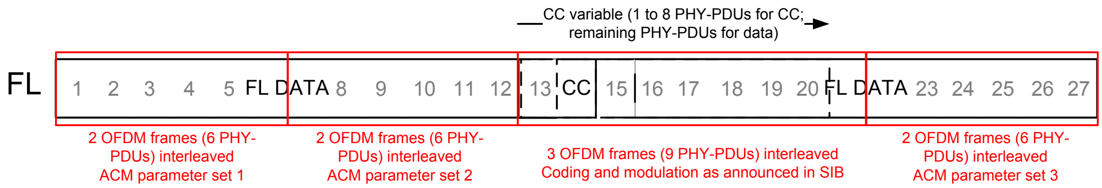

Figure 36: Joint interleaving in the FL MF in user specific ACM mode

Note: The FL DATA slot carrying FL PHY-PDUs for data is not aligned with the multi-frame boundary, but between two consecutive CC slots as illustrated in Figure 45*!*

Table 26: Parameters for FL BC PHY-SDUs

PHY-SDU type	Modulation scheme	Conv. Coding Rate	RS Parameter	Total Coding Rate	PHY-SDU size (uncoded bits)	Helical Interleaver Parameter (a, b)	Number of coded bits after helical interleaver
FL $BC_{1,3}$ PHY-SDU	QPSK	1/2	RS(74, 66, 4)	0.45	528	(43, 28)	1204
FL BC_2 PHY-SDU	QPSK	1/2	RS(139, 125, 7)	0.45	1000	(40, 56)	2240

NOTE: For the BC frame, the block interleaver is obsolete, as the number of RS codewords per interleaving block is always 1.

Table 27: Parameters for FL PHY-SDUs

PHY-SDU type	Modulation scheme	Conv. Coding Rate	RS Parameter	Total Coding Rate	PHY-SDU size (uncoded bits)	Number of RS codewords per PHY-SDU	Number of PHY-SDUs per interleaving block	Block interleaver matrix size in byte	Helical Interleaver Parameter (a, b)	Number of coded bits after helical interleaver
FL PHY-SDU	QPSK	1/2	RS(101, 91, 5)	0.45	728	1	6	(6, 101)	(132, 74)	9768
							9	(9, 101)	(111, 132)	14652
FL PHY-SDU	QPSK	2/3	RS(134, 120, 7)	0.60	960	1	6	(6, 134)	(132, 74)	9768
							9	(9, 134)	(111, 132)	14652
FL PHY-SDU	QPSK	3/4	RS(151, 135, 8)	0.67	1080	1	6	(6, 151)	(132, 74)	9768
							9	(9, 151)	(111, 132)	14652
FL PHY-SDU	16QAM	1/2	RS(202, 182, 10)	0.45	1456	1	6	(6, 202)	(132, 148)	19536
							9	(9, 202)	(132, 222)	29304
FL PHY-SDU	16QAM	2/3	RS(135, 121, 7)	0.60	1936	2	6	(12, 135)	(132, 148)	19536
							9	(18, 135)	(132, 222)	29304
FL PHY-SDU	64QAM	1/2	RS(152, 136, 8)	0.45	2176	2	6	(12, 152)	(132, 222)	29304
							9	(18, 152)	(198, 222)	43788

PHY-SDU type	Modulation scheme	Conv. Coding Rate	RS Parameter	Total Coding Rate	PHY-SDU size (uncoded bits)	Number of RS codewords per PHY-SDU	Number of PHY-SDUs per interleaving block	Block interleaver matrix size in byte	Helical Interleaver Parameter (a, b)	Number of coded bits after helical interleaver
FL PHY-SDU	64QAM	2/3	RS(203, 183, 10)	0.60	2928	2	6	(12, 203)	(132, 222)	29304
							9	(18, 203)	(198, 222)	43788
FL PHY-SDU	64QAM	3/4	RS(228, 206, 11)	0.68	3296	2	6	(12, 228)	(132, 222)	29304
							9	(18, 228)	(198, 222)	43788

8.6.2.6 RL Coding

The combination of QPSK modulation and a convolutional code with $r_{cc} = 1/3$ is mandatory for the RL DC and the RL RA PHY-SDUs. In this case Table 28 gives the modulation schemes, channel coding parameters, interleaver parameters and block sizes for these RL PHY-SDUs.

The modulation schemes are described in Section 8.6.3.

Table 28: Parameters for RL DC and RL RA PHY-SDUs

PHY-SDU type	Modulation	Convolutional Coding Rate	Total Coding Rate	PHY-SDU size (uncoded bits)	Helical Interleaver Parameter (a, b)	Number of coded bits after helical interleaver
RL DC PHY-SDU	QPSK	1/3	0.33	83	(67, 4)	268
RL RA PHY-SDU	QPSK	1/3	0.33	54	(15, 12)	180

In the RL, ACM is supported only for data segments.

In general, N_{SDU} RL PHY-SDUs of an AS in a MF are jointly RS coded, convolutional coded and helical interleaved. However, the number of jointly coded RL PHY-SDUs is limited either by the maximum size of a RS codeword (255 byte) or 10 RL PHY-SDUs. In Table 29 the limit N_{lim} is given for the different ACM parameter sets.

Table 29: Maximum Coding Block Size for RL PHY-SDUs

Modulation	Convolutional Coding Rate	Maximal Coding Block Size, N_{lim}
QPSK	1/2	10
QPSK	2/3	10
QPSK	3/4	10
16QAM	1/2	7
16QAM	2/3	5
64QAM	1/2	5
64QAM	2/3	3
64QAM	3/4	3

If more than N_{lim} RL PHY-SDUs are assigned to an AS, the PHY-SDUs are separated into different coding blocks in the following way:

Calculate the number of coding blocks:

$$N_{\mathrm{cod}} = \left\lceil \frac{N_{\mathrm{SDU}}}{N_{\mathrm{lim}}} \right\rceil$$

Calculate the sizes of the coding blocks:

- N_{cod} – 1 coding blocks shall be encoded using N_{lim} coding block size.
- The last coding block shall encode the remaining RL PHY-SDUs.

Since the maximal coding block size is limited by one RS codeword, no block interleaver is needed.

Table 30 provides the parameters for RL PHY-SDU-based ACM in the RL data segments.

The selection of a coding and modulation scheme for a certain AS is carried out by the GS. The selected coding and modulation scheme is communicated to this AS via the CMS RL MAP (see Section 9.4.3.2).

Table 30: Parameters for RL PHY-SDUs

PHY-SDU type	Modulation scheme	Conv. Coding Rate	PHY-SDU size (uncoded bits)	Number of PHY-SDUs per coding block	RS Parameter	Total Coding Rate	Helical Interleaver Parameter (a, b)	Number of coded bits after helical interleaver
RL PHY-SDU	QPSK	1/2	112	1	RS(16, 14, 1)	0.44	(67, 4)	268
				2	RS(32, 28, 2)	0.44	(67, 8)	536
				3	RS(48, 42, 3)	0.44	(67, 12)	804
				4	RS(66, 56, 5)	0.42	(67, 16)	1072
				5	RS(82, 70, 6)	0.43	(67, 20)	1340
				6	RS(98, 84, 7)	0.43	(67, 24)	1608
				7	RS(116, 98, 9)	0.42	(67, 28)	1876
				8	RS(132, 112, 10)	0.42	(67, 32)	2144
				9	RS(150, 126, 12)	0.42	(67, 36)	2412
				10	RS(166, 140, 13)	0.42	(67, 40)	2680
RL PHY-SDU	QPSK	2/3	152	1	RS(21, 19, 1)	0.60	(67, 4)	268
				2	RS(42, 38, 2)	0.60	(67, 8)	536
				3	RS(65, 57, 4)	0.58	(67, 12)	804
				4	RS(88, 76, 6)	0.58	(67, 16)	1072
				5	RS(109, 95, 7)	0.58	(67, 20)	1340
				6	RS(132, 114, 9)	0.58	(67, 24)	1608
				7	RS(155, 133, 11)	0.57	(67, 28)	1876
				8	RS(176, 152, 12)	0.58	(67, 32)	2144

PHY-SDU type	Modulation scheme	Conv. Coding Rate	PHY-SDU size (uncoded bits)	Number of PHY-SDUs per coding block	RS Parameter	Total Coding Rate	Helical Interleaver Parameter (a, b)	Number of coded bits after helical interleaver
				9	RS(199, 171, 14)	0.57	(67, 36)	2412
				10	RS(222, 190, 16)	0.57	(67, 40)	2680
RL PHY-SDU	QPSK	3/4	176	1	RS(24, 22, 1)	0.69	(67, 4)	268
				2	RS(48, 44, 2)	0.69	(67, 8)	536
				3	RS(74, 66, 4)	0.67	(67, 12)	804
				4	RS(98, 88, 5)	0.67	(67, 16)	1072
				5	RS(124, 110, 7)	0.67	(67, 20)	1340
				6	RS(150, 132, 9)	0.66	(67, 24)	1608
				7	RS(174, 154, 10)	0.66	(67, 28)	1876
				8	RS(200, 176, 12)	0.66	(67, 32)	2144
				9	RS(224, 198, 13)	0.66	(67, 36)	2412
				10	RS(250, 220, 15)	0.66	(67, 40)	2680
RL PHY-SDU	16QAM	1/2	224	1	RS(32, 28, 2)	0.44	(67, 8)	536
				2	RS(66, 56, 5)	0.42	(67, 16)	1072
				3	RS(98, 84, 7)	0.43	(67, 24)	1608
				4	RS(132, 112, 10)	0.42	(67, 32)	2144
				5	RS(166, 140, 13)	0.42	(67, 40)	2680
				6	RS(200, 168, 16)	0.42	(67, 48)	3216
				7	RS(232, 196, 18)	0.42	(67, 56)	3752

PHY-SDU type	Modulation scheme	Conv. Coding Rate	PHY-SDU size (uncoded bits)	Number of PHY-SDUs per coding block	RS Parameter	Total Coding Rate	Helical Interleaver Parameter (a, b)	Number of coded bits after helical interleaver
RL PHY-SDU	16QAM	2/3	312	1	RS(43, 39, 2)	0.60	(67, 8)	536
				2	RS(88, 78, 5)	0.59	(67, 16)	1072
				3	RS(133, 117, 8)	0.59	(67, 24)	1608
				4	RS(176, 156, 10)	0.59	(67, 32)	2144
				5	RS(221, 195, 13)	0.59	(67, 40)	2680
RL PHY-SDU	64QAM	1/2	360	1	RS(49, 45, 2)	0.46	(67, 12)	804
				2	RS(98, 90, 4)	0.46	(67, 24)	1608
				3	RS(149, 135, 7)	0.45	(67, 36)	2412
				4	RS(200, 180, 10)	0.45	(67, 48)	3216
				5	RS(249, 225, 12)	0.45	(67, 60)	4020
RL PHY-SDU	64QAM	2/3	480	1	RS(66, 60, 3)	0.61	(67, 12)	804
				2	RS(132, 120, 6)	0.61	(67, 24)	1608
				3	RS(200, 180, 10)	0.60	(67, 36)	2412
RL PHY-SDU	64QAM	3/4	528	1	RS(74, 66, 4)	0.67	(67, 12)	804
				2	RS(150, 132, 9)	0.67	(67, 24)	1608
				3	RS(224, 198, 13)	0.67	(67, 36)	2412

8.6.3 Modulation

After the interleaving, the encoded data bits enter serially the constellation mapper. Gray-mapped QPSK, 16QAM and 64QAM shall be supported. Figure 37 shows the constellation diagrams for QPSK, 16QAM and 64QAM. The constellation diagram of the modulation is normalised to an average power of 1 by multiplying the constellation points with the indicated factor c. In Figure 37, b_0 denotes the Least Significant Bit (LSB).

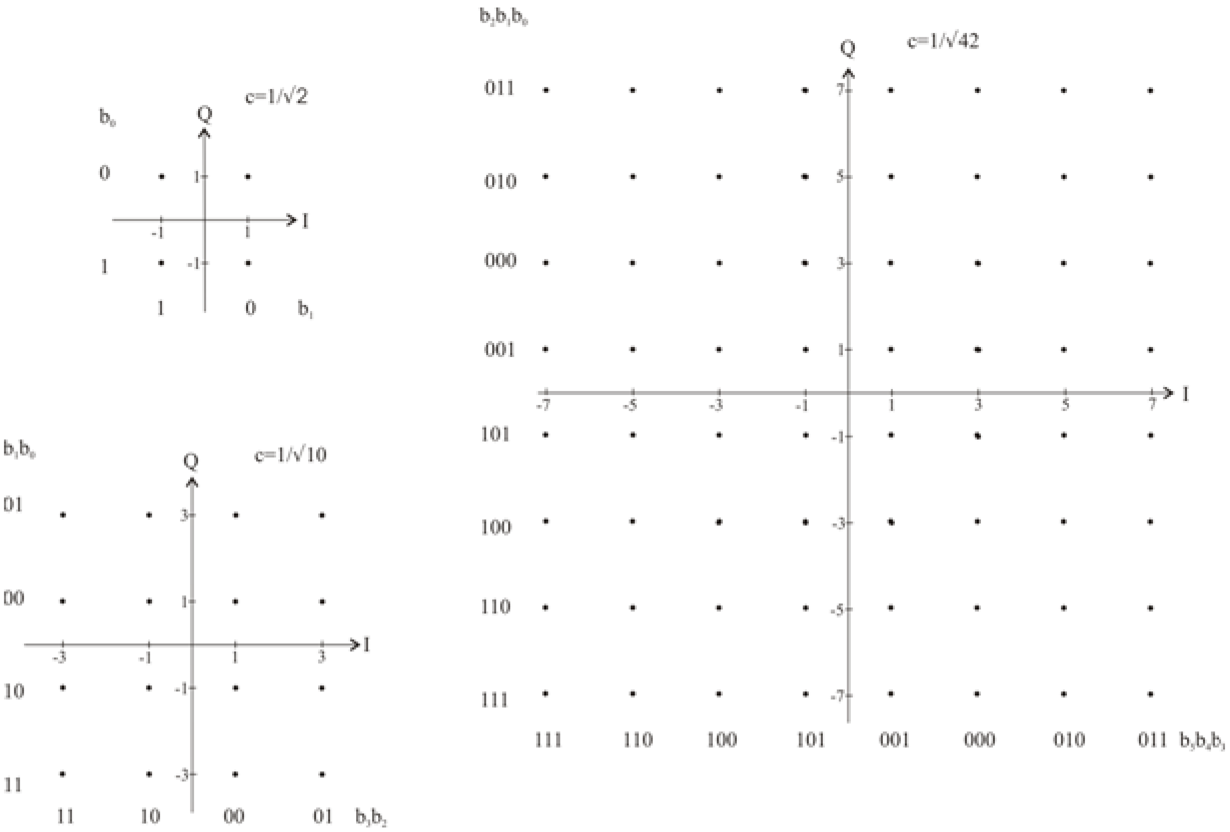

Figure 37: Constellation Diagrams for QPSK, 16QAM and 64QAM

The modulation rate r_{mod} is

- For QPSK: r_{mod} = 2 bits/modulation symbol
- For 16QAM: r_{mod} = 4 bits/modulation symbol
- For 64QAM: r_{mod} = 6 bits/modulation symbol

8.6.4 Data Mapping onto Frames

Multiplexing of the signalling, header and user data into one PHY-PDU is done by the MAC sub-layer and is described in Chapter 8. PHY layer makes sure that the payload received from the MAC sub-layer (PHY-SDUs) is encoded, modulated and properly mapped onto PHY-PDUs within FL frames (that the available modulated symbols in the time-frequency plane are used in the proper order). The mapping of the blocks of modulated symbols onto PHY-PDUs shall be carried out as follows:

- Each FL BC PHY-SDU is encoded and modulated separately and each block of modulated symbols shall be mapped onto the corresponding PHY-PDU.
- {6,9} FL PHY-SDUs within a MF are first RS coded (separately for each PHY-SDU) and then jointly conv. coded, interleaved and modulated. After the modulation, each block of modulated symbols shall be mapped onto {6,9} FL PHY-PDUs.
- For cell-specific ACM all FL PHY-SDUs are modulated and encoded in the same way.
- For user-specific ACM, all FL PHY-SDUs not interleaved with the CC within a MF possessing the same ACM parameter sets are RS coded (separately for each PHY-SDU) and then jointly conv. coded, interleaved and modulated in blocks of 6 PHY-SDUs. After the modulation, each block of modulated symbols shall be mapped onto 6 PHY-PDUs.
- Each RL RA PHY-SDU is encoded and modulated separately and each block of modulated symbols shall be mapped onto the corresponding PHY-PDU.
- Each RL DC PHY-SDU is encoded and modulated separately and each block of modulated symbols shall be mapped onto the corresponding PHY-PDU.
- All RL PHY-SDUs assigned to an AS within a MF are jointly coded and modulated. After the modulation, each block of modulated symbols shall be mapped onto the corresponding number of PHY-PDUs.

NOTE: As a part of the layer interaction, described in Section 7.2.1, additional signalling information is locally exchanged between the PHY and the MAC sub-layer, but is not transmitted from TX to RX.

8.6.4.1 FL Data Mapping

Before mapping FL PHY-PDUs onto a frame, two OFDM symbols with the synchronisation sequences and pilot symbols shall be inserted into the frame. Pilot insertion follows the pilot pattern defined in Section 8.5.

The FL PHY-PDUs shall be mapped in frequency direction onto the FL frame or sub-frame, i.e. symbols are placed subsequently on the free positions in the following order: (1,-25) (1,-24) (1,-23) … (2,-25) (2,-24) etc. Symbol positions are defined in Section 8.5.

In each MF, the N_{CC} FL PHY-PDUs shall be mapped onto the FL PHY-SDUs numbered 13,…,12 + N_{CC}. The N_D FL PHY-PDUs shall be mapped onto the remaining frames. For both types, exactly 3 PHY-PDUs are mapped onto one frame.

Table 31 provides the indices of the OFDM symbols and sub-carriers, on which the FL PHY-PDUs shall be mapped.

NOTE: These tables ignore pilot symbols and the DC sub-carrier, i.e. the encoded and modulated content of PHY-PDUs shall be mapped only onto data symbols at free positions in the section of the frame as given by the indices.

Table 31: Mapping Indices for FL CC/Data PHY-PDUs

Number of the FL PHY-PDU	OFDM symbol index	Sub-carrier index
1	3, …, 19	-25, …, -1,1,…,25
	20	-25, …,-12

Number of the FL PHY-PDU	OFDM symbol index	Sub-carrier index
2	20	-11, …,-1,1,…, 25
	21, …, 36	-25, …,-1,1,…, 25
	37	-25, …,-1,1,2
3	37	3, …, 25
	38, …, 54	-25, …, -1,1,…, 25

8.6.4.2 RL Data Mapping

In the RL, the DC slot and the data slot are subdivided into tiles. Data mapping shall map RL DC PHY-PDUs and RL PHY-PDUs onto tiles, where one PHY-PDU is always mapped exactly onto one tile. Before mapping a PHY-PDU onto a tile, pilot symbols and PAPR reduction symbols shall be inserted into the tile. RL PHY-PDUs shall be mapped onto the tile in frequency direction, i.e. symbols are placed subsequently on the free positions within the tile in the following order: (1,-25) (1,-24) (1,-23) … (2,-25) (2,-24) etc. The RL PHY-PDU order for mapping is controlled by the MAC sub-layer.

In the RA frame, the mapping procedure follows the steps described for the BC FL sub-frames in Section 8.6.4.1.

8.6.5 User Data Rate

The example data rates provided in this section consider overhead produced by controlling channels, such as the DC segment, the CC information, the RA frame and the BC frame, as well as overhead due to pilot symbols, synchronisation sequences or PAPR reduction symbols.

Note that the data rate can change slightly if the DC segment and CC segment are configured differently.

8.6.5.1 FL User Data Rate

The data rate in the FL depends on the chosen coding rate and modulation scheme for user data and the size of the CC slot. Table 32 shows the data rates for the cell-specific ACM mode at a glance. The associated RS coding parameters are not given here, but can be found in Table 27. When calculating data rates, a CC slot of size 1 FL PHY-PDU is assumed, resulting in num_{PHY_PDU} = 26 FL PHY-PDUs for the data slot per MF.

Table 32: User data rates in the FL

Modulation	FL Convolutional Coding Rate	Data Rate [kbit/s]
QPSK	1/2	315.47
QPSK	2/3	416.00
QPSK	3/4	468.00

16QAM	1/2	630.93
16QAM	2/3	838.93
64QAM	1/2	942.93
64QAM	2/3	1268.80
64QAM	3/4	1428.27

The first row in this table relates to the default coding and modulation configuration. The other combinations represent possible options.

8.6.5.2 RL User Data Rate

In the RL, user data rates cannot be easily specified, since the ratio of DC slot duration to data slot duration is variable. However, assuming a minimal DC slot size of 2 RL PHY-PDUs the user data rates shown in Table 33: are obtained.

Table 33: Data Rates in the RL

Modulation	RL Convolutional Coding Rate	Data Rate [kbit/s]
QPSK	1/2	294.93
QPSK	2/3	400.27
QPSK	3/4	463.47
16QAM	1/2	589.87
16QAM	2/3	821.60
64QAM	1/2	948.00
64QAM	2/3	1264.00
64QAM	3/4	1390.40

8.7 Pilot-, Synchronisation-, PAPR- and AGC-sequences

In this section the sequences and preambles used for synchronisation, channel estimation (CE), PAPR reduction and AGC issues are described.

8.7.1 Pilot Sequences

Pilot sequences defined in this section shall be inserted in the FL frames and the RL tiles. The mapping shall be applied in frequency direction, i.e. consecutively on the OFDM symbols which contain pilot symbols. The exact pilot positions on which the pilot symbols shall be mapped are defined in Table 18, Table 19 and Table 20 for the FL and in Table 21, Table 22, Table 23 and Table 24 for the RL.

For the frames in the FL, for each set of pilot positions within an OFDM symbol, a pilot sequence is defined, which is given in Table 34

Table 34: Pilot Values for FL Frames

Sub-carrier indices of pilots	Pilot values
-25, -1, 1, 25	1, -1, -1, -1
-17, 17	1, -1
-21, -13, 13, 21	1, 1, j, -j
-25, -9, 9, 25	1, -1, -j, -j
-5, 5	1, -j
-1, 1	1, -1
-25, -21, -17, -13, -9, -5, -1, 1, 5, 9, 13, 17, 21, 25	1, -j, j, 1, j, j, -1, -1, j, j, 1, j, -j, 1

In the RL RA frame, the pilot sequences of each sub-frame shall be calculated as follows:

$$S_{RA}(k) = \exp\left(j \cdot \frac{2\pi}{64} P_{RA}(k) \right), k = 1,\ldots,8$$

with

$$P_{RA} = \{61, 46, 11, 57, 40, 50, 18, 28\}.$$

In the RL synchronization tile the pilot sequences of section 8.7.4 shall be used.

In the RL DC and data segment, the pilot sequences of each tile shall be calculated as follows:

$$S_{tile}(k) = \exp\left(j \cdot \frac{2\pi}{64} P_{tile,l/r}(k) \right), k = 1,\ldots,12$$

with

- $P_{tile,l}$ = {2, 40, 10, 2, 56, 4, 2, 40, 10, 2, 56, 4}, for left tiles and
- $P_{tile,r}$ = {4, 56, 2, 10, 40, 2, 4, 56, 2, 10, 40, 2}, for right tiles.

The pilot symbols may be transmitted with a boosting of n_B = 0 … 4 dB over the average power of each data symbol.

The boosting level for FL and RL shall be separately adjustable (n_{B_FL} /n_{B_RL}, respectively).

As the phases of the pilot symbols have no influence on the performance of the channel estimation, they have been chosen to provide a low PAPR.

8.7.2 PAPR Reduction Symbols

For reducing the Peak to Average Power Ratio (PAPR), four symbols shall be inserted into every tile for RL transmission and six symbols into every RA frame. The sub-carrier indices of these symbols are defined in Table 22, Table 23 and Table 24. These symbols carry no information and can be discarded at the receiver. They are calculated data-dependent, in order to reduce the PAPR.

The optimal selection of these PAPR reduction symbols can be formulated as a convex optimisation problem. The particular algorithm is beyond the scope of this specification.

8.7.3 Synchronisation Sequences

All synchronisation OFDM symbols are structured as depicted in Figure 38:. In the first OFDM symbol, every forth sub-carrier of the used spectrum is occupied by a synchronisation symbol. The indices of these sub-carriers are given in Table 35. As a result, the time domain waveform of the first OFDM symbol consists of four identical parts. The occupation of the even sub-carriers of the used spectrum in the second synchronisation OFDM symbol yields a time domain waveform with two identical halves.

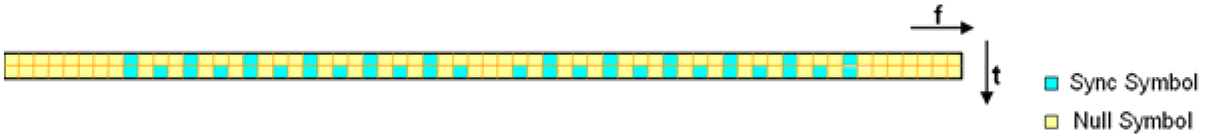

Figure 38: Structure of the Synchronisation OFDM Symbols

Table 35: Synchronisation Symbol Position

Synchronisation OFDM symbol number	Synchronisation symbol positions
1	-24, -20, -16, -12, -8, -4, 4, 8, 12, 16, 20, 24
2	-24, -22, -20, -18, -16, -14, -12, -10, -8, -6, -4, -2, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24

The structure of the two synchronisation OFDM symbols in the time domain is depicted in Figure 39. The synchronisation sequences in the frequency domain shall be calculated by

$$S_{sy1,k} = \sqrt{4}\exp\left(j \cdot \pi \frac{5k^2}{N_{sy1}} \right) \quad ,k = 0,\ldots,N_{sy1} - 1$$

and

$$S_{sy2,k} = \sqrt{2}\exp\left(j \cdot \pi \frac{k^2}{N_{sy2}} \right) \quad ,k = 0,\ldots,N_{sy2} - 1$$

with

- $S_{sy1/2}$: Synchronisation symbols for the first and the second OFDM synchronisation symbol,
- $N_{sy1/2}$: Number of synchronisation symbols per OFDM synchronisation symbol (12 for the first OFDM synchronisation symbol and 24 for the second OFDM synchronisation symbol).

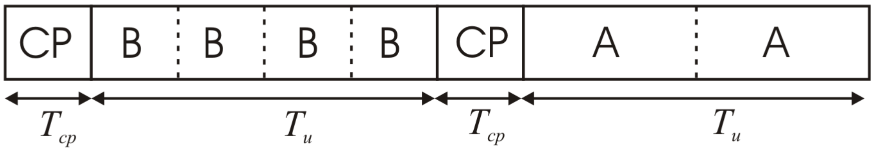

Figure 39: Time Domain Representation of Synchronisation OFDM Symbols

NOTE: The chosen synchronisation sequences are so called CAZAC (constant amplitude, zero autocorrelation) sequences, which preserve their good correlation properties when transforming them from the frequency to the time domain.

8.7.4 AGC Preamble

The first OFDM symbol in an RL RA frame, the first OFDM symbol in a synchronisation tile and the OFDM symbol preceding the DC tiles contain AGC preambles. The AGC preamble in the frequency domain shall occupy all used sub-carriers,_numbered by: -25, -24, …, -1, 1, 2, …, 25, and it shall be calculated by:

$$S_{AGC}(k) = \exp\left(j \cdot \frac{2\pi}{64} P_{AGC}(k) \right), k = 1, \ldots, 50$$

with

P_{AGC} = {29, 8, 35, 53, 30, 17, 21, 16, 7, 37, 23, 35, 40, 41, 8, 46, 32, 47, 8, 36, 26, 53, 12, 26, 33, 4, 31, 42, 0, 6, 48, 18, 60 24, 2, 15, 16, 58, 48, 37, 61, 22, 38, 52, 23, 3, 63, 36, 49, 42}.

NOTE: This sequence was chosen by minimising the PAPR of the AGC preamble.

8.8 Interference Mitigation Techniques

As in the aeronautical L-band environment many other systems are already operational, there is a need to reduce the interference impact of LDACS onto these systems. One method that is inherent to the LDACS design is presented in Section 8.8.1 below.

On the other hand, the interference produced by L-band systems onto LDACS receivers has also to be mitigated. Some appropriate techniques are presented in Appendix C.

8.8.1 TX Windowing

The method presented in this section aims at mitigating the undesired influence of LDACS onto existing L-band systems.

In Section 8.2.2, the generation of the time domain TX signal is described, including windowing. TX windowing is the mandatory method that must be implemented at the LDACS TX in order to reduce the undesired influence of LDACS onto existing L-band systems.

TX windowing is applied in order to smooth the sharp phase transitions between consecutive OFDM symbols which would otherwise cause out-of-band radiation. The windowing function is illustrated in Figure 40.

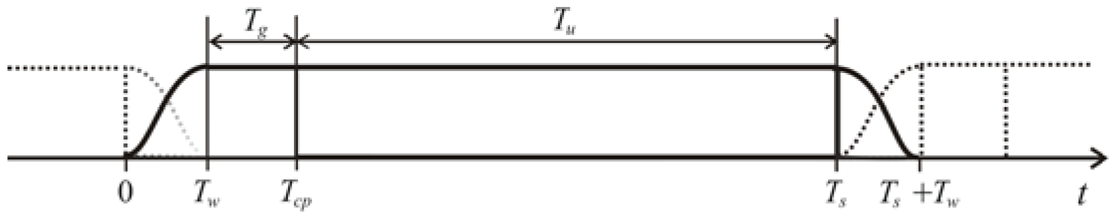

Figure 40: Windowing Function

The raised cosine (RC) function with a roll-off factor of $\alpha = 0.107$, given by

$$w(t) = \begin{cases} \frac{1}{2} + \frac{1}{2}\cos\left(\pi + \frac{\pi t}{T_w}\right) & 0 \le t < T_w \\ 1 & T_w \le t < T_s \\ \frac{1}{2} + \frac{1}{2}\cos\left(\frac{\pi\left(t - T_s\right)}{T_w}\right) & T_s \le t < T_s + T_w \\ 0 & else \end{cases}$$

shall be applied for windowing. The duration of the flanks of the window is defined as

$$T_w = \left(T_u + T_g\right)\frac{\alpha}{1-\alpha}.$$

The following equation specifies the complex baseband signal of the l-th OFDM symbol within one frame, before windowing the signal

$$s_l(t) = \begin{cases} \sum_{k=-N_u/2}^{N_u/2-1} c_{k,l} \cdot \exp\left\{ j2\pi k \Delta f \left(t - T_{cp}\right)\right\} & 0 \le t < T_s + T_w \\ 0 & else \end{cases}$$

where $c_{k,l}$ specifies data symbols, pilot symbols, synchronisation symbols, PAPR reduction symbols or AGC preamble symbols. TX windowing results from the following multiplication

$$s_{l,wi}(t) = s_l(t) \cdot w(t).$$

Finally, the continuous complex baseband signal is obtained by partially overlapping the consecutive OFDM symbols:

$$s(t) = s_{0,wi}(t) + s_{1,wi}(t - T_s) + s_{2,wi}(t - 2T_s) + \ldots$$

8.9 Physical Layer Services

NOTE: This entire section is for information only. It explains how the PHY layer facilities could be used by external entities for their specific purposes, but does not prescribe the detailed implementation (practical implementation may deviate from the description provided here).

8.9.1 Support for AS RX AGC

As the transmission in the FL is continuous, no dedicated preamble is needed for supporting the AGC in the airborne RX.

8.9.2 Support for GS RX AGC

In the RL, the RA frames and the synchronisation tiles in the DC segments start with an AGC preamble. In addition, the first OFDM symbol following the synchronisation tile is occupied by an AGC preamble. This symbol shall be sent by the AS that occupies the first left DC tile in the DC segment.

8.9.3 AS RX Synchronisation to FL Frames

8.9.3.1 Time Synchronisation Maintenance

In the FL, every frame and BC sub-frame begins with two synchronisation symbols. The structure of these two symbols is described in Section 8.7.3. This structure can be exploited in the AS RX for time synchronisation maintenance, applying an appropriate time domain correlation. As the length of these frames and sub-frames is $T_{DF/CC}$ = 6.48 ms, $T_{BC1/3}$ = 1.8 ms and T_{BC2} = 3.12 ms, the time synchronisation can be updated at least every 6.48 ms based solely on the received synchronisation symbols.

8.9.3.2 Frequency Synchronisation Maintenance

The OFDM synchronisation symbols at the beginning of every frame and BC sub-frame can be used for the frequency synchronisation maintenance. Like for time synchronisation, the frequency synchronisation can be updated at least every 6.48 ms based solely on the received synchronisation symbols.

8.9.4 GS RX Synchronisation to RL Frames

8.9.4.1 Time Synchronisation Maintenance

In the RL, each RA frame starts with two OFDM synchronisation symbols. The structure of these OFDM symbols is described in Section 8.7.3. Hence, GS RX can measure the timing offset of RA frames sent by an AS which executes a cell entry relative to the GS own SF timing. The results will be communicated to the AS. Based on these results, the AS can apply the timing advance and transmit with pre-compensated timing offset.

An update of the timing offset compensation can be produced by the GS, based on the measurements performed over DC tiles sent by each AS in the DC segment, depicted in Figure 26.

Between the cell entry and the update of the timing offset, an AS shall track the time synchronisation, e.g. by employing the OFDM synchronisation sequences in the FL frames. As this tracking is a differential procedure, errors may accumulate, which justifies the update procedure.

8.9.4.2 Frequency Synchronisation Maintenance

Like for time synchronisation, the two OFDM synchronisation symbols at the beginning of each RA frame can be used for frequency synchronisation. Hence, it is possible for a GS to measure the frequency offset of an AS which executes a cell entry. The results will be communicated to this AS. Based on these results, the AS can pre-compensate on the RL the measured frequency offset.

An update of the frequency offset compensation can be produced by the GS, based on the measurements performed over DC tiles sent by each AS in the DC segment, depicted in Figure 26.

Like for time synchronisation, an AS shall track the frequency synchronisation between the cell entry and the update, e.g. by employing the OFDM synchronisation sequences in the FL frames.

8.9.5 Notification Services

8.9.5.1 Ground Station RX RL Signal Power Measurements

Initial signal power measurement is performed during the cell entry of an AS, based on RL RA frames. In the following, the GS PHY layer shall monitor the received signal power separately for each RL user and report results to the GS LME. This monitoring can be executed based on the DC tiles sent by the particular AS. Since an AS regularly transmits DC tiles, the GS can continuously monitor the received signal power for each AS.

8.9.5.2 AS RX FL Signal Power Measurements

An AS PHY layer shall regularly monitor the FL transmission of its controlling GS and report the received signal power to the AS LME.

During a BC frame, an AS PHY layer may be requested by the AS LME to scan the channels of adjacent non-controlling GSs. In this case the AS PHY layer shall measure the received signal power of the specified neighbouring cell and report the received signal power to the AS LME.

8.9.6 AS TX Power Management

A power management algorithm shall be supported for the RL with both an initial power calibration during cell entry and a periodic adjustment during normal operation. The objective of the power management algorithm is to let the AS LME (Section 10.3.2.2) adapt the transmitting power of the AS TX, therefore aligning the received power density from all ASs to a similar level. For this purpose, the GS LME has to instruct the AS LME whether it should increase or decrease the current transmit power level. The GS precision when measuring received signal power is defined in Section 5.4.9, the power adjustment step is defined in Section 6.3.3. The range and the step size of the power level which is communicated to the ASs are defined in Section 10.5.4.6 and Section 10.6.30. The LME power control procedure in defined in Section 10.3.2.2.

8.9.7 Reception by the Receiver

The sampled signal shall be processed, before providing the data to the MAC sub-layer, according to the following steps:

- Start of the frame shall be detected
- Based on the OFDM synchronisation sequences, the time and frequency offset shall be estimated
- The frame shall be de-rotated based on the estimated frequency offset
- The serial data stream shall be converted into a matrix, so that one OFDM symbol occupies one row of the matrix
- The useful part of each OFDM symbol shall be extracted
- The extracted part of each OFDM symbol shall be transformed via an FFT operation into the frequency domain
- Complex channel response coefficients shall be estimated based on the received pilot symbols and the data symbols shall be multiplied with the corresponding coefficients
- Reliability information for each bit shall be computed via the Euclidean distances of the data symbols to the constellation points. This procedure relates to the demodulation
- Helical de-interleaving and convolutional soft decoding, making use of the reliability information shall be performed
- Block de-interleaving shall be performed
- RS decoding shall be performed

As the RL data segments shall be already time/frequency pre-compensated (see Section 8.9.4), steps 1-3 shall be discarded in the GS RX.

8.9.8 Data Transmission

In the PHY layer, data received from the MAC sub-layer shall be processed according to the following steps, prior to sending the data over an A/G interface:

- Data received from the MAC sub-layer shall be encoded and interleaved as illustrated in Figure 32
- Data shall be modulated
- The pilot symbols within one frame or tile shall be allocated
- The AGC preamble (if existent) and the synchronisation symbols shall be allocated
- The modulated data shall be mapped onto this frame or tile
- Each OFDM symbol within the frame or tile shall be transformed via an IFFT into the time domain
- Adding of a cyclic prefix and windowing shall be applied
- The frame shall be converted into a serial stream

8.10 Physical Layer Support for Voice Operations

The transfer of voice streams works basically the same way as the transfer of data. LDACS is designed to operate with the AMBE-ATC-10B vocoder which generates a 96 bit voice frame every 20 ms. Three voice frames (i.e. 60 ms of digital voice) are conveyed in one VI VOICE PDU. This requires the transmission of one VI VOICE PDU per 60 ms, which corresponds to the average duration of one MF. The periodic insertion of VI VOICE PDUs into the data stream is conducted by the MAC sub-layer.

8.11 PHY Interface to Service Users

The physical layer shall provide an interface to its service users as described in Section 7.2.1.

8.12 Physical Layer Parameters

Table 36 summarises all parameters, which were defined or mentioned in this chapter. In addition, a reference to the corresponding sections is provided.

Table 36: Physical Layer Parameters

Parameter	Abbr.	Value	Unit
FFT size (8.4.1)	N_{FFT}	64	
Sampling time (8.4.1)	T_{sa}	1.6	µs
Sub-carrier spacing (8.4.1)	Δf	9.765625	kHz
Useful symbol time (8.4.1)	T_u	102.4	µs
Cyclic prefix ratio (8.4.1)	G	11/64	
Cyclic prefix time (8.4.1)	T_{cp}	17.6	µs
OFDM symbol time (8.4.1)	T_s	120	µs
Guard time (8.4.1)	T_g	4.8	µs
Windowing time (8.4.1)	T_w	12.8	µs
Number of used sub-carriers (8.4.1)	N_u	50	
Number of lower frequency guard sub-carriers (8.4.1)	$N_{g,left}$	7	
Number of higher frequency guard sub-carriers (8.4.1)	$N_{g,right}$	6	
Total FFT bandwidth (8.4.2)	B_0	625.0	kHz
Effective RF bandwidth (8.4.2)	B_{occ}	498.05	kHz
Number of OFDM symbols within one frame (8.5)	N_{OFDM}	variable	
Duration of a Data/CC frame (8.5.1.1)	$T_{DF/CC}$	6.48	ms
Duration of a BC1 and BC3 sub-frame (8.5.1.2)	$T_{BC1/3}$	1.8	ms
Duration of a BC2 sub-frame (8.5.1.2)	T_{BC2}	3.12	ms
Duration of a BC frame (8.5.1.2)	T_{BC}	6.72	ms
Duration of a synchronisation tile (8.5.2.2)	T_{SYNC}	0.6	ms
Duration of an AGC preamble (8.5.2.2)	T_{AGC}	0.12	ms
Number of OFDM symbols in a DC segment (8.5.2.2)	N_{dc}	variable	
Guard time in a RA frame (8.5.2.3)	$T_{g,RA}$	1.26	ms

Parameter	Abbr.	Value	Unit
Duration of a RA frame (8.5.2.3)	$T_{sub,RA}$	840	µs
Duration of a Super-Frame (8.5.3)	T_{SF}	240	ms
Duration of a Multi-Frame (8.5.3.1)	T_{MF}	58.32	ms
Number of CC PHY-PDUs per MF (8.5.3.1)	N_{CC}	variable	
Duration of a RA frame (8.5.3.2)	T_{RA}	6.72	ms
Duration of a DC segment (8.5.3.2)	T_{DC}	variable	ms
Duration of an RL Data segment (8.5.3.2)	T_{DF}	variable	ms
Number of input byte of a RS code word (8.6.2.1)	K	variable	
Number of output byte of a RS code word (8.6.2.1)	N	variable	
Native coding rate of convolutional coder (8.6.2.2)	r_{CC}	variable	
Size of a helical interleaver block (8.6.2.4)	N_{I2}	variable	
Number of FL Data PHY-PDUs per MF (8.6.2.5)	N_D	variable	
Number of RL Data PHY-SDUs, assigned to an AS (8.6.2.6)	N_{SDU}	variable	
Number of coding blocks of an AS in a MF (8.6.2.6)	N_{cod}	variable	
Maximum coding block size for RL Data PHY-SDUs (8.6.2.6)	N_{lim}	variable	
Multiplication factor for the modulation (8.6.3)	c	variable	
Modulation rate (8.6.3)	r_{mod}	variable	
Roll-off factor for RC window (8.8.1)	α	0.107	

9 Medium Access Control (MAC) Sub-layer Specification

9.1 General Description

The Medium Access Control (MAC) is the lower sub-layer of the Data Link Layer (DLL). It interfaces with the Logical Link Control (LLC) sub-layer, which is the upper part of the DLL (which comprises the DLS and VI), and the Physical (PHY) layer. The MAC sub-layer relies upon the PHY-PDU structure provided by the PHY layer to create a MAC slot structure, which is derived from, but not identical to the PHY-PDU structure[15]. This slot structure is used to provide logical channels to the MAC service users – LLC entities. This is illustrated in Figure 41 and Figure 43. Note that the FL slot structure is shifted versus the MF structure.

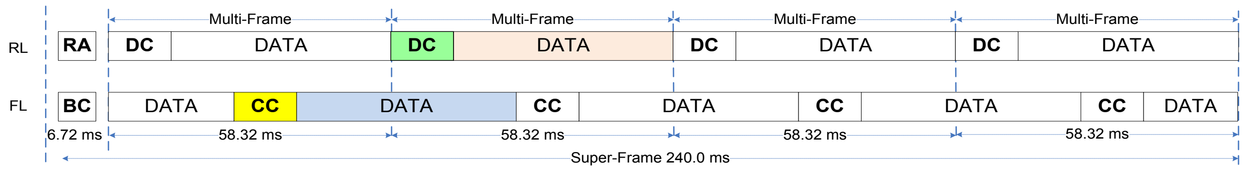

Figure 41: LDACS MAC Slot Structure

The GS locally allocates FL channel resources (i.e. FL PHY-SDUs) within slots and manages the access priorities. The RL uses a bandwidth on demand scheme. ASs have to request channel resources (RL PHY-SDUs) from the GS before they can transmit in the RL data channel (DCH). Resource requests are signalled over the Dedicated Control Channel (DCCH) to the GS. Access to the DCCH is deterministic and contention free as each AS has a dedicated sub-slot (identified by the control offset) within the DC slot that carries its DCCH. The GS collects the resource requests for DCH transmissions from all ASs and computes a suitable resource allocation. This resource allocation is announced to the ASs over the Common Control Channel (CCCH). ASs that have received a resource allocation in the DATA slot may now use the assigned PHY-SDUs for the transmission of their DCH.

The MAC sub-layer supports the transmission of user data and control data over logical channels. The AS's MAC has to keep track of the current RL PHY-SDU within each RL super-frame. Based on the "RL PHY-SDU number" an AS identifies slots and resource allocations and knows when it is allowed to transmit. A similar approach (based on Byte offsets instead of PHY-SDU offsets) is implemented on the FL. By this, the MAC of a particular AS is able to determine which FL data is intended for this AS (see Section 9.3 and Section 9.4).

[15] MAC slots carry PHY-SDUs. However, PHY-SDUs have fixed relationship to the PHY-PDUs. In particular, the number of PHY-PDUs allocated to the user corresponds to the number of PHY-SDUs.

9.1.1 Services

The MAC sub-layer manages the access of the LLC entities to the resources of the PHY layer. It provides the LLC with services to transmit user and control data over logical channels.

Internally the MAC sub-layer maintains its own time framing and synchronises with the PHY layer for Time Division Multiplexing (TDM) medium access.

9.1.1.1 MAC Time Framing Service

The MAC time framing provides the structure necessary to realise slot-based TDM access on the link. It provides the functions for the synchronisation of the MAC slot structure and the physical layer framing. The MAC time framing provides a dedicated time slot for each logical channel.

9.1.1.2 Medium Access Service

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

9.1.1.2.1 Broadcast Control Channel (BCCH)

The BCCH is a logical channel of the FL control plane. It is used by the GS to announce cell configuration information and to issue mobility management commands to ASs. Only the GS may transmit on this channel. The MAC sub-layer maps the BCCH onto the BC slot.

9.1.1.2.2 Random Access Channel (RACH)

The RACH is a logical channel of the RL control plane. It is used by ASs to request cell entry. Only ASs may transmit on this channel. The MAC sub-layer maps the RACH onto the RA slot.

Note: This allows RL synchronization at GS PHY layer and identifying which aircraft is requesting cell entry through the UA transmitted in the cell entry request.

9.1.1.2.3 Common Control Channel (CCCH)

The CCCH is a logical channel of the FL control plane. It is used to announce the TDM layout (i.e. MAC slot layout) and resource allocation of the FL and RL to the ASs. In addition, it is used by the GS to convey MAC and LLC control messages. Only the GS may transmit on this channel. The MAC sub-layer maps the CCCH onto the CC slot.

9.1.1.2.4 Dedicated Control Channel (DCCH)

The DCCH is a logical channel of the RL control plane. It is used by ASs to convey MAC and LLC control messages to the GS. Each AS has its own DCCH: no other entity than this AS may transmit on this channel. The MAC sub-layer maps the DCCH into (a dedicated sub-slot of) the DC slot.

9.1.1.2.5 Data Channel (DCH)

The DCH is a logical channel of the user plane. The DCH is used to convey the DLS PDUs and VI PDUs of the LLC sub-layer. The DCH exists on the RL and the FL. The MAC sub-layer maps the DCH onto FL or RL data slots.

9.1.2 State Transition Diagrams

The state transitions of the MAC sub-layer are specific for the AS and the GS.

9.1.2.1 State Transition Diagram for the Aircraft

Figure 42 shows the state transition diagram to be used in the AS MAC sub-layer.

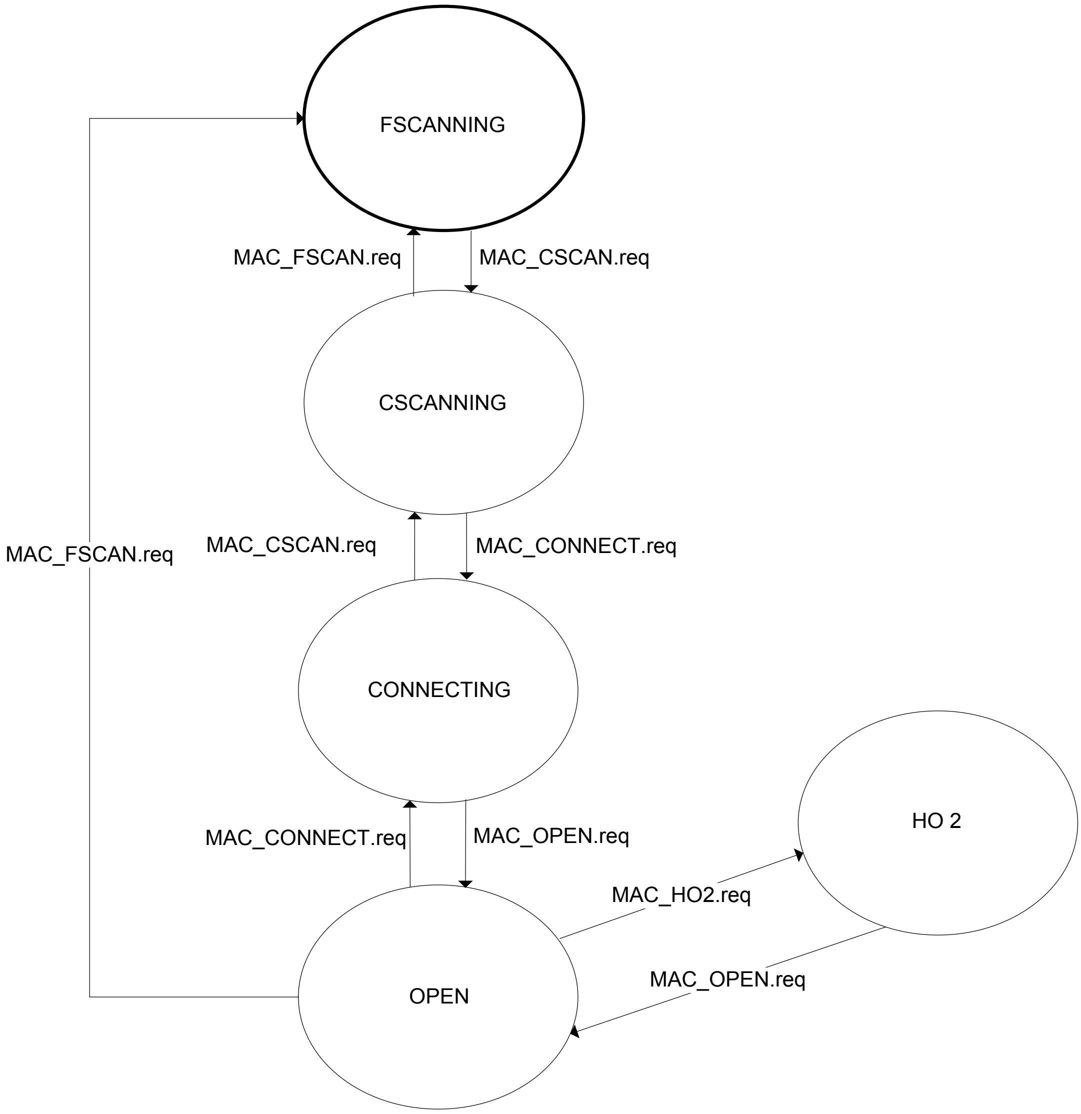

Figure 42: MAC State Transition Diagram of the Aircraft

9.1.2.1.1 FSCANNING State

The FSCANNING state is the initial state of the AS MAC – the AS MAC enters this state after POWER ON and remains in this state until its state is changed by the LME.

In the FSCANNING state no GS has yet allocated a AS Sub-net Access Code (AS SAC) and Control Offset (CO) to the AS, therefore user communication is not possible.

In the FSCANNING state the AS MAC shall continuously trigger fast scanning requests of the LDACS channels. The AS MAC shall repeat the call of the PHY_FSCAN.req primitive for each channel in round-robin while as it remains in the FSCANNING state. When the PHY layer reports the received power via the PHY_FSCAN.res, the AS MAC shall forward this information to the AS LME via the MAC_FSCAN.res.

9.1.2.1.2 CSCANNING State

In the CSCANNING state no GS has yet allocated a AS Sub-net Access Code (AS SAC) and Control Offset (CO) to the AS, therefore user communication does not take place.

In the CSCANNING state the AS MAC shall scan a given frequency (indicated in the primitive call) for a valid FL LDACS signal. The AS MAC shall report the result of the AS controlled scanning procedure via the MAC_CSCAN.res. After this it shall remain idle in the CSCANNING state until the MAC_CSCAN.req primitive is called again or the AS MAC state is changed.

NOTE: The difference between the FSCANNING state and the CSCANNING state is that in the FSCANNING state the AS scans only for power on the channel, and in the CSCANNING state actually decodes the signal.

9.1.2.1.3 CONNECTING State

In the CONNECTING state the AS MAC shall configure the physical layer for a given RL frequency (provided in the primitive call) via the PHY_CONF.req. The AS MAC shall wait for the successful synchronization of the physical layer (indicated by the PHY_FLSYNC.ind) to synchronize the MAC framing.

After FL synchronization has been achieved the AS MAC shall perform the random access procedure to request cell entry and synchronize the RL. In the CONNECTING state the AS MAC shall therefore transmit CELL_RQST control messages via the random-access channel (RACH) and receive CELL_RESP control message via the common control channel (CCCH).

If the random-access procedure succeeds and the AS received a CELL_RESP control message, the AS LME shall transition the MAC into the open state. The MAC shall use the assigned AS SAC immediately. The AS's LME shall then transit the DLS and VI into open state, too. In the CONNECTING state the AS MAC shall therefore forward all CELL_RESP messages received on the CCCH to the AS LME.

In the CONNECTING state the GS has not yet allocated an AS Sub-net Access Code (AS SAC) and Control Offset (CO) to the AS, therefore no user communication can take place.

9.1.2.1.4 Open State

In the OPEN state the GS has allocated an AS Sub-net Access Code (AS SAC) and Control Offset (CO) to the AS and user communication may take place. The MAC shall only process MAC-PDUs with its own AS SAC or the broadcast AS SAC.

In the OPEN state the AS MAC shall transmit control messages via its dedicated control channel (DCCH).

In the OPEN state the AS may transmit user data over the RL DCH if previously RL PHY-SDUs have been allocated to it by the resource management service of the GS LME.

In the OPEN state the AS LME may trigger the AS MAC (on request by the GS in the STB on the BCCH) to transiently scan a given frequency in order to prepare handover to the next GS. After scanning the AS physical layer shall be reset to the previous configuration to retain connectivity with the current GS.

9.1.2.1.5 HO2 State

The AS MAC is in the HO2 state from the beginning of the execution of the handover type 2 until the RL is completely synchronized to the new GS. In the HO2 state the new GS has allocated an AS Sub-net Access Code (AS SAC) address to the AS. RL user communication is suspended until full RL synchronization with the new GS has been achieved.

In the HO2 state the AS MAC may transmit the synchronization tile to the new GS.

The AS MAC shall configure the physical layer for the new GS and transmit a synchronization tile in the DC slot (PHY_SYNC.req) upon request of the LME. When the new GS LME entity receives the synchronization tile (PHY_SYNC.resp), it shall update the AS time advance, frequency, and power value, via the Link Management Data message (LM_DATA). After receiving the LM_DATA message the AS LME shall transition the AS MAC into OPEN state (via the MAC_OPEN.req primitive) to restore full connectivity.

9.1.2.2 States in the Ground-Station

The GS MAC shall be permanently in the OPEN state while the GS is running.

9.1.3 Interface to Service Users

The MAC sub-layer shall offer services to its service users via an interface described in Section 7.2.2.

9.2 Operation of the MAC Time Framing Service

9.2.1 Functions

The MAC time framing provides the frame structure necessary to realise slot-based TDM access on the link. It provides the functions for synchronisation of the MAC framing structure and the PHY layer framing. The MAC time framing provides a dedicated time slot for each logical channel.

9.2.2 MAC Time Framing Procedures

The MAC TDM frame structure shall be composed of Super-Frames (SF), and Multi-Frames (MF). Additionally, at the interface to the PHY layer, FL PHY-SDUs and RL PHY-SDUs of different capacities shall be used for FL and RL time framing, respectively. The elements are described below and illustrated in Figure 43.

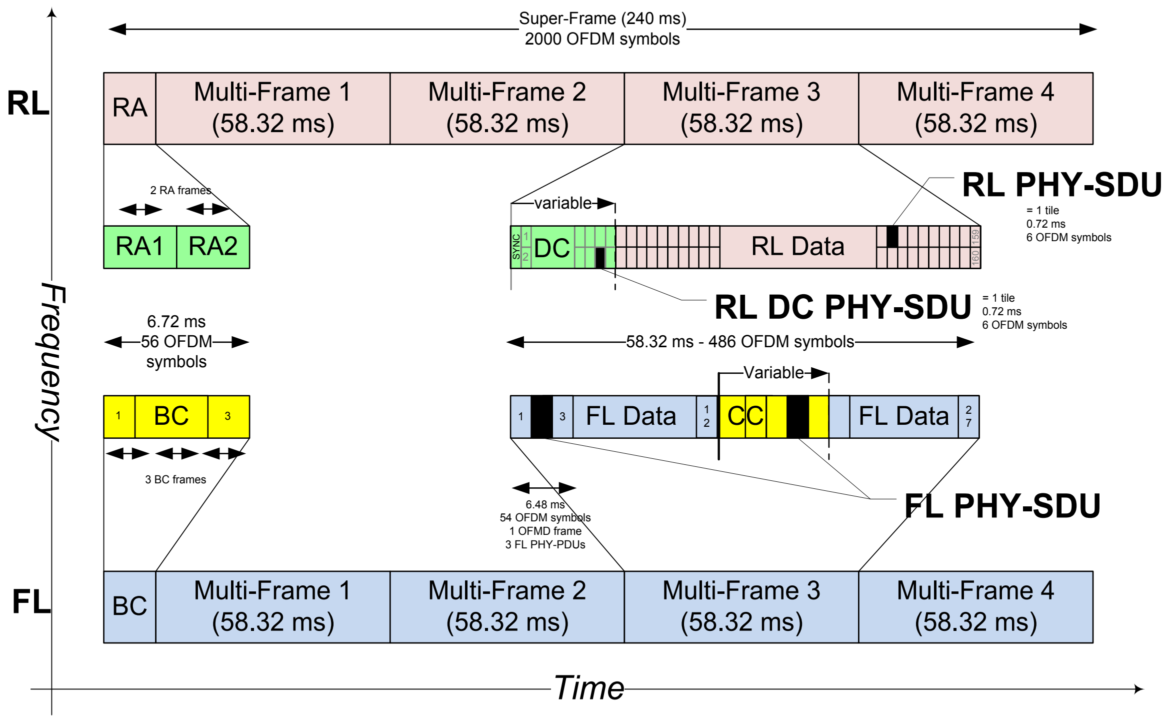

Figure 43: TDM Frame Structure Based on PHY-SDUs

9.2.2.1 Super-Frame

An RL Super-Frame (SF) shall consist of a Random Access (RA) slot and four Multi-Frames (MF). The RA slot shall contain two opportunities for random access.

An FL SF shall consist of a Broadcast Control (BC) slot for dissemination of cell based broadcast information and four MFs. After the BC slot, an FL SF shall contain four consecutive FL MFs.

9.2.2.2 Multi-Frame

An RL MF shall consist of a Dedicated Control (DC) slot and an RL DATA slot. The DC slot shall have a variable length, which shall be signalled via the CCCH.

Dependent on the length of the DC slot, a variable amount of RL PHY-SDUs for the RL DATA slot shall be available.

An FL MF shall consist of a Common Control (CC) slot and an FL DATA slot. The CC slot shall have a variable length, which shall be signalled towards the PHY layer through the CCCH (Section 9.6.5).

Dependent on the length of the MAC CC slot, a variable amount of FL PHY-SDUs for the FL DATA slot shall be available.

Note: The FL DATA slot is not aligned with the multi-frame boundary, but between two consecutive CC slots as illustrated in Figure 45*!*

9.3 Operation of the Medium Access Service on the FL

9.3.1 Functions

9.3.1.1 FL Data Channel (DCH) Medium Access

The FL DCH medium access is provided by the MAC and supported by the Radio Resource Management (RRM) function implemented by the LME. According to the granted resources the DLS requests transmission of data via the DCH from the MAC. This request shall include all necessary parameters signalled by the RRM (i.e. ACM, position in TDM frame and length).

9.3.1.2 Common Control Channel (CCCH) Medium Access

The FL CCCH medium access is conducted by the MAC sub-layer. The content transferred via the CCCH is coordinated by the LME. The amount of data transmitted via each CC slot may vary dependent on the amount of signalling data available per MF. The MAC time framing function shall adjust the size of the CC slot in each MF to the necessary minimum.

9.3.1.3 Broadcast Control Channel (BCCH) Medium Access

The BCCH medium access is conducted by the MAC sub-layer. The content transferred via the BCCH is coordinated by the LME. The size of the BC slot is constant.

9.3.2 FL Data Channel (DCH) Medium Access Procedures

The resources for the FL user data and control data transfer via the DCH shall be granted by the Radio Resource Management (RRM) function implemented by the GS LME. The DLS shall request transmission of data (i.e. one or several complete DLS PDUs) via the DCH from the MAC sub-layer.

The FL MAC headers shall be transmitted via the preceding CCCH, such that the receiving MAC (i.e. the AS MAC) is able to build the FL MAP (refer to Section 9.3.2.1). The FL MAP shall be used to identify PHY-SDUs destined for a specific AS.

Note: The FL_ALLOC message can be interpreted as the actual MAC header and is transmitted separately form the MAC payload (which is transmitted in the DCH) in the CCCH because of the stronger protection of the CCCH.

If user-specific ACM is supported, the modulation and coding scheme for the next FL data transmissions shall be announced in advance, via CCCH, such that the receiving PHY layer (i.e. the AS PHY layer) is able to analyse the CMS FL MAP (refer to Section 9.3.2.2). The CMS FL MAP shall be used to demodulate and decode incoming data accordingly.

9.3.2.1 FL MAP

The AS's MAC shall maintain a Forward Link Map (FL MAP) data structure. This data structure shall contain the information on the FL data being sent within the FL DATA slot following the CC slot (Section 9.3.2.2 and Section 10.5.4.7).

The FL MAP shall be built from FL_ALLOC control messages. FL_ALLOC control messages announce MAC Data PDUs and demand assigned voice circuits (which might have been established earlier). In addition to demand assigned voice circuits, the LME may configure dedicated voice circuits for its cell.

Dedicated voice circuits shall be announced via the BCCH. If available, this information shall be used by the FL MAP data structure.

The FL MAP enables the MAC to filter data from incoming PHY-SDUs using the Byte offsets given in the FL MAP. Data not destined for the AS shall be discarded silently by the MAC.

9.3.2.2 CMS FL MAP

The coding and modulation scheme (CMS) FL MAP shall only be used if user-specific adaptive coding and modulation is used.

The AS's PHY layer shall maintain a CMS Forward Link Map (CMS FL MAP) data structure. This data structure shall contain the information on the FL coding and modulation scheme used for the PHY-PDUs sent within the next FL DATA slots.

The CMS FL MAP data structure shall be announced via the CCCH using the CMS FL control message.

The CMS FL MAP shall only be maintained in the user-specific ACM mode.

9.3.3 Common Control Channel (CCCH) Medium Access Procedures

The GS's MAC sub-layer shall provide an interface towards the LLC entities (LME and DLS) to support the transfer of variable sized MAC Common Control PDUs. The MAC Common Control PDUs shall be used to multiplex signalling information of several simultaneous data link connections onto the CCCH.

The AS's MAC sub-layer shall provide an interface towards the LLC entities to support the exchange of signalling between peer entities. Thus, the AS's MAC shall de-multiplex control messages contained within CCCH. If a control message is addressed to this particular AS, the MAC shall forward the control message to the according LLC entity (i.e. DLS or LME).

9.3.4 Broadcast Control Channel (BCCH) Medium Access Procedures

The GS's MAC sub-layer shall provide an interface towards the LME to support transmissions on the BCCH. The BCCH shall be used in such a way that MAC Broadcast PDUs can be transmitted via the various BC slots.

The AS's MAC sub-layer shall provide an interface towards the LME to support the reception of MAC Broadcast PDUs on the BCCH. The MAC sub-layer shall forward the received MAC Broadcast PDUs to the LME.

9.4 Operation of the Medium Access Service on the RL

9.4.1 Functions

9.4.1.1 Dedicated Control Channel (DCCH) Medium Access

Medium access to the DCCH slot is performed using a sub-slot (having exactly the size of one RL DC PHY-SDU) in the DC slot. Each AS has one recurring dedicated sub-slot within the DC slot. This sub-slot is identified with a Control Offset (CO). Each AS is assigned a CO at cell entry. The CO shall be a unique number within the LDACS cell. The dedicated DCCH sub-slot of an AS need not recur in every DC slot.

The CO is used in the medium access control cycle. The medium access control cycle is a deterministic approach to grant AS dedicated resources on the RL medium (refer to Section 9.4.2.2). Dependent on the amount of simultaneously registered users the access time may increase or decrease. Each of the RL DC PHY-SDUs (i.e. sub-slot) is used by one AS in round-robin. This creates the RL DCH medium access control cycle.

The periodic assignment of COs within the current MF is provided to the AS MAC by the GS LME within the DCCH_DESC message. The DCCH_DESC message is mandatory in each CCCH.

Additional assignments may be provided to the AS MAC by the GS LME with DCCH_POLL messages.

9.4.1.2 RL Data Channel (DCH) Resource Acquisition

In order to acquire RL communications resources on the DCH, each AS has to report its resource needs to the GS. On the basis of these reports, the GS will then allocate RL channel resources (i.e. RL PHY-SDUs) according to the configured allocation policy. ASs transmit their resource requests over the DCCH channel in the DC slot.

9.4.1.3 Random Access Channel (RACH) Medium Access

The RACH is solely used to transmit cell entry request (CELL_RQST) control messages. The random-access algorithm applied shall be the “Random Delay Counter” approach with an exponential back-off mechanism.

9.4.2 DCCH Medium Access Procedures

9.4.2.1 A/C MAC Control Offset

Access to the DCCH is contention free for individual ASs. Each AS has a recurring sub-slot (carrying the RL DC PHY-SDU that is in a fixed relationship to the corresponding PHY-PDU) within the DC slot that conveys its DCCH. An AS identifies its DC sub-slot with its Control Offset (CO). The CO is assigned at cell entry with the cell entry response control message (CELL_RESP) by the LME. Note that the CO may be changed by the GS using the CHANGE_CO message. This allows the GS to keep the CO range (reasonably) contiguous.

Within the DCCH descriptor (DCCH_DESC) of each CCCH the Control Offset Start (COS), Control Offset Modul (COM), and the number of served control offsets (COL) in the next DC slot are announced. The first RL DC PHY-SDU of the DC slot shall be used by the AS with the CO equal to COS. The second RL DC PHY-SDU shall be used by the AS with the control offset (COS+1) modulo COM, and so forth up to (COS+COL) modulo COM. Each AS shall use the RL DC PHY-SDU identified by its CO in the DC to transmit its DCCH.

The GS may use the DCCH_POLL message to assign additional RL DC PHY-SDUs to specific AS. The AS is identified by its control offset (CO). The AS shall use the RL DC PHY-SDU identified by Control Offset Index (COI), which identifies the COIth RL DC PHY-SDU in the DC slot.

The GS shall maintain the pool of COs assigned to individual ASs.

9.4.2.2 Medium Access Control Cycle

The medium access control cycle applies only for aircraft. Dependent on the amount of simultaneously active users the medium access control cycle can grow or shrink. Each SF contains four DC slots which start at a fixed position within the SF. These slots also indicate the start of an MF.

The size of the DC slot shall be set by the GS.

Note: The GS may adapt the size of the DC to trade of lower medium access latency (larger DC) against higher data capacity (smaller DC and therefore larger DATA slot).

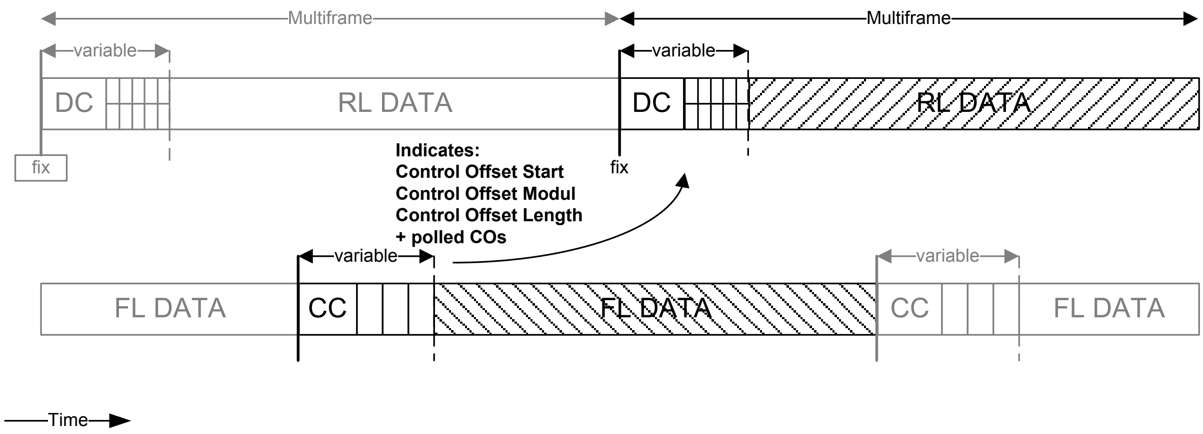

Figure 44: DCCH Control Offset

Note: The length of the CC slot may only change within the limits of the physical layer implementation i.e. in steps of 1 FL PHY-SDU, see Section 8.5.3.1.

Note: The FL DATA slot is not aligned with the multi-frame boundary, but between two consecutive CC slots as illustrated in Figure 45*!*

9.4.2.3 Allocating the DCCH

The DC RL DC PHY-SDUs shall be assigned to the AS's DCCHs in round-robin. The AS population is limited (by the CO size: 9 Bit) to at most 512 AS per GS (per cell). In this case, the DC slots in all MFs will always be used as the length of the medium access cycle is adjusted to the AS population.

9.4.3 RL Data Channel (DCH) Resource Acquisition Procedures

The resource acquisition procedure for RL transmissions shall utilize the media access control cycle as described in the previous section. Each time a DC slot is announced in the CCCH, the AS's MAC shall check whether its CO is handled (included) within this DC slot. If the number of registered AS is larger than the DC size, not every CO can be handled in the same DC slot. The DCCH_DESC announces which COs are handled in the DC slot. If its CO is handled in this slot, the AS's DCCH is transmitted within the indicated RL DC PHY-SDU (which is identified by the CO.) The MAC shall then encapsulate (among other control messages) the reported DLS resource needs (RSC_RQST control message) of the DLS queues (i.e. service classes) into a MAC Dedicated Control PDU. This PDU shall be transmitted in the next DCCH.

The DLS status information shall be updated by the DLS every time the resource needs have changed (refer to Section 11.2.3). The MAC shall transmit the resource request(s) among other control messages via the DCCH in the current DC slot and shall receive a response message (RL_ALLOC) in the CCCH in the following CC slot. Note that an RL_ALLOC control message is only transmitted by the GS if bandwidth has been allocated toward an AS.

All resource requests for RL data transmissions shall be aligned to the size of RL PHY-SDUs. The number of octets conveyed within a single RL PHY-SDU is dependent on the used ACM scheme.

Constant resource requests (indicated by the PRSC_RQST) shall be used to request demand assigned voice circuits. They shall be issued only once. If the resource is not needed anymore (i.e. the voice circuit is de-allocated) the request shall be withdrawn via the resource cancellation control message (RSC_CANCEL).

9.4.3.1 RL MAP

The GS MAC shall maintain a Reverse Link Map (RL MAP) data structure. This data structure shall contain the information on the RL data being sent within the next MF (Figure 45).

The RL MAP shall be built using the RL_ALLOC control messages announcing the data messages and the P_RL_ALLOC (periodic RL allocation) control messages that announce on demand assigned voice circuits of the next MF. Additionally, the GS LME may permanently configure dedicated voice circuits for its cell. If dedicated voice circuits are configured, they shall be included into the RL MAP, too.

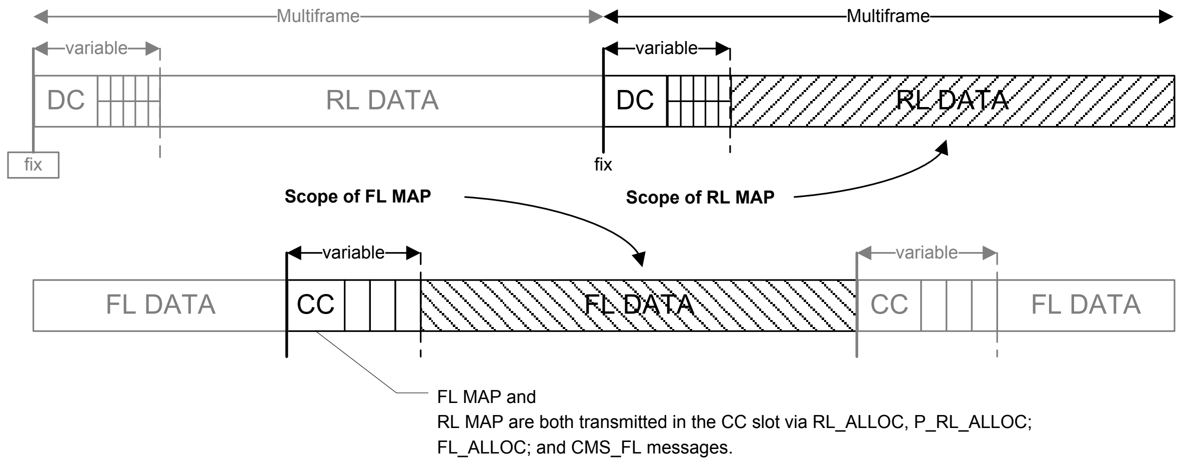

Figure 45: Scope of RL MAP and FL MAP.

Note that he FL DATA slot is shifted relative to the multiframe boundary.

9.4.3.2 CMS RL MAP

The Coding and Modulation Scheme (CMS) RL MAP shall only be used if user-specific adaptive coding and modulation is used.

The GS's PHY layer shall maintain a CMS RL MAP data structure. This data structure shall contain the information on the RL coding and modulation scheme used for the data being sent within the next RL MF. The data structure shall be built locally by the GS as it is assigning the resources (including CMS) of the upcoming RL MF.

9.4.4 RACH Medium Access Procedures

Within each SF two random access opportunities shall be available for each RA slot. The RA slot shall be exclusively used for cell entry request control messages (CELL_RQST).

The medium access algorithm applied for the RACH shall be the "Random Delay Counter" approach. This approach uses a range of available slots and selects one randomly on which the message is going to be sent. The first access on the random-access slot shall consider the RA slot available within the next SF (i.e. two random access opportunities); the CELL_RQST shall be retransmitted using an exponential back-off algorithm until the MAC is transitioned into another state by the AS LME. This means that with each iteration the amount of random access opportunities considered for the next transmission shall be increased exponentially (i.e. 4, 8, 16, 32, etc. up to MAC_P_RAC - compare Figure 46).

A new random access shall only be allowed after all random-access possibilities of the previous attempt have passed.

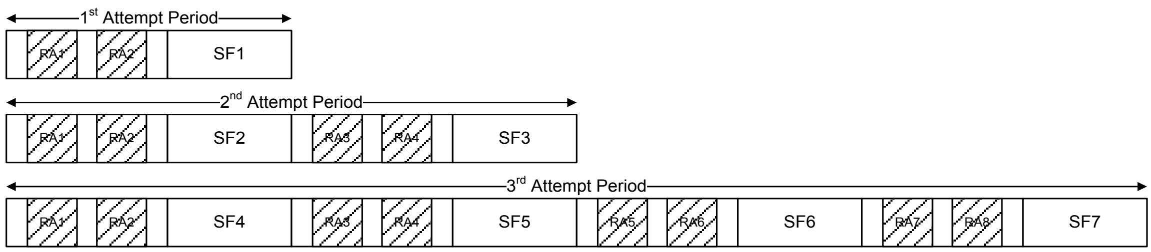

Figure 46: RACH Exponential Back-Off

9.5 MAC Parameters

9.5.1 Random Access Maximum Back-off (MAC_P_RAC)

The random-access maximum back-off parameter shall indicate the maximum length of the RACH exponential back-off. The default value shall be 64 (i.e., no further back-off after 6 attempts).

9.6 MAC PDU Format Definition

9.6.1 MAC Data PDU

The Data Channel DCH shall be transmitted in allocated parts of the FL and RL DATA slots. Allocations are made with FL/RL_ALLOC control messages in the CCCH. Each resource allocation shall convey data received from the DLS entity (a MAC-SDU, i.e. concatenated DLS-PDUs). This is illustrated in Figure 47.The MAC does not append a Frame Check Sequence (FCS) as each DLS-PDU conveyed within the resource allocation already includes its own CRC-32.

The receiving MAC returns the complete MAC-PDU (i.e. FL/RL allocation) to the DLS. The DLS extracts DLS-PDUs from the MAC-PDU according to the DLS-PDU header information.

Note that on DCH may contain multiple MAC-SDUs addressed to different SACs. The addressee is identified in the corresponding FL_ALLOC/RL_ALLOC message.

Note that a MAC-SDU may contain multiple DLS-PDUs since (fragments of) only one DLS-SDU (i.e. higher layer packet) are encapsulated in one DLS-PDU.

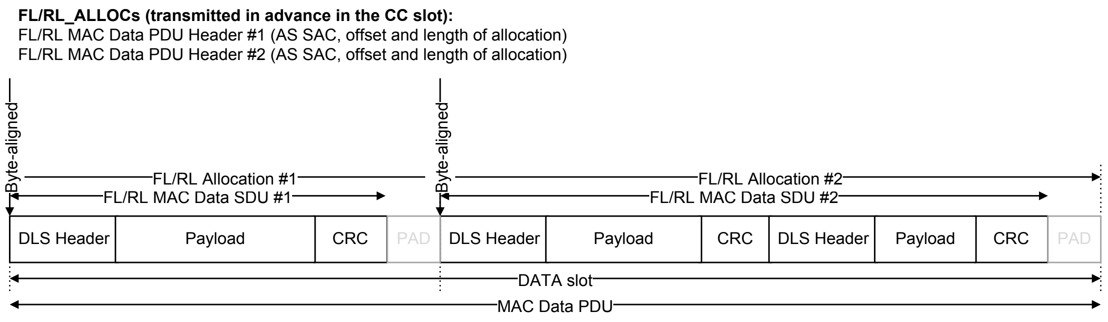

Figure 47: DCH

9.6.2 MAC Random Access PDU

The RACH shall use the two sub-slots of the RA slot. Each slot can carry on MAC Random Access PDU. The MAC Random Access PDU is exclusively used to convey the cell entry request control message (CELL_RQST). The transmission of a CELL_RQST control message shall be initiated by the AS LME.

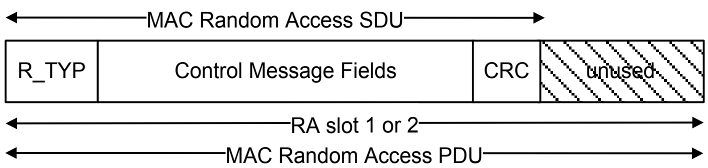

Figure 48: RACH. Note that the only legal control message is CELL_RQST.

9.6.3 MAC Broadcast Control PDU

The BCCH shall use the three sub-slots of the BC slot. It shall contain management information for the operation of LDACS. MAC Broadcast Control PDUs shall be transmitted in the structure illustrated in Figure 49.

All MAC broadcast control PDUs shall be transmitted byte-aligned and contain therefore appropriate padding fields. Unused parts of the MAC Broadcast Control PDU shall be padded with zeros. In case of a transmission error the MAC can find the next intact MAC broadcast control PDU by CRC hunting using well-known B_TYP and CRC tuples which start always byte-aligned. If applicable, unused bits of the BC sub-slot shall be padded with zeros. This is illustrated in Figure 49.

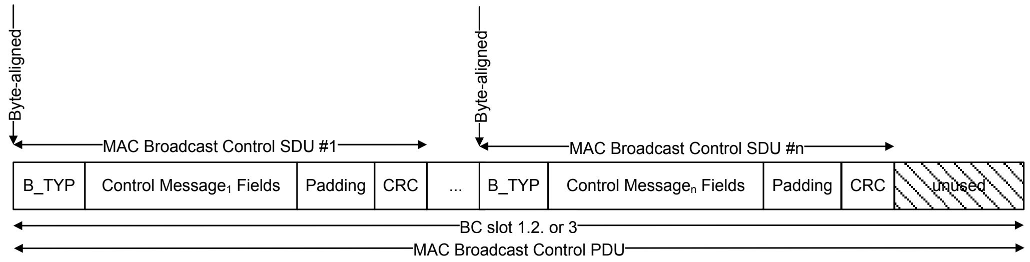

Figure 49: BCCH

BC sub-slot 1 and BC sub-slot 3 shall convey information about adjacent cells. That is, the Adjacent Cell Broadcast control message. BC sub-slot 2 shall convey information about the current cell (i.e. System Identification Broadcast). In addition, all Broadcast PDUs shall allow transferring information about the ASs, which are allowed to scan within the next BC slot (i.e. Scanning Table Broadcast), and dedicated voice services.

9.6.4 MAC Dedicated Control PDU

The MAC Dedicated Control PDU (MDCP) shall be transmitted in one 83 Bit RL DC PHY-SDU. It may convey several signalling messages. The MDCP trailer shall consist of a CRC-8 FCS. Each user shall transmit a single MDCP if its Control Offset (CO) is handled within the next MF. The MDCP shall be conveyed using the most robust coding and modulation.

Control messages (D_TYP, Msg.) are generated by the LLC and encapsulated by the MAC adding PADDING and CRC. If no control messages are being requested for transmission a keep-alive control message shall be generated by the MAC, encapsulated, and transmitted (this means that an AS shall transmit always in its DCCH).

Note that control message sizes are chosen such that all messages start byte-aligned.

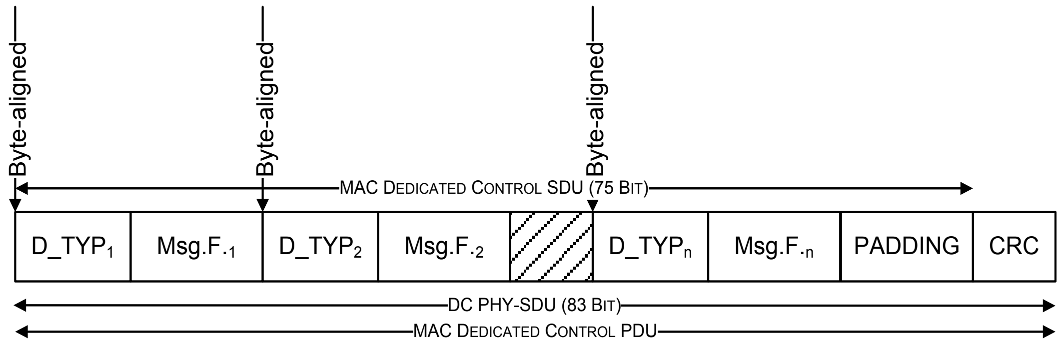

Figure 50: DCCH

The MAC Dedicated Control PDU may contain several control messages, which are transmitted using a defined priority order. Bits which are not used within the RL DC PHY-SDU shall be padded with zeros. The AS's MAC shall build and transmit an MDCP according to the received internal signalling.

9.6.4.1 Keep Alive (KEEP_ALIVE)

The keep-alive control message shall be transmitted by the MAC if no other control message is being sent such that the peer entity is always informed about the AS presence. The KEEP_ALIVE control message shall contain the following values.

Table 37: Keep Alive

Field	Size	Description
D_TYP = %1001	4 Bit	Keep Alive
PAD	4 Bit	Reserved

9.6.5 MAC Common Control PDU

MAC Common Control PDUs shall convey one or several signalling messages.

The length of the CC slot (in which the MAC Common Control PDUs are conveyed) is indicated by the GS physical layer to the AS physical layer. The CC slot shall always start with the slot descriptor (SLOT_DESC) control message.

The CC slot may contain several MAC Common Control PDUs conveying control messages generated by the LLC transmitted using a predefined order (see table below).

All MAC Common Control PDUs shall be transmitted byte-aligned and the message sizes have been chosen to support this. In case of a transmission error the MAC can find the next intact MAC Common Control PDU by CRC hunting using well-known C_TYP, CRC tuples.

The SLOT_DESCRIPTOR, DCCH_DESC, and (in the case of user-specific ACM) CMS_FL messages are always sent first. This concept is illustrated in Figure 51 and Figure 52.

Unused Bytes at the end of the CC slot shall be padded with binary zeros, which is equivalent to the PADDING C_TYP (see Table 39) followed by binary zeros.

The MAC shall discard all PDUs of the current CC slot and the next DC slot if the SLOT_DESCRIPTOR or DCCH_DESC message is destroyed.

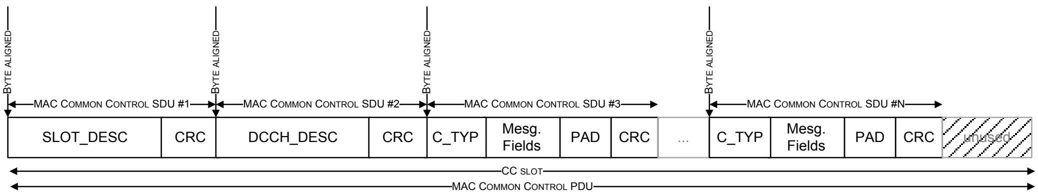

Figure 51: CCCH in Cell-specific ACM mode

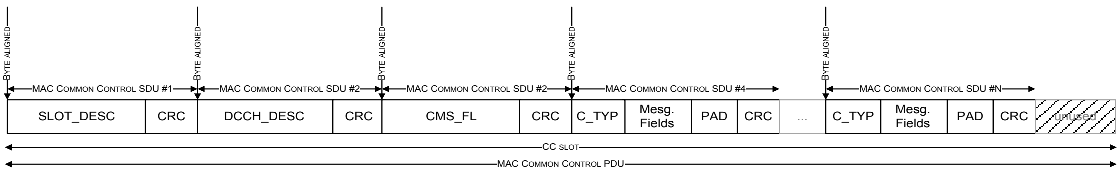

Figure 52: CCCH in User-specific ACM mode

NOTE: The AS MAC can determine the message receiver (LME or DLS) from the C_TYP field.

9.6.6 MAC Frame Check Sequence

For the MAC Dedicated Control PDU the MAC shall use as Frame Check Sequence (FCS) algorithm a Cyclic Redundancy Check (CRC). The following CRC shall be used for error detecting:

- CRC-8: 0x97

CRC computation shall start with the Most-Significant-Bit (MSBit) of the Most-Significant-Byte (MSByte) and ends with the Least-Significant-Bit (LSBit) of the Least-Significant-Byte (LSByte).

Messages with incorrect CRC shall be discarded.

9.7 MAC Information Element Definition

The following information element definition describes all fields used within the individual control messages described for the MAC Random Access PDU, the MAC Broadcast Control PDU, the MAC Common Control PDU, and the MAC Dedicated Control PDU.

All information elements shall be encoded in network bit and byte order i.e. big-endian bit and byte order.

9.7.1 B_TYP – Broadcast Control Type

This field indicates the broadcast control type. B_TYP shall have a size of 4 bits.

Table 38: Broadcast Control Message Overview.

Broadcast control message	Message ID	B_TYP Bit Value
Reserved	PADDING	%0000
Adjacent Cell Broadcast	ACB	%0001
System Identification Broadcast	SIB	%0010
Scanning Table Broadcast	STB	%0011
Voice Service Broadcast	VSB	%0100
GS Position Broadcast	GSPM	%0101
Reserved	-	%0110 - %1111

9.7.2 C_TYP – Common Control Type

This field indicates the common control type. C_TYP shall have a size of 5 bits.

Table 39: Common Control Messages Overview

Common Control Message	Acronym	Initiated by	Order	C_TYP Bit Value
Reserved	PADDING	MAC	-	%00000
Slot Descriptor	SLOT_DESC	LME	1	-
DCCH Descriptor	DCCH_DESC	LME	1	%00001
CMS FL Map	CMS_FL	LME	2	%00010
DCCH Poll	DCCH_POLL	LME	2	%00011
Cell Entry Response	CELL_RESP	LME	3	%00100
Change CO	CHANGE_CO	LME	3	%00101
Cell Entry Denied	CELL_DENIED	LME	3	%00110
Link Management Data	LM_DATA	LME	4	%00111
Cumulative Acknowledgement	ACK_CUM	DLS	5	%01000
Selective Acknowledgement	ACK_SEL	DLS	5	%01001

Common Control Message	Acronym	Initiated by	Order	C_TYP Bit Value
Fragment Acknowledgement	ACK_FRAG	DLS	6	%01010
FL Allocation	FL_ALLOC	LME	7	%01011
RL Allocation	RL_ALLOC	LME	8	%01100
Periodic RL Allocation	P_RL_ALLOC	LME	8	%01101
SYNC Signalling	SYNC_POLL	LME	9	%01110
Handover Command	HO_COM	LME	10	%01111
Keep Alive	KEEP_ALIVE	LME	11	%10000
Reserved	-	-	-	%10001 – %11111

9.7.3 D_TYP – Dedicated Control Type

This field indicates the dedicated control type. D_TYP shall have a size of 4 bits.

Table 40: Dedicated Control Messages Overview

Dedicated control message	Message ID	Priority	Initiated by	D_TYP Bit Value
Reserved	PADDING	-	MAC	%0000
Power Report	POW_REP	1	LME	%0001
Cumulative Acknowledgement	ACK_CUM	2	DLS	%0010
Selective Acknowledgement	ACK_SEL	2	DLS	%0011
Fragment Acknowledgement	ACK_FRAG	3	DLS	%0100
Cell Exit	CELL_EXIT	3	LME	%0101
Resource Cancellation	RSC_CANCEL	4	DLS	%0110
Resource Request	RSC_RQST	5	DLS	%0111
Permanent Resource Request	PRSC_RQST	5	LME	%1000
Keep Alive	KEEP_ALIVE	6	MAC	%1001
Reserved				%1010 - %1111

9.7.4 R_TYP – Random Access Type

This field indicates the random-access type. R_TYP shall have a size of 2 bits and shall take on the following values:

Table 41: Random Access Type Values

MDCP message	Message ID	Priority	Bit Value

Reserved		-	%00
Cell Entry Request	CELL_RQST	1	%01
Reserved		-	%10 - %11

9.7.5 SAC – Sub-net Access Code

This field indicates the Sub-net Access Code (SAC). This field shall have a size of 12 bits and shall take on the following values.

Table 42: Sub-net Access Code Values

Description	Value
Reserved	%000000000000
Ground Station Sub-net Access Codes (GS SAC) or Aircraft Station Sub-net Access Codes (AS SAC)	%000000000001 to %111111111110
Broadcast AS SAC	%111111111111

10 LDACS Management Entity (LME) Specification

10.1 General Description

The LDACS Management Entity (LME) supports the configuration, resource management and mobility management of LDACS.

10.1.1 Services

10.1.1.1 Mobility Management Service

The mobility management service provides support for registration and de-registration (cell entry and cell exit), the scanning of neighbouring cells, and handover between cells. In addition, it manages the addressing of ASs within cells.

The mobility management of the GS LME shall be coordinated by the GSC.

10.1.1.2 Resource Management Service

The resource management service provides link maintenance (power, frequency, and time adjust), support for adaptive coding and modulation, and resource allocation in the user plane.

10.1.2 State Transition Diagram

Only the AS LME experiences state transitions according to the status of the link.

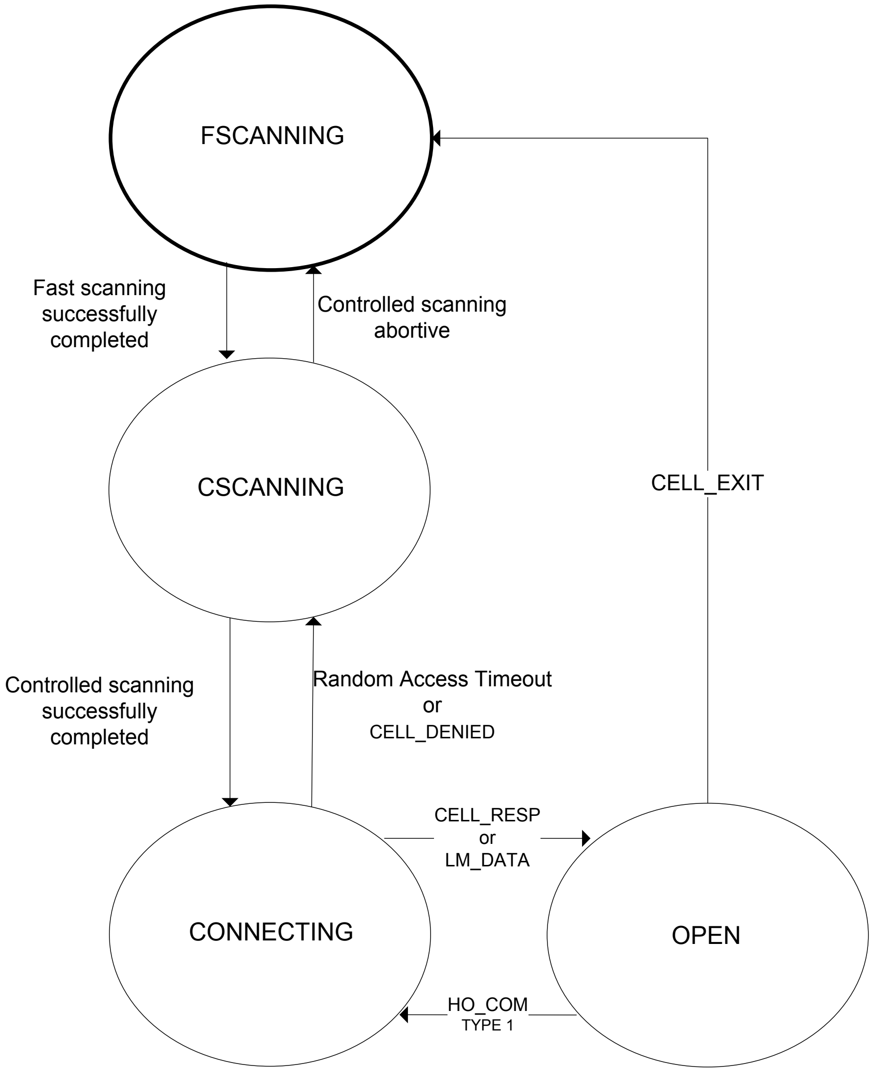

Figure 53: Aircraft LME State Transition Diagram

NOTE: This figure visualizes a situation, where loss of synchronization or other failures were not considered.

10.1.2.1 FSCANNING State

The airborne LME enters the FSCANNING state after POWER ON.

Within the FSCANNING state the AS LME shall trigger the fast scan procedure in the MAC by issuing the MAC_FSCAN.req primitive. Once triggered, the scanning procedure is autonomously executed for all LDACS channels by the MAC, without further LME assistance. If the FSCANNING procedure delivered useful results (at least one active LDACS GS was detected), the AS LME may command the MAC transition into the CSCANNING state and itself shall transit into the CSCANNING State. Otherwise the LME shall remain in the FSCANNING state.

10.1.2.2 CSCANNING State

Having entered the CSCANNING state, the AS LME shall invoke the AS controlled scanning procedure of the selected channels by repeatedly calling the MAC_CSCAN.req primitive. That primitive provides to the AS MAC a list of candidate channels to be scanned via the AS controlled scanning procedure (one channel is scanned at a time). When the procedure is completed for a particular channel, the LME shall be informed via MAC_CSCAN.res primitive. After each scan the LME shall decide whether the scanned GS is suitable for an initial cell entry.

If the LME finds the scanned GS acceptable, it shall transit into the CONNECTING state. Otherwise the AS LME remains in the CSCANNING state where it shall request the scan of the next channel from the list. Therefore, the AS will by default try to contact the first GS that proves to be acceptable.

If the CSCANNING procedure does not return any acceptable GS channel within pre-defined time (LME_T_CSCAN) or the list of GSs was exhausted, the AS LME shall return into the FSCANNING state.

10.1.2.3 CONNECTING State

Within this state an AS is not allowed to send user data. After having entered this state the LME shall issue a MAC_CONNECT.req toward its MAC, the MAC then waits for the FL synchronization indication of the PHY layer.

Upon having received the MAC_RACH.req (CELL_RQST) from the AS LME, the AS MAC will send the RA sub-frame to the GS on the specified RL channel (determined in the CSCANNING state) using the random-access procedure.

When the LME receives via MAC_CCCH.ind primitive with the cell entry response (CELL_RESP) from the GS, it shall change its state to OPEN state and set the MAC into OPEN state via MAC_OPEN.req primitive.

If the LME receives via MAC_CCCH.ind primitive the cell denied control message (CELL_DENIED) from the GS, it shall change its state to CSCANNING state.

If the MAC_CCCH.ind primitive with the GS response is not received in LME_T_CELL_RESP time, the LME shall return into the CSCANNING state.

NOTE: The CELL_RESP and LM_DATA messages contain the same configuration information for the PHY layer.

10.1.2.4 OPEN State

Within this state an AS shall be able to transmit and receive user plane data.

When no HOV command to the next GS has been issued, but the AS PHY has signalled (via PHY_CONF.ind) that the FL signal quality has become unacceptably poor (the AS is about to leave the coverage of the LDACS network), the AS LME shall initiate sending the CELL_EXIT message to the current GS by issuing the MAC_DCCH.req (CELL_EXIT). After that, the AS LME shall issue the MAC_FSCAN.req to the MAC and transit to the FSCANNING state.

Handovers to a next GS are initiated from the OPEN state. There are two types of handovers, Type 1 and Type 2. Both kinds of handovers are prepared by the current GS and supported by the AS via background scanning of adjacent GSs while being in the OPEN state. In case of handover Type 2, the background GS controlled scanning of adjacent GSs is facilitated by the fact that FL SFs of all GSs controlled by the same GSC must be synchronized to a common network time reference.

NOTE: It is not possible to execute a HO Type 2 to the GS of another sub-network if the sub-network does not use the same time reference. In this case a Type 1 HO (i.e. an explicit cell entry procedure) is required.

10.1.3 LME Interface to Service Users

The LME shall provide an interface to its service users as described in Section 7.2.4.

10.2 Operation of the Mobility Management Service

10.2.1 General Description

The mobility management service is supported by the broadcast control messages adjacent cell broadcast (ACB) and scanning table broadcast (STB). Adjacent cell broadcast indicates neighbouring cells and the scanning table broadcast indicates the AS which are allowed to scan adjacent cells during the next broadcast control slot.

10.2.2 Functions of the Mobility Management Service

10.2.2.1 Scanning

The scanning function is necessary to determine signal qualities of adjacent cells. The GS, which is aware of the surrounding LDACS network topology, indicates toward the AS when it is allowed to scan an adjacent cell. The received signal quality is reported back toward the GS in order to support the handover decision.

10.2.2.2 Cell Entry

The cell entry function is necessary to initiate communication services. During cell entry an AS acquires a valid AS Sub-net Access Code (AS SAC) and a Control Offset (CO), which is necessary to determine the individual DC slot. The cell entry function is also necessary to synchronise the LDACS radio on the RL.

10.2.2.3 Cell Exit

The cell exit function is used to acknowledge the receipt of a handover command from the GS. An explicit cell exit, if an AS is leaving the LDACS coverage zone or is simply turning off the LDACS radio, is not needed. The GS is recognizing that an AS has left the cell using its own mechanisms.

10.2.2.4 Addressing

The GS's LME shall coordinate the allocation of subscriber access codes (AS SACs) toward individual AS with its GSC. The allocation of a sub-net access code shall be unique within the GSC's sub-network. Additionally, the LME shall assign a unique control offset (CO) only valid for the cell an AS is registering to.

10.2.2.5 Handover

The handover function provides seamless inter-cell aircraft mobility. The LDACS handover is GS controlled. Two different types are supported, one where interconnected adjacent GSs are coordinating the handover, and one where no coordination among GSs takes place (e.g. GSs are not interconnected).

10.2.3 Scanning Procedures

10.2.3.1 Fast Scanning Procedure

The fast scanning procedure shall be used by the AS, when the AS is turned "ON" and it starts to scan the a-priori known LDACS channels, searching for active GSs. The Fast Scanning is conducted by the AS, without any GS assistance.

The aim of the Fast Scanning procedure is to identify active LDACS FL channels and measure the received signal power on each scanned channel, without attempting to retrieve any additional information. Measuring the received FL signal power is possible as all LDACS GSs transmit continuously on FL.

10.2.3.2 AS Controlled Scanning Procedure

After the Fast Scanning has stopped, the AS LME selects – among all scanned channels – a pre-defined number of active LDACS channels with highest indicated estimated received signal power for subsequent AS Controlled Scanning.

The AS Controlled Scanning is conducted without any GS assistance.

10.2.3.3 GS Controlled Scanning Procedure

The GS controlled scanning procedure is initiated for a particular AS by the controlling GS when the GS wants this AS to conduct a handover. In order to select the new GS, the current GS must assess the signal power levels of all candidate neighbour GSs as received by the AS and reported by the AS using the POW_REP message. These measurements are periodically triggered by the current GS using the STB message.

Therefore, scanning of a specific frequency shall be initiated by the GS through the scanning table broadcast (STB) control message transmitted via the broadcast control channel (BCCH). This control message indicates the AS allowed to scan during the next broadcast control slot and also the GS SAC of the GS to be scanned.

After a successful GS controlled scanning procedure, the AS physical layer shall report via MAC to the LME the measured signal quality and optionally provide the content of the received PHY-SDUs (if it could be decoded). If the signal quality was good enough, the BC slot of the scanned GS could be recognized and its content properly decoded, the information contained within the BC2 slot shall be forwarded to the LME. Otherwise, only measured FL power is submitted to the LME. The LME shall store the information received by the physical layer and shall forward the information about received FL signal power through a power report control message (POW_REP) towards the GS. The collected power reports shall provide the basis for handover decisions at the current GS.

10.2.4 Cell Entry and Cell Exit Procedures

10.2.4.1 Cell Entry

The cell entry procedure requiring a cell entry request (CELL_RQST) message is necessary each time the system is initialized and if Type 1 Handovers are used. The AS LDACS Management Entity (LME) shall request the transmission of a cell entry request (CELL_RQST) message via the random-access channel (RACH) from the MAC. The cell entry request message shall contain a unique address identifying the LDACS radio. If the MAC sub-layer has already resource reservation requests, it may include control messages accordingly.

The GS's MAC shall receive the MAC Random Access PDU from the GS's physical layer. The received CELL_RQST message and the current time, frequency, and power offset (signalled from the GS physical layer towards the MAC) shall be reported to the GS LME via the MAC_RACH.ind primitive. After the GS's LME assigned a proper sub-net access code AS SAC the GS's MAC shall transmit a cell entry response (CELL_RESP) message via the common control channel (CCCH) notifying the AS of its SAC.

The AS MAC shall receive the cell entry response message (CELL_RESP) and forward it towards the LME. The AS LME shall then transition into the OPEN state and transition the AS MAC into the OPEN state with the MAC_OPEN.req. The AS MAC shall then configure the physical layer (PHY_CONF.req) in such a way that timing, frequency, and power values are adapted to the requested values. After this procedure the synchronisation of the reverse link shall be complete and the data link shall be fully operational. If the MAC_CCCH.ind primitive with the GS response is not received in LME_T_CELL_RESP time, the LME shall return into the CSCANNING state.

10.2.4.2 Cell Exit

Prior to the handover procedure the AS LDACS Management Entity LME shall receive a handover command control message (HO_COM) from the GS. If an AS receives such a control message (regardless whether type 1 or type 2 handover is supported) a cell exit control message (CELL_EXIT) shall be sent via the dedicated control channel (DCCH).

> *NOTE: The handover command control message (HO_COM) shall be sent in such a way that the concerned AS is able to respond immediately in the upcoming DCCH.*

10.2.5 Addressing Procedure

The GSC's NME and the GS's LDACS Management Entity (LME) shall coordinate the allocation of subscriber access codes (AS SAC) to individual AS.

The GSC's NME is responsible for the allocation of a unique sub-net access code (AS SAC) within the sub-net and the GS's LME is responsible for the allocation of a unique control offset within the cell.

10.2.6 Handover Procedures

LDACS shall support a GS based handover strategy. That is, all handovers shall be triggered by the GS on the basis of POW_REP messages received from the AS triggered by the GS through the STB message. Two types of handover shall be supported:

- Type 1 - Involved GSs are not interconnected and do not coordinate the handover procedure
- Type 2 - Involved GSs are interconnected and coordinate the handover procedure

Type 1 handovers are supported by the AS MAC through the cell entry procedure. Type 2 handovers are supported by the AS MAC through the handover state where active data transmissions are suspended and the dedicated synchronisation slot is utilized to retrieve time advance, power, and frequency adjustments.

10.2.6.1 Type 1 Handover

The Type 1 handover procedure is triggered through a handover command control message (HO_COM) where the HOT bit is cleared. The handover command control message (HO_COM) shall contain the GS identifier (GS SAC) an AS shall hand over to. Based on the GS SAC an AS shall be able to determine the forward link and reverse link frequencies, which shall be permanently broadcast via the BCCH. A Type 1 handover shall be conducted through a cell entry procedure.

The Handover Command Type 1 shall not be acknowledged, instead a cell exit control message shall be sent. For the commanding GS a transmission error of the handover command control message (HO_COM) shall be recognized through the keep-alive control message (KEEP_ALIVE) which shall always be sent by AS if it has no other control messages to send. A transmission error of the cell exit control message (CELL_EXIT) shall be recognized through the keep-alive time-out at MAC.

10.2.6.2 Type 2 Handover

In order to support a Type 2 handover, the link management entities of adjacent GSs shall be coordinated by a common GSC. Furthermore, adjacent GSs shall be synchronised on the same time source.

The Type 2 handover procedure is triggered through a handover command control message (HO_COM) where the HOT bit is set. The handover command control message shall contain the GS identifier (GS SAC) and the new control offset for the next cell. The sub-net access code (AS SAC) remains the same. Based on the GS SAC an AS shall be able to determine the forward link and reverse link frequencies, which shall be permanently broadcast via the BCCH via the ACB message. The updated sub-net access code as well as the unique control offset for the next cell shall be retrieved from the LME of the next GS.

A Type 2 handover shall be conducted through the transmission of a synchronisation tile in the DC slot of the next cell. Therefore, the AS needs to know when it is allowed to use the DC slot, which shall be indicated by the next LME through the transmission of a synchronisation polling control message (SYNC_POLL) for the (new) control offset.

> *NOTE: The LME polls the new AS until it will get the first synchronisation tile from it.*

> *NOTE: This procedure is possible because the next reverse link time advance value can be calculated relative to the received forward link time offset on the next link (i.e. the next cell). This is only achievable for the time advance value, the power value could be approximated, but the frequency value cannot be determined. For a Type 2 handover an AS shall be able to determine the next reverse link time advance value based on the next cell's forward link time offset.*

10.3 Operation of the Resource Management Service

10.3.1 Functions of the Resource Management Service

10.3.1.1 Link Maintenance

The link maintenance service supports the transmit power, frequency adjust, and time advance adaptation of the AS PHY layer. Link maintenance is performed in closed loop: aircraft are polled to transmit synchronisation tiles and receive update messages from the GS.

10.3.1.2 Adaptive Coding and Modulation

Adaptive Coding and Modulation (ACM) is provided in two modes. The default mode is cell-specific ACM provision. The second mode is user-specific ACM on the FL and RL. The ACM mode of a cell is announced periodically via the BCCH.

10.3.1.3 Resource Allocation

Resource allocation procedures are not defined within this specification. If reverse link channel occupancy limitations exist, this shall be respected by the GS's radio resource management function.

The GS shall supplement each FL resource allocation with a DCCH_POLL message in the next CC slot (one CC slot after the FL allocation) to the same AS to provide an early acknowledgement opportunity for the AS in the DC slot after the FL transmission.

10.3.2 Link Maintenance Procedures

Link maintenance is necessary for aircraft. It comprises transmit power control, frequency value control, and time advance maintenance.

Each DC slot starts with one synchronisation opportunity. An AS shall transmit a synchronisation tile if its control offset is polled for synchronisation.

After the GS has received a synchronisation tile (check Section 8.7.3) from an AS it shall update the AS time advance, frequency, and power value. This update shall be transmitted via the CCCH.

Note: The link maintenance procedure is not *responsible for conducting handovers, but only for synchronization/power/frequency/timing control of the current connection. The link maintenance procedure is periodically driven through SYNC_POLL and LM_DATA messages sent in the CCCH.*

10.3.2.1 Timing Maintenance

The initial time advance value (TAV) shall be received through the exchange of a CELL_RQST and a CELL_RESP control message in a closed loop procedure. During nominal operation the time advance value should be tracked relatively to the received signal on the forward link.

The time advance value shall be updated whenever polled by the GS through a closed loop procedure (i.e. a synchronisation tile is sent on the DC slot and feedback is received via the CCCH, i.e. the TAV field within the LM_DATA control message).

10.3.2.2 Power Control

The initial power adaptation value (PAV) shall be received through the exchange of a CELL_RQST and a CELL_RESP control message in a closed loop procedure. During nominal operation the power adaptation value should be tracked relatively to the received signal on the FL.

The power adaptation value shall be updated whenever polled by the GS through a closed loop procedure (i.e. a synchronisation tile is sent on the DC slot and feedback is received via the CCCH, i.e. the PAV field within the LM_DATA control message).

10.3.2.3 Frequency Control

The initial frequency adaptation value (FAV) shall be received through the exchange of a CELL_RQST and a CELL_RESP control message in a closed loop procedure. During nominal operation the frequency adaptation value should be tracked relatively to the received signal on the FL.

The frequency adaptation value shall be updated whenever polled by the GS through a closed loop procedure (i.e. a synchronisation tile is sent on the DC slot and feedback is received via the CCCH, i.e. the FAV field within the LM_DATA control message).

10.3.3 Adaptive Coding and Modulation Procedures

LDACS shall support two modes of operation:

- Cell-specific coding and modulation
- User-specific coding and modulation

The mode in use shall be signalled via the system identification broadcast (SIB) control message.

The cell-specific mode shall support coding and modulation schemes (CMS) in such that a single configuration (i.e. coding and modulation) for forward link and reverse link is used for all users within the cell. Only PHY-SDUs with fixed coding and modulation (RL RA PHY-SDU, RL DC PHY-SDU, and FL BC PHY-SDU) are exempt from this rule.

The user-specific mode shall support the assignment of different coding and modulation schemes (CMS) for FL- and RL MAC Data PDUs. This requires that the physical layer is re-configurable during operation. The CMS to be used for the next FL- or RL MAC Data PDU shall be signalled in advance, via the common control channel (CMS FL MAP and the RL_ALLOC control messages). Only PHY-SDUs with fixed coding and modulation (RL RA PHY-SDU, RL DC PHY-SDU, and FL BC PHY-SDU) are exempt from this rule.

10.3.3.1 Cell-specific Coding and Modulation

If adaptive coding and modulation (ACM) is provided on a cell-specific basis for both FL and RL, the physical layer shall be configured only once, after the cell entry.

10.3.3.2 User-specific Adaptive Coding and Modulation

If adaptive coding and modulation (ACM) is provided on user-specific basis for both FL and RL, the physical layer shall be re-configurable during operation. The MAC shall support such reconfiguration by signalling the ACM parameters prior to the actual data transmission. The type of coding and modulation used shall be determined by the GS's radio resource management function. The decision algorithm for adaptive coding and modulation is outside the scope of this specification.

For forward link user plane data transmissions the MAC Common Control PDU shall be used to convey the CMS parameters (CMS_FL_MAP). This information shall be read by the AS physical layer to configure its receiver accordingly.

For reverse link user plane data transmissions the MAC Common Control PDU shall be used to convey an RL allocation control message (RL_ALLOC) which contains (among others) the CMS parameters. The CMS parameters indicate the coding and modulation of MAC Data PDUs. As the GS itself announces the CMS parameters to the AS; it knows the CMS parameters that the AS will apply on RL in advance. Thus, the GS can configure its physical layer to receive the MAC Data PDU correctly (Section 9.4.3).

10.3.4 Resource Allocation Procedures

Both FL and RL resources shall be assigned by the GS's Radio resource management RRM function. Implementation-specific details of the resource allocation procedures are outside the scope of this specification.

Note that the resource allocation procedure defines the slot layout. The relevant parameters for the MAC entity are transmitted in the SLOT_DESCRIPTOR control message. The relevant parameters for the GS physical layer are configured directly by the LME.

10.3.4.1 RL Channel Occupancy Limitations

Resources for reverse link user plane data transmissions shall be granted centrally at the GS. If channel occupancy limitations exist the radio resource management RRM function of the GS's LME shall be configured such that these limitations can be recognized.

10.4 LME Parameters

10.4.1 Cell Entry Timer (LME_T_CELL_RESP)

The LME_T_CELL_RESP timer shall be used to abort an unsuccessful cell entry if the GS did not respond in due time. If the CELL_RESP message from the GS is not received in LME_T_CELL_RESP time, the LME shall return into the CSCANNING state. The default LME_T_CELL_RESP value shall be 30 seconds.

10.4.2 Reverse Link Keep Alive Timer (LME_T_RLK)

The RL keep-alive timer included in the GS LME shall be an indicator whether an aircraft/AS is still within a cell, or not. This is based on observing regular DCCH transmissions of this AS. If the RL keep-alive timer expires, this aircraft/AS shall be considered as absent and shall be deregistered from the GS. The default time-out value shall be 10 seconds.

10.4.3 AS Forward Link Keep Alive Timer (LME_T_FLK)

The AS LME shall include a keep-alive timer, which is an indicator for the AS whether it is still connected to the GS, or not. Each time the AS receives a message from the GS the keep-alive timer shall be reset. The expiration of the timer is an indicator for the AS LME that the link connection to the GS has been broken. According to that the AS LME shall change its status to FSCANNING state and trigger its MAC to start the fast scanning procedure. The default value shall be 10 seconds.

10.4.4 GS Forward Link Keep Alive Timer (LME_T1_FLK)

The GS shall observe, in a certain period of time, if there are message to be sent to the specific AS. If no message is scheduled, the GS LME shall after LME_T1_FLK (by default 3 seconds) period following the last sent FL message transmit a keep-alive message to the specific AS. This message shall reset the keep-alive timer in the AS LME.

10.4.5 MAX CSCAN Timer (LME_T_CSCAN)

The CSCAN timer shall be used to determine if the CSCAN procedure was completed successfully. If no valid LDACS signal could be decoded before the timer expires the AS LME shall transit back into the FSCANNING state. The time-out value is determined by the LME_T_CSCAN parameter.

10.4.6 Periodic RL Allocation Counter (LME_C_PRLA)

The periodic RL allocation counter shall indicate the maximum number of retry attempts for sending permanent RL resource requests until a failure condition shall be declared. The default value shall be set to 4.

10.5 LME PDU Format Definition

10.5.1 Random Access Control Messages

10.5.1.1 Cell Entry Request (CELL_RQST)

The cell entry request control message shall contain a Unique Address (UA), the GS identifier (GS SAC), and the requested protocol version (VER).

Note that the CELL_RQST message uses one complete RA slot and is therefore not Byte aligned.

Table 43: Cell Entry Request

Field	Size	Description
R_TYP = %11	2 Bit	Cell Entry Request
UA	28 Bit	Unique Address
GS SAC	12 Bit	Ground-station ID
VER	3 Bit	Protocol Version
PAD	1 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

10.5.2 Broadcast Control Messages

10.5.2.1 Adjacent Cell Broadcast

The Adjacent Cell Broadcast (ACB) is transmitted periodically (e.g. once per SF). The ACB control message is transmitted via the BCCH using the BC slot number one and three. The ACB control message contains information about the GS Identifier (GS SAC), the Forward Link Channel (FLF) and the Reverse Link Channel (RLF) of one adjacent cell.

Table 44: Adjacent Cell Broadcast

Field	Size	Description
B_TYP = %0001	4 Bit	Adjacent Cell Broadcast
GS SAC	12 Bit	GS Identifier
FLF	9 Bit	Forward Link Channel
RLF	9 Bit	Reverse Link Channel
PAD	6 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

NOTE: If more than one adjacent GS need to be announced multiple ACB messages shall be sent.

10.5.2.2 System Identification Broadcast

The System Identification Broadcast (SIB) is transmitted periodically (e.g. once per SF). The SIB control message is transmitted via the BCCH using the BC slot number two. The SIB control message contains information about the GS SAC, the used channels (FLF and RLF), the ACM mode (MOD), Coding and Modulation Scheme (CMS) and the Equivalent Isotropic Radiated Power (EIRP).

Note that in user specific ACM mode the coding and modulation scheme (CMS) applies only to FL PHY-SDUs 13 to21 (see Figure 36) while the CMS of all other FL and RL PHY-SDUs is determined by the FL MAP and RL MAP.

Table 45: System Identification Broadcast

Field	Size	Description
B_TYP = %0010	4 Bit	System Identification Broadcast
GS SAC	12 Bit	GS Identifier
VER	3 Bit	Protocol Version
FLF	9 Bit	Forward Link Channel
RLF	9 Bit	Reverse Link Channel
MOD	1 Bit	User-specific / Cell-specific ACM
CMS	3 Bit	Coding and Modulation Scheme
EIRP	7 Bit	GS Equivalent Isotropic Radiated Power
PAD	0 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

NOTE: If the user-specific flag is set, the CMS field shall be ignored and filled with binary zero.

10.5.2.3 Scanning Table Broadcast

The Scanning Table Broadcast (STB) is transmitted periodically (e.g. once per SF). The STB control message is transmitted via the BCCH using one of the three BC slots dependent on the currently available capacity. The STB control message contains information about the AS Sub-net Access Code (AS SAC) and the GS Identifier (GS SAC). The AS SAC shall identify the ASs which are allowed to use the upcoming BC slot for scanning an adjacent cell. Each AS SAC has to be unique.

Note: There is no fixed rule how the GS has to choose the AS allowed to scan.

Table 46: Scanning Table Broadcast

Field	Size	Description
B_TYP = %0011	4 Bit	Scanning Table Broadcast
AS SAC	12 Bit	AS Sub-net Access Code
GS SAC	12 Bit	GS Identifier
PAD	4 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

NOTE: If more than one scanning commands need to be announced multiple messages shall be sent.

10.5.2.4 Voice Service Broadcast

The Voice Service Broadcast (VSB) shall be transmitted periodically. The VSB control message is transmitted via the BCCH using the BC slot number two. The VSB control message contains information about the number of available Voice Circuits within this cell (VC), the Logical Voice Channel Number (LVC), Voice Channel Identifier (VCI), and the parameters related to reserved resource space for both FL and RL.

Table 47: Voice Service Broadcast

Field	Size	Description
B_TYP = %0100	4 Bit	Voice Service Broadcast
LVC	6 Bit	Logical Voice Channel Number
VCI	12 Bit	Voice Channel Identifier
RPSO	8 Bit	RL PHY-SDU Offset
NRPS	8 Bit	Number of RL PHY-SDUs
CMS	3 Bit	Coding and Modulation Scheme (RL)
BO	14 Bit	Byte Offset (FL)
BLV	6 Bit	Byte Length (FL)
PAD	3 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

NOTE: If more than one voice circuits need to be announced multiple messages shall be sent.

10.5.2.5 GS Position Broadcast

The GS position message is optional and shall be sent to signal the Latitude and Longitude of a GS.

Table 48: GS Position Broadcast

Field	Size	Description
B_TYP = %0101	4 Bit	GS Position Message
GS SAC	12 Bit	GS Identifier
GS_LAT	32 Bit	GS Latitude
GS_LONG	32 Bit	GS Longitude
PAD	0 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

NOTE: If more than one GS position needs to be announced multiple messages shall be sent.

10.5.3 Dedicated Control Messages

Note that all dedicated control messages are augmented with a CRC as indicated in Section 9.6.4 and that the AS SAC can be inferred from the RL PHY-PDU position in the DC since each AS is assigned one RL PHY-PDU with the SLOT_DESCRIPTOR. Additional AS SAC and CRC fields are therefore not necessary in the messages themselves.

10.5.3.1 Power Report (POW_REP)

The power report control message shall be used to report the received power of (the current or a neighbouring) cell towards the GS. The POW_REP control message shall contain the following values.

Table 49: Power Report

Field	Size	Description
D_TYP = %0001	4 Bit	Power Report
GS SAC	12 Bit	GS identifier
RXP	6 Bit	Received Power in dBm
GSYN	1 Bit	GS Sync Status
PAD	1 Bit	Reserved

10.5.3.2 Cell Exit (CELL_EXIT)

The cell exit control message shall be used to acknowledge previously received handover command control message. The cell exit control message shall contain the GS SAC of the next cell. This is the last message an AS shall transmit to its current GS, after the end of the current SF the AS shall transmit data only toward the next GS. The CELL_EXIT control message shall contain the following values.

Table 50: Cell Exit

Field	Size	Description
D_TYP = %0101	4 Bit	Cell Exit
GS SAC	12 Bit	GS identifier
PAD	0 Bit	Reserved

10.5.3.3 Permanent Resource Request (PRSC_RQST)

The permanent resource request control message shall be transmitted if the AS wants to transfer data or voice samples periodically in each Multi-Frame. The PRSC_RQST shall contain the following values.

Table 51: Permanent Resource Request

Field	Size	Description
D_TYP = %1000	4 Bit	Permanent Resource Request
SC	3 Bit	Service Class
REQ	15 Bit	Octets requested per MF
ID	4 Bit	Connection identifier postfix (note that the full CID = AS SAC+ID and has to be reconstructed by the receiver)
PAD	6 Bit	Reserved

10.5.3.4 Resource Cancellation (RSC_CANCEL)

The resource cancellation control message shall be used to cancel permanently allocated resources. The RSC_CANCEL control message shall contain the following values.

Table 52: Resource Cancellation

Field	Size	Description
D_TYP = %0110	4 Bit	Resource Cancellation
SC	3 Bit	Service Class
ID	4 Bit	Connection identifier postfix (note that the full CID = AS SAC+ID and has to be reconstructed by the receiver)
PAD	5 Bit	Reserved

10.5.4 Common Control Messages

Note that all common control messages (except for the slot descriptor, which is always transmitted first) start with the Byte-aligned C_TYP field indicating the type and length of the message. Since the last Byte of the message is always the CRC field, the correctness of a message in the CCCH can immediately be verified. After a corrupted message the next correct message can be found by CRC hunting: Interpret the next Byte as C_TYP, check for a valid CRC at the position indicated by the C_TYP, repeat until success or the last Byte of the CCCH has been processed.

10.5.4.1 Slot Descriptor (SLOT_DESC)

The slot descriptor shall always be transmitted at the beginning of the CCCH. The content of the slot descriptor is the length of the current CC slot (CCL) and the length of the DC slot in the next MF (DCL).

Note that the slot descriptor can always be decoded, because it is transmitted at the beginning of FL PHY-PDU 13, which is interleaved with FL PHY-PDUs 13 to 21, using QPSK 1/2 modulation and coding (see section 8.6.2.5).

In the CCL flield %000 shall indicate a CC slot length of 1 FL PHY-SDU, and %111 shall indicate a CC slot length of 8 FL PHY-SDUs. Note that the CC slot will always be in the same interleaving block (Figure 35 and Figure 36)

In the DCL flield %00000 shall indicate a DC slot length of 1 RL PHY-SDU, and %11111 shall indicate a DC slot length of 32 RL PHY-SDUs.

Table 53: Slot Descriptor

Field	Size	Description
CCL	3 Bit	CC Slot Length
DCL	5 Bit	DC Slot Length
CRC-8	8 Bit	Cyclic Redundancy Checksum

NOTE The DC segment length must be equal or greater than the sum of the COL field in the DCCH descriptor message plus the number of DCCH_POLL messages.

10.5.4.2 DCCH Descriptor (DCCH_DESC)

The DCCH descriptor message shall be used to schedule the periodically recurring DCCH medium accesses of all registered AS. The content of the DCCH descriptor message is the COS, COL, and COM indicating the starting control offset (COS) and the ending control offset ((COS+COL) modulo COM) within the following DC slot, respectively. The scheduled DCCH medium accesses shall be mapped to the first COL RL PHY-SDUs within the DC slot in the order of COS.

Note that the DCCH descriptor message is not required if no aircraft are registered in the cell, or DCCH Poll messages (see 10.5.4.4) are used instead.

Table 54: DCCH Descriptor

Field	Size	Description
C_TYP = %00001	5 Bit	DCCH Descriptor
COL	5 Bit	Control Offset Length
COS	9 Bit	Control Offset Start
COM	9 Bit	Control Offset Modul
PAD	4 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

10.5.4.3 CMS FL MAP (CMS_FL)

The CMS_FL message is addressed to the broadcast AS SAC. If present, it is transmitted immediately after the slot descriptor.

The CMS_FL message must not be transmitted in cell-specific ACM mode.

If user-specific ACM is provided the CMS FL MAP control message must be present within each CCCH. The CMS FL MAP control message shall be read by the PHY layer in order to decode the upcoming FL data slot properly. The CMS FL MAP does not apply to FL PHY-SDUs 13 to21 (see Figure 36) which must use the coding and modulation specified in the CMS field of the SIB message. Note that the FL Data Slot is shifted versus the MF (Figure 54).

If the CMS FL MAP control message or parts of it cannot be interpreted correctly due to detected bit errors (i.e. the CRC of the control message indicated an error) the content of affected FL data transmissions shall not be forwarded to the MAC.

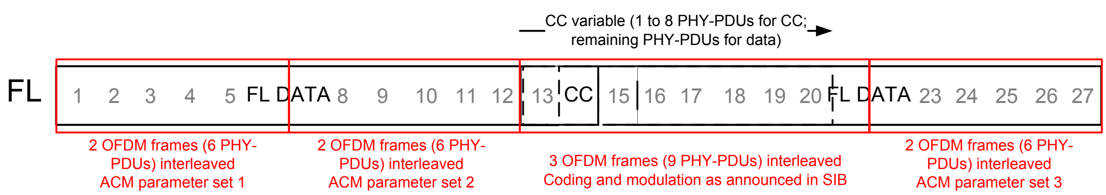

Figure 54: Application of CMS FL MAP message to FL Data Slot

Note: The FL DATA slot is not aligned with the multi-frame boundary, but between two consecutive CC slots as illustrated in Figure 45*!*

Table 55: CMS FL MAP Control Message

Field	Size	Description
C_TYP =	5 Bit	CMS FL Map

%00010		
CMS_1	3 Bit	Coding and Modulation Parameter Set 1
CMS_2	3 Bit	Coding and Modulation Parameter Set 2
CMS_3	3 Bit	Coding and Modulation Parameter Set 3
PAD	2 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

10.5.4.4 DCCH Poll (DCCH_POLL)

The DCCH poll message shall be used to poll for the DCCH of a specific AS. The content of the DCCH poll message is the index of the RL PHY-SDU assigned to the polled AS's DCCH (COI).

The DCCH_Poll message shall be addressed to the AS SAC of the polled AS.

Table 56: DCCH Poll

Field	Size	Description
C_TYP = %00011	5 Bit	DCCH Poll
AS SAC	12 Bit	AS Identifier
COI	6 Bit	Control Offset Index
PAD	1 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

10.5.4.5 Cell Entry Response (CELL_RESP)

The cell entry response control message shall be transmitted on a successful receipt of a cell entry request (CELL_RQST) control message. The cell entry response control message shall be transmitted in the CC slot of the first MF after the random-access slot.

The Unique Address (UA) shall contain the value received within the cell entry request control message. The AS Sub-net Access Code in the message header (AS SAC) shall be unique within its scope and shall be assigned by the GS's LME and GSC. Note that the MAC has to forward all messages (independently of the AS SAC) to the LME in the CONNECTING state. The LME will then identify the assigned AS SAC from the UA. The Power Adaptation Value (PAV), the Frequency Adaptation Value (FAV), and the Time Advance Value (TAV) shall include the correction parameters for the addressed AS, which shall be determined by the GS's PHY layer.

Table 57: Cell Entry Response

Field	Size	Description
C_TYP = %00100	5 Bit	Cell Entry Response
AS SAC	12 Bit	AS Identifier

Field	Size	Description
UA	28 Bit	Unique Address
PAV	7 Bit	Power Adaptation Value
FAV	10 Bit	Frequency Adaptation Value
TAV	10 Bit	Time Advance Value
CO	9 Bit	Control Offset
VER	3 Bit	Protocol Version
PAD	4 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

10.5.4.6 Link Management Data (LM_DATA)

The link management data control message shall be addressed to a specific subscriber access code. The LM_DATA control message shall contain correction parameters regarding power (PAV), frequency (FAV), and time (TAV). The LM_DATA control message shall be sent if a synchronisation tile has been received previously.

Table 58: Link Management Data

Field	Size	Description
C_TYP = %00111	5 Bit	Link Management Data
AS SAC	12 Bit	AS Identifier
PAV	7 Bit	Power Adaptation Value
FAV	10 Bit	Frequency Adaptation Value
TAV	10 Bit	Time Advance Value
PAD	4 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

10.5.4.7 FL Allocation (FL_ALLOC)

The FL Allocation control message shall contain the MAC header of an individual forward link MAC Data PDU. The FL_ALLOC control message shall indicate the Byte Offset (BO) and the Byte Length (BL) of an individual MAC Data PDU. The byte count shall be reset after each CC slot. The length of the FL DATA slot in bytes may vary according to the coding and modulation scheme.

NOTE: In case of the FL data transmission the length of allocated resources is given in bytes.

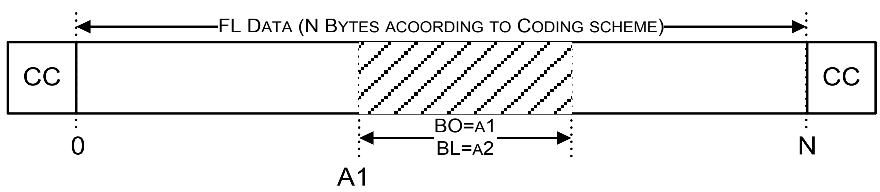

Figure 55: FL_ALLOC Byte Offset

Note: The FL DATA slot is not aligned with the multi-frame boundary, but between two consecutive CC slots as illustrated in Figure 45*!*

Table 59: FL Allocation

Field	Size	Description
C_TYP = %01011	5 Bit	FL Allocation
AS SAC	12 Bit	AS Identifier
BO	14 Bit	Byte Offset
BL	14 Bit	Length in Byte
PAD	3 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

10.5.4.8 RL Allocation (RL_ALLOC)

The RL allocation control message shall be addressed to a specific AS SAC. The resource reservation mechanism aligns requests on an RL PHY-SDU basis. An RL allocation control message shall use RL PHY-SDUs to address the position (RPSO) and length (NRPS) of an RL data transmission. Thereby the RL PHY-SDU Offset (RPSO) shall be counted on a per MF basis. Additionally, the ACM type shall be indicated in the CMS field. In case of cell-specific ACM the CMS field must be set to the value of the SIB CMS field.

Figure 56 depicts an example RL allocation where the RL PHY-SDU Offset is 71 and the length of the assigned resources is 18 RL PHY-SDUs.

NOTE: RL resource allocations shall be given by indicating the number of RL PHY-SDUs allocated to the particular AS that in turn corresponds to the number of RL Data tiles allocated to that AS.

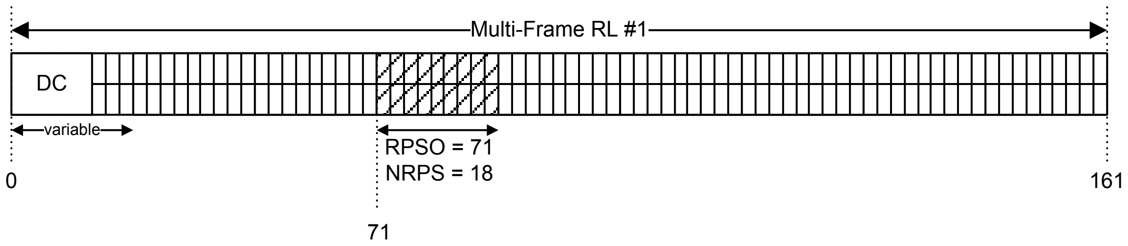

Figure 56: RL_ALLOC RL PHY-SDU offset

Table 60: RL Allocation

Field	Size	Description

Field	Size	Description
C_TYP = %01100	5 Bit	RL Allocation
AS SAC	12 Bit	AS Identifier
RPSO	8 Bit	RL PHY-SDU Offset
NRPS	8 Bit	Number RL PHY-SDUs
CMS	3 Bit	Coding and Modulation Scheme
PAD	4 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

10.5.4.9 Synchronisation Polling (SYNC_POLL)

The synchronisation polling control message shall be used to poll an AS for the transmission of a synchronization tile in the next MF.

Note: The GS shall issue this message periodically to all registered AS in round robin to refresh its LM_DATA. However, if the GS detects that the link to an AS has deteriorated beyond the point where the GS can derive LM_DATA on its own, it shall issue a SYNC_POLL message to this AS immediately.

Table 61: Synchronisation Polling

Field	Size	Description
C_TYP = %01110	5 Bit	Synchronisation Polling
AS SAC	12 Bit	AS Identifier
PAD	7 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

10.5.4.10 Handover Command (HO_COM)

The handover command control message shall be addressed to a specific user. The HOT flag shall indicate whether this control message initiates a type 1 or a type 2 handover.

If a type 1 handover is initiated the New Control Offset (NEXT CO) field must be ignored by the AS and set to binary zero by the GS.

If a type 2 handover is initiated the control message shall contain the Control Offset (CO) valid in the next cell. The GS Identifier (GS SAC) shall indicate the next cell the concerned AS shall switch to.

NOTE: The corresponding frequency of this cell is known from the adjacent cell broadcast control message received via the BCCH.

NOTE: In case of Type 2 handover, the AS SAC of the old cell remains valid in the new cell since the addressing has been coordinated by the GSC.

Table 62: Handover Command

Field	Size	Description
C_TYP = %01111	5 Bit	Handover Command
AS SAC	12 Bit	AS Identifier
GS SAC	12 Bit	GS Identifier
HOT	1 Bit	Handover Type 1 or Type 2
NEXT CO	9 Bit	New Control Offset (new cell)
PAD	1 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

10.5.4.11 Cell Entry Denied (CELL_DENIED)

The cell entry denied control message shall be transmitted if the GS has to reject the cell entry request of an AS. The cell entry denied control message shall be transmitted in the first CC slot after the random-access slot.

NOTE: The AS MAC has to forward all messages (independently of the AS SAC) to the LME in the CONNECTING state. The LME will then identify the CELL_DENIED message by the UA.

NOTE: The Cell Entry Denied control message shall signal an AS to abort the cell entry procedure to that cell (the GS of that cell is currently unable to accept new aircraft for whatever reason). Without that control message the AS would try to reattempt the cell entry procedure causing unnecessary collisions in the RA slot. Additionally, the AS would have to wait ca. 30 seconds before an error is reported.

NOTE: Under normal circumstances the GS should never deny the cell entry request of an AS.

The Unique Address (UA) shall contain the value received within the cell entry request control message. Additionally, the cell entry denied control message shall include a reason field which shall explain the reason of rejection.

Table 63: Cell Entry Denied

Field	Size	Description
C_TYP = %00110	5 Bit	Cell Entry Denied
AS SAC = %000000000000	12 Bit	AS Identifier set to zero
UA	28 Bit	Unique Address
REA	3 Bit	Reason
PAD	4 Bit	Reserved

Field	Size	Description
CRC-8	8 Bit	Cyclic Redundancy Checksum

10.5.4.12 Periodic RL Allocation (P_RL_ALLOC)

The periodic RL allocation control message shall be addressed to a specific AS SAC. The resource reservation mechanism aligns requests on an RL PHY-SDU basis; therefore, a periodic RL allocation control message shall use RL PHY-SDUs to address the position (RPPO) and length (NRPP) of a permanent RL data or VI sample transmission. Thereby the RL PHY-SDU offset (RPPO) shall be counted on a per MF basis. Additionally, the ACM type shall be indicated in the CMS field. The unique identifier is used to identify the permanent resource request.

NOTE: The periodic RL allocation control message shall be considered in the RL_MAP.

Table 64: Periodic RL Allocation

Field	Size	Description
C_TYP = %01101	5 Bit	RL Allocation
AS SAC	12 Bit	AS Identifier
ID	4 Bit	Connection Identifier postfix
RPPO	8 Bit	RL PHY-SDU Offset
NRPP	8 Bit	Number RL PHY-SDUs
CMS	3 Bit	Coding and Modulation Scheme
PAD	0 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

NOTE: The combination of AS SAC and ID defines the connection identifier (CID = AS SAC+ID), which identifies the permanent RL allocation in the RL_MAP. The CID has to be reconstructed by the receiver.

10.5.4.13 Change CO (CHANGE_CO)

The change CO control message shall be transmitted if the GS successfully reassigned a CO. This may happen if an AS with a lower CO would leave the LDACS cell. The length of the change CO control message shall be 48 bit.

Table 65: Change CO

Field	Size	Description
C_TYP = %00101	5 Bit	CO Change
AS SAC	12 Bit	AS Identifier
NEXT_CO	9 Bit	New Control Offset

Field	Size	Description
PAD	6 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

10.5.4.14 Keep-Alive (KEEP_ALIVE)

The GS shall transmit keep-alive control message if no other control message is scheduled to be sent to the particular AS within a defined time (LME_T1_FLK), to keep the AS informed that it is still connected to the GS.

The keep-alive control message shall be the last message transmitted in the MAC Common Control PDU. This message shall reset the FL keep alive timer (LME_T_FLK) in the AS LME. The KEEP_ALIVE control message shall contain the following fields:

Table 66: Keep-Alive

Field	Size	Description
C_TYP = %10000	5 Bit	Keep Alive
AS SAC	12 Bit	AS Identifier
PAD	7 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

10.6 LME Information Element Definition

The following information element definition describes all fields used within the individual control messages.

All information elements shall be encoded in network bit and byte order i.e. big-endian bit and byte order.

10.6.1 B_TYP – Broadcast Control Type

This field indicates the broadcast control type. B_TYP shall have a size of 4 bits.

10.6.2 BL – Byte Length

This field indicates the data length in bytes (octets). The bit value shall indicate the length in bytes (octets). BL shall have a size of 14 bits.

10.6.3 BLV – Byte Length Voice

This field indicates the data length in bytes (octets) for digital voice transmissions. The bit value shall indicate the length in bytes (octets). BLV shall have a size of 6 bits.

10.6.4 BO – Byte Offset

This field indicates the offset within the byte stream. The bit value shall indicate the starting point of the data stream. BO shall have a size of 14 bits.

10.6.5 C_TYP – Common Control Type

This field indicates the common control type. C_TYP shall have a size of 5 bits.

10.6.6 CCL - CC Slot Length

This field indicated the length of the CC slot in FL PHY-PDUs. CCL shall have a length of 3 bits.

10.6.7 CID – Connection Identifier (AS SAC+ Identifier)

This field indicates the connection identifier, which is a combination of the AS SAC and the ID. CID shall have a size of 16 bits. The CID shall be used to request, allocate, and cancel permanent resource requests i.e. connections.

10.6.8 CMS – Coding and Modulation Scheme

This field indicates the coding and modulation scheme. The CMS field shall have a size of 3 bits and shall take on the following values:

Table 67: Coding and Modulation Scheme Values

Type	Code-Rate	Modulation	Value
1	1/2	QPSK	%000
2	2/3	QPSK	%001
3	3/4	QPSK	%010
4	1/2	16QAM	%011
5	2/3	16QAM	%100
6	1/2	64QAM	%101
7	2/3	64QAM	%110
8	3/4	64QAM	%111

10.6.9 CO – Control Offset

This field indicates the local ID of an AS which shall be unique within a single cell. The control offset shall be assigned during the cell entry or handover procedure. CO shall have a size of 9 bits.

10.6.10 COI – Control Offset Index

The COI field (6 bits) identifies the index of the RL PHY-SDU assigned to the polled DCCH.

10.6.11 COL – Control Offset Length

The COI field (5 bits) specifies the number of COs served in the periodic DCCH assignment in the DCCH_DESC message.

10.6.12 COM – Control Offset Modul

This field (9 bits) indicates the number of COs in use.

10.6.13 COS – Control Offset Start

This field (9 bits) indicates the control offset start and its value shall be set to a valid control offset. The starting and ending control offset (which is (COS+DCL) modulo COM) numbers indicate the range of control offsets which are allowed to transmit within the upcoming DC slot.

10.6.14 CRC – Cyclic Redundancy Check

The following CRC shall be used for error detecting:

- CRC-8: 0x97

CRC computation shall start with the Most-Significant-Bit (MSBit) of the Most-Significant-Byte (MSByte) and ends with the Least-Significant-Bit (LSBit) of the Least-Significant-Byte (LSByte).

10.6.15 D_TYP – Dedicated Control Type

This field indicates the dedicated control type. D_TYP shall have a size of 4 bits.

10.6.16 DCL – DC Segment Length

This field indicates the DC Segment Length not including the SYNC tiles. The DCL shall have a size of 5 Bit.

10.6.17 EIRP – Equivalent Isotropically Radiated Power

This field indicates the equivalent isotropically radiated power. The EIRP shall have a size of 7 Bit.

10.6.18 FAV – Frequency Adaptation Value

This field indicates the frequency adaptation value in order to compensate the effect of Doppler of reverse link transmissions. The resolution is set to 20 Hz. FAV shall have a size of 10 bits.

Table 68: Frequency Adaptation Value Range

Description	Value
Decrease 10.24 kHz	%1000000000
Decrement in 20Hz steps	%1000000001 to %1111111111

No Adjustment	%0000000000
Increment in 20Hz steps	%0000000001 to %0111111110
Increase 10.22 kHz	%0111111111

10.6.19 FLF – Forward Link Channel

This field indicates the forward link channel according to section 4.5.1.

10.6.20 GS_LAT – GS Latitude

This field indicates the GS latitude. The GS_LAT shall have a size of 32 Bit. It shall use degrees as unit and be encoded in IEEE 754-2008 binary32 format.

10.6.21 GS_LONG – GS Longitude

This field indicates the GS Longitude. The GS_LONG shall have a size of 32 Bit. It shall use degrees as unit and be encoded in IEEE 754-2008 binary32 format.

10.6.22 GSYN – GS Sync Status

This field indicates the GS sync status. The GSYN shall have a size of 1 Bit.

10.6.23 HOT – Handover Type Flag

This field indicates the handover type flag and determines which kind of handover shall be used.

Table 69: Handover Type Flag Values

Description	Value
Type 1	%0
Type 2	%1

10.6.24 ID – Connection Identifier (AS SAC+ Identifier)

This field indicates the ID postfix of the connection identifier, which is a combination of the AS SAC and an ID. CID shall have a size of 16 bits.

10.6.25 LVC – Logical Voice Channel

This field indicates the logical voice channel and shall have a size of 6 bits. The LVC number shall be used to numerate the voice channels offered within a single LDACS cell and shall not relate to any other context.

10.6.26 MOD – ACM Mode

This field indicates the adaptive coding and modulation mode used for this LDACS cell. The MOD field is a flag and shall take on the following values.

Table 70: ACM Mode Values

Description	Value
User-specific ACM	%0
Cell-specific ACM	%1

10.6.27 NEXT_CO – Next Control Offset

This field indicates the Next Control Offset. The NEXT_CO shall have a size of 9 Bit.

10.6.28 NRPS – Number of RL PHY-SDUs

This field indicates the number of RL PHY-SDUs and shall have a size of 8 bits. NRPS shall be used in combination with RPSO and shall indicate the number of coherent consecutive RL PHY-SDUs allocated.

NRPS shall be used to address the individual RL PHY-SDUs within a single reveres link MF. Bit-value 1 shall indicate the first and bit-value 160 shall indicate the last RL PHY-SDU within an RL MF. Bit-values outside of this range shall be invalid. The first six RL OFDMA symbols of the MF used for synchronization and AGC cannot be addressed.

10.6.29 PAD – Padding

This field indicates padding. PAD shall be used if a control message has some unused space left.

10.6.30 PAV – Power Adaptation Value

This field indicates the power adaptation value in order to compensate received transmission power differences from various users at the GS. The resolution is set to 1 dB. PAV shall have a size of 7 bits.

Table 71: Power Adaptation Value Range

Description	Value
Decrease 64 dB	%1000000
Decrement in 1 dB steps	%1000001 to %1111111
No Adjustment	%0000000
Increment in 1 dB steps	%0000001 to %0111110

Description	Value
Increase 63 dB	%0111111

10.6.31 REQ – Octets Requested

This field indicates the number of octets requested. This field shall have a size of 15 bits.

10.6.32 RPSO – RL PHY-SDU Offset

This field indicates the RL PHY-SDU offset and shall have a size of 8 bits. TO shall be used to address the individual RL PHY-SDUs within a single RL MF. Bit-value 0 shall indicate the first and bit-value 161 shall indicate the last RL PHY-SDU within an RL MF. Bit-values outside of this range shall be invalid.

10.6.33 REA - Reason for Cell Entry Denied Control Message

Table 72 illustrates the reason, which leads to a cell entry denied control message. The REA shall have 3 Bit.

Table 72: Reason Cell Entry Denied

Reason	Bit Value	Description
Reserved	%000	
OTHER	%001	Unspecified error
GS_FULL	%010	Max. number of AS exceeded
GS_MAINT	%011	GS down for maintenance
Reserved	%100	
Reserved	%101	
Reserved	%110	
Reserved	%111	

10.6.34 RLF – Reverse Link Channel

This field indicates the reverse link channel according to section 4.5.1.

10.6.35 RXP – Received Power

This field indicates the received power (RXP) in dBm. This field shall have a size of 6 bits and shall take on the following values:

Table 73: Received Power Values

Description	Value
Less or equal-103 dBm	%000000

Increment in 1 dB steps	%000001 to %111110
Greater or equal -40 dBm	%111111

10.6.36 SC – Service Class

This field indicates the Service Class (SC). This field shall have a size of 3 bits and shall assume the values indicated in Section 11.1.1.5.

10.6.37 TAV – Time Advance Value

This field indicates the time advance value in order to compensate propagation delay variations caused through movement. The resolution is set to 1.6 microsecond steps. TAV shall have a size of 10 bits.

NOTE: The TAV value is considering a maximum cell range of 200 nm.

Table 74: Time Advance Value Range

Description	Value
Retreat 0.38 ms	%0000000000
Increment in 1.6 μs steps	%0000000001 to %1111111110
Advance 1.2568 ms	%1111111111

10.6.38 UA – Unique Address

This field indicates the unique address (UA). This field shall have a length of 28 bits. This field may contain the 24-bit unique ICAO aircraft address.

10.6.39 VC – Number of Voice Channels

This field indicates the number of voice channels supported within this cell. VC shall have a size of 6 bits.

10.6.40 VCI – Voice Channel Identifier

This field indicates the voice channel identifier valid within an LDACS communication system. VCI shall have a size of 12 bits.

10.6.41 VER – Protocol Version

This field indicates the Protocol Version. The VER shall have a size of 3 Bit.

VER shall have the value %000 for this version of the protocol.

11 Data Link Service (DLS) Specification

11.1 General Description

The DLS sub-layer offers its users acknowledged and unacknowledged bidirectional exchange of user data (including packet mode voice). This service may be utilized by the sub-network protocol (SNP).

11.1.1 Services

11.1.1.1 Acknowledged Data Link Service

The DLS shall support acknowledged data transmissions for the SNP. To achieve low latency and a low overhead without losing reliability, the LDACS DLS shall employ selective repeat ARQ with transparent fragmentation and reassembly to the resource allocation size.

The acknowledged transport function ensures that DLS service data units (DLS-SDUs) are delivered in the correct order and without duplicates. In case of a transmission error DLS shall initiate a retransmission. The segmentation and reassembly functions shall care for the encapsulation and decapsulation of DLS-SDUs in DLS protocol data units (DLS-PDUs). If DLS-SDUs have to be fragmented (e.g. due to a mismatch of resource allocation size and DLS-SDU size) the segmentation and reassembly function shall carry out this task transparently for the acknowledged transport function.

If the sending acknowledged transport function receives an acknowledgement for a complete DLS-SDU, it shall inform the SNP that the transmission was successful.

After DLS_P_MaxRT failed retransmissions, the sending acknowledged transport function shall abandon further attempts to transmit the DLS-SDU and inform its SNP about the failure.

11.1.1.2 Unacknowledged Data Link Service

The DLS shall support unacknowledged data transmissions for the SNP. The unacknowledged transport function shall transmit DLS-SDUs without acknowledgements or retransmissions.

The segmentation and reassembly functions shall care for the encapsulation and decapsulation of DLS-SDUs in DLS-PDUs. If DLS-SDUs have to be fragmented (e.g. due to a mismatch of resource allocation size and DLS-SDU size) the segmentation and reassembly function shall carry out this task transparently for the unacknowledged transport function.

11.1.1.3 Broadcast Data Link Service

The GS DLS shall support broadcast data transmissions for the SNP. Broadcast transmissions shall be addressed to the broadcast AS SAC, otherwise the broadcast transport function is identical to the unacknowledged transport function.

Note: The AS and the GS shall have a broadcast DLS instance in addition to the point-to-point DLS instances.

11.1.1.4 Packet Mode Voice Service

The packet mode voice service shall provide support for packetized voice (e.g. VoIP). The packet mode voice service is identical to the unacknowledged transport function. However, it has a reserved class of service in the DLS.

11.1.1.5 Classes of Service

The DLS offers its services with different classes of service. Service classes map directly to priorities. The requested service class shall be used by the GS to determine the order and size of resource allocations. Within the DLS the service class is used to determine the precedence of concurrent service requests by order of priority. The classes of service supported by the LDACS DLS are displayed in Table 75.

Table 75: LLC Classes of Service

Class of Service	SC Field	Priority	Comment
DLS_CoS_7	%111	Highest	Reserved for signalling.
DLS_CoS_6	%110		Reserved for packet mode voice
DLS_CoS_5	%101		
DLS_CoS_4	%100		
DLS_CoS_3	%011		
DLS_CoS_2	%010		
DLS_CoS_1	%001		
DLS_CoS_0	%000	Lowest	

Service class DLS_CoS_7 shall designate the service class with the highest priority and DLS_CoS_0 shall designate the service class with the lowest priority. DLS_CoS_7 shall be reserved for sub-network signalling. DLS_CoS_6 shall be reserved for the packet mode voice service.

Note that service classes have to be assigned to DLS-SDUs by the higher layers. Usually this would be the convergence layer between the network layer and LDACS.

11.1.2 Interface to Service Users

The DLS shall provide an interface to its service users as described in Section 7.2.3.

11.1.3 State Transition Diagram

The DLS may either be in OPEN state or in CLOSED state. The DLS shall reject all requests in CLOSED state. DLS state changes shall be invoked by the LME through DLS_OPEN.req or DLS_CLOSE.req primitives.

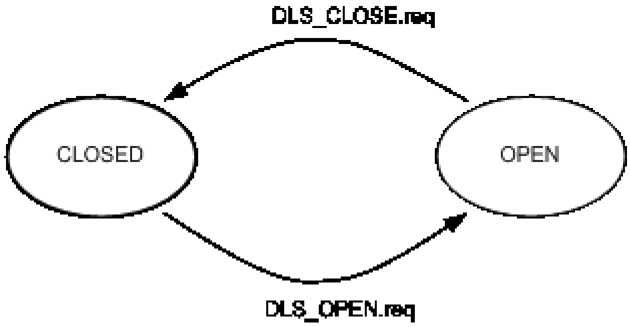

Figure 57: DLS State Transition Diagram

11.2 Operation of the Data Link Services

11.2.1 General Description

The data link services define procedures and message formats that permit acknowledged and unacknowledged bidirectional exchange of DLS-SDUs over the point-to-point reverse link or point-to-multipoint forward link. There shall be one DLS in the AS and one peer DLS for each aircraft in the GS.

The AS DLS shall periodically request from the GS (over the DCCH) reverse link resources for each of its service classes. The transmission of resource requests is managed by the AS DLS resource acquisition function. It stores the resource requests of all acknowledged and unacknowledged transport functions and generates the appropriate control messages (e.g. combing several resource requests in one control message). This resource request shall be retransmitted in each DCCH until it is updated by the resource acquisition function. The GS DLSs shall periodically request forward link transmission capacities from the Radio Resource Management (RRM) function of its local LME in an analogue way.

The allocation of FL and RL resources shall take quality of service into account. Provisioning of quality of service shall be distributed between the local quality of service function at the DLS and the RRM function in the GS LME. The RRM in the GS LME shall provide centralized management of quality of service among different aircraft, while the quality of service function in the DLS shall arbitrate between concurrent transmission requests and service classes of the same user.

DLS-PDUs encapsulating DLS-SDUs shall be generated according to the resource allocation size and the maximum DLS-SDU size. In case of DLS-SDU fragmentation, the segmentation and reassembly of DLS-SDUs into DLS-PDUs shall be handled transparently by the segmentation and reassembly functions of the DLS.

11.2.2 Functions of the Data Link Service

11.2.2.1 Resource Acquisition

The amount of transmission resources required by the AS DLS changes over time, therefore, the resource acquisition function of the AS DLS shall periodically signal the required resources to the GS LME.

The AS DLS resource acquisition function shall collect the resource needs of all transport functions and queues whenever their status changed. It shall then generate the appropriate control message (possibly combing several resource requests into one control message), and update the DCCH buffer in the AS. This resource request shall be retransmitted in each DCCH until it is updated by the resource acquisition function. In the GS the control message shall be forwarded directly to the RRM of the GS LME.

The GS LME RRM function shall collect the resource requests of all aircraft in the cell and shall determine the FL and RL resource allocations to aircraft dependent on the size and the service class of their requests. The resulting resource allocation shall be announced to the aircraft ASs via the CCCH.

11.2.2.2 Quality of Service

If an AS DLS instance has received a resource allocation, the local quality of service function of the DLS shall assign the allocation to its service classes. The quality of service function may assign the complete resource allocation to a single service class or split it among several service classes.

The assignment algorithm of the quality of service function shall depend on the desired performance characteristics and is out of scope of this specification.

11.2.2.3 Acknowledged Data Transport

The acknowledged transport function performs the transmission of DLS-PDUs (i.e. encapsulated DLS-SDUs or encapsulated DLS-SDU segments) using the selective repeat ARQ protocol.

The sending acknowledged transport function shall wait for an acknowledgement of the receiving acknowledged transport function. If no acknowledgement is received within a specified time frame, the sending side shall reset the according transmission buffers to ensure the retransmission of unacknowledged data. After the maximum number of retransmissions has been reached, the sender shall abandon further retransmission attempts.

Note that several transmissions may be necessary to convey a complete DLS-SDU if it is fragmented into several DLS-PDUs. This fragmentation shall be transparent to the acknowledged transport function.

During the procedures of transmission and acknowledgement the DLS identifies distinct SDUs with a unique combination of service class (SC) and packet identifier (PID). The PID is used as a sequence number for the selective repeat protocol and is conveyed in the DLS-PDU header.

There shall be one acknowledged transport function for each service class.

11.2.2.4 Unacknowledged Data Transport

If the DLS client has requested an unacknowledged data transmission the sending unacknowledged transport function shall not expect acknowledgements or perform retransmissions.

Note that several transmissions may be necessary to convey a complete DLS-SDU if it is fragmented into several DLS-PDUs. This fragmentation shall be transparent to the unacknowledged transport function.

During the procedures of transmission and acknowledgement the DLS identifies distinct SDUs with a unique combination of service class (SC) and packet identifier (PID) conveyed in the DLS-PDU header.

There shall be one unacknowledged transport function for each service class.

11.2.2.5 Segmentation

Based on the resource assignment of the quality of service function the segmentation function shall generate one or several DLS protocol data units (DLS-PDUs) from the DLS service data units (DLS-SDUs) in the transmission buffers. Each DLS-PDU shall contain data from a single queued DLS-SDU, only. Each resource allocation shall be consumed by an integral number of complete DLS-PDUs. The generated DLS-PDUs are forwarded - as MAC-SDU - to the MAC for transmission.

11.2.2.6 Reassembly

The reassembly function of the DLS shall collect DLS-PDUs from the received MAC-SDU and reconstruct/re-assemble DLS-SDUs from them. In case of a transmission error the reassembly function shall find the next intact DLS-PDU by CRC hunting inside the received MAC-PDU using the DLS Header and FCS.

11.2.3 Resource Acquisition Procedures

Whenever the state of one or more transmission buffers or queues has changed, the resource acquisition function of the AS DLS shall compute the total amount of needed resources for each service class. The resource status indication function of the AS DLS shall then communicate an update of the needed transmission resources to the GS LME RRM function.

The signalling of the resource request is specific in the AS and the GS (see Section 11.3.1 and Section 11.4.1).

11.2.4 Quality of Service Procedures

Upon the receipt of a resource allocation the DLS quality of service function shall assign (parts of) the granted transmission resources to one or several service classes. This is referred to as resource assignment.

The assignment algorithm of the quality of service function shall depend on the desired performance characteristics and is out of scope for this specification. However, certain requirements shall be respected by all assignment algorithms:

- A resource assignment algorithm shall respect the priority levels of the DLS service classes.
- A resource assignment shall be at least the size of the minimum DLS DATA_FRAG PDU + 1 octet payload.
- A resource assignment shall comprise an integral number of RL PHY-SDUs for RL transmissions.

11.2.5 Segmentation Procedures

The SNP may request data transport services form the DLS. If a request for an acknowledged data transmission has been previously signalled towards the DLS, the received DLS-SDU shall be queued by the acknowledged transport function of the according class of service. The acknowledged transport function‘s selective repeat protocol shall initialize a transmission buffer for the DLS-SDU when the DLS-SDU is shifted into the sending window of the selective repeat ARQ protocol. Each transmission buffer shall be managed by the segmentation and reassembly function which shall transparently encapsulate, fragment and reassemble the DLS-SDU to and from the DLS-PDUs.

If a request for an unacknowledged data transmission has been previously signalled towards the DLS, the received DLS-SDU shall be queued by the unacknowledged transport function of the according class of service. The unacknowledged transport function shall initialize a transmission buffer for each DLS-SDU in the queue individually. Each transmission buffer shall be managed by the segmentation and reassembly function which shall transparently encapsulate, fragment and reassemble DLS-SDUs to and from DLS-PDUs.

Upon receipt of a resource assignment from the quality of service function the DLS segmentation function shall create one or several DLS-PDUs of appropriate size(s) from the transmission buffers. Note that a DLS-PDU shall not contain multiple DLS-SDUs or fragments of multiple DLS-SDUs. If the size of a resource assignment allows transmitting multiple DLS-SDUs or fragments of multiple DLS-SDUs, the segmentation function shall create separate DLS-PDUs for (fragments of) different DLS-SDUs. This concept is illustrated for four active transmission buffers in Figure 58 (only the relevant header fields are displayed).

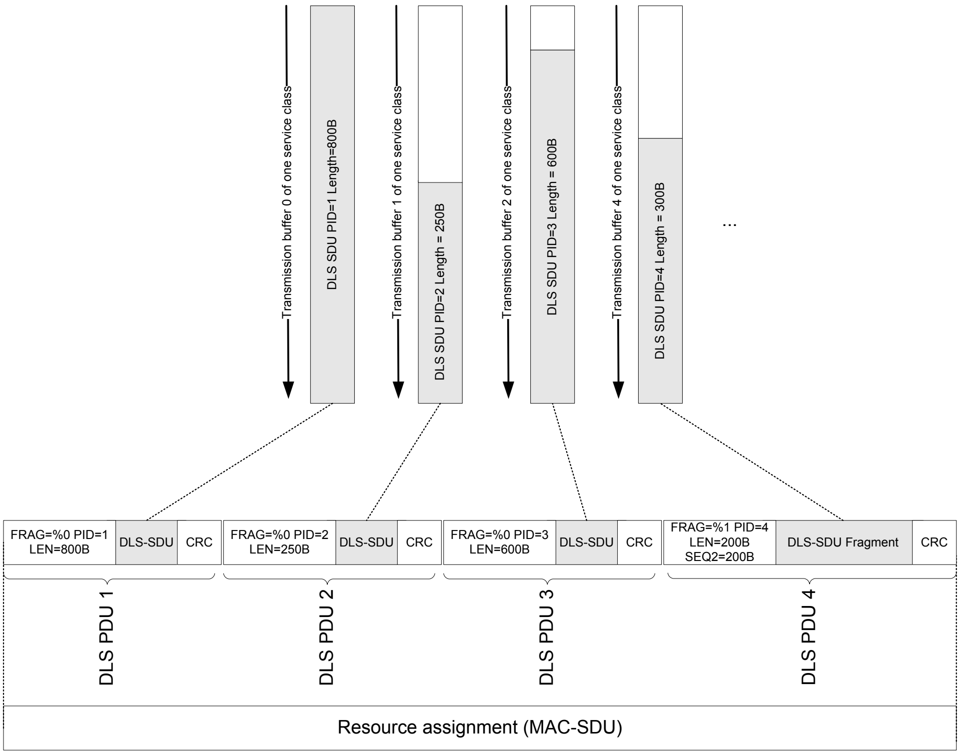

Figure 58: Example operation of the DLS Segmentation Function.

Note that the given PDU lengths are for illustration only.

The segmentation function shall set all header and trailer fields of the DLS-PDUs. All DLS-PDUs generated from fragments of the same DLS-SDU shall have the same PID value (i.e. selective repeat sequence number). The fragmentation and reassembly function shall make the segmentation of DLS-SDUs (which may change with each retransmission) transparent to the selective repeat protocol.

Note that fragmentation of DLS-SDUs will usually only occur at the end of a resource allocation, if the size of the allocation does not permit to send the complete SDU, or at the start of an allocation, if the transmission of a fragment is continued.

11.2.6 Acknowledged Data Transport Procedures

The DLS shall implement one acknowledged data transport function for each service class.

11.2.6.1 Transmission of Data

The segmentation and reassembly function shall manage each transmission buffer of the acknowledged data transfer function. In case of DLS-SDU fragmentation it shall keep track of:

- which data shall be sent next
- which data has been sent and acknowledged

If no retransmission time-out occurred, the next fragment generated by the segmentation function shall contain only unsent data.

If a retransmission time-out occurs, the acknowledged data transfer function shall reset the transmission buffer to the position of the last acknowledged data fragment before the next segment is generated.

The acknowledged data transfer function shall transmit DLS-PDUs with the TYP header field set to %0 via the data channel (DCH).

11.2.6.2 Reception of Data

The acknowledged data transfer function shall accept received DLS-SDUs (reassembled from DLS-PDUs by the reassembly function) according to the receive window setting of the selective repeat protocol. The reassembly function shall evaluate the Frame Check Sequence (FCS) of received DLS-PDUs. If the FCS is invalid, the received DLS-PDU shall be discarded. If the FCS is valid, the received DLS-PDU shall be accepted.

If the DLS-PDU was accepted and the FRAG header field is set to %0 or the FRAG field is set to %1 and the RST field to %1 (i.e. this is either a complete DLS-SDU or the first fragment of a DLS-SDU) an empty receive buffer shall be created for this SC/PID (i.e. DLS-SDU of this service class). The payload of the accepted DLS-PDU shall be stored in the receive buffer for this SC/PID as indicated by the SEQ2 and LEN fields (if present).

If the DLS-PDU was accepted and the FRAG field was set to %1 the receive buffer shall request the transfer of a fragment acknowledgement (ACK_FRAG) to the peer transmission buffer. It shall acknowledge the last octet that was received in order of the DLS-SDU indicated by the SC/PID.

If the DLS-PDU was accepted and the FRAG field was set to %0 or the FRAG field was set to %1 and the LFR field was set to %1 (i.e. either a complete DLS_SDU or the last fragment of the DLS-SDU was received), the acknowledged transport function shall acknowledge the complete DLS-SDU identified by the SC/PID with a cumulative acknowledgement (ACK_CUM) or selective acknowledgement (ACK_SEL). Note that the acknowledged transport function shall combine all outstanding acknowledgements in a single ACK_SEL or ACK_CUM control message. No ACK_FRAG control message shall be sent for DLS-SDUs acknowledged in ACK_CUM or ACK_SEL control messages.

The signalling of the acknowledgement request is specific in the AS and the GS (Section 11.3.1.1 and Section 11.4.2.1).

11.2.6.3 Reception of Acknowledgements

If the transmission buffer receives a fragment acknowledgement (ACK_FRAG) from the peer receive buffer, the state of the corresponding transmission buffer shall be updated.

If the acknowledged transport function receives a cumulative acknowledgement (ACK_CUM) or selective acknowledgement (ACK_SEL) the sending window of the selective repeat protocol shall be shifted and the DLS-SDU shall be removed from the transmission buffer of the acknowledged data transport function if the sending window allows the action. The DLS shall then report the successful transmission to its SNDCP entity.

The reception of an acknowledgement is specific in the AS and the GS (Section 11.3.1.2 and Section 11.4.2.2).

11.2.6.4 Retransmission Timer Management

The DLS retransmission timer of the transmission buffers shall operate by counting acknowledgement opportunities. The MAC entity shall signal each opportunity for an acknowledgement reception to the DLS. The signalling of acknowledgement opportunities is specific in the AS and the GS.

The acknowledgement opportunity of the multi-frame in which the DLS-PDU was sent shall always be counted by the AS and GS DLS. Later acknowledgement opportunities shall only be counted if they are applicable for the AS associated with the DLS (i.e. if the DCCH of the AS is scheduled in this multi-frames DC slot).

There shall be one retransmission timer for each DLS-PDU sent. After each acknowledgement opportunity, the transmission buffer shall update its retransmission timers. If the DLS_PDU has not been acknowledged after DLS_P_RT1 acknowledgement opportunities, the transmission buffer shall be reset to ensure the retransmission of unacknowledged data.

If a transmission buffer has experienced more than DLS_P_MaxRT retransmission time-outs in a row, the transmission shall be aborted. The failure shall be reported to the selective repeat protocol.

11.2.7 Unacknowledged Data Transfer Procedures

The unacknowledged data transport function shall transmit DLS-PDUs generated by the segmentation function with the TYP header field set to %1 via the data channel (DCH). The DLS shall report the transmission to its service clients.

11.2.8 Reassembly Procedures

The acknowledged transfer function and the unacknowledged transfer function shall have reception buffers for each service class (SC) and packet identifier (PID).

In case of acknowledged data transport with fragmentation, the fragment acknowledgement (ACK_FRAG) is sent, defining the number of bytes reassembled completely and in correct order. In this case the fragmentation and reassembly function operates like a go-back-n ARQ protocol on the fragments.

If all fragments of a DLS-SDU have been received, the reassembly function shall reconstruct the DLS-SDU and forward it to the acknowledged or unacknowledged data transport function.

11.2.9 Packet Mode Voice Procedures

Packet mode voice transmissions shall use the unacknowledged data transport function with the reserved DLS_CoS_6 service class.

11.3 Aircraft DLS Specifics

The operation of the functions of the AS DLS is illustrated in Figure 59 and Figure 60. Specifics of the airborne DLS procedures are specified below the corresponding figures.

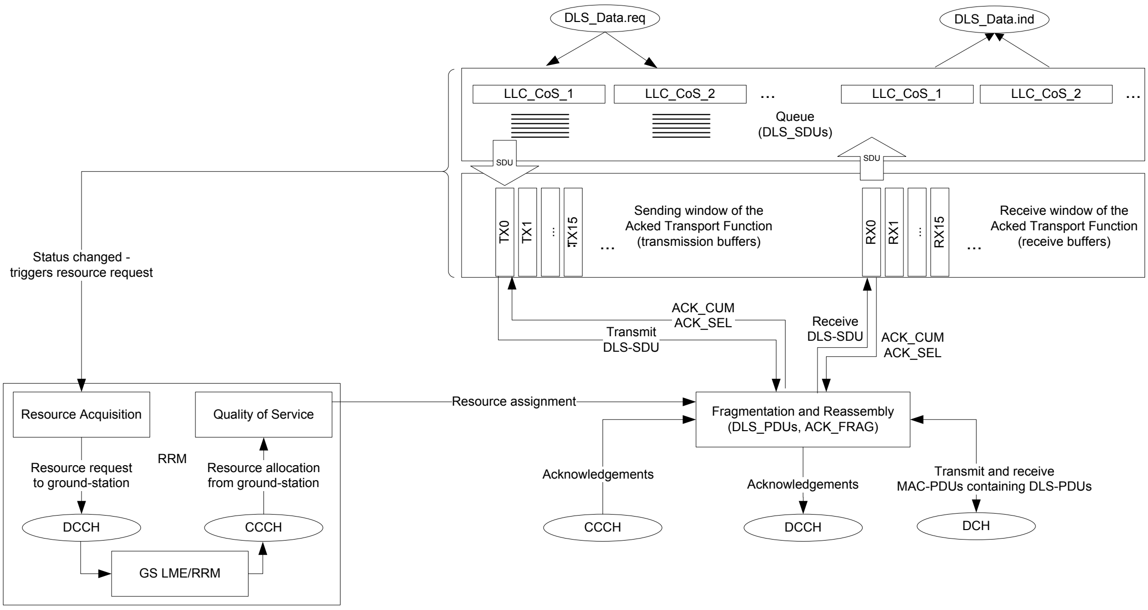

Figure 59: Acknowledged Operation of the AS DLS

Figure 59 illustrates the acknowledged operations of the AS DLS. The acknowledged transport function initializes the transmission buffers in the selective repeat sending window with DLS-SDUs from the transmission queue. Each buffer shall only contain one SDU. The maximum size of the transmission buffer is therefore DLS_P_SDU octets. The fragmentation and reassembly function manages each buffer separately on DLS-PDU level and supports the (re)transmission of corrupted DLS-PDUs.

The AS receives acknowledgements on the CCCH and transmits acknowledgements on the DCCH.

The AS requests RL transmission resources form the RRM in the GS LME via the DCCH.

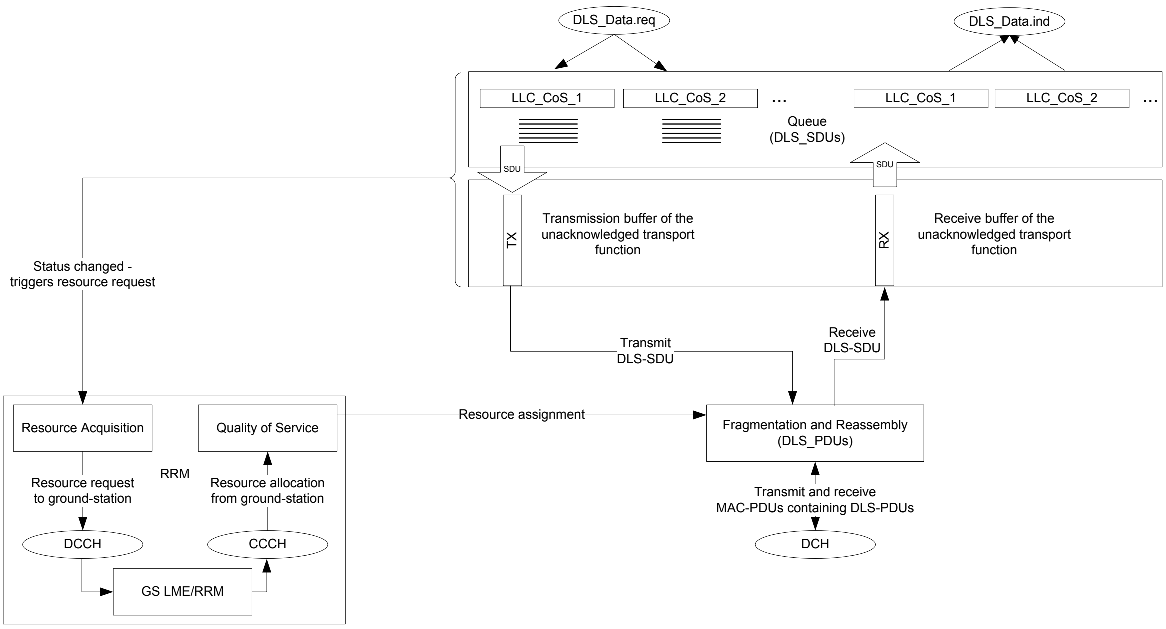

Figure 60: Unacknowledged Operation of the AS DLS

Figure 60 visualizes the unacknowledged operations of the AS DLS. DLS-SDUs from the transmission queue are put into the transmission buffer for consecutive transmission. If necessary, transparent fragmentation and reassembly is applied.

The AS requests RL transmission resources form the RRM in the GS LME via the DCCH.

11.3.1 Specifics of Resource Status Indication Procedures

An AS shall signal a resource request via the DCCH. The AS MAC entity shall retransmit the last known resource request in every DCCH.

11.3.1.1 Transmission of Acknowledgements

An AS shall request the transmission of acknowledgements via the DCCH.

11.3.1.2 Reception of acknowledgements

The AS MAC entity shall signal the reception of acknowledgements on the CCCH to the DLS. If no acknowledgement is received the MAC shall still signal the acknowledgement opportunity.

11.3.2 Specifics of Broadcast Data Transfer Procedures

Broadcast transmission of DLS-SDUs shall be available in the GS, only.

11.4 Ground-Station DLS Specifics

Opposite to the RL, LDACS FL is a point-to-multipoint link. This requires the instantiation of one DLS entity in the GS for each AS in the cell. These DLS entities are identified by the sub-net access code (AS SAC) address of the peer AS.

The operation of the functions of the GS DLS is illustrated in Figure 61 and Figure 62. Specifics of the GS DLS procedures are specified below the figures.

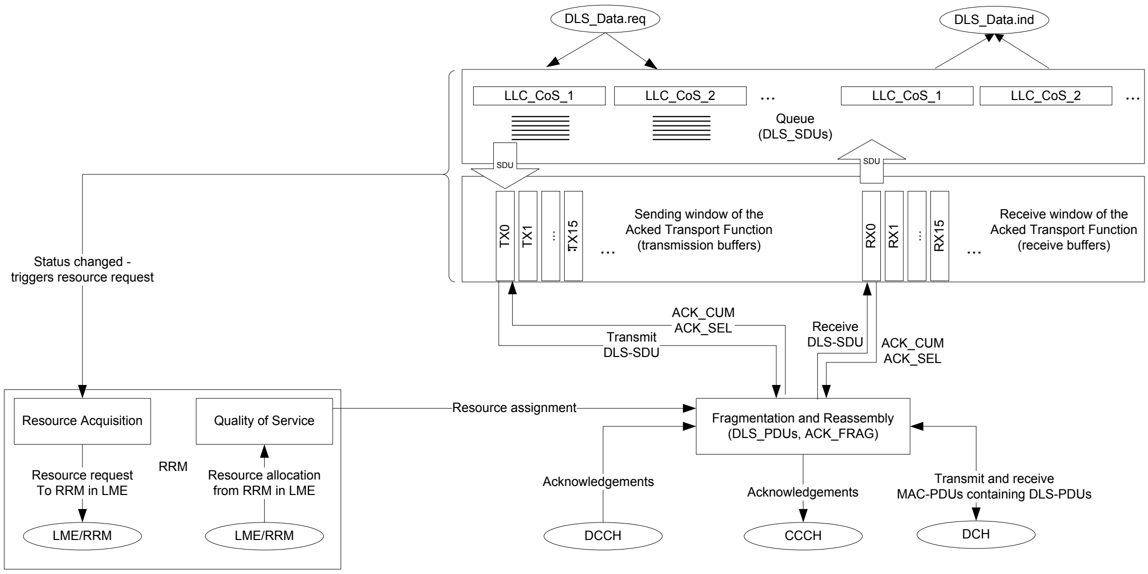

Figure 61: Acknowledged Operation of the GS DLS

Figure 61 illustrates the acknowledged operations of the GS DLS. The acknowledged transport function initializes the transmission buffers in the selective repeat sending window with DLS-SDUs from the transmission queue. The maximum size of the transmission buffer is therefore DLS_P_SDU octets. Each buffer shall only contain one DLS-SDU. The fragmentation and reassembly function manages each buffer separately on DLS-PDU level and supports the (re)transmission of corrupted DLS-PDUs.

The GS receives acknowledgements on the DCCH and transmits acknowledgements on the CCCH.

The GS requests FL transmission resources form the RRM in the GS LME locally.

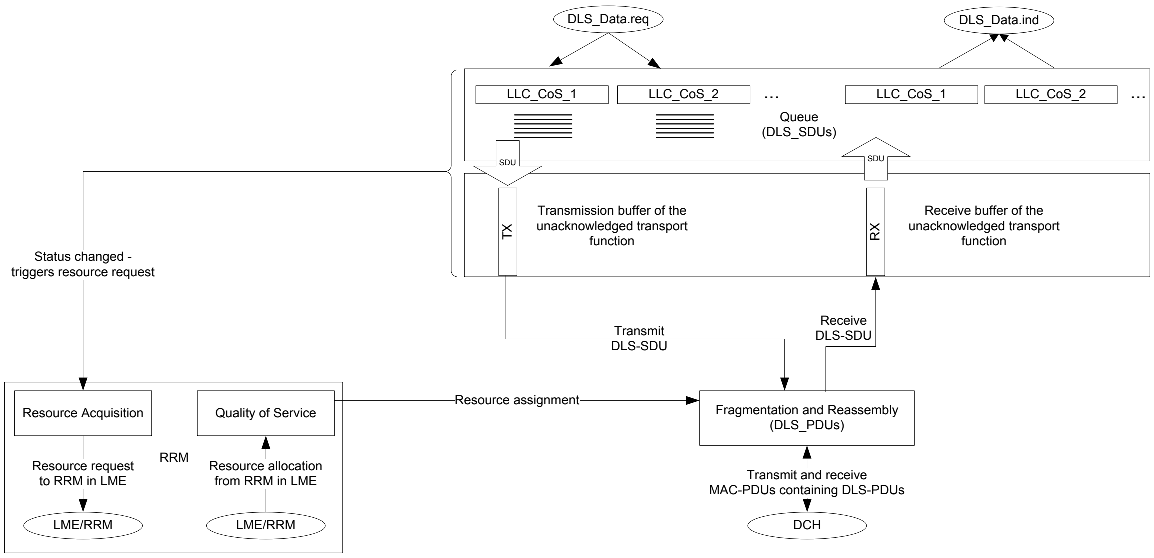

Figure 62: Unacknowledged Operations of the GS DLS

Figure 62 depicts the unacknowledged operations of the GS DLS. DLS-SDUs from the transmission queue are put into the transmission buffer for consecutive transmission. If necessary, transparent fragmentation and reassembly is applied.

The GS requests FL transmission resources form the RRM in the GS LME locally.

11.4.1 Specifics of Resource Acquisition Procedures

A GS shall perform the resource request locally via the RRM function implemented by the LME.

11.4.2 Specifics of Acknowledged Data Transfer Procedures

11.4.2.1 Transmission of Acknowledgements

A GS shall request the transmission of acknowledgements via the CCCH.

11.4.2.2 Reception of acknowledgements

The MAC entity of a GS shall signal the reception of acknowledgements on the DCCH to the DLS. If no acknowledgement is received the MAC shall still signal the acknowledgement opportunity.

11.4.3 Specifics of Broadcast Data Transfer Procedures

Broadcast transmission of DLS-SDUs shall be available for GS, only. Broadcast DLS-SDUs shall be transmitted using the unacknowledged data transfer function using the broadcast AS SAC address in the FL MAP of the CCCH.

11.5 DLS Parameters

11.5.1 Maximum DLS-SDU size (DLS_P_SDU)

This parameter defines the maximum DLS-SDU size of the DLS entity. DLS_P_SDU shall be between 8 and 2048 octets.

Note: The maximum DLS-SDU size (2048 Octets minus SNP overhead) defines also the MTU of LDACS. Packets larger than the MTU shall be dropped.

Note: Table 76 displays recommended maximum DLS_P_SDU sizes for different bit error rates in the DCH (after FEC). The parameters have been chosen for maximum DLS efficiency assuming uniformly distributed residual bit errors. In case of channel usage restrictions, it is recommended to set DLS_P_SDU not higher than the maximum allowed resource allocation size.

Table 76: Recommended DLS_P_SDU Settings.

Bit error rate	DLS_P_SDU (B)
$5*10^{-8}$	2048
$5*10^{-7}$	1121
$5*10^{-6}$	356
10^{-5}	253
$5*10^{-5}$	114
10^{-4}	82

If the maximum size of the resource allocation is restricted, the parameter DLS_P_SDU shall not be larger than the maximum allocation size.

11.5.2 Maximum DLS-PDU size (DLS_P_PDU)

This parameter defines the maximum DLS-PDU size of the DLS entity. DLS_P_SDU shall be less than DLS_P_PDU. It is recommended to set DLS_P_PDU equal to DLS_P_SDU plus the maximum DLS header size. In this case, minimum fragmentation will occur.

11.5.3 Retransmission Timer 1 (DLS_P_RT1)

This parameter defines the maximum number of missed acknowledgement opportunities before a retransmission is triggered by the acknowledged transport function. The default value shall be 2 acknowledgement opportunities.

Note: Although this parameter is called a timer, its most likely implementation is a counter of acknowledgement opportunities.

Note: Figure 63 illustrates the DLS retransmission timer on the reverse link. After the aircraft-station has sent a DLS-PDU in the RL Data slot there are two possible acknowledgment opportunities on the forward link. The first opportunity could be in the CC slot during the RL Data slot of the transmission if the physical layer supports the immediate forwarding of received data. However, only the CC slot in the next multi-frame is an acknowledgement opportunity available independently of the physical *layer implementation. The DLS retransmission timer shall therefore be set to the end of this acknowledgement opportunity.*

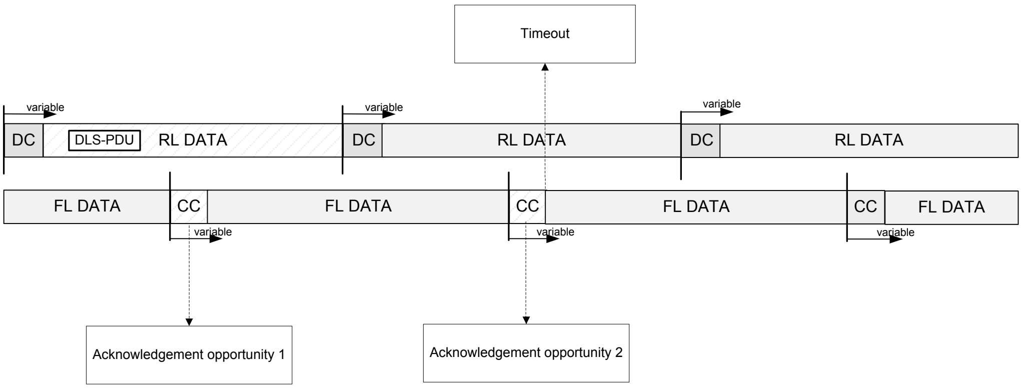

Figure 63: LDACS RL DLS retransmission timer.

Note: Figure 64 displays the same concept for the forward link DLS retransmission timer. There are two acknowledgement opportunities on the reverse link after the DLS Data PDU is sent. The first opportunity could be in the DC slot during the FL Data slot of the transmission. The second acknowledgement opportunity is the next appearance of the receiving aircraft-station's DCCH. According to the number of registered aircraft-stations not every AS is able to send its DC in each multi-frame. The ground-station has therefore to check the assignment of the aircraft-station's control offsets CO to identify valid acknowledgement opportunities. The timeout is therefore set to the end of the next DC slot where the aircraft-stations DCCH is transmitted.

Note that the first DC slot can always be counted as an acknowledgement opportunity, as the acknowledgement has to be sent in the next DC slot in any case.

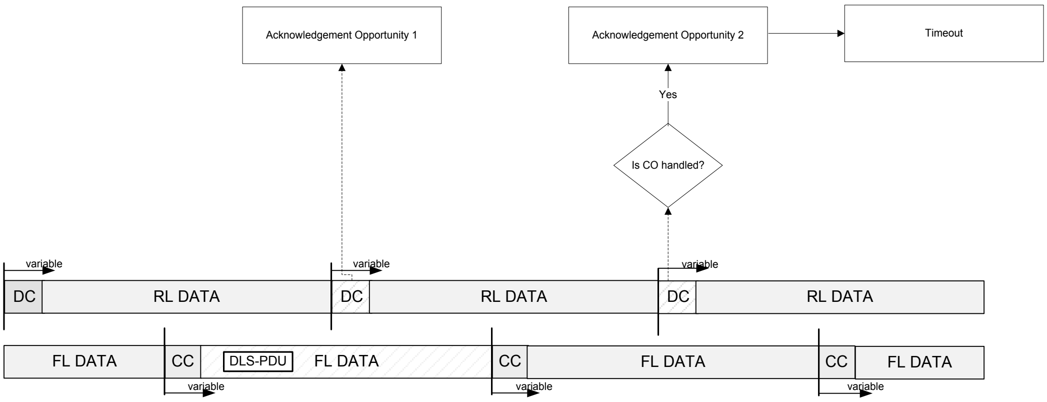

Figure 64: LDACS FL DLS retransmission timer.

11.5.4 Maximum Number of Retransmissions (DLS_P_MaxRT)

This parameter defines the maximum number of retransmissions that is tolerated before a DLS-SDU transmission is aborted by the acknowledged transport function. The default value shall be 4.

11.6 DLS-PDU Format Definition

Each DLS-PDU shall contain an integral number of octets, and shall comprise a header part and a data part. A DLS-PDU shall contain data from a single DLS-SDU only. Two different DLS-PDU formats are defined.

11.6.1 Dedicated Control Messages

11.6.1.1 Cumulative Acknowledgement (ACK_CUM)

The cumulative acknowledgement control message shall be used to acknowledge the error-free reception of all DLS-SDUs belonging to a single SC up to the given PID. The ACK_CUM control message shall contain the following values.

Table 77: Cumulative Acknowledgement

Field	Size	Description
D_TYP = %0010	4 Bit	Cumulative Acknowledgement
SC	3 Bit	Service Class
PID	5 Bit	Packet Identifier
PAD	4 Bit	Reserved

11.6.1.2 Selective Acknowledgement (ACK_SEL)

The selective acknowledgement control message shall be used to acknowledge an error-free receipt of two or more DLS-SDUs belonging to the same SC (i.e. acknowledged transport function). At most 16 different PIDs (i.e. one complete DLS ARQ window) may be acknowledged. The ACK_SEL control message shall contain the following values.

Table 78: Selective Acknowledgement

Field	Size	Description
D_TYP = %0011	4 Bit	Selective Acknowledgement
SC	3 Bit	Service Class
PID	5 Bit	First PID in acknowledgement bitmap.
BITMAP	16 Bit	Acknowledgement bitmap.
PAD	0 Bit	Reserved

Binary one %1 in the BITMAP field shall signal the successful reception of the corresponding DLS-SDU.

11.6.1.3 Fragment Acknowledgement (ACK_FRAG)

The fragment acknowledgement control message shall be used to cumulatively acknowledge the error-free reception of parts of a DLS-SDU. This message shall only be used to acknowledge received error-free fragment(s) belonging to the same DLS-SDU; if the complete DLS_SDU has been received the cumulative acknowledgement message (ACK_CUM) or selective acknowledgement message (ACK_SEL) shall be used instead. The ACK_FRAG control message shall contain the following values.

Table 79: Fragment Acknowledgement

Field	Size	Description
D_TYP = %0100	4 Bits	Single Acknowledgement
SC	3 Bit	Service Class
PID	5 Bit	Packet Identifier
SEQ1	11 Bit	Sequence Number
PAD	1 Bit	Reserved

11.6.1.4 Resource Request (RSC_RQST)

The resource request control message shall be used to signal resource requirements towards the GS. The resource requirement shall be expressed in number of RL PHY-SDUs (NRPS) according to the last announced coding and modulation. This message shall be used if resources are needed for a single packet of a given service class (SC) only. The RSC_RQST control message shall contain the following values.

Table 80: Resource Request

Field	Size	Description
D_TYP = %0111	4 Bit	Resource Request
SC	3 Bit	Service Class
REQ	11 Bit	Octets requested i.e. size of the packet to be transmitted
PAD	6 Bit	Reserved

11.6.2 Common Control Messages

11.6.2.1 Cumulative Acknowledgement (ACK_CUM)

The cumulative acknowledgement control message shall be used to acknowledge the error-free reception of DLS-SDUs belonging to a single SC up to the given PID[16]. The ACK_CUM control message shall contain the following values.

Table 81: Cumulative Acknowledgement

[16] NOTE that the CCCH message format is analogue to the DCCH message format.

Field	Size	Description
C_TYP = %01000	5 Bit	Cumulative Acknowledgement
AS SAC	12 Bit	AS Identifier
SC	3 Bit	Service Class
PID	5 Bit	Packet Identifier
PAD	7 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

11.6.2.2 Selective Acknowledgement (ACK_SEL)

The selective acknowledgement control message[17] shall be used to acknowledge an error-free receipt of two or more DLS-SDUs belonging to the same SC (i.e. acknowledged transport function). At most 16 different PIDs (i.e. one complete DLS ARQ window) may be acknowledged. The ACK_SEL control message shall contain the following values.

Table 82: Selective Acknowledgement

Field	Size	Description
C_TYP = %01001	5 Bit	Selective Acknowledgement
AS SAC	12 Bit	AS Identifier
SC	3 Bit	Service Class
PID	5 Bit	First PID in acknowledgement bitmap.
BITMAP	16 Bit	Acknowledgement bitmap.
PAD	7 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

Binary one %1 in the BITMAP field shall signal the successful reception of the corresponding DLS-PDU.

11.6.2.3 Fragment Acknowledgement (ACK_FRAG)

The fragment acknowledgement control message shall be used to cumulatively acknowledge the error-free reception of parts of a DLS-SDU. This message shall only be used to acknowledge received error-free fragment(s) belonging to the same DLS-SDU; if the complete DLS_SDU has been received the cumulative acknowledgement message (ACK_CUM) or selective acknowledgement message (ACK_SEL) shall be used instead. The ACK_FRAG control message shall contain the following values.

[17] The CCCH message format is analogue to the DCCH message format for ACK_SEL and ACK_FRAG messages.

Table 83: Fragment Acknowledgement

Field	Size	Description
C_TYP = %01010	5 Bits	Single Acknowledgement
AS SAC	12 Bit	AS Identifier
SC	3 Bit	Service Class
PID	5 Bit	Packet Identifier
SEQ1	11 Bit	Sequence Number
PAD	4 Bit	Reserved
CRC-8	8 Bit	Cyclic Redundancy Checksum

11.6.3 User Data

Each DLS-PDU shall contain an integral number of octets, and shall comprise a header and data. A DLS-PDU shall contain data from a single DLS-SDU only. Two different DLS-PDU formats are defined.

11.6.3.1 DATA

The DLS DATA PDU shall convey one unfragmented DLS-SDU.

Table 84: DATA

Field	Size	Description
TYP	1 Bit	Acknowledged/Unacknowledged Flag
FRAG	1 Bit	%0 (No Fragment)
SC	3 Bit	Service Class
PID	5 Bit	Packet Identifier
LEN	11 Bit	Length of PDU
PAD	3 Bit	Padding
User Data	≤ DLS_P_SDU octets	Variable Length User Data Payload
CRC-32	32 Bit	Frame Check Sequence

11.6.3.2 DATA_FRAG

The DLS DATA_FRAG PDU conveys a fragment of one DLS-SDU. The RST flag shall be %1 in the first fragment. The LFR flag shall be %1 in the last fragment.

Table 85: DATA_FRAG

Field	Size	Description

TYP	1 Bit	Acknowledged/Unacknowledged Flag
FRAG	1 Bit	%1 (Fragment)
RST	1 Bit	Reset
LFR	1 Bit	Last Fragment
SC	3 Bit	Service Class
PID	5 Bit	Packet Identifier
SEQ2	11 Bit	Offset (in the DLS_SDU) of the last octet of user data conveyed in this fragment.
LEN	11 Bit	Length of PDU
PAD	6 Bit	Padding
User Data	< DLS_P_SDU octets	Variable Length User Data Payload
CRC-32	32 Bit	Frame Check Sequence

11.6.4 DLS Frame Check Sequence

For control data the DLS shall use a 8 bit Cyclic Redundancy Check (CRC). The following standardized CRCs shall be used for error detecting:

- CRC-8: 0x97

CRC computation shall start with the Most-Significant-Bit (MSBit) of the Most-Significant-Byte (MSByte) and ends with the Least-Significant-Bit (LSBit) of the Least-Significant-Byte (LSByte).

Messages with incorrect CRC shall be discarded.

For user data the DLS shall use as Frame Check Sequence (FCS) algorithm a 32 bit Cyclic Redundancy Check (CRC). The following standardized CRCs shall be used for error detecting:

- CRC-32: 0xFA567D89

CRC computation shall start with the Most-Significant-Bit (MSBit) of the Most-Significant-Byte (MSByte) and ends with the Least-Significant-Bit (LSBit) of the Least-Significant-Byte (LSByte).

Messages with incorrect CRC shall be discarded.

11.7 DLS Information Element Definition

All information elements shall be encoded in network bit and byte order i.e. big-endian bit and byte order.

11.7.1 C_TYP – Common Control Type

This field indicates the common control type. C_TYP shall have a size of 5 bits.

11.7.2 D_TYP – Dedicated Control Type

This field indicates the dedicated control type. D_TYP shall have a size of 4 bits.

11.7.3 FCS - Frame Check Sequence

This field is the 32-bit frame check sequence used for error detection in the DLS entity. The FCS shall be calculated over the complete DLS-PDU (i.e. header plus payload).

11.7.4 FRAG – Fragment Flag

If the fragment flag is set to %0 this shall indicate that the DLS-PDU is not a fragment of a DLS-SDU. If the fragment flag is set to %1 this shall indicate that the DLS-PDU is a fragment of a DLS-SDU.

11.7.5 LFR - Last Fragment

If the DLS_FRAG-PDU does not contain the last fragment of a DLS-SDU, the LFR field shall be set to %0. If the DLS_FRAG-PDU contains the last fragment of a DLS-SDU the LFR field shall be set to %1.

11.7.6 LEN - Length

The LEN field shall indicate the length of complete DLS-PDU in octets.

11.7.7 PID – Packet Identifier

This field indicates the packet identifier (PID). This field shall have a size of 5 bits.

Note: The size of the PID implies also the maximum size of the window sizes of the selective repeat ARQ protocol. The maximum window size is (maximum sequence number + 1)/2. The maximum window size is therefore 16 for LDACS.

11.7.8 REQ – Octets Requested

This field indicates the number of octets requested. This field shall have a size of 15 bits.

11.7.9 RST - Reset

If the DLS_FRAG-PDU does not contain the first fragment of a DLS-SDU, the RST field shall be set to %0. If the DLS_FRAG-PDU contains the first fragment of a DLS-SDU the RST field shall be set to %1.

11.7.10 SC – Service Class

This field indicates the Service Class (SC). This field shall have a size of 3 bits and shall assume the values indicated in Section 11.1.1.5.

11.7.11 SEQ1 – Sequence Number

The SEQ1 field shall indicate the number of correctly received octets (i.e. the offset of the next expected octet which is SEQ2+1 of the last receive DLS_FRAG-PDU).

11.7.12 SEQ2 - Sequence Number

The SEQ2 field shall indicate the offset of the last octet of the DLS-SDU conveyed in the DLS_FRAG-PDU.

11.7.13 TYP - Type

The acknowledged data transport function shall transmit DLS-PDUs with the TYP header field set to %0.

The unacknowledged data transport function shall transmit DLS-PDUs with the TYP header field set to %1.

12 Voice Interface (VI) Specification

12.1 General Description

The LDACS VI entity provides support for virtual voice circuits. Voice circuits may either be set-up permanently by the GS (to emulate legacy party line voice service) or be created on demand. The establishment or withdrawal of voice channels is performed in the LME. The VI provides only the transmission and reception services.

12.1.1 Services

12.1.1.1 Dedicated Circuit Voice Service

The dedicated circuit voice service supports party line voice transmission on dedicated voice channels. The voice service is provided to a specific user group (party-line) on an exclusive basis not sharing the voice circuit with other users outside the group. Access shall be based on a "listen-before-push-to-talk" discipline. Dedicated voice channels have to be configured via the GS.

12.1.1.2 Demand Assigned Circuit Voice Service

The demand assigned circuit voice service provides access to voice circuits that are created on demand by the arbitration of the GS. Both the GS and the AS may request the creation of a demand assigned voice circuit.

12.1.2 VI State Transition Diagram

The VI may either be in open state or in closed state. The VI shall fail all requests in closed state. State changes shall be invoked by the LME through open or close commands.

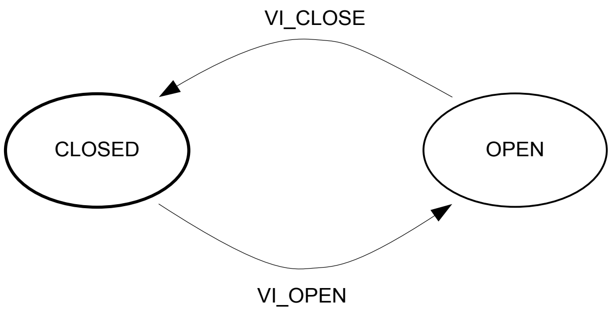

Figure 65: VI State Transmission Diagram

12.1.3 VI Interface to Service Users

The VI shall provide an interface to its service users as described in Section 7.2.5.

12.2 Operation of the Voice Interface

12.2.1 General Description

The voice interface (VI) provides support for two types of virtual voice circuits: Dedicated voice circuits and demand assigned voice circuits. Dedicated voice circuits may only be set-up by the GS (to emulated party line voice). Demand assigned voice circuits may be requested by the AS as well as from the GS. Both types of voice channels are transmitted over the data channel (DCH).

The general functions of the voice interface (VI) are to define procedures and message formats that permit the transmission of digital voice over the data channel (DCH). The set-up and withdrawal of voice channels is performed in the LME.

12.2.2 Functions of the Voice Interface

12.2.2.1 Voice Transport

The VI shall provide support for digital, low-bit rate encoding of speech for efficient transmission over the voice channel. The VI shall support notification to the user of the source of a received voice message.

12.2.2.2 Voice Channel Access

The VI shall provide an interface for "push-to-talk" voice channel access. The VI shall support priority override access for authorized ground users.

12.2.3 Voice Transport Procedures

12.2.3.1 Voice Message Encoding

The VI shall use the Augmented Multiband Excitation (AMBE) 4.8 kbps encoding/decoding algorithm, version number AMBE-ATC-10B, developed by Digital Voice Systems Incorporated (DVSI) for the encoding of voice samples.

12.2.3.2 Voice Message Transport

Encoded voice shall be conveyed in VI-PDUs (Section 12.3). Each VI-PDU contains three 20 ms voice samples of the AMBE-ATC-10B vocoder and the AS SAC address of the message source. VI-PDUs shall be transmitted over the (FL or RL) data channel (DCH).

The transmission queue of the VI-PDU shall provide a buffer for the synchronous mapping of the voice samples produced by the AMBE ATCC10B vocoder onto the MAC framing structure. As the average multi-frame length (60 ms) is a multiple of the sample length of the vocoder, long term synchronisation is assured if three voice samples are transmitted per multi-frame. This is provided by the VI set-up procedures in the LME. If a VI-PDU is correctly received by the GS on the RL DCH, the VI-PDU shall be relayed on the FL DCH to emulate a party-line voice channel. An AS VI shall not transmit voice samples on the RL DCH if it is currently receiving VI-PDUs on the FL DCH.

NOTE: The GS shall relay received voice packets on the upcoming FL voice slot with a total delay not longer than 60 ms. Moreover, RS coding, block interleaver, and CC coding could be probably omitted when handling voice packets (only the permutation interleaver would be used).

12.2.3.3 Voice Message Source Identification

When the VI receives a VI-PDU the source of the encoded voice message shall be indicated to the service user. The source of the voice message is encoded in the header of each VI-PDU.

12.2.4 Voice Channel Access Procedures

12.2.4.1 Push-to-Talk Access

Access to a voice channel shall be managed by the human supported listen-before-push-to-talk protocol. If a user request voice channel access (i.e. by pushing the talk button) VI-PDUs containing vocoder frames shall be transmitted over the DCH. Note that no VI-PDUs will be transmitted by the AS voice transport function, if there is an ongoing voice transmission on the FL DCH for this voice channel.

12.2.4.2 Priority Access

Priority access to a voice channel shall only be provided at the GS. Ground-based priority access shall be realised through the GS's control over the FL DCH and the VI-PDU relaying function. If a privileged ground user request channel access, the relaying of VI-PDUs received on the RL DCH shall be pre-empted over the duration of the transmission of the VI-PDUs of the privileged user on the FL DCH. The user of AS voice shall then be alerted that his/her voice access was overruled by the GS in favour of the prioritized ground user.

12.3 VI PDU Format Definition

12.3.1 VOICE

The VOICE PDU conveys three AMBE-ATC-10B voice frames (60 ms). Note that the VOICE PDU payload does not need a FCS, as the AMBE-ATC-10B vocoder embeds its own error detection functions into the voice samples. The size of the VOICE PDU is aligned with the size of three CMS type 1 RL PHY-PDUs (see Section 10.6.8).

Table 86: VOICE PDU Format

Field	Size	Description
AS SAC	12 Bit	Subscriber access code
PAD	36 Bit	Reserved
VOICE	288 Bit	AMBE-ATC-10B vocoder samples

12.4 VI Information Element Definition

12.4.1 AS Sub-net Access Code (AS SAC)

This field indicates the sub-net access code (AS SAC) of the peer AS. For FL party line voice transmissions the AS SAC field shall be set to broadcast AS SAC address.

13 Sub-Network Protocol (SNP)

Note: The contents of this section will be developed together with the LDACS architecture definition.

13.1 General SNP Description

The SNP provides end-to-end connectivity between the AS and GS within the LDACS sub-network. It cryptographically secures communication as configured by the GSC. It also compresses IPv6 headers, ascertains integrity, and routes data packets according to their class of service.

13.1.1 Services

13.1.1.1 Data Link Service

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

It shall provide the functionality to route SNP-SDUs according to their requested class of service to the appropriate DLS class of service

Note that classes of service are requested via the DSCP field of the IPv6 header. If other network layers shall be supported the data link service has to be extended accordingly.

It shall provide the functionality to separate user plane from control plane packets.

13.1.1.2 Security Service

The security service (ciphering and integrity protection services) shall provide functions for secure communication over the LDACS sub-network.

Note that LDACS security is managed by the GSC. The SNP security service applies cryptographic measures as configured by the GSC.

13.1.1.3 Header compression service

The header compression service shall be based on the Robust Header Compression (RoHC) framework.

Note that RoHC is defined for IPv6 packets. The header compression service has therefore to be extended with additional header compression modes if other network layers shall be supported.

13.1.2 SNP Interface to Service Users

The SNDCP shall provide an interface to IPv6 as described in Section 7.2.6.

13.2 Operation of the Data Link Service

The data link service shall accept SNP-SDUs from the IPv6 network layer for transmission. It shall mark the SNP-SDU as a user plane packet. It shall mark the SNP-SDU with the appropriate DLS-CoS as a function of the DSCP value of the IPv6 header in the SN-SDU.

Note the mapping of DSCP values to DLS-CoS values is out of the scope of this specification.

The data link service shall accept SNP-SDUs from the LME for transmission. It shall mark the SNP-SDU as control plane packet. It shall mark the SNP-PDU with DLS_CoS_7 as indicated in Table 75.

The data link service shall accept received SNP-PDUs from the DLS. SNP-SDUs marked as user plane packets shall be handed to the network layer. SNP-SDUs marked as control plane packets shall be handed to the LME.

13.3 Operation of the Header Compression Service

The header compression service shall apply RoHC to IPv6 packets received as SNP-SDUs.

13.4 Operation of the Security Service

The security service shall construct SNP-PDUs from the marked SNP-SDUs received from the data link service and header compression service. It shall add the SNP header and a message authentication code according to its configuration. The security service is configured by the GSC.

The security service shall check the integrity of received SNP-PDUs using the message authentication code. SNP-PDUs with invalid message authentication code shall be discarded.

Note: Security will be developed together with the LDACS architecture definition.

13.5 SNP Parameters

13.5.1 Maximum SNP-SDU size (SNP_P_SDU)

This parameter defines the maximum SNP-SDU size of the DLS entity. SNP_P_SDU shall be equal to 2031 octets. Received packets larger than SNP_P_SDU shall be discarded.

13.6 SNP PDU Format Definition

Each SNP-PDU shall contain an integral number of octets, and shall comprise a header part, a data part, and a trailer part. A SNP-PDU shall contain data from a single SNP-SDU only.

Table 87: SNP-PDU

Field	Size	Description
CTRL	1 Bit	Control data flag
NSEL	7 Bits	Network selector
MAC	128 Bits	Message authentication code

User Data	≤ SNP_P_SDU octets	Variable Length User Data Payload

13.7 SNP Information Element Definition

13.7.1 CTRL – Control Data Flag

CTRL=%0 shall indicate a user plane packet.

CTRL=%1 shall indicate a control plane packet.

Note: Only SDUs received from the LME may have the CTRL bit set.

13.7.2 NSAP – Network Selector

The NSEL identifies the network layer service to which a SNP-SDU should be sent.

If CTRL is set to %1 the field NSEL shall be set to %0000000.

For IPv6 NSEL shall be set to %0000001.

13.7.3 MAC - Message authentication code

Cryptographic message authentication code.

Note: Security will be developed together with the LDACS architecture definition.

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Appendix A LDACS Link Budget

In this section two link budget calculations are provided for LDACS; one for an interference-free case, and another one for a case where the system operates under real L-band interference.

A.1 General Assumptions and Remarks

Combined negative effects of the currently assumed low gain airborne antenna (0 dBi) and the banking margin (7 dB) on the link budget require further investigation. In particular, it must be clarified how much allowance for banking losses is required when using an omni-directional airborne antenna with 0 dBi peak gain and the agreed value should be proposed for different airspace types.

The opportunity for using ground LDACS antennas with peak gain higher than 8 dBi should be investigated in the further work as well.

When calculating the preliminary LDACS link budget some general assumptions have been made. As these assumptions may apply to any L-band communications system, they must be confirmed outside this work.

- Airborne antenna peak gain: 0 dBi

Airborne antenna gain has been assumed as in UAT link budget (for conformance with parallel tasks), but may have to be revised in the future work (may be too conservative when applied to the forward-fit LDACS case). UAT is an ADS-B system that requires omni-directional antenna pattern that has been composed by combining two (top- and bottom-mounted) antennas. UAT link budget for the air-air case provided in [DO_282A]/Appendix F considers the omni-directional airborne antenna pattern with 0 dBi gain as adequate to cover all possible air-air orientations (no further margin for antenna misalignment or banking has been considered). An omni-directional pattern is not really required for LDACS operation, so the airborne antennas with gain above 0 dBi may well be used. Such antennas are available on the market. [UAT_M]/Appendix B.2 suggests 4.1 dBi peak gain for a single airborne antenna. Reference [ECC 96] proposes the peak gain 5.4 dBi (also specified in Recommendation ITU-R M.1639). However, using such airborne antennas within link budget calculations is conditioned by a common agreement about applicable banking loss figures in different airspace types.

- Airborne cable losses: 3 dB
- Airborne duplexer losses: 0.5 dB

In [UAT_M]/Section 5.3 diplexer losses in the 0.5 dB range have been considered as feasible, allowing for both forward-fit and in the most cases even retrofit of UAT equipment with diplexer included. In the LDACS case only forward-fit case would apply. The feasibility of a duplexer with 0.5 dB loss has been questioned and is yet to be demonstrated, however an eventual minor loss increase compared to the UAT diplexer can be compensated for, e.g. by requiring better airborne cabling. Alternatively, airborne antennas with peak gain above 0 dBi may be required for forward-fit.

- Banking loss allowance: 7 dBi

The figure represents the best current guess for the TMA airspace. The same figure has been used for possible excess losses due to bottom-mounted AS antenna in APT environment ("worse-than-Rayleigh" propagation channel type). The banking loss has been considered in the link budget independently of the safety margin.

- Ground antenna peak gain: 8 dBi

This is the typical value used in L-band link budget calculations. For new LDACS GS installations, ground antennas with peak gain above 8 dBi can probably be used. In particular, when calculating the link budgets for 200 nm cells within this Annex, ground antenna with 13 dBi gain has been assumed.

- Ground cable losses: 2 dB

This value may be achieved e.g. by using 40 m of high quality cable with 0.05 dB/m losses. Higher cable cost can be easier justified for the GS than for an AS. Moreover, the cabling cost will be a fraction of the total GS installation costs and should not become a constraint in link budget calculations. If a longer cable would be required, excess loss can be compensated for by using omni-directional ground antennas with more than 8 dBi peak gain of sectorised ground antennas.

- Receiver NF: 5 dB/6 dB for GS/AS RX

The proposed NF values are seen as realistic by the LDACS team. It should be noted that the impact of external components upon the link budget (cabling loss, antenna gains, duplexer loss) has been separately captured (the declared NF is related to the RX alone). The LDACS link budget includes relatively large system implementation margin (4 dB) that has been effectively combined with the receiver noise figure (resulting in an “equivalent receiver NF”, still referred to the receiver input, of 9/10 dB, respectively). Assumed NF values may be traded against assumed implementation margin without impact upon the link budget as long as the sum remains below such “equivalent RX NF”.

A.2 Operation without L-band Interference

Table Annex 2 provides an LDACS link budget for the interference-free case.

The calculation considers LDACS FL and RL as well as different operating environments (ENR, TMA and APT). In an ENR environment, the results are provided for three different ranges (200/120/60 nm). The maximum LDACS transmitting power has been indicated, but in the practical implementation the transmitting power would be adapted to different cell sizes and types.

This link budget considers mobile channel effects which are expressed as different Eb/N0 values for a target BER of 10^{-6}, leading to different values of the RX Sensitivity S0. When calculating S0, the system implementation margin has been considered as an increase of the total RX noise power. Losses due to the misalignment between the airborne and ground antenna have been included as an increase of the total path loss between the TX and RX. However, when determining S0, no interference from multiple L-band sources has been considered. Therefore, this scenario applies to the LDACS deployment in the free L-band spectrum, allowing for a fair comparison with other candidate systems.

The RX operating point S1 is a minimum required RX input signal power (nominal level) for a satisfactory RX operation, derived by applying the aeronautical safety margin (6 dB) above the RX sensitivity S0.

The resulting system operating margin (OM) represents the difference between the actual received desired signal power and the calculated RX operating point S1, both referenced to the receiver input.

A.3 Operation under L-band Interference

Table Annex 3 provides an alternative LDACS link budget for the case where the system is deployed as an inlay system, operating under interference coming from multiple L-band transmitters (relevant airborne and ground L-band transmitters within the RX radio coverage range).

The results are provided for three different operating environments. The maximum LDACS transmitting power has been indicated, but in the practical implementation the transmitting power would be adapted to different cell sizes and types.

Opposite to the case without interference, the RX sensitivity value S0 now considers real interference conditions in addition to the appropriate aeronautical channel applicable to the particular environment. S0 is based on the Eb/N0 values derived from the simulations conducted in the previous B-AMC work. These figures, in conjunction with erasure decoding and pulse blanking as a combined interference mitigation method in the RX (see Appendix C) have shown promising system performance. The S0 values under interference derived by this way are higher than the corresponding S0 for the interference-free case. In this case, no additional interference margin needs to be used in the link budget calculation.

The RX operating point S1 is a minimum required RX input signal power (nominal level) for a satisfactory RX operation, derived by applying the aeronautical safety margin (6 dB) above the RX sensitivity S0.

Again, the system implementation margin has been considered as an increase of the total RX noise power. Losses due to the misalignment between the airborne and ground antenna have been included as an increase of the total path loss between the TX and RX.

As in the previous case, the resulting system operating margin (OM) represents the difference between the actual received desired signal power and the calculated RX operating point S1, both referenced to the receiver input.

> *NOTE: The entire link budget calculation indirectly depends on the assumptions/scenarios used when deriving S/N and Eb/No values. Should these assumptions change in the future, the link budget calculation may have to be updated as well.*

A.4 Deriving Eb/No Values

The link budget regards mobile channel effects which are expressed as different Eb/N0 values for a target BER of 10-6, leading to different RX sensitivity values S0. The Eb/N0 figures were retrieved from simulations of the LDACS physical layer as specified in Chapter 7. OFDM parameters are set according to Table 7-1.

Airborne RX sensitivity S0 has been calculated assuming that GS is using all FL sub-carriers ($N_{used} = N_u$) with QPSK modulation, convolutional coding with r_{cc} = ½, interleaving over 8 FL data frames and Reed-Solomon RS (101, 91, 5) coding in FL data frames.

Ground RX sensitivity S0 has been calculated assuming that AS is using all RL sub-carriers ($N_{used} = N_u$) with QPSK modulation, convolutional coding with r_{cc} = ½, interleaving over 6 tiles and Reed-Solomon RS (98, 84, 7) coding in RL data segments.

At the TX, the concatenation of an RS code and convolutional coding with r_{cc} = ½, as specified in Section 7.6.1 and QPSK modulation are used. At the RX, ideal synchronisation and channel estimation are assumed. Performance losses occurring with real synchronisation and channel estimation are assumed to be covered by the considered implementation margin.

The transmission over the radio channel is modelled by a Wide Sense Stationary Uncorrelated Scattering (WSSUS) channel model. In this channel model, three characteristics of a propagation channel are considered, namely fading, delayed paths, and Doppler effects. To model different flight phases, parameters are set as listed in Table Annex 1. For a more detailed description of the used channel models please refer to [B-AMC_D5].

Table Annex 1: Channel Model Parameters

Scenario	Fading	Delay	Doppler
ENR	Rician k_R = 15 dB (direct / total scattered) near-spec / off-path SR 6 dB	direct + 2 delayed paths delays: τ_0 = 0.3 µs τ_1 = 15 µs	Gaussian, f_D = 1250 Hz means: $fM_0 = 0.85 \cdot f_D$, $fM_1 = -0.6 \cdot f_D$ spreads: $fS_0 = 0.05 \cdot f_D$, $fS_1 = 0.15 \cdot f_D$
TM	Rician k_R = 10 dB	exponentially decaying power delay profile, max delay: τ_{max} = 20 µs	Jakes f_D = 624 Hz
APT	Rayleigh k_R = -100 dB	exponentially decaying power delay profile, max delay: τ_{max} = 3 µs	Jakes f_D = 413 Hz

Scenarios with L-band interference are based on simulations that consider only the strongest (multiple) sources of interference, which are DME/TACAN stations operating in channels at +/- 0.5 MHz offset to the LDACS centre frequency. The parameters for the interference and a description for the derivation of the assumptions can be found in [B-AMC_D5]. In addition for the FL, co-site interference from onboard SSR, UAT and DME was taken into account.

At the GS RX, the interference conditions are the same, independent of the considered operating environment. Differences between operating environments occur due to different channel models for the desired signal. The resulting interference scenario is described in more detail in [B-AMC2, D1].

When operating L-DASC1 as an inlay system, the impact of interference has to be mitigated at the RX. In the simulations with interference, four-times oversampling and an enhanced version of the erasure decoding as proposed in Appendix C has been applied for the RL transmission. For erasure decoding, the threshold T_e is set to 0 dB. For FL transmissions, pulse blanking in combination with an iterative interference cancellation (see [SB_09]) was adopted.

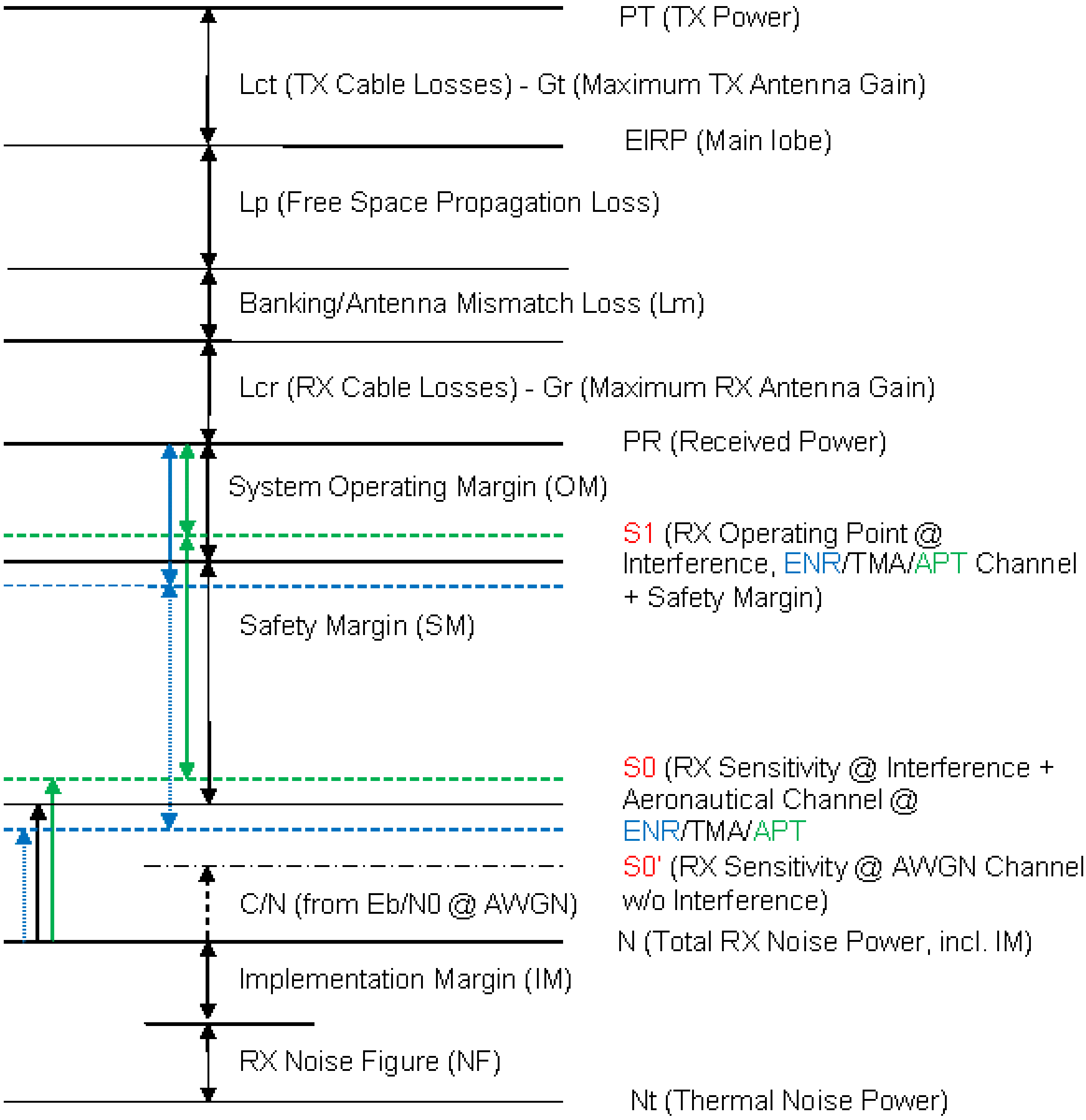

Figure Annex 1: Link Budget Relations

Table Annex 2: LDACS Link Budget, no Interference

Without Interference	Unit	ENR	TMA	APT	ENR	TMA	APT
TX Parameters		FL	FL	FL	RL	RL	RL
TX output power	dBm	42	42	42	42	42	42
TX antenna gain	dBi	12	12	12	3	3	3
TX cable loss	DB	2	2	2	3	3	3
Duplexer loss	dB	0	0	0	1	1	1
TX EiRP	dBm	52	52	52	41	41	41
Propagation Parameters		FL	FL	FL	RL	RL	RL
Transmit mid-band frequency	MHz	1133	1133	1133	987	987	987
TX-RX Distance	nm	120	40	10	120	40	10
Path loss	dB	140.47	130.93	118.88	139.27	129.73	117.69
Miscellaneous Margins		FL	FL	FL	RL	RL	RL
Interference Margin	dB	0	0	0	0	0	0
Implementation Margin	dB	4	4	4	4	4	4
Safety Margin	dB	6	6	6	6	6	6
Banking Loss Allowance	dB	0	7	7	0	7	7

RX Parameters		FL	FL	FL	RL	RL	RL
Maximum RX Antenna Gain	dBi	3	3	3	12	12	12
Duplexer Loss	dB	1	1	1	0	0	0
RX Cable Loss	dB	3	3	3	2	2	2
RX received signal power	dBm	-89.47	-86.93	-74.88	-88.27	-85.73	-73.69
Thermal Noise density		-174	-174	-174	-174	-174	-174
Bandwidth		498050	498050	498050	498050	498050	498050
Thermal Noise Power		-117.03	-117.03	-117.03	-117.03	-117.03	-117.03
Receiver Noise Figure		6	6	6	5	5	5
Total RX noise power		-107.03	-107.03	-107.03	-108.03	-108.03	-108.03
Eb/No @ Interference		5.23	5.53	7.13	7.53	8.23	16.13
LDACS bit rate		291200	291200	291200	291200	291200	291200
Required C/N @BER =10-6		2.9	3.2	4.8	5.2	5.9	13.8
RX Sensitivity (S0)		-104.13	-103.83	-102.23	-102.83	-102.13	-94.23
RX Operating Point (S1)		-98.13	-97.83	-96.23	-96.83	-96.13	-88.23
System Operating Margin		8.66	10.90	21.34	8.56	10.40	14.54

Table Annex 3: LDACS Link Budget, with Interference

With Interference	Unit	ENR	TMA	APT	ENR	TMA	APT
TX Parameters		FL	FL	FL	RL	RL	RL
TX output power	dBm	42	42	42	42	42	42
TX antenna gain	dBi	12	12	12	3	3	3
TX cable loss	DB	2	2	2	3	3	3
Dupler loss	dB	0	0	0	1	1	1
TX EiRP	dBm	52	52	52	41	41	41
Propagation Parameters		FL	FL	FL	RL	RL	RL
Transmit mid-band frequency	MHz	1133	1133	1133	987	987	987
TX-RX Distance	nm	120	40	10	120	40	10
Path loss	dB	140.47	130.93	118.88	139.27	129.73	117.69
Miscellaneous Margins		FL	FL	FL	RL	RL	RL
Interference Margin	dB	0	0	0	0	0	0
Implementation Margin	dB	4	4	4	4	4	4
Safety Margin	dB	6	6	6	6	6	6
Banking Loss Allowance	dB	0	7	7	0	7	7

RX Parameters		FL	FL	FL	RL	RL	RL
Maximum RX Antenna Gain	dBi	3	3	3	12	12	12
Duplexer Loss	dB	1	1	1	0	0	0
RX Cable Loss	dB	3	3	3	2	2	2
RX received signal power	dBm	-89.47	-86.93	-74.88	-88.27	-85.73	-73.69
Thermal Noise density		-174	-174	-174	-174	-174	-174
Bandwidth		498050	498050	498050	498050	498050	498050
Thermal Noise Power		-117.03	-117.03	-117.03	-117.03	-117.03	-117.03
Receiver Noise Figure		6	6	6	5	5	5
Total RX noise power		-107.03	-107.03	-107.03	-108.03	-108.03	-108.03
Eb/No @ Interference		5.33	7.93	10.63	8.53	11.33	18.93
LDACS bit rate		291200	291200	291200	291200	291200	291200
Required C/N @BER =10-6		3	5.6	8.3	6.2	9	16.6
RX Sensitivity (S0)		-104.03	-101.43	-98.73	-101.83	-99.03	-91.43
RX Operating Point (S1)		-98.03	-95.43	-92.73	-95.83	-93.03	-85.43
System Operating Margin		8.56	8.50	17.84	7.56	7.30	11.74

Appendix B Extended LDACS System Capabilities

B.1 LDACS A/G Voice Capability

> *NOTE: LDACS voice functionality is outlined in this section, but not addressed in depth within the scope of this specification. Further information about LDACS voice capability is provided in Sections 7.1.3, 8.10, 10.5, 10.6, 11.1, 11.2 and 12.*

The LDACS A/G sub-system physical layer and data link layer are optimised for data link communications, but the system still supports air-ground party-line voice communications (with re-transmissions via the GS), selective A/G voice communications and packet voice concepts (VoIP).

The voice capability has been retained within the LDACS functional scope as a “configurable optional feature”. Although not expected to be widely used, voice services may be selectively configured at selected LDACS cells and used e.g. to provide a certain number of party-line voice channels in regions where VHF channels are fully congested.

A space for voice packets can be reserved within regularly occurring FL/RL OFDM frames.

> *NOTE: Support for digital voice has influenced LDACS framing structure, both on the FL and on the RL, but without adverse impact upon data link capacity/performance.*

LDACS supports a transparent, simplex voice operation based on a “Listen-Before-Push-To-Talk” channel access. When configured for voice operation, LDACS provides following modes of operation:

- Circuit mode voice
- Packet mode voice

In the circuit mode, LDACS provides support for two separate voice circuit types:

- Dedicated circuits – voice service is provided to a specific user group (party-line) on exclusive basis not sharing the voice circuit with other users outside the group. Access shall be based on a “listen-before-push-to-talk” discipline.

  > *NOTE: In order to resemble the existing operational procedures, the arbitration of the access to the voice channel is delegated to the humans – pilots and controllers.*

- Demand assigned circuits – access to the voice circuit is arbitrated by the LDACS GS in response to an access request received from the LDACS AS. This type of operation shall allow dynamic sharing of the voice channel resource, increasing efficiency.

In the packet mode, LDACS supports packetized voice (VoIP).

The LDACS radio provides an interface for a simplex, “push-to-talk” audio as well as signalling interface to the external Voice Unit.

When providing voice services, LDACS adopts the VHF Digital Link (VDL) Mode 3 vocoder algorithm. The LDACS Voice Unit shall use the Augmented Multiband Excitation (AMBE) 4.8 kbps encoding/decoding algorithm, version number AMBE-ATC-10.

NOTE: Speech encoding definition, voice unit parameters, and procedure descriptions for VDL Mode 3 Voice Unit operation are contained in the Manual on VDL Technical Specifications.

The Voice Unit operation shall support a priority override access for authorized ground users as well as a notification to the user of the source of a received voice message. The LDACS GS provides an access arbitration function, which always allows a controller's FL voice transmission to interrupt (pre-empt) any ongoing re-transmission of pilot's RL voice.

Appendix C Interference Reduction at LDACS RX

This section deals with the mitigation of interference onto LDACS system. In order to achieve target sensitivity value under presence of composite L-band interference, it is mandatory to implement appropriate interference reduction methods. Some appropriate methods are presented in the following. However, the choice of the methods is an implementation issue and the methods presented below are not obligatory, one may also apply other suitable methods.

C.1 Erasure Decoding

For applying erasure decoding, the interference power received in the guard bands of the used FFT bandwidth has to be measured. Based on the measured interference power in the guard bands and the spectral shape of the interference, the interference power at the data sub-carriers can be approximated.

If the approximated interference power exceeds a predefined threshold Te, the affected symbol with index (k, m) shall be set to erasure. Setting "erasure" means that the reliability information for the encoded bits inheriting in this data symbol shall be set to zero at the convolutional decoder input.

The threshold value T_e is a function of the average OFDM symbol power at RX. Additional pulse blanking (Section C.3) requires an adaptation of the threshold.

C.2 Oversampling

It is recommended to over-sample the received time domain signal at least by a factor of 4. Since the interference signal power can be very high, the selective RX channel (IF) filter may not be able to completely remove the out-of-band interference power. When applying the FFT in the OFDM receiver, periodic repetitions of these undesired signal parts would fall into the used spectrum. These aliasing effects are an inherent property of sampling associated with the FFT. Thus, down sampling to the original grid should be processed not before the FFT in the OFDM receiver.

C.3 Pulse Blanking

Interference cancellation approaches like pulse blanking may be applied for mitigating the interference from existing L-band systems. Interference pulses must be detected in the discrete time domain. As long as the values of the corresponding samples in the RX signal exceed a threshold T_{PB}, these samples are set to zero. Afterwards, the modified RX signal is transformed to the frequency domain as usual. The threshold is optimised as a trade-off between the achieved interference power reduction and the impact on the desired signal and may have to be adapted if other interference mitigation techniques such as erasure decoding are applied in addition.

> *NOTE: Autonomous pulse blanking is highly recommended for AS receivers. It avoids the need for connecting LDACS AS receiver to the common suppression bus (that may not always be available).*

Appendix D Tracking of Comments and Changes

This section tracks all comments received to this document and lists known issues of this specification that will be updated.

comment_sheet
(1.1.2).xlsx