Updated LDACS1 System Specification

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Abstract

This document represents the final deliverable D1 of the P15.2.4 EWA04-1 task T2, providing an update of the initial LDACS1 specification produced in the course of the EUROCONTROL LDACS1 study, with modified wording and additional clarifications in some areas. The updated specification shall provide a stable baseline for further LDACS1 design and testing activities.

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EXECUTIVE SUMMARY

This document represents the final deliverable D1 of the P15.2.4 EWA04-1 task T2: Updating LDACS1 Specifications. It provides the overall system specification of the L-Band Digital Aeronautical Communications System Type 1 (LDACS1).

The second deliverable (D2) of the P15.2.4 EWA04-1 task T2 provides an updated specification for LDACS1 prototype equipment.

Both deliverables – D1 and D2 – aim at updating initial LDACS1 specifications [LDACS1_D2] and [LDACS1_D3] produced in the course of the EUROCONTROL LDACS1 specification study.

This report corrects errors identified so far in [LDACS1_D2] and implements additional identified modifications elaborated within the SJU framework that will further improve LDACS1 performance. The D1 report will provide a solid baseline for all further LDACS1 design and validation activities. The deliverable D2 will be produced based on this report.

It is expected that some of parameters provided in this specification will be subject to further validation/confirmation and possibly adjustment in the course of the P15.2.4 project.

Initial LDACS1 TX and RX prototypes are planned to be developed under the SESAR JU framework (P15.2.4) aiming at demonstrating the compatibility of LDACS1 with the existing systems operating in the L-band as well as showing that the LDACS1 performance is meeting the requirements. Further modifications of the system specification are expected based on the feedback from the laboratory measurements with the prototype LDACS1 radio equipment.

1 Introduction

1.1 Purpose of the Document

The Early Tasks activity EWA04 is linked with Task 3 (Recommendation for the terrestrial system) of the P15.2.4 original DoW and is addressing the LDACS system: the terrestrial air-ground data link system.

The EWA04 activities aim to initiate the work that will facilitate the recommendation for the terrestrial air-ground data link system. There are 3 separate key tasks (with sub activities) identified as follows:

- EWA04-1: LDACS1 Refinement
- EWA04-2: LDACS Evaluation Criteria
- EWA04-3: LDACS1 Evaluation Support

The EWA04-1 activities aim to refine and mature the LDACS1 specifications to enable the building of a limited functionality prototype for spectrum compatibility testing (to be initiated under EWA04-3 activities and considering the evaluation framework defined in EWA04-2)

The main objectives of the EWA04-1 activities are the following:

- Propose solutions for LDACS interference mitigation techniques
- Critically review existing LDACS1 specifications both for completeness and correctness of proposed parameters
- Identify issues not optimally covered in existing specifications, propose solutions
- Produce an updated set of LDACS1 specifications

The EWA04-1 task covers both the refinement of the LDACS1 system specifications as well as the specifications for initial prototyping activities for the LDACS1 system.

There are two major activities identified in EWA04-1:

- T1: Investigating interference mitigation techniques
- T2: Updating LDACS1 specifications

Task T1 aims at improving the LDACS robustness against interference received from other L band systems located on the same aircraft (co-site interference). It will also produce proposals for intra-network interference (produced by "other" LDACS transmitters) mitigation. Overall, task T1 will develop a report at the end of the Early Tasks phase but its activities are expected to continue into the full P15.2.4 project

Task T1 will be organized into 2 sub-tasks:

- T1a: A preliminary analysis of interference mitigation techniques aiming to provide early input to the LDACS1 specifications ,
- T1b: The continuing analysis and definition of general L band interference mitigation techniques (task will start after the results of the SJU COM study are available and will continue to end of the Early Tasks part.

The sub task T1a will concentrate on cosite interference. T1a aims at feeding the LDACS 1 definition with preliminary inputs regarding the interference mitigation techniques which will be subsequently further analyzed within the sub-task T1b.

Task T2 aims at increasing the maturity of existing LDACS1 specifications – both the overall system specification and the specifications for initial prototyping activities). The final outcome will be an updated set of LDACS1 specifications, comprising all improvements that have been elaborated within this sub-task, and considering applicable intermediate results of the above task T1a.

This document represents the final deliverable D1 of the P15.2.4 EWA04-1 task T2: Updating LDACS1 Specifications. It provides an update of the overall system specification of the L-Band Digital Aeronautical Communications System Type 1 (LDACS1).

The specification presented herein focuses on elements of the LDACS1 system design that are relevant for the subsequent development of the related ICAO standard.

The updated LDACS1 system specification is based on the initial LDACS1 specification [LDACS1_D2]. It corrects all errors identified so far in [LDACS1_D2]. Additionally, improved wording and clarifications are provided in some areas. Minor modifications that will further improve LDACS1 system specification have been implemented.

In the course of reviewing the initial LDACS1 specification, some major modifications have been proposed in order to further improve LDACS1 design. After having been validated up to the possible extent, such items are now also captured in this report.

LDACS1 specifications being produced within the P15.2.4 EWA04-1 task T2 may require further iterations after completion of this task. Further improvements are expected to be carried out with the framework of the SESAR JU development activities (P15.2.4) following the P15.2.4 Early Tasks.

1.1.1 Organisation of the Document

In order to preserve the traceability to the initial LDACS1 specification [LDACS1_D2], this report follows the same structure that was used in the original [LDACS1_D2] document.

This report is structured as follows:

- Introductory part, comprising:
    - Chapter 1 (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 LDACS1-specific terms.
    - Chapter 2 – overview of the LDACS1 System, summarising the main characteristics for the A/G mode, and briefly presents the A/A mode of operation.
- The main body of the LDACS1 system specification, comprising:
    - Chapter 3 – characteristics and capabilities that apply to the entire LDACS1 system.
    - Chapter 4 – the specification of the ground LDACS1 installation (transmitter, receiver, timing/frequency requirements shared between the ground transmitter and receiver).
    - Chapter 5 – the specification of the airborne LDACS1 (transmitter, receiver, timing/frequency requirements shared between the airborne transmitter and receiver).
    - Chapter 6 – the description of the LDACS1 protocol architecture.
    - Chapter 7 – the specification of the LDACS1 Physical Layer (PHY) layer.
    - Chapter 8 – the specification of the LDACS1 Medium Access Layer (MAC) sub-layer.
    - Chapter 0 – the specification of the LDACS1 Link Management Entity (LME).
    - Chapter 10 – the specification of the LDACS1 Data Link Service (DLS) entity.
    - Chapter 11 – the specification of the LDACS1 Voice Interface (VI).

    - Chapter 12 – the specification of the LDACS1 Sub-Network Dependent Convergence Protocol (SNDCP).
- Appendices, providing supplementary information:
    - Appendix A – LDACS1 Link Budget.
    - Appendix B – brief overview of LDACS1 system extended functionalities (A/G voice, A/A data link).
    - Appendix C – Interference Reduction at LDACS1 RX
- List of references used for producing this report.

1.1.2 Conventions

For the purposes of this specification the following conventions are used in Chapters 3-12 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 an absolute (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.

As the LDACS1 specification may be revised once the results from the prototype tests become available, the category of requirements may change in the future versions of this specification.

The requirements themselves are formatted as normal text.

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

1.2 Intended Readership

The updated LDACS1 system 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).

In particular, Partners that will be involved with LDACS1 prototyping activities and system validation tasks will rely upon an updated system specification. Understanding the system design, including trade-offs between system complexity, capacity/performance and its deployability in the aeronautical L-band, will be an important pre-requisite for planning the prototyping activities, laboratory validation tasks, as well as further specification improvements and development of detailed LDACS1 deployment concepts after the initial laboratory trials.

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 the LDACS1 system.

Finally, final versions of updated LDACS1 system specifications will help in achieving the necessary acceptance for this new system within the world-wide aeronautical community.

1.3 Background

1.3.1 General Context

In EUROCONTROL, the Communications Domain within the Communications Systems and Programmes (CSP) Unit in EATM is leading the investigations on the Future Communications Infrastructure (FCI) which is required to support future aeronautical communications.

This work has been coordinated with FAA in the frame of Action Plan 17 (AP17) of the EUROCONTROL/FAA Memorandum of Cooperation and has been a key input to the Single European Sky ATM Research (SESAR) Definition Phase in Europe and NextGen in the USA. The results have also been endorsed by the ICAO Aeronautical Communications Panel (ACP).

The goal of the FCI was to support the future aeronautical communication requirements with a minimum set of globally deployed technologies. The FCI is the key enabler for new ATM services and applications that in turn will bring operational benefits in terms of capacity, efficiency, and safety. The FCI needs to support both data and voice communication with an emphasis on data communication in the shorter term. In terms of applications, the FCI must support the new operational concepts that are being developed in SESAR and NextGen.

The FCI will be a system of systems, integrating existing and new technological components. As described in the AP17 Final Report [OTH 1] and the SESAR Definition Phase Deliverables [OTH 2], [OTH 3] and [OTH 4], there are three key recommendations for new data link developments:

[R1] *Develop a data link based on the IEEE 802.16e standard operating in the C-band and supporting the airport surface environment*

[R2] *Finalise the selection of a data link operating in the L-band (LDACS) and supporting the continental airspace environment*

[R3] *Develop a satellite system to support oceanic, remote and continental environments (complementing terrestrial systems)*

1.3.2 L-band Data Link System – LDACS

Under AP17 activities, various candidate technologies were considered and evaluated. Some of the considered and evaluated technologies shall operate in the L-band, supporting the [COCRv2] requirements. However, it was found that none of the considered technologies could be fully recommended primarily due to concerns about the operational compatibility (spectrum interference) with existing systems in the L-band. Nevertheless, the assessment of the candidate technologies led to the identification of desirable technology features that could be used as a basis for the development of an L-band data link solution that would be spectrally compatible.

Considering these features and the most promising candidates, two technology options for the L-band Digital Aeronautical Communication System (LDACS) were identified. These options need further consideration before final selection of a single data link technology.

The first option for LDACS (LDACS1) is a frequency division duplex (FDD) configuration utilizing Orthogonal Frequency Division Multiplexing (OFDM), reservation based access control and advanced network protocols. This solution is closely related to the Broadband - Aeronautical Multi-Carrier Communication (B-AMC) and TIA-902 (P34) technologies.

The second LDACS option (LDACS2) is a time division duplex (TDD) configuration utilizing a binary modulation derivative (Continuous-Phase Frequency-Shift Keying - CPFSK - family) of the already implemented Universal Access Transceiver (UAT) system and of existing commercial (e.g. GSM) systems as well as custom protocols for lower layers, providing high quality-of-service management capability. This solution is a derivative of the L-band Data Link (LDL) and All-purpose Multi-carrier Aviation Communication System (AMACS) technologies.

AP17 and SESAR proposed follow-on activities are required in order to further specify the proposed LDACS options, validate their performance, aiming at a final decision (single technology recommendation for the L-band).

Based on the information given above, in order to facilitate the selection of the LDACS, it is required to:

- Develop detailed specifications for LDACS1 and LDACS2
- Develop and test LDACS1 and LDACS2 prototypes, and
- Assess the overall performance of LDACS1 and LDACS2 systems.

A specific EUROCONTROL contract covered the initial activities to develop detailed specifications for the LDACS1 system.

Note: A separate EUROCONTROL contract has been awarded for the development of the detailed specifications for LDACS2.

When doing the testing of the LDACS prototypes, it is important that the spectrum compatibility investigations are made in a consistent way (e.g. the same interference situation for both systems under consideration) to ensure a fair assessment of the two options.

Note: Another EUROCONTROL contract has focussed on the development of the interference scenarios to be investigated and the definition of acceptability criteria for each scenario.

1.3.3 Objective and Scope of EUROCONTROL LDACS1 Study

The EUROCONTROL LDACS1 Study (contract PE 08-111383-E) was a necessary step to realise Recommendation 2 of AP17 - to develop an L-band data link. The development of the L-band data link is identified in the development activities for the SESAR Implementation Package 3 (IP3) in the post 2020 timeframe. Therefore, the outcome of the LDACS1 study represents an input to the SESAR JU activities.

The prime objective of the EUROCONTROL LDACS1 study was to produce a proposal for an initial system specification for the entire LDACS1 system operating in Air-Ground (A/G) mode. Another parallel task has produced design specifications for LDACS1 prototype equipment by extracting items relevant to prototyping activities from the initial LDACS1 system specification and supplementing these items by specific radio issues.

The LDACS1 system specification and the LDACS1 prototype specification represent enablers for LDACS1 prototyping activities that in turn should clarify system compatibility issues that could not be covered analytically or via modelling.

There are two final deliverables of the LDACS1 study:

- Proposed LDACS1 specifications [LDACS1_D2]
- Design Specifications for LDACS1 TX and RX Prototype [LDACS1_D3]

A detailed specification for the LDACS1 Air-Air (A/A) mode was not within the scope of the LDACS1 Study. The current initial LDACS1 specification covers the Air-Ground (A/G) mode including support for digital voice.

The initial LDACS1 specification is widely based on the previous B-AMC system design. This baseline has been further improved within the course of the LDACS1 Study. Specifications of commercial systems like IEEE 802.16e and P34 have been considered, where appropriate. In addition, the scope for the target LDACS1 specification has been finally defined by inspecting and then merging items of specifications of other aeronautical communications systems (UAT, VDL Mode 3 and VDL Mode 4).

1.4 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

Term	Definition
ACK_FRAG	Fragment Acknowledgement.
ACK_SEL	Selective Acknowledgement
ACM	Adaptive Coding and Modulation
AGC	Automatic Gain Control
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 Rate
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
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 withih the RL DC segment
DC segment	RL segment carrying Dedicated Control Channel (DCCH) information
DCCH	Dedicated Control Channel used for LLC signalling information (RL).

Term	Definition
DCH	Logical channel used on FL/RL for the transmission of data DLL-PDUs.
DLL	Data Link Layer
DLL_PDU	Data Link Layer Protocol Data Unit. Protocol unit exchanged between two LLC sub-layer (of the DLL) instances over the logical channels.
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 Data/CC 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
GNSS	Global Navigation Satellite Systems
GS	Ground Station
GSM	Global System for Mobile Communications

Term	Definition
HO_COM	Handover Command
ISI	Inter Symbol Interference
JTIDS	Joint Tactical Information Distribution System
KEEP_ALIVE	Keep alive
LDACS1	L-band Digital Aeronautical Communication System 1
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, SACH, 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 LDACS1 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
MRSC_RQST	Multiple resource request
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

Term	Definition
	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 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
PID_COMP	PID completed
POW_REP	Power report.
ppm	Parts per million
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying

Term	Definition
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 DC segment	RL Dedicated Control segment, containing control data of a particular user
RL Data segment	RL Data segment, containing user's data or control information together with pilot symbols and PAPR reduction symbols.
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.
RLE	Radio Link Entity (within MAC sub-layer), dealing with radio management
RL PHY-PDU	Reverse Link Physical Layer Protocol Data Unit (PDU)
RMS	Root-Mean-Square
RRM	Radio Resource Management Entity of the logical link control sub-layer.
RS	Reed-Solomon (coding)
RSBN	Радиотехническая система ближней навигации (Short-range radio-navigation system)
RSC_CANCEL	Resource Cancellation
RX	Receiver
SAC	Subscriber Access Code

Term	Definition
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.
SF	Super-frame. This item has two equivalent meanings in the LDACS1 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 LDACS1 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
TME	Transmission Multiplexing Entity (within MAC sub-layer), dealing with various QoS data streams
TRA	RL Transport channel carrying the logical RACH channel.
Transport channel	The MAC sub-layer provides data transfer services to the BSS entity on transport channels. Transport channels are defined by HOW the information is transferred. A set of transport channels (TBC, TRA, Tn) is defined for different kinds of data transfer services. The MAC-entity assigns transport channels to

Term	Definition
	physical channels.
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 LDACS1 cell. Such service must be installed at multiple LDACS1 cells, with seamless service handover between the cells.
WSSUS	Wide Sense Stationary Uncorrelated Scattering

2 Overview of the LDACS1 System

This section gives an overview of the past activities that have led to the LDACS1 technology development and briefly explains the LDACS1 system concept.

2.1 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 System (FCS) suitable for planned ATM operations, the Federal Aviation Administration (FAA) and EUROCONTROL initiated a joint study in the frame of Action Plan 17 (AP17), with support from the National Aeronautics and Space Administration (NASA) and the 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 as feasible within the B-VHF project, but it would require high effort. Considering 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) that has recently been made potentially available for the Aeronautical Mobile (Route) Service (AM(R)S). The related B-VHF system re-design work was conducted within a specific EUROCONTROL study. The generic name given to the new L-band system is Broadband - Aeronautical 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 B-AMC system has been designed according to the Communications Operating Concept and Requirements document [COCRv2]. In particular, the scope of supported services has been limited to ATS and AOC classes that are relevant to the safety of the flight (other service classes like AAC or APC have been intentionally excluded). The system per-cell capacity has been tailored for ENR Large and ENR Super Large service volumes as specified in [FCI_EVS]. Assuming combined ATS and AOC traffic and A-EXEC service, the total FL/RL capacity requirements in these service volumes are 300/40 kbps and 500/50 kbps, respectively.

Due to the specific nature of the interference in the L-band, significant modifications were required compared to the basic B-VHF design, in particular affecting the design of the B-AMC physical layer (PHY).

2.2 LDACS System Concept

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 LDACS1 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.

The specific EUROCONTROL task has produced an initial set of system specifications for the LDACS1, as well as a set of initial specifications for LDACS1 prototype equipment. A similar parallel task has been executed with respect to the LDACS2 option.

2.3 LDACS1 System Description

The FCI system full functionality comprises both A/G and A/A data links. LDACS1 concept provides both required functionalities based on the common technology.

LDACS1 offers 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.

The ground LDACS1 is only required for A/G communications. If a ground user should participate in (e.g. monitor) A/A communications, a ground radio station similar to these installed on aircraft platforms would be required.

In both modes, LDACS1 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 (GSM/UMTS). LDACS1 has been designed to minimize interference to and from these other systems. The specific interference situation has influenced decisions related to the LDACS1 high-level system design.

2.3.1 A/G Communications Mode

LDACS1 operating in A/G mode represents the main body of this specification and is covered in detail in the following chapters.

2.3.1.1 Main Capabilities

LDACS1 design (A/G mode) inherits the main features of the B-AMC system design[1].

Like B-VHF (and B-AMC), the LDACS1 A/G sub-system is a multi-application cellular broadband system capable of simultaneously providing various kinds of Air Traffic Services (ATS) and Aeronautical Operational Control (AOC) communications services from deployed Ground Stations (GS).

The physical LDACS1 cell coverage is effectively de-coupled from the operational coverage required for a particular service. Services requiring wide-area coverage (e.g. A/G data link) are installed at several adjacent LDACS1 cells. From the wide-area coverage service point of view, the handover between the involved LDACS1 cells is seamless, automatic, and transparent to the user. Therefore, the LDACS1 A/G communications concept is open to the future dynamic airspace management concept.

The LDACS1 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 LDACS1 data link sub-system can be integrated as a sub-network of an Aeronautical Telecommunication Network based either on IP protocol suite (ATN/IPS) or ATN/OSI.

The LDACS1 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 (with re-transmissions via the GS)[2].

[1] Details of the B-AMC design are available under

http://www.eurocontrol.int/communications/public/standard_page/LBANDLIB.html

2.3.1.2 Topology

LDACS1 operating in the A/G mode is a cellular point-to-multipoint system. The A/G mode assumes a star-topology (Figure 2-1) where Airborne Stations (AS) belonging to aircraft within a certain volume of space (the LDACS1 cell) are connected to the controlling GS. The LDACS1 GS is a centralised instance that controls the LDACS1 A/G communications. The LDACS1 GS can simultaneously support multiple bi-directional links to the ASs under its control.

Prior to utilizing the system an AS has to register at the controlling GS in order 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. Direct voice and data transmissions between AS of the same cell cannot be performed without a relay function operating at the GS.

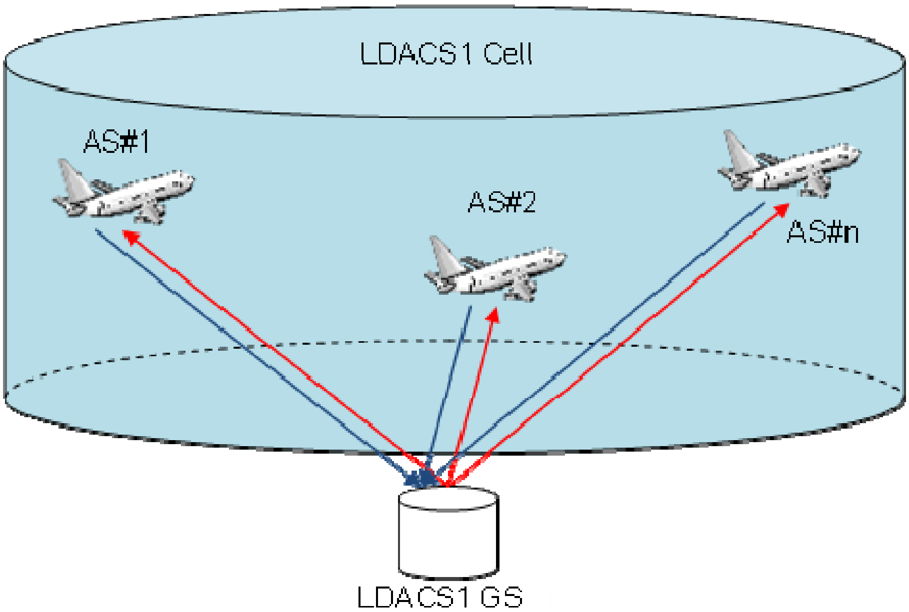

Figure 2-1: LDACS1 Topology

2.3.1.3 L-band Specifics

LDACS1 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 2-2.

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[2] LDACS1 voice functionality is not addressed in depth within this specification. Some further information about LDACS1 voice capability is provided in Section 11 - Voice Interface (VI) Specification and Appendix B- Extended LDACS1 System Capabilities.

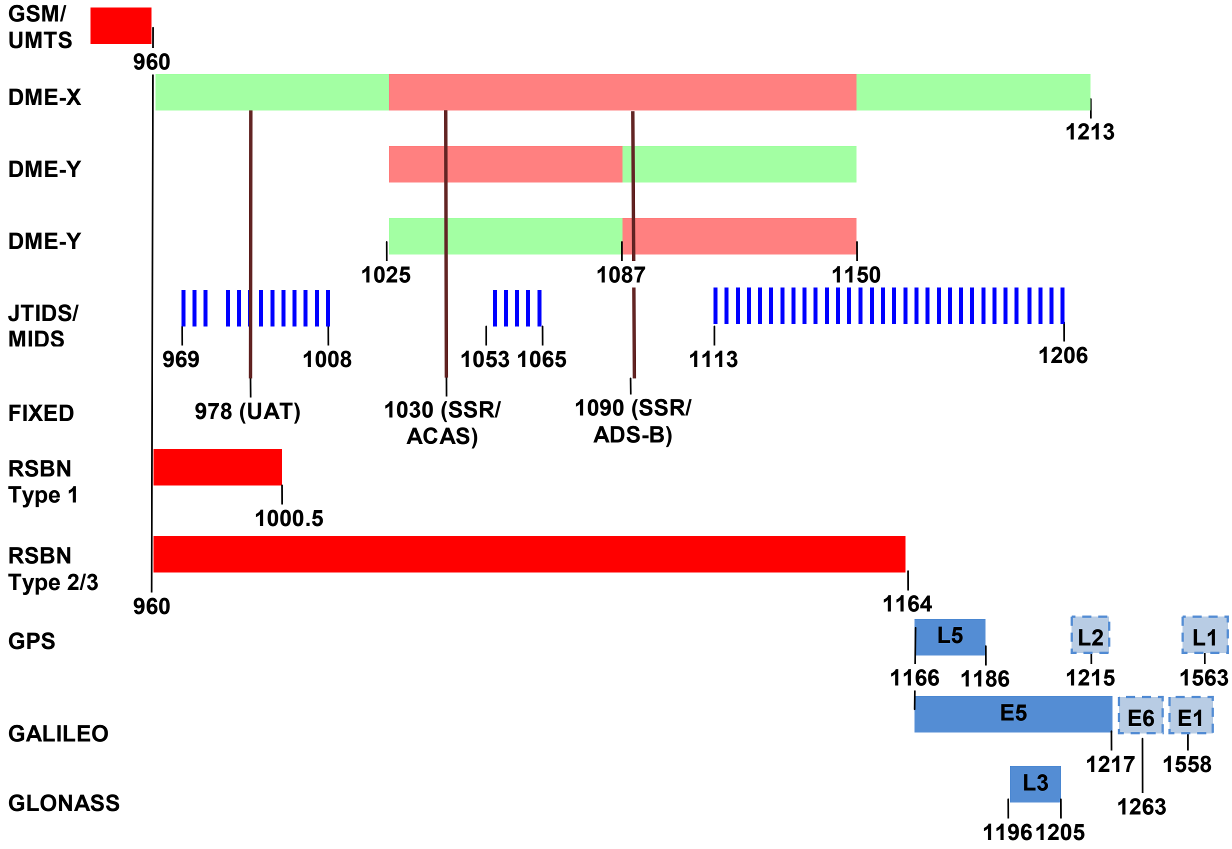

Figure 2-2: Current L-band Usage

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) systems may be found in some parts of the world, operating on channels between 960 MHz and 1164 MHz.

The free space attenuation in the L-band is higher than in the VHF range, but this can be compensated by antenna gains that are in the L-band higher than in the VHF range. Beam-forming (simple antenna array) may also be applicable to the L-band, e.g. to provide off-shore coverage from the GS located on-shore.

2.3.1.4 Physical Layer Design

In order to maximise the capacity per channel and to optimally use the available spectrum, LDACS1 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[3]. Within that

[3] The occupied bandwidth comprises an unmodulated DC carrier and 25 OFDM carriers on each side of the DC carrier. The LDACS1 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 LDACS1 radios and other L band radio stations).

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.

LDACS1 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. The capacity of the physical layer Protocol Data Units (PHY-PDUs)[4] that carry logical data and control channels adapts to system loading and service requirements. Adaptive modulation and coding feature is supported only for the data channel.

LDACS1 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. Up to two AS can transmit in parallel on RL.

LDACS1 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 LDACS1 OFDM symbols. Large target operational coverage imposed some constraints upon the LDACS1 PHY layer design (definition of PHY frames). In a practical deployment, LDACS1 can be designed for any range up to this maximum range.

2.3.1.5 Framing Structure

The LDACS1 framing structure (Figure 2-3) 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 (from the view of the GS).

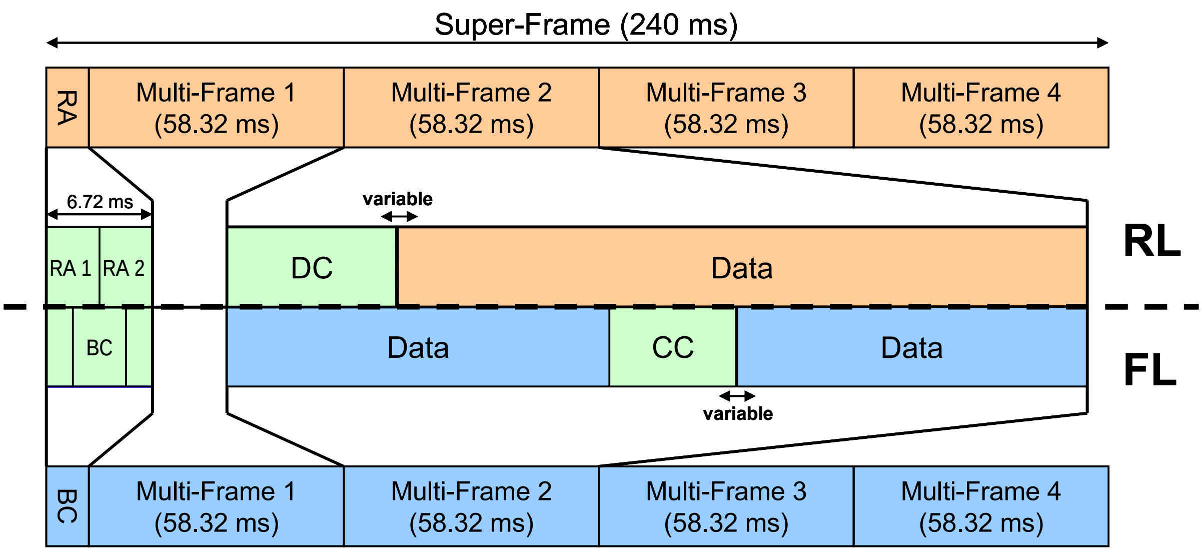

Figure 2-3: LDACS1 Framing Structure

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 MF contains 9 Data/CC frames with a frame duration of $T_{DF/CC}$ = 6.48 ms (54 OFDM symbols). Each Data/CC frame has a total data capacity of 2442 symbols[5] and comprises exactly three FL PHY-PDUs that are used for transmitting either the common control (CC) information or payload data. Within each MF, the first four frames contain user payload data. The block with CC information starts with the beginning of the fifth frame. It can have variable length of multiples of 3 FL PHY-PDUs, with a maximum of 12 FL PHY-PDUs. The remaining MF PHY-PDUs again contain user payload data.

[4] PHY-PDUs are explained in Section 1.4.

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

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.

Within the RL MF, instead of frames, data- and control (DC) segments are used that are further divided into tiles. A 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-PDU corresponds to the number of modulated data symbols of a corresponding DC/Data tile. Special synchronisation tiles do not contain any user data.

The usage of tiles enables the optimisation of the resource assignments by the MAC sub-layer. Furthermore, bandwidth and duty cycle can be selected according to the interference conditions.

Each MF in the RL starts with an RL DC segment, followed by an RL data segment. The size of the DC segment, and thus also the size of the data segment is variable.

The minimum size of the DC segment is 12 OFDM symbols, corresponding to a 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 segment duration is 162 OFDM symbols, corresponding to $T_{DC,max}$ = 19.44 ms. The duration of the data segment in the RL is variable, equal to $T_{DF} = T_{MF} – T_{DC}$, resulting in $T_{DF,min}$ = 38.88 ms and $T_{DF,max}$ = 56.88 ms.

2.3.1.6 DLL Design

The LDACS1 protocol architecture (Figure 2-4) defines five major functional blocks above the PHY layer.

Four are placed in the Data Link Layer (DLL):

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

One entity resides within the network layer:

- Sub-Network Dependent Convergence Protocol (SNDCP)

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 LDACS1 DLL are organised into two sub-layers, the Medium Access Control (MAC) sub-layer and the Logical Link Control (LLC) sub-layer.

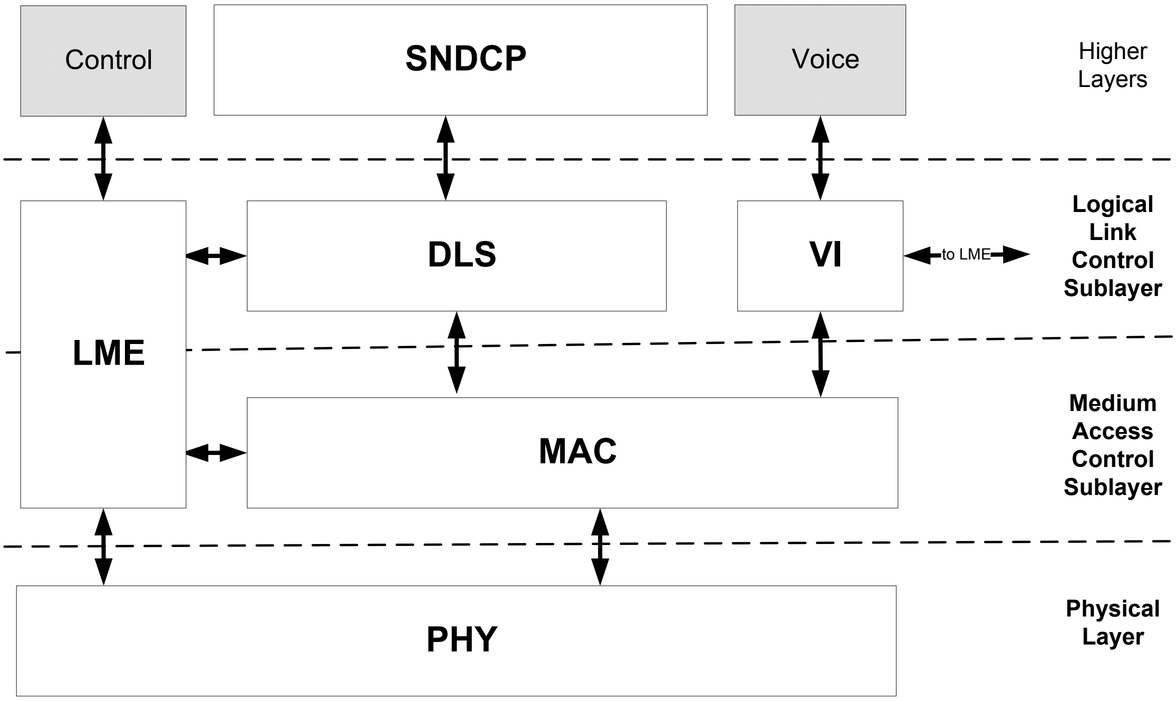

Figure 2-4: LDACS1 Protocol Suite

2.3.1.7 MAC Sub-layer

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 2-5) to PHY layer resources.

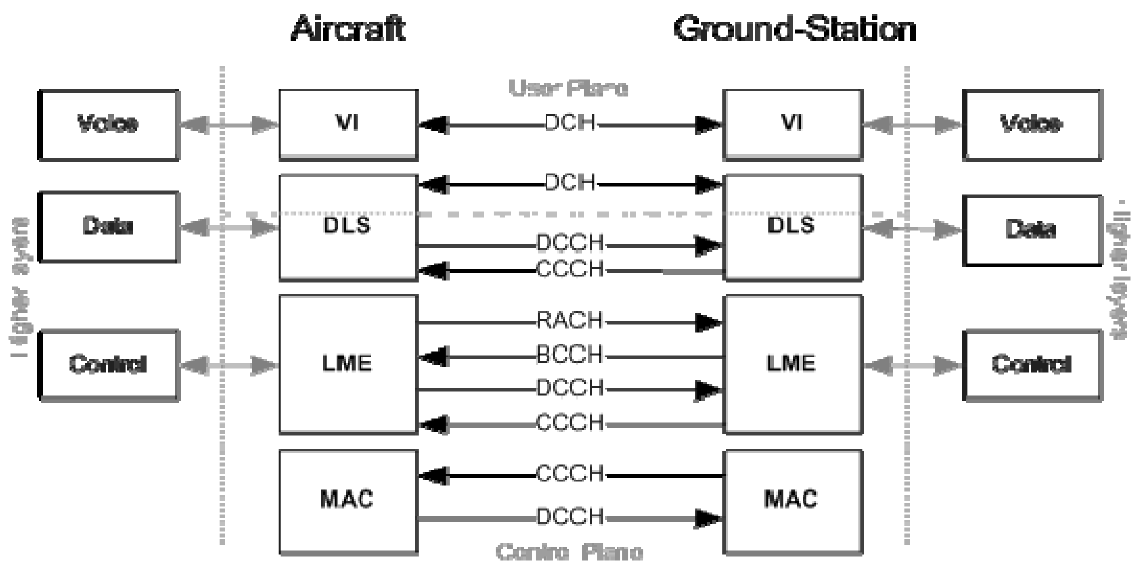

Figure 2-5: LDACS1 Logical Channel Structure

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. MAC slots provide opportunities for conveying different logical channels (Figure 2-6).

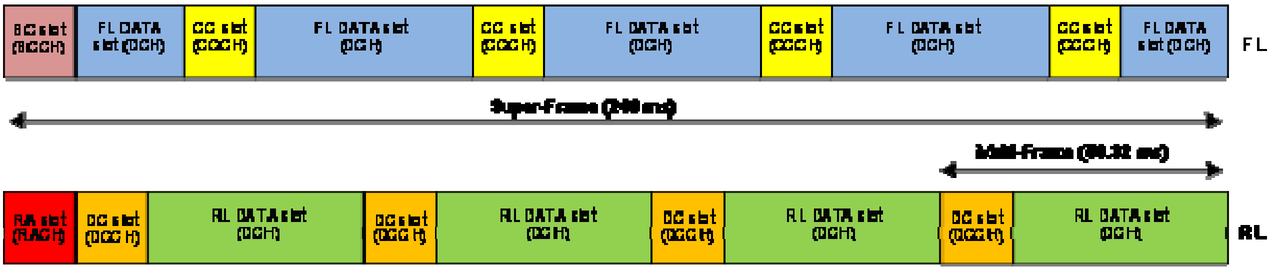

Figure 2-6: LDACS1 Slot Structure

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)

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.

2.3.1.8 LLC Sub-layer

The LLC sub-layer of the DLL (Figure 2-4) manages the radio link and offers to the higher layers 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.

LDACS1 is able to support multiple network layer protocols providing protocol transparency for the user of the service. The introduction of new network protocols to operate over LDACS1 shall be possible without any changes to the LDACS1 protocols. Therefore, all functions related to the transfer of network layer PDUs (N-PDUs) are carried out in a transparent way by the LDACS1 SNDCP. Additionally, the SNDCP provides functions for improving the channel efficiency. This is realised by the compression of redundant protocol information as well as the compression of redundant user data.

There is one LME in each AS and one peer LME for each AS in the GS. The peer LMEs co-operatively perform the link maintenance and manage AS registration (cell-entry) and deregistration (cell-exit) at a particular GS as well as handovers between GSs (mobility). 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 permanently available to all AS within a cell. Otherwise, excluding the registration events, the LME uses the CCCH and the DCCH for exchanging of 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 transmissions 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.

LDACS1 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 LDACS1 radio channel, LME selects the logical voice channel to be used via the VI (in this case LME is controlled from an external system).

2.3.1.9 LDACS1 Deployment

LDACS1 is intended to operate as a FDD system in the lower part of the L-band (960-1164 MHz). The elaboration of a detailed deployment concept is not within the scope of the LDACS1 specification, therefore only an outline is provided here.

With any deployment option, co-location constraints of an airborne platform apply to an LDACS1 AS.

Under these constraints, multiple options for the system deployment are possible:

- The selected system RF bandwidth (approximately 0.5 MHz) enables an inlay deployment, where LDACS1 channels, nominally separated by 1 MHz, are placed at 0.5 MHz offset from DME channels.
- LDACS1 can also be deployed as non-inlay system with FL/RL channels placed within contiguous blocks of the L-band spectrum, which are not occupied by the DME system.
- LDACS1 can be deployed alongside with the DME system by re-using a set of non-contiguous DME channels that have been vacated for that purpose.

Different combinations of above scenarios are possible as well. The non-inlay deployment options generally provide better performance and higher capacity than the inlay option, as with these options LDACS1 would operate in an environment with considerably reduced interference.

NOTE: The final decision about FL/RL channel allocations will also depend on the outcome of the laboratory tests with system prototypes.

NOTE: With any deployment option, fixed L-band channels (978/1030/1090 MHz) as well as GNSS channels must be sufficiently isolated from LDACS1 channels by appropriate guard bands. Additionally, frequency planning rules for LDACS1 shall ensure that the airborne and ground DME/TACAN receivers operationed within the Radio Line of Sight (RLOS) of LDACS transmitter are sufficiently protected.

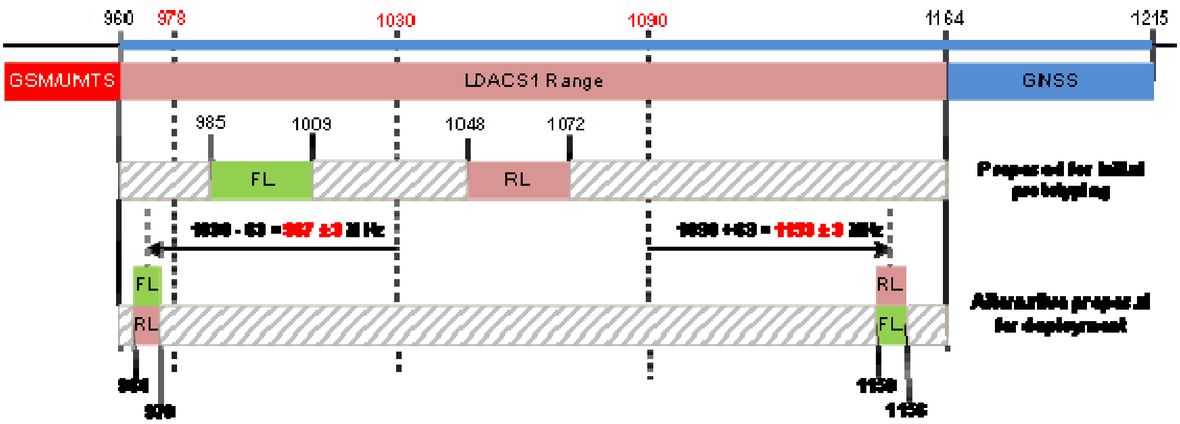

Figure 2-7: L-band Usage Options for LDACS1 A/G Communications

An airborne LDACS1 system (AS) using FDD with a single airborne antenna relies upon an airborne TX/RX duplexer. Due to the duplexer feasibility, the blocks of FL and RL channels must be sufficiently separated[6] in frequency domain.

Figure 2-7 shows the L-band sub-range (960 - 1164 MHz) within which LDACS1 can be deployed (Section 3.3). Currently, three basic options for the LDACS1 deployment within that range are visible (further options may be possible):

- Option proposed for initial LDACS1 prototyping (inlay, with 1 MHz LDACS1 channel grid). LDACS1 FL channels would be placed in the area 985 -1009 MHz, while the RL channels would be placed in the area 1048 - 1072 MHz[7].
    - Within this option, assuming that some DME channels could be vacated, some LDACS1 channels could be put directly onto vacated DME allocations (a mix of inlay and non-inlay).
- Option with reversed frequency blocks for FL and RL as proposed for initial LDACS1 prototyping (inlay, with 1 MHz LDACS1 channel grid). LDACS1 FL channels would be placed in the area 1048 - 1072 MHz, while the RL channels would be placed in the area 985 -1009 MHz[8].
    - Within this option, assuming that some DME channels could be vacated, some LDACS1 channels could be put directly onto vacated DME allocations (a mix of inlay and non-inlay).
- Alternative option for LDACS1 deployment (no inlay, with 0.5 MHz LDACS1 channel grid, over areas not heavily occupied by DMEs)[9].
    - LDACS1 FL channels would be placed in the area 1150 - 1156 MHz, while the RL channels would be placed in the area 964 - 970 MHz, or
    - LDACS1 FL channels would be placed in the area 964 - 970 MHz, while the RL channels would be placed in the area 1150 - 1156 MHz.

2.3.2 A/A Mode

When operating in A/A mode[10], the LDACS1 system offers a broadcast A/A surveillance link and an addressed (point-to-point) A/A data link, both with direct air-air connectivity. A/A communication between involved LDACS1 ASs takes place in a decentralized, self-organised way without any need for ground support (GSs may be optionally deployed, e.g. for monitoring A/A traffic). For A/A network synchronisation purposes, the availability of a common global time reference is assumed at each AS. No A/A voice services are offered in this mode. LDACS1 operating in A/A mode assumes a dedicated

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[6] 40 MHz has been assumed to be the minimum practical width of a transition area for an airborne duplexer. This value should be confirmed. Larger transition areas above 40 MHz (and larger duplex spacings above 63 MHz) are considered feasible as well.

[7] In the course of the previous B-AMC work a draft deployment concept for an inlay system was produced where B-AMC FL/RL channels were placed in the 985-1009/1048-1072 MHz range, respectively, a pair of FL/RL channels being separated by 63 MHz. The preliminary frequency planning exercise produced in the course of the B-AMC activities for an inlay system has indicated that the deployment would be easier if more flexibility were allowed with respect to the selection of FL and RL channels and their duplex spacing. Therefore, extended areas for blocks of FL/RL channels as well as variable duplex spacing for FL/RL channel pairs should be investigated within the corresponding deployment concept.

[8] This option has been recently proposed by the JTIDS/MIDS Multi-National Working Group (MNWG).

[9] This proposal has recently been submitted by the DFS Deutsche Flugsicherung GmbH.

[10] LDACS1 A/A mode is not addressed in depth within this specification. Nevertheless, some additional information about this mode is provided in Appendix B - Extended LDACS1 System Capabilities.

global RF resource, the "Common Communications Channel" (CCC). The LDACS1 A/A mode uses an Orthogonal Frequency Division Multiplex (OFDM)-based physical layer with parameters (e.g. sub-carrier spacing) different than those used for the A/G mode.

3 LDACS1 System Characteristics

This section describes radio aspects, characteristics and capabilities of LDACS1 that affect both AS and GS, considering the LDACS1 A/G mode of operation. [11]

3.1 Polarization of LDACS1 Emissions

The design polarization of LDACS1 emissions shall be vertical[12].

3.2 LDACS1 Designed Coverage

The maximum designed coverage range of LDACS1 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.*

3.3 LDACS1 Radio Frequency Range

LDACS1 shall operate in the 960 –1164 MHz range.

In order to reduce the airborne co-site interference towards the LDACS1 AS RX, the AS RL transmission range should preferably use the range 1025.5-1149.5 MHz, currently used by airborne DME interrogators, while the FL transmissions should preferably lie outside this range.

> *In this specification further deployment options are proposed where LDACS1 RL range may be placed outside the 1025.5-1149.5 MHz sub-range, therefore the above requirement is not a mandatory one.*
>
> *The sub-range for the LDACS1 Forward Link (FL) transmissions initially preferred in [LDACS1_D2] and [LDACS1_D3] was 985.5 – 1008.5 MHz while the preferred sub-range for LDACS1 Reverse Link (RL) transmissions was1048.5 – 1071.5 MHz.*

3.4 LDACS1 FL/RL Duplex Spacing

The currently proposed duplex spacings between LDACS1 FL and RL are 63 MHz and 186 MHz.

> *The duplex spacing of 63 MHz is currently used by airborne DME equipment. In order to facilitate system deployment under inlay conditions, LDACS1 duplex spacing may be made variable (different FL/RL channel pairs may use different duplex spacing), conditioned by the feasibility of the airborne duplexer. Additional deployment options proposed in this specification may require duplex spacing different than 63 MHz.*

3.5 LDACS1 RF Channel Grid

3.5.1 FL/RL Channel Grid

The nominal frequency of FL/RL channels for LDACS1 within the respective transmission/reception range shall lie on the 0.5 MHz grid, either at a full MHz or at an offset of 0.5 MHz from full MHz.

> *The proposed 0.5 MHz channel grid offers maximum flexibility with respect to the system deployment. With an inlay LDACS1 deployment option, LDACS1 channels would be placed at 0.5 MHz offset from DME channels that themselves are separated by 1 MHz. With a deployment in spectrum blocks free of DMEs, the 0.5 MHz grid would allow for dense packing of LDACS1 channels.*

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[11] In this LDACS1 specification no detailed information is provided for the A/A mode of operation.

[12] In the follow-on work, it may be relevant to study the feasibility of having different polarisation.

3.5.2 LDACS1 RF Channel Bandwidth

The occupied bandwidth of the LDACS1 signal is B_{occ} = 498.05 kHz (Section 7.4.2).

> *LDACS1 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).*

4 System Characteristics of the Ground Installation

This section comprises items that are specific to the implementation of the LDACS1 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.

4.1 GS Radio Frequency Range

The GS radio frequency range shall be as specified in Section 3.3.

4.2 GS Transmitting Function

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

4.2.1 GS Operational Coverage

The effective radiated power of the LDACS1 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 5.3.3.*

LDACS1 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 LDACS1 system designed coverage of 200 nm (Section 3.2).

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 5.3.3. These parameters are selected based on satisfactory interference performance, considering also safety and banking margins.

4.2.2 Ground TX Maximum Transmitting Power

The GS TX transmitting power measured at the TX output terminal averaged over an FL super-frame (240 ms), if the GS uses all OFDM sub-carriers, shall not exceed +41 dBm.

This value represents a compromise between different interference situations observed so far under inlay conditions and shall be confirmed by the future work.

In order to assure interference-free operation towards other L-band receivers at minimum operationally allowed separation distances, the maximum transmitting power and the EIRP of the LDACS1 GS must be limited. ENR cells with 200 nm rangemay require GS antennas with more than 8 dBi (e.g. 13 dBi) peak gain.

Dependent on the application area, the actual average transmitting power of the GS TX may be less than +41 dBm, but must be sufficient to provide operational coverage stated in Section 4.2.1.

The EIRP for the ground TX measured in the direction of the peak of the main lobe of the ground antenna with 8 dBi maximum gain and averaged over an FL super-frame shall not exceed +47 dBm.

The EIRP for the ground TX measured in the direction of the peak of the main lobe of the ground antenna with 13 dBi maximum gain and averaged over an FL super-frame shall not exceed +52 dBm.

When calculating the maximum EIRP, specified nominal GS TX transmitting power of +41 dBm, ground cable losses of 2 dB and the ground antenna with 8 dBi gain have been assumed.

4.2.3 Ground TX Maximum PAPR

The GS TX peak-to-average power ratio (PAPR), measured at the TX output terminal, shall not exceed 11 dB relative to the GS TX average transmitting power specified in Section 4.2.2.

4.2.4 Ground TX Power Setting

The GS TX shall transmit with declared nominal average power P_{TGS}. Declared power is measured (must be maintained) over the duration of the FL SF.

P_{TGS} may vary between different service volumes (e.g. en-route, TMA, airport), but once selected, P_{TGS} does not change during operation.

When transmitting synchronisation sequences that do not use all FL carriers, GS TX shall adjust the average per-symbol transmitting power such that it becomes equal to the average per-symbol transmitting power of FL OFDM data symbos.

4.2.5 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 4.2.6), 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 4-1) 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).

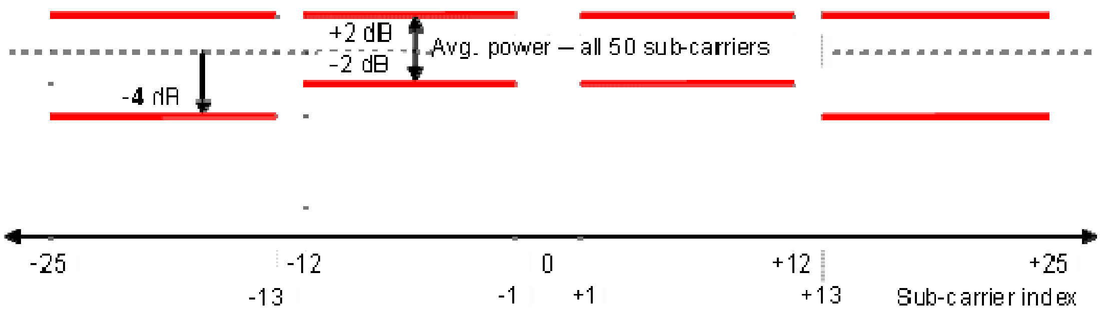

Figure 4-1: TX Spectral Flatness

The boosting level n_{B_FL} shall be adjustable (Section 7.7.1).

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.

4.2.6 Ground TX Maximum Number of Used Sub-carriers

Except for the synchronisation symbols where some sub-carriers are not transmitted, the ground LDACS1 TX uses in all FL frames the maximum number of OFDM sub-carriers: $N_{used} = N_u = 50$ sub-carriers.

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

4.2.7 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 4-1.

Table 4-1: 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
64QAM, 2/3	-28,5
64QAM, 3/4	-31.0

The relative constellation RMS error is calculated as

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

where

- 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(l,j,k), Q(l,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.

4.2.8 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.

> *TX spurious emissions arise from the internal TX architecture, due to the technical impossibility to realise ideal waveforms and frequency conversion stages. Such discrete spectral components may induce interference to receivers of other L-band systems.*
>
> *Spurious emissions should be measured in a reference bandwidth of 100 kHz in the frequency range from 30 MHz to 1 GHz, and in a reference bandwidth of 1 MHz in the frequency band of 1 GHz to 5.1175 GHz.*
>
> *Spurious domain starts at an offset ±B_{occ}*2.5 from the LDACS1 nominal transmit frequency f_c. B_{occ} = 498.05 kHz is the occupied bandwidth of the LDACS1 TX signal, see Section 7.4.2.*

The broadband noise power density measured across the spurious domain (Figure 4-2) at the GS TX output, when the TX terminated in a matched impedance load operates at the maximum power (Section 4.2.2) shall not exceed -133 dBc/Hz.

> *This preliminary value needs to be confirmed. A more stringent value may be required at larger frequency offsets to protect non-aeronautical systems operating below 960 MHz as well as GNSS receivers. Additional spurious and broadband noise attenuation can be achieved via external duplexer or filtering equipment.*
>
> *The target broadband noise power density, including such RF post-filtering, should be -145 dBc/Hz or less at frequency offset $\Delta f \geq 4.0$ MHz measured from the edge of the LDACS1 GS TX transmission range.*

4.2.9 Ground TX Spectrum Mask

Within the OOB domain, the spectral density of the transmitted LDACS1 signal shall fall within the spectral mask shown in Figure 4-2 and Table 4-2. 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 LDACS1 TX in-band power density.

> *The values in Figure 4-2 are not to scale. The "Δf" axis is linear and the "Att" axis is logarithmic. [802.16]/Table 341 has been used as a generic template for determining the frequency breakpoints B and D for an OFDM signal, and then the bandwidth occupied by LDACS1 has been applied (498.05 kHz), The point C and the corresponding "Att" value have been elicited from the preliminary B-AMC spectral mask provided in [B-AMC_D4]/Figure 7-2.*
>
> *The range of ±1.245 MHz around the TX operating frequency fc is defined as Out-Of-Band (OOB) range. The OOB domain boundary (1.245 MHz) is given in Figure 4-2 Table 4-2. The boundary has been calculated based on the occupied bandwidth of the LDACS1 signal-in-space B_{occ} = 498.05 kHz using the ITU-R definition for the start of the spurious domain [f_c-B_{occ}*2.5 … f_c+B_{occ}*2.5] that was also used for the UAT system [UAT_M].*

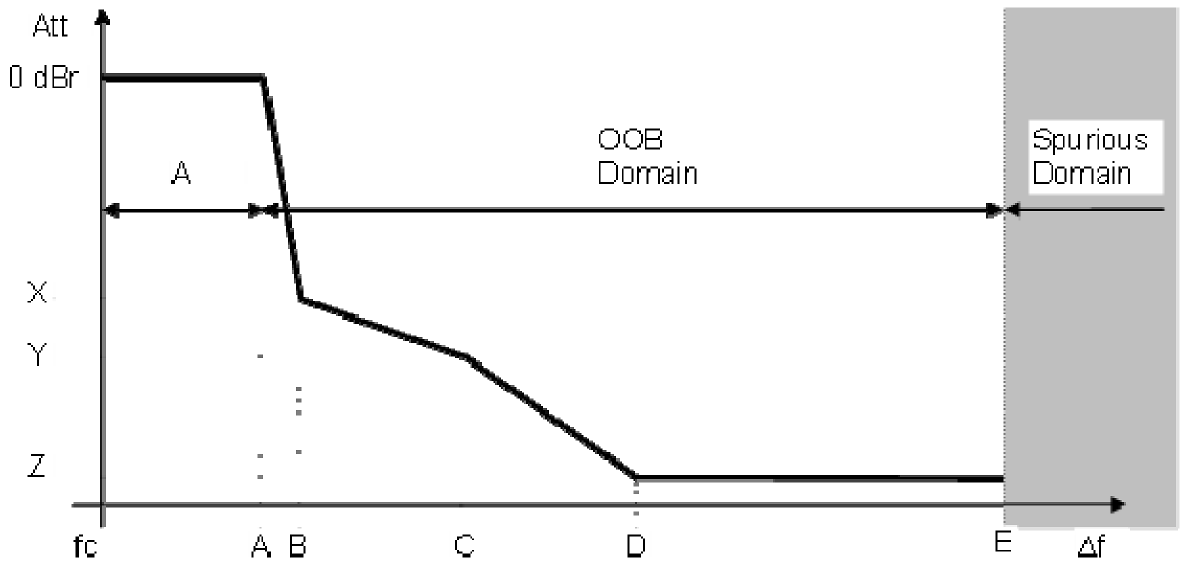

Figure 4-2: LDACS1 Ground TX Spectral Mask

Table 4-2: LDACS1 Ground TX Spectral Mask

	A = B_{occ}/2	**B = 1.35*A**	**C = 2.5*A**	**D = 3.1*A**	**E= 5*A**	**≥ E**
Δf (kHz)	249.025	336.174	622.563	771.978	1245.125	≥ 1245.125
Att (dBr)	0	X = 40	Y = 56	Z = 76	Z = 76	<spurs>

The preliminary LDACS1 TX spectral mask as provided in this specification may have to be further adjusted based on the forthcoming laboratory measurements using real radio equipment.

4.2.10 Ground TX Time/Amplitude Profile

LDACS1 ground transmissions are continuous, without ramp-up or ramp-down phases.

4.3 GS Receiving Function

4.3.1 Ground RX Reference Bit Error Rate

For the LDACS1 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.

4.3.2 Ground RX Sensitivity

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, 6) coding in RL data segments, the ground

LDACS1 RX shall fulfil the reference BER requirement (4.3.1) when operating at the level S0 ≤ -102.83 dBm[13].The requirement shall be fulfilled when the desired airborne TX signal is produced with the maximum tolerable frequency offset on RL (see Section 5.4) and is simultaneously subject to the maximum Doppler shift relative to the GS corresponding to the aircraft speed of ± 850 knots.

The minimum input level (receiver sensitivity) is measured as follows:

- *Using the defined standardized message packet formats (TBD)*
- *Using an AWGN channel (no interference)*
- *Using a specified RL channel (RL data transmission with Data tiles where AS uses full RL bandwidth)*

The initial sensitivity figure S0 stated above has been derived by assuming an implementation loss of 4 dB (which includes non-ideal receiver effects such as channel estimation errors, tracking errors, quantization errors and phase noise), as well as ground receiver noise figure NF = 5 dB, both referenced to the antenna port. The sensitivity figure S0 may have to be further fine adjusted.

When using on RL $N_{used} < N_u$ sub-carriers, the correction factor of $10*\log_{10}(N_{used}/N_u)$ shall be added to the above sensitivity figure that was obtained with all sub-carriers (N_u).

4.3.3 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, 6) coding, using RL Data tiles where AS uses full RL bandwidth, the ground LDACS1 RX shall fulfil the BER specified under 4.3.1 when the signal S1[14] as defined in Table 4-3 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 4-3: GS RX Operating Point S1 and Power Density Pd

Antenna Conversion	Unit	ENR	TMA	APT	Equation
Tx-Rx Distance	nm	120,00	40,00	10,00	d
Speed of light	m/s	3,E+08	3,E+08	3,E+08	c
Transmit mid-band Frequency	MHz	1087	1087	1087	f
Wavelength	m	0,28	0,28	0,28	λ =c/f
Correction Factor	dB	-22,17	-22,17	-22,17	CF=10*log10(λ^2/4/π)
Rx operating point (S1)	dBm	-95,83	-95,03	-87,43	S1
RX cable loss	dB	2,00	2,00	2,00	Lca
Duplexer loss	dB	0,00	0,00	0,00	Lda
Minimum RX Antenna Gain	dBi	8,00	6,00	6,00	Lra
Required power at RX antenna	dBm	-101,83	-99,03	-91,43	Pa=S1+Lca-Lra
Required power at RX antenna	dBW	-131,83	-129,03	-121,43	Pa1=Pa-30
Spatial power density at RX ant.	dBW/m2	-109,65	-106,85	-99,25	Pd=Pa1-CF

Assuming fixed antenna gain and cable losses, the GS RX operating point S1 for particular LDACS1 designed operational coverage (environment) is related to the

[13] The S0 value has been derived from the LDACS1 link budget in Appendix A - LDACS1 Link Budget for the case without interference, considering ENR environment and including the impact of the mobile channel.

[14] The S1 value has been derived from the LDACS1 link budget in Appendix A - LDACS1 Link Budget and may have to be further adjusted.

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 4.3.1 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 4-3.

When calculating Pd, the conversion formula from ICAO Annex 10, Volume I, Attachment C, Section 7.2.1 has been used: $Pd = Pa - 10 \cdot \log_{10}(\lambda 2/(4 \cdot \pi))$, 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.

4.3.4 Ground RX Interference Immunity Performance

This section is for information only.

The LDACS1 receiver shall be able to receive the desired LDACS1 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 LDACS1 parameters. Instead, it should be measured in the laboratory on LDACS GS RX prototype.The detailed test plan for LDACS1 receivers is being separately produced and is out of scope of this specification.

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 LDACS1 channel and the on-channel desired LDACS1 signal, for specified desired signal level (D) and specified reference BER (Section 4.3.1).

IR shall be measured by setting the desired LDACS1 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 4.3.2) and raising the power level "U" (dBm) of the interfering signal until the target BER (as specified in 4.3.1) 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 LDACS1 channel), peak power, and duty-cycle.**Error! Reference source not found.** 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 LDACS1 signal and undesired interference signal.*

Table 4-4: 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 4-4 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 in the course of the laboratory measurements.

4.3.5 Ground RX Maximum Desired Signal

The GS receiver shall be capable of decoding on-channel desired LDACS1 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[15], the peak received LDACS1 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).

4.3.6 Ground RX Maximum Tolerable Input Signal Power

The ground LDACS1 receiver shall tolerate at its input a pulsed interference signal with peak power of up to +25 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 5.3.6). 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.

[15] 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 7.7.2).

4.3.7 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.

LDACS1 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, LDACS1 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 required, the GS can request the AS to transmit a synchronisation tile within the RL DC segment..

4.3.8 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.

4.4 GS Frequency/Timing Requirements

4.4.1 Network Synchronisation

In order to support hand-over procedures between GSs, all LDACS1 GSs from a particular LDACS1 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 loosing synchronisation to (and having to re-enter) the current cell. Type 2 handover is also not available between GSs of different LDACS1 networks that are not using common timing reference.

The frequency- and symbol clock accuracy of a “free running” GS is specified in Section 4.4.4.

4.4.2 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.

4.4.3 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 7.4.1).*

4.4.4 GS Centre Frequency and Symbol Clock Frequency Accurracy

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 4.4.1).

4.4.5 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[16] that is sufficient for satisfactory reception on the RL (sensitivity requirement, as specified in Section 4.3.2).

The initial GS RX frequency capture range shall be sufficient for accommodating both imperfect AS TX - GS RX reference frequency accuracy (Sections 5.4.1 and 4.4.4) and the maximum applicable GS - AS Doppler shift (1.7 kHz at 850 knots and 1156.5 MHz).

When an LDACS1 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.

4.4.6 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[17] that is sufficient for satisfactory reception on the RL (sensitivity requirement, as specified in Section 4.3.2).

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[16] 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.

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 7.5.2.3 and by the synchronisation symbol pairs that occur at the start of RL RA frames.

4.4.7 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.

4.4.8 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.

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

5 System Characteristics of the Aircraft Installation

This section comprises specification items that are specific to the implementation of the LDACS1 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.

5.1 AS Radio Frequency Range

The AS radio frequency range shall be as specified in Section 3.3.

5.2 AS Transmitting Function

5.2.1 AS Operational Coverage

The effective radiated power of the LDACS1 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 4.3.3*. 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 4.3.3 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.

5.2.2 Airborne TX Maximum Transmitting Power

The AS TX transmitting power measured at the TX output terminal averaged over any continuous RL transmission that uses all N_u OFDM sub-carriers shall not exceed +42 dBm.

AS TX instantaneous peak transmitting power may be higher than +42 dBm due to the transmitter PAPR.

The above preliminary AS maximum TX power setting has been selected as a compromise between different interference situations encountered so far under inlay conditions and shall be confirmed in the future work.

ENR cells with 200 nm rangemay require GS antennas with more than 8 dBi (e.g. 13 dBi) peak gain.

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 symbos 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.

The EIRP for the airborne TX measured in the direction of the main lobe of the airborne antenna and averaged over continuous RL transmissions shall not exceed +38.5 dBm.

When calculating the maximum airborne EIRP, specified AS transmitting power of +42 dBm, airborne cable and duplexer losses of 3.5 dB and the airborne antenna peak gain of 0 dBi have been assumed.

5.2.3 Airborne TX Maximum PAPR

The AS TX peak-to-average power ratio (PAPR), measured at the TX output terminal, shall not exceed 11 dB relative to the AS TX average transmitting power specified in Section 5.2.2.

5.2.4 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 5.2.2).

Airborne LDACS1 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.

The smallest TX power adjustment step shall not be greater than 1 dB.

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

5.2.5 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 4-1) 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 7.7.1).

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

5.2.6 Airborne TX Maximum Number of Used Sub-carriers

AS TX shall be configurable to use either $N_{used} = N_u /2$ or $N_{used} = N_u$ 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 7.5.2.3).

5.2.7 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 4-1 (Section 4.2.7).

The relative constellation RMS error is calculated as described in Section 4.2.7.

5.2.8 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.

Spurious emissions should be measured in a reference bandwidth of 100 kHz in the frequency range from 30 MHz to 1 GHz, and in a reference bandwidth of 1 MHz in the frequency band of 1 GHz to 5.1175 GHz.

*Spurious domain starts at an offset ±B_{occ}*2.5 from the LDACS1 nominal transmit frequency f_c. B_{occ} = 498.05 MHz is the occupied bandwidth of the LDACS1 TX signal, see Section 7.4.2.*

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 4.2.8.The broadband noise power density measured across the spurious domain (Figure 4-2) at the AS TX output when the TX terminated in a matched impedance load operates at full power (Section 5.2.2) shall not exceed -133 dBc/Hz.

More stringent value may be required at larger frequency offsets to protect non-aeronautical systems operating below 960 MHz. Additional spurious and broadband noise attenuation can be achieved via external duplexer or filtering equipment. The target broadband noise power density, including such RF post-filtering, should be -145 dBc/Hz or less at frequency offset $\Delta f \geq 4.0$ MHz measured from the edge of the LDACS1 AS TX transmission range.

5.2.9 Airborne TX Spectrum Mask

In the OOB domain, the spectral density of the LDACS1 signal transmitted by an AS TX shall fall within the spectral mask defined in Section 4.2.9 (Figure 4-2 and Table 4-2).

For further details, including the measurement method, please refer to Section 4.2.9.

The preliminary LDACS1 TX spectral mask as specified in this specification may have to be adjusted, based on the laboratory measurements using real radio equipment.

5.2.10 Airborne TX Time-Amplitude Profile

The ramp-up/ramp-down behaviour of the RL RF burst is determined by the RC windowing function (Section 7.8.1). Therefore, the ramp-up/ramp-down time roughly corresponds to the window time T_W (12.8 μs) as defined in Section 7.4.1.

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.

5.2.11 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 9.3.2.2).

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 9.3.3.

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.

5.2.12 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 5.2.3) 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.

5.2.13 Airborne TX Switch-over Time

When commanded to switch the RL RF channel, an airborne LDACS1 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.

5.3 AS Receiving Function

5.3.1 Airborne RX Reference Bit Error Rate

For the LDACS1 AS receiver, the reference corrected BER is 10^{-6}.

5.3.2 Airborne RX Sensitivity

When 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, the airborne LDACS1 RX shall fulfil the reference BER requirement (5.3.1) when operating at the level S0 ≤ -104.13 dBm[18]. The requirement shall be fulfilled assuming the maximum GS TX – AS RX frequency offset as well as maximum AS Doppler shift relative to the GS corresponding to the aircraft speed of ± 850 knots.

Except for the fact that the AS RX sensitivity is measured over FL CC/Data frames, the sensitivity is measured as described in Section 4.3.2.

5.3.3 Airborne RX Operating Point

When 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 CC/Data frames, the airborne LDACS1 RX shall fulfil the BER specified under 5.3.1 when the signal S1[19] as defined in Table 5-1 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.

[18] The S0 value has been derived from the LDACS1 link budget in Appendix A - LDACS1 Link Budget, for the case without interference, considering ENR environment and including the impact of the mobile channel.

[19] The S1 value has been derived from the LDACS1 link budget in Appendix A - LDACS1 Link Budget and may have to be further adjusted.

Table 5-1: AS RX Operating Point S1 and Power Density Pd

Antenna Conversion	Unit	ENR	TMA	APT	Equation
Tx-Rx Distance	nm	120,00	40,00	10,00	d
Speed of light	m/s	3,E+08	3,E+08	3,E+08	c
Transmit mid-band Frequency	MHz	993	993	993	f
Wavelength	m	0,30	0,30	0,30	λ =c/f
Correction Factor	dB	-21,39	-21,39	-21,39	CF=10*log10(λ^2/4/π)
Rx operating point (S1)	dBm	-95,93	-95,43	-92,73	S1
RX cable loss	dB	3,00	3,00	3,00	Lca
Duplexer loss	dB	0,50	0,50	0,50	Lda
Minimum RX Antenna Gain	dBi	0,00	-5,00	-5,00	Lra
Required power at RX antenna	dBm	-92,43	-86,93	-84,23	Pa=S1+Lca-Lra
Required power at RX antenna	dBW	-122,43	-116,93	-114,23	Pa1=Pa-30
Spatial power density at RX ant.	dBW/m2	-101,04	-95,54	-92,84	Pd=Pa1-CF

Assuming fixed antenna gain and cable/duplexer losses, the AS RX operating point S1 for particular LDACS1 designed operational coverage (environment), is related to the minimum required signal power density Pd (dBW/m2) in front of the AS receive antenna.

Under above conditions, the AS RX operating in a corresponding environment shall provide the BER specified under 5.3.1 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 5-1.

When calculating Pd, the conversion formula from ICAO Annex 10, Volume I, Attachment C, Section 7.2.1 has been used: Pd = Pa – 10$\log_{10}(\lambda 2/(4*\pi))$, 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.

5.3.4 Airborne RX Interference Immunity Performance

This section is for information only.

The LDACS1 receiver shall be able to receive the desired LDACS1 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 LDACS1 parameters. Instead, it should be measured in the laboratory on LDACS AS RX prototype.The detailed test plan for LDACS1 receivers is being separately produced and is out of scope of this specification.

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 LDACS1 channel and the on-channel desired LDACS1 signal, for specified desired signal level (D) and specified reference BER (Section 5.3.1).

IR shall be measured by setting the desired LDACS1 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 5.3.2) and raising the power level "U" (dBm) of the interfering signal until the target BER (as specified in 5.3.1) 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 LDACS1 channel), peak power, and duty-cycle.

***Error! Reference source not found.** 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 LDACS1 signal and undesired interference signal.*

The Interference Rejection (IR) represents the power difference (in dB) between the interfering signal at specified frequency offset and the on-channel desired LDACS1 signal, for the specified desired signal level and specified error rate.

IR shall be measured by setting the desired LDACS1 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 5.3.2) and raising the power level "U" (dBm) of the interfering signal until the error rate (as specified in 5.3.1) 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 LDACS1 signal), peak power, and duty-cycle.

Table 4-4 illustrates one example of stating IR for a particular interfering L-band system "X".

5.3.5 Airborne RX Maximum Desired Signal

The AS receiver shall be capable of decoding on-channel desired LDACS1 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[20], the peak received LDACS1 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.

5.3.6 Airborne RX Maximum Tolerable Input Signal Power

The airborne LDACS1 receiver shall tolerate at its input a peak pulsed interference signal power of +25 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 LDACS1 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 LDACS1 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.

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[20] 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 7.7.2).

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.

5.3.7 Airborne RX Switchover Time

An airborne radio is requested by the controlling GS to regular scan FL broadcast frames (BC2 sub-frames, see Section 7.5.1.2) of adjacent non-controlling GSs operating on different RF channels.

When commanded to switch the FL RF channel, an airborne LDACS1 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 LDACS1 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.*

5.3.8 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.

5.4 AS Frequency/Timing Requirements

5.4.1 AS Centre Frequency and Symbol Clock Accurracy

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.

5.4.2 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 2% of the sub-carrier spacing[21].

This requirement has been taken-over from the WiMAX specification [802.16e]. Its applicability to LDACS1 has to be confirmed.

During the synchronisation period, the AS shall acquire frequency synchronisation on FL within the tolerance[22] that is sufficient for satisfactory reception on the FL (sensitivity requirement, as specified in Section 5.3.2) before attempting any RL transmission.

[21] 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.

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 4.4.4 and 5.4.1) 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.

5.4.3 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.

> *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[23] that is sufficient for satisfactory reception on the FL (sensitivity requirement, as specified in Section 5.3.2) 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.

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

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

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.

6 LDACS1 Protocol Services and Interfaces

This chapter deals with services of LDACS1 functional blocks above the PHY layer as well as with interfaces between these functional blocks. The description provided here is based on the LDACS1 protocol architecture as provided in Section 2.3.1.6. For better clarity, the LDACS1 protocol stack representation (Figure 2-4) from Section 2.3.1.6. is replicated in this section as well (Figure 6-1).

The description is covering the LDACS1 A/G mode of operation.

The LDACS1 PHY layer is described in detail in CHAPTER 7. Details about LDACS1 MAC, LME, DLS, VI, and SNDCP entities are provided in CHAPTER 8, CHAPTER 9, CHAPTER 10, CHAPTER 11 and CHAPTER 12, respectively.

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

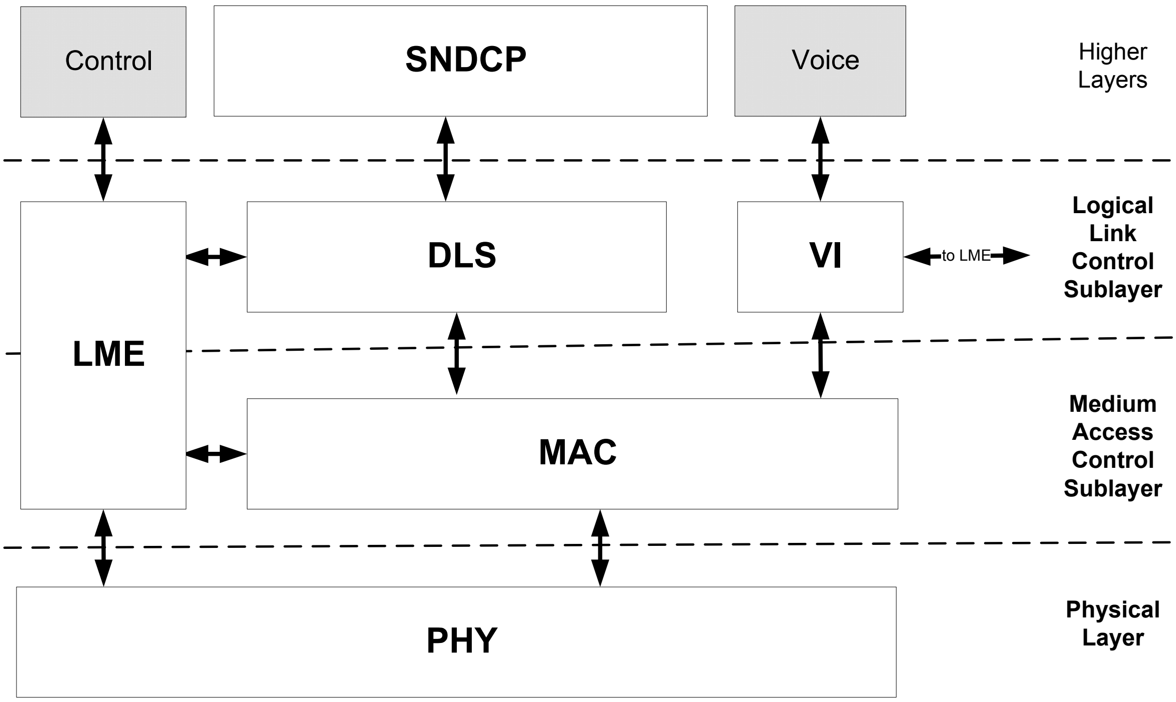

Figure 6-1: LDACS1 Protocol Stack

6.1 Services of the Data Link Layer and SNDCP

6.1.1 Medium Access Control (MAC) Entity Services

6.1.1.1 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.

6.1.1.2 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.

6.1.2 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.

6.1.3 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.

6.1.4 Link Management Entity (LME) Services

6.1.4.1 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.

6.1.4.2 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.

6.1.5 Sub-Network Dependent Convergence Protocol (SNDCP) Services

6.1.5.1 Network layer Adaptation

The network layer adaptation service provides functions required for transparent transfer of network layer N-PDUs of (possibly different) network protocols over LDACS1 A/G system.

6.1.5.2 Compression Service

The compression service provides functions to improve the channel efficiency. This is realised by the compression of redundant protocol information and by the compression of redundant user data.

6.2 LDACS1 Internal Interfaces

The interface between the functional blocks of the LDACS1 system shall be realised via service primitives.

6.2.1 PHY Service Primitives

The interface of the PHY layer towards the DLL shall be realised by the primitives shown in Table 6-1.

Table 6-1: Physical Layer Interface

Primitive	SAP	Request	Indication	Response	Confirmation
PHY_FSCAN	P_SAPC	X	X		
PHY_GSCAN	P_SAPC	X	X		

Primitive	SAP	Request	Indication	Response	Confirmation
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		

6.2.1.1 PHY Time Framing Service (PHY_RTX)

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.

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

The PHY_BC, PHY_RA, PHY_CC, PHY_DC, and PHY_DATA primitives shall be used to request access to the physical medium in the given slot. 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.

6.2.1.3 Aircraft Synchronisation (PHY_SYNC, PHY_FLSYNC)

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 PHY_FLSYNC primitives shall indicate the PHY layer synchronisation status to the AS.

6.2.1.4 Aircraft PHY Configuration (PHY_CONF)

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 the current PHY parameters (e.g measured received power) to the LME.

6.2.1.5 Ground-Station PHY Configuration (PHY_CONF)

The PHY_CONF.req primitive shall be used by the GS LME to set PHY parameters.

The PHY_CONF.ind indication shall be used by the GS PHY to indicate PHY parameters to the LME (e.g. measured received power of a particular AS).

6.2.1.6 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.

6.2.1.7 GS Controlled Scanning of Neighbour Cells (PHY_GSCAN)

The PHY_GSCAN primitive shall be used by the AS MAC to perform the GS controlled background scanning of a given LDACS1 frequency for the preparation of a handover. It shall return the received power on FL and the first fully decoded FL BC PHY-PDU.

6.2.1.8 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 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 PHY layer evaluates the CMS FL MAP. The CMS FL MAP contains information on the position, size, and coding and modulation schemes of the single data blocks. 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.

6.2.1.9 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 primitives.

In the case that not all RL PHY-PDUs are used by the same aircraft/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.

6.2.1.10 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.

6.2.1.11 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.

6.2.1.12 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.

6.2.2 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 6-2.

Table 6-2: Medium Access Control Entity Interface

Primitive	SAP	Request	Indication	Response	Confirmation
MAC_CONNECT	M_SAPI	X	X		
MAC_FSCAN	M_SAPI	X	X		
MAC_CSCAN	M_SAPI	X	X		
MAC_GSCAN	M_SAPI	X	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		

6.2.2.1 MAC Control (MAC_CONNECT, MAC_OPEN and MAC_HO2)

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.

6.2.2.2 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 LDACS1 radio channels. In FSCAN state the MAC will fast scan all known LDACS1 frequencies and indicate the received power to the LME.

6.2.2.3 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 LDACS1 signal and the GS properties.

6.2.2.4 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.

6.2.2.5 Access to Logical Channels

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.

6.2.2.6 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.

6.2.2.7 CC Status Report (MAC_CC_STATUS)

The MAC_CC_STATUS primitive shall be used by the AS MAC to report the current size of the CC slot to the LME.

6.2.3 DLS Service Primitives

The interface of the DLS entity towards LME shall be realised by the primitives shown in Table 6-3.

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

Table 6-3: Data Link Service Interface

Primitive	SAP	Request	Indication	Response	Confirmation
DLS_DATA	D_SAPD	X	X		X
DLS_UDATA	D_SAPD	X	X		X
DLS_OPEN	D_SAPD	X	X		

DLS_CLOSE	D_SAPD	X	X		

6.2.3.1 Acknowledged Data Link Service (DLS_DATA)

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

6.2.3.2 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 confirmation shall be used for internal feedback.

The DLS broadcast data link service shall only be available in the GS. It shall use the DLS_UDATA primitives in combination with the Subscriber Access Code (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).

6.2.3.3 Data Link Service Control (DLS_OPEN and DLS_CLOSE)

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.

6.2.4 LME Service Primitives

The interface of the LME towards its service users shall be realised by the primitives shown in Table 6-4.

Table 6-4: Link Management Entity Interface

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

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

6.2.4.1 Link Configuration (LME_CONF)

The LME_CONF primitives shall be used to configure LDACS1 (data link layer and physical layer).

6.2.4.2 Link Control (LME_OPEN)

The LME_OPEN primitive shall be used to activate LDACS1 AS radio.

6.2.4.3 Voice Service Configuration (LME_VC_CONF)

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

6.2.4.4 Radio Resource Management (LME_R)

The LME_R primitives shall be used by the GS for the resource management of the FL.

6.2.4.5 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.

6.2.5 VI Service Primitives

The interface of the VI towards its service users shall be realised by the primitives shown in Table 6-5.

Table 6-5: VI Interface

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

6.2.5.1 Dedicated Circuit Voice Service (VI_VOICE and VI_OVERRULE)

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.

6.2.5.2 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.

6.2.5.3 Voice Interface Control (VI_OPEN and VI_CLOSE)

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.

6.2.5.4 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.

6.2.6 SNDCP Service Primitives

The interface of the SNDCP towards its service users shall be realised by the primitives shown in Table 6-6.

Table 6-6: Sub-Network Dependent Protocol Interface

Primitive	SAP	Request	Indication	Response	Confirmation

SN_DATA	SN_SAPD	X	X		
SN_UDATA	SN_SAPD	X	X		

6.2.6.1 Acknowledged Data Link Service (SN_DATA)

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

6.2.6.2 Unacknowledged Data Link Service (SN_UDATA)

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

6.2.7 Aircraft Interface

Figure 6-2 shows LDACS1 protocol entities applicable to an LDACS1 AS, together with service primitives and Service Access Points (SAPs).

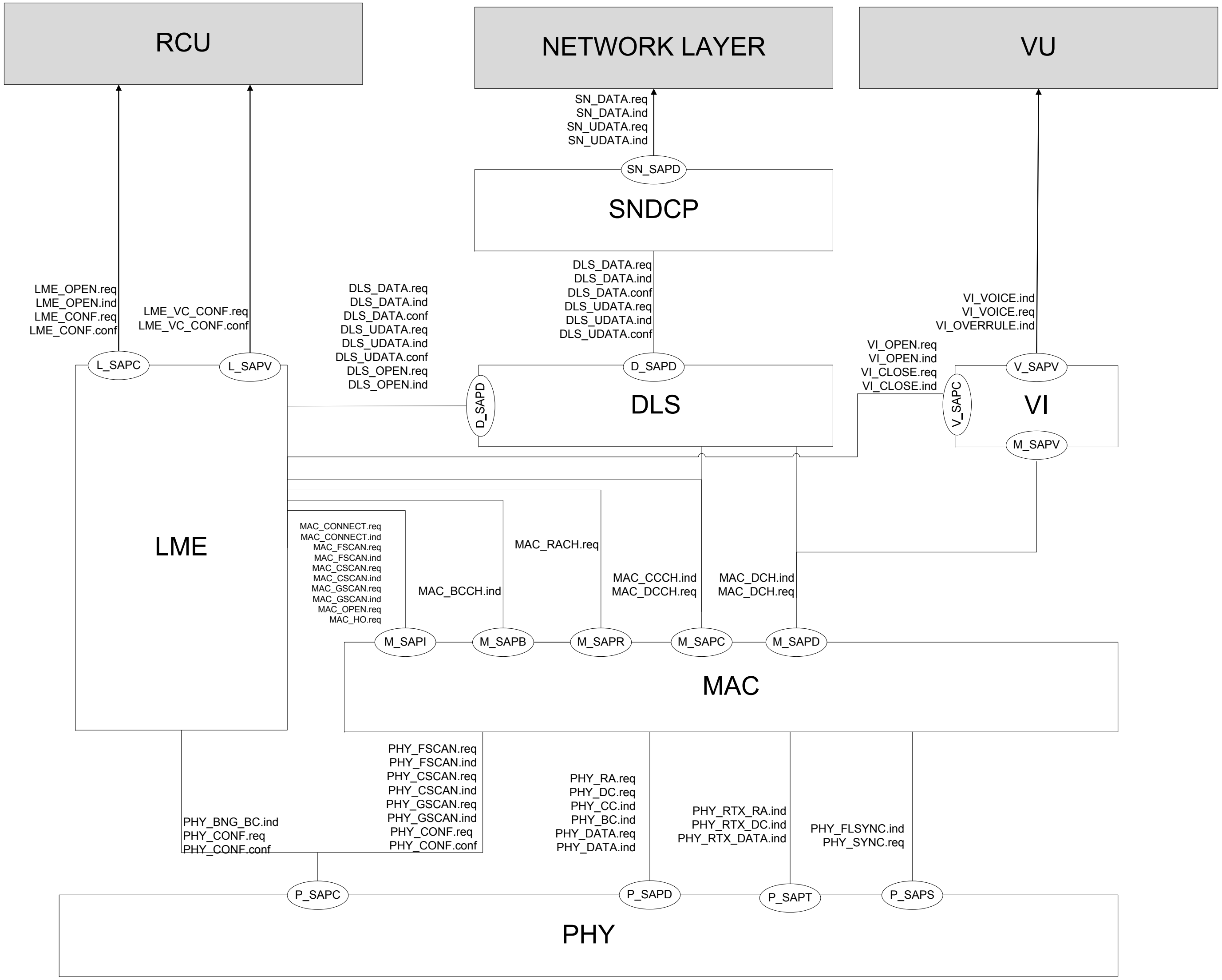

Figure 6-2: LDACS1 Interfaces in the Aircraft Station

6.2.8 Ground-Station Interface

Figure 6-3 shows LDACS1 protocol entities applicable to an LDACS1 GS, together with service primitives and SAPs.

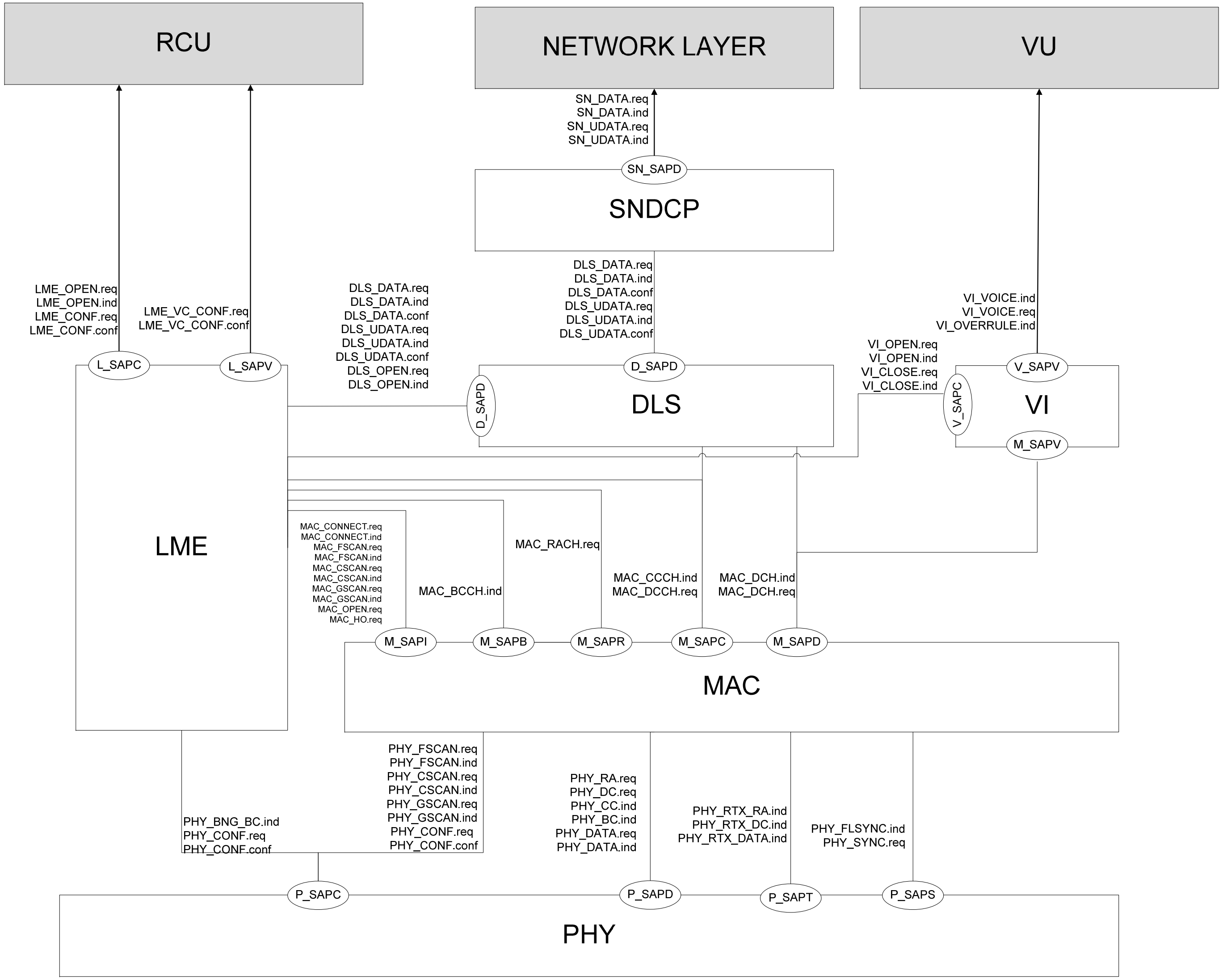

Figure 6-3: LDACS1 Interfaces in the GS

7 Physical Layer Protocols and Services

7.1 Physical Layer Characteristics

The LDACS1 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, LDACS1 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.

This enables an inlay deployment, using the spectrum between the DME frequencies with an LDACS1 channel separation of 1 MHz. Besides the inlay approach, LDACS1 can also be deployed as non-inlay system as detailed in Section 2.3.1.9 and ANNEX 4. Note, the deployment scenario has neither impact on the physical layer nor on the protocol suite of LDACS1, i.e. the same LDACS1 system can be used for both approaches.

Whereas the LDACS1 system has been designed to fulfil the [COCRv2] requirements with the more stringent inlay deployment concept, an even higher system capacity for the non-inlay deployment is expected due to operation in an environment with considerably less interference.

LDACS1 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.

LDACS1 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.

7.2 FL – OFDM Transmission

7.2.1 Frequency Domain Description

The typical structure of an FL OFDM symbol in the frequency domain is depicted in Figure 7-1.

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.

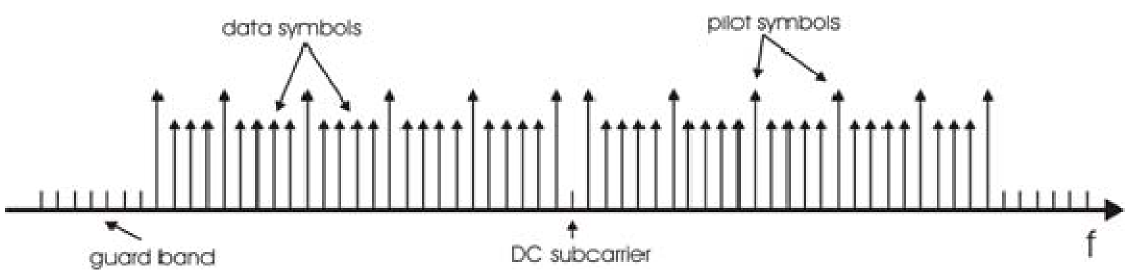

Figure 7-1: OFDM Symbol, Frequency Domain Structure

7.2.2 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 7-2 shows this procedure in two steps. The windowing method is addressed in Section 7.8.1.

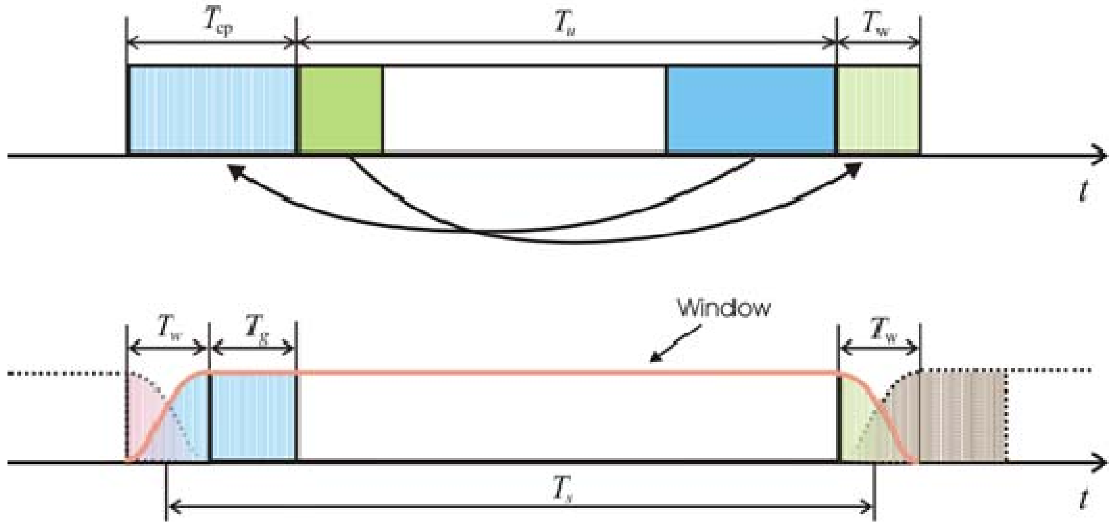

Figure 7-2: OFDM Symbol, Time Domain Structure

7.3 RL – OFDMA-TDMA Transmission

7.3.1 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 LDACS1 RL bandwidth in an OFDMA transmission. The OFDMA structure in the RL is clarified in Figure 7-3. The tile structure is further defined in Section 7.5.2.1.

Tiles as defined above are the main building block for RL DC segments and are also used 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 7.5.2.2).

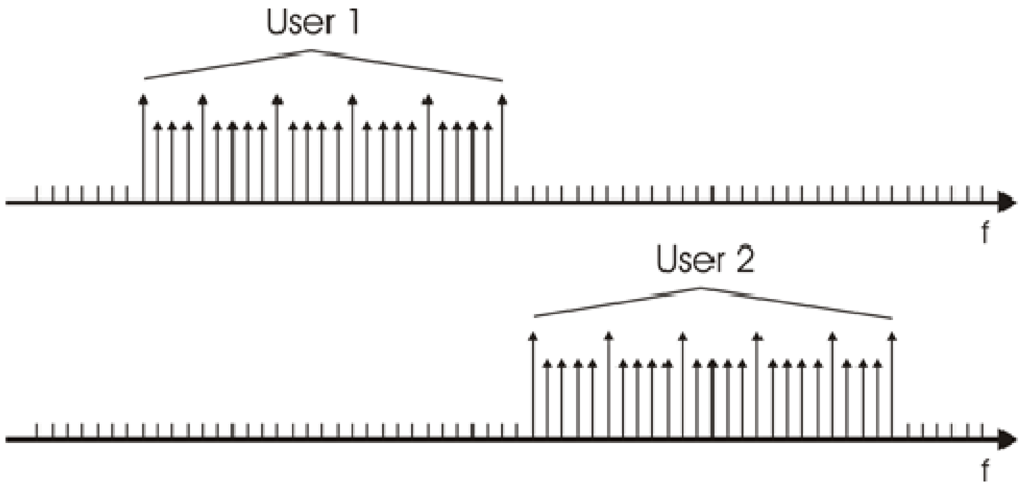

Figure 7-3: OFDMA Structure in the RL

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

7.3.2 Time Domain Description

In the RL, each involved AS creates separately its time domain OFDM symbol as described in Section 7.2.2. 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.

7.4 PHY Layer Parameters

7.4.1 OFDM Parameters

The parameters summarised in Table 7-1 are valid both in the FL and in the RL.

Table 7-1: 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[24]
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 7-2, Table 7-3 and Table 7-4 for the FL and in Table 7-5, Table 7-6, Table 7-7 and Table 7-8 for the RL
Sub-carrier indices of PAPR sub-carriers	-24, 23, only in the RL tiles

7.4.2 LDACS1 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.

7.5 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 7-4.

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

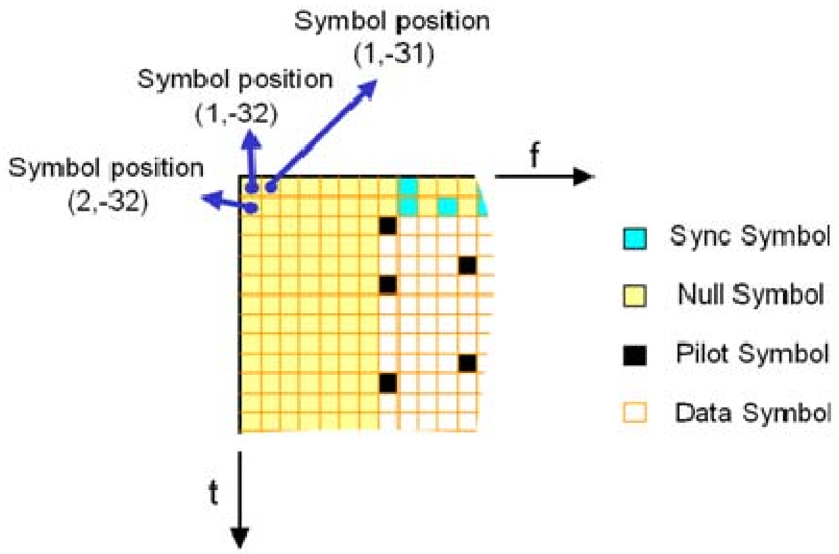

Figure 7-4: Numbering of the Symbols in the Time-Frequency Plane

7.5.1 Forward Link Frame Types

7.5.1.1 FL Data/Common Control Frame

The structure of an FL Data/Common Control (CC) frame is depicted in Figure 7-5. It contains 54 OFDM symbols resulting in a frame duration of $T_{DF/CC}$ = 6.48 ms.

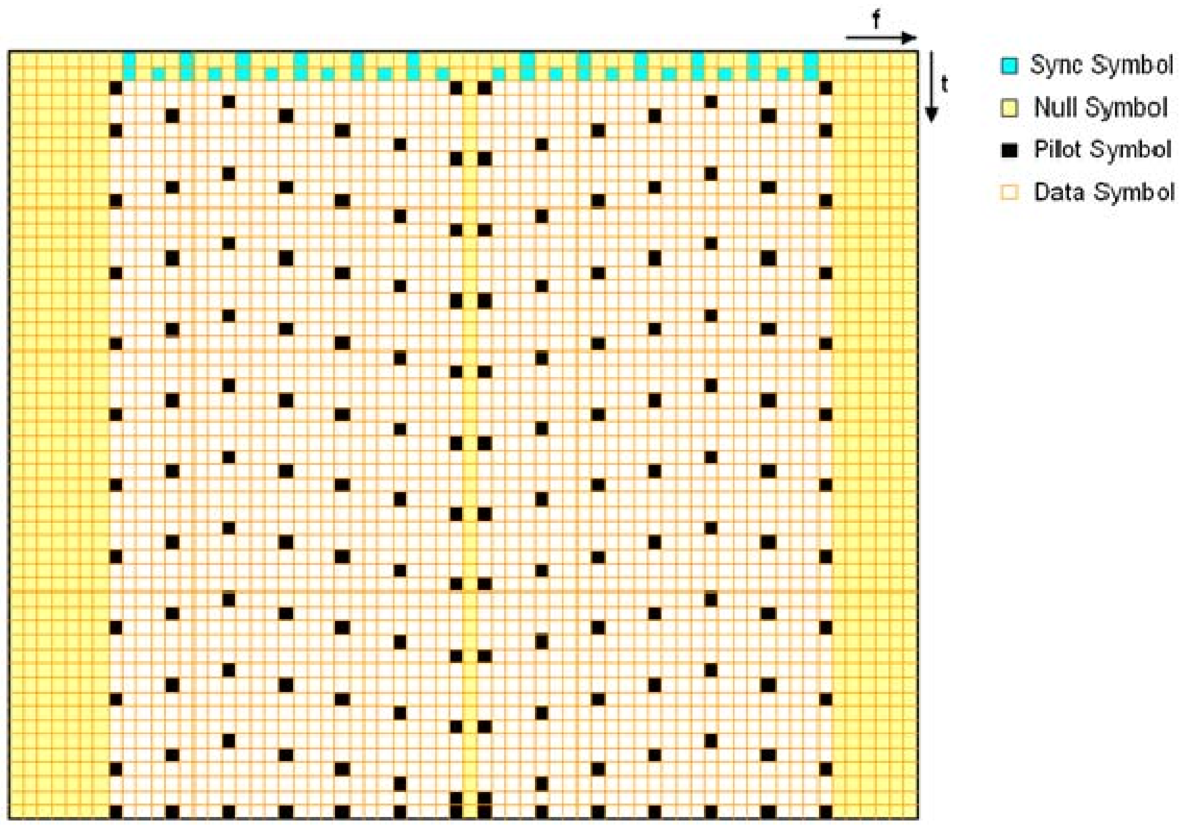

Figure 7-5: Structure of an FL Data/CC Frame

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 7.5.3.1.

The pilot pattern is depicted in Figure 7-5 and described in Table 7-2. 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 Data/CC frame.

Table 7-2: Pilot Symbol Positions for FL Data/CC 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

7.5.1.2 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 7-6 shows the structure of these sub-frames.

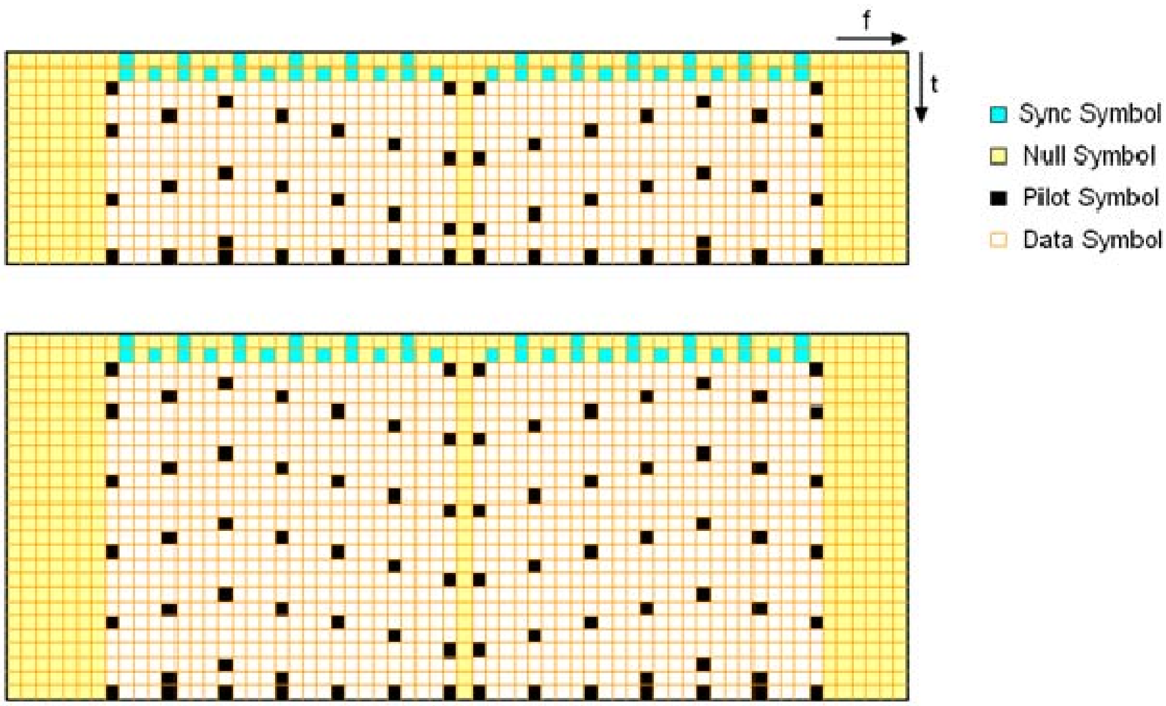

Figure 7-6: Structure of BC1 and BC3 Sub-frames (above) and BC2 Sub-frame (below)

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 7-3 and Table 7-4. 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 7-3: Pilot Symbol Positions for BC1 and BC3 Sub-frame

OFDM symbol position n		Pilot symbol positions
n = 3		-25, -1, 1, 25
n = 3+5·p + i, p = 0,1	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 = 14		-17, 17
n = 15		-25, -21, -17,-13, -9, -5, -1, 1, 5, 9, 13, 17, 21, 25

Table 7-4: Pilot Symbol Positions for BC2 Sub-frame

OFDM symbol position n		Pilot symbol positions
n = 3		-25, -1, 1, 25
n = 3+5·p + i, p = 0,..,3	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 = 24		-17, 17
n = 25		-21, -13, 13, 21
n = 26		-25, -21, -17,-13, -9, -5, -1, 1, 5, 9, 13, 17, 21, 25

7.5.2 Reverse Link Frame Types

To realise multiple access via OFDMA-TDMA in the RL, except for the RA frame, the transmission is organised in segments and tiles/blocks of tiles within these segments, rather than in OFDM frames and sub-frames as in the FL.

7.5.2.1 RL Data Segment

In the RL, Data segment consists of tiles. One tile spans 25 symbols in frequency and 6 symbols in time direction and is illustrated in Figure 7-7. 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 7-5 for a tile on the left side of the DC sub-carrier and in Table 7-6 for a tile on the right side of the DC sub-carrier.

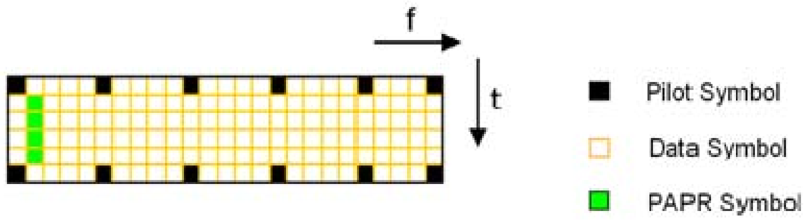

Figure 7-7: Structure of a Tile in the RL

Table 7-5: Pilot and PAPR Reduction Symbol Positions in a Left Tile

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

Table 7-6: Pilot and PAPR Reduction Symbol Positions in a Right Tile

OFDM symbol	Pilot symbol positions
n = □, 6	1, 6, 11, 16, 21, 25
	PAPR reduction symbol positions
n = 2, 3, 4,	23

An RL data segment, comprising 8 tiles, is depicted in Figure 7-8.

The length of an RL data segment is variable and is described in Section 7.5.3.2.

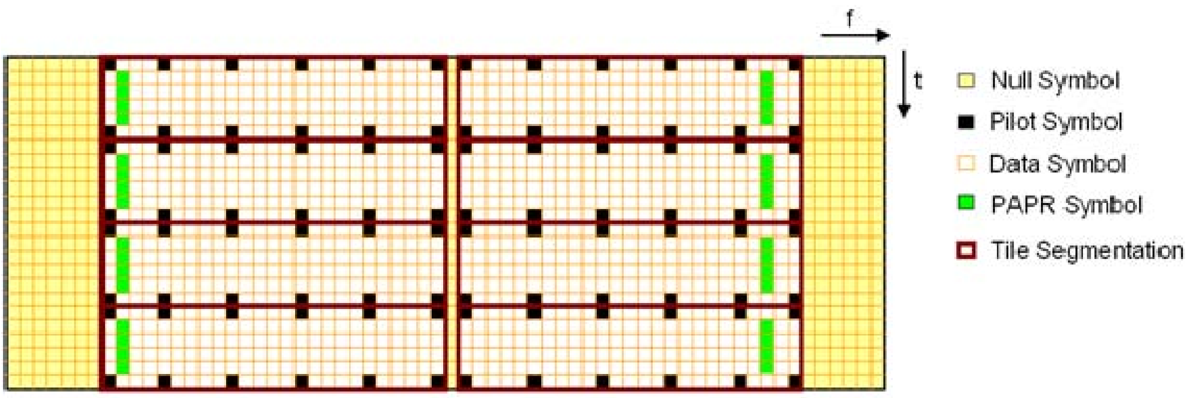

Figure 7-8: Structure of an RL Data Segment

7.5.2.2 RL Dedicated Control Segment

A dedicated control (DC) segment has the same tile structure as the RL data segment (see Figure 7-7).

The DC segment 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 7-9. 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 7-7. The synchronisation tile provides a possibility for an AS to execute a Handover Type 2.

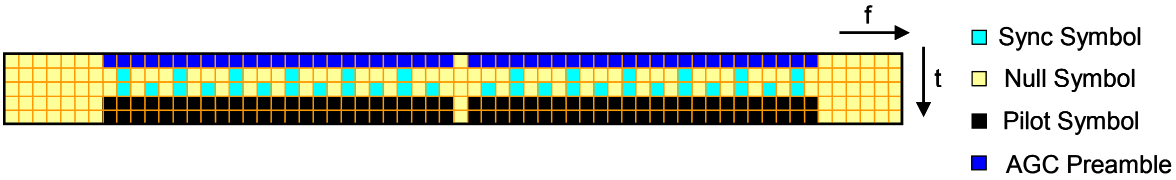

Figure 7-9: Structure of a Synchronisation Tile

Table 7-7: 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 segment, exactly one tile is assigned to one AS. The length of a DC segment is variable and is described in Section 7.5.3.2. Therefore, the number of OFDM symbols in the DC segment is also variable (N_{dc}). As an example one DC segment comprising the synchronisation tile, the single AGC preamble and six tiles is depicted in Figure 7-10.

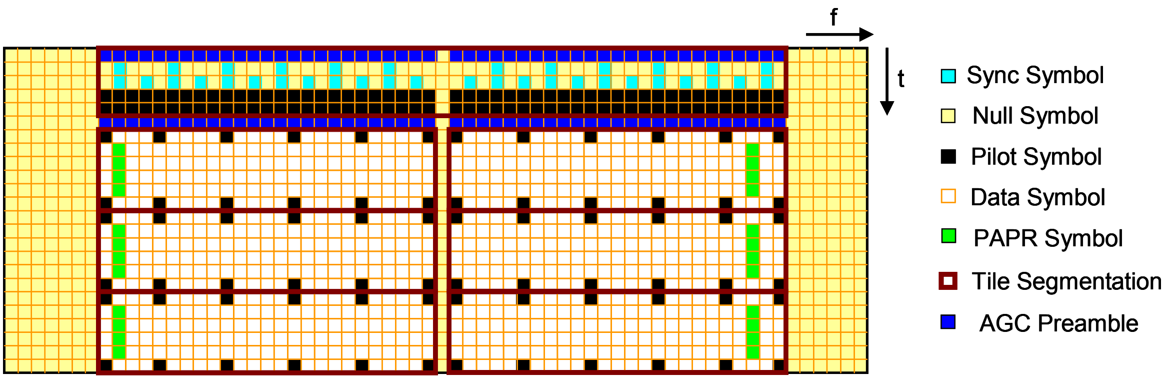

Figure 7-10: Structure of an RL DC Segment

7.5.2.3 RL Random Access Frame

NOTE: As 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 7-11). 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 7-11). 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 7-11: 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 7-12.

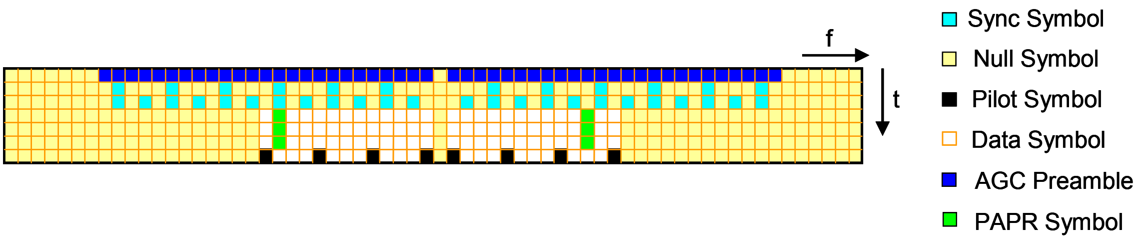

Figure 7-12: Structure of an RA Frame

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 7-8. 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 7-8: 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

7.5.3 Framing

The LDACS1 physical layer framing is hierarchically arranged. In Figure 7-13 and Figure 7-14, 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.

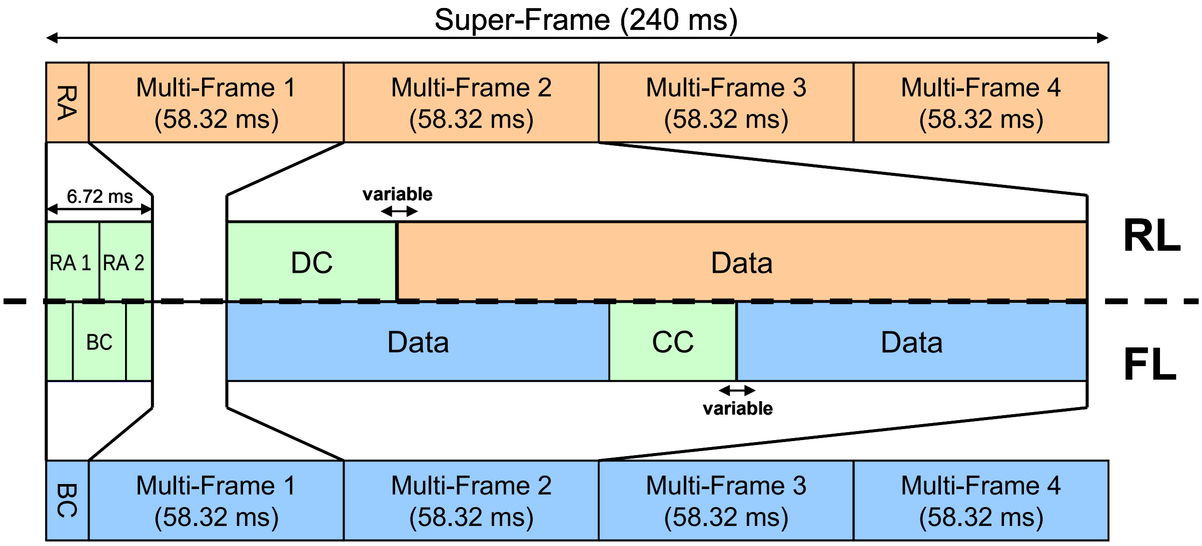

Figure 7-13: Super-Frame Structure

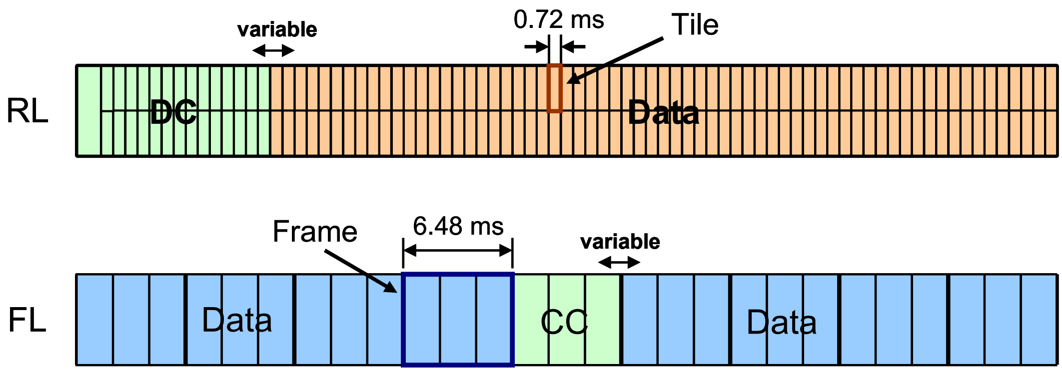

Figure 7-14: Multi-Frame Structure

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.

7.5.3.1 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 Data/CC frames. Onto these frames, FL CC PHY-PDUs and FL Data PHY-PDUs are mapped. The size of an FL CC PHY-PDUs is 814 symbols, i.e. 1/3 of an FL Data/CC frame. Within the MF, starting from the frame number 5, N_{CC} = 3, 6, 9, or 12 FL CC PHY-PDUs can be mapped onto the subsequent frames. The remainder of the MF shall be filled with FL Data PHY-PDUs. The size of an FL Data PHY-PDU is 814 symbols. The numbering of the FL PHY-PDUs shall start at the beginning of the MF.

7.5.3.2 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 segment, followed by an RL data segment. RL DC and Data segments are sub-divided in tiles. Within one MF, the DC segment size and thus also the size of the data segment is variable. One RL Data/DC PHY-PDU is mapped onto one tile. The size of an RL Data PHY-PDU and an RL DC PHY-PDU corresponds to the number of data symbols of a tile.

The minimal size of the DC segment 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 $T_{DC,max}$ = 19.44 ms.

The duration of the data segment in the RL is $T_{DF} = T_{MF} - T_{DC}$, resulting in $T_{DF,min}$ = 38.88 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 7.6.2.5 and 7.6.2.6.*

Note: *Maximum length of the DC segment limits the number of AS that can be controlled by single GS to 208. More ASs can be accommodated by increasing the length of the control cycle to two SFs or more. In any case, the maximum number of ASs per GS cannot be greater than 512, limited by the maximum size (9 bits) of the control offset field (Section 9.6.12).*

7.6 Coding and Modulation

7.6.1 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 7-15, 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

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

The output bits of the randomizer enter the channel coding.

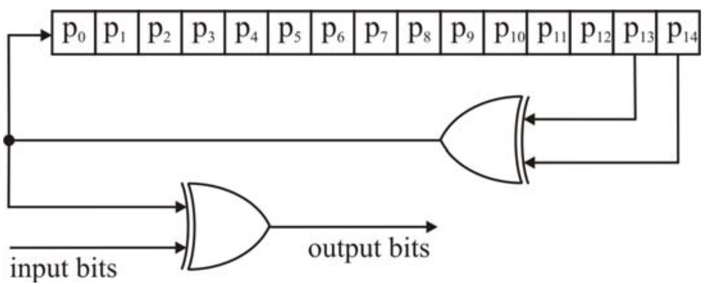

Figure 7-15: Randomizer Structure

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

7.6.2 Channel Coding

As FEC scheme, LDACS1 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 7-16.

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 helix interleaver.

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

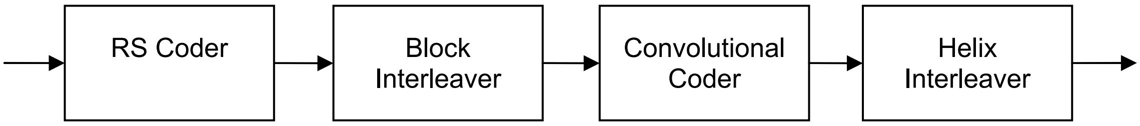

Figure 7-16: Channel Coding and Interleaving

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.

7.6.2.1 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

7.6.2.2 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 7-17. 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 7-9, a “1” means a transmitted bit and a “0” denotes a removed bit, whereas $X^{(1)}$ and $X^{(2)}$ are in accordance to Figure 7-17.

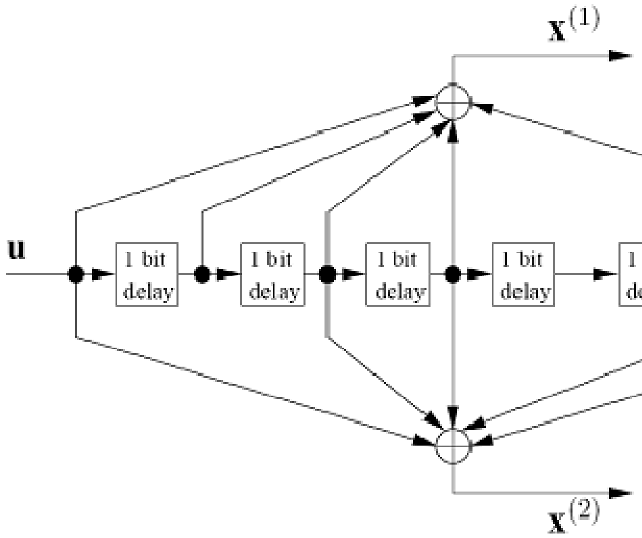

Figure 7-17: Block Diagram of Convolutional Coder (171, 133, 7)

Table 7-9: 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 7-18. 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. $X^{(1)}{}_1$, $X^{(2)}{}_1$, $X^{(3)}{}_1$,$X^{(1)}{}_2$, $X^{(2)}{}_2$,…

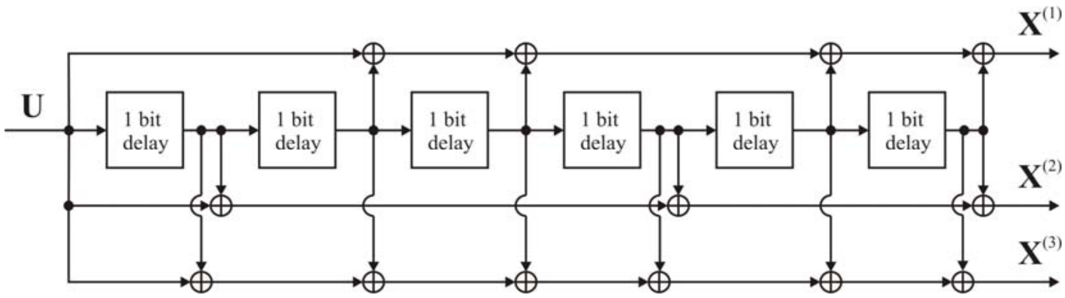

Figure 7-18: Block Diagram of Convolutional Coder (133, 145, 177, 7)

7.6.2.3 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 7.6.2.5 and 7.6.2.6.

7.6.2.4 Helix Interleaver

The interleaving of the output of the convolutional encoder is done by a helix 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 7.6.2.5 and 7.6.2.6. The following calculation specifies the pattern of the interleaver

for l = 0:a-1

for n = 0:b-1

$$k = l \cdot b + n + 1,$$

$$m_k = b \cdot (3 \cdot n + l)_{\bmod a} + n + 1$$

end

end

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

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

7.6.2.5 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 helix interleaved. Table 7-10 gives the modulation schemes, channel coding parameters, interleaver parameters and block sizes for these FL PHY-SDUs.

The modulation schemes are described in Section 7.6.3.

The combination of QPSK modulation, a fixed RS code and a convolutional code with r_{cc} = ½ is mandatory for the FL CC PHY-SDUs. Each FL CC PHY-SDU is separately RS encoded. The block interleaving, convolutional coding and helix interleaving is performed jointly for all FL CC PHY-SDUs in a MF. Table 7-11 gives the modulation schemes, channel coding parameters, interleaver parameters and block sizes for the different number of FL CC PHY-SDUs per MF, which are defined in Section 7.5.3.1.

Note: In Section 7.5.3.1, the number of PHY-PDUs and not PHY-SDUs is defined. However, after the modulation, the modulated symbols are subdivided into PHY-PDUs, with the total number of PHY-PDUs equal to the total number of PHY-SDUs. This does also hold for the Data PHY-SDUs.

In the FL, Adaptive Coding and Modulation (ACM) is provided only for user data.

Two modes are defined for ACM:

- Cell-specific ACM mode, which means that all data within the cell is 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.

In case of cell-specific ACM, the information about the chosen coding and modulation scheme is transmitted via the System Identification Broadcast (see Section 9.5.2.2). 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 8.3.2.2).

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 Data PHY-PDUs of 814 modulated symbols, always $N_D = 27 - N_{CC}$ = {15, 18, 21, 24} FL Data PHY-PDUs are mapped onto a MF, for both ACM modes. The RS encoding is performed separately for each FL Data PHY-SDU.

In the case of cell-specific ACM, all RS codewords within a MF are jointly block interleaved, convolutional coded and helix interleaved.

In the case of user-specific ACM, the block interleaving, convolutional coding and helix interleaving is performed jointly for all users, having the same ACM parameter set. The allowed sizes for an ACM parameter set are 3, 6, 9, …, 24 FL Data PHY-SDUs, which may be assigned arbitrarily to different users. The resulting parameters are shown in Table 7-12.

Table 7-10: Parameters for FL BC PHY-SDUs

PHY-SDU type	Modulation scheme	Conv. Coding Rate	RS Parameter	Total Coding Rate	PHY-SDU size (uncoded bits)	Helix Interleaver Parameter (a, b)	Number of coded bits after helix 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 7-11: Parameters for FL CC 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	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
FL CC PHY-SDU	QPSK	1/2	RS(101, 91, 5)	0.45	728	1	3	(3, 101)	(66, 74)	4884
							6	(6, 101)	(132, 74)	9768
							9	(9, 101)	(111, 132)	14652
							12	(12, 101)	(132, 148)	19536

Table 7-12: Parameters for FL Data 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	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
FL Data PHY-SDU	QPSK	1/2	RS(101, 91, 5)	0.45	728	1	3	(3, 101)	(66, 74)	4884
							6	(6, 101)	(132, 74)	9768
							9	(9, 101)	(111, 132)	14652
							12	(12, 101)	(132, 148)	19536
							15	(15, 101)	(111, 220)	24420
							18	(18, 101)	(132, 222)	29304
							21	(21, 101)	(154, 222)	34188
							24	(24, 101)	(264, 148)	39072
FL Data PHY-	QPSK	2/3	RS(134, 120, 7)	0.60	960	1	3	(3, 134)	(66, 74)	4884
							6	(6, 134)	(132, 74)	9768

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	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
SDU							9	(9, 134)	(111, 132)	14652
							12	(12, 134)	(132, 148)	19536
							15	(15, 134)	(111, 220)	24420
							18	(18, 134)	(132, 222)	29304
							21	(21, 134)	(154, 222)	34188
							24	(24, 134)	(264, 148)	39072
FL Data PHY-SDU	QPSK	3/4	RS(151, 135, 8)	0.67	1080	1	3	(3, 151)	(66, 74)	4884
							6	(6, 151)	(132, 74)	9768
							9	(9, 151)	(111, 132)	14652
							12	(12, 151)	(132, 148)	19536
							15	(15, 151)	(111, 220)	24420

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	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
							18	(18, 151)	(132, 222)	29304
							21	(21, 151)	(154, 222)	34188
							24	(24, 151)	(264, 148)	39072
FL Data PHY-SDU	16QAM	1/2	RS(202, 182, 10)	0.45	1456	1	3	(3, 202)	(132, 74)	9768
							6	(6, 202)	(132, 148)	19536
							9	(9, 202)	(132, 222)	29304
							12	(12, 202)	(264, 148)	39072
							15	(15, 202)	(220, 222)	48840
							18	(18, 202)	(264, 222)	58608
							21	(21, 202)	(308, 222)	68376
							24	(24, 202)	(264, 296)	78144

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	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
FL Data PHY-SDU	16QAM	2/3	RS(135, 121, 7)	0.60	1936	2	3	(6, 135)	(132, 74)	9768
							6	(12, 135)	(132, 148)	19536
							9	(18, 135)	(132, 222)	29304
							12	(24, 135)	(264, 148)	39072
							15	(30, 135)	(220, 222)	48840
							18	(36, 135)	(264, 222)	58608
							21	(42, 135)	(308, 222)	68376
							24	(48, 135)	(264, 296)	78144
FL Data PHY-SDU	64QAM	1/2	RS(152, 136, 8)	0.45	2176	2	3	(6, 152)	(111, 132)	14652
							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	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
							12	(24, 152)	(264, 222)	58608
							15	(30, 152)	(330, 222)	73260
							18	(36, 152)	(396, 222)	87912
							21	(42, 152)	(333, 308)	102564
							24	(48, 152)	(264, 444)	117216
FL Data PHY-SDU	64QAM	2/3	RS(203, 183, 10)	0.60	2928	2	3	(6, 203)	(111, 132)	14652
							6	(12, 203)	(132, 222)	29304
							9	(18, 203)	(198, 222)	43788
							12	(24, 203)	(264, 222)	58608
							15	(30, 203)	(330, 222)	73260
							18	(36, 203)	(396, 222)	87912

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	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
							21	(42, 203)	(333, 308)	102564
							24	(48, 203)	(264, 444)	117216
FL Data PHY-SDU	64QAM	3/4	RS(228, 206, 11)	0.68	3296	2	3	(6, 228)	(111, 132)	14652
							6	(12, 228)	(132, 222)	29304
							9	(18, 228)	(198, 222)	43788
							12	(24, 228)	(264, 222)	58608
							15	(30, 228)	(330, 222)	73260
							18	(36, 228)	(396, 222)	87912
							21	(42, 228)	(333, 308)	102564
							24	(48, 228)	(264, 444)	117216

7.6.2.6 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 7-13 gives the modulation schemes, channel coding parameters, interleaver parameters and block sizes for these RL PHY-SDUs.

The modulation schemes are described in Section 7.6.3.

Table 7-13: Parameters for RL DC and RL RA PHY-SDUs

PHY-SDU type	Modulation	Convolutional Coding Rate	Total Coding Rate	PHY-SDU size (uncoded bits)	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
RL DC PHY-SDU	QPSK	1/3	0.33	85	(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} PHY-SDUs of an AS in a MF are jointly RS coded, convolutional coded and helix interleaved. However, the number of jointly coded PHY-SDUs is limited either by the maximum size of a RS codeword (255 byte) or 10 PHY-SDUs. In Table 7-14 the limit N_{lim} is given for the different ACM parameter sets.

Table 7-14: Maximum Coding Block Size for RL Data 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} 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:

- *Auxiliary calculation:*

$$u = \left\lfloor \frac{N_{\mathrm{SDU}}}{N_{\mathrm{cod}}} \right\rfloor; \quad v = \left(N_{\mathrm{SDU}}\right)_{\mathrm{mod}\, N_{\mathrm{cod}}}$$

- *Number of coding blocks comprising u + 1 PHY-SDUs:* v
- *Number of coding blocks comprising u PHY-SDUs: Ncod -* v

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

Table 7-15 provides the parameters for 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 8.4.3.2).

Table 7-15: Parameters for RL Data 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	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
RL Data 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

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	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
RL Data 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
				9	RS(199, 171, 14)	0.57	(67, 36)	2412
				10	RS(222, 190, 16)	0.57	(67, 40)	2680
RL Data PHY-SDU	QPSK	3/4	176	1	RS(24, 22, 1)	0.69	(67, 4)	268

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	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
				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 Data 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

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	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
				3	RS(98, 84, 7)	0.43	(67, 24)	1608
				4	RS(132, 112, 10)	0.42	(67, 32)	2144
				5	RS(166, 140, 12)	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
RL Data 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 Data PHY-SDU	64QAM	1/2	360	1	RS(49, 45, 2)	0.46	(67, 12)	804

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	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
				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 Data 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 Data 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

7.6.3 Modulation

After the interleaving, the encoded data bits enter serially the constellation mapper. Gray-mapped QPSK, 16QAM and 64QAM shall be supported. Figure 7-19 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 7-19, b_0 denotes the Least Significant Bit (LSB).

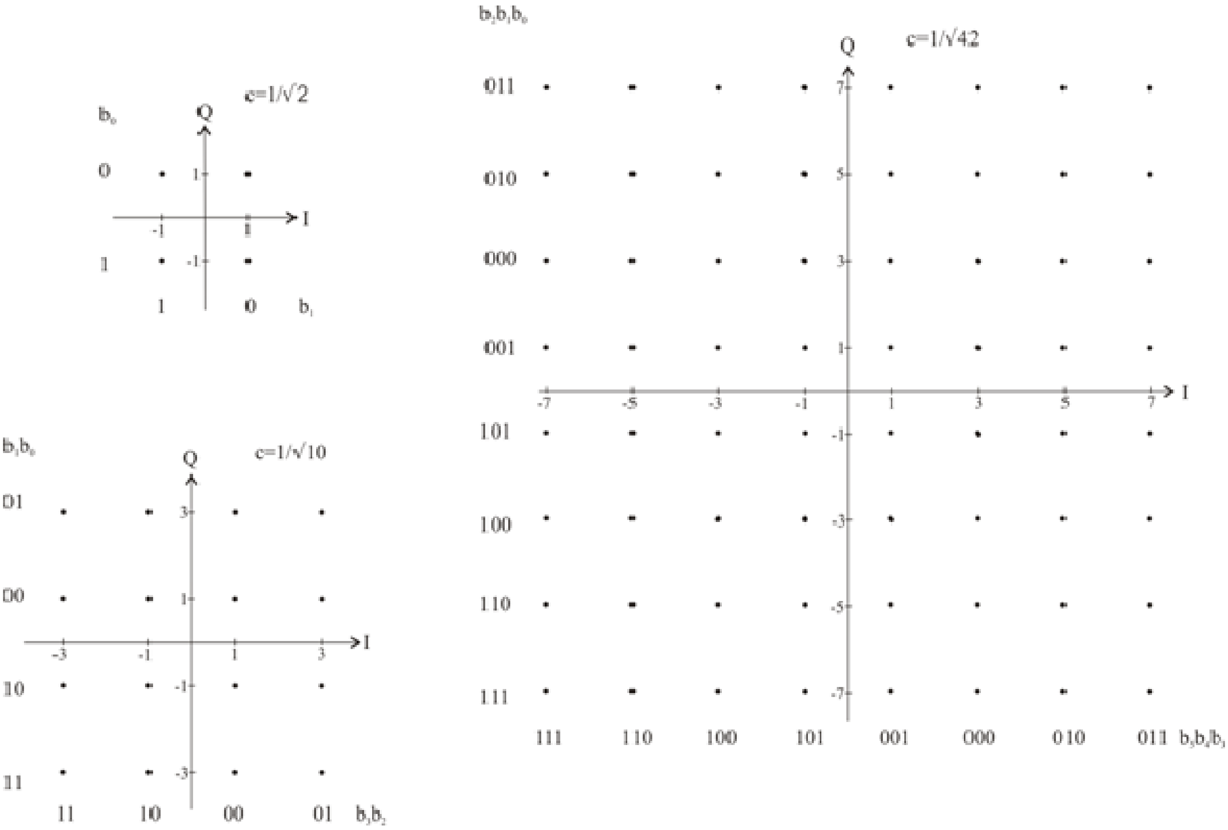

Figure 7-19: Constellation Diagrams for QPSK, 16QAM and 64QAM

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

7.6.4 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 withihn 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.
- N_{CC} FL CC 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 N_{CC} PHY-PDUs.

- For cell-specific ACM, N_D FL Data PHY-SDUs within a MF are 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 N_D PHY-PDUs.
- For user-specific ACM, all N_D FL Data PHY-SDUs 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. After the modulation, each block of modulated symbols shall be mapped onto N_D 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 Data 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 6.2.1, additional signalling information is locally exchanged between the PHY and the MAC sub-layer, but is not transmitted from TX to RX.

7.6.4.1 FL Data Mapping

Before mapping FL PHY-PDUs onto a BC sub-frame or a Data/CC frame, two OFDM symbols with the synchronisation sequences and pilot symbols shall be inserted into an FL frame. Pilot insertion follows the pilot pattern defined in Section 7.5.

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 7.5.

In each MF, the N_{CC} FL CC PHY-PDUs shall be mapped onto the frames numbered 5,…,4 + N_{CC}/3. The N_D FL Data PHY-PDUs shall be mapped onto the remaining frames, starting with frame number 1. For both types, exactly 3 PHY-PDUs are mapped onto one frame.

Table 7-16 provides the indices of the OFDM symbols and sub-carriers, on which the FL CC and FL Data PHY-PDUs shall be mapped. Note that 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 7-16: Mapping Indices for CC and 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
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

7.6.4.2 RL Data Mapping

In the RL, the DC segment and the data segment are subdivided into tiles. Data mapping shall map RL DC PHY-PDUs and RL Data 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 7.6.4.1.

7.6.5 Data Rate

The 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.

7.6.5.1 FL Data Rate

The data rate in the FL depends on the chosen coding rate and modulation scheme for user data. Table 7-17 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 7-12. When calculating data rates, three CC PHY-PDUs are assumed, resulting in num_{PHY_PDU} = 24 Data PHY-PDUs per MF. The number of uncoded bits num_{unc} per PHY-PDU (PHY-SDU size) is given in Table 7-12. Taking T_{SF} = 0.24 s and num_{MF} = 4 MF per SF into account, the data rate e.g. for QPSK, r_{cc} = ½ is calculated as follows:

$$r_{data} = \frac{num_{unc} \cdot num_{PHY\_PDU} \cdot num_{MF}}{T_{SF}} = \frac{728bit \cdot 24 \cdot 4}{0.24s} = 291.2 \frac{kbit}{s}.$$

Table 7-17: Data Rates in the FL

Modulation	Convolutional Coding Rate	Total Coding Rate	Data Rate [kbit/s]
QPSK	1/2	0.45	291.2
QPSK	2/3	0.60	384.0
QPSK	3/4	0.67	432.0
16QAM	1/2	0.45	582.4
16QAM	2/3	0.60	774.4
64QAM	1/2	0.45	870.4
64QAM	2/3	0.60	1171.2
64QAM	3/4	0.68	1318.4

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

7.6.5.2 RL Data Rate

In the RL, data rates cannot be easily specified, since the ratio of DC segment duration to data segment duration is variable. However, assuming an average DC segment duration of 15.84 ms, average data rates shown in Table 7-18 are obtained.

Table 7-18: Data Rates in the RL

Modulation	Convolutional Coding Rate	Total Coding Rate	Data Rate [kbit/s]
QPSK	1/2	0.44	220.3
QPSK	2/3	0.60	299.0
QPSK	3/4	0.69	346.1
16QAM	1/2	0.44	440.5
16QAM	2/3	0.60	613.6
64QAM	1/2	0.46	708.0
64QAM	2/3	0.61	944.0
64QAM	3/4	0.67	1038.4

7.7 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.

7.7.1 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 7-2, Table 7-3 and Table 7-4 for the FL and in Table 7-5, Table 7-6, Table 7-7 and Table 7-8 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 7-19

Table 7-19: 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 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.

7.7.2 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 7-5, Table 7-6 and Table 7-8. 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.

7.7.3 Synchronisation Sequences

All synchronisation OFDM symbols are structured as depicted in Figure 7-20. 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 7-20. 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.

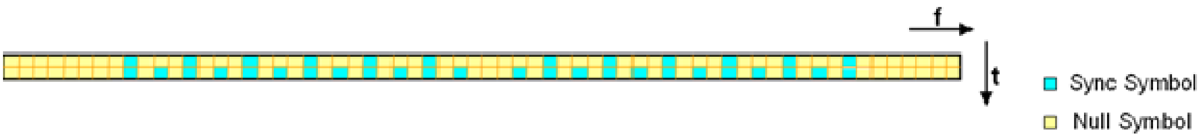

Figure 7-20: Structure of the Synchronisation OFDM Symbols

Table 7-20: 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 7-21. 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).

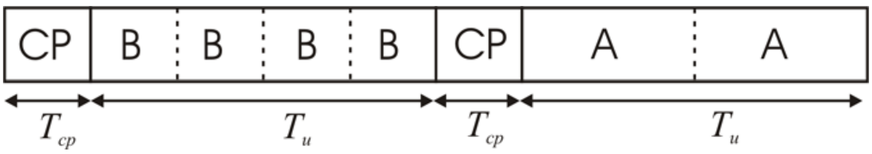

Figure 7-21: Time Domain Representation of Synchronisation OFDM Symbols

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.

7.7.4 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.

7.8 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 LDACS1 onto these systems. One method that is inherent to the LDACS1 design is presented in Section 7.8.1 below.

On the other hand, the interference produced by L-band systems onto LDACS1 receivers has also to be mitigated. Some appropriate techniques are presented in Appendix C.

7.8.1 TX Windowing

The method presented in this section aims at mitigating the undesired influence of LDACS1 onto existing L-band systems.

In Section 7.2.2, the generation of the time domain TX signal is described, including windowing. TX windowing is the mandatory method that must be implemented at the LDACS1 TX in order to reduce the undesired influence of LDACS1 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 7-22.

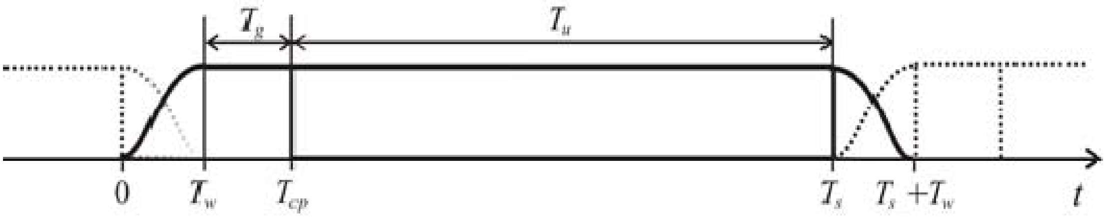

Figure 7-22: Windowing Function

The raised cosine (RC) function with a roll-off factor of α = 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:

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

7.9 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).

7.9.1 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.

7.9.2 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.

7.9.3 AS RX Synchronisation to FL Frames

7.9.3.1 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 7.7.3. 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.

7.9.3.2 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.

7.9.4 GS RX Synchronisation to RL Frames

7.9.4.1 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 7.7.3. 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 7-10.

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.

7.9.4.2 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 7-10.

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.

7.9.5 Notification Services

7.9.5.1 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.

7.9.5.2 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.

7.9.6 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 9.3.2.2) 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 4.3.7, the power adjustment step is defined in Section 5.2.3. The range and the step size of the power level which is communicated to the ASs are defined in Section 9.5.4.6 and Section 9.6.34. The LME power control procedure in defined in Section 9.3.2.2.

7.9.7 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
- Helix 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 7.9.4), steps 1-3 shall be discarded in the GS RX.

7.9.8 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 7-16
- 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

7.10 Physical Layer Support for Voice Operations

The transfer of voice streams works basically the same way as the transfer of data. LDACS1 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.

7.11 PHY Interface to Service Users

The physical layer shall provide an interface to its service users as described in Section 6.2.1.

7.12 Physical Layer Parameters

Table 7-21 summarises all parameters, which were defined or mentioned in this chapter. In addition, a reference to the corresponding sections is provided.

Table 7-21: Physical Layer Parameters

Parameter	Abbr.	Value	Unit

Parameter	Abbr.	Value	Unit
FFT size (7.4.1)	N_{FFT}	64	
Sampling time (7.4.1)	T_{sa}	1.6	µs
Sub-carrier spacing (7.4.1)	Δf	9.765625	kHz
Useful symbol time (7.4.1)	T_u	102.4	µs
Cyclic prefix ratio (7.4.1)	G	11/64	
Cyclic prefix time (7.4.1)	T_{cp}	17.6	µs
OFDM symbol time (7.4.1)	T_s	120	µs
Guard time (7.4.1)	T_g	4.8	µs
Windowing time (7.4.1)	T_w	12.8	µs
Number of used sub-carriers (7.4.1)	N_u	50	
Number of lower frequency guard sub-carriers (7.4.1)	$N_{g,left}$	7	
Number of higher frequency guard sub-carriers (7.4.1)	$N_{g,right}$	6	
Total FFT bandwidth (7.4.2)	B_0	625.0	kHz
Effective RF bandwidth (7.4.2)	B_{occ}	498.05	kHz
Number of OFDM symbols within one frame (7.5)	N_{OFDM}	variable	
Duration of a Data/CC frame (7.5.1.1)	$T_{DF/CC}$	6.48	ms
Duration of a BC1 and BC3 sub-frame (7.5.1.2)	$T_{BC1/3}$	1.8	ms
Duration of a BC2 sub-frame (7.5.1.2)	T_{BC2}	3.12	ms
Duration of a BC frame (7.5.1.2)	T_{BC}	6.72	ms
Duration of a synchronisation tile (7.5.2.2)	T_{SYNC}	0.6	ms
Duration of an AGC preamble (7.5.2.2)	T_{AGC}	0.12	ms
Number of OFDM symbols in a DC segment (7.5.2.2)	N_{dc}	variable	
Guard time in a RA frame (7.5.2.3)	$T_{g,RA}$	1.26	ms
Duration of a RA frame (7.5.2.3)	$T_{sub,RA}$	840	µs
Duration of a Super-Frame (7.5.3)	T_{SF}	240	ms

Parameter	Abbr.	Value	Unit
Duration of a Multi-Frame (7.5.3.1)	T_{MF}	58.32	ms
Number of CC PHY-PDUs per MF (7.5.3.1)	N_{CC}	variable	
Duration of a RA frame (7.5.3.2)	T_{RA}	6.72	ms
Duration of a DC segment (7.5.3.2)	T_{DC}	variable	ms
Duration of an RL Data segment (7.5.3.2)	T_{DF}	variable	ms
Number of input byte of a RS code word (7.6.2.1)	K	variable	
Number of output byte of a RS code word (7.6.2.1)	N	variable	
Native coding rate of convolutional coder (7.6.2.2)	r_{CC}	variable	
Size of a helix interleaver block (7.6.2.4)	N_{I2}	variable	
Number of FL Data PHY-PDUs per MF (7.6.2.5)	N_D	variable	
Number of RL Data PHY-SDUs, assigned to an AS (7.6.2.6)	N_{SDU}	variable	
Number of coding blocks of an AS in a MF (7.6.2.6)	N_{cod}	variable	
Maximum coding block size for RL Data PHY-SDUs (7.6.2.6)	N_{lim}	variable	
Multiplication factor for the modulation (7.6.3)	c	variable	
Modulation rate (7.6.3)	r_{mod}	variable	
Roll-off factor for RC window (7.8.1)	α	0.107	

8 Medium Access Control (MAC) Sub-layer Specification

8.1 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, 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[25]. This slot structure is used to provide logical channels to the MAC service users – LLC entities. This is illustrated in Figure 8-1 and Figure 8-3.

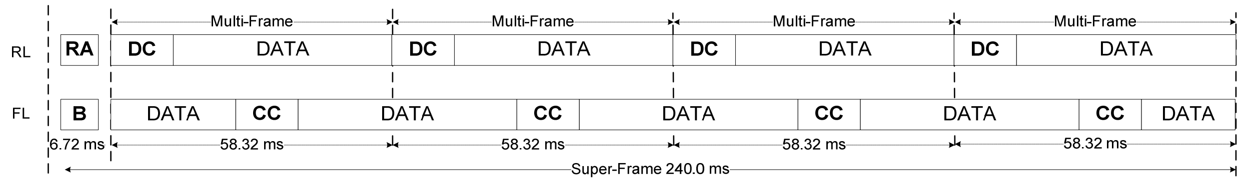

Figure 8-1: LDACS1 MAC Slot Structure

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 8.3 and Section 8.4).

8.1.1 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.

8.1.1.1 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.

[25] 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.

8.1.1.2 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.

8.1.1.2.1 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.

8.1.1.2.2 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.

8.1.1.2.3 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.

8.1.1.2.4 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.

8.1.1.2.5 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.

8.1.2 State Transition Diagrams

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

8.1.2.1 State Transition Diagram for the Aircraft

Figure 8-2 shows the state transition diagram to be used in the AS MAC sub-layer.

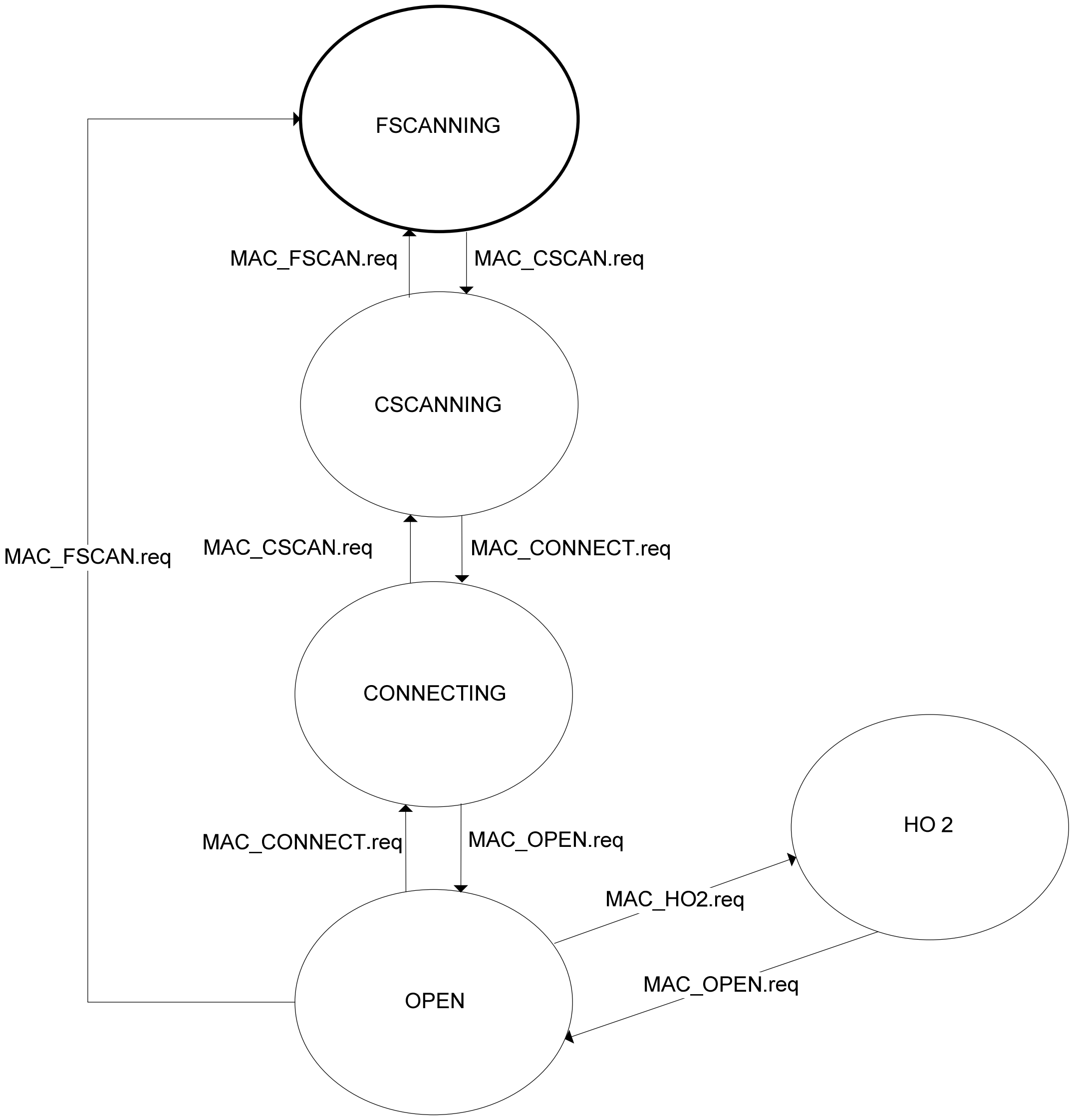

Figure 8-2: MAC State Transition Diagram of the Aircraft

8.1.2.1.1 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 Subscriber Access Code (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 LDACS1 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.ind, the AS MAC shall forward this information to the AS LME via the MAC_FSCAN.ind.

8.1.2.1.2 CSCANNING State

In the CSCANNING state no GS has yet allocated a Subscriber Access Code (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 LDACS1 signal. The AS MAC shall report the result of the AS controlled scanning procedure via the MAC_CSCAN.ind. 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.

8.1.2.1.3 CONNECTING State

In the CONNECTING state the GS has not yet allocated a Subscriber Access Code (SAC) and Control Offset (CO) to the AS, therefore no user communication shall take place. The MAC shall process all MAC-PDUs (Section 8.6) regardless of the SAC.

In the CONNECTING state the AS MAC may transmit control messages via the random access channel (RACH) and receive control message via the common control channel (CCCH).

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 forward all received control messages of the CCCH to the AS LME.

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 SAC immediately. The AS's LME shall then transit the DLS and VI into open state, too.

8.1.2.1.4 Open State

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

8.1.2.1.5 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 a Subscriber Access Code (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.ind), 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.

8.1.2.2 States in the Ground-Station

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

8.1.3 Interface to Service Users

The MAC sub-layer shall offer services to its service users via an interface described in Section 6.2.2.

8.2 Operation of the MAC Time Framing Service

8.2.1 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.

8.2.2 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 8-3.

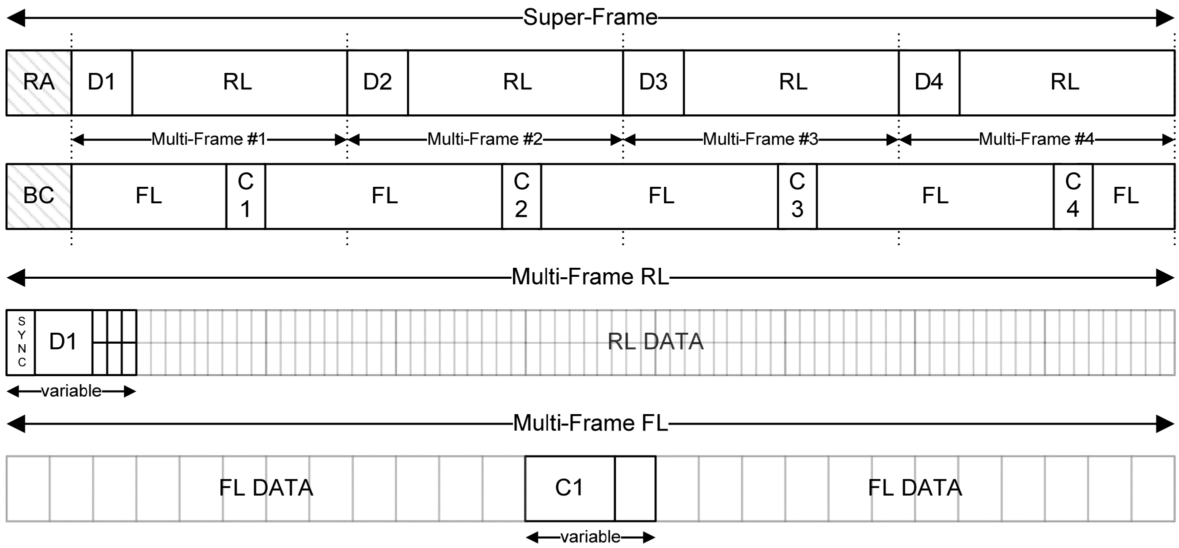

Figure 8-3: TDM Frame Structure Based on PHY-SDUs

8.2.2.1 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.

8.2.2.2 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 Data 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 8.6.5).

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

8.3 Operation of the Medium Access Service on the FL

8.3.1 Functions

8.3.1.1 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).

8.3.1.2 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.

8.3.1.3 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.

8.3.2 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 8.3.2.1). The FL MAP shall be used to identify PHY-SDUs destined for a specific AS.

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 analyze the CMS FL MAP (refer to Section 8.3.2.2). The CMS FL MAP shall be used to demodulate and decode incoming data accordingly.

8.3.2.1 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 next MF (Section 8.3.2.2).

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.

8.3.2.2 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.

8.3.3 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).

8.3.4 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.

8.4 Operation of the Medium Access Service on the RL

8.4.1 Functions

8.4.1.1 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 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 LDACS1 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 8.4.2.2). Dependent on the amount of simultaneously registered users the access time may increase or decrease. Each of the DC RL 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.

8.4.1.2 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.

8.4.1.3 RL Full/Half Bandwidth Support

An AS LDACS1 radio may be built to utilize only the half RL bandwidth when sending user data on RL.

In this case the AS shall indicate this to the GS in the CELL_RQST message with the Full Bandwidth support (FBW) flag set to %0 (i.e. False). The GS allocates two regions in the DCH. ASs serviced within the first region must support full bandwidth access to the RL. In the second region ASs may use only halve of all available RL sub-carriers. The border between these regions is indicated by the Full Bandwidth Length (FBL) field in the SLOT_DESC message.

Full/half bandwidth access is implicitly enforced by the RL PHY-SDU numbering in the two regions. This is illustrated for an exemplary case in Figure 8-4. Note that AS are always allocated contiguous numbers of RL Data PHY-SDUs regardless of the full/half bandwidth access.

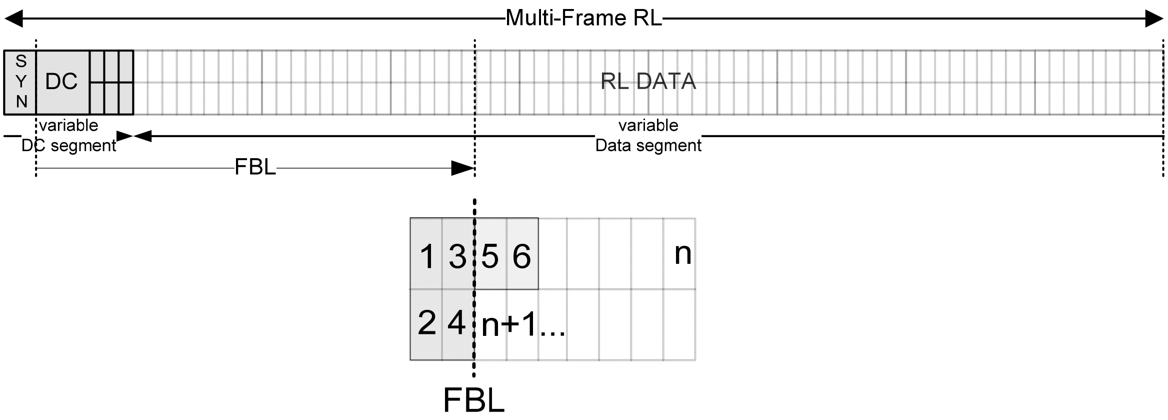

Figure 8-4: Full/half RL Bandwidth Access Enforced by RL PHY-SDU Numbering.

8.4.1.4 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.

8.4.2 DCCH Medium Access Procedures

8.4.2.1 A/C MAC Control Offset

Access to the DCCH is contention free for individual ASs. Each AS has a recurring sub-slot (carrying the 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.

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 PHY-SDU of the DC slot shall be used by the AS with the CO equal to COS. The second 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 PHY-SDU identified by its CO in the DC to transmit its DCCH.

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

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

8.4.2.2 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 adapted to the number of registered ASs.

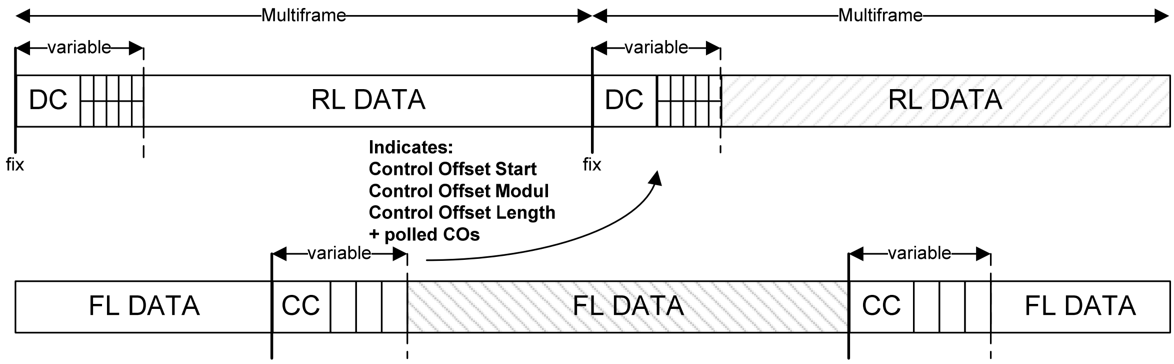

Figure 8-5: DCCH Control Offset

Note that the length of the CC slot may only change within the limits of the physical layer implementation (in steps of three FL CC PHY-SDUs, see Section 7.5.3.1).

8.4.2.3 Allocating the DCCH

The DC tiles 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 segments in all MFs will always be used as the length of the medium access cycle is adjusted to the AS population.

8.4.3 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 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 10.2.3). 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- PDUs. 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).

8.4.3.1 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 8-6).

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.

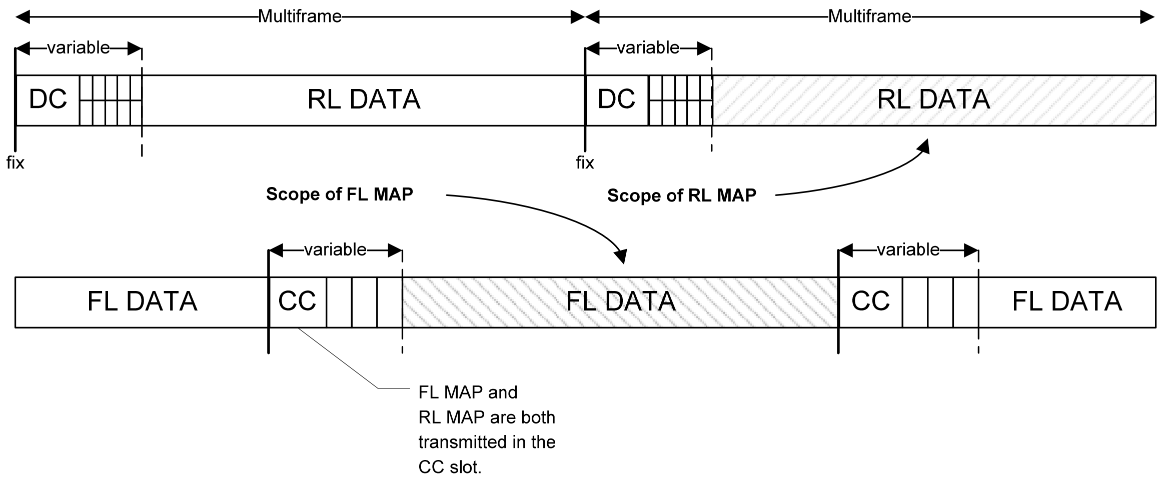

Figure 8-6: Scope of RL MAP and FL MAP

8.4.3.2 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.

8.4.4 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 backoff 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 8-7).

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

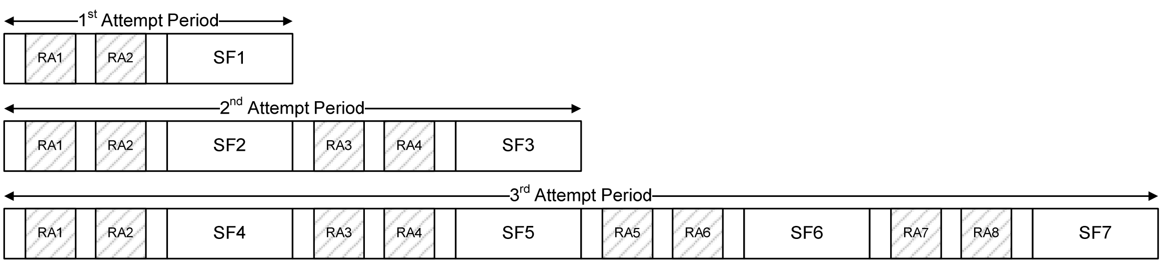

Figure 8-7: RACH Exponential Back-Off

8.5 MAC Parameters

8.5.1 Random Access Maximum Backoff (MAC_P_RAC)

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

8.6 MAC PDU Format Definition

8.6.1 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 8-8.The MAC does not append a Frame Check Sequence (FCS) as each DLS-PDU conveyed within the resource allocation already includes its own CRC-16.

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.

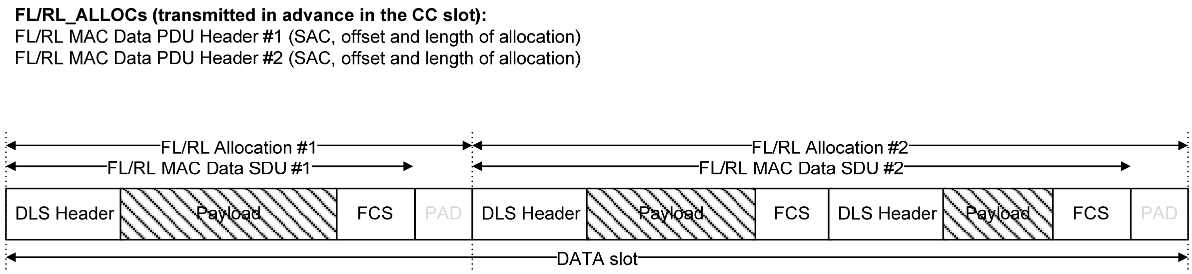

Figure 8-8: DCH

8.6.2 MAC Random Access PDU

MAC Random Access PDU shall be conveyed via the RACH. A MAC Random Access PDU shall be conveyed using the most robust coding and modulation (CMS type 1, see Section 9.6.7)). 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.

MAC Random Access PDUs do not internally use any FCS algorithm. The CELL_RQST control message within MAC Random Access SDUs already includes a CRC-4 field.

8.6.3 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 LDACS1. MAC Broadcast Control PDUs shall be transmitted in the structure illustrated in Figure 8-9. MAC appends 8 Bit CRC to Broadcast control messages.. Note that an SAC address in the header is not necessary as all BCCH messages are broadcast messages.

All MAC broadcast control PDUs shall be transmitted byte-aligned. In case of a transmission error the MAC shall find the next intact MAC broadcast control PDU by CRC hunting using the B_TYP, LEN and CRC tuple. If applicable, unused bits of the BC sub-slot shall be padded with zeros. This is illustrated in Figure 8-9.

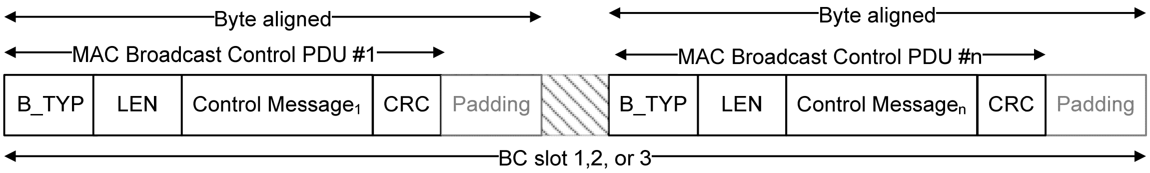

Figure 8-9: BCCH

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 PDU 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

Table 8-1: 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
GS Service Capability Broadcast	GSCM	%0110
Reserved	-	%0111 - %1111

8.6.4 MAC Dedicated Control PDU

The MAC Dedicated Control PDU (MDCP) shall be transmitted in an 85 Bit DC PHY-SDU. It may convey several signalling messages. The MDCP trailer shall consist of a CRC-6 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).

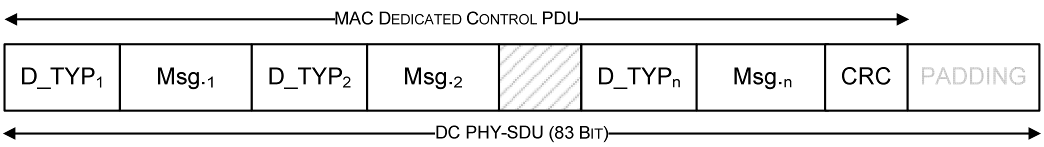

Figure 8-10: DCCH

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 DC PHY-SDU shall be padded with zeros. The AS's MAC shall build and transmit an MDCP according to the received internal signalling.

Table 8-2: 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
Single Resource Request	SRSC_RQST	5	DLS	%0111
Multiple Resource Requests	MRSC_RQST	5	DLS	%1000
Permanent Resource Request	PRSC_RQST	5	LME	%1001
Keep Alive	KEEP_ALIVE	6	MAC	%1010
Reserved				%1011 - %1111

8.6.4.1 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 8-3: Keep Alive

Field	Size	Description
D_TYP	4 Bit	Keep Alive

8.6.5 MAC Common Control PDU

MAC Common Control PDUs shall convey one or several signalling messages. MAC Common Control PDUs shall always be conveyed using the most robust coding and modulation (i.e. CMS type 1, see Section 9.6.7).

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). Each message shall be encapsulated by the MAC with the SAC (12 Bit) and a trailing 8 bit CRC (and padding if necessary).

All MAC Common Control PDUs shall be transmitted byte-aligned. In case of a transmission error the MAC shall find the next intact MAC Common Control PDU by CRC hunting using the C_TYP, CRC tuple. The SLOT_DESCRIPTOR and (in the case of user-specific ACM) CMS_FL messages are always sent first without the preceding SAC. This concept is illustrated in Figure 8-11 and Figure 8-12. Note that additional padding may be required at the end of the CC slot.

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

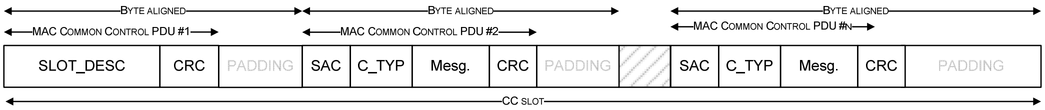

Figure 8-11: CCCH in Cell-specific ACM mode.

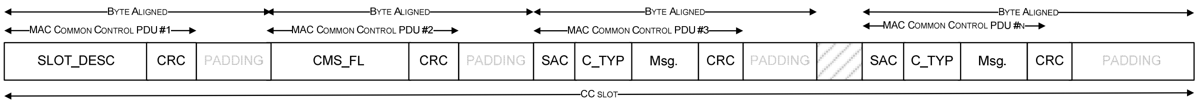

Figure 8-12: CCCH in User-specific ACM mode.

Note that the AS MAC can determine the message receiver (LME or DLS) from the C_TYP field.

Table 8-4: Common Control Messages Overview

Common Control Message	Acronym	Initiated by	Order	C_TYP Bit Value
Reserved	PADDING	MAC	-	%0000
Slot Descriptor	SLOT_DESC	LME	1	-
DCCH Descriptor	DCCH_DESC	LME	1	%0001
CMS FL Map	CMS_FL	LME	2	-
DCCH Poll	DCCH_POLL	LME	2	%0010
Cell Entry Response	CELL_RESP	LME	3	%0011
Change CO	CHANGE_CO	LME	3	%0100
Cell Entry Denied	CELL_DENIED	LME	3	%0101
Link Management Data	LM_DATA	LME	4	%0110
Cumulative Acknowledgement	ACK_CUM	DLS	5	%0111

Common Control Message	Acronym	Initiated by	Order	C_TYP Bit Value
Selective Acknowledgement	ACK_SEL	DLS	5	%1000
Fragment Acknowledgement	ACK_FRAG	DLS	6	%1001
FL Allocation	FL_ALLOC	LME	7	%1010
RL Allocation	RL_ALLOC	LME	8	%1011
Periodic RL Allocation	P_RL_ALLOC	LME	8	%1100
SYNC Signalling	SYNC_POLL	LME	9	%1101
Handover Command	HO_COM	LME	10	%1110
Keep Alive	KEEP_ALIVE	LME	11	%1111

8.6.6 MAC Frame Check Sequence

The MAC shall use as Frame Check Sequence (FCS) algorithm a Cyclic Redundancy Check (CRC). The following standardized CRCs shall be used for error detecting:

- CRC-6: x^6+x+1
- CRC-8: $x^8 + x^7 + x^6 + x^4 + x^2 + 1$

8.7 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.

8.7.1 B_TYP – Dedicated Control Type

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

8.7.2 C_TYP – Dedicated Control Type

This field indicates the common control type. C_TYP shall have a size of 4 bits.

8.7.3 D_TYP – Dedicated Control Type

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

8.7.4 LEN – Length in Bits

This field indicates the length in bits and shall have a size of 10 bits. The LEN field shall state the length of the following control message including its header. This field shall be used for broadcast control messages only.

8.7.5 SAC – Subscriber Access Code

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

Table 8-5: Subscriber Access Code Values

Description	Value
Reserved	%000000000000
Individual SAC	%000000000001 to %111111111110
Broadcast SAC	%111111111111

9 Link Management Entity (LME) Specification

9.1 General Description

The link management entity (LME) supports the configuration, resource management and mobility management of LDACS1.

9.1.1 Services

9.1.1.1 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.

9.1.1.2 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.

9.1.2 State Transition Diagram

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

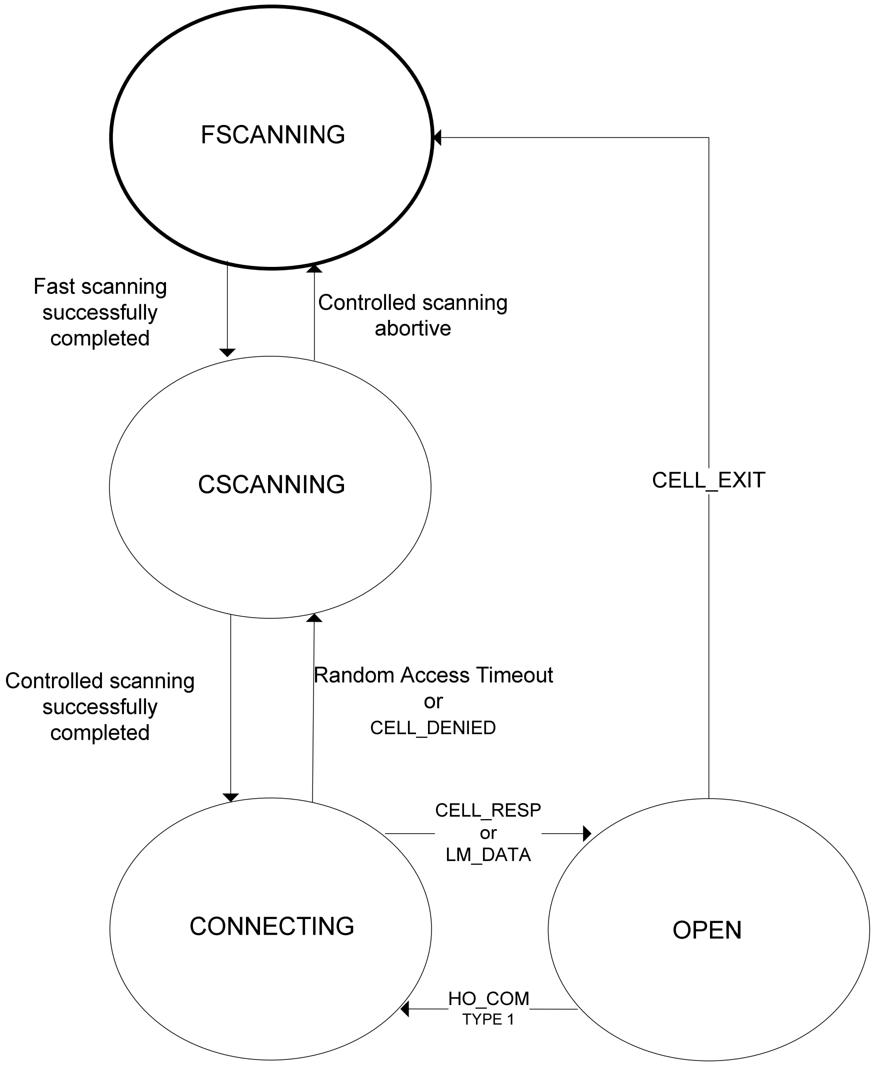

Figure 9-1: Aircraft LME State Transition Diagram

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

9.1.2.1 FSCANNING State

The airborne LME enterers 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 LDACS1 channels by the MAC, without further LME assistance. If the FSCANNING procedure delivered useful results (at least one active LDACS1 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.

9.1.2.2 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.ind 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.

9.1.2.3 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.

9.1.2.4 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 signaled (via PHY_CONF.conf) that the FL signal quality has became unacceptably poor (the AS is about to leave the coverage of the LDACS1 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 of the same network shall 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.

9.1.3 LME Interface to Service Users

The LME shall provide an interface to its service users as described in Section 6.2.4.

9.2 Operation of the Mobility Management Service

9.2.1 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.

9.2.2 Functions of the Mobility Management Service

9.2.2.1 Scanning

The scanning function is necessary to determine signal qualities of adjacent cells. The GS, which is aware of the surrounding LDACS1 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.

9.2.2.2 Cell Entry

The cell entry function is necessary to initiate communication services. During cell entry an AS acquires a valid Subscriber Access Code (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 LDACS1 radio on the RL.

9.2.2.3 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 LDACS1 coverage zone or is simply turning off the LDACS1 radio is not needed. The GS is recognizing that an AS has left the cell using its own mechanisms.

9.2.2.4 Addressing

The GS's LME shall coordinate the allocation of subscriber access codes (SACs) toward individual AS. The allocation of a subscriber access code shall be unique within the scope of its validity (e.g. a cluster of cells). Additionally, the LME shall assign a unique control offset valid for the cell an AS is registering to.

9.2.2.5 Handover

The handover function provides seamless inter-cell aircraft mobility. The LDACS1 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).

9.2.3 Scanning Procedures

9.2.3.1 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 LDACS1 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 LDACS1 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 LDACS1 GSs transmit continuously on FL.

9.2.3.2 AS Controlled Scanning Procedure

After the Fast Scanning has stopped, the AS LME selects – among all scanned channels – a pre-defined number of active LDACS1 channels with highest indicated estimated received signal power for subsequent AS Controlled Scanning.

The AS Controlled Scanning is conducted without any GS assistance.

9.2.3.3 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 neighbor GSs as received by the AS that is subject to the handover.

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 GSID of the GS to be scanned.

After a successful 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.

9.2.4 Cell Entry and Cell Exit Procedures

9.2.4.1 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 link management entity (LME) shall request the transmission of a cell entry request (CELL_RQST) message via the random access channel (RACH) at the MAC. The cell entry request message shall contain a unique address identifying the LDACS1 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 vie the MAC_RACH.ind primitive. After the GS’s LME assigned a proper subscriber access code SAC the GS’s MAC shall transmit a cell entry response (CELL_RESP) message via the common control channel (CCCH).

The AS MAC shall receive the cell entry response message (CELL_RESP) and forward it towards the LME. The LME shall configure the physical layer 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.

9.2.4.2 Cell Exit

Prior to the handover procedure the link 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.*

9.2.5 Addressing Procedure

The GS’s link management entity (LME) shall coordinate the allocation of subscriber access codes (SAC) to individual AS. Dependent on the deployment strategy and the regarding network topology this may be backed by a hierarchical structure.

The GS's link management entity is responsible for the allocation of a unique subscriber access code (SAC) and the allocation of a unique control offset.

9.2.6 Handover Procedures

LDACS1 shall support a GS based handover strategy. That is, all handovers shall be triggered by the GS. 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.

9.2.6.1 Type 1 Handover

The Type 1 handover procedure is triggered through a handover command control message (HO_COM) where the T bit is cleared. The handover command control message (HO_COM) shall contain the GS identifier (GSID) an AIRCRAFT shall hand over to. Based on the GSID an AIRCRAFT 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 not 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.

9.2.6.2 Type 2 Handover

In order to support a Type 2 handover, the link management entities of adjacent GSs shall communicate with each other via the ground network. 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 T bit is set. The handover command control message shall contain the GS identifier (GSID) and the new control offset for the next cell. The subscriber access code (SAC) remains the same. Based on the GSID an AS shall be able to determine the forward link and reverse link frequencies, which shall be permanently broadcast via the BCCH. The updated subscriber 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. This new control offset shall be obtained by the AS through the handover command Type 2 (HO_COM).

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.

9.3 Operation of the Resource Management Service

9.3.1 Functions of the Resource Management Service

9.3.1.1 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.

9.3.1.2 Adaptive Coding and Modulation

Adaptive Coding and Modulation (ACM) is provided in two modes. The default mode is cell-specific ACM provision. The second (optional) mode is user-specific ACM on the FL and RL. The ACM mode of a cell is announced periodically via the BCCH.

ACM is only utilized for user plane transmissions. Control plane transmissions use always the most robust coding and modulation provided by the PHY layer.

9.3.1.3 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.

9.3.2 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 7.7.3) from an AS it shall update the AS time advance, frequency, and power value. This update shall be transmitted via the CCCH.

9.3.2.1 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).

9.3.2.2 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).

9.3.2.3 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).

9.3.3 Adaptive Coding and Modulation Procedures

The LDACS1 system shall support two modes of operation:

- Cell-specific coding and modulation
- Uuser-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 exist for MAC Data PDUs of all users within a given cell. Control channels are exempted from the announced coding and modulation scheme. Control channels are always transmitted with the most robust coding and modulation scheme.

The user-specific mode shall support individual assigmnement of coding and modulation schemes (CMS) for FL- and RL MAC Data PDUs individually for each user. 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). Control channels are always transmitted using the most robust coding and modulation scheme.

9.3.3.1 Cell-specific Adaptive 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.

9.3.3.2 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 (Section 8.3.2). 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 announced 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 8.4.3).

9.3.4 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.

9.3.4.1 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.

9.4 LME Parameters

9.4.1 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.

9.4.2 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.

9.4.3 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.

9.4.4 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.

9.4.5 MAX CSCAN Timer (LME_T_CSCAN)

The CSCAN timer shall be used to determine if the CSCAN procedure was completed successfully. If no valid LDACS1 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.

9.4.6 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.

9.5 LME PDU Format Definition

9.5.1 Random Access Control Messages

9.5.1.1 Cell Entry Request (CELL_RQST)

The cell entry request control message shall contain a Unique Address (UA), the GS identifier (GSID), the requested protocol version (VER), and a flag (FBW) indicating the AS's capability to use the full RL bandwidth.

Table 9-1: Cell Entry Request

Field	Size	Description
R_TYP	2 Bit	Cell Entry Request
UA	28 Bit	Unique Address
GSID	12 Bit	Ground-station ID
VER	3 Bit	Protocol Version
FBW	1 Bit	Support for full bandwidth on RL
CRC	4 Bit	Cyclic Redundancy Checksum

9.5.2 Broadcast Control Messages

9.5.2.1 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 (GSID), the Forward Link Frequency (FLF) and the Reverse Link Frequency (RLF).

Table 9-2: Adjacent Cell Broadcast

Field	Size	Description
B_TYP	4 Bit	Adjacent Cell Broadcast
LEN	10 Bit	Length in Bit
$GSID_1$	12 Bit	GS Identifier
FLF_1	12 Bit	Forward Link Frequency
RLF_1	12 Bit	Reverse Link Frequency
…		
$GSID_n$	12 Bit	GS Identifier
FLF_n	12 Bit	Forward Link Frequency
RLF_n	12 Bit	Reverse Link Frequency

NOTE: The value "n" (number of GSs that fit into ACB field) may be at most n= 18.

9.5.2.2 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 GSID, the used frequencies (FLF and RLF), the ACM mode (MOD), Coding and Modulation Scheme (CMS) and the Equivalent Isotropic radiated Power (EIRP).

Table 9-3: System Identification Broadcast.

Field	Size	Description
B_TYP	4 Bit	System Identification Broadcast
LEN	10 Bit	Length in Bit
GSID	12 Bit	GS Identifier
VER	3 Bit	Protocol Version
FLF	12 Bit	Forward Link Frequency
RLF	12 Bit	Reverse Link Frequency
MOD	1 Bit	User-specific / Cell-specific ACM
CMS	3 Bit	Coding and Modulation Scheme
EIRP	7 Bit	GS Equivalent Isotropic radiated Power

GSS	2 Bit	GS Status Indicator

Note: If the user-specific flag is set, the CMS field shall be ignored and filled with binary zero.

9.5.2.3 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 Subscriber Access Code (SAC) and the GS Identifier (GSID). The SAC shall identify the ASs which are allowed to use the upcoming BC slot for scanning an adjacent cell.

Table 9-4: Scanning Table Broadcast.

Field	Size	Description
B_TYP	4 Bit	Scanning Table Broadcast
LEN	10 Bit	Length in Bit
SAC_1	12 Bit	Subscriber Access Code
$GSID_1$	12 Bit	GS Identifier
…		
SAC_n	12 Bit	Subscriber Access Code
$GSID_n$	12 Bit	GS Identifier

9.5.2.4 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 9-5: Voice Service Broadcast

Field	Size	Description
B_TYP	4 Bit	Voice Service Broadcast
LEN	10 Bit	Length in Bit
VC	6 Bit	Number of Voice circuits
LVC_1	6 Bit	Logical Voice Channel Number
VCI_1	12 Bit	Voice Channel Identifier
$RPSO_1$	8 Bit	RL PHY-SDU Offset
$NRPS_1$	8 Bit	Number of RL PHY-SDUs
CMS_1	3 Bit	Coding and Modulation Scheme (RL)
BO_1	14 Bit	Byte Offset (FL)
BLV_1	6 Bit	Byte Length (FL)
…		
LVC_n	6 Bit	Logical Voice Channel Number
VCI_n	12 Bit	Voice Channel Identifier
$RPSO_n$	8 Bit	RL PHY-SDU Offset
NT_n	8 Bit	Number of RL PHY-SDUs
CMS_n	3 Bit	Coding and Modulation Scheme (RL)
BO_n	14 Bit	Byte Offset (FL)
BLV_n	6 Bit	Byte Length (FL)

9.5.2.5 GS Position Broadcast

The GS position message is optional and shall be sent to signal the Latitude and Longitude of adjacent GS.

Table 9-6: GS Position Broadcast

Field	Size	Description
B_TYP	4 Bit	GS Position Message
LEN	10 Bit	Length in Bit

$GSID_1$	12 Bit	GS Identifier
GS_1_LAT	32 Bit	GS Latitude
GS_1_LONG	32 Bit	GS Longitude
….		
$GSID_n$	12 Bit	GS Identifier
GS_n_LAT	32 Bit	GS Latitude
GS_n_LONG	32 Bit	GS Longitude

9.5.2.6 GS Service Capability Broadcast

The GS Service capability control message is optional and shall indicate the optional service capability of the GS.

Table 9-7: GS Service Capability Broadcast

Field	Size	Description
B_TYP	4 Bit	GS Service Capability Message
LEN	10 Bit	Length in Bit
$GSID_1$	12 Bit	GS Identifier
OPTS1	1 Bit	OPT Service #1 Available
OPTS2	1 Bit	OPT Service #2 Available
…		
$GSID_n$	12 Bit	GS Identifier
OPTS1	1 Bit	OPT Service #1 Available
OPTS2	1 Bit	OPT Service #2 Available

9.5.3 Dedicated Control Messages

9.5.3.1 Power Report (POW_REP)

The power report control message shall be used to report the received power of a neighbouring cell towards the GS. The POW_REP control message shall contain the following values.

Table 9-8: Power Report

Field	Size	Description

D_TYP	4 Bit	Power Report
GSID	12 Bit	GS Channel ID
RXP	6 Bit	Received Power in dBm
GSYN	1 Bit	GS Sync Status

9.5.3.2 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 GSID 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 9-9: Cell Exit

Field	Size	Description
D_TYP	4 Bit	Cell Exit
GSID	12 Bit	GS ID

9.5.3.3 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 9-10: Permanent Resource Request

Field	Size	Description
D_TYP	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 = SAC+ID and has to be reconstructed by the receiver)

9.5.3.4 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 9-11: Resource Cancellation

Field	Size	Description
D_TYP	4 Bit	Resource Cancellation

Field	Size	Description
SC	3 Bit	Service Class
ID	4 Bit	Connection identifier postfix (note that the full CID = SAC+ID and has to be reconstructed by the receiver)

9.5.4 Common Control Messages

9.5.4.1 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 the length of the current CC slot (CCL) and the length of the DC slot in the next MF (DCL). Furthermore the slot descriptor shall contain the FBL field wich defines the border between full-bandwidth and half-bandwidth RL regions.

Table 9-12: Slot Descriptor

Field	Size	Description
CCL	4 Bit	CC Segment Length
DCL	6 Bit	DC Segment Length
FBL	7 Bit	Full Bandwidth Segment Length/2

Note that the DC segment length must be equal to the sum of the COL field in the DCCH descriptor message and the number of DCCH_POLL messages.

9.5.4.2 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.

The DCCH descriptor message is mandatory in each CCCH and shall be addressed to the broadcast SAC address.

Table 9-13: DCCH Descriptor

Field	Size	Description
COL	6 Bit	Control Offset Length
COS	9 Bit	Control Offset Start
COM	9 Bit	Control Offset Modul

9.5.4.3 CMS FL MAP (CMS_FL)

The CMS_FL message is addressed to the broadcast SAC. If present, it is transmitted immediately after the slot descriptor.

If user-specific ACM is provided the CMS FL MAP control message shall 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 transmissions properly.

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.

Table 9-14: CMS FL MAP Control Message

Field	Size	Description
C_TYP	4 Bit	CMS FL Map
ENT	2 Bit	Number of Entries
CMS_1	3 Bit	Coding and Modulation Scheme
START_1	5 Bit	Index of first PHY-SDU with this CMS
CMS_2	3 Bit	Coding and Modulation Scheme
START_2	5 Bit	Index of first PHY-SDU with this CMS
CMS_3	3 Bit	Coding and Modulation Scheme
START_3	5 Bit	Index of first PHY-SDU with this CMS
CMS_4	3 Bit	Coding and Modulation Scheme
START_4	5 Bit	Index of first PHY-SDU with this CMS

9.5.4.4 DCCH Poll (DCCH_POLL)

The DCCH poll message shall be used to poll for the DCCH of a specific AS. This control message shall only be used as a supplement to the DCCH descriptor message (e.g. to poll for an acknowledgement in advance of the recurring DCCH). 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 SAC of the polled AS.

Table 9-15: DCCH Poll

Field	Size	Description
COI	6 Bit	Control Offset Index

9.5.4.5 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 theCC slot of the first MF after the random access slot.

The length of the MAC-PDU conveying the cell entry response control message shall be 96 bits. The Unique Address (UA) shall contain the value received within the cell entry request control message. The Subscriber Access Code in the MAC-PDU header (SAC) shall be unique within its scope and shall be assigned by the GS's LME. Note that the MAC has to forward all messages (independently of the SAC) to the LME in the CONNECTING state. The LME will then identify the assigned 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. The Validity Field (VAL) may contain the scope of the assigned SAC (e.g. geographical area within which the SAC is unique).

Table 9-16: Cell Entry Response

Field	Size	Description
C_TYP	4 Bit	Cell Entry Response
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
VAL	2 Bit	Validity of Address
VER	3 Bit	Protocol Version

9.5.4.6 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 9-17: Link Management Data

Field	Size	Description
C_TYP	4 Bit	Link Management Data
PAV	7 Bit	Power Adaptation Value
FAV	10 Bit	Frequency Adaptation Value
TAV	10 Bit	Time Advance Value

9.5.4.7 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.*

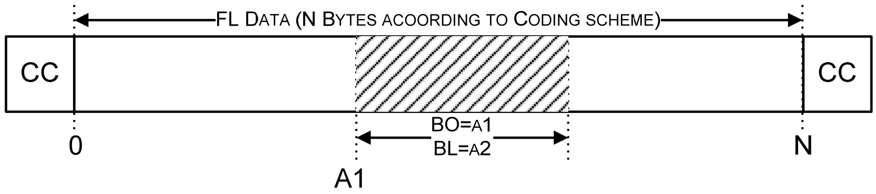

Figure 9-2: FL_ALLOC Byte Offset

Table 9-18: FL Allocation

Field	Size	Description
C_TYP	4 Bit	FL Allocation
BO	14 Bit	Byte Offset
BL	14 Bit	Length in Byte

9.5.4.8 RL Allocation (RL_ALLOC)

The RL allocation control message shall be addressed to a specific 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 shall be ignored by all receivers and set to binary zero.

Figure 9-3 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 (assuming full bandwidth transmission).

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.*

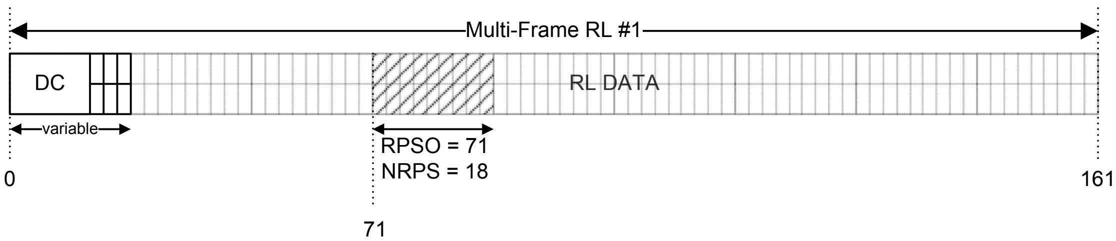

Figure 9-3: RL_ALLOC RL PHY-SDU offset

Table 9-19: RL Allocation

Field	Size	Description
C_TYP	4 Bit	RL Allocation
RPSO	8 Bit	RL PHY-SDU Offset
NRPS	8 Bit	Number RL PHY-SDUs
CMS	3 Bit	Coding and Modulation Scheme

9.5.4.9 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.

Table 9-20: Synchronisation Polling

Field	Size	Description
C_TYP	4 Bit	Synchronisation Polling

9.5.4.10 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 2 handover is initiated the control message shall contain the Control Offset (CO) valid in the next cell. The GS Identifier (GSID) shall indicate the next cell the concerned AS shall switch to.

NOTE: If the old GS did not define the next GS, the GSID field shall be set to binary zero.

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 SAC valid in the old cell remains preserved in the new cell – needs not to be signalled.

Table 9-21: Handover Command

Field	Size	Description
C_TYP	4 Bit	Handover Command
GSID	12 Bit	GS Identifier
HOT	1 Bit	Handover Type 1 or Type 2
NEXT CO	9 Bit	New Control Offset (new cell)

9.5.4.11 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 that the MAC has to forward all messages (independently of the 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 length of the MAC-PDU conveying the cell entry denied control message shall be 96 bits. 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 9-22: Cell Entry Denied

Field	Size	Description
C_TYP	4 Bit	Cell Entry Denied
UA	28 Bit	Unique Address
REA	3 Bit	Reason

9.5.4.12 Periodic RL Allocation (P_RL_ALLOC)

The periodic RL allocation control message shall be addressed to a specific 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 9-23: Periodic RL Allocation

Field	Size	Description
C_TYP	4 Bit	RL Allocation
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

NOTE: The combination of SAC and ID defines the connection identifier (CID = SAC+ID), which identifies the permanent RL allocation in the RL_MAP. The CID has to be reconstructed by the receiver.

9.5.4.13 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 LDACS1 cell. The length of the change CO control message shall be 48 bit.

Table 9-24: Change CO

Field	Size	Description
C_TYP	4 Bit	CO Change
NEXT_CO	9 Bit	New Control Offset

9.5.4.14 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 9-25: Keep-Alive

Field	Size	Description
C_TYP	4 Bit	Keep Alive

9.6 LME Information Element Definition

The following information element definition describes all fields used within the individual control messages.

9.6.1 B_TYP – Broadcast Control Type

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

9.6.2 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.

9.6.3 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.

9.6.4 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.

9.6.5 C_TYP – Common Control Type

This field indicates the common control type. C_TYP shall have a size of 4 bits.

9.6.6 CID – Connection Identifier (SAC+ Identifier)

This field indicates the connection identifier, which is a combination of the SAC and the ID. CID shall have a size of 16 bits.

9.6.7 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 9-26: 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

9.6.8 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.

9.6.9 COI – Control Offset Index

The COI field (6 bits) identifies the index of the RL PHY-SDU assigned to the polled DCCH.

9.6.10 COL – Control Offset Length

The COI field (6 bits) specifies the number of COs served in the periodic DCCH assignment in the DCCH_DESC message.

9.6.11 COM – Control Offset Modul

This field (9 bits) indicates the number of COs in use.

9.6.12 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.

9.6.13 D_TYP – Dedicated Control Type

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

9.6.14 DCL – DC Segment Length

This field indicates the DC Segment Length. The DCL shall have a size of 6 Bit.

9.6.15 EIRP – Equivalent Isotropically Radiated Power

This field indicates the equivalent isotropically radiadted power. The EIRP shall have a size of 7 Bit.

9.6.16 ENT – Number of Entries

This field indicates the number of entries and shall have a size of 3 bits. It shall indicate the amount of consecutive coherent information entries within a single control message.

9.6.17 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 9-27: 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

9.6.18 FBL – Full Bandwidth Length

This field indicates the length of the RL full bandwidth segment/2 in RL PHY-SDUs. That is, the FBL value has to be multiplied by two to get the real full bandwidth segment length in RL PHY-SDUs.

9.6.19 FBW – Support for Full RL Bandwidth

This field indicates whether the AS radio is able to utilize the full RL bandwidth. If full bandwidth access to the RL is supported FBW shall be set to %1, otherwise to %0.

9.6.20 FLF – Forward Link Frequency

This field indicates the forward link frequency and shall have a size of 12 bits. The frequency shall be determined using the following formula:

Frequency = base frequency + FLF * step size

Where the base frequency is 960 MHz and the step size is 100 kHz.

9.6.21 GS_LAT – GS Latitude

This field indicates the GS latitude. The GS_LAT shall have a size of 32 Bit.

9.6.22 GS_LONG – GS Longitude

This field indicates the GS Longitude. The GS_LONG shall have a size of 32 Bit.

9.6.23 GSID – GS Identifier

This field indicates the GS identifier. GSID shall have a size of 12 bits.

NOTE: If the GSID is not defined, the field shall be set to binary zero.

9.6.24 GSS – GS Status Indicator

This field indicates the GS Status Indicator. The GSS shall have a size of 2 Bit.

9.6.25 GSYN – GS Sync Status

This field indicates the GS sync status. The GSYN shall have a size of 1 Bit.

9.6.26 HOT – Handover Type Flag

This field indicates the handover type flag and determines which kind of handover shall be used.

Table 9-28: Handover Type Flag Values

Description	Value
Type 1	%0
Type 2	%1

9.6.27 ID – Connection Identifier (SAC+ Identifier)

This field indicates the ID postfix of the connection identifier, which is a combination of the SAC and the an ID. CID shall have a size of 16 bits.

9.6.28 LEN – Length in Bits

This field indicates the length in bits and shall have a size of 10 bits. The LEN field shall state the length of the following control message including its header. This field shall be used for broadcast control messages only.

9.6.29 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 LDACS1 cell and shall not relate to any other context.

9.6.30 MOD – ACM Mode

This field indicates the adaptive coding and modulation mode used for this LDACS1 cell. The MOD field is a flag and shall take on the following values.

Table 9-29: ACM Mode Values

Description	Value

User-specific ACM	%0
Cell-specific ACM	%1

9.6.31 NEXT_CO – Next Control Offset

This field indicates the Next Control Offset. The NEXT_CO shall have a size of 9 Bit.

9.6.32 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 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.

9.6.33 PAD – Padding

This field indicates padding. PAD shall be used if a control message has some unused space left.

9.6.34 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 9-30: 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
Increase 63 dB	%0111111

9.6.35 REQ – Octets Requested

This field indicates the number of octets requested. This field shall have a size of 15 bits.

9.6.36 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.

9.6.37 R_TYP – Random Access Type

This field indicates the random access type. R_TYP shall have a size of 4 bits and shall take on the following values.

Table 9-31: Random Access Type Values

MDCP message	Message ID	Priority	Bit Value
Reserved		-	%0000
Cell Entry Request	CELL_RQST	1	%0001
Reserved		-	%0010 – %1111

9.6.38 REA - Reason for Cell Entry Denied Control Message

Table 8 48 illustrates the reason, which leads to a cell entry denied control message. The REA shall have 3 Bit.

Table 9-32: 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	

9.6.39 RLF – Reverse Link Frequency

This field indicates the reverse link frequency and shall have a size of 12 bits. The frequency shall be determined using the following formula:

Frequency = base frequency + RLF * step size

Where the base frequency is 960 MHz and the step size is 100 kHz.

9.6.40 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 9-33: 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

9.6.41 START – Begin of CMS Block

This field indicates the index of the first FL PHY-SDU of the CMS block.

9.6.42 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 9-34: 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

9.6.43 TXP – Transmit Power

This field indicates the transmit power of the LDACS1 GS. This field shall have a size of 7 bits.

9.6.44 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.

9.6.45 VAL – Validity of Address

This field shall be used to signify validity of the allocated SAC in relation to system boundaries.

Note: For this version of the specification standard values have not been assigned yet.

9.6.46 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.

9.6.47 VCI – Voice Channel Identifier

This field indicates the voice channel identifier valid within an LDACS1 communication system. VCI shall have a size of 12 bits.

9.6.48 VER – Protocol Version

This field indicates the Protocol Version. The VER shall have a size of 3 Bit.

10 Data Link Service (DLS) Specification

10.1 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 link management entity (LME) for the conveyance of signalling/management data and the Sub-Network Dependent Convergence Protocol (SNDCP) for the conveyance of SNDCP data PDUs or signalling.

10.1.1 Services

10.1.1.1 Acknowledged Data Link Service

The DLS shall support acknowledged data transmissions for the LME and SNDCP. To achieve low latency and a low overhead without losing reliability, the LDACS1 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 acknowleged transport function.

If the sending acknowleged transport function receives an acknowledgement for a complete DLS-SDU, it shall inform the SNDCP that the transmission was successful.

After DLS_P_RT2 failed retransmissions, the sending acknowleged transport function shall abandon further attempts to transmit the DLS-SDU and inform its SNDCP about the failure.

10.1.1.2 Unacknowledged Data Link Service

The DLS shall support unacknowledged data transmissions for the LME and the SNDCP. 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 unacknowleged transport function.

10.1.1.3 Broadcast Data Link Service

The GS DLS shall support broadcast data transmissions for the LME and the SNDCP. Broadcast transmissions shall be addressed to the broadcast SAC, otherwise the broadcast transport function is identical to the unacknowledged transport function.

10.1.1.4 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.

10.1.1.5 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 LDACS1 DLS are displayed in Table 10-1.

Table 10-1: LLC Classes of Service

Class of Service	SC Field	Priority	Comment
DLS_CoS_7	%111	Highest	Reserved for LME.
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 LME signalling. DLS_CoS_6 shall be reserved for the packet mode voice service.

10.1.2 Interface to Service Users

The DLS shall provide an interface to its service users as described in Section 6.2.3.

10.1.3 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.

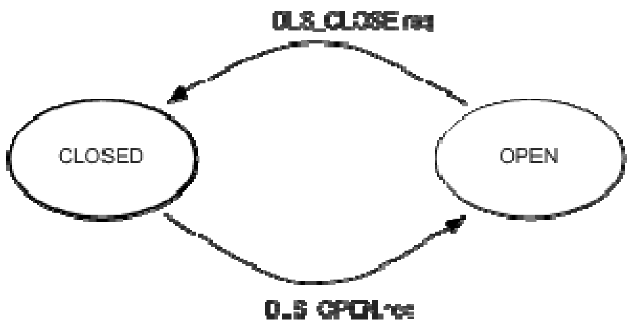

Figure 10-1: DLS State Transition Diagram

10.2 Operation of the Data Link Services

10.2.1 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.

10.2.2 Functions of the Data Link Service

10.2.2.1 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.

10.2.2.2 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.

10.2.2.3 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 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.

10.2.2.4 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.

10.2.2.5 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.

10.2.2.6 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.

10.2.3 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 0 and Section 0).

10.2.4 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.

10.2.5 Segmentation Procedures

Both the LME and the SNDCP 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. 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.

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 after each other (i.e. transmit the DLS-SDUs in sequence). The 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 segementation 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 10-2 (only the relevant header fields are displayed).header fields are displayed).

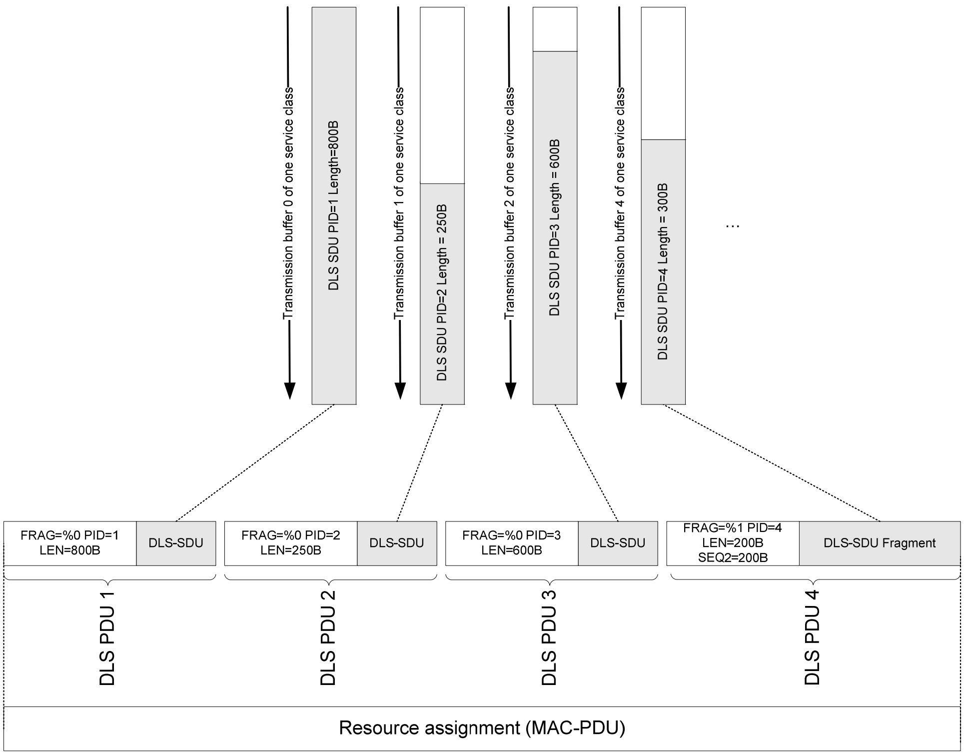

Figure 10-2: Operation of the DLS Segmentation Function.

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.

10.2.6 Acknowledged Data Transport Procedures

The DLS shall implement one acknowledged data transport function for each service class.

10.2.6.1 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).

10.2.6.2 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 0 and Section 10.4).

10.2.6.3 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 10.3 and Section 0).

10.2.6.4 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-PSU 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_RT2 retransmission time-outs in a row, the transmission shall be aborted. The failure shall be reported to the selective repeat protocol.

10.2.7 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.

10.2.8 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 compleltely and in correct order. In this case the fragmentation and reassembly function operates lilke 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.

10.2.9 Packet Mode Voice Procedures

Packet mode voice transmissions shall use the unacknowledged data transport function with the reserved DLS_CoS_6 service class.

10.3 Aircraft DLS Specifics

The operation of the functions of the AS DLS is illustrated in Figure 10-3 and Figure 10-4. Specifics of the airborne DLS procedures are specified below the corresponding figures.

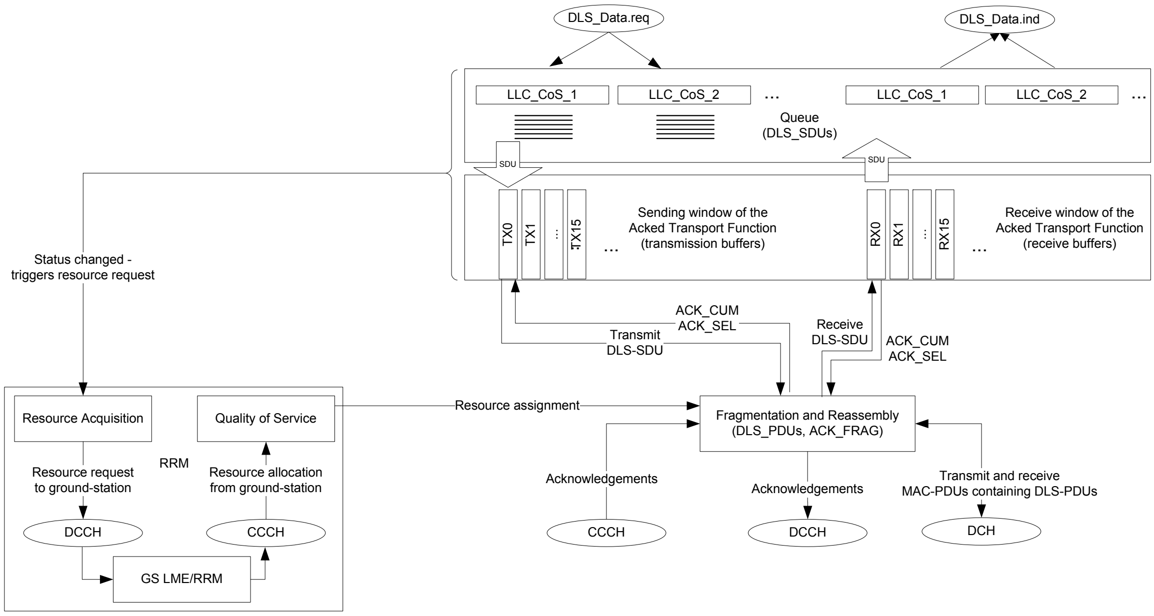

Figure 10-3: Acknowledged Operation of the AS DLS

Figure 10-3 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 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 transmites acknowledgements on the DCCH.

The AS requests RL transmission resources form the RRM in the GS LME via the DCCH.

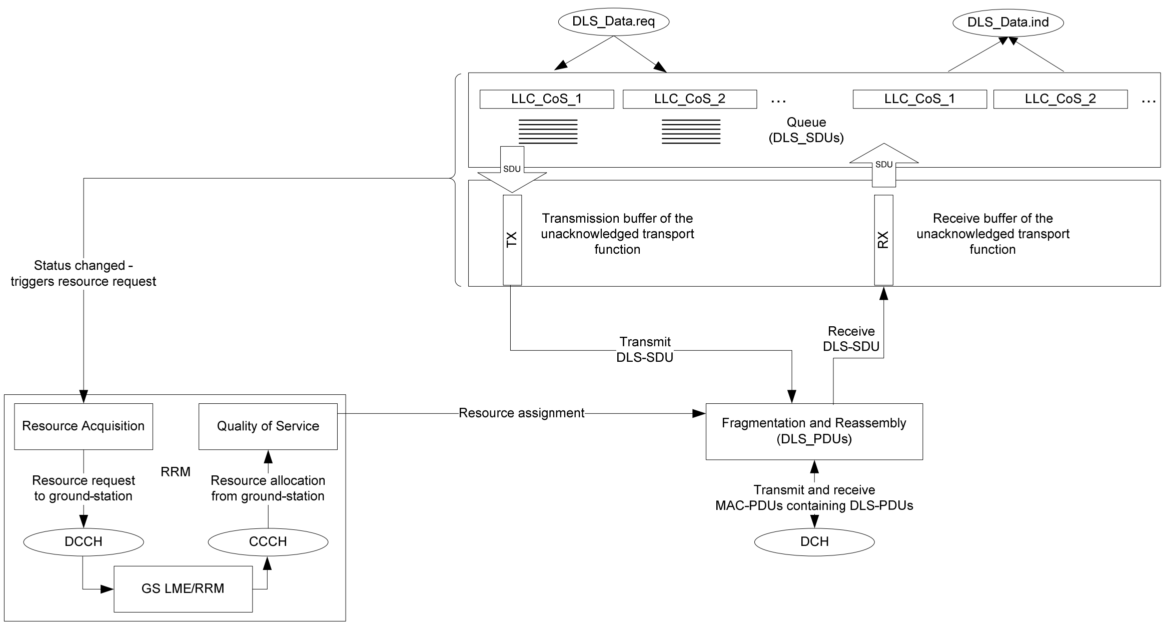

Figure 10-4: Unacknowledged Operation of the AS DLS

Figure 10-4 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 fragemention and reassembly is applied.

The AS requests RL transmission resources form the RRM in the GS LME via the DCCH.

10.3.1 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.

10.3.1.1 Transmission of Acknowledgements

An AS shall request the transmission of acknowledgements via the DCCH.

10.3.1.2 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.

10.3.2 Specifics of Broadcast Data Transfer Procedures

Broadcast transmission of DLS-SDUs shall be available in the GS, only.

10.4 Ground-Station DLS Specifics

Opposite to the RL, LDACS1 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 subscriber access code (SAC) address of the peer AS.

The operation of the functions of the GS DLS is illustrated in Figure 10-5 and Figure 10-6. Specifics of the GS DLS procedures are specified below the figures.

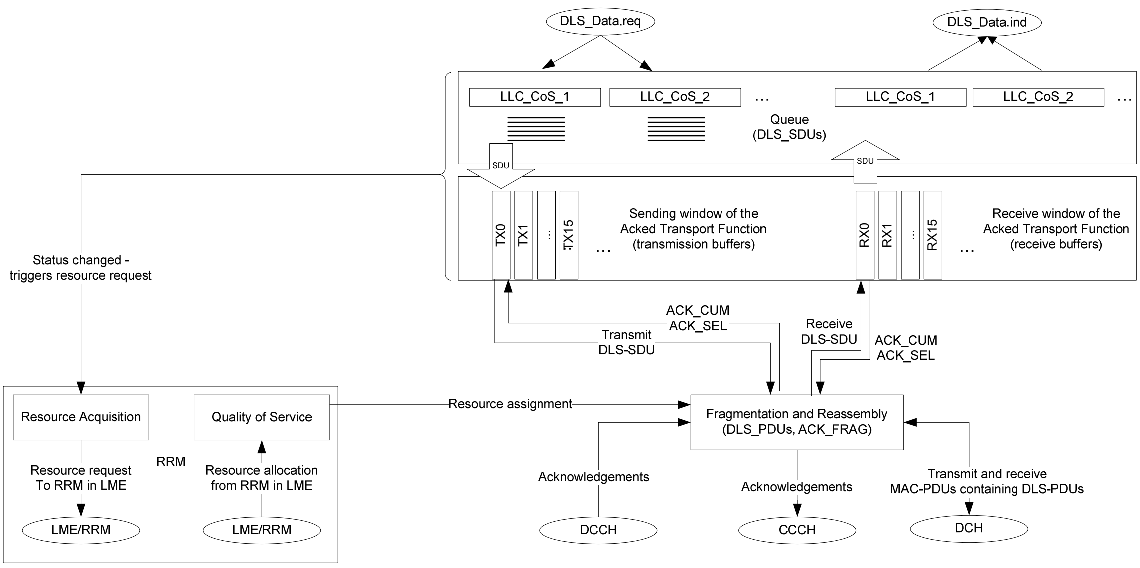

Figure 10-5: Acknowledged Operation of the GS DLS

Figure 10-5 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. 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 transmites acknowledgements on the CCCH.

The GS requests FL transmission resources form the RRM in the GS LME locally.

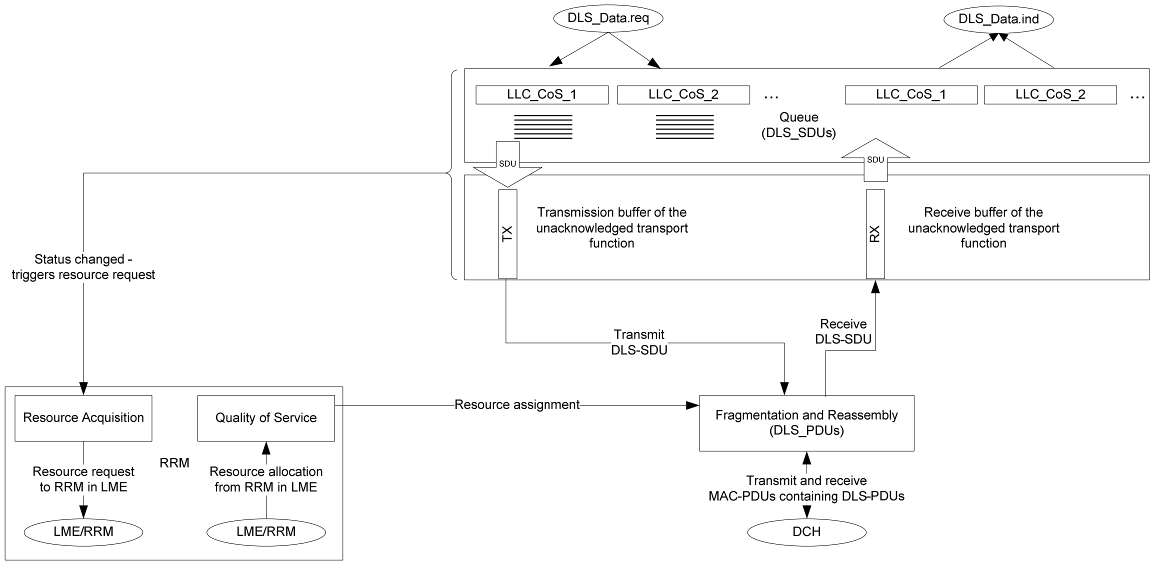

Figure 10-6: Unacknowledged Operations of the GS DLS

Figure 10-6 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 fragemention and reassembly is applied.

The GS requests FL transmission resources form the RRM in the GS LME locally.

10.4.1 Specifics of Resource Acquisition Procedures

A GS shall perform the resource request locally via the RRM function implemented by the LME.

10.4.2 Specifics of Acknowledged Data Transfer Procedures

10.4.2.1 Transmission of Acknowledgements

A GS shall request the transmission of acknowledgements via the CCCH.

10.4.2.2 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.

10.4.3 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 SAC address in the FL MAP of the CCCH.

10.5 DLS Parameters

10.5.1 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. Table 10-2 displays recommended DLS_P_SDU settings for different bit error rates in the DCH (specified at the PHY layer 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 10-2: 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.

10.5.2 Maximum DLS-PDU size (DLS_P_PDU)

This parameter defines the maximum DLS-SDU size of the DLS entity. DLS_P_SDU shall be less than DLS_P_SDU. 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.

10.5.3 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.

10.5.4 Retransmission Timer 2 (DLS_P_RT2)

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.

10.6 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.

10.6.1 Dedicated Control Messages

10.6.1.1 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. The ACK_CUM control message shall contain the following values.

Table 10-3: Cumulative Acknowledgement

Field	Size	Description
D_TYP	4 Bit	Cumulative Acknowledgement
SC	3 Bit	Service Class
PID	5 Bit	Packet Identifier

10.6.1.2 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 10-4: Selective Acknowledgement

Field	Size	Description
D_TYP	4 Bit	Selective Acknowledgement
SC	3 Bit	Service Class
PID	5 Bit	First PID in acknowledgement bitmap.
BITMAP	16 Bit	Acknowledgement bitmap.

Binary one %1 in the BITMAP field shall signal the successful reception of the corresponding DLS-PDU.

10.6.1.3 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 10-5: Fragment Acknowledgement

Field	Size	Description
D_TYP	4 Bits	Single Acknowledgement
SC	3 Bit	Service Class
PID	5 Bit	Packet Identifier
SEQ1	11 Bit	Sequence Number

10.6.1.4 Single Resource Request (SRSC_RQST)

The single 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 service class (SC) only. The SRSC_RQST control message shall contain the following values.

Table 10-6: Resource Request

Field	Size	Description
D_TYP	4 Bit	Resource Request
SC	3 Bit	Service Class
REQ	15 Bit	Octets requested

10.6.1.5 Multiple Resource Requests (MRSC_RQST)

The multiple resource requests control message shall be used to signal multiple resource requirements towards the GS. This message shall be used if resources are needed for multiple service classes (SC). The MRSC_RQST control message shall contain the following values.

Table 10-7: Multiple Resource Requests

Field	Size	Description
D_TYP	4 Bit	Multiple Resource Requests
ENT	2 Bit	Number of Entries
SC_1	3 Bit	Service Class
REQ_1	15 Bit	Octets requested
…		
SC_4	3 Bit	Service Class
REQ_4	15 Bit	Octets requested

The multiple resource requests message can contain at most four different requests; according to the defined MDCP size of 85 Bit, including the 6 Bit CRC.

10.6.2 Common Control Messages

10.6.2.1 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[26]. The ACK_CUM control message shall contain the following values.

[26] Note that the CCCH message format is analogue to the DCCH message format.

Table 10-8: Cumulative Acknowledgement

Field	Size	Description
C_TYP	4 Bit	Cumulative Acknowledgement
SC	3 Bit	Service Class
PID	5 Bit	Packet Identifier

10.6.2.2 Selective Acknowledgement (ACK_SEL)

The selective acknowledgement control message[27] 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 10-9: Selective Acknowledgement

Field	Size	Description
C_TYP	4 Bit	Selective Acknowledgement
SC	3 Bit	Service Class
PID	5 Bit	First PID in acknowledgement bitmap.
BITMAP	16 Bit	Acknowledgement bitmap.

Binary one %1 in the BITMAP field shall signal the successful reception of the corresponding DLS-PDU.

10.6.2.3 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.

Table 10-10: Fragment Acknowledgement

Field	Size	Description
C_TYP	4 Bits	Single Acknowledgement
SC	3 Bit	Service Class
PID	5 Bit	Packet Identifier

[27] The CCCH message format is analogue to the DCCH message format for ACK_SEL and ACK_FRAG messages.

Field	Size	Description
SEQ1	11 Bit	Sequence Number

10.6.3 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.

10.6.3.1 DATA

The DLS DATA PDU shall convey one unfragmented DLS-SDU.

Table 10-11: 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
FCS	16 Bit	Frame Check Sequence

10.6.3.2 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 10-12: 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
FCS	16 Bit	Frame Check Sequence

10.6.4 DLS Frame Check Sequence

The DLS shall use as Frame Check Sequence (FCS) algorithm a Cyclic Redundancy Check (CRC). The following standardized CRCs shall be used for error detecting:

- CRC-16: $x^{16} + x^{12} + x^5 + 1$

10.7 DLS Information Element Definition

10.7.1 C_TYP – Common Control Type

This field indicates the common control type. C_TYP shall have a size of 4 bits.

10.7.2 D_TYP – Dedicated Control Type

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

10.7.3 FCS - Frame Check Sequence

This field is the 16-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).

10.7.4 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.

10.7.5 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.

10.7.6 LEN - Length

The LEN field shall indicate the length of complete DLS-PDU in octets.

10.7.7 PID – Packet Identifier

This field indicates the packet identifier (PID). This field shall have a size of 3 bits.

10.7.8 REQ – Octets Requested

This field indicates the number of octets requested. This field shall have a size of 15 bits.

10.7.9 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.

10.7.10 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 0.

10.7.11 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).

10.7.12 SEQ2 - Sequence Number

The SEQ2 field shall indicate the offset of the last octet of the DLS-SDU conveyed in the DLS_FRAG-PDU.

10.7.13 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.

11 Voice Interface (VI) Specification

11.1 General Description

The LDACS1 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 withdrawalof voice channels is performed in the LME. The VI provides only the transmission and reception services.

11.1.1 Services

11.1.1.1 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.

11.1.1.2 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.

11.1.2 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.

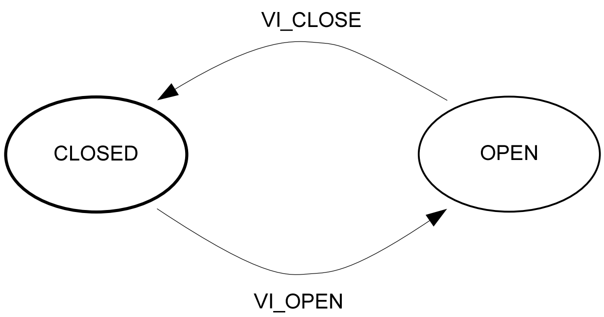

Figure 11-1: VI State Transmission Diagram

11.1.3 VI Interface to Service Users

The VI shall provide an interface to its service users as described in Section 6.2.5.

11.2 Operation of the Voice Interface

11.2.1 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.

11.2.2 Functions of the Voice Interface

11.2.2.1 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.

11.2.2.2 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.

11.2.3 Voice Transport Procedures

11.2.3.1 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.

11.2.3.2 Voice Message Transport

Encoded voice shall be conveyed in VI-PDUs (Section 11.3). Each VI-PDU contains three 20 ms voice samples of the AMBE-ATC-10B vocoder and the 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).

11.2.3.3 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.

11.2.4 Voice Channel Access Procedures

11.2.4.1 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.

11.2.4.2 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 favor of the prioritized ground user.

11.3 VI PDU Format Definition

11.3.1 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 9.6.7).

Table 11-1: VOICE PDU Format

Field	Size	Description
SAC	12 Bit	Subscriber access code
PAD	36 Bit	Reserved
VOICE	288 bit	AMBE-ATC-10B vocoder samples

11.4 VI Information Element Definition

11.4.1 Subscriber Access Code (SAC)

This field indicates the subscriber access code (SAC) of the peer AS. For FL party line voice transmissions the SAC field shall be set to broadcast SAC address.

12 Sub-Network Dependent Convergence Protocol (SNDCP)

12.1 General SNDCP Description

Network layer protocols are intended to operate over services provided by a variety of sub-networks and data links. LDACS1 sub-network can support several network layer protocols while providing protocol transparency for the user of the sub-network service. The introduction of new network protocols to be transferred over LDACS1 technology shall be possible without any changes to the LDACS1 protocol. Therefore, all functions related to the mapping of Network Layer PDUs (N-PDUs) to the LDACS1-specific Sub-network Layer PDUs (SN-PDUs) shall be carried out in a transparent way by the LDACS1 SNDCP. The SNDCP shall thus provide functions for the authentication and configuration of the network layer. The second service of the SNDCP is to provide functions for improving the channel efficiency. This shall be realised by the compression of redundant protocol information (e.g. header compression) and by the compression of redundant user data.

The adaptation of different network layer protocols to SNDCP is implementation-dependent and not defined in this specification. The L-DACS 1 SNDP shall be based on the Point to Point Protocol (RFC1661).

12.1.1 Services

12.1.1.1 Authentication Service

The authentication service shall provide functions to control the access to the L-DACS 1 data link.

12.1.1.2 Configuration Service

The network layer configuration service of the SNDCP shall provide functions to configure the network layer for the transfer N-PDUs over LDACS1 sub-network.

12.1.1.3 Compression Service

The compression service of the SNDCP shall provide functions to improve the channel efficiency. This shall be realised by the compression of redundant protocol information (e.g. header compression) and by the compression of redundant user data.

12.1.2 SNDCP Interface to Service Users

The SNDCP shall provide an interface to its service users as described in Section 6.2.6.

12.2 Operation of the SNDCP

The operation of the SNDCP shall be based on the Point to Point Protocol. There shall be one PPP connection for each DLS class of service.

Appendix A LDACS1 Link Budget

In this section two link budget calculations are provided for LDACS1; 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 LDACS1 antennas with peak gain higher than 8 dBi should be investigated in the further work as well.

When calculating the preliminary LDACS1 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 LDACS1 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 LDACS1 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 LDACS1 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 LDACS1 GS installations, ground antennas with peak gain above 8 dBi can probably be used.In particular, when calculating the linkg 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 LDACS1 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 LDACS1 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 LDACS1 link budget for the interference-free case.

The calculation considers LDACS1 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 LDACS1 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 LDACS1 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 LDACS1 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 LDACS1 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 LDACS1 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, 6) 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 · f_D, fM_1 = -0.6 · f_D spreads: fS_0 = 0.05 · f_D, fS_1 = 0.15 · 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 LDACS1 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.

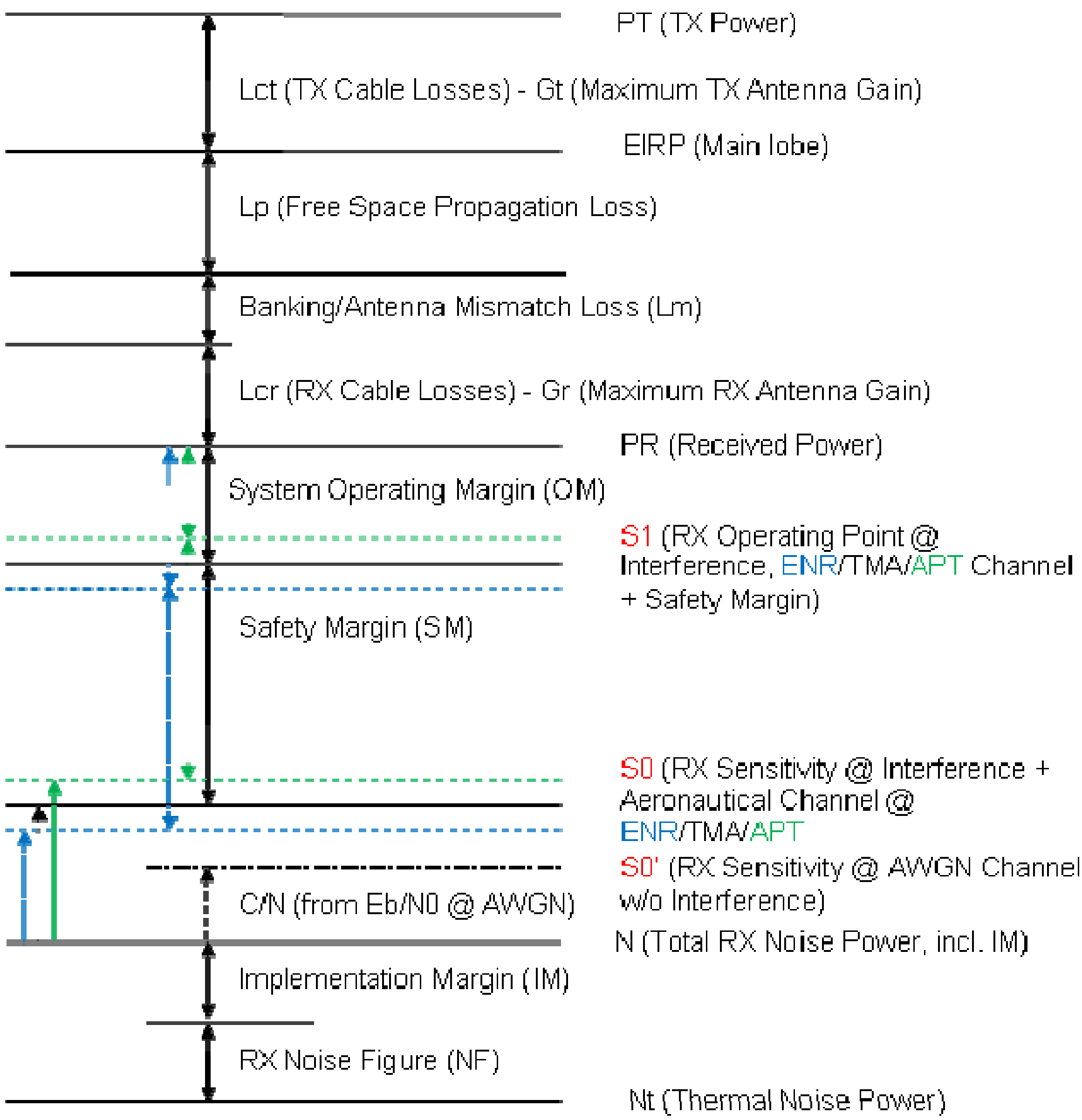

Figure Annex 1: Link Budget Relations

Table Annex 2: LDACS1 Link Budget, no Interference

Without Interference	Unit	ENR	ENR	ENR	TMA	APT	ENR	ENR	ENR	TMA	APT	Equation	Notes
TX Parameters		FL					RL						
TX ouput Power	dBm	41	41	41	41	41	42	42	42	42	42	a	Tx_Pout
TX Antenna Gain	dBi	13	8	8	8	8	0	0	0	0	0	b	TX_AntGain
Tx Cable loss	dB	2	2	2	2	2	3	3	3	3	3	c	TX_CableLoss
Duplexer loss	dB	0	0	0	0	0	0,5	0,5	0,5	0,5	0,5	c1	Duplexer Loss
TX EiRP	dBm	52	47	47	47	47	38,5	38,5	38,5	38,5	38,5	d =a + b - c - c1	TX EiRP = TX_Pout + TX_AntGain - TX_CableLoss - Duplexer Loss
Propagation Parameters		FL					RL						
Transmit mid-band Frequency	MHz	993	993	993	993	993	1087	1087	1087	1087	1087	e	
Tx-Rx Distance	nm	200	120	60	40	10	200	120	60	40	10	f	
Path Loss	dB	143,76	139,32	133,30	129,78	117,74	144,55	140,11	134,09	130,57	118,52	g = 37,8 + 20log(f*e)	Free Space model (distance in nm, frequency in MHz)
Miscellaneous Margins		FL					RL						
Interference Margin	dB	0	0	0	0	0	0	0	0	0	0	h	InterfMargin
Implementation Margin	dB	4	4	4	4	4	4	4	4	4	4	i	ImpMargin - considered as an increase in total RX noise power
Safety Margin	dB	6	6	6	6	6	6	6	6	6	6	j	SafetyMargin - considered as a signal power increase above sensitivity
Banking Loss Allowance	dB	0	0	0	7	7	0	0	0	7	7	k	BankingLoss - considered as an increase in path loss
RX Parameters		FL					RL						
Maximum RX Antenna Gain	dBi	0	0	0	0	0	13	8	8	8	8	l	RX_AntGain
Duplexer loss	dB	0,5	0,5	0,5	0,5	0,5	0	0	0	0	0	m	Duplexer Loss
Rx Cable loss	dB	3	3	3	3	3	2	2	2	2	2	m1	RX_CableLoss
RX received signal Power	dBm	-95,26	-95,82	-89,80	-93,28	-81,24	-95,05	-95,61	-89,59	-93,07	-81,02	n = d - g + l - m - k - m1	RxPower = TX_EiRP - PathLoss - BankingLoss + Rx_AntGain - Rx_CableLoss - Duplexer Loss
Thermal Noise Density@290K	dBm/Hz	-174	-174	-174	-174	-174	-174	-174	-174	-174	-174	o	10log(k*T)
Bandwidth	Hz	498050	498050	498050	498050	498050	498050	498050	498050	498050	498050	p	BW
Thermal Noise Power	dBm	-117,03	-117,03	-117,03	-117,03	-117,03	-117,03	-117,03	-117,03	-117,03	-117,03	q = o + 10log(p)	10log(k*T) +10log(BW)
Receiver Noise Figure	dB	6	6	6	6	6	5	5	5	5	5	r	Rx_NF
Total Rx Noise Power	dBm	-107,03	-107,03	-107,03	-107,03	-107,03	-108,03	-108,03	-108,03	-108,03	-108,03	s = q + r + i	N = Rx_NF + 10log(k*T) +10log(BW) +
Eb/No @ No Interference	dB	5,23	5,23	5,23	5,53	7,13	8,74	8,74	8,74	9,44	17,34	t = v - 10log(u/p)	Eb/No = C/N - 10log(R/BW), without
L-DACS1 bit rate	bps	291200	291200	291200	291200	291200	220300	220300	220300	220300	220300	u	R
Required C/N @ BER=10-6	dB	2,90	2,90	2,90	3,20	4,80	5,2	5,2	5,2	5,9	13,8	v	C/N
Rx Sensitivity (S0)	dBm	-104,13	-104,13	-104,13	-103,83	-102,23	-102,83	-102,83	-102,83	-102,13	-94,23	w = v + s	Cmin = C/N + N
Rx operating point (S1)	dBm	-98,13	-98,13	-98,13	-97,83	-96,23	-96,83	-96,83	-96,83	-96,13	-88,23	x = w + j	RxOP = Cmin + SafetyMargin
		FL					RL						
System operating margin (OM)	dB	2,87	2,30	8,33	4,55	14,99	1,78	1,22	7,24	3,06	7,20	z=n-x	OM = RxPower - RxOP

Table Annex 3: LDACS1 Link Budget, with Interference

With Interference	Unit	ENR	ENR	ENR	TMA	APT	ENR	ENR	ENR	TMA	APT	Equation	Notes
TX Parameters		FL					RL						
TX ouput Power	dBm	41	41	41	41	41	42	42	42	42	42	a	Tx_Pout
TX Antenna Gain	dBi	13	8	8	8	8	0	0	0	0	0	b	TX_AntGain
Tx Cable loss	dB	2	2	2	2	2	3	3	3	3	3	c	TX_CableLoss
Duplexer loss	dB	0	0	0	0	0	0,5	0,5	0,5	0,5	0,5	c1	Duplexer Loss
TX EiRP	dBm	52	47	47	47	47	38,5	38,5	38,5	38,5	38,5	d =a + b - c - c1	TX EiRP = TX_Pout + TX_AntGain - TX_CableLoss - Duplexer Loss
Propagation Parameters		FL					RL						
Transmit mid-band Frequency	MHz	993	993	993	993	993	1087	1087	1087	1087	1087	e	
Tx-Rx Distance	nm	200	120	60	40	10	200	120	60	40	10	f	
Path Loss	dB	143,76	139,32	133,30	129,78	117,74	144,55	140,11	134,09	130,57	118,52	g = 37,8 + 20log(f*e)	Free Space model (distance in nm, frequency in MHz)
Miscellaneous Margins		FL					RL						
Interference Margin	dB	0	0	0	0	0	0	0	0	0	0	h	InterfMargin - N/A (included in Eb/No figure)
Implementation Margin	dB	4	4	4	4	4	4	4	4	4	4	i	ImpMargin - considered as an increase in total RX noise power
Safety Margin	dB	6	6	6	6	6	6	6	6	6	6	j	SafetyMargin - considered as a signal power increase above sensitivity
Banking Loss Allowance	dB	0	0	0	7	7	0	0	0	7	7	k	BankingLoss - considered as an increase in path loss
RX Parameters		FL					RL						
Maximum RX Antenna Gain	dBi	0	0	0	0	0	13	8	8	8	8	l	RX_AntGain
Duplexer loss	dB	0,5	0,5	0,5	0,5	0,5	0	0	0	0	0	m	Duplexer Loss
Rx Cable loss	dB	3	3	3	3	3	2	2	2	2	2	m1	RX_CableLoss
RX received signal Power	dBm	-95,26	-95,82	-89,80	-93,28	-81,24	-95,05	-95,61	-89,59	-93,07	-81,02	n = d - g + l - m - k - m1	RxPower = TX_EiRP - PathLoss - BankingLoss + Rx_AntGain - Rx_CableLoss - Duplexer Loss
Thermal Noise Density@290K	dBm/Hz	-174	-174	-174	-174	-174	-174	-174	-174	-174	-174	o	10log(k*T)
Bandwidth	Hz	498050	498050	498050	498050	498050	498050	498050	498050	498050	498050	p	BW
Thermal Noise Power	dBm	-117,03	-117,03	-117,03	-117,03	-117,03	-117,03	-117,03	-117,03	-117,03	-117,03	q = o + 10log(p)	10log(k*T) +10log(BW)
Receiver Noise Figure	dB	6	6	6	6	6	5	5	5	5	5	r	Rx_NF
Total Rx Noise Power	dBm	-107,03	-107,03	-107,03	-107,03	-107,03	-108,03	-108,03	-108,03	-108,03	-108,03	s = q + r + i	N = Rx_NF + 10log(k*T) +10log(BW) +
Eb/No @ Interference	dB	7,43	7,43	7,43	7,93	10,63	9,74	9,74	9,74	10,54	18,14	t = v - 10log(u/p)	Eb/No = C/N - 10log(R/BW), with interference!
L-DACS1 bit rate	bps	291200	291200	291200	291200	291200	220300	220300	220300	220300	220300	u	R
Required C/N @ BER=10-6	dB	5,10	5,10	5,10	5,60	8,30	6,2	6,2	6,2	7	14,6	v	C/N
Rx Sensitivity (S0)	dBm	-101,93	-101,93	-101,93	-101,43	-98,73	-101,83	-101,83	-101,83	-101,03	-93,43	w = v + s	Cmin = C/N + N
Rx operating point (S1)	dBm	-95,93	-95,93	-95,93	-95,43	-92,73	-95,83	-95,83	-95,83	-95,03	-87,43	x = w + j	RxOP = Cmin + SafetyMargin
		FL					RL						
System operating margin (OM)	dB	0,67	0,10	6,13	2,15	11,49	0,78	0,22	6,24	1,96	6,40	z=n-x	OM = RxPower - RxOP

Appendix B Extended LDACS1 System Capabilities

B.1 LDACS1 A/G Voice Capability

Note: LDACS1 voice functionality is outlined in this section, but not addressed in depth within the scope of this specification. Further information about LDACS1 voice capability is provided in Sections 6.1.3, 7.10, 9.5, 9.6, 10.1, 10.2 and 11.

The LDACS1 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 LDACS1 functional scope as a "configurable optional feature". Although not expected to be widely used, voice services may be selectively configured at selected LDACS1 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 LDACS1 framing structure, both on the FL and on the RL, but without adverse impact upon data link capacity/performance.

LDACS1 supports a transparent, simplex voice operation based on a "Listen-Before-Push-To-Talk" channel access. When configured for voice operation, LDACS1 provides following modes of operation:

- Circuit mode voice
- Packet mode voice

In the circuit mode, LDACS1 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 LDACS1 GS in response to an access request received from the LDACS1 AS. This type of operation shall allow dynamic sharing of the voice channel resource, increasing efficiency.

In the packet mode, LDACS1 supports packetized voice (VoIP).

The LDACS1 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, LDACS1 adopts the VHF Digital Link (VDL) Mode 3 vocoder algorithm. The LDACS1 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 LDACS1 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.

B.2 A/A Communications Mode

> Note: *LDACS1 system A/A mode is outlined in this section as it was developed in the course of the B-AMC study, but is not further detailed within the scope of this specification. The current status of the A/A mode will require further refinements/modifications prior to detailed formal specification.*

LDACS1 operated in A/A mode offers direct A/A communications without ground support. This mode has been designed in the course of the B-AMC study, with the goal to cover addressed and broadcast data link demands indicated in [COCRv2]. The basic B-AMC principles apply to LDACS1 as well.

No A/A voice services are offered in A/A mode.

B.2.1 LDACS1 A/A Mode of Operation

LDACS1 operated in A/A mode offers direct A/A communications (without ground support), covering addressed and broadcast A/A data link demands indicated in [COCRv2].

In A/A mode, communication between Aircraft Stations (ASs) takes place in a decentralized, self-organised way within "communication bubbles" defined by the radio range of the ASs. For synchronisation purposes, the availability of a global time reference (e.g. GPS-derived time) is assumed at each AS.

No ground infrastructure is required for operating LDACS1 in A/A mode. GSs may optionally appear within the LDACS1 A/A network, but are basically handled like ASs.

LDACS1 operating in A/A mode assumes a dedicated global RF resource, the "Common Communications Channel" (CCC).

The CCC has a larger bandwidth than channels in the A/G mode und requires a part of L-band spectrum free of DMEs.

The currently proposed global CCC allocation is at 968 MHz. Dependent on the local demands, additional local CCCs may be used.

All data on the CCC are broadcast, accompanied by a short header that identifies the type (broadcast/multicast/unicast) and the destination address of the transmission. Any user listening on the common CCC can directly synchronise to the transmission of any other user as long as this one remains within the defined range around the receiver.

If a given A/A addressed message requires operational acknowledgement, it is provided within a different addressed message that is again broadcast on the CCC.

B.2.2 A/A Physical Layer Description

LDACS1 A/A mode uses an OFDM-based PHY layer with different parameters (e.g. sub-carrier spacing) than those specified for A/G mode. An OFDM based PHY layer is combined with the TDMA-based users' access to the shared broadcast channel.

The sub-carrier spacing[28] is greater than for A/C mode due to the different characteristics of an A/A communication channel and higher relative aircraft-to-aircraft speed. Increased sub-carrier spacing leads to reduced symbol duration.

The usage of TDMA, high number of potential users and propagation guard times mandate the usage of A/A data frames that are relatively short compared with frames in the A/G mode. The selected data frame size and OFDM symbol duration lead to the required RF channel bandwidth that is higher than for the A/G mode.

Robust modulation has been selected together with strong FEC (Forward Error Correction) coding due to the broadcast nature of A/A communications.

[28] The sub-carrier spacing and other PHY parameters proposed in the B-AMC study may need to be adjusted in the future work.

B.2.3 A/A MAC Layer Description

A flexible LDACS1 A/A protocol has been designed to support the aircraft population within the operational range defined by the physical layer design.

The AS in A/A mode uses a simplex exchange method, using the CCC that is shared among all airborne and/or ground users. The access of users to the shared broadcast channel is based on a self-organising reservation-based TDMA concept with fixed time slots. No central control instance is used or required for resource management.

All A/A transmissions are broadcast. Such a broadcast system also supports addressed A/A transmissions of a particular AS directed to the specific recipient, another AS. The actual type of the transmission (broadcast/multicast/unicast address) is advertised in the header of the transmitted message.

One A/A MAC frame is one UTC second long and consists of 512 data slots and 64 management slots. A management slot occurs always after eight data slots. The data slots are used by ASs for the transmission of user data, e.g. surveillance data like ADS-B, whereas management slots are used by the ASs for the transmission of information concerning slot occupancy.

The periodical transmission of management data is used to overcome the hidden station problem: simultaneous transmission of two or more nodes which are not directly within each others transmission range, but are both within the transmission range of the victim receiver.

Appendix C Interference Reduction at LDACS1 RX

This section deals with the mitigation of interference onto LDACS1 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 LDACS1 AS receiver to the common suppression bus (that may not always be available).

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