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NATO LETTER OF PROMULGATION

4 November 2020

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CHAPTER	RECORD OF RESERVATION BY NATIONS
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RECORD OF SPECIFIC RESERVATIONS

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Chapter 1: Introduction

The Aim of this standard is to provide the common requirements specifications for NATO interoperable digital sonobuoy telemetry links, for Interoperability between Maritime Air (MA) (Maritime Patrol Aircraft and Maritime Helicopters) and Maritime Air Support Centers (MASC). They are based upon the output of a U.S Naval Air Warfare Center (NAWC) Generic Protocols Working Group activity to further develop and refine the NATO Industrial Advisory Group (NIAG) Subgroup 90 (SG-90) sonobuoy data link recommendations documented in Sonobuoy Digital Telemetry Link Study, Final Report [Ref. NIAG-D(2006)0025 AC/141-D/768 AC/141(NG/4-SG/41)D/3], 13 March 2007.

1.1 Encompassing Framework

The current RF interface between sonobuoys and maritime patrol aircraft has been in use for over 40 years, and provides the basis of interoperability of sonobuoys manufactured by NATO nations, with NATO ASW aircraft and associated equipment and facilities. The uplink is provided by 99 VHF FM channels in the band 136 to 174 MHz. This uplink is susceptible to both intentional and non-intentional radio frequency interference (RFI), particularly in littoral waters. The downlink is provided by a single channel in the UHF band at either 291.3 MHz or 291.4 MHz and provides a limited number of commands.

The current telemetry links were designed to transmit primarily passive acoustic data from the sonobuoy to the aircraft. Emerging multistatic active sonobuoy systems require a robust two way data link that permits the aircraft to command the sonobuoy and that accommodates a variety of data types that must be sent by the buoy to the aircraft. The US and UK have taken different approaches to solving this requirement for high bandwidth, high dynamic range uplinks and command downlinks, and the resulting up and down links are not interoperable, and are not robust to RFI.

The recommended standard specified in this document provides for an interoperable, flexible, digital telemetry link with improved resistance to RFI that is able to support high data rates and/or high integrity data. This standard provides the waveforms and protocols that support the vision of a networked sonobuoy telemetry system that provides multiple uplink data rates, optimal coherent and noncoherent reception in the aircraft, RFI mitigation through adaptive narrowband notch filtering and wideband spatial beamforming, and error handling through error detection, correction, and retransmission.

In future years this telemetry link can support an expansive quality of service (QoS) management system that is part of a buoy field management function in the aircraft. This system would monitor RF signal quality on channels in use, measure RFI statistics on all uplink channels, provide automatic adaptive assignments and changes of uplink frequencies according to the prevailing RF environment, and adjust uplink data rates based on tradeoffs between RF quality, buoy type, and data importance and required integrity.

Addressing schemes and protocols are included to enable this telemetry standard to be used with networks of sensors (e.g. undersea sensor networks via gateway buoys) or with networks of monitoring platforms (e.g. networks of UAVs and aircraft).

1.2 Scope

The scope of this standard includes the following aspects of a digital sonobuoy telemetry system:

- Uplink waveform specification.
- Downlink waveform specification.
- Communications protocol requirements, including Physical layer, Data Link layer, and Network and Transport layer protocols.
- Recommendations and guidance for the aircraft receiver signal processing.

Aspects explicitly excluded from the scope of this standard are as follows:

- Sonobuoy physical, functional, and environmental requirements; the generic sonobuoy specifications (USA PSS, UK GSS and ANEP-80) continue to apply, as appropriate.
- Particular sonobuoy data formats and functions; these should continue to be defined in the specific sonobuoy specifications, but in compliance with the Physical Layer, Data Link Layer, and Network and Transport Layer protocol specified herein.
- Implementation of airborne RF signal processing functions; the detailed implementation and level of performance and sophistication of airborne RF signal processing is left to the discretion of individual programs and nations, but should not conflict with the guidance and structure outlined herein.
- Implementation of the Application layer functions and formats; the detailed functionality and general operation of the sonobuoy system are left to the discretion of individual programs and nations, but should be consistent with the guidance and structure outlined herein.
- Sonobuoy recording, replay, and pre-mission planning aspects; such aspects should continue to be standardized separately (e.g. via STANAG 4283) but future developments of STANAG 4283 and of this standard should be harmonized.

Chapter 2: Definitions and Abbreviations

2.1 Definitions

For the purposes of this standard, the following terms and definitions apply.

- **Data link layer ACK/NACK** – An acknowledgement (or negative acknowledgement) sent to indicate that an **MPDU** is received without (with) errors.
- **Defragmentation** – The function of reassembling a higher layer **SDU** from the fragments contained in multiple **PDUs**.
- **Downlink** – The transmission direction from the aircraft to the sonobuoys.
- **Frequency division multiple access (FDMA)** – A medium access scheme in which each user is assigned a separate RF channel.
- **Footer** – Data appended to the end of an **SDU** in the formation of a **PDU**.
- **Fragmentation** – The function of segmenting a higher layer **SDU** into two or more smaller **PDUs**.
- **Frequency division duplex (FDD)** – A duplex scheme in which the uplink and downlink use different RF frequencies and are simultaneous.
- **Generic Sonobuoy Specification (GSS)** –UK document defining generic sonobuoy specification aspects (e.g. environmental, mechanical, VHF uplink frequencies etc.). Equivalent in scope to ANEP-80
- **Header** – Data attached to the beginning of an **SDU** to form a **PDU**.
- **MAC protocol data unit (MPDU)** – The unit of data exchanged between a buoy data link layer and the aircraft data link layer using the services of the physical layer.
- **Message** – A complete application layer communication that may span more than one **uplink transmission frame** or one **downlink packet**.
- **Modulation Index (h)** – The cumulative phase difference between two transmissions differing by one bit is πh (radians). The frequency deviation for a contiguous transmitted sequence of ‘1’s is (h/2)fb, where fb is the bit rate.
- **Packet** – The aggregate of all bits assembled for a unit of transmission at the physical layer on the **downlink**.
- **Packing** – The act of combining multiple **SDUs** from a higher layer into a single **MPDU**.
- **Protocol data unit (PDU)** – The data unit exchanged between peer entities of the same protocol layer. On the downward direction it is the data unit generated for the next lower layer of the protocol stack. On the upward direction it is the data unit received from the previous lower layer.

- **Production Sonobuoy Specification (PSS)** – USA document encompassing generic and particular aspects of sonobuoy specifications. Equivalent in scope to the UK GSS + UK Particular Sonobuoy Specifications.
- **Service data unit (SDU)** – The data unit exchanged between two adjacent protocol layers. On the downward direction it is the data unit received from the previous higher layer. On the upward direction it is the data unit sent to the next higher layer.
- **Transmission frame** – The aggregate of all bits assembled for a unit of transmission at the physical layer on the **uplink**.
- **Uplink** – The transmission direction from the sonobuoys to the aircraft.

2.2 Abbreviations and Acronyms

- ACK acknowledgement
- ARQ automatic repeat request
- BER bit error rate
- BPS bits per second
- BT Bandwidth-Time product
- CMF command message format
- CPFSK continuous phase frequency shift keying
- CRC cyclic redundancy check
- DLL data link layer
- DLMP downlink MAC protocol
- DMF data message format
- FDD frequency division duplex
- FEC forward error correction
- GFSK Gaussian frequency shift keying
- GSS Generic Sonobuoy Specification (UK)
- IP internet protocol
- LFSR linear feedback shift register
- LMF link management format
- LSB least significant bit
- MAC medium access control
- MPDU MAC protocol data unit
- MSB most significant bit
- NACK negative acknowledgement
- NRZ non return to zero
- NTL network and transport layer
- OSI open systems interconnect
- PDU protocol data unit
- PHY physical layer

- PRBS pseudo random bit sequence
- PREA preamble
- PSS Production Sonobuoy Specification (USA)
- PSS Particular Sonobuoy Specification (UK)
- RFI radio frequency interference
- RSSI received signal strength indicator
- SDF streaming data format
- SDU service data unit
- TBD to be determined
- TCP transport control protocol
- UDP user datagram protocol
- ULMP uplink MAC protocol

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Chapter 3: General Description

The sonobuoy telemetry system consists of the uplink and downlink communications channels and associated equipment used by a field of sonobuoys and an aircraft that is monitoring the field. The system operates in a star network topology in which the aircraft is the hub and each sonobuoy has a point-to-point RF connection to the aircraft. The telemetry system uses a frequency division duplex (FDD) link in which the uplink and the downlink operate concurrently at different RF frequencies

3.1 Uplink

The uplink is a one way connection containing the transmissions from sonobuoys to the aircraft. Frequency division multiple access (FDMA) is used to divide the RF uplink into 99 standard sonobuoy channels with each sonobuoy being assigned to its own uplink channel.

3.2 Downlink

The downlink is a one way connection containing the transmissions from the aircraft to the sonobuoys. The downlink is a single RF channel that is broadcast to all of the sonobuoys.

3.3 Protocols Reference Model

The protocols reference model for this standard is the four layer model shown in **Figure 1**. This model is a reduced version of the open systems interconnection (OSI) seven layer model. Each layer of this reference model is responsible for one part of the standard and provides services to the adjacent layers. This model is applicable to both the uplink and the downlink.

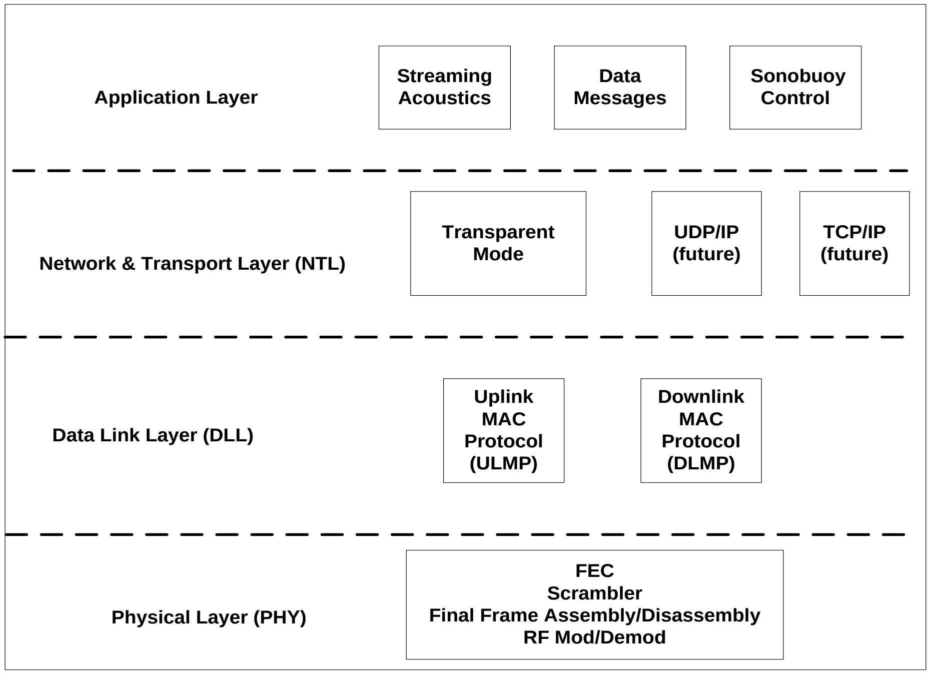

Figure 1. Protocols reference model

The process of passing data from one layer of the model to the next is one of encapsulation as illustrated in **Figure 2**. On the sending side of the link, the specific unit of data passed from a higher layer to a lower layer is a Service Data Unit (SDU). The lower layer performs some functions on the SDU and adds a header or footer or both using a process of encapsulation to form a Protocol Data Unit (PDU). The PDU is then passed to the next lower layer as the SDU for that layer. The header and footer of a PDU contains the information the peer layer on the receive side needs to recover the SDU from the PDU and pass it on to the next higher layer. The dashed lines in the figure represent the exchange of PDUs between peer layers of the model using the services of the lower layers.

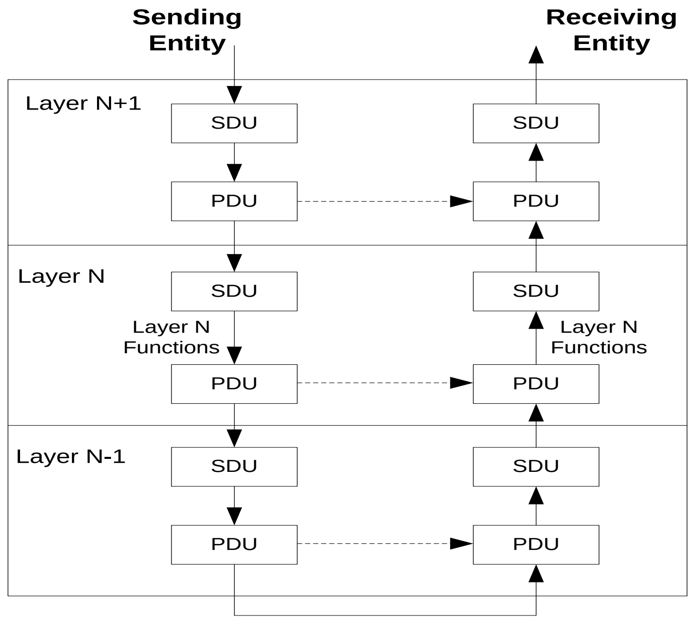

Figure 2. PDU and SDU in a protocol stack

The primary functions performed in of each of the four layers in the reference model are as follows:

- The **Application Layer** (or **User Layer**) provides the interface between the acoustic signal processing in the buoy or the aircraft and the lower layers of the reference model. In the buoy this layer is responsible for the assembly of acoustic payloads, GPS data messages, sonobuoy status messages, etc. that are sent on the uplink and for the parsing and distribution of commands and data received on the downlink. In the aircraft this layer is responsible for recovery and forwarding of the acoustic data and other messages received on the uplink and the assembly of commands and data messages sent on the downlink. The functionality of this layer is not a part of this standard, but is left to the specification of the specific sonobuoys and to the aircraft receiver and processor specifications. Annex A contains recommendations for protocols and formats for the Application layer.

- The **Network and Transport Layer (NTL)** provides routing and addressing functions and breaks up and reassembles large Applications layer SDUs into datagrams of manageable size using protocols such as User Datagram Protocol/Internet Protocol (UDP/IP) and Transport Control Protocol/Internet Protocol (TCP/IP). For the initial implementations of this standard, the NTL operates in a Transparent Mode (TM) in which it is just a pass-through between the Data Link Layer and the Applications layer. In this mode no NTL header or footer data is added to the SDU. Internet protocols such as UDP/IP and TCP/IP are growth features that can be added in the future without changes to the lower layer protocols.

- The **Data Link Layer (DLL)** is where the MAC functions are performed. These functions include the definition of the logical format of the transmitted data, incorporating the control and addressing information from the higher layers, the fragmentation and reassembly of large SDUs from the higher layers, and ARQ functions for reliable transmission between DLL peers. Since the data and transmission formats of the uplink and downlink are very different, this standard separates the DLL functions into an uplink MAC protocol (ULMP) and a downlink MAC protocol (DLMP). This standards specifies four basic data or message types that these protocols support:

  – The **Streaming Data Format (SDF)** is used to continually send acoustic data from the sonobuoy to the aircraft. This format is only used by the ULMP on the uplink.

  – The **Data Message Format (DMF)** is used on both the uplink and the downlink. On the uplink this format is used by the buoy to send non-acoustic messages such as GPS data, engineering data, buoy status information, buoy responses to downlink commands, and high integrity data requiring reliable transmission. On the downlink this format is used by the aircraft to send data messages such as signal processing parameter updates, ping tables, data files, etc. The ULMP and DLMP both support error detection and message retransmission and SDU fragmentation and reassembly for this data format.

  – The **Link Management Format (LMF)** is used to send DLL messages on both the uplink and the downlink for purposes of managing the telemetry link. These messages originate at the sending DLL and are utilized at the receiving DLL.

  – The **Command Message Format (CMF)** is used on the downlink for buoy command and control. This protocol provides for variable length command messages and retransmission of corrupted or missed messages.

- The **Physical Layer (PHY)** is the lowest layer of the protocol stack which provides the interface between the DLL and the physical RF channel by performing functions such as data scrambling for spectral balancing, error correction coding, synchronization, modulation/demodulation, and transmission/reception.

3.4 Bit Numbering and Nomenclature

In this document, MPDUs and transmission frames are described in figures as a sequence of fields in a specific order. The following conventions are used to identify the bit numbering in a field and the transmission order of each field.

The bit numbering convention for an N-bit field shall be as shown in **Figure 3.** The bits are numbered 0 through N-1. The left most bit in the figure is the MSB and is numbered as bit N-1. The right most bit is the LSB and is numbered as bit zero. Bits within the field are transmitted “MSB first”, i.e. in the order of bit N-1, bit N-2, …, bit 0.

The term byte shall refer to an 8-bit quantity or field. Fields that require more than one byte of information shall be transmitted most significant byte first.

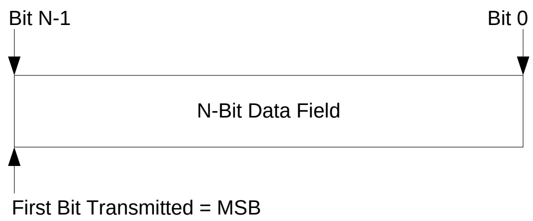

Figure 3. Bit numbering convention

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Chapter 4: Uplink

The uplink from the sonobuoys to the aircraft consists of 99 standard sonobuoy channels in the VHF band. Each sonobuoy is assigned one channel or sub-channel within a channel on which to transmit. Once the buoy commences transmission, it transmits continuously until commanded to cease transmission or until a predefined end of lifetime, or for a predefined burst transmission time, according to the particular buoy specification.

4.1 Uplink Telemetry Frame Structures

4.1.1 Synchronous Transmission Format

The transmissions from a sonobuoy shall consist of a series of variable length frames transmitted in a continuous, synchronous manner as shown in **Figure 4.** A Data Frame shall be comprised of a Header block followed by 0-31 Data blocks. Single-block Preamble Frames shall fill any gaps between Data Frames. Each block shall be 528 bits in length. The Data Frames are transmitted asynchronously relative to each other.

When transmission is initiated, a sequence of at least nPreStart Preamble frames shall be transmitted in order to synchronize the aircraft receiver.

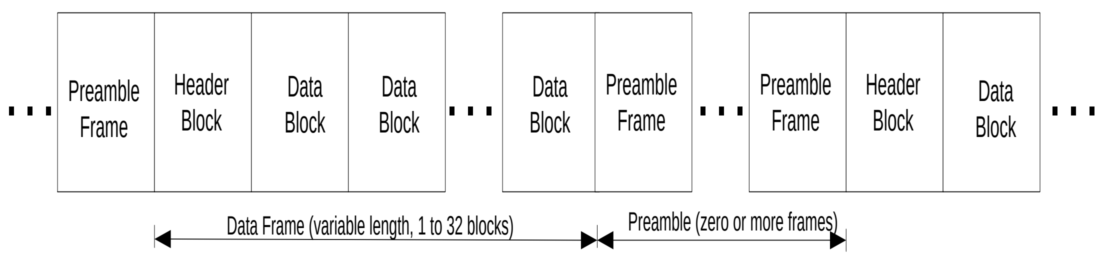


Figure 4. Physical uplink transmission format

The application data rate should be designed such that under normal operation at least 0.5% of the frames contain the buoy address (e.g. preamble frames).

4.1.2 Uplink Generic Frame Format

All uplink transmission frames are built from the Generic uplink frame structure shown in **Figure 5.** Each block of the frame shall be 528 bits in length (viewed as 33 words by 16 bits each).

Words 0 – 5 of the Header block are mandatory for all uplink frames. The structure of the remainder of the Header block is specific to the data format being used for the frame.

All applications data shall be a multiple of 16-bit words.

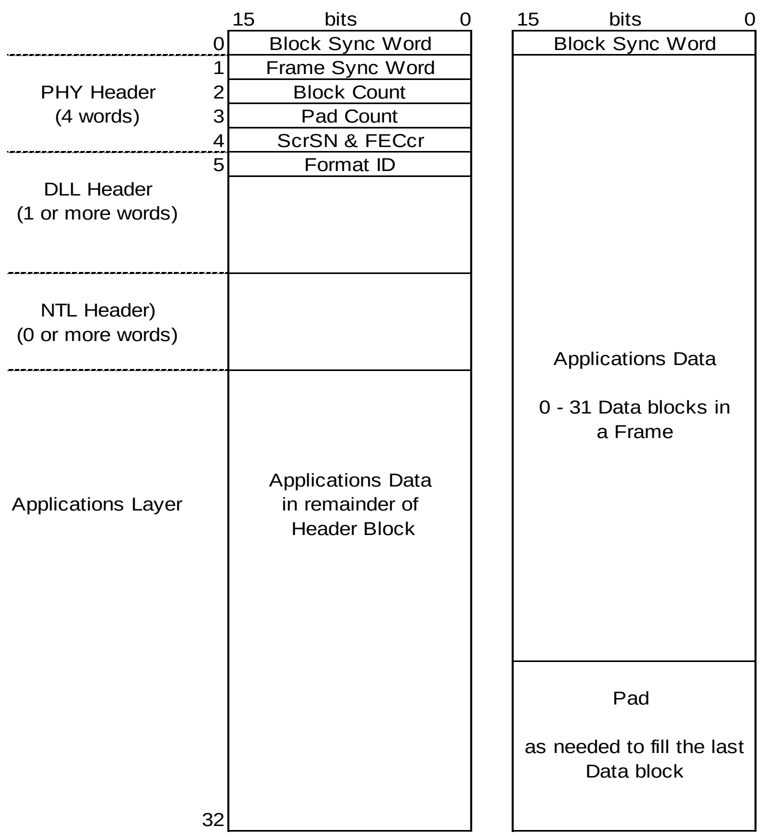


Figure 5. Uplink Generic frame format

4.1.2.1 Block Sync Word

The Block Sync word shall be the first word at the beginning of each 528-bit block. This word establishes the synchronous structure of the uplink transmission.

The 16-bit Block Sync word shall be as defined in **Table 1.**

Binary Value	Hex Value
0000 0110 1011 0111	0x06B7

Table 1. Block Sync word

4.1.2.2 Frame Sync Word

The Frame Sync word shall be the second word in the Header block of each frame. This word identifies the start of a new frame.

The 16-bit Frame Sync word shall be as defined in **Table 2**.

Binary Value	Hex Value
1101 1000 0110 1001	0xD869

Table 2. Frame Sync word

4.1.2.3 Block Count

The Block Count specifies the number of Data blocks in the frame that follow the Header block. The block count is a 5-bit integer with values of 0, 1, …, 31 that shall be encoded as a 16-bit word using the code specified in section 4.2.6. A value of zero indicates that the next block will be the start of the next frame. The number of blocks in the frame is Block Count + 1.

4.1.2.4 Pad Count

The Pad Count specifies the number of 16-bit words of pad data that are inserted at the end of the last Data block in the frame in order to fill out the frame to an integer number of blocks. The Pad Count is a 5-bit integer with values of 0, 1, …, 31 that shall be encoded as a 16-bit word using the code specified in section 4.2.6.

4.1.2.5 Scrambler Initial State and FEC Code Rate

The Scrambler Initial State and FEC Code Rate (ScrSN & FECcr) is a 5-bit field that shall be encoded as a 16-bit word using the code specified in section 4.2.6.

The structure of the 5-bit field shall be as shown in **Figure 6.** The Scrambler Initial State Number (ScrSN) sub-field is specified in section 4.2.5 and the FEC Code Rate Indicator (FECcr) sub-field is specified in section 4.2.3.

Scrambler Initial State Number (ScrSN)		FEC Code Rate Indicator (FECcr)		
b1	b0	b2	b1	b0

Figure 6. Scrambler Initial State and FEC Code Rate Indicator Fields

4.1.2.6 Format ID

The Format ID is a 5-bit integer that shall be encoded as a 16-bit word using the code specified in section 4.2.6. This is the first word in the DLL header and it identifies the DLL or NTL format associated with the frame. The values of the Format ID shall be as specified in **Table 3**.

In the aircraft, the data in the frame is passed to the protocol or process that is associated with the Format ID. SDF and DMF data are passed to Applications layer processes by way of the NTL Transparent Mode. LMF data remains at the data link layer and is used by a MAC process for link management purposes.

Format ID Value	Format
0	Preamble
1	Streaming Data Format (SDF)
2	Data Message Format (DMF)
3	Link Management Format (LMF)
4	UDP/IP
5	TCP/IP
6 thru 31	Reserved for future use

Table 3. Downlink Format ID word (5-bit value encoded to 16 bits)

4.1.2.7 Pad Word

Pad words are inserted as necessary at the end of the last Data block in the frame in order to fill out the frame to an integer number of blocks. The Pad word shall be a 16-bit integer with a value of zero. The Pad words are scrambled by the PHY prior to transmission. The Pad words may be discarded by the aircraft receiver.

4.1.3 Preamble (PREA) Frame Structure

In order to maintain continuous and synchronous transmission on the uplink, Preamble Frames are inserted to fill any gaps between Data Frames. The Preamble frame is a one block frame and shall have the structure shown in **Figure 7**. The Preamble frame consists of the six mandatory generic Header words, the Aircraft and Sonobuoy physical addresses, a 16-bit CRC, and a 24-word Preamble Body.

The Aircraft and Sonobuoy physical addresses are as specified in section 4.3.1. The CRC, as specified in section 4.3.6, is computed over the Aircraft and Sonobuoy physical addresses. The Preamble Body is obtained by applying the FEC encoder of section 4.2.3 and the PRB scrambler of section 4.2.5 to a sequence of Pad words, with the scrambler Initial State Indicator of zero, ScrSN= 0.

The FEC encoding shall begin with word #6 of the frame, the first word of the Aircraft and Sonobuoy Physical Addresses. The default FEC rate shall be rate 1 (no FEC encoding). The FEC rate used for the Preambles can be changed using the DLL parameter preaFECRate (see section 5.2.5.3). The support for one or more of the FEC code rates in a particular sonobuoy is optional (as defined in section 4.2.3).

The Preamble frame is generally static and only changes when either the Sonobuoy or Aircraft address changes or the FEC rate selection is changed.

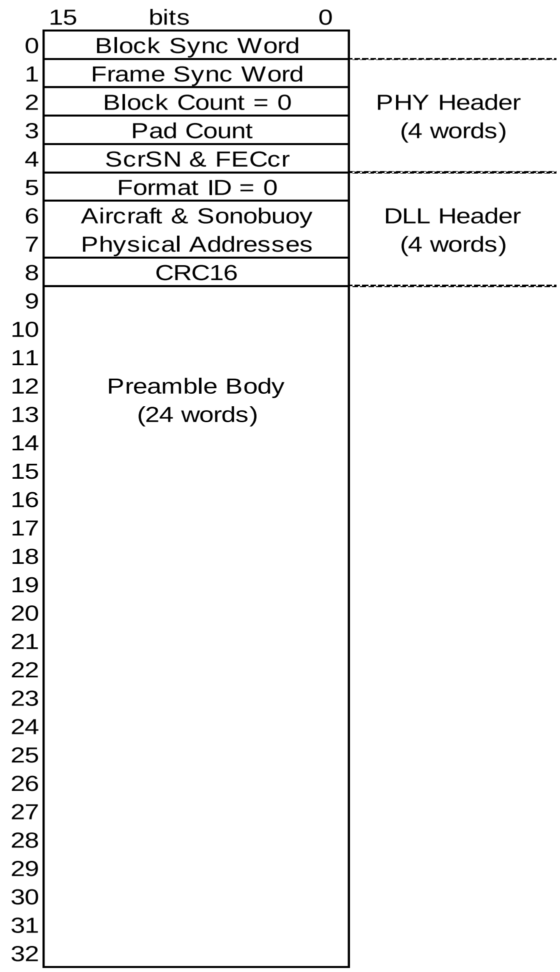


Figure 7. Uplink Preamble frame

The contents of the Preamble Body shall be as shown in **Table 4**.

FEC Rate	preaFECRate Indicator	Number of Pad Words Input to FEC Encoder	Number of Pad Words Inserted After FEC Encoding
1	1	24	0
7/8	2	20	0
3/4	3	16	1
1/2	4	10	0

Table 4. Contents of the Preamble Body

4.1.4 Streaming Data Format (SDF) Frame Structure

The SDF frame is used to transmit a continuous flow of acoustic data to the aircraft. An SDF frame consists of a Header block followed by as many as 31 Data blocks. The SDF frame shall have the structure shown in **Figure 8**.

The Header block of the SDF frame contains the mandatory 6 generic header words followed by the start of the acoustic payload. Aircraft and sonobuoy addresses are not included in the header in order to minimize the number of overhead words.

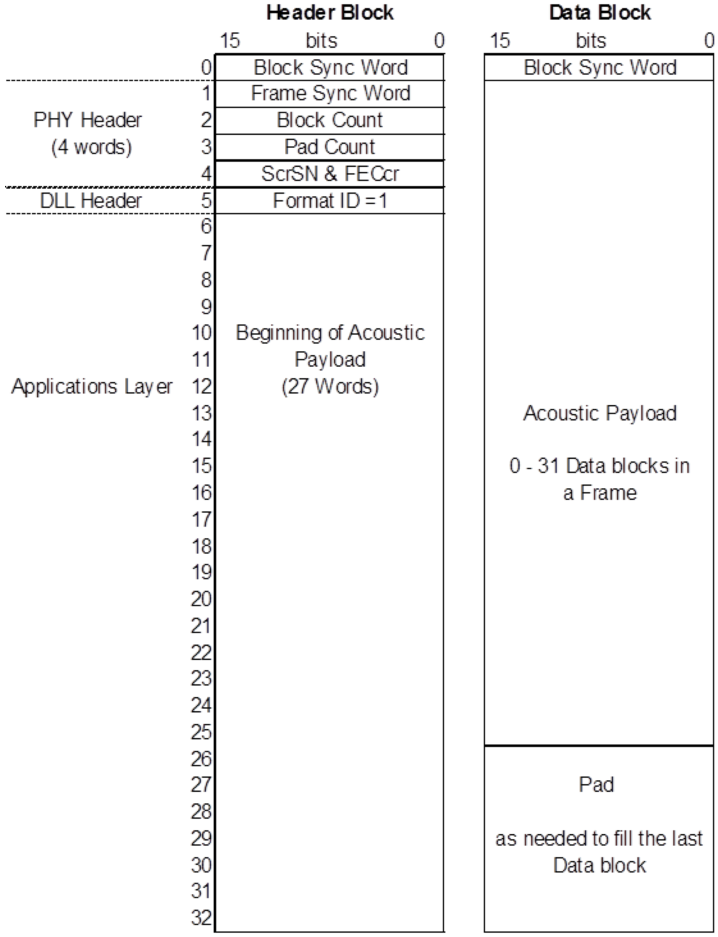


Figure 8. Uplink SDF frame structure

4.1.5 Data Message Format (DMF) Frame Structure

The DMF frame on the uplink is used to send non-acoustic messages such as GPS data, engineering data, buoy status information, buoy responses to downlink commands, and high integrity data requiring reliable transmission.

The structure of the DMF header block shall be as shown in **Figure 9.**

The header words consist of the 6 mandatory generic header words, followed by the Aircraft and Sonobuoy physical addresses and a DMF Control word. The remainder of the Header block contains the Message payload which is continued in additional Data blocks as necessary.

A 16-bit CRC follows the Message payload. The CRC shall be computed over the Aircraft and Sonobuoy physical addresses, the DMF Control word, and the Message payload using the algorithm specified in section 4.3.6.

The format of the Aircraft and Sonobuoy physical addresses is specified in section 4.3.1.

The format of the DMF Control word is specified in section 4.3.2.

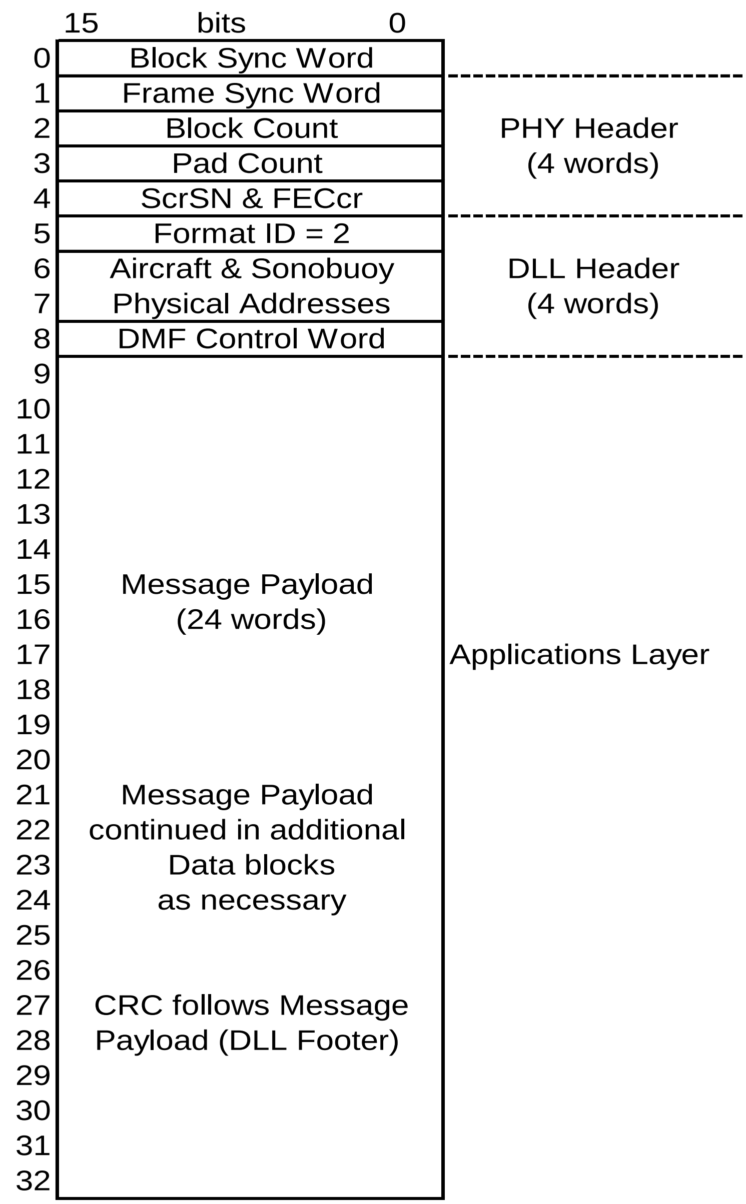


Figure 9. Uplink DMF header block structure

4.1.6 Link Management Format (LMF) Frame Structure

The LMF frame on the uplink is used to send messages from the DLL in the buoy to the DLL in the aircraft for purposes of managing the uplink. One such message is an acknowledgement to a downlink transmission.
The structure of the LMF header block shall be as shown in **Figure 10.**

The header words consist of the 6 mandatory generic header words, followed by the Aircraft and Sonobuoy physical addresses and an LMF Control word. The remainder of the Header block contains the Message payload, which is continued in additional Data blocks as necessary.

A 16-bit CRC follows the Message payload. The CRC shall be computed over the Aircraft and Sonobuoy physical addresses, the LMF Control word, and the Message payload using the algorithm specified in section 4.3.6.

The format of the Aircraft and Sonobuoy physical addresses is specified in section 4.3.1.

The format of the LMF Control word is specified in section 4.3.2.

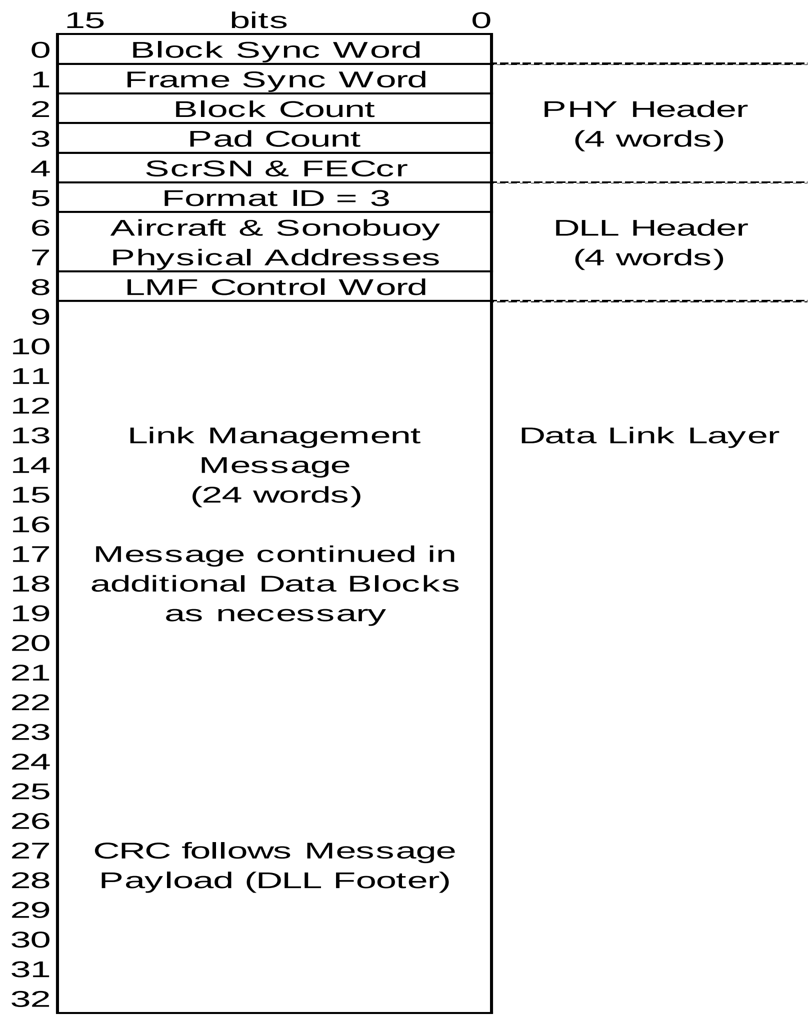


Figure 10. Uplink LMF header block structure

4.1.7 UDP/IP Frame Structure

The Generic uplink frame structure as specified in section 4.1.2 can support UDP/IP as an optional protocol in the future. **Figure 11** shows the notional header structure for an uplink frame that uses UDP/IP. The NTL header is comprised of the IPv4 header, the UDP header, and a 16-bit CRC. The CRC is computed over the Aircraft and Sonobuoy addresses, the IPv4 header, and the UDP header.

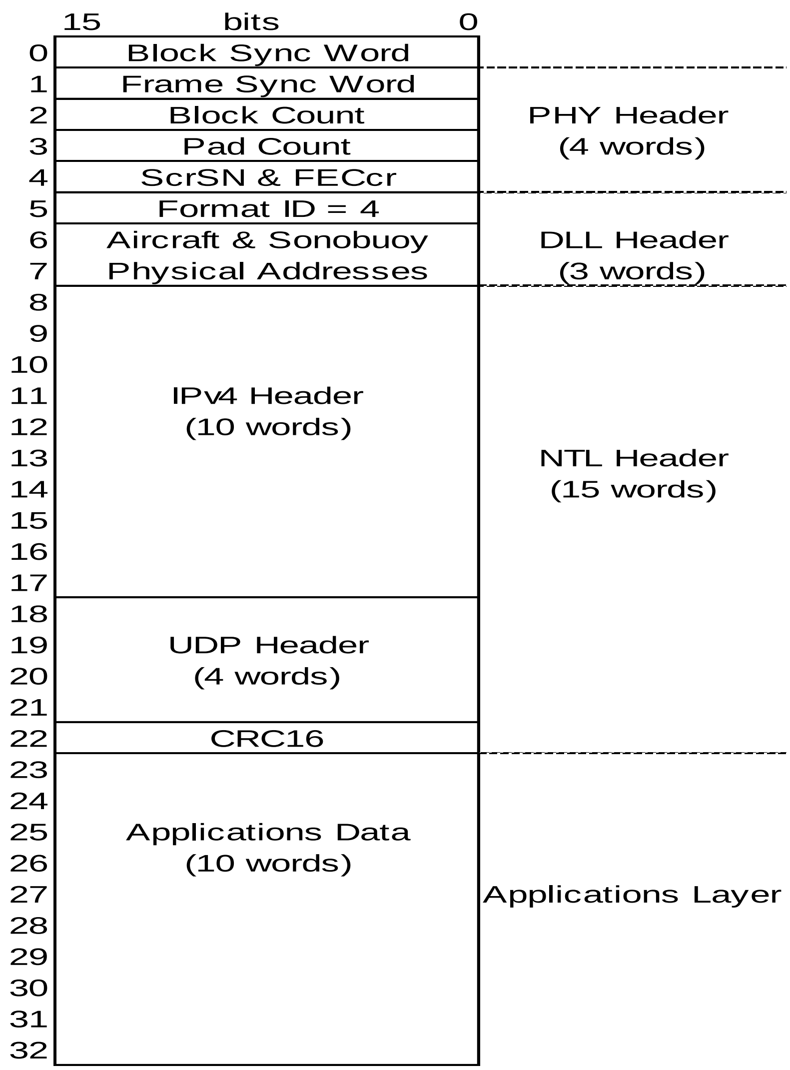
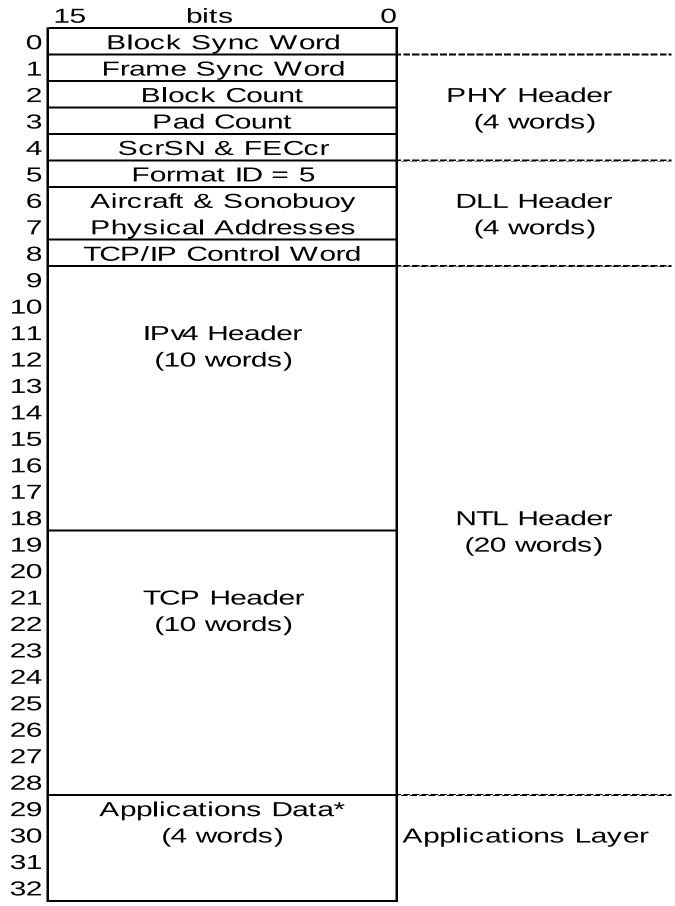


Figure 11. Uplink UDP/IP frame header structure (future capability)

4.1.8 TCP/IP Frame Structure

The Generic uplink frame structure as specified in section 4.1.2 can support TCP/IP as an optional protocol in the future. **Figure 12** shows the notional header structure for an uplink frame that uses TCP/IP. The TCP/IP control word specifies whether ARQ and message fragmentation are being utilized. If fragmentation is being used, the IPv4 and TCP headers will only be included in the first transmission frame of the fragmented DLL SDU.



*CRC16 at end of Applications Data (DLL Footer)

Figure 12. Uplink TCP/IP frame header structure (future capability)

4.2 Uplink Physical Layer (PHY)

4.2.1 Uplink Waveform

4.2.1.1 RF Frequencies

The uplink shall operate on any of the 99 standard sonobuoy VHF RF channels, at 375 kHz spacing, as defined in ANEP-80.

4.2.1.2 Transmission Data Rates

The Normal or default over the air transmission data rate shall be 320 kbps.

Allowable reduced transmission rates shall be 256 kbps, 192 kbps, 128 kbps, and 64 kbps.

The transmission rates supported by a particular sonobuoy type may be tailored to the needs of that sonobuoy.

4.2.1.3 Transmission Rate Tolerance

The transmitted bit rate shall be accurate to within +/- 25 ppm.

4.2.1.4 Uplink Sub-Channels

The uplink may operate centered on any of 5 sub-channels, spaced at 75 kHz within each of the standard 99 sonobuoy channels.

When sub-channels are used, the sonobuoy channels shall be denoted as follows:

RF channel = mc.sc, e.g. 32.1

Where mc is the main channel number and sc is the sub-channel identifier.
Sub-channel frequency offsets shall be identified as follows:

sc=1 is -150 kHz
sc=2 is -75 kHz
sc=3 is 0 kHz
sc=4 is 75 kHz
sc=5 is 150 kHz

The sub-channels shall be restricted to be fully contained within the 375 kHz main channel. This means that there are no sub-channels for the 320 kbps and 256 kbps rates (sc=3 is the only selection). For the 192 kbps rate there is one sub-channel available with sc=2, 3, or 4. For the 128 kbps rate, there is one sub-channel available with sc=2, 3, or 4 or two sub-channels available concurrently with sc=2 and 4. For the 64 kbps rate, there are 5 sub-channels available concurrently.

The support for sub-channels in the sonobuoy is optional.

4.2.1.5 Modulation

The uplink waveform shall be a binary coherent Gaussian Frequency Shift Keying (GFSK) modulation, with a modulation index of exactly h=3/4 and a pulse shaping corresponding to using a Gaussian pre-modulation filter with a bandwidth-time product of nominally BT = 0.315. A bit value of 0 shall correspond to a negative frequency deviation and a bit value of 1 shall correspond to a positive frequency deviation.

Compliance with this requirement shall be demonstrated by reference to the transmitted discrete phase constellation diagram, with the phase samples aligned with the zero crossings of the corresponding instantaneous FM waveform. The resulting phase constellation shall be focused at eight phase values, separated by 45 degrees, to within a tolerance of +/- 5 degrees at each focal point.

4.2.1.6 Adjacent Channel Leakage

When operating at a transmission bit rate of 320 kbps, at zero center frequency offset, with a random data stream, the proportion of power falling in a rectangular RF bandwidth of 375 kHz, centered in either of the adjacent 375 kHz channels, shall not exceed -26 dB. This allows for 1dB of degradation relative to the theoretical performance of the waveform.

The leakage into any other RF channel shall not exceed -50 dB.

When operating at a reduced transmission rate, the adjacent channel bands shall scale proportional to the ratio of the reduce transmission rate to the Normal rate of 320 kbps.

4.2.1.7 Center Frequency Error

The center frequency error shall not exceed +/- 4.5 kHz.

4.2.2 Formation of a Transmission Frame

The data that is passed from the DLL to the PHY for transmission is the MPDU, which consists of all of the data shown in the Generic frame format of **Figure 5** beginning with word 5 in the Header block (the Format ID) down to the start of the PAD in the last Data block. The PHY completes the formation of the transmission frame by performing the following sequence of operations:

- Convolutional encoding of the MPDU if FEC is selected.
- Append Pad words as needed to fill out the last Data block.
- Scramble the FEC encoded data and the Pad.
- Add the encoded PHY header words at the beginning of the data.
- Interleave the data.
- Insert the Block Sync word at the beginning of each 512-bit block of data to form 528-bit data blocks that make up the transmission frame.
- Modulate and transmit the frame of data.

4.2.3 Forward Error Correction (FEC) Coding

This standard provides for optional Convolutional FEC in the sonobuoy. There shall be three choices of code rates: 1/2, 3/4, and 7/8. The code rates of 7/8 and 3/4 shall be obtained using puncturing of the rate 1/2 encoder output. The support of one or more of these code rates in a particular sonobuoy is optional.

The code rate used for the frame shall be indicated by the FECcr field that is in the fifth word of the Header block using the values shown in **Table 5.**

FECcr	Code Rate
0	1 (No FEC)
1	7/8
2	3/4
3	1/2
4-7	Reserved

Table 5. FEC code rate indicator

The rate 1/2 encoder with a memory length of 6 shall have the form shown in **Figure 13**. The summations are modulo-2 with the outputs being either 0 or 1. For each bit input to the encoder, two bits are taken from the encoder with the upper bit C0 taken first. The resulting output bit stream is bits_out = C0(1), C1(1), C0(2), C1(2), …

The generating polynomials for this encoder shall be (octal format)

$$g_0 = 133$$
$$g_1 = 171$$

or in polynomial form

$$g_0(x) = 1 + x^2 + x^3 + x^5 + x^6$$
$$g_1(x) = 1 + x + x^2 + x^3 + x^6$$

These polynomials in binary format indicate the connections, left-to-right, of the shift register to the summers as shown in **Figure 13**.

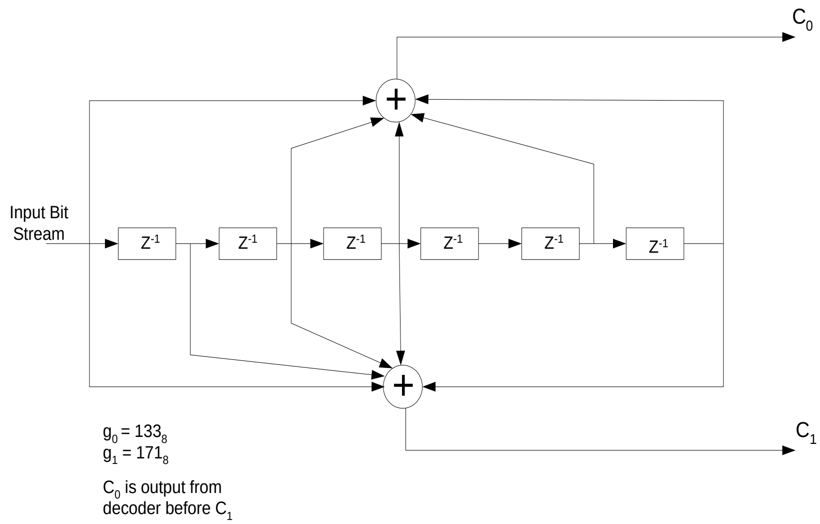


Figure 13. Rate 1/2 Convolutional encoder

The starting state of the encoder shall be all zeros in the shift register. At the end of the encoding, the encoder shall be returned to the all zero state by inserting 8 zero-valued bits into the end of the bit stream. This process is used to provide the same quality of error correction to the last few bits as to the rest of the data. This process will produce 16 additional bits (1 additional word) out of the encoder.

Puncturing shall be used to obtain the rate 7/8 and rate 3/4 encoding. Puncturing involves deleting certain bits at the output of the rate ½ encoder in order to obtain the desired code rate. The puncturing is performed by applying a repetitive mask to the rate 1/2 encoder output bit stream, bits_out.

The puncture mask for the rate 7/8 code shall be the 14-bit pattern 11101010011001 and the puncturing mask for the rate 3/4 code shall be the 6-bit pattern 111001. Bits that align with the zeros in the masks are discarded. For example if b0, b1, b2, b3, b4, b5 are the first 6 bits out of the rate 1/2 encoder, the output from the rate 3/4 code puncturing will be b0, b1, b2, b5.

When the input to the encoder is an integer number N of 16-bit words, the output of the rate 1/2 encoder will be 2N+1 words. The output from the rate 3/4 and rate 7/8 punctured encoders will not always be an integer number of 16-bit words. When this condition occurs, zero-valued bits shall be used extend the output to an integer number of words. The number of output words will then be ceil[(2/3)(2N+1)] for the rate 3/4 encoder and ceil[(4/7)(2N+1)] for the rate 7/8 encoder, where ceil[a] is the smallest integer greater than or equal to a.

The first word in the MPDU that is passed down from the DLL is the Format ID word. FEC encoding shall begin with word # 6 of **Figure 5**, the first word following the Format ID word, and shall include the remainder of the MPDU. The 16-bit words shall be input to the encoder MSB first.

The FEC encoder and the puncture pattern shall be reset at the start of each frame.

4.2.4 Insertion of Pad Words

Sixteen-bit, zero-valued pad words shall be inserted as needed into the end of the last Data block in the frame in order to fill out the frame to an integer number of blocks.

4.2.5 Data Scrambler

Following the insertion of Pad words, a frame synchronous data scrambler shall be used to whiten the waveform spectrum of the data frames by reducing the occurrence of long sequences of either 1's or 0's in the transmitted data stream. The scrambler shall randomize the data by adding modulo 2 (XOR) the input data for transmission with a pseudo-random bit sequence (PRBS).

The generator polynomial for the PRBS shall be

$$g(x) = x^{15} + x + 1 .$$

This polynomial defines a linear feedback shift register (LFSR) configuration of the form shown in **Figure 14**. This LFSR generator will produce a maximal length PRBS of length 215-1 bits.

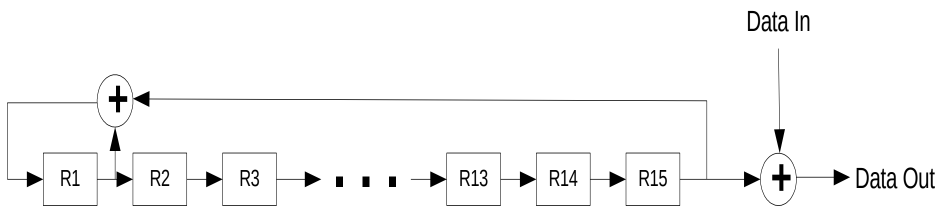


Figure 14. PRB data scrambler

At the start of each frame the LFSR shall be loaded with one of 4 possible initial states. These states shall be as listed in **Table 6.**

State #	LFSR Registers														
(ScrSN)	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15
0	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
1	1	0	1	0	1	1	1	1	1	1	1	1	0	1	0
2	1	1	1	1	1	1	1	1	1	0	1	0	1	0	1
3	0	1	0	1	0	1	0	1	0	0	0	0	0	1	0

Table 6. Scrambler Initial States

The state number (ScrSN) shall be sequentially incremented by one, modulo 4, for each successive frame, excluding Preamble frames. Preamble frames are always scrambled with state number zero.

As an example, if an SDF frame that is scrambled with ScrSN=2 is followed by a Preamble frame which is then followed by another SDF frame, the Preamble frame would be scrambled with ScrSN=0 and the second SDF frame would be scrambled with ScrSN=3. If the second SDF frame were then followed by a DMF frame, that frame would be scrambled with ScrSN=0.

The first 32 bits out of the LFSR when ScrSN=0 are 0101 0101 0101 0100 1100 1100 1100 1110 or 0x5554 CCCE.

The PRBS generated by the LFSR shall be XORed with all of the data in the frame beginning with the 7th word in the header block (the word following the Format ID), but prior to the insertion of the Block Sync word at the beginning of each Data block. The 16-bit words shall be passed through the scrambler MSB first.

4.2.6 Header Word Encoding

The Block Count, Pad Count, Scrambler Initial State-FEC Code Rate, and Format ID are 5-bit values that shall be encoded to 16-bit words using the distance-8 32-word code set shown in **Table 7**.

The header words should be decoded by choosing the code word which is the best match.

5-bit Integer	Binary Value (MSB first)	Hex Value
0	0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1	0x1111
1	0 0 0 1 0 0 0 1 1 1 1 0 1 1 1 0	0x11EE
2	0 0 0 1 1 1 1 0 0 0 0 1 1 1 1 0	0x1E1E
3	0 0 0 1 1 1 1 0 1 1 1 0 0 0 0 1	0x1EE1
4	0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0	0x2222
5	0 0 1 0 0 0 1 0 1 1 0 1 1 1 0 1	0x22DD
6	0 0 1 0 1 1 0 1 0 0 1 0 1 1 0 1	0x2D2D
7	0 0 1 0 1 1 0 1 1 1 0 1 0 0 1 0	0x2DD2
8	0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0	0x4444
9	0 1 0 0 0 1 0 0 1 0 1 1 1 0 1 1	0x44BB
10	0 1 0 0 1 0 1 1 0 1 0 0 1 0 1 1	0x4B4B
11	0 1 0 0 1 0 1 1 1 0 1 1 0 1 0 0	0x4BB4
12	0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1	0x7777
13	0 1 1 1 0 1 1 1 1 0 0 0 1 0 0 0	0x7788
14	0 1 1 1 1 0 0 0 0 1 1 1 1 0 0 0	0x7878
15	0 1 1 1 1 0 0 0 1 0 0 0 0 1 1 1	0x7887
16	1 0 0 0 0 1 1 1 0 1 1 1 1 0 0 0	0x8778
17	1 0 0 0 0 1 1 1 1 0 0 0 0 1 1 1	0x8787
18	1 0 0 0 1 0 0 0 0 1 1 1 0 1 1 1	0x8877
19	1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0	0x8888
20	1 0 1 1 0 1 0 0 0 1 0 0 1 0 1 1	0xB44B
21	1 0 1 1 0 1 0 0 1 0 1 1 0 1 0 0	0xB4B4
22	1 0 1 1 1 0 1 1 0 1 0 0 0 1 0 0	0xBB44
23	1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1	0xBBBB
24	1 1 0 1 0 0 1 0 0 0 1 0 1 1 0 1	0xD22D
25	1 1 0 1 0 0 1 0 1 1 0 1 0 0 1 0	0xD2D2
26	1 1 0 1 1 1 0 1 0 0 1 0 0 0 1 0	0xDD22
27	1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1	0xDDDD
28	1 1 1 0 0 0 0 1 0 0 0 1 1 1 1 0	0xE11E
29	1 1 1 0 0 0 0 1 1 1 1 0 0 0 0 1	0xE1E1
30	1 1 1 0 1 1 1 0 0 0 0 1 0 0 0 1	0xEE11
31	1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0	0xEEEE

Table 7. Code words for 5-bit integers

4.2.7 Data Interleaver

Each Data block in a transmission frame is made up of a 16-bit Block Sync word followed by a 512-bit block of header words and data or just data. This 512-bit data block shall be interleaved using a 16x32 matrix interleaver in which the data is read into the matrix row by row and read out column by column. The input to the interleaver matrix are Words 1 through 32 of each Data Block. The words are read into the matrix by row as shown in **Figure 15** and then read out by column. In the figure B (k,n) denotes bit number n of word k with the words numbered from 1 through 32 and the bits numbered from 15 (MSB) through 0 (LSB).

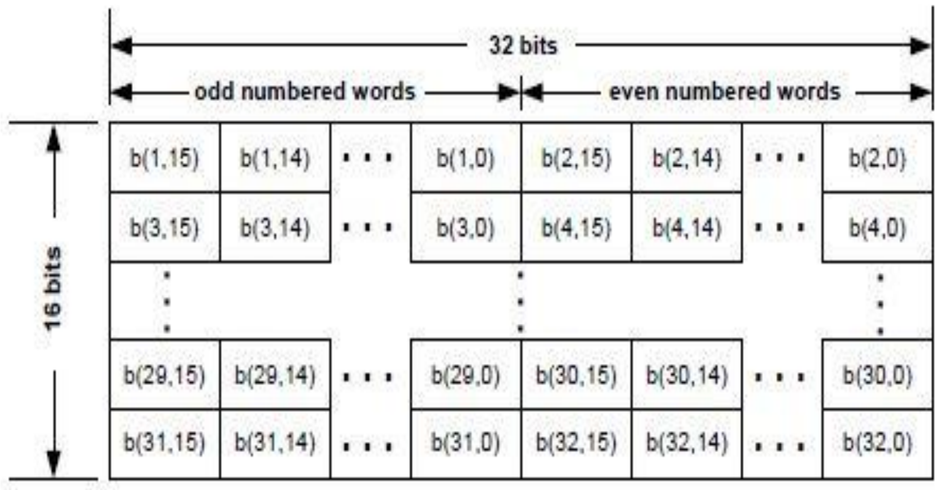


Figure 15. Block interleaver matrix

The output of the interleaver will be the bit sequence

b(1,15), …, b(3,15), …, b(31,15), …, b(1,14), …, b(3,14), …, b(31,14), …, b(1,0), b(3,0), …, b(31,0), …, b(2,15), …, b(4,15), …, b(32,15), …, b(2,14), …, b(2,14), …, b(32,14), …, b(2,0), …, b(4,0), …, b(32,0).

4.3 Uplink MAC Protocol (ULMP)

The ULMP is responsible for the following functions:

- Generating and maintaining a sonobuoy physical address.
- Fragmentation of a higher layer SDU into smaller MPDUs and reassembly of MPDUs into a higher layer SDU.
- Error detection and the selective retransmission of MPDUs using an ARQ process.
- Detection and discarding of duplicate MPDUs when using selective retransmission.
- Reordering and reassembly of received MPDUs when using selective retransmission.

4.3.1 Aircraft and Sonobuoy Physical Addresses

An Aircraft destination and a Sonobuoy source physical address shall be included in the DLL header of all uplink Preamble, DMF, and LMF frames.

The address fields shall occupy two 16-bit words as shown in **Figure 16**. The Aircraft physical address is an 8-bit word that occupies the upper byte of the first 16-bit word. The Sonobuoy physical address is a 24-bit word that occupies the lower byte of the first 16-bit word and the two bytes of the second 16-bit word.

On the uplink, the buoy shall echo the most recent aircraft address that it has received on the downlink. If it has not received any downlink transmissions, it shall use the default aircraft address of zero (0x00).

Aircraft Address (8 bits)	Buoy Address (Upper 8-bits)
Buoy Address (Middle 8 bits)	Buoy Address (Lower 8 bits)

Figure 16. Aircraft and buoy address field structure

A 24-bit buoy-unique physical address shall be used for the sonobuoy. This address shall be a 24-bit hardware address assigned to the buoy or a buoy generated physical address if the buoy has not been assigned a hardware address. The buoy generated physical address shall consist of the 8-bit initial RF channel number InitRF of the buoy followed by a 16-bit integer randomly chosen from the interval [1 65534].

Reserved buoy addresses are as follows:

An address with the number 0xFFFF in the lower 16 bits shall be reserved for use on the downlink to indicate a broadcast address to all sonobuoys with an initial RF channel assignment of InitRF.

An address with the number 0xFFFFFF (all ones) shall be reserved for use on the downlink to indicate a broadcast message to all sonobuoys regardless of their initial RF channel assignments.

An address of all zeros shall be reserved as a default uninitialized address for use with test equipment and simulators

4.3.2 Uplink DMF Control Word

The DMF Control word shall have the format shown in **Figure 17**. The sub-fields of the control word are as follows:

AM is a 1-bit **Acknowledge Mode** flag. AM=1 indicates that an acknowledgement is requested for the frame; AM=0 indicates that no acknowledgement is requested. The ARQ algorithm of section 4.3.5 shall be used when AM=1.

SN is a free running 7-bit **Sequence Number** field that is sequentially incremented, modulo 128, with each new DMF or LMF frame. SN is incremented even when AM=0.

FC is a 2-bit **Fragmentation Control** field that has the following values:

00 – denotes no fragmentation

01 – denotes the first segment of a fragmented SDU

10 – denotes a continuing segment of a fragmented SDU

11 – denotes the last segment of a fragmented SDU

R is a 6-bit **Reserved** field for future use**.**

AM (1 bit)	SN (7 bits)	FC (2 bits)	R (6 bits)

Figure 17. DMF Control word structure

4.3.3 Uplink LMF Control Word

The LMF Control word shall have the format detailed in **Figure 18**. The sub-fields of this control word are as follows:

AM is a 1-bit **Acknowledge Mode** flag. AM=1 indicates that an acknowledgement is requested for this frame; AM=0 indicates that no acknowledgement is requested. The ARQ algorithm of section 4.3.5 shall be used when AM=1.

SN is a free running 7-bit **Sequence Number** field that is sequentially incremented, modulo 128, with each new DMF or LMF frame. SN is incremented even when AM=0.

MsgID is a 6-bit LMF message identifier.

R is a 2-bit reserved field for future use.

AM (1 bit)	SN (7bits)	MsgID (6 bits)	R (2 bits)

Figure 18. LMF Control word structure

4.3.4 SDU Fragmentation

MAC SDU fragmentation and reassembly shall be supported for large DMF SDUs. This functionality is provided so that large DMF messages from the buoy can be split into smaller frames that can be interleaved between SDF frames. The reassembly in the aircraft is controlled by the FC field and the sequence numbers in the DMF control word as specified in section 4.3.2.

The use of fragmentation shall be controlled by an upFragMax parameter which specifies the maximum size in Data blocks allowed for a DMF frame. Whenever a DMF SDU requires a larger frame size, the SDU shall be fragmented and transmitted using multiple frames. The determination of SDU frame size shall account for any use of FEC.

When SDU fragmentation is used in conjunction with ARQ, the ULMP in the aircraft shall reassemble the fragments in the correct order according to the frame sequence numbers (SN) and shall discard any duplicate error-free fragments that may be received due to retransmissions.

4.3.5 Uplink Automatic Repeat Request (ARQ)

Reliable uplink transmission of high integrity messages is provided at the Data Link Layer for DMF and LMF transmissions when using the Acknowledge mode (AM=1) with ARQ. Each frame of a DMF or LMF message contains the AM flag, an FC field, and a sequence number as part of the DLL control word (section 4.3.2). In the Acknowledged mode, when an uplink frame is received at the aircraft and the CRC check passes, an acknowledgement (ACK) shall be sent to the buoy over the downlink. If the CRC check fails, a NACK shall be sent to the buoy and the buoy shall retransmit the frame.

The ARQ process is a selective-repeat type of sliding window algorithm. Because frame sequence numbers are assigned using modulo arithmetic, it is convenient to represent the sliding window as a segment of a circular buffer. This buffer contains the sequence numbers of those frames awaiting acknowledgement along with the number of transmission tries and the transmission time for each of the frames.

The ARQ process shall operate according to the following rules:

- Sequence numbers shall be assigned sequentially to new frames modulo 128.
- In a buoy the window size is variable and shall not exceed winMax.
- When an ACK is received for a frame, the sequence number for that frame is removed from the window.
- When a NACK is received for a frame, the frame is retransmitted with the same sequence number if the number of tries is less than upRetryMax. Otherwise the sequence number for that frame is removed from the window and the frame is discarded.
- When the elapsed time since the last transmission of a frame in the window is greater than upEtMax, the frame is retransmitted with the same sequence number if the number of tries is less than upRetryMax. Otherwise the sequence number for that frame is removed from the window and the frame is discarded.
- The transmit lower window edge (txLwe) shall indicate the “oldest” unacknowledged frame, allowing for the modulo 128 sequence number operation.
- The transmit upper window edge (txUwe) shall indicate the last new frame that was transmitted that requires acknowledgement.

- When the distance (in a modulo 128 sense) between txUwe and txLwe is equal to winMax, no additional new frames requiring acknowledgment shall be transmitted until txLwe is advanced and the distance is less than winMax.

The support for ARQ on the uplink is optional in a sonobuoy.

4.3.6 Cyclic Redundancy Check (CRC)

The Message Payload of every DMF and LMF frame shall be followed by a 16-bit CRC. The CRC shall be calculated using the CCITT V.41 standard polynomial $x^{16} + x^{12} + x^{5} + 1$. When calculating the CRC, the initial value shall be zero.

Annex C contains example C code for the CRC computation.

4.3.7 LMF Uplink Messages

LMF uplink frames are used to send messages from the DLL in the buoy to the DLL in the aircraft for purposes of managing the telemetry link. The message type is defined by the MsgID field in the LMF control word (section 4.3.3). The LMF control word is followed by the message body which shall consist of an integer number of bytes. If the length of the message body is an odd number of bytes, a one byte pad of zero shall be appended to the end of the message body so as to fill out the final 16-bit frame word. The message body is then followed by the 16-bit CRC of section 4.3.6.

4.3.7.1 ARQ Response Message

The uplink LMF ARQ Response message is the response to a downlink message or message segment that requests DLL acknowledgement. The message type shall be MsgID = 1 (0x01). The fields of the message body shall be:

AN – a 1-bit AKC/NACK field with AN=1 denoting positive acknowledgement (CRC passed) and AN=0 denoting negative acknowledgement (CRC failure).

BSN – the 7-bit buoy sequence number of the downlink message or message segment being acknowledged.

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Chapter 5: Downlink

The downlink from the aircraft to the sonobuoys is a single UHF RF channel over which messages and commands are broadcast to all of the buoys as burst transmissions. The unit of transmission on the downlink is denoted as the PHY packet.

5.1 Downlink Physical Layer (PHY)

5.1.1 Downlink Waveform

The downlink carrier frequency shall be 291.4 MHz. The carrier frequency accuracy shall be +/- 1450 Hz (5 ppm).

The transmission data rate shall be 9600 bps with an accuracy of +/- 25 ppm.

The modulation shall be continuous phase frequency shift keying (CPFSK) of a binary NRZ coded waveform. The peak frequency deviation shall be 3360 Hz +/- 65 Hz (i.e. a modulation index of h~0.7).

A bit value of zero shall correspond to a negative frequency deviation and a bit value of one shall correspond to a positive frequency deviation.

Pre-modulation filtering may be performed on the NRZ baseband waveform such that the equivalent lowpass filter has a 3 dB bandwidth > 9.6 kHz (i.e. BT > 1), and has linear phase within +/- 10 degrees over the frequency range 0 to 12 kHz.

5.1.2 Downlink Packet Structure

Each downlink PHY packet shall consist of a PHY Header followed by a PHY Payload as shown in **Figure 19.**

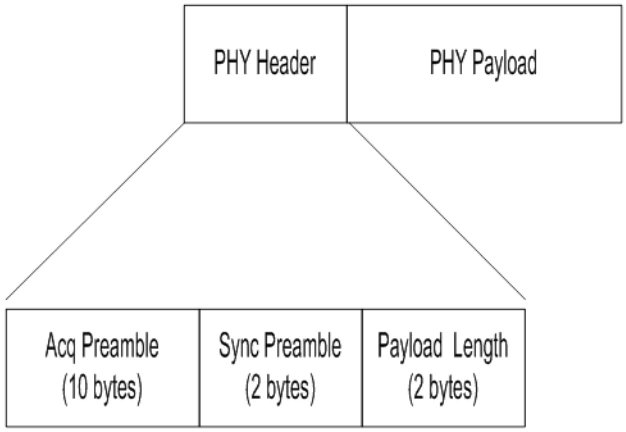

Figure 19. Downlink packet structure

The PHY packet shall contain the following fields:

Acq Preamble – This is a 10-byte acquisition preamble that consists of an alternating zero-one bit pattern. The transmitted bit sequence shall be [01010101] repeated 10 times.

Sync Preamble – A 2-byte synchronization preamble is used to identify the start of the packet and to indicate whether FEC has been applied to the PHY Payload. The Sync Preamble shall be as shown in **Table 8**. The Sync Preamble shall be transmitted as a 16-bit word, MSB first.

	Binary Value (MSB first)	**Hex Value**
No FEC	0000 0110 1011 0111	0x06B7
With FEC	1111 1001 0100 1000	0xF948

Table 8. Downlink synchronization preambles

A buoy shall process the downlink transmission with both preambles in order to determine whether or not FEC has been applied to the packet.

Payload Length – A 2-byte payload length field that specifies the length of the PHY Payload in bytes before FEC encoding. The Payload Length field shall be transmitted one byte at a time, MSB first. The maximum value for the Payload Length shall be 2047 bytes.

The Payload Length value shall be encoded using a (16,11) systematic linear block code. The 2-byte Payload Length field shall consist of the Payload Length value [L10, L9, …, L0] in the lower 11 bits of the field and the five parity bits [P4, P3, P2, P1, P0] in the upper 5 bits.

The code generator matrix shall be as shown in **Table 9**. This code is a variant of an Extended Hamming code with a minimum distance of 4, and so may be used to detect up to 3 bit errors, or to detect 2 bit errors and correct 1 bit error.

The parity bits shall be computed as follows (⊕ denotes XOR):

$P4 = L10 \oplus L9 \oplus L6 \oplus L4 \oplus L3 \oplus L2 \oplus L0$

$P3 = L10 \oplus L9 \oplus L8 \oplus L6 \oplus L5 \oplus L2 \oplus L1$

$P2 = L10 \oplus L9 \oplus L8 \oplus L7 \oplus L5 \oplus L4 \oplus L0$

$P1 = L10 \oplus L8 \oplus L7 \oplus L6 \oplus L4 \oplus L3 \oplus L1$

$P0 = L10 \oplus L7 \oplus L5 \oplus L3 \oplus L2 \oplus L1 \oplus L0$

	P4	P3	P2	P1	P0	L10	L9	L8	L7	L6	L5	L4	L3	L2	L1	L0
L10	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
L9	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0
L8	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0
L7	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0
L6	1	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0
L5	0	1	1	0	1	0	0	0	0	0	1	0	0	0	0	0
L4	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0
L3	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0
L2	1	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0
L1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0
L0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1

Table 9. Payload Length code generator matrix

Each of the five parity bits is computed over 7 bits and should yield EVEN parity.
When FEC encoding is used (section 5.1.4), the 2-byte Payload Length field (containing the 11-bit payload length value and the 5 parity bits) will be expanded to four bytes.

PHY Payload – This is formed by applying a data scrambler and FEC encoder to the MPDU that is passed from the DLL to the PHY. The PHY Payload shall be transmitted a byte at a time, MSB first.

5.1.3 Data Scrambler

A data scrambler shall be applied to the MPDU to whiten the waveform spectrum of the transmitted packet by reducing the occurrence of long sequences of either 1's or 0's in the transmitted bit stream. The scrambler shall be the same as the one used on the uplink (section 4.2.5). The scrambler initial state shall be set to state #0 of **Table 10** at the start of each packet. The scrambler shall be applied to the MPDU in bit transmission order.

State # (ScrSN)	LFSR Registers														
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15
0	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
1	1	0	1	0	1	1	1	1	1	1	1	1	0	1	0
2	1	1	1	1	1	1	1	1	1	0	1	0	1	0	1
3	0	1	0	1	0	1	0	1	0	0	0	0	0	1	0

Table 10. Scrambler Initial States

5.1.4 Forward Error Correction (FEC) Coding

Convolutional FEC shall be a selectable capability on the downlink. If FEC is selected, the 16-bit PHY Payload Length field and the scrambled MPDU shall be processed with a rate 1/2 convolutional encoder. The encoder shall be the same as that specified for the uplink in section 4.2.3. At the end of the encoding, the encoder shall be returned to the all zero state by inserting 8 zero-valued bits into the end of the bit stream. This process will produce 2 additional bytes out of the encoder.

The inclusion of FEC decoding capability in a sonobuoy is optional. When a buoy without FEC decoding capability detects a packet with FEC, it shall discard the packet.

5.2 Downlink MAC Protocol (DLMP)

The DLMP is responsible for the following functions:

- Generating and maintaining an aircraft physical address.
- Concatenation of messages to multiple buoys into a single MPDU.
- Fragmentation of a buoy message into smaller message segments and reassembly of the message segments into a complete buoy message.
- Error detection and the selective retransmission of buoy message segments using an ARQ process.
- Detection and discarding of duplicate buoy message segments when using selective retransmission.
- Reordering and reassembly of received buoy message segments when using selective retransmission.

5.2.1 MAC Protocol Data Unit (MPDU)

The MPDU is the unit of data passed from the DLL to the PHY to be scrambled and transmitted as a single packet. The structure of the MPDU shall be as shown in **Figure 20.**

A single MPDU will support the packing of messages or message segments to multiple buoys in a single transmission. The first byte in the MPDU is the source Aircraft address.

This is followed by one or more variable length messages. The last message is followed by a 16-bit CRC.

The message header shall consist of the following fields:

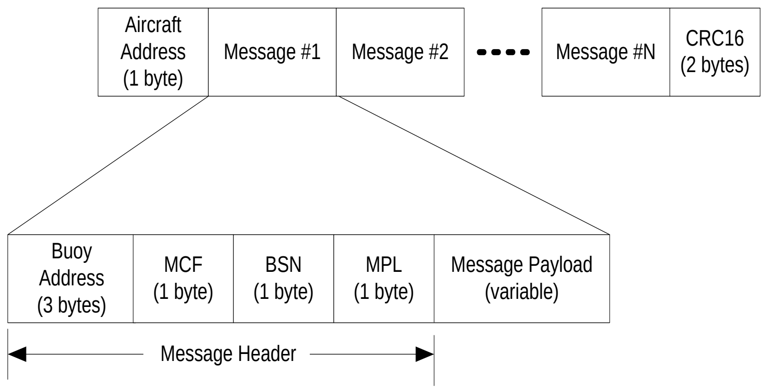

Figure 20. Downlink MPDU structure

Buoy Address – This is the 24-bit unique address of a specific sonobuoy or a broadcast address, as defined in section 4.3.1.

MCF – This is a 1 byte Message Control Field (section 5.2.1.1).

BSN – This is a 7-bit Buoy Sequence Number that increments modulo 128 with each successive new message to a particular buoy address (the upper bit of the BSN field is always zero). There shall be a separate sequence number maintained for each active buoy address.

MPL – This is an 8-bit Message Payload Length that specifies the length in bytes of the message payload. The maximum length of a message payload shall be 255 bytes.

5.2.1.1 Message Control Field (MCF)

The message control field (MCF) shall have the format shown in **Figure 21**.

The sub-fields of the MCF are as follows:

Format ID is a 4-bit integer that identifies the data type and format associated with the message. The values of the Format ID shall be as specified in **Table 11**.

AM is a 1-bit **Acknowledge Mode** flag. AM=1 indicates that an acknowledgement is requested for this message; AM=0 indicates that no acknowledgement is requested. The ARQ process of section 5.2.4 shall be used when AM=1.

FC is a 2-bit **Fragmentation Control** field that has the following values:

00 – denotes no fragmentation

01 – denotes the first segment of a fragmented message

10 – denotes a continuing segment of a fragmented message

11 – denotes the last segment of a fragmented message

R is a 1-bit reserved field for future use.

Format ID (4 bits)	AM (1 bit)	FC (2 bits)	R (1 bit)

Figure 21. Downlink message control field structure

0	Link Management Format (LMF)
1	Data Message Format (DMF)
2	Command Message Format (CMF)
3	UDP/IP
4	TCP/IP
5 thru 15	Reserved for future use

Table 11. Downlink message Format ID values

Downlink DMF and CMF messages and associated formats are unique to each sonobuoy type and should be defined in the specification for the specific sonobuoy.

5.2.2 Message Fragmentation

Downlink message fragmentation and reassembly shall be supported for DMF messages. This functionality is provided so that large DMF messages to the buoy can be split into smaller segments for more reliable transmission to the buoy and so that the message segment size is less than the maximum MPL of 255 bytes (section 5.2.1.1).

The reassembly of message segments in the buoy is controlled by the FC field and the buoy sequence numbers in the DMF control word as specified in section 5.2.1.1.

The use of fragmentation shall be controlled by a downFragMax parameter which specifies the maximum size in bytes allowed for a message segment. Whenever a DMF message is larger than this maximum size, it shall be fragmented and transmitted in multiple packets. The determination of the size of a message segment shall account for any bit growth due to FEC.

When message fragmentation is used in conjunction with ARQ, the DLMP in the sonobuoy shall reassemble the fragments in the correct order according to the buoy sequence numbers (BSN) and shall discard any duplicate error-free fragments that may be received due to retransmissions.

5.2.3 Cyclic Redundancy Check (CRC)

The MPDU is terminated with a 16-bit CRC. The CRC shall be calculated over the whole MPDU beginning with the Aircraft address. The CRC calculation shall be the same as specified for the uplink in section 4.3.6.

5.2.4 Downlink Automatic Repeat Request (ARQ)

Reliable downlink message transmission is provided at the Data Link Layer when using the Acknowledge mode (AM=1) with ARQ. When a message addressed to a particular buoy is received at the buoy with AM=1, the buoy responds by sending the ARQ Response message (section 4.3.7.1) back to the aircraft.

The downlink ARQ shall be a stop-and-wait type of process that operates according to the following rules:

- When a message with AM=1 is sent to a particular buoy, the aircraft shall wait for an ARQ response to that message before sending another new message requiring acknowledgement to that buoy.
- When an ACK is received from the buoy, the aircraft can increment the sequence number for that buoy and send a new message with AM=1 to the buoy.
- When a NACK is received, the aircraft shall retransmit the message with the same BSN if the number of tries is less than downRetryMax. Otherwise the message is discarded.
- When the elapsed time since the last transmission of the message becomes greater than downEtMax, the message is retransmitted with the same BSN if the number of tries is less than downRetryMax. Otherwise the message is discarded.

The aircraft shall maintain a separate sequence number for each buoy in the field.

5.2.5 Downlink LMF Message Payload

The Message payload for LMF messages shall have the structure shown in **Figure 22.**

MsgID (1 byte)	Message Body (variable bytes)

Figure 22. Downlink LMF message payload structure

5.2.5.1 ARQ Response Message

This LMF message is the response to an uplink frame that requests acknowledgement. This message can accommodate ARQ responses to multiple uplink frames. The format of the message payload shall be as shown in **Figure 23**.

The fields in the message payload are as follows:

MsgID = 1 (0x01)

AN – A 1-bit ACK/NACK field. AN=1 denotes an ACK and AN=0 denotes a NACK.

SN – The 7-bit uplink sequence number of the frame being acknowledged.
There is an AN/SN byte for each uplink frame being acknowledged.

MsgID = 0x01 (1 byte)	AN (1 bit)	SN (7 bits)	AN (1 bit)	SN (7 bits)	…	AN (1 bit)	SN (7 bits)

Figure 23. Payload format of the LMF ARQ Response message

5.2.5.2 Regenerate Buoy Address Message

This LMF message is used to command the buoy to regenerate its buoy address. This new address will consists of an 8-bit field containing the buoys' initial uplink RF channel followed by a 16-bit integer randomly chosen from the interval [1 65534]. This message is intended to be used when the buoy has not been assigned a hardware address and its randomly generated address (section 4.3.1) conflicts with another buoy.

The message payload consists of only the **MsgID**=2 (0x02). There is no message body since there are no parameters to be passed to the buoy for this message.

5.2.5.3 Change DLL Parameters Message

This LMF message is used to change the values of various ULMP and DLMP parameters. Multiple parameters can be changed with one message. The format of the message payload shall be as shown in **Figure 24.**

The fields in this message payload are as follows:

MsgID = 3 (0x03)

Parm ID – The ID of the parameter being changed. The IDs are listed in **Table 12.**

Parm Value – A one byte value for the parameter.

MsgID = 0x03	Parm ID	Parm Value	…	Parm ID	Parm Value
(1 byte)	(1 byte)	(1 byte)		(1 byte)	(1 byte)

Figure 24. Payload format of the Change DLL Parameters message

Standardized parameter names and default values are defined in **Table 12**. Default values may be overridden by the specification for the specific sonobuoy or by the Change DLL Parameters command.

Parm ID	Parameter	Section Reference	Default Value
1	nPreStart	4.1.1	64
2	winMax	4.3.5	16
3	upRetryMax	4.3.5	4
4	upEtMax	4.3.5	250 ms
5	downRetryMax	5.2.4	4
6	downEtMax	5.2.4	100 ms
7	upFragMax	4.3.4	32 blocks
8	downFragMax	5.2.2	128 bytes
9	preaFECRate	4.1.3	1

Table 12. Parameter IDs

Note: The minimum preamble duration after onset of RF power should be 100 ms, which corresponds to nPreStart > 61 blocks at 320 kbps.

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ANNEX A - Application Layer Protocols and Formats

The functionality of the Applications layer of the protocols reference model is not a part of this standard, but is left to the specification of the specific sonobuoy and to the aircraft receiver and processor specifications. This annex provides guidance and recommendations as to protocols and message formats that should be considered for the Applications layer.

A.1 Uplink SDF Acoustic Payload Header

The contents and format of the acoustic payloads in the streaming data format will be tailored to the particular buoy and mode that is producing the data. The payload will consist of a payload header followed by the payload data. It is recommended that a payload header be defined that is common for all buoys. It is recommended that this header contain the following information:

Buoy Type (8 bits)

Buoy Mode (16 bits)

Acoustic Payload Counter (24 bits)

The buoy type and mode are used by the receiving system to identify how the SDF frame is to be unpacked. The 24-bit acoustic payload counter indicates the number of payloads that have been transmitted from the buoy to the aircraft since the buoy was deployed and is specific to a buoy operating mode. A separate payload counter should be maintained for each operating mode of the buoy.

A coordination effort will be required to allocate Buoy Type and Buoy Mode identifiers across the various nation’s buoys.

A.2 Uplink DMF Message Payload

A recommended format for DMF message payloads on the uplink is shown in **Figure A-1**. This payload begins at word 9 in the uplink Header frame. The payload consists of a 7-bit message ID (MsgID), a 1-bit fill indicator (Fill_id), followed by the message body. Since 16-bit words are used in the uplink frame, a one byte fill of all zeros is appended to the message payload when the message body consists of an even number of bytes. This makes the message payload be an even number of bytes. The fill indicator is set to one when the 1 byte of fill is appended to the payload. Otherwise the fill indicator is zero.

MsgID (7 bits)	Fill_id (1 bit)	Message Body (variable bytes)	Fill as needed (0 or 1 byte)

Figure A-1. Uplink DMF message payload structure

The downlink DMF message payload format can be similar to the uplink structure except that the one byte fill is not needed on the byte-oriented downlink.

A.3 Legacy Telemetry Compatibility

Since the SG90 digital sonobuoy telemetry link defined by this standard will coexist with legacy analog and digital links for several years, most sonobuoys will initially be required to support both types of links. Consequently a pair of buoy control commands should be defined that switch a buoy from a legacy link to the SG90 link and from the SG90 link back to the legacy link.

The command to switch from a legacy link to the SG90 link must be transmitted to the buoy using the legacy format. For example, this could be a new command that is added to a legacy CFS command set.

The command to switch from the SG90 link back to a legacy link will be a CMF message.

Since the specification for a sonobuoy will initially need to define both a set of legacy control commands and a set of SG90 control commands, the formats of the commands required to switch between telemetry links should be included in the specification for the specific sonobuoy.

ANNEX B - Implementation Guidance

Certain functions defined in this standard are specified as being optional in sonobuoys. The specification for each sonobuoy type should specify which of these optional functions are to be implemented in that particular sonobuoy. **Table B-1** lists the functions that are optional in sonobuoys.

Sonobuoy Optional Functions	Comments
Uplink transmission rates	A sonobuoy type may support one or more of the uplink transmission rates of 320, 256, 192, 128, and 64 kbps.
Uplink sub-channels	The sonobuoy specification should define any uplink sub-channels that a sonobuoy must support.
Uplink FEC	A sonobuoy type may support none or one or more of the FEC code rates of 7/8, 3/4, and 1/2.
Uplink ARQ	Uplink ARQ is optional in a sonobuoy. A sonobuoy type that never requires reliable delivery of a DMF or LMF message has no need for ARQ.
Downlink FEC	The support for decoding of rate ½ FEC on the downlink is optional

Table B-1. Optional sonobuoy functions

This standard does not mandate particular aircraft signal processing algorithms or implementations. But cardinal functional signal processing requirements which should be satisfied by the aircraft receiving system are summarized in **Table B-2**.

Function	Essential	Desirable
Implementation of all PHY layer and Data Link Layer functions (including those that are optional in a sonobuoy).	√	
Optimized coherent detection, accounting for the GFSK continuous phase, partial response waveform, modulation index, and shaping.	√	
Optimized non-coherent detection, accounting for the GFSK partial response waveform, modulation index, and shaping.	√	
Adjustable channel filter width and center frequency offset.	√	
Automatic adaptive narrowband interference rejection on all uplink channels in use simultaneously, at least one interferer per channel.	√	
Telemetry quality monitoring via RSSI and BER measurements.	√	
RFI statistics monitoring and reporting over the full sonobuoy uplink band.	√	
Automatic adaptive narrowband interference rejection on all uplink channels in use simultaneously, at least two interferers per channel.		√
Automatic adaptive beamforming for wideband spatial interference rejection on each in-use uplink channel using at least 3 antennae.		√
Soft decision decoding of uplink FEC encoded data.		√
Telemetry quality output for recording and mission control.		√
Reporting of RFI and telemetry status to the mission control function to enable automatic Quality of Service (QoS) Management.		√

Table B-2. Aircraft receiver system functional requirements

The bit synchronization and detection process in the airborne receiver should achieve a BER close to theoretical performance, for the given receiver noise figure, equivalent to 1 dB receiver degradation, with respect to the received RF level needed to achieve a BER of 10-2. This shall be evaluated based on the raw bit error rate, excluding any FEC.

The airborne receiver frame synchronization process should maintain Frame Lock in the presence of random bit errors, when the raw BER is 10-1 or less.

Error detection and concealment coding within application-specific acoustic payload data, when using the streaming data format (SDF) should be designed to achieve the following performance:

- Reconstructed acoustic data should produce degraded but usable acoustic displays (i.e. increased background noise and occasional artifacts) for raw random BER≤10-2.
- Reconstructed acoustic data should produce effectively perfect acoustic displays (no discernible degradation) for raw random BER≤10-3.

Bit errors will also occur in bursts, due to interference, fading and shading (e.g. due to airframe effects), and interruption (e.g. due to wash over). The reception system (detection and synchronization), and the application data error checking scheme, should be robust to both random errors and burst errors.

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ANNEX C - Example C Code for the CRC Calculation

The following is an example of C code that performs the CRC-16 calculations a byte at a time using a lookup table.

```
// CRC-16-CCITT, Reversed, x^(16) + x^(12) + x^(5) + 1, 0x8408
unsigned short crc_table[256] = {
    0x0000, 0x1189, 0x2312, 0x329b, 0x4624, 0x57ad, 0x6536, 0x74bf,
    0x8c48, 0x9dc1, 0xaf5a, 0xbed3, 0xca6c, 0xdbe5, 0xe97e, 0xf8f7,
    0x1081, 0x0108, 0x3393, 0x221a, 0x56a5, 0x472c, 0x75b7, 0x643e,
    0x9cc9, 0x8d40, 0xbfdb, 0xae52, 0xdaed, 0xcb64, 0xf9ff, 0xe876,
    0x2102, 0x308b, 0x0210, 0x1399, 0x6726, 0x76af, 0x4434, 0x55bd,
    0xad4a, 0xbcc3, 0x8e58, 0x9fd1, 0xeb6e, 0xfae7, 0xc87c, 0xd9f5,
    0x3183, 0x200a, 0x1291, 0x0318, 0x77a7, 0x662e, 0x54b5, 0x453c,
    0xbdcb, 0xac42, 0x9ed9, 0x8f50, 0xfbef, 0xea66, 0xd8fd, 0xc974,
    0x4204, 0x538d, 0x6116, 0x709f, 0x0420, 0x15a9, 0x2732, 0x36bb,
    0xce4c, 0xdfc5, 0xed5e, 0xfcd7, 0x8868, 0x99e1, 0xab7a, 0xbaf3,
    0x5285, 0x430c, 0x7197, 0x601e, 0x14a1, 0x0528, 0x37b3, 0x263a,
    0xdecd, 0xcf44, 0xfddf, 0xec56, 0x98e9, 0x8960, 0xbbfb, 0xaa72,
    0x6306, 0x728f, 0x4014, 0x519d, 0x2522, 0x34ab, 0x0630, 0x17b9,
    0xef4e, 0xfec7, 0xcc5c, 0xddd5, 0xa96a, 0xb8e3, 0x8a78, 0x9bf1,
    0x7387, 0x620e, 0x5095, 0x411c, 0x35a3, 0x242a, 0x16b1, 0x0738,
    0xffcf, 0xee46, 0xdcdd, 0xcd54, 0xb9eb, 0xa862, 0x9af9, 0x8b70,
    0x8408, 0x9581, 0xa71a, 0xb693, 0xc22c, 0xd3a5, 0xe13e, 0xf0b7,
    0x0840, 0x19c9, 0x2b52, 0x3adb, 0x4e64, 0x5fed, 0x6d76, 0x7cff,
    0x9489, 0x8500, 0xb79b, 0xa612, 0xd2ad, 0xc324, 0xf1bf, 0xe036,
    0x18c1, 0x0948, 0x3bd3, 0x2a5a, 0x5ee5, 0x4f6c, 0x7df7, 0x6c7e,
    0xa50a, 0xb483, 0x8618, 0x9791, 0xe32e, 0xf2a7, 0xc03c, 0xd1b5,
    0x2942, 0x38cb, 0x0a50, 0x1bd9, 0x6f66, 0x7eef, 0x4c74, 0x5dfd,
    0xb58b, 0xa402, 0x9699, 0x8710, 0xf3af, 0xe226, 0xd0bd, 0xc134,
    0x39c3, 0x284a, 0x1ad1, 0x0b58, 0x7fe7, 0x6e6e, 0x5cf5, 0x4d7c,
    0xc60c, 0xd785, 0xe51e, 0xf497, 0x8028, 0x91a1, 0xa33a, 0xb2b3,
    0x4a44, 0x5bcd, 0x6956, 0x78df, 0x0c60, 0x1de9, 0x2f72, 0x3efb,
    0xd68d, 0xc704, 0xf59f, 0xe416, 0x90a9, 0x8120, 0xb3bb, 0xa232,
    0x5ac5, 0x4b4c, 0x79d7, 0x685e, 0x1ce1, 0x0d68, 0x3ff3, 0x2e7a,
    0xe70e, 0xf687, 0xc41c, 0xd595, 0xa12a, 0xb0a3, 0x8238, 0x93b1,
    0x6b46, 0x7acf, 0x4854, 0x59dd, 0x2d62, 0x3ceb, 0x0e70, 0x1ff9,
    0xf78f, 0xe606, 0xd49d, 0xc514, 0xb1ab, 0xa022, 0x92b9, 0x8330,
    0x7bc7, 0x6a4e, 0x58d5, 0x495c, 0x3de3, 0x2c6a, 0x1ef1, 0x0f78};
```

```
define CRC_INIT (unsigned short)0x0000
unsigned short get_buffer_crc(unsigned short init_crc, unsigned char *buf, unsigned int length)
{
unsigned short crc = init_crc;
while (length>0)
{
crc = crc_byte(crc, *buf);
length--;
buf++;
}
return(crc);
}
unsigned short crc_byte(unsigned short working_crc, unsigned char uc)
{
return ((working_crc>>8) ^ (crc_table[(working_crc ^ uc) & 0xFF]));
}
```

Verification Test Data
The following is a sequence of test data for verification of the CRC algorithm. This data consists of 16, 16-bit words (in Hex format). This data is the first 256 bits of the PRBS from the scrambler with state number zero (ScrSN = 0).
0x 5554 CCCE EEE9 6963 637B 7B5B 5B24 DB8E DA16 D836 DFB6 D5B6 CDB6 EDB6
9249 C71D
The CRC for this data sequence is 0x86DE

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