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NARROWBAND WAVEFORM FOR VHF/UHF RADIOS - PHYSICAL LAYER AND PROPAGATION MODELS

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NATO LETTER OF PROMULGATION

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ALLIED COMMUNICATION PUBLICATION AComP-5631

NARROWBAND WAVEFORM FOR VHF/UHF RADIOS – PHYSICAL LAYER AND PROPAGATION MODELS

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1 INTRODUCTION

A physical layer (PHY) specification for modern VHF and UHF fixed-frequency tactical communications physical layer is made. This Narrowband Waveform (NBWF) is designed to satisfy NATO requirements for air-interface interoperability [N1]. Legacy VHF tactical radios exist as national waveforms in various NATO countries, and operate historically in the VHF tactical communications band: 30MHz – 88MHz in NATO, with channelization 25 kHz. The NBWF is expected to operate in the same band with the same channelization initially, and is designed to allow eventual operation in the tactical UHF band (225MHz – 400MHz). All aspects of this AComP support future bandwidth and data-rate scalability requirements, as well as dynamic data-rate adaption schemes. A follow-on edition of the AComP 5631 will provide a waveform with a similar architecture offering EPM capabilities. The initial application for this waveform is land tactical communications, and so it is designated NBWF(Land).

The NBWF specification for fixed frequency modulation has capabilities offering instantaneous throughputs from 10kbps to 82kbps in 25kHz and up to 63kbps in 50kHz bandwidth. Message formats are specifically designed to operate with the NATO NBWF(Link Layer) specification [N2], as well as providing generic burst modem capability for TDMA, CSMA, and other network access schemes. This ACOMP follows the approach of other recent standards in utilizing constant envelope characteristics with continuous-phase coded modulation (CPM).

Physical layer spectral characteristics conform to the 99% total mean radiated power within the necessary bandwidth, (ie. the 99% radiated power constraint in 25kHz as specified in STANAG 4204 [N3]) and the out-of band and spurious emission spectrum occupancy mask constraints specified in ITU-R SM.1541.41 “FDMA Systems” spectral constraints [ITU].

The NBWF is designed to carry packetized secure vocoded voice and data messages and support mobile wireless ad-hoc networking. It supports a variety of data rates, and delays, and can therefore offer a quality of service, but whose performance is limited by the characteristics of the propagation channel. It supports legacy VHF CNR (Combat Net Radio) operation, by offering point-to-point continuous transmissions.

1.1 Summary of Technology

The physical-layer characteristics of the waveform are specified in this AComP. The format of all transmission bursts are specified, and the technique to construct these on-air emissions from basic modulation, coding and interleaving functions are given. The different on-air data-rate capabilities of the waveform are described in terms of modes, each with different parameters, and baud rates. The overall structure of a PHY emission contains preamble, and data fields that are concatenated in time. The selection of a required PHY message format is signaled to the physical layer via the Link layer [N2] interface using primitives defined in this AComP.

A preamble is used for acquisition of the waveform when communications commences. Frequency offsets due to the combined effects of Doppler and errors in synthesizer tuning in the received signal are explicitly measured by performing analysis on the received preamble. Information about the timing, the mode of operation, and other parameters are also signalled within the preamble. This specification supports inclusion of an equalizer, although the equalizer may only be required under severe multipath propagation conditions not usually encountered by legacy radios due to the low data-rate of legacy radios [N3].

1.2 Information about CPM Modulation Waveform Modes

The CPM modulation has constant envelope (near-constant envelope when transmit filtering is used) and therefore allows for maximum efficiency of transmit power management, giving excellent range and power utilization capabilities to the waveform and low spurious emissions. The data payload is carried using a coding and modulation approach consisting of a convolutional code serially-concatenated with the CPM coded modulation, and with the two encoders separated by an interleaver, denoted *SC+CPM*. Such a system can utilize either coherent or non-coherent iterative ("turbo") decoding, which provides improvement (as compared with conventional waveforms) in inherent robustness to jamming and multipath, and allows digital communications at a very low Eb/No as compared with non-iterative coded waveforms having the same bandwidth.

1.3 Outline of the Document

In Chapter 2 the services provided by the NBWF(Land) PHY emissions are described as a state machine, in particular the role of the preamble, payload, and how the generic burst formats interact with the link layer [N2]. In Chapter 3 the detailed description of the preamble and training fields is made. Chapter 4 contains descriptions of the format and timing of transmitted bursts, as they are configured according to the header. Chapter 5 contains a description of the CPM modulation, coding and interleaving.

Annex A contains a list of abbreviations and Annex B information on completion of NPICS proforma. Annex C contains multipath and fading propagation models for the tactical VHF band. Annex D lists tolerances of components in the radio products implementing the NBWF specification. Annex E.1 contains the specification for RF spectral occupancy, and the technique for measuring conformance. Annex E.2 contains specification of physical layer NBWF modem performance. Annex F contains parameters that define the NBWF(Land). Annex G contains the NATO Protocol Implementation Conformance Specification (NPICS) proforma to this AComP.

1.4 Legacy STANAGs

The legacy standards relevant to narrowband Combat Net Radio physical layer are:

STANAG 4204 Technical Standards for Single Channel VHF Radio Equipment

STANAG 4205 Technical Standards for Single Channel UHF Radio Equipment

1.5 Referenced documents

[N1] NC3A Scenarios for NNEC.

[N2] NATO AComP-5632 (A)(1) "Narrowband Waveform for VHF/UHF Radios - Link Layer"

[N3] NATO STANAG 4204, Edition 2, Amendment 2, "Technical standards for single channel VHF radio equipment."

[N4] NATO STANAG 4205, Edition 3, "Technical standards for single channel UHF radio equipment," 29 July 2005.

[ITU] Recommendation ITU-R SM.1541-1, "Unwanted emissions in the out-of-band domain," Document 1/BL/11-E , 2 April 2001.

[ITU2] ITU Recommendation: ITU-R SM.329-9 Spurious Emissions, July 2001.

[ITU3] ITU-T Rec. X.210 (11/93): Information Technology- Open Systems Interconnections- Basic Reference Model.

[ETSI] ETSI EN 300 392-2 V2.3.2 (2001-03): Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI).

[IEEE] IEEE 802.17: Resilient Packet Rings.

[T1] *Coded Modulation Systems,* J.B. Anderson and A. Svensson, Kluwer Academic/Plenum, 2003, New York, (ref. Chapter 5).

[T2] *Digital Communications,* J.G. Proakis, 4th ed., McGraw-Hill, New York.

[R1] C. Brown and P. Vigneron, "A reduced complexity iterative non-coherent CPM detector for frequency hopped wireless military communications systems*," in Proc. IEEE MILCOM 2005*, pp.2345-2349, Atlantic City N.J.

[R2] C. Brown and P. Vigneron, "Coarse and fine timing synchronisation for partial response CPM in a frequency hopped tactical network*," in Proc. IEEE MILCOM 2007,* Orlando.

[R3] A.P. Worthen and P.H. Wu, "CPM Optimization for low-complexity serial concatenated CPM," *in Proc. MILCOM 2003*, Vol.1, pp.46-50, Boston.

[R4] C. Brown and P. Vigneron, "Channel estimation and equalization for single carrier continuous phase modulation," *in Proc. MILCOM 2011*, Baltimore.

[R6] P.J. Vigneron and J.A. Pugh, "Propagation models for mobile terrestrial VHF communications," in Proc. MILCOM 2008, San Diego.

[ACP] ACP 167(H) Glossary of Communications-Electronics Terms, April 1998.

The Narrowband Waveform STANAG is defined by the following documents;

STANAG 5630	Narrowband Waveform for VHF/UHF Radios
AComP-5630	Narrowband Waveform for VHF/UHF Radios – Head Specification
AComP-5631	Narrowband Waveform for VHF/UHF Radios – Physical Layer
AComP-5632	Narrowband Waveform for VHF/UHF Radios – Link Layer
AComP-5633	Narrowband Waveform for VHF/UHF Radios – Network Layer

2. PROTOCOL SPECIFICATION

This chapter specifies the physical layer (PHY) protocol and the services that PHY as a service provider offers to the PHY service user. The protocol specification is not limited to the use of the PHY combined with the AComP 5632 NBWF Link Layer (NBWF Optimized operation), but will also cover other types of operation using this specification (General TDMA, Continuous Transmission and Future Use operations). The specification and generation of transmission bursts for these four different types of operation are described in Chapters 3 and 4.

When the network is operational, a segment of waveform (a burst) of finite duration is transmitted. Modern networking operates using short burst transmission, in contrast to some legacy systems that may offer long duration point-to-point links. Properties of the burst are signalled within the burst, with the philosophy being that a receiver can acquire, demodulate and decode the information without external information save the frequency allocations and crypto keys (if used). Therefore the specification supports autobaud.

For the NBWF Optimized type of operation some specific timing and performance requirements must be met by a PHY implementation conforming to this standard. These requirements are specified in sections 2.3.4.3, 2.3.5.7 and 2.3.5.12.

2.1 Overview

All PHY protocol specifications are mandatory for an implementation of the PHY layer interfacing an external implementation of the NBWF link layer and all other types of operation of the PHY. For a system implementing both NBWF link layer and the PHY layer, the service specification can be treated as an implementation guideline only, as it in such a case will be system internal. It is not mandatory to implement support for all the defined types of operation, but a system is not allowed to state support of NBWF without full support for the NBWF Optimized type of operation.

The specification and interpretation of the Protocol Control Information carried internally by the service primitives and externally by the Protocol Data Units (PDUs) is mandatory in all cases. Figure 2-1 shows how the PHY services are utilized through service primitives exchanged between the PHY service user and the physical layer service provider through the Physical layer Service Access Point (PHY-SAP).

In this specification the PHY service user is denoted by the generic term LINK. For NBWF Optimized operation, the PHY service user (lowest sublayer of link layer) is the Air Interface Encryption. A service primitive of type *request* is sent from LINK to PHY on the A-side and can result in an indication from PHY to LINK on the B-side. The terminology is adapted from [ITU3].

All external peer-to-peer service primitives can carry a number of parameters in addition to the payload. These parameters (and the payload) from the link layer constitute the Service Data Unit (SDU) that must be transported by the PHY layer to the remote side PHY service user in a PHY PDU. In addition, the primitives can carry interface control information (ICI) which is local within the system (not to be transported by the PHY to the remote side). Local sublayer-to-sublayer service primitives are not visible outside the system and are thus not mapped to any PDU.

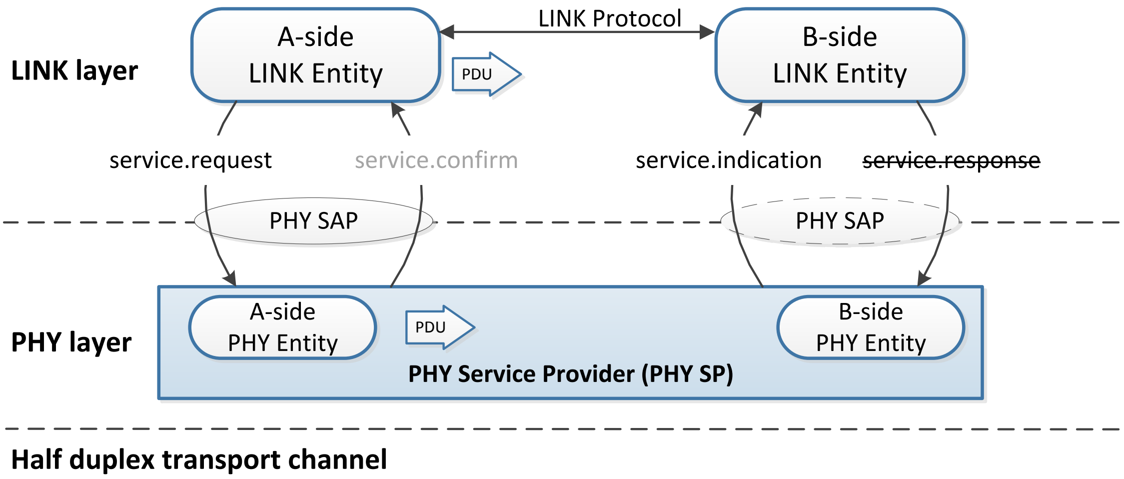

Figure 2-1 Protocol Data Units (PDUs) are exchanged between peer entities while PHY Service primitives are exchanged between LINK entities and the PHY SP.

All PHY services are available to the PHY service user, LINK, through the PHY-SAP.

The PHY layer offers the following mandatory services to the LINK layer:

- PHY-TRANSPORT (PHY Transport Service)

This is a connectionless multi-peer service. Any transmitted PHY PDU can be received by all radios within the actual radio range, which will deliver the payload to the PHY service user in an *indication* service primitive. The PHY always operates in a one-way point-to-multipoint mode. There are no external peer-to-peer *response* or *confirm* primitives at the interface between PHY and LINK, only one local *confirm* primitive.

2.2 Protocol Description

This chapter specifies all the functions that describe the protocol behaviour of PHY to the level of details which is required for the PHY service user. PHY protocol behaviour is described as a finite state machine.

The default state for PHY is SEARCH. There are only two trigger conditions that can bring PHY out of SEARCH state. In SEARCH, the PHY will constantly search for the (CW part of) the preamble of an incoming transmission (E and P fields as described in chapter 3). As soon as CW is detected, the PHY shall transit to the RECEIVE state. On the other hand, a PHY-TX.request primitive from the PHY service user shall bring PHY into the TRANSMIT state. With a few exceptions to be shown in Table 2-1, all other events in SEARCH state shall be ignored.

PHY primitives used: PHY-DATA.request
PHY-DATA.indication
PHY-TX.request
PHY-TX.indication

Local primitives used: PHY-ABORT.request
PHY-ACTIVITY.indication
PHY-DATA.confirm

PHY-FAULT.indication
PHY-INITIALIZE.request
PHY-INITIALIZE.confirm
PHY-NOISE.indication
PHY-PAR.request
PHY-RADIO.request

PHY PDUs used: DT

Events used: CW, CW-timer, DataTx-timer, EndCW, EndDECODE, EndINTERLEAVER, EndRXDATA, EndTXDATA, FatalERROR, PAR, Par-timer, SOM- SHORT, SOM-STD, SOM-timer

Figure 2-2 shows a simplified state diagram of PHY.

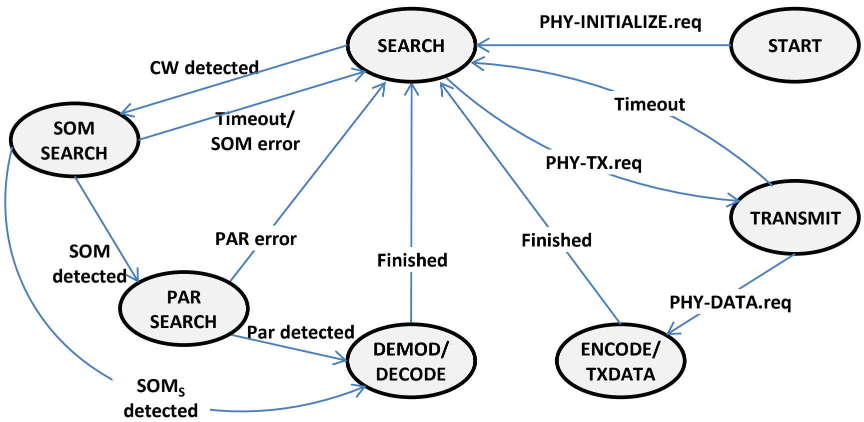

Figure 2-2 Depiction of State Machine for PHY.

The state diagram of Figure 2-2 does not describe all details, only the event that triggers a transition but no action. A more detailed description is given in state table notation (adopted from [IEEE]); see Table 2-1.

Table 2-1 Detailed state table for PHY operating in TDMA mode

Current state		Row	Next state	
state	**condition**		**action**	**state**
START	PHY-INITIALIZE.req	1	Initialise()	
		2	PHY-INITIALIZE.conf	SEARCH
SEARCH	CW	3	Start Timer(SOM-timer)	
		4	PHY-ACTIVITY.ind(PCAS)	SOM_SEARCH
	PHY-TX.req AND POWERON	5	TxPreamble()	
		6	Start Timer(DataTx-timer)	TRANSMIT
SOM_SEARCH	SOM-SHORT	7	PHY-ACTIVITY(SCAS)	
		8	PHY-TX.ind	
		9	Start Timer (Length of burst)	
		10	DemodulateData()	RXDATA
	SOM-STD	11	PHY-ACTIVITY.ind(NCAS)	
		12	Start Timer(Par-timer)	PAR_SEARCH
	Timeout	13	PHY-ACTIVITY.ind(NO)	SEARCH
PAR_SEARCH	PAR	14	PHY-TX.ind	
		15	Start Timer (Length of burst)	
		16	DemodulateData()	RXDATA
	Timeout	17	PHY-ACTIVITY.ind(NO)	SEARCH
RXDATA	Timeout or EndRXDATA(EOM)	18	PHY.ACTIVITY.ind(END)	SEARCH
		19	DecodeData()	
TRANSMIT	PHY-DATA.req AND POWERON	20	EncodeData()	ENCODE
	Timeout	21	PHY-FAULT.ind(MISSING_DATA)	SEARCH
ENCODE	Timeout	22	TxData(Encoded DT)	TXDATA
TXDATA	EndTXDATA	23	PHY-DATA.conf	SEARCH
any	EndDECODE	24	PHY-DATA.ind	previous state
	FatalERROR	25	Reset timers & stop functions	
		26	PHY-FAULT.ind(FATAL)	ERROR
	PHY-ABORT.req	27	Reset timers & stop functions	SEARCH
	PHY-RADIO.req(POWERON)	28		previous state
	PHY-PAR.req	29	Enforce PAR values for current or upcoming reception	previous state

Row 1-2: The initialisation of PHY can start automatically at power up, or optionally by command from the PHY service user.

Row 3-4: The CW event is triggered when PHY has detected the CW part of the preamble. This event can, in principle, be triggered any time during the CW reception (T_P, see Table F-4). The actual time of detection will depend on e.g. the signal strength. A primitive signalling Preliminary CAS is sent to PHY service user and a timer is set to the maximum time until a SOM shall be received (<T_{P} + T_{SOM}).

Row 5-6: When a PHY-TX.request is received and the radio is allowed to transmit; PHY shall start transmitting a preamble with parameters from the primitive. The TxPreamble() function can be described as a separate process that first transmits the CW part of the preamble, followed by a SOM and possibly by a Par. The function is started, but not ended when transiting to the next state. A timer is set to the time when the transmission of data in a subsequent PHY-DATA.request primitive shall start.

Rows 7-10: When a SOM_S is received, there will be no Par following. PHY shall signal with both a PHY-ACTIVITY.indication(SCAS) and a PHY-TX.indication. The PHY-TX.indication primitive is constructed with parameters MODE=N1, LENGTH=0, PROCTIME=FALSE. A timer is set for the length of the incoming interleaver, and demodulation of data starts.

Row 11-12: A normal SOM is detected, PHY shall signal with a PHY-ACTIVITY.indication(NCAS), set a timer when Par shall be received an start searching for PAR.

Row 13: After CW, if no SOM is received within the specified maximum time, it is assumed to be a false alarm. A primitive informing that there is no activity detected is sent.

Row 14-16: The PAR event is triggered immediately when the last symbol of the Par field is received and decoded. PHY service user is informed about the Par reception in a PHY-TX.indication, with parameters from the Par. The Par will be checked for bit errors and the result is included in the primitive. A timer is set for the duration of the burst and PHY starts demodulating data.

Row 17: If no Par is receive, PHY service user is informed. This probably will never happen. PHY will try to receive Par and the error check will fail if no Par is present.

Rows 18-19: When all incoming data has been received (length in Par or terminated with EOM), PHY shall signal end of reception to its service user and start de-interleaving and decoding the data. For transmissions containing more than one interleaver block, the DecodeData() of one interleaver block will be performed concurrently with the DemodulateData() of the next interleaver block.

DecodeData() is the iterative process of extracting the PHY service user information from the received symbols of one interleaver block. When finished, it will trigger the EndDECODE event.

Row 20-21: PHY needs to receive the PHY-DATA.request service primitive containing the data to transmit before the transmission of the preamble is complete; otherwise an error is reported to LINK. The data will be encoded and prepared for transmission.

Row 22: When the preamble transmission is complete, the transmission of the encoded data can start if the radio is allowed to transmit. End of transmission triggers the EndTXDATA event.

Row 23: When the data transmission is complete (one or more interleaver blocks) this is signalled to the PHY service user.

Row 24: When PHY has received all data it is still busy decoding the last interleaver block. Meantime the PHY will transit to SEARCH, and can even prepare for a transmission. This line is executed when the decoding is finished, independent of current state. PHY shall send a service primitive containing all the received data. For TDMA types of operation all interleaver blocks shall be delivered to LINK in a single PHY-DATA.indication primitive. Other types of operation shall deliver each interleaver block individually (not described here).

Row 25-26: This event is triggered whenever a fatal error is detected by PHY, which cannot be corrected. Fatal means that PHY is unable to perform its task. There is no way out of the ERROR state; possibly apart from a restart. The PHY service user is informed.

Row 27: Whenever a PHY-ABORT.request primitive is received, irrespective of the current PHY state, PHY shall immediately abort all ongoing procedures, reset all timers and return to SEARCH state. But, any on-going DecodeData() function of the last received interleaver block shall not be affected.

Row 28: Whenever a PHY-RADIO.request primitive is received, irrespective of the current PHY state, PHY shall register the new condition to allow or forbid all radio transmissions. Any on-going transmission is not aborted.

Row 29: The PHY service user can optionally enforce a certain decoding of a reception. This can be useful when higher layers know which Par values that are used, in case there are bit errors in the received Par field. An example is multicast voice reception, where the same Par values are used in every burst.

NOTE: The state table is not complete, as it does not cover all possible erroneous situations that can occur.

2.3 PHY-TRANSPORT Service Specification

2.3.1 Service Description

The PHY transport service is accessed through the PHY-SAP. It is used to transport blocks of data over the air from one radio to another.

2.3.2 External Peer-to-Peer Service Primitives

The following peer-to-peer service primitives are exchanged between the LINK layer and the PHY layer through the PHY-SAP:

- PHY-DATA.request
- PHY-DATA.indication
- PHY-TX.request
- PHY-TX.indication

Table 2-2 PHY DATA service primitive parameters

PHY-DATA			
Parameter	**Description**	**request**	**indication**
	Payload	M	M(=)
	Interface Control Information (ICI)		
RSSI	Received signal strength indicator		M

BGNOISE	Background noise level (during the reception)		M
LTRXSTART	Local time of arrival		M

Table 2-3 PHY TX service primitive parameters. (The * indicates that this parameter is not used in all types of operation, see parameter description)

PHY-TX			
Parameter	**Description**	**request**	**indication**
MODE	PHY mode	M	M(=)
LENGTH	Number of merged slots	M*	M*(=)
PROCTIME	Processing time allocated (shorter last interleaver)	M*	M*(=)
INTLEAV	Full/half slot interleaver	M*	M*(=)
	Interface Control Information (ICI)		
ERRCHK	Result of Par parity check		M*
PWR	Output power	O	
RSSI	Received signal strength indicator (of preamble)		O
BGNOISE	Background noise level (during preamble reception)		O
LTRXSTART	Local time of arrival		M

Since the PHY-DATA service primitive is always preceded by a PHY-TX primitive containing the four required PHY parameters (for the PDU) these parameters are omitted in the PHY-DATA primitive.

2.3.3 Local Sublayer-to-Sublayer Service Primitives

The following local sublayer-to-sublayer service primitives are exchanged between the LINK layer and the PHY layer through the PHY-SAP:

- PHY-ABORT.request
- PHY-ACTIVITY.indication
- PHY-DATA.confirm
- PHY-FAULT.indication
- PHY-INITIALIZE.request (Optional. Normally sent only once during power-up)
- PHY-INITIALIZE.confirm (Optional. Normally sent only once during power-up)
- PHY-NOISE.indication (Optional. Reported regularly from PHY to LINK)
- PHY-PAR.request

- PHY-RADIO.request

Table 2-4 PHY local sublayer-to-sublayer ABORT service primitive parameters

PHY-ABORT (Local)				
	Interface Control Information (ICI)			
Parameter	**Description**	**request**	**indication**	**confirm**
	None	O		

Table 2-5 PHY ACTIVITY service primitive parameters

PHY-ACTIVITY (local)			
	Interface Control Information (ICI)		
Parameter	**Description**	**request**	**indication**
ACTYPE	Type of activity detected		M
RSSI	Received signal strength indicator		O
BGNOISE	Background noise level (during the reception)		O

Table 2-6 PHY local sublayer-to-sublayer DATA service primitive parameters

PHY-DATA (Local)				
	Interface Control Information (ICI)			
Parameter	**Description**	**request**	**indication**	**confirm**
LTTXEND	Local time for end of transmission			O

Table 2-7 PHY local sublayer-to-sublayer FAULT service primitive parameters

PHY-FAULT (Local)				
	Interface Control Information (ICI)			
Parameter	**Description**	**request**	**indication**	**confirm**
REASON	Reason for failure		M	

Table 2-8 Optional PHY local sublayer-to-sublayer INITIALIZE service primitive parameters. (The * indicates that this parameter is not used in all types of operation, see parameter description)

PHY-INITIALIZE (Local)				
	Interface Control Information (ICI)			
Parameter	**Description**	**request**	**indication**	**confirm**
TOPER	Type of operation of PHY layer	M		
SLENGTH	Slot length	M		
MAXSLOT	Maximum number of slots for a transmission	M*		
PHYMODES	List of data rates available			M
PWRLEVELS	List of power levels available			M
PERCLASS	PHY Performance class			M*
INTLENGTHS	List of interleaver lengths available to LINK			M*

Table 2-9 Optional PHY local sublayer-to-sublayer NOISE service primitive parameters

PHY-NOISE (Local)				
	Interface Control Information (ICI)			
Parameter	**Description**	**request**	**indication**	**confirm**
BGNOISE	Background noise level		M	

Table 2-10 PHY local sublayer-to-sublayer PAR service primitive parameters. (The * indicates that this parameter is not used in all types of operation, see parameter description)

PHY-PAR (Local)				
	Interface Control Information (ICI)			
Parameter	**Description**	**request**	**indication**	**confirm**
MODE	PHY mode	M	M(=)	
LENGTH	Number of merged slots	M*	M*(=)	
PROCTIME	Processing time allocated (shorter last interleaver)	M*	M*(=)	
INTLEAV	Full/half slot interleaver	M*	M*(=)	
EOM	End of message	M*	M*(=)	

Table 2-11 PHY local sublayer-to-sublayer RADIO service primitive parameters

PHY-RADIO (Local)				
	Interface Control Information (ICI)			
Parameter	**Description**	**request**	**indication**	**confirm**
POWERON	Enforce radio amplifier status	M		

2.3.4 PHY-SAP Detailed Service Specification

This is a detailed description of the service primitives exchanged between the PHY layer and the PHY service user.

2.3.4.1 PHY-DATA.request

This service primitive from the PHY service user (LINK) defines the transfer of a data block from the LINK sublayer to the local PHY entity. It is generated when the LINK sublayer has a block of data ready for transmission. PHY will use the parameters (MODE, LENGTH, PROCTIME, INTERLEAVER and PWR) from the corresponding PHY-TX.request primitive for the transmission of the data.

2.3.4.2 PHY-DATA.indication

This service primitive from the PHY entity to the PHY service user (LINK) indicates the successful reception of a block of data from a peer PHY entity.

2.3.4.3 PHY-TX.request

This service primitive from the PHY service user (LINK) defines the transfer of the preamble (of a data transmission) from the LINK sublayer to the local PHY entity. If the output power is not signalled, PHY will use the default value. The PHY-TX.request must be succeeded by a corresponding PHY-

DATA.request in time for the PHY to be ready to transmit the DATA as soon as the preamble is finished.

The first symbol of the SOM shall be transmitted exactly $T_{TXRX} + T_{AGC} + T_P$ after the time when PHY receives the PHY-TX.request. For TDMA types of operation this shall be performed with an accuracy ≤ 8 µs relative to the time when LINK decides that transmission shall start (combined requirement to LINK and PHY).

2.3.4.4 PHY-TX.indication

This service primitive from the PHY entity to the PHY service user (LINK) indicates the reception of a preamble from a peer PHY entity.

2.3.4.5 PHY-ABORT.request

This local service primitive from the PHY service user (LINK) is used whenever there is a need to stop PHY from performing whatever action it is currently performing. Typically, this could be used to abort an on-going transmission or reception.

2.3.4.6 PHY-ACTIVITY.indication

This local service primitive from the PHY entity to the PHY service user (LINK) is used to inform higher layers about any activity detected in the receive channel, whether it is caused by an expected or unexpected signal. It is used by PHY to inform about the reception of an expected preamble (CW and a succeeding SOM). In addition, it is used to inform about unexpected events in the reception phase..

2.3.4.7 PHY-DATA.confirm

This local service primitive from the PHY entity to the PHY service user (LINK) is used to inform higher layers about the completion of a data transmission.

2.3.4.8 PHY-FAULT.indication

This local service primitive from the PHY entity to the PHY service user (LINK) is used to inform higher layers about a problem in the PHY that possibly can affect its ability to transmit or receive.

2.3.4.9 PHY-INITIALIZE.request (Optional)

This local service primitive from the PHY service user (LINK) is typically sent once, at the start-up of the system, in order to exchange data between the layers. It is used to inform PHY about type of operation and TDMA slot size.

2.3.4.10 PHY-INITIALIZE.confirm (Optional)

This local service primitive from the PHY entity to the PHY service user (LINK) is used to inform higher layers about the PHY layer parameters: available modes (data rates), output power levels and PHY layer performance class. In addition PHY informs about available data block sizes available to upper layer, based on the slot size from LINK.

2.3.4.11 PHY-NOISE.indication (Optional)

This local service primitive from the PHY entity to the PHY service user (LINK) is used to inform higher layers about the background noise level at the receiver (BGNOISE). This should be reported regularly or at least when the level has changed with a value greater than the offered resolution of BGNOISE.

2.3.4.12 PHY-PAR.request

This local service primitive from the PHY entity to the PHY service user (LINK) is used to enforce a certain parameter set for the demodulation and decoding of received data. This primitive can be used by LINK e.g. in circuit-mode operation when the received Par is erroneous. PHY shall ignore the received Par and use the parameters from this primitive.

2.3.4.13 PHY-RADIO.request

This local service primitive from the PHY service user (LINK) is used whenever there is a need to shut down the radio power amplifier and turn it on again. Typically, this will be used whenever loading new crypto keys. This primitive shall override all PHY-TX.request and TX-DATA.request primitives. It does not affect radio reception.

2.3.5 Service Primitive Parameter Description

This section gives a detailed description of the different parameters of all the service primitives. This includes the allowed values each parameter can take and the meaning of those parameter values.

2.3.5.1 ACTYPE

The parameter is used to indicate what type of activity was detected. Valid values are:

- “NO” when an unexpected signal is detected. This could e.g. be due to the detection of a modulated signal when searching for the CW, or timeout on waiting for a SOM or Par.
- “PCAS” for Preliminary CAS when the first part of a valid preamble is detected, i.e. the CW.
- “NCAS” for Carrier Sense when a standard SOM sequence (see Table F-4) has been successfully detected.
- “SCAS” for Carrier Sense when a SOM_S sequence (see Table F-4) for a special short interleaver (Connect/Disconnect Confirm) has been successfully detected.
- “END” at the end of the received signal. E.g. at the end of the reception as signalled in the Par. PHY terminates demodulation.

2.3.5.2 BGNOISE

The parameter BGNOISE is used to report the background noise during a reception or in idle periods. It is stated as an integer number of dBm as specified in Annex F.

2.3.5.3 ERRCHK

This Boolean parameter indicates the result of the FCS parity check on received transmissions. When false, this indicates an error in the Par field. The parameter is only used for the NBWF Optimized type of operation.

2.3.5.4 INTLEAV

This parameter indicates whether long or short interleavers are used. See parameter coding description for Par register in section 3.6.4. The parameter is only used for the two types of TDMA operation (NBWF Optimized and General TDMA). This parameter is not used in combination with the special ½ slot transmission.

2.3.5.5 INTLENGTHS

This parameter is a list of maximum block sizes for each combination of mode (data rate) and number of slots. The block size is the maximum number of bits of the payload of a PHY-DATA.request. All block sizes are integer values. The format is a text string as: "PHYMODE, <# of slots>, PROCDEL, block size; PHYMODE; <# of slots>; …;" The parameter is only used for the two types of TDMA operation (NBWF Optimized and General TDMA).

2.3.5.6 LENGTH

This is the number of merged slots (to be) used for the transmission. See Slot Merge parameter coding description for Par register in Chapter 3. This parameter is only used for the two types of TDMA operation (NBWF Optimized and General TDMA).
For NBWF Optimized operation the relationship between the slot merge coding in the Par register (see Table 3-4) and the LENGTH parameter is:
Decimal equivalence of Slot Merge Descriptor = LENGTH-1 for LENGTH>0,
while LENGTH=0 is used to indicate the special ½ slot transmission using a dedicated SOM (SOM_S), where no Par is sent.

2.3.5.7 LTRXSTART

This is the local time (available both to PHY and LINK) when the burst was received. LTRXSTART is the estimated time when the source radio decided to transmit, not compensated for propagation delay. The time reference is the end of the last symbol of the SOM, $T_{SOMDetect}$.
LTRXSTART = $T_{SOMDetect} - (T_{TXRX} + T_{AGC} + T_P + T_{SOM} + T_{N1})$.
NOTE: This time shall be estimated with an accuracy ≤ 8 µs.

2.3.5.8 LTTXEND

This is the local time (available both to PHY and LINK) when the transmission of a burst is complete. Accuracy in the order of a few ms is acceptable for this parameter.

2.3.5.9 MAXSLOT

This integer parameter is used to inform PHY about the maximum number of slots that can be merged by the PHY service user for a transmission. The parameter is only used for the two types of TDMA operation (NBWF Optimized and General TDMA). Valid range is specified in Annex F.

2.3.5.10 MODE

This is the PHY mode (to be) used for the transmission. See parameter coding description for Par register in Chapter 3.

2.3.5.11 PROCTIME

The Boolean parameter PROCTIME is used to indicate whether or not the physical layer for the given transmission must select/has selected a shorter last interleaver in order to allow the receiver some time to decode the message within the end of the last time slot. See parameter coding description for Par register in Chapter 3. The parameter is only used for the two types of TDMA operation (NBWF Optimized and General TDMA).

2.3.5.12 PERCLASS

The parameter PERCLASS is currently only used for the NBWF Optimized type of operation. This parameter is used to inform the higher layers of the performance (processing power) class of the physical layer hardware implementation. Allowed values are: ‘1’ and ‘2’. The requirements related to these performance classes are stated in AComP-5632 [N2].

2.3.5.13 PHYMODES

This parameter is a comma separated list of the PHY modes that are available to the PHY service user. See parameter coding description for Par register in Chapter 3.

2.3.5.14 POWERON

This Boolean parameter is set to FALSE to disable all transmissions, and TRUE to enable transmissions.

2.3.5.15 PWR

The parameter PWR is the output power level to be used for the radio’s Power Amplifier. It is stated as an integer number of dBm as specified in Annex F. NOTE: An implementation is not required to be able to support all values. The PHY shall select the nearest available output power value ≥ the indicated value if LINK specifies a value that is not supported.

2.3.5.16 PWRLEVELS

This parameter is a comma separated list of power levels that are available to the PHY service user. All values are given in decimal dBm.

2.3.5.17 REASON

The parameter REASON indicates what caused the fault report. Allowed values are:

- “OK” when a previous error has been successfully corrected. Indicates normal operation.
- “TIMER” for timeout on data from PHY service user after receiving a PHY-TX.request.
- “ERROR” when an error has been detected in PHY. PHY will try to correct error, possibly by restarting. In that case a new primitive is sent after restart.
- “FATAL” when a fatal error has been detected which PHY is unable to correct. This means that PHY is unable to perform its operation.

2.3.5.18 RSSI

The parameter RSSI gives the measured Received Signal Strength Indication of the associated radio reception. It is stated as an integer number of dBm. Valid range is specified in Annex F.

2.3.5.19 SLENGTH

This parameter is used to inform PHY about the length of the TDMA slot. Values are given in number of milliseconds (ms) as a real number. Valid range is specified in Annex F.

2.3.5.20 TOPER

The parameter TOPER is used to indicate the type of operation for the physical layer. This is specified in Chapter 3 as bits 12 and 11 of the Par (Burst Generation Approach).

2.3.5.21 Service Primitive Parameter Values

Annex F states the allowed range of values for the primitive parameters. For some of the parameters the required resolution is also stated.

2.4 PHY Protocol Data Units (PDUs)

The PHY protocol defines a single Protocol Data Unit (PHY PDU). All transmission processes (bursts) are constituted by a number of elements as described in Chapters 3 and 4.

2.4.1 PHY DT PDU

The waveform physical layer (PHY) DT PDU consists of a preamble, a data transmission segment, and equalization training words for longer duration transmissions, see Figure 2-3. These are all modulated on the same carrier, and are multiplexed in time. Annex F contains the parameters and descriptors of all modes, timings and formulas for some key calculations. The different parts of the DT PDU are:

- A Continuous Wave signal in the fields E and P as described in Chapter 3.
- A Start-of-Message (SOM) which is a CPM modulated signal of length N_{SOM} symbols (unique PN sequence) as described in chapter 3 with values defined in Table F-4. The use of the normal SOM pattern indicates that a PAR shall follow, while the use of the SOM_S indicates that no PAR will follow. It is designed in such a way for the receiver to obtain sufficient information about the transmitted signal for initial acquisition. Analysis of the received preamble allows the receiver to compute initial carrier frequency offset (including Doppler), signal amplitude, and timing information.
- A parameter register (PAR) which is a modulated signal of length N_{PAR} symbols protected by a forward error correction block code. The parameter register contains all the information about the format of the burst required for the receiver to recover the transmitted data. The end of the header delimiter indicates the end of the preamble. Some of the header information may be determined by blind time series analysis of the received waveform, enabling enhanced reliability operation when fused with the header information. The bit allocation of the PAR is defined in chapter 3. The content of the PAR is mapped from the PHY-TX.request primitive and from the PAR to the PHY-TX.indication primitive.
  PHY PDUs that do not contain a PAR field shall always use mode NR and have a fixed length interleaver of N_{SHORT} bits as defined in Table F-4. No processing time is allocated for these PDUs.
- Transition symbols as described in Chapter 3.
- The data payload follows (one or more interleaver blocks), and is interspersed with repeated transition symbols and a training sequence for long duration transmissions to allow tracking of variations in the propagation channel and radio equipment as described in chapter 4. The interleavers shall transport the payload of the PHY-DATA.request, which shall be mapped to the payload field of PHY-DATA.indication at the receiver. Padding shall be performed by the PHY service user.

- For some types of operation the transmission will be terminated by an end of message (EOM) as described in chapter 4.

In Figure 2-3 a depiction is made of the different segments of the waveform constituting a PHY PDU.

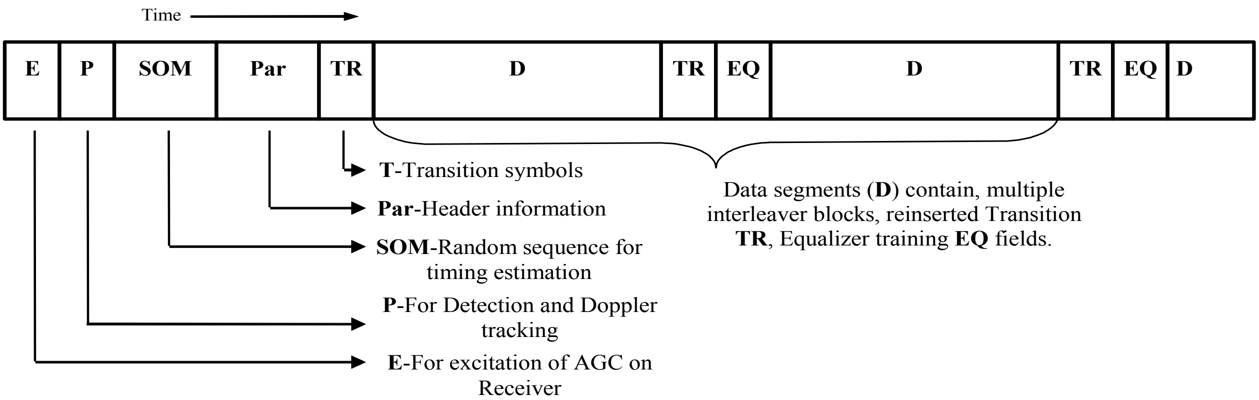

Figure 2-3 Depiction of preamble and data payload construction of fixed-frequency waveform burst

2.5 PHY Events

The PHY protocol must implement a number of timers and other events related to channel reception. This section specifies all events required and their purpose. How they are used in detail is described in previous sections. Only one timer can be active at a given time. The starting of one timer implicitly stops all other timers.

2.5.1 CW

This event is triggered as soon as the PHY detects the presence of a continuous wave signal. Depending on the received signal level, this event can happen almost any time of the actual duration of the CW.

2.5.2 CWTimer (Continuous Wave wait timer)

This optional timer is used by the receive process to set a maximum time after detecting a CW before a modulated signal must be received (start of SOM), triggering the EndCW event. This is used to reduce the impact of false alarm when receiving a CW signal which is not the start of a valid transmission. The value of this timer is maximum T_p (see Table F-4). It can be made adaptable to the received SNR.

2.5.3 DataTxTimer (Data wait timer)

This timer is used by the transmit process. The PHY-TX.request from the LINK shall be followed by a subsequent PHY-DATA.request before PHY has finished transmitting the preamble.

This timer shall be set to $T_{AGC} + T_p + T_{SOM} + T_{PAR}$ (see Table F-4).

2.5.4 EndCW

This event is triggered as soon as the receiver is able to detect that the CW is being succeeded by a modulated signal.

2.5.5 EndDECODE

This event is triggered when an interleaver block has been decoded. For some types of operation the data is directly delivered to the PHY service user.

2.5.6 EndINTERLEAVER

This event is triggered by the DemodulateData() function each time a new complete interleaver block has been received.

2.5.7 EndRXDATA

This event is triggered either when PHY has received the number of interleaver blocks as indicated in the Par field or by the reception of an EOM.

2.5.8 EndTXDATA

This event is triggered when the last symbol (tail) has been transmitted, and the PHY is ready to perform a new task.

2.5.9 FatalERROR

This event is triggered whenever a fatal error has been detected by PHY. This error is so severe that PHY is unable to continue delivering its service (PHY Transport Service), either by transmitting or receiving data.

2.5.10 PAR

This event is triggered when the receiver has received the Par field, even when the parity check fails.

2.5.11 ParTimer (Par length timer)

This timer is used by the receive process to set a maximum time after SOM to wait for the Par field. The value of this timer shall be T_{PAR} (see Table F-4).

2.5.12 SOM-SHORT

This event is triggered when the receiver, when searching for SOM, recognises the special SOM_S pattern. A Par field is not needed since mode N_R shall be used and the interleaver length is always N_{SHORT} (see Table F-4).

2.5.13 SOM-STD

This event is triggered when the receiver, when searching for SOM, recognises the standard SOM pattern (see Table F-4).

2.5.14 SOMTimer (Start of Message wait timer)

This timer is used by the receive process to set a maximum time after CW to wait for SOM. The value of this timer depends on the implementation. For an implementation that is not using the optional CWTimer, it shall be set to $T_p + T_{SOM}$ - length of AGC (see Table F-4). For an implementation using the CWTimer, it shall be set to T_{SOM}.

3. SPECIFICATION OF WAVEFORM FIELDS

3.1 Introduction

In this section the segments of the preamble are specified: *i)* the excitation field E, *ii)* the acquisition field P, *iii)* the start-of-massage field SOM, *iv)* the header register Par, *v)* the transition region TR, *vi)* and the equalizer training word EQ are specified.

Fields E and P are a continuous-wave (CW) signal, with duration expressed in terms of the baud period of PHY waveform mode N1. The bits in *SOM, Par* and the *TR* fields of the preamble are modulated using the modulation parameters of mode N1 (but with no error-correction code) having the following parameters:

Modulation:	**Binary CPM with single-h**
Baud rate:	**30000.0 sps**
Modulation parameters:	**L=2, M_C=2, h=1/2**
Phase Pulse Shape:	**REC**
	No FEC Coding
	No Interleaving.

The Data field is modulated using any of the modes N1, N2, … where parameters are listed in Annex F.

3.2 Excitation (E) Field

The beginning of the transmission uses a signal element intended to “wake up” the automatic gain control (AGC) on the receiver. The duration of this field, T_{AGC}, is specified as the maximum required for all conforming radios to allow front end dynamics to settle sufficiently so that the signal can be acquired with minimal distortion.

When generating a waveform burst a CW signal segment is used as the E waveform.

The duration of the CW in terms of baud intervals required to generate the E field is

$$N_E = ceil\left\{ T_{AGC} / T_{N1} \right\}$$

where T_{N1} is the basic baud period of the preamble, derived from the on-air baud rate of mode N1, 30kbaud.

3.3 Acquisition (P) Field

The acquisition preamble P consists of a CW signal having duration expressed in terms of baud periods T_{N1}. The P field is a CW signal segment with duration N_P x T_{N1}. Since the Excitation field uses the same CW form as the P field, the phase of the Excitation field shall be made continuous with the P field, to avoid spectral regrowth.

The duration of the combined Excitation and Acquisition (P) field is then

$T_P = N_P \times T_{N1} + T_{AGC}$ = 1.5ms + 0.3ms = 1.8ms

Therefore a CW is emitted having combined duration 1.8ms for the Excitation and Acquisition fields.

3.4 Start of Message (SOM) Field

The P field is immediately followed by a known SOM, of duration $N_{SOM.}$ There are currently two different SOM words both having same lengths: One indicates a regular transmission, and another indicates the presence of a short transmission burst. The logical contents of the SOM word are defined in Table F-4.

The SOM field is generated by modulating the SOM word using CPM modulation with Mode N1 parameters. The combined phase and correlative state at the beginning of the SOM is (0,-1), denoting a phase state of 0 radians and a correlative state corresponding to the symbol -1. The P field that precedes the SOM signal segment shall be made phase continuous with the SOM, by ensuring that the final phase of the P field is continuous with the zero initial phase of the SOM to avoid spectral regrowth. This also ensures that the CPM modulation begins in a known state.

3.5 Equalizer Training (EQ) Field

The NBWF can be implemented using an optional equalizer. The EQ field provides a training word at the beginning of each merged slot for retraining. Single slot transmissions use the SOM field for equalizer training. Equalizer training sequence is different for the 25kHz NBWF modes and the 50kHz NBWF modes since they are constructed to efficiently sound the underlying bandwidth. Therefore the time duration of the equalizer training segment will be indicated as in Table 3-1

Table 3-1 Equalizer Training Field coding

Name	Mode	Bandwidth	EQ Training Sequence Length	Time for EQ Training Sequence
EQU_{25}	N1, N2, N3, N4, NR	25kHz	$N_{EQ25} = 16$	$T_{EQ25} = N_{EQ25} \times T_{N1}$
EQU_{50}	N5, N6	50kHz	$N_{EQ50} = 64$	$T_{EQ50} = N_{EQ50} \times T_{N5}$

The modulation used to generate the EQ field for the 25kHz modes is N1. The modulation used to generate the EQ field for the 50kHz modes is N5. This allows the relative flatness of the N1 and the N5 spectra to sound the entire channel bandwidth most efficiently.

The bit sequences that make up the EQU fields, EQU_{25} and EQU_{50} are provided in Annex F.

3.6 Parameter (Par) Register

The Par register is a sequence of header bits that is coded and modulated, and when decoded, is used by the receiver to convey important parameters that, along with the acquisition of signal detection, timing and frequency achieved by processing the P and SOM fields, allows the transmission burst to be demodulated and decoded without any external information.

The terminating phase of the SOM field shall be made continuous with the beginning phase of the Par field, to avoid spectral regrowth.

The parameters contained in the Par register are used to specify information concerning the duration and structure of the incoming waveform the modulation and coding parameters and other essential information.

The contents of the register Par are shown as a row containing 12 information bits as shown in Figure 3-1. Bit contents containing a “?” indicate the bit is unused at the present and is set aside for definition of new functionality included in future versions of the waveform. There are four forms of the Par register, which are chosen by setting bit 11 and bit 12, and are described in Table 3-2.

Table 3-2 Lookup Table for Bit 12, Bit 11 Settings of PAR.

Bit 12 , Bit 11	Burst Generation Approach
0,0	NBWF Optimized PHY, FCS, never EOM
0,1	General TDMA PHY, optional EOM
1,0	Continuous Transmission PHY, always EOM
1,1	Future Use PHY

The NBWF optimized PHY is applicable to the NBWF MAC and contains only that functionality required by the NBWF MAC.

The more generally applicable General TDMA PHY is oriented to a wide variety of TDMA MAC layers, and is intended to support future systems. It allows for longer duration bursts, including bursts of unspecified duration which are terminated using EOM.

The Continuous Transmission PHY replicates the point-to-point approach of legacy communications, only using efficient modern modulation and coding schemes.

The Future Expansion PHY gives scope to define characteristics applicable to future evolution of the NBWF not currently anticipated, but that can be consistently accessed via the header and NBWF interfaces. All Par schemes support slot merging, and optional half and full interleavers in each slot, and facilitate inserting extra processing time for processing at the end of the final slot of the burst.

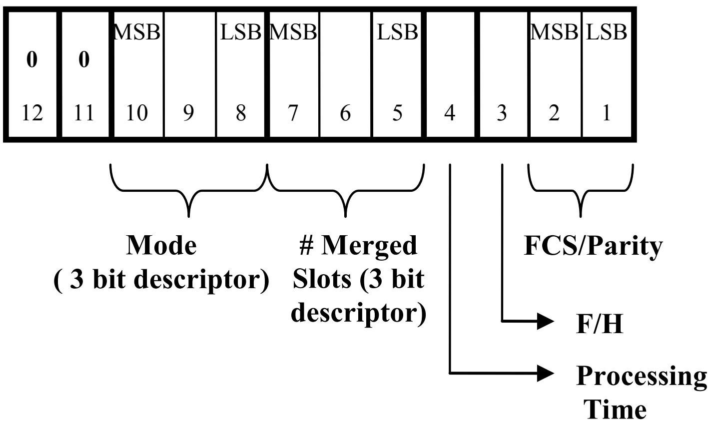

Figure 3-1 Par register specification NBWF Optimized PHY.

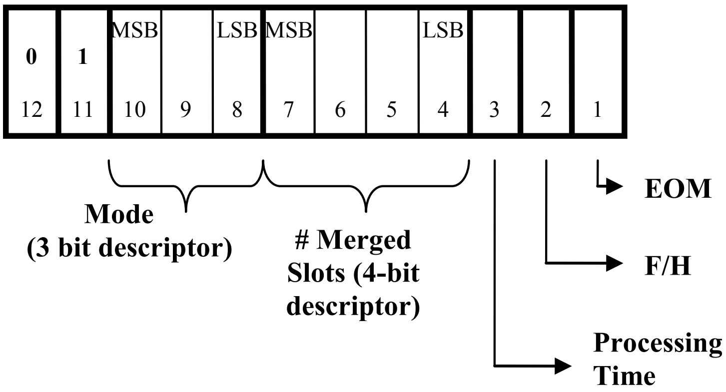

Figure 3-2 Par register specification General TDMA PHY.

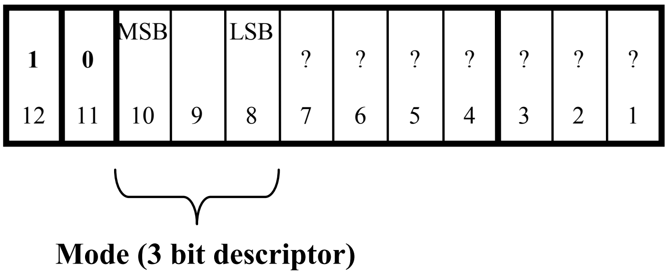

Figure 3-3 Par register specification Continuos Transmission PHY, EOM Termination

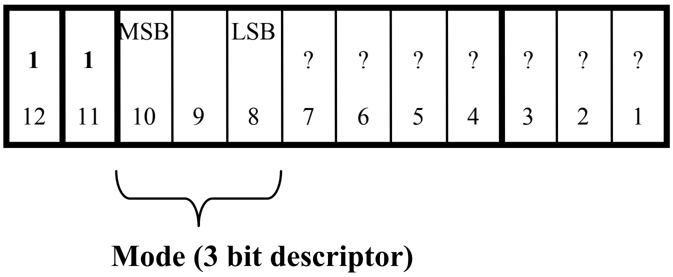

Figure 3-4 Par register specification Future Expansion PHY

In Figure 3-1 through Figure 3-4, bits 1 through 12 contain information bits describing the PHY waveform Mode, Slot Merge, Processing Time insertion, an interleaver-related flag F/H and EOM. Field contents are defined in sections 3.6.1 to 3.6.4.

3.6.1 Mode

The 3-bit mode descriptor defines a decimal equivalent number, which is an index to Table 3-3, where the definition of data transmission mode is made. Values 0_{10} through 5_{10} are currently defined, and values 6_{10} and 7_{10} are left for future expansion.

Table 3-3 Par Mode Bits, descriptor definitions

Decimal Equiv.:	0	1	2	3	4	5	6	7
Mode:	N1	N2	N3	N4	N5	N6	N/A	N/A

3.6.2 Slot Merge

Transmission bursts have duration based either on the amount of slot merging required by the host MAC layer, or based on a payload size “building block” specified by the host MAC layer.

For merged slot-based bursts, the Par register defines either 3-bit Slot Merge Descriptor the NBWF PHY MAC (up to 8 merged slots), or 4-bit Slot Merge Descriptors (up to 16 merged slots for General TDMA PHY). The decimal equivalent of the Slot Merge Descriptor and the corresponding number of merged slots is defined in Table 3-4.

Table 3-4 Look-up table for burst format applicable to all slot-based formats

Decimal Equivalent of Slot Merge Descriptor	Occupancy of Burst Transmission, In Terms of Slot Durations
0	1
1	2
2	3
3	4
4	5
5	6
6	7
7	8
8	9
9	10
10	11
11	12
12	13
13	14
14	15
15	16

3.6.3 Processing Time

Indicates that the slot occupancy is slightly shortened to provide enough time at the receiver to receive data, and re-modulate in the next slot.

This value is dependent on the interleaver duration, as processing requirements are approximately proportional to number of bits, and is defined in Annex F. In the case of merges slots, it is only the final slot in which processing time is inserted.

Table 3-5 Signalling of Processing time

Use Processing Time	Set Proc = 1
No Processing Time	Set Proc = 0

3.6.4 Full Slot/Half Slot Interleavers

Transmission bursts occupying entire slots may be generated using two smaller interleavers, or alternatively using a single longer interleaver, occupying the same total time duration of the T_s slot, which is the slot duration less the preamble, etc. Received data is only available to the host MAC once the full interleaver has been received. So the half interleaver option gives designers flexibility to pipeline data flows accordingly.

Table 3-6 Signalling Full/Half slot interleavers

Half Slot Interleaver	Set F/H = 0
Full Slot Interleaver	Set F/H = 1

3.6.5 EOM

Use of the optional EOM feature signals an end of data transmission.

Table 3-7 EOM signalling

EOM not used	Set EOM = 0
EOM used	Set EOM = 1

Rule for EOM when EOM Active: The block of user data is extended by the N_{EOM} EOM message bits, then encoded and punctured. Any unused bits in the final interleaver are filled with unspecified bits, usually logical zeros. Note that the EOM extends the payload by N_{EOM} bits plus the extension due to the code rate. The EOM may cause an extra interleaver to be used.

When EOM is used, after demodulation and decoding of each interleaver, data is scanned for detection of the EOM bit pattern. The last bit of the legitimate user data is the last bit preceding the EOM pattern and is delivered to the host.

When EOM is not used, all interleavers within a transmission burst are entirely filled with legitimate payload (which are coded and punctured bits).

When the EOM flag is set to EOM = 1, the data transmission is terminated once the following sequence of events is completed:

1) At the input to the convolutional encoder, the sequence of user transmit bits ends.
2) The N_{EOM} bit EOM sequence is concatenated to the transmit sequence after the final user transmit bit, starting with the LSB and ending with the MSB.

3) A sequence of bits is concatenated to the end of the EOM message with sufficient length to fill the final interleaver once encoded and punctured, including the impact of tail bits for the convolutional code
4) The bit sequence is convolutionally encoded, punctured, interleaved, modulated, and transmitted.
5) Transmission ends once the final interleaver has been transmitted.

The specification of the N_{EOM} bit EOM sequence is shown in Table F-4.

3.6.6 Frame Check Sequence (FCS) Bits in NBWF Mode of PAR

A simple frame check functionality is generated using bit 2 and bit 1 of the PAR when in NBWF mode (with bit 12, bit 11) = (0,0). This simple parity detection mode operates as an inner code to the repeated extended Golay code providing the majority of the protection for the Par. The two codes together form a concatenated code.

The FCS is generated from the information bits (bit 12, bit 11, …, bit 3), and inserted into the PAR in (bit 2, bit 1) according to the logical rule in Table 3-8.

Par error detection can be optimized by jointly detecting the concatenated double extended Golay and the inner parity bits.

Table 3-8 Rule for signalling of Frame Check Sequence

Bit 2	XOR(Bit 12,Bit 10, bit 8, bit 6, bit 4)
Bit 1	XOR(Bit 11,Bit 9, bit 7, bit 5, bit 3)

3.6.7 Protection of the Par Header

The 12 bit Par register is block coded using a “double-Golay” scheme, which makes use of the well-known extended Golay(24,12) code.

The Golay (24,12) codeword is generated, and then repeated immediately following the original codeword, resulting in a net code rate ¼ for the resulting (48,12) code. In the example depicted in Figure 3-5, the original Par bits are encoded into a Golay(24,12) codeword, which is then repeated prior to modulation.

On demodulation, Golay codewords can be decoded one at a time, but improved performance is obtained by jointly decoding the two codewords.

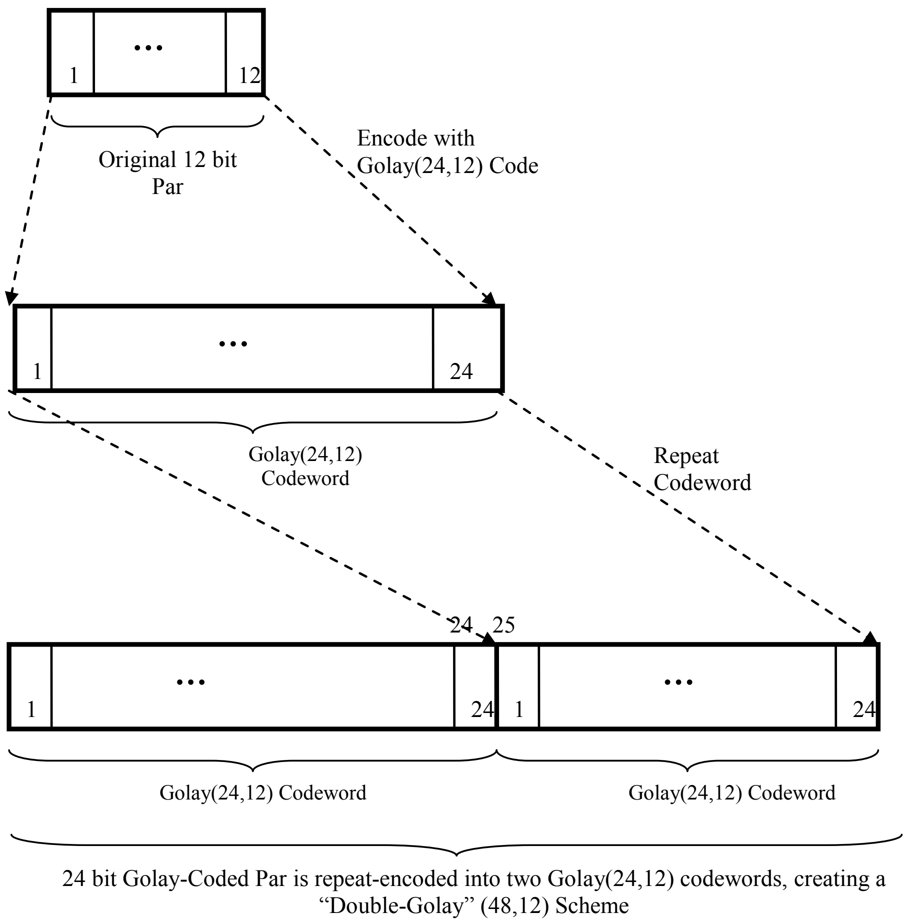

Figure 3-5 Demonstration of "Double-Golay" (48,12) scheme as applied to the 12 bits of header information in the Par register.

3.6.8 Transition Bits TR

The modulation format used for the E, P, SOM and Par fields (the *front matter*) in the preamble is that used in data mode N1. The payload of the transmission burst follows the Par field, and can be modulated using either modes N1, N2, ….

When the front matter, which uses modulation N1 changes into payload having any of modes N1, N2, … there is the possibility of a discontinuous phase, or at minimum an unknown phase, which may cause spectral regrowth and may complicate demodulation. Therefore transition symbols following the Par are required for the phase to arrive at a known state and to properly bridge the changing modulation.

Transition symbols are also used preceding the EQ field, which sets the equalizer training field to a known state at the beginning of each slot interval. The rule defining which modulation scheme used to modulate TR symbols is as in Table 3-9.

Table 3-9 Transition bit TR modulation

Waveform Segment	Rule for Modulation of TR
Preamble, following front matter	N1 Modulation
TR preceding EQ for D with N1	N1 Modulation
TR preceding EQ for D with N2	N2 Modulation
TR preceding EQ for D with N3	N3 Modulation
TR preceding EQ for D with N4	N4 Modulation
TR preceding EQ for D with NR	N1 Modulation
TR preceding EQ for D with N5	N5 Modulation
TR preceding EQ for D with N6	N6 Modulation

The two scenarios where transition symbols are used is between front matter and data as depicted in Figure 3-6 and alternatively between data and equalizer training word as depicted in Figure 3-7.

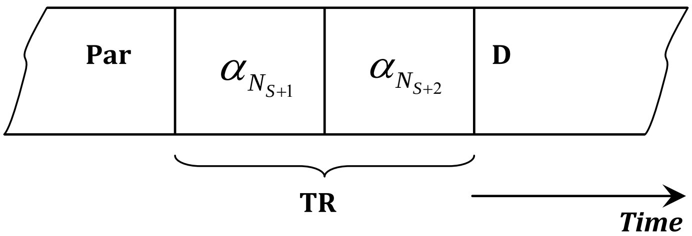

Figure 3-6 Transition Symbols used between "front matter" and data

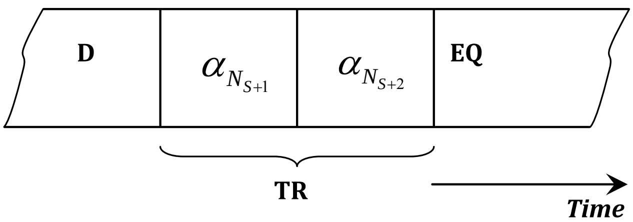

Figure 3-7 Transition Symbols used between data and equalizer training word

In both cases the same rule is followed for generating transition symbols, and this is given below.

The number of transition symbols is equivalent to the modulation memory length parameter, L, of the waveform segment preceding the transition symbols. Assuming that there are N_s symbols in the waveform sequence and denoting $(\alpha_{N_s+1}, \alpha_{N_s+2}, \ldots, \alpha_{N_s+L})$ as the transition symbols, calculation of the first transition symbol, α_{N_s+1}, is according to:

$$\alpha_{N_s+1} = \frac{-\theta_{N_s+L}}{\pi h},$$

where θ_i is the waveform phase state, in radians, calculated by the recursion

$$\theta_i = [\theta_{i-1} + \pi h\, \alpha_{i-L}]_{2\pi} \quad \text{for } i = 1,2,\dots,N_s + L$$

with $[\quad]_{2\pi}$ denoting the modulo 2π operation and α_i are CPM symbols with the mapping rule defined in section 5.5 “Data Mapping”. Note, the value for the first transition symbol, α_{N_s+1}, may not follow the mapping rule, as it is designed to drive the waveform into a known state using as few symbols as possible.

The remaining L-1 symbols $(\alpha_{N_s+2},\dots,\alpha_{N_s+L})$ of the transition symbols are assigned the value of -1, ensuring the phase and correlative state at the end of the transition symbols correspond to the waveform state $\left(\theta_{N_s+L+1},\alpha_{N_s+2},\dots,\alpha_{N_s+L}\right) = (0,-1,\dots,-1)$.

3.6.9 Acquisition Signal Processing

A simple and effective approach for implementing the preamble acquisition signal processing in the receiver is described by the heuristic algorithm:

1) Detect CW segment of preamble, and process to obtain frequency, Doppler frequency offset and phase,
2) Compensate for frequency offset in the SOM, and process to obtain frame and baud timing information,
3) Demodulate Par parameters in either a coherent or non-coherent manner, then decode giving autobaud information for the data section.
4) Revisit detection of above parameters for enhanced performance by conducting analysis jointly on data section and preamble.

The use of conventional signal processing techniques should give parameters of sufficient quality to perform data detection. Enhanced performance will be obtained when using more sophisticated acquisition and parameter detection techniques (e.g. see [R2]).

4. GENERATION OF PHY TRANSMISSION BURSTS

4.1 Introduction

Par bit 11 and bit 12 identify the nature of the burst as specifically meeting the needs of the NBWF MAC layer, or as supporting other general schemes (such as general TDMA).

Bit 1 through bit 10 of the Par register specify the precise format of the burst. In this section the burst formats are described diagrammatically how fields E, P, SOM, Par, TR, EQ and data interleavers are put together.

The fundamental time resolution of the PHY transmissions is based on the TDMA slot size utilized by the NBWF(Link Layer) [N2], which is T_S.

A *Merged Slot* is common whereby a burst occupies two or more adjacent slots, with only a single preamble used in the first slot. This way, the preamble overheads are saved in subsequent slots. Each merged slot begins with an equalizer (re-) training word to facilitate update of the optional receiver equalizer channel estimate. This training reinsertion is automatically done at the beginning of every extended slot by the PHY. In some cases it is useful to split up the slot occupancy with two interleavers, each occupying roughly a half slot. This is done so that received payload from the first half-slot interleaver can be obtained and forwarded to the Link Layer before the entire slot has been received, aiding real-time processing and aiding construction of next-slot voice relays. This functionality is available in the NBWF.

The NBWF PHY allows for several different types of burst transmissions, which are described in this section. Numerical values are found in Annex F.

4.2 Burst Format for Single Slot

Figure 4-1 shows a general single slot burst with processing time specified generated using Par selection.

		MSB		LSB	MSB		LSB			MSB	LSB
0	**0**				**0**	**0**	**0**	**1**	**1**		
12	11	10	9	8	7	6	5	4	3	2	1

Computed FCS

Figure 4-1 Par for Single slot burst

Figure 4-2 depicts a Par without FCS protection for generalized TDMA with processing time specified.

		MSB		LSB	MSB			LSB			
0	**1**				**0**	**0**	**0**	**0**	**1**	**1**	
12	11	10	9	8	7	6	5	4	3	2	1

Figure 4-2 Par without FCS for generalized TDMA

This burst format contains a preamble followed by an interleaver that occupies the time within the slot. The preamble has duration $T_P + T_{SOM} + T_{PAR} + T_{TR}$. The graphic depicting this burst format is shown in Figure 4-3.

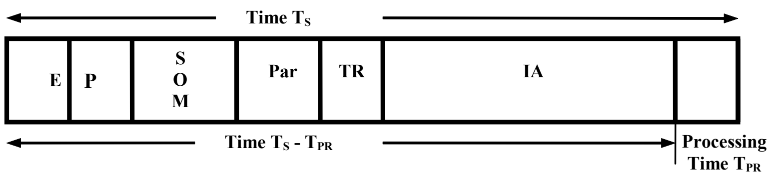

Figure 4-3 Interleaver IA occupies sufficient contents of first slot supporting Multicast Voice Transmission message.

With processing time reserved at the end of the slot plus switching time, guard time and propagation delay taken into account, the size of the interleavers are listed in Table 4-1.

Table 4-1 IA Interleavers vs Mode

IA Size	Mode
$Size(IA)_{N1}$	N1
$Size(IA)_{N2}$	N2
$Size(IA)_{N3}$	N3
$Size(IA)_{N4}$	N4
$Size(IA)_{N5}$	N5
$Size(IA)_{N6}$	N6

The numerical values of interleaver sizes are found in Annex F.

Figure 4-4 shows the Par with FCS protection for NBWF MAC with no processing time specified.

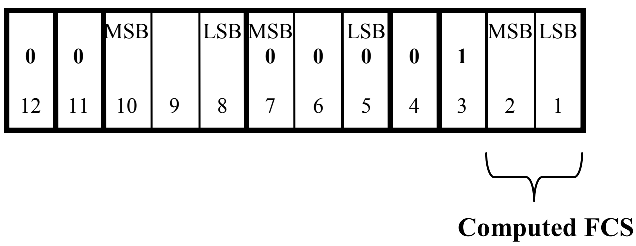

Figure 4-4 Par with FCS in NBWF MAC – no processing time

Figure 4-5 shows a Par without FCS protection for generalized TDMA with no processing time specified.

		MSB		LSB	MSB			LSB			
0	**1**				**0**	**0**	**0**	**0**	**0**	**1**	
12	11	10	9	8	7	6	5	4	3	2	1

Figure 4-5 Par without FCS for generalized TDMA- no processing time

Interleaver IB is used for this burst, which has fixed duration, and therefore size based on mode.

With no processing time reserved at the end of the slot, there is still accommodation for switching time, guard time and propagation delay. With these items taken into account, the size of the interleavers are listed in Table 4-2.

Table 4-2 IB interlavers vs Mode

IB Size	Mode
$Size(IB)_{N1}$	N1
$Size(IB)_{N2}$	N2
$Size(IB)_{N3}$	N3
$Size(IBA)_{N4}$	N4
$Size(IBA)_{N5}$	N5
$Size(IBA)_{N6}$	N6

The numerical values of interleavers are found in Annex F.

The graphic depicting this burst format is shown in Figure 4-6, which is an approximation as it does not depict the time set aside for guard time, propagation time and for TX/RX switching.

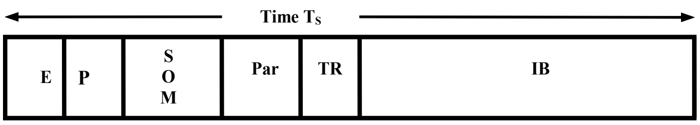

Figure 4-6 Preamble and Interleaver IB occupy entire slot.

4.3 Burst Format for Merged Slots with Full Interleavers

Merged slot with payload occupying remainder of slot, and full slot interleavers tailored for NBWF (MAC).

Par selection for this message is depicted in Figure 4-7.

		MSB		LSB	MSB		LSB			MSB	LSB
0	**0**				**0**	**0**	**1**		**1**		
12	11	10	9	8	7	6	5	4	3	2	1

Computed FCS (bits 2–1)

Figure 4-7 Par for merged slot in NBWF(MAC)

Without FCS protection for generalized TDMA, the Par is depicted in Figure 4-8.

		MSB		LSB	MSB			LSB			
0	**1**				**0**	**0**	**0**	**1**		**1**	
12	11	10	9	8	7	6	5	4	3	2	1

Figure 4-8 Par for FCS protection in generalized TDMA

This burst spans two slots, and is a result of a single “merge”. The second slot uses a single interleaver IE of duration a full slot less the transition and equalizer training word times when processing time is specified. When no processing time is specified interleaver IF is used with duration such that processing time is made available at the end of the last slot. The first slot content is identical to Burst Format B, where the Preamble is followed by Interleaver IB. When processing time is specified in the Par, it is only the final slot in the burst where processing time T_{PR} is made available.

Bursts longer than 2 slots are constructed with a duration dependent on the #Merged Slots descriptor of the Par. In Table 3-4 a total number of slots up to 16 is indicated with the base 10 index.

The rule defined in Table 3-8 applies irrespective of having a 3-bit (for NBWF MAC PHY) or a 4-bit (for General TDMA PHY) # Merged Slots descriptor. For example, for a total of 4 merged slots, the decimal index is 3. Then Par # Merged Slots descriptor is $[0\ 0\ 1\ 1]_2$. All merged slots (except the first, which has the preamble) use full slot IF interleavers (Par F/H bit = 1).

When the processing time is specified, the final slot uses interleavers IE to leave time for processing. This is depicted in Figure 4-9.

When no processing time is specified, the final slot uses interleaver IF as depicted in Figure 4-10. With processing time reserved at the end of the slot, there is still accommodation for equalizer training word .time. With these taken into account, the interleaver sizes are listed in Table 4-3.

Table 4-3 IE interleaver sizes vs Modes

IE Size	Mode
$Size(IE)_{N1}$	N1
$Size(IE)_{N2}$	N2
$Size(IE)_{N3}$	N3
$Size(IE)_{N4}$	N4
$Size(IE)_{N5}$	N5
$Size(IE)_{N6}$	N6

The numerical values of the interleaver sizes are found in Annex F.

With no processing time reserved at the end of the slot, there is still accommodation for equalizer training word time. The interleaver sizes are listed in Table 4-4.

Table 4-4 IF interleaver vs Modes

IF Size	Mode
$Size(IF)_{N1}$	N1
$Size(IF)_{N2}$	N2
$Size(IF)_{N3}$	N3
$Size(IF)_{N4}$	N4
$Size(IF)_{N5}$	N5
$Size(IF)_{N6}$	N6

The numerical values of the interleaver sizes are found in Annex D.

The burst format is depicted in Figure 4-9 for processing time specified, and Figure 4-10 when no processing time is specified. Note that the figure is an approximation, as the guard time, time for signal propagation and for Tx/Rx switching is not depicted.

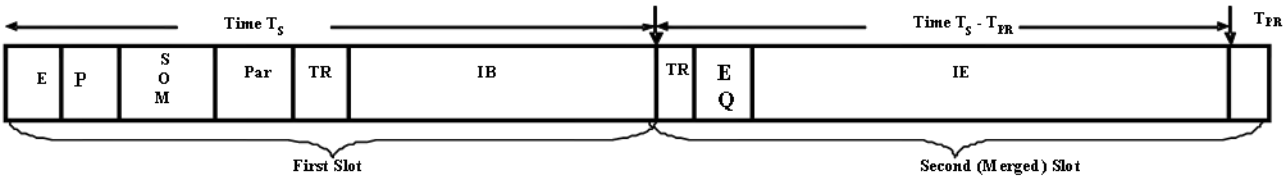

Figure 4-9 Two slot burst, where Interleaver IE with processing time is specified

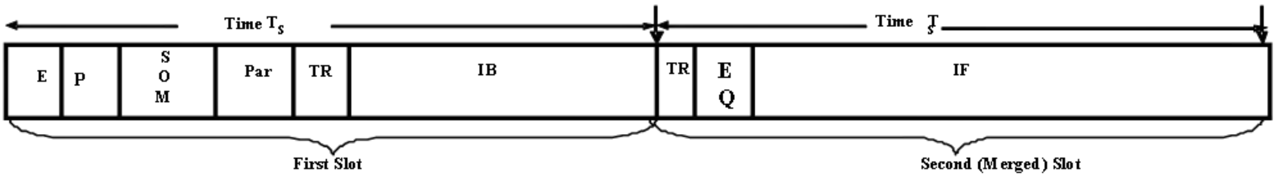

Figure 4-10 No interleaver IF Processing Time specified.

The graphic in Figure 4-11 shows the burst construction for more than two slots when processing time is specified. In Figure 4-11, notice that the processing time is placed only at the end of the final slot following the IE interleaver.

Each merged slot begins with transition and equalizer training words. The total number of slots is specified in the # Merged Slots field of the Par.

In Figure 4-11, for a burst with no processing time specified, the final slot would instead use the IF interleaver.

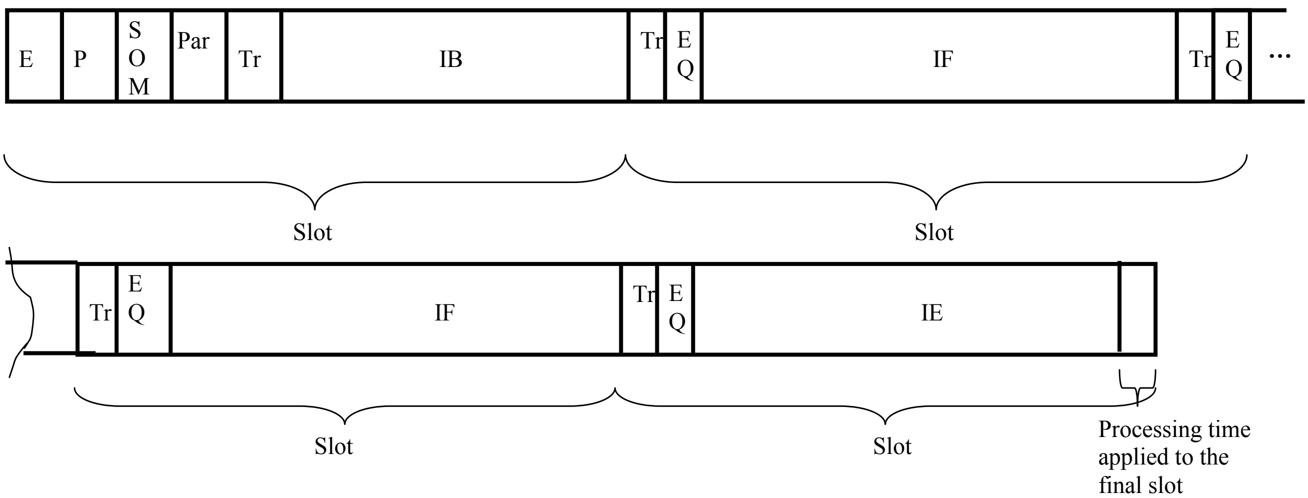

Figure 4-11 Burst construction graphic showing pattern followed for greater than two slots, with processing time specified.

4.4 Burst Format for Continuous Transmissions (CT)

Burst of arbitrary payload size, with time resolution expressed in terms of interleaver durations. Always terminate using EOM.

Par selection for this message is depicted in Figure 4-12.

1	0	MSB		LSB	?	?	?	?	?	?	?
12	11	10	9	8	7	6	5	4	3	2	1

Figure 4-12 Par for Burst Format – continuous transmission

This message is used when the transmission duration is unknown at start, and the termination is inserted using EOM. It may also be used for long duration transmissions that exceed the maximum duration of $[1\ 1\ 1\ 1]_2$ signalled using the # merged Slots field in the Par. The time occupancy of the burst will vary depending on the waveform mode. No specification on number of interleavers is required since burst is terminated using EOM.

The procedure to construct a burst that carries a payload of size N_{PAY} bits (where N_{PAY} is the payload *beyond* the capacity of a single slot using interleaver IB), using either Mode N1, N2, …. Since the basic slot building block carrying data is capacity of interleaver IE, which can carry payload bits equal to the size of interleaver IE, reduced by the coderate of the currently used mode and the convolutional code tail bits overhead, which is:

$(Size(IE)_{N1} - N_{TAIL}) \times CR_{N1}$
$(Size(IE)_{N2} - N_{TAIL}) \times CR_{N2}$
$(Size(IE)_{N3} - N_{TAIL}) \times CR_{N3}$
$(Size(IE)_{N4} - N_{TAIL}) \times CR_{N4}$
$(Size(IE)_{N5} - N_{TAIL}) \times CR_{N5}$
$(Size(IE)_{N6} - N_{TAIL}) \times CR_{N6}$

where $Size(IE)_{N1}$, $Size(IE)_{N2}$, … are fully defined based on the known slot size.

The number of slots required to carry the payload N_{PAY} plus the required EOM is then:

$NUMB_{CT}(N1) = ceil[(N_{PAY} + N_{EOM}) / (Size(IE)_{N1} - N_{TAIL}) \times CR_{N1}]$
$NUMB_{CT}(N2) = ceil[(N_{PAY} + N_{EOM}) / (Size(IE)_{N2} - N_{TAIL}) \times CR_{N2}]$
$NUMB_{CT}(N3) = ceil[(N_{PAY} + N_{EOM}) / (Size(IE)_{N3} - N_{TAIL}) \times CR_{N3}]$
$NUMB_{CT}(N4) = ceil[(N_{PAY} + N_{EOM}) / (Size(IE)_{N4} - N_{TAIL}) \times CR_{N4}]$
$NUMB_{CT}(N5) = ceil[(N_{PAY} + N_{EOM}) / (Size(IE)_{N5} - N_{TAIL}) \times CR_{N5}]$
$NUMB_{CT}(N6) = ceil[(N_{PAY} + N_{EOM}) / (Size(IE)_{N6} - N_{TAIL}) \times CR_{N6}]$

The time duration of this sequence of interleavers is approximately

$T_{IR}(N1) = NUMB_{CT}(N1) \times T_S$
$T_{IR}(N2) = NUMB_{CT}(N2) \times T_S$
$T_{IR}(N3) = NUMB_{CT}(N3) \times T_S$
$T_{IR}(N4) = NUMB_{CT}(N4) \times T_S$
$T_{IR}(N5) = NUMB_{CT}(N5) \times T_S$
$T_{IR}(N6) = NUMB_{CT}(N6) \times T_S$

The end of the valid data within the burst is the last bit preceding the EOM message.

The graphic depicting the continuous transmission PHY burst is depicted in Figure 4-13.

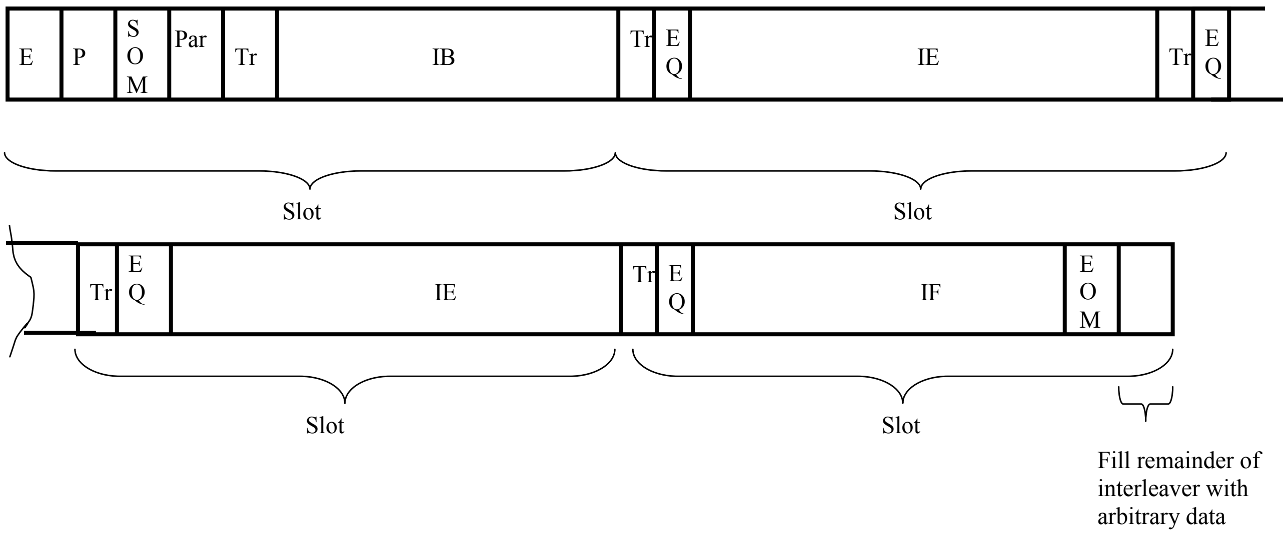

Figure 4-13 Burst Format depiction for continuous transmission PHY

4.5 Special Short Duration Burst Used for Signalling

This special message is designed to carry a small fixed payload, and is modulated using the robust mode NR. When used to support operation of the NBWF(Link Layer) the Short Burst for dedicated responses to slot reservation messages.

Generation and detection of this message is made using the E field, the P field, and then a custom SOM word, called SOM_S .

SOM_S has the same duration and numbers of logical bits as SOM. There is no Par in this message. The message is modulated using Mode NR, and the same P and SOM sizes as when using modes N1, N2, … namely N_P and N_{PSOM} respectively. No transition bits are required to bridge the SOMs field and the data payload, since the modulation mode does not change at that point.

The payload is designed to be N_{SHORT} (65 bits) long and the NR code has rate CR_{NR} = 1/3. There are therefore (N_{SHORT} / CR_{NR}) coded bits. The Interleaver IG size is:

$$Size(IG) = (N_{SHORT} / CR_{NR}) + N_{TAIL}$$

$$Size(IG) = 65/(1/3) + 9 = 204 \text{ bits}$$

Interleaver IG has duration

$$T_{IG} = Size(IG) \times T_{NR} = 204 / R_{NR} = 204 / 30000 = 6.8ms.$$

The duration of the entire *short* transmission is

$$T_{AGC} + T_P + T_{SOM} + T_{IF}$$

Figure 4-14 depicts Short Burst for a *short slot.*

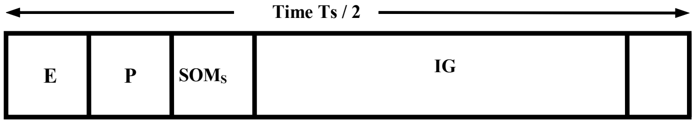

Figure 4-14 Short burst/short slot transmission

4.6 Robust Mode

The Robust Mode offers 10kbps long range service to the applications near 0dB SNR.

The Robust Mode has been designed to operate at very low SNR, offering robust communications near the noise level, and achieving very long range. The acquisition fields (P, SOM) are by necessity longer in duration than those used for the regular modes N1, N2, ….

In Robust Mode, the P field has duration corresponding to N_{PR} baud intervals at the robust baud rate T_{NR} and the SOM field has duration N_{SOMR} bits.

The Robust Mode is not currently required to support operation of the NBWF(Land) MAC, but is available for other applications.

5. SPECIFICATION OF DATA CHANNEL

5.1 Overview and Block Diagram

The NBWF PHY currently uses six primary bearers: 20kbps, 31.5kbps, 64kbps and 82kbps with a 25kHz channelization, and 40kbps and 63kbps with a 50kHz channelization. A 10kbps robust bearer is used for short messages.

The characteristics of the bearers are grouped in three categories, depicted in Table 5-1, and are described as being complementary.

Table 5-1 Description of broad categories of NBWF PHY.

Description	Throughput	Spectral Occupancy
Long Range, Low Throughput	10kbps 20kbps 31.5kbps	25kHz
Long Range, Medium Throughput	40kbps 63kbps	50kHz
Short Range, High Throughput	64kbps 82kbps	25kHz

The modulation used is in the same family of the legacy radio, which uses frequency modulation. In the NBWF the generalized frequency modulation, known as Continuous Phase Modulation (CPM) is used whereby information is signalled entirely in the phase of the carrier. This allows amplitude to be degraded and distorted with minimal impact on performance.

The sequence of signal processing steps involved is generation of the RF CPM waveform is depicted in the block diagram in Figure 5-1and are:

1) Encode
2) Puncture
3) Interleave
4) Modulate
5) Filter

Steps 1) through 5) are described in detail in the following sections.

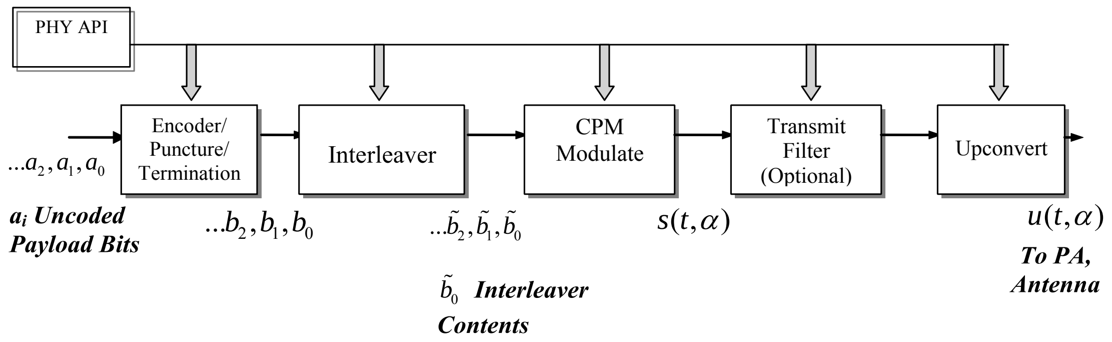

Figure 5-1 Generation of data channel, showing transfer of parameters to PHY via the API from the MAC.

5.2 Spectrum Utilization

In Figure 5-2 we see the depiction of the legacy 25kHz raster that lies within the 30MHz – 88MHz tactical VHF band. Spectrum occupancy of legacy and of NBWF in 25kHz is 99% total mean radiated power in the 25kHz channel raster.

Out-of-band (OOB) power and spurious emissions occupy adjacent channels in the legacy system, as it does in the NBWF (OOB and spurious spectral occupancy are not shown in Figure 5-2). For waveforms with 25kHz spectral occupancy (NBWF N1, N2, N3, N4, NR) the carrier lies in the middle of the 25kHz channels.

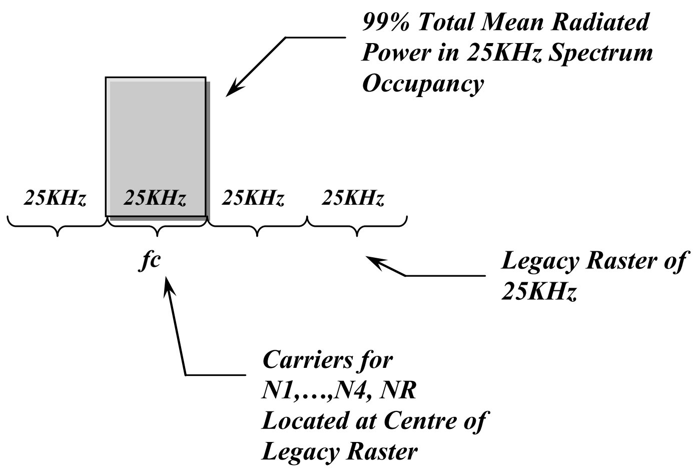

Figure 5-2 Spectrum occupancy of 25kHz modes of NBWF.

In Figure 5-3 we see that when the 50kHz modes of the NBWF are used, it will occupy two adjacent 25kHz legacy channels entirely. That means that 99% of the total mean radiated power of waveform modes N5 and N6 will lie in the two adjacent 25kHz channels. In this case it is seen in Figure 5-3 that the carrier frequency for NBWF mode N5 and mode N6 will now be located at the band edge between the two occupied 25kHz channels.

The impact on radio equipment is the necessity to be able to tune not only at the legacy raster channel centres, but also at the legacy raster channel edges. When a 25kHz centre frequency f_c is assigned, the centre frequency shall be shifted 12.5kHz up from f_c for 50kHz transmissions. To allow for 50 kHz operation the highest usable f_c is 25kHz+12.5kHz down from the edge of the allowed frequency band.

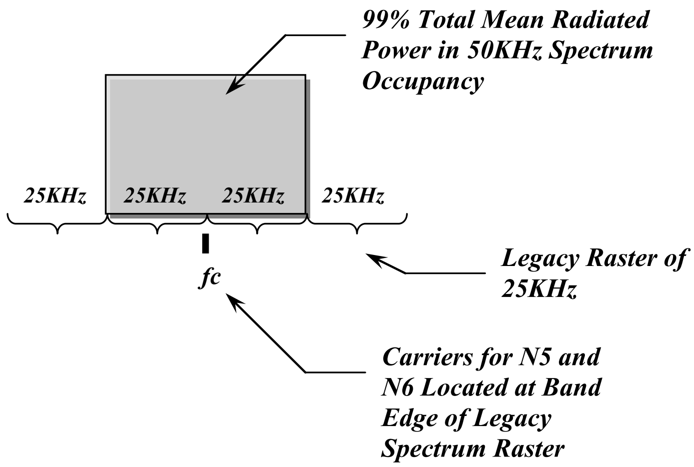

Figure 5-3 Spectrum occupancy of 50kHz modes of NBWF in relation to the legacy 25kHz channelization raster.

Regular NBWF operation sees transmissions using 25kHz modes modulated at the legacy raster centre frequencies (ie. at the centre of the 25kHz channelization) as shown in Figure 5-2, and when NBWF uses 50kHz modes the carrier is modulated at the legacy raster band edge as depicted in Figure 5-3. It is therefore clear that the acquisition by the receiver will need to detect where the carrier lies as a way to learn the bandwidth of the incoming burst.

The analysis of the CW segment of the incoming signal will provide this information. Once established, the regular preamble detection and demodulation is done.

Note that the 12.5kHz offset carrier is significantly beyond the expected Doppler shifts due to platform mobility or LO uncertainty and so there will not be uncertainty to the 25kHz versus 50kHz bandwidth due to channel or hardware-induced frequency offsets. The header information then provides information about specific mode, interleaver formats, etc.

It is anticipated that the front end will sample with sufficient bandwidth to capture both the 25kHz and 50kHz waveform options. Indeed, this is a type of frequency offset signalling of bandwidth.

5.3 Outer Convolutional Encoder

Data are convolutionally encoded and punctured with convolutional code termination "tail" bits included. These bits form an interleaver block which are then interleaved then modulated using the CPM modulation.

The user data is denoted as a stream of bits $[\ldots a_2, a_1, a_0]$ starting with a_0. Data is encoded using the convolutional encoder into bits $[\ldots c_2, c_1, c_0]$. The convolutional encoder has rate 1/3, constraint length 4, and outputs designated by octal generators $\{13, 15, 17\}_8$, and is non-recursive (from Table 8.2-2, [T2]).

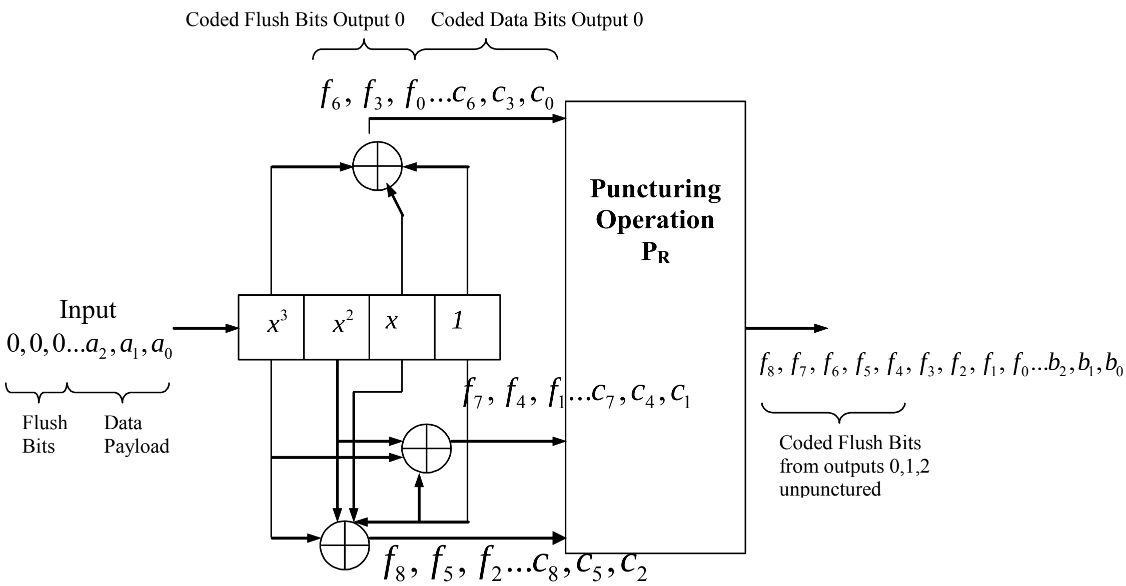

Figure 5-4 Convolutional encoder of mother code with puncturing operation.

This encoding operation is depicted in Figure 5-4, and is the *mother* code, from which encoded bit streams with specific code rates are obtained via a puncturing operation, where selected bits are eliminated from the encoded bit stream. The elimination patterns are defined by the matrices $P_{1/3}$, , $P_{2/3}$, $P_{3/4}$, $P_{4/5}$, and $P_{6/7}$.

Rate $R_c = 1/3$ is derived from rate 1/3 mother code using the puncturing matrix:

$$P_{1/3} = \left[\begin{vmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{vmatrix}\right]$$

Rate $R_c = 2/3$ is derived from rate 1/3 mother code using the puncturing matrix:

$$P_{2/3} = \left[\begin{vmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{vmatrix}\right]$$

(from Table 8.2-13, [T2]).

Rate $R_c = 3/4$ is derived from rate 1/3 mother code using the puncturing matrix:

$$P_{3/4} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

(from Table 8.2-13, [T2]).

Rate $R_c = 4/5$ is derived from rate 1/3 mother code using the puncturing matrix:

$$P_{4/5} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

(from Table 8.2-13, [T2]).

Rate $R_c = 6/7$ is derived from rate 1/3 mother code using the puncturing matrix:

$$P_{6/7} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Each of the three rows of the puncturing matrix controls puncturing of the respective three outputs of the mother code. The rate 1/3 mother code operates on the source bits $[...a_2, a_1, a_0]$ and generates the output stream $[...c_8, c_7, c_6, c_5, c_4, c_3, c_2, c_1, c_0]$ which is denoted as the vector $\underline{b} = [...b_2, b_1, b_0]$.

The columns of the puncturing matrix contain one's where bits are kept, and zeros where bits are dropped for the successive three outputs, and columns are processed from left to right. Once the entire matrix has been processed it is repeated.

As an example, for the puncturing matrix $P_{2/3}$ the encoded and punctured bitstream having effective coderate 2/3 is $[...c_7, c_6, c_3, c_1, c_0]$ and so on. Notice that all bits from the first output of the mother code are kept, every second bit from the second output is kept, and the third output is eliminated entirely by the puncturing defined in $P_{2/3}$.

5.3.1 Code Termination

At the end of each interleaver block, the CC is flushed with (Constraint Length - 1) = 4-1 = 3 zeros. This brings the code memory to the known zero state, aiding the decoder performance and complexity.

The three flush bits at the CC input are converted into $3 \times 3 = 9$ encoded flush bits, for the rate 1/3 code.

The 9 encoded flush bits from the first two code outputs $\{13,15,17\}_8$ are *not* punctured during the aforementioned puncturing scheme. These bits are transmitted as the last 9 bits into each interleaver, irrespective of the punctured code-rate, as shown in Figure 5-4.

5.4 Interleaver

The punctured and coded bits and flush bits $[f_8, f_7, f_6, f_5, f_4, f_3, f_2, f_1, f_0 ... b_2, b_1, b_0]$ are then processed by an interleaver with depth N_I bits. N_I Bits are read into the interleaver, and then all bits are output in a pseudorandom order, giving $[..., \tilde{b}_2, \tilde{b}_1, \tilde{b}_0]$. All CPM modes use binary modulation, and so interleaving is conducted bitwise. This imparts a fundamental latency of $T_s N_I$ on the communications link, when T_s is the on-air symbol rate.

Notice that the CPM modulator does not have visibility of when one interleaver ends, and when the next interleaver begins, because the interleaver contains logical coded bits. Therefore a series of interleaved coded bits constituting several interleavers is fed into the CPM modulator as a single uninterrupted stream, and in the receiver they are demodulated as a single uninterrupted stream prior to deinterleaving, insertion, and decoding.

The interleaver tables are provided in as appendices in electronic format. The interleavers used for the NBWF(Land) waveform are listed in Table 5-2, which contains a listing of the required interleavers, their sizes, and of the electronic file names of the interleavers that correspond to those required as described where Burst Formats are specified. They are first defined in the noted Burst Format section.

Table 5-2 Interleavers used in NBWF(Land)

Interleaver Family	Size(Name)	FileName	Number
IA	$Size(IA)_{N1}$ $Size(IA)_{N2}$ $Size(IA)_{N3}$ $Size(IA)_{N4}$ $Size(IA)_{N5}$ $Size(IA)_{N6}$	TBD	6
IB	$Size(IB)_{N1}$ $Size(IB)_{N2}$ $Size(IB)_{N3}$ $Size(IB)_{N4}$ $Size(IB)_{N5}$ $Size(IB)_{N6}$	TBD	6
IE	$Size(IE)_{N1}$ $Size(IE)_{N2}$ $Size(IE)_{N3}$ $Size(IE)_{N4}$ $Size(IE)_{N5}$ $Size(IE)_{N6}$	TBD	6
IF	$Size(IF)_{N1}$ $Size(IF)_{N2}$ $Size(IF)_{N3}$ $Size(IF)_{N4}$ $Size(IF)_{N5}$ $Size(IF)_{N6}$	TBD	6
IG	N.A.		1
		Total Number of Interleavers:	25

5.4.1 Electronic Format for Interleavers

The electronic files specifying the interleavers are all located as attachments in ZIP format. The ZIP files contain a total of 36 interleaver files. Each file contains a single interleaver. The interleaver files can be read by any text editor, for example MS Notepad. The interleaver indices are stored as a column of numbers, and each index is followed immediately by a carriage return.

The format of the electronic appendices specifying the interleavers is presently described. Refer to Figure 5-5, where the first five lines of one of the files is shown in plain text format. The first two rows are informative, and contain a "%" symbol followed by comments about the interleaver.

The example in Figure 5-5 depicts an interleaver for waveform Mode 2, delay 50ms, describing an interleaver of 1219 bits. The two informative rows are followed by the 1219 rows of the interleaver itself. Each row contains an integer which refers to the place in the interleaver that the data bit is read out. The first bit read into the interleaver is read out as the 1152[th] bit. The second bit read into the interleaver is read out as the 286[th] bit.

This pattern is followed for all 1219 interleaver bits in the example case shown in Figure 5-5.

% Communications Research Centre (CRC), Canada
% Mode 2, Delay 50ms, Interleaver Size 1219
1152
286
736
…

Figure 5-5 Example of the first five lines of the electronic file specifying CPM interleaver.

NOTE: It is suggested that random interleavers be used for testing, especially if developers are assessing performance for different size interleavers. Final interleavers that support interoperability are provided in the electronic format described above.

5.5 Data Mapping

The logical representation of the data is $b_i \in \{0,1\}$, which is mapped onto the binary phase constellation points $\alpha_i \in \{-1,+1\}$ using the rule logical $"0" \rightarrow +1$ and logical $"1" \rightarrow -1$. The binary alphabet is denoted by M=2. CPM Encoder

CPM is a digital phase modulation of the same family as the CPFSK used in many legacy VHF tactical waveforms. The significant properties are a constant envelope time-domain waveform, a fundamental robustness to amplitude modulation distortion, and efficient utilization of power in the transmit amplifiers. A thorough overview of CPM is found in many publications, but notably in the book by Anderson and Svensson [T1].

The complex baseband representation of the CPM waveform without filtering is

$$s(t,\underline{\alpha}) = \sqrt{\frac{2E_s}{T_s}} e^{-j\psi(t,\underline{\alpha})}$$

with E_s and T_s the symbol energy and symbol period, respectively. The vector of data symbols α_i is $\underline{\alpha}$.

The phase in the nth symbol period of this single-h CPM modulation is (with $nT_s \le t \le (n+1)T_s$)

$$\psi(t,\underline{\alpha}) = 2\pi h \sum_{i=-\infty}^{n} \alpha_i q(t - iT_s)$$

$$\psi(t,\underline{\alpha}) = \theta_n + 2\pi h \sum_{i=n-L+1}^{n} \alpha_i q(t - iT_s)$$

with the definition of accumulated phase

$$\theta_n = \pi h \sum_{i=-\infty}^{n-L} \alpha_i$$

The phase pulse shape is

$$q(t) = \int_{-\infty}^{t} g(\tau) d\tau$$

and $g(\tau)$ is the conventional LREC partial response phase pulse shape with volume 1/2. The RF signal with carrier frequency w_c is

$$u(t,\underline{\alpha}) = \mathrm{Re}\left\{ s(t,\underline{\alpha}) e^{j w_c t} \right\} \qquad (1)$$

The communications waveform $s(t,\underline{\alpha})$ is generated at baseband and can be up-converted to IF digitally. The further up-conversion to RF, giving (1), can be done in the analog domain, or via direct digital RF conversion.

The expression (1) depicts a waveform starting with zero phase offset for notational simplicity. At various places in the specification it is mandated that waveform segments be phase continuous with adjacent segments.

This is accomplished via the transition symbols inserted into the packet structure and the sequence of symbols used for the EQ re-training which are designed to end in a known state of (0,-1) corresponding to the phase and correlative states of the waveform.

5.6 Transmit/Receive Filtering

Some users of the interoperable waveform may require transmit and receiver filtering in order to conform to specific requirements. Filtering may be accomplished with some combination of analog (RF or IF) filtering, or digital filtering.

Transmit and receive filter parameters describing digital baseband filters provided in Table F-3 describe the *net effect* of all analog and digital filtering near the carrier, and are provided for advice on design of non-mandatory transmit and receiver filtering.

Filter characteristics are described in terms of a passband frequency (F_P) and a stopband frequency (F_S). The stopband attenuation used may be -50dB.

There is latitude for optimizing filter designs, and so the values in Table F-3 in Annex F are given for guidance, and are not necessarily the only acceptable values. Filter should be implemented, and may be optionally unused.

5.7 CPM Waveform Parameters

The specification describes a variety of data transmission modes for 25kHz and 50kHz channelization, all of which are selectable by simple choice of parameters in a software-defined modem implementation. The list of waveform modes is given in Annex F for the NBWF(Land) PHY.

All modes must be implemented as they may be required by the NBWF(Link Layer) specification [2], and may be invoked during run-time as the network uses adaptive modulation and coding approaches for capacity optimization in tactical environments.

Modes N1, … , N6 and NR provide 10kbps through 82kbps, and the CPM modulation and coding parameters are described in Annex F. These modes conform to the bandwidth constraint that 99% total mean radiated power lie within the necessary bandwidth of 25kHz, as specified in STANAG 4204 [N3], and 99% total mean radiated power lie within 50kHz for the 50kHz channelization modes.

The out-of-band emissions will conform to the spectral mask recommendation in ITU-R SM.1541-41 “FDMA Systems” [ITU]. The definitive procedure for measuring and assessing RF spectrum occupancy of the NBWF(Land) PHY is specified in Annex E.

The waveform modes are generated using only binary alphabets and variable baud rates, which are implemented from a single decimated clock using variable oversampling techniques. Reasons for binary alphabets include [R1]

i) low complexity signal processing in typical receiver implementations, since complexity is proportional to the alphabet taken to a positive integer power

ii) significant gains in robustness of the waveform to interference, timing and Doppler offsets as compared with non-binary alphabets [R2], and

iii) spectral efficiency [R3].

This architecture requires consideration of implementation constraints, more so than when specifying waveforms with single baud rates. Baud rates of all modes and preambles have been chosen to be derivable from a single external frequency source, and can be obtained using either hardware or software resampling. A typical external crystal (for example, consider a common one with frequency 20MHz) can be divided in hardware or software down to several useful rates required by the baseband signal processing; higher rates to be used for precise timing recovery, and lower rates for data demodulation (while still respecting the Nyquist rate of the waveform modes).

5.8 Clock and Sampling Rates

Figure 5-6 shows a block diagram indicating one approach of how variable down-sampling can be used to generate the required NBWF sampling rates from a single reference clock. The preamble and data segments of the waveform are implemented using variable oversampling rates. An example uses a 20MHz external reference crystal that is decimated by a different factor to support each operating mode. This decimation may be done either in a hardware or a software re-sampler. Table 5-3 provides the integer decimation factors (for this example case of using a 20MHz external source) taking the sampled waveform down to the desired baud rates for all modes. Therefore, all resulting exact baud rates in Table 5-3 are obtainable in such a manner. Interleaver sizes are based on the exact baud rates defined Table 5-3.

Table 5-3 Example definition of exact baud rates for waveform modes, with divide down factor based on 20MHz crystal, divided down by factor as shown.

Mode	Target Baud Rate (sps) for 4x Oversampling	Sampling Step-Down Factor	Exact Baud rate (sps)
N1	120.0	166666	120.0005
N2	168.0	119047	168.0009
N3	320.0	62500	320.0000
N4	384.0	52083	384.0025
N5	240.0	83333	240.0010
N6	336.0	59523	336.0050
NR	120.0	166666	120.0005

Samples are processed at different oversampling rates at the preamble, and at the data demodulation. Generally, the higher resolution sampling of the preamble processing can enables fine timing acquisition to be made, after which point the sample stream is decimated down to a lower oversampling rate for demodulation and decoding.

Referring to the diagram in Figure 5-6, the samples are received by the preamble processing block at A. This may be decimated down to a lower rate at B for matched filtering, which brings the waveform to the symbol rate at C.

The preamble may be processed at a higher oversampling rate initially at E while conducting timing recovery, then decimated to a lower rate at F for demodulation of the header.

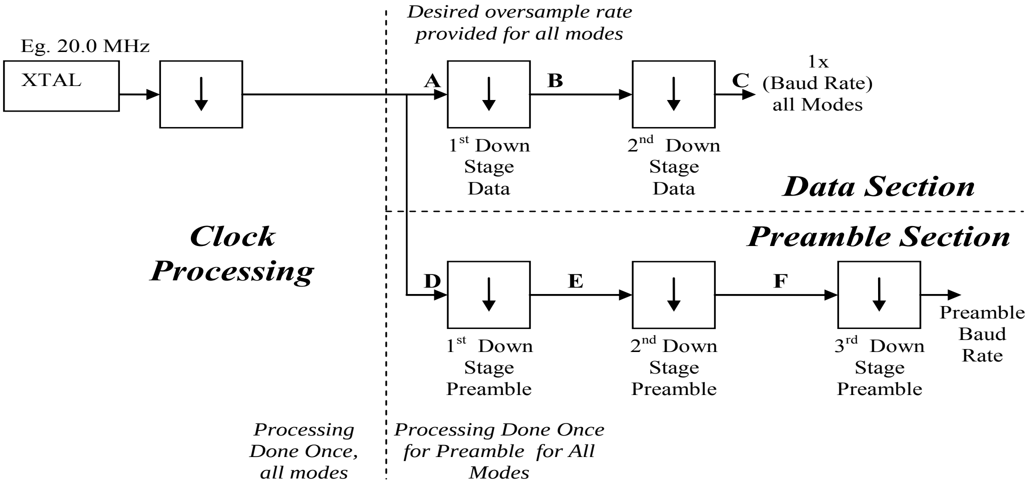

Figure 5-6 One possible sampling clock generation approach supporting all NBWF modes.

5.9 Receiver Equalization

In some mountainous terrain there may be intersymbol interference to the extent that NBWF performance would benefit from an equalizer. Future spectrum use trends also indicate that NBWF may be considered for use at higher frequencies than the current legacy radios (for example, use in the tactical A-G-A band will result in operation up to 400MHz instead of the current top frequency 88MHz.). The small wavelengths of the higher bands may lead to increased intersymbol interference. For this reason the facility for equalizers has been incorporated into the current NBWF specification as a way to future proof the technology by way of regular equalizer training words at the beginning of each merged slot. One technique demonstrating how this equalization can be done for SC+CPM, including showing performance results, can be found in [R4].

In the 25kHz modes (N1, N2, N3, N4, NR) the equalizer training word sequence EQ is optimized for channel sounding of the 25kHz channel. The transition symbols TR brings the phase of the modulation at the end of the previous time slot to a known phase. Therefore both TR and EQ are modulated using the N1 modulation scheme (uncoded) since N1 modulation has the flattest spectrum of the 25kHz modulations schemes (ie. most noise-like), thereby providing the best channel estimate.

For the 50kHz modes (N5, N6) the equalizer training word sequence is optimized for channel sounding of the 50kHz channel. It is therefore a longer sequence than the EQ word for 25kHz in order to catch the shorter echos that are of greater importance to a higher bandwidth modulation. The TR and EQ symbols are modulated using the N5 modulation scheme (no coding) for the reason the N5 has the flattest modulation spectrum of the 50kHz modulations schemes.

ANNEX A ABBREVIATIONS AND DEFINITIONS

1 ABBREVIATIONS

Abbreviation	Description
AComP	Allied Communications Publication
A-G-A	Air Ground Air communication
ARQ	Automatic Repeat Request
API	Application Protocol Interface
APSK	Amplitude Phase-shift Keying
CC	Convolutional Code
CDF	Cumulative Density Function
CNR	Combat Net radio
CPFSK	Continuous Phase Frequency Shift Keying
CPM	Continuous Phase Modulation
CRC	Cyclic Redundancy Check
CRC Canada	Communications Research Centre Canada
CSMA	Carrier Sense Multiple Access
CT	Continuous Transmission [NBWF]
CW	Continuous Wave
dB	Decibel
dBc	Decibel referenced to Carrier power
DRP	Dithered Relative Prime
EOM	End of Message
EQ	Equalizer Training field [NBWF]
FCS	Frame Check Sequence
FDMA	Frequency Divided Multipla Access
FEC	Forward Error Correction

Abbreviation	Description
FFT	Fast Fourier Transform
Hz	Hertz
ICI	Interface Control Information
IEEE	Institute of Electrical and Electronic Engineers
IP	Internet Protocol
ITU	International Telecommunication Union
kHz	Kilohertz
LINK	Link Layer
LSB	Least Significant bit
MAC	Medium Access Control
MANET	Mobile ad-hoc Network
MHz	Megahertz
MELPe	Mixed Exitation Linear Predictive Coding enhanced
MSB	Most Significant bit
NATO	North Atlantic Treaty Organization
NBWF	Narrowband Waveform
NNEC	NATO Network Enabled Capability
NPICS	NATO Protocol Information Conformance Specification
OOB	Out of Band
PAR	Parameter Register [NBWF]
PDU	Protocol Data Unit
PHY	Physical layer
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RF	Radio Frequency
RS	Reed-Solomon

Abbreviation	Description
RSSI	Received Signal Strength Indication
SAP	Service Access Point
STANAG	NATO Standardization Agreement
SC	Serial Concatenated
SDU	Service Data Unit
SOM	Start of Message [NBWF]
TDMA	Time Division Multiple Access
TR	Transition Bits [NBWF]
TRANSEC	Transmission Security
UHF	Ultra High Frequency
VCO	Voltage Controlled Oscillator
VHF	Very High Frequency
VoIP	Voice over IP
ZIP	Compressed file format

2 DEFINITIONS

None

ANNEX B GUIDANCE FOR NSPICS/NPICS COMPLETION

TABLE OF CONTENTS

1 INTRODUCTION

For an implementation claimed to conform to the NBWF specification, the NATO Protocol Implementation Conformance Statement (NPICS) proformas shall be completed.

For a NATO standard, the NPICS corresponds to the Protocol Implementation Conformance Statement (PICS) defined in ISO/IEC 9646-1 for an International Standard. The term NPICS is used to avoid confusion where the requirements for NPICS and PICS differ.

A completed NPICS proforma is the NPICS for the implementation in question.

The implementation of the NSPICS proforma shall follow the same rules as for the NPICS.

The NPICS is a statement of which capabilities and options of the protocol have been implemented. The NPICS can have a number of uses, including use:

a. by a protocol tester, as the basis for selecting appropriate tests against which to assess the claim for conformance of the implementation;

b. by the protocol implementer, as a check-list to reduce the risk of failure to conform to the standard through oversight;

c. by the supplier and acquirer - or potential acquirer - of the implementation, as a detailed indication of the capabilities of the implementation, stated relative to the common basis for understanding provided by the standard NPICS proforma; and

d. by the user - or potential user - of the implementation, as a basis for initially checking the possibility of interworking with another implementation (while interworking can never be guaranteed, failure to interwork can often be predicted from incompatible NPICSs).

All material in the base standard is considered mandatory unless another status is specifically indicated in this NPICS Proforma.

2 ABBREVIATIONS AND SPECIAL SYMBOLS

2.1 Status Symbols

M mandatory

O optional

<n> optional; required to choose one (or more then one) of the group of options labelled by the same numeral <n> (1, 2, etc.); an example is shown in Table B-1;

X prohibited

<pred>: conditional-item symbol, including predicate identification, see 3.4

¬ logical negation, applied to a conditional item's predicate see 3.4.2

Table B-1 reports a dummy example. The optional fields marked as “O.1” represent the list of possible values that the quantity “Information transfer rate” can assume: the implementer must choose one of them to support the requirement.

Table B-1 Example Optional Field

Item	Protocol Feature	Reference	Status	Support
	Are the system’s bearer service attributes and values defined for information transfer mode:			
EITM.1	Circuit?	C.3.1.2.	M	Yes [ ]
	Are the system’s bearer service attributes and values defined for information transfer rate:			
EITR16	16 kb/s?	C.3.1.2.	O.1	Yes [ ] No [ ]
EITR32.1	32 kb/s?	C.3.1.2.	O.1	Yes [ ] No [ ]
EITR32.2	32kb/s with 2 time slots?	C.3.1.2.	O.1	Yes [ ] No [ ]
EITR48	48 kb/s with 3 time slots?	C.3.1.2.	O.1	Yes [ ] No [ ]
EITR64.1	64 kb/s with 2 time slots?	C.3.1.2.	O.1	Yes [ ] No [ ]

O.1 Support for at least one of these options is required

2.2 Item References

Items in the NPICS proforma are identified by mnemonic item references. NPICS items dealing with related functions are identified by item references sharing the same initial letter or letter sequence (in capitals).

2.3 Base Standard References

The NBWF specification suite is partly based on existing civilian or military standards. However, these standards are described for use in generic systems. When an existing standard is adopted, the base standard includes only a reference to the existing standard.

The standards include a number of options and parameters to be selected. For each standard, a table describing which parameter is optional or mandatory is provided. This table is defined as the PICS proforma.

When an existing standard is adopted, including a PICS proforma fully applicable to NWBF, a specific NBWF PICS proforma is not defined and only the link to the existing PICS is given. Otherwise, a specific NBWF PICS proforma is defined.

3 INSTRUCTIONS FOR COMPLETING THE NPICS PROFORMA

3.1 General Structure of the NPICS Proforma

In general, the PICS proformas are organised as follows:

a. Identification;

b. Protocol Summary;

c. Implementation; and

d. References.

The first part of the NPICS proforma - Implementation Identification and Protocol Summary - is to be completed as indicated with the information necessary to identify fully both the supplier and the implementation.

The main part of the NPICS proforma is a fixed-format questionnaire, divided into a number of major subclauses; these can be divided into further subclauses each containing a group of individual items. Answers to the questionnaire items are to be provided in the rightmost column, either by simply marking an answer to indicate a restricted choice (usually Yes or No), or by entering a value or a set or range of values. There are some items where two or more choices from a set of possible answers can apply. In this case, all relevant choices are to be marked.

Each item is identified by an item reference in the first column; the second column contains the question to be answered; the third column contains the reference or references to the NBWF specification, according to 2.3 above. The remaining columns record the status of the item, i.e., whether support is mandatory, optional, prohibited, or conditional. In the conditional case, space is provided for the answers (see Section 3.4).

A supplier may provide, or be required to provide, further information, categorised as either Additional Information or Exception Information. In this case, the information is to be provided in a further subclause of items labelled A<i> or X<i> respectively for cross-referencing purposes, where <i> is any unambiguous identification for the item (e.g., a numeral); there are no other restrictions on its format and presentation.

A completed NPICS proforma, including any Additional Information and Exception Information, is the NATO Protocol Implementation Conformance Statement for the implementation in question.

Where an implementation is capable of being configured in more than one way, a single NPICS may be able to describe all such configurations. However, for presentation clarity, the supplier may provide more than one NPICS, each covering some subset of the implementation's configuration capabilities.

3.2 Additional Information

Items of Additional Information allow a supplier to provide additional information intended to assist in the interpretation of the NPICS. It is not intended or expected that a large quantity will be supplied, and an NPICS can be considered complete without any such information. An example is an outline of the ways in which a single implementation can be set up to operate in a variety of environments and configurations. Another example is a brief rationale (based perhaps upon specific application needs) for the exclusion of features, which, although optional, are nonetheless present in typical implementations of this protocol.

References to items of Additional Information may be entered next to any answer in the questionnaire, and may be included in items of Exception Information.

3.3 Exception Information

It may occasionally happen that a supplier will wish to answer an item with mandatory or prohibited status (after any conditions have been applied) in a way that conflicts with the indicated requirement. No pre-printed answer will be found in the Support column for this case. Instead, the supplier shall write the answer in the Support column, together with an X<i> reference to an item of Exception Information, and shall provide the appropriate rationale in the Exception item itself.

An implementation for which an Exception item is required does not conform to the NBWF specification.

The situation described above may arise when a defect in the standard has been reported and the correction is expected to change the requirement not met by the implementation.

3.4 Conditional Status

3.4.1 Conditional Items

The NPICS proforma contains a number of conditional items. These are items for which the status (mandatory, optional, or prohibited) that applies is dependent upon whether or not certain other items are supported, or upon the values supported for other items.

In many cases, whether or not the item applies at all is conditional in this way, as well as the status when the item does apply.

Where a group of items is subject to the same condition for applicability, a separate preliminary question about the condition appears at the head of the group, with an instruction to skip to a later point in the questionnaire if the "Not Applicable" answer is selected. Otherwise, individual conditional items are indicated by one or more conditional symbols (on separate lines) in the status column.

A conditional symbol is of the form "<pred>:<x>" where "<pred>" is a predicate as described in 3.4.2 below, and "<x>" is one of the status symbols M, O, O.<n>, or X.

If the value of the predicate in any line of a conditional item is true (see 3.4.2), the conditional item is applicable, and its status is that indicated by the status symbol following the predicate; the answer column is to be marked in the usual way. If the value of a predicate is false, the Not Applicable (N/A) answer is to be marked in the relevant line. Each line in a multi-line conditional item should be marked.

3.4.2 Predicates

A predicate is one of the following:

a. an item-reference for an item in the NPICS proforma: the predicate is true if the item is marked as supported, and is false otherwise;

b. predicate name for a predicate defined elsewhere in the NPICS proforma item. The definition for a predicate name is a Boolean expression constructed by combining simple predicates, using the Boolean operators AND, OR and NOT, and parentheses, in the usual way. The value of such a predicate is true if the Boolean expression evaluates to true; or

c. the logical negation symbol "¬" prefixed to an item-reference or predicate name; the value of the predicate is true if the value of the predicate formed by omitting the "¬" is false, and vice versa.

Each item whose reference is used in a predicate or predicate definition is indicated by an asterisk in the Item column.

A dummy example is given in the following Table B-2.

Table B-2 Example of Use of “predicate”

Item	Protocol Feature	Reference	Status	Support
*DSTI4	Does the implementation provide one or more PRA interfaces?	B.2.4	O	Yes [ ] No [ ]
DSTI5	Is the PRA implementation compliant with ETS 300011?	B.2.4	DSTI4:M	N/A [ ] Yes[ ]

4 IDENTIFICATION

The NBWF NPICS reference and its corresponding protocol are identified in table form as shown in the following two sections.

4.1 Implementation Identification

Nation/Supplier	
Contact point for queries about the NPICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification - e.g., name(s) and version(s) of machines and/or operating systems; system names	

NOTES: Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirement for full identification.
The terms Name and Version should be interpreted appropriately to correspond with a supllier’s terminology (e.g. Type, Series, Model).

4.2 Protocol Identification

Identification of protocol, specification	NBWF STANAG on INTERFACES
Identification of amendments and corrigenda to this NPICS proforma which have been completed as part of this NPICS	Am. : Corr. : Am. : Corr. : Am. : Corr. : Am. : Corr. :
Have any Exception items been required (see 3.3) The answer Yes means that the implementations does not confirm to the NBWF specification	No [ ] Yes [ ]

ANNEX C PROPAGATION CHANNEL MODELS AND PERFORMANCE SPECIFICATIONS

C.1 Multipath and Fading Measurements

Performance of the NBWF can be predicted for various operational environments when propagation models are known. Fading and multipath models of the VHF and UHF tactical channels are provided in this AComP in order to support the assessment of performance requirements for the NBWF. Models are also useful when performing system planning, and assessing options analysis for various alternative scenarios.

Definition of draft operational scenarios for NATO have been made by NC3A [N1], which include:

1) Amphibious entry
   i) Potential hostile force interference,
   ii) Crowd control,
   iii) Maritime force protection,
2) Counter terrorism, and
   i) Base protection,
   ii) Counter ambush,
   iii) Neutralisation of a strategic target,
3) Urban control
   i) Preventing the hi-jack of an aid convoy,
   ii) Preventing a bomb attack on NATO forces,
   iii) Neutralisation of a gang leader stronghold.

Measurements have been conducted in the tactical VHF band around Ottawa, Canada, using vehicle-to-vehicle antennas, and in a manner that emulates tactical radio equipment setups for ranges up to about 5km. Measurement environments have been carefully chosen in order to apply to the proposed NC3A scenarios. The measurement environments reported in [R6] are the following:

a) Rural
b) Suburban
c) Urban
d) Off-shore to Urban

Applicability of Models to NC3A Scenarios:

The model for measurements in the Rural areas (A) will apply to NC3A scenarios: 2.a, 3.a, 3.c.
The model for measurements in the Suburban areas (B) will apply to NC3A scenarios 2.a., 2.b., 2.c., 3.b., 3.c.
The model for measurements in the Urban areas (C) will apply to NC3A scenarios 2.a., 2.b., 2.c., 3.b., 3.c.

The model for measurements in the Off-shore-to-Urban areas (D) will apply to NC3A scenarios 1.a., 1.b., 1.c.

C.2 Model of Multipath and Fading

The reported modelling results are observational results, with no assumptions about their spectrum. The consequence of this approach is that the observational results must apply only in the bands in which they were taken. For this reason the 30MHz – 88MHz NATO band has models representing three regions that taken together span the entire band. Results are valid for ranges up to about 5km, reflecting the range of propagation measurements used to optimize the models. Simulation of the propagation channel using these models must therefore be conducted using the identified parameters that are valid for the frequencies of operation. All parameters provided in this work are stated for their valid frequency ranges. These frequency ranges are notated as listed in Table C-1.

Table C-1 Frequency ranges and notations

Range	67.3MHz-108MHz	47.4MHz-67.3MHz	30MHz-47.4MHz
Notation	High Band **H**	Mid Band **M**	Low Band **L**

The table names are a concatenation of the environment code, and the band notation. For example, Table RH (using concatenation "R" || "H") refers to parameters for operation in a rural environment "R" operation in the high part "H" of the tactical VHF band. Model parameters are provided in Table RH through Table SL, where the table names are setup according to the legend:

Rural:

Table RH: applicable within 67.3MHz-108MHz,

Table RM: applicable within 47.4MHz-67.3MHz,

Table RL: applicable within 30MHz-47.4MHz,

Urban:

Table UH: applicable within 67.3MHz-108MHz,

Table UM: applicable within 47.4MHz-67.3MHz,

Table UL: applicable within 30MHz-47.4MHz,

Littoral:

Table LH: applicable within 67.3MHz-108MHz,

Table LM: applicable within 47.4MHz-67.3MHz,

Table LL: applicable within 30MHz-47.4MHz,

Suburban:

Table SH: applicable within 67.3MHz-108MHz,

Table SM: applicable within 47.4MHz-67.3MHz,

Table SL: applicable within 30MHz-47.4MHz.

The guideline to the entries in the tables is parameters of the fixed tap delays, the average power, and the Rician parameter (ratio of direct-to-diffuse power, commonly referred to as “K”).

Table C-2 Frequency ranges and notations

Group	Delay [ns]	Power [dB]	K-Factor [linear]
1	0	Ω_1	K1
2	τ_2	Ω_2	K2
3	τ_3	Ω_3	K3
4	τ_4	Ω_4	K4

C.3 Simulation Approach

Modern waveforms use packet-based transmissions at the physical layer. The format of these transmissions will be discrete bursts of finite durations. Note that this is a significant divergence from traditional point-to-point communications, where the transmitter may be active indefinitely.

At VHF, the propagation channel starts to have small time variation (de-correlation) over time intervals determined by the coherence times. For the majority of operational scenarios, the channel measurements have been found to be static for the duration of TDMA slots. This allows for a particularly straight-forward simulation approach, and is depicted in Figure C-1. An enumerated list describing the steps for TDMA slot simulations follows:

Start: For each Tx slot between two radio platforms

1. For the frequency of operation, look-up propagation parameters of multipath group in the provided tables.
2. Generate the Rice random numbers for the tap attenuations, and the uniform random numbers in $[0, 2\pi)$ for the associated tap phases: this defines the tap-delay line.
3. Calculate path loss.
4. Apply the tapped-delay line to transmitted signal using deterministic tap delay s given in the table.
5. Apply normalization gain.

6. Apply the path loss to the signal from 5
7. Apply additive thermal and channel noise to the signal from 6.

End.

The numerical quantities used in Figure C-1 are either random, or deterministic. Random variables in the block diagram are denoted by their density functions, while fixed quantities are given explicitly in the block diagram. Random variables are X_1, X_2, X_3, X_4, (all Rice pdf's), $\theta_1, \theta_2, \theta_3, \theta_4$ (all uniform phase pdf's) $L_P(d)$ (path loss) , *T* (noise) and the deterministic quantities are τ_2, τ_3, τ_4 (tap delays), G_T (a normalization constant ensuring the gain of the tapped delay line is unity), and depend on operating frequency and on operating environment.

This procedure is followed at every TDMA MAC slot. The simplicity is that the complex channel coefficient that results from the channel model is a single complex number applied to each multipath of the transmitted waveform for the duration of the slot, before combining in a tapped-delay line structure. There is no channel correlation assumed between different MAC slots, and so the procedure is restarted at each MAC slot in a manner independent of that used in previous slots.

The tap-delay line imparts important phenomena of intersymbol interference on the communications waveform, and tap attenuations impart slow, flat Rician fading on each tap.

Table C-3 Table RH (Rural) is applicable within 67.3MHz-108MHz.

Group	Delay [ns]	Power [dB]	K-Factor [dB]
1	0	0	6.7
2	710	-15.9	-0.1
3	1220	-20.9	-1.1

Table C-4 Table RM (Rural) is applicable within 47.4MHz-67.3MHz.

Group	Delay [ns]	Power [dB]	K-Factor [dB]
1	0	0	7.5
2	720	-18.2	4.8
3	1320	-23.5	6.9

Table C-5 Table RL (Rural) is applicable within 30MHz-47.4MHz.

Group	Delay [ns]	Power [dB]	K-Factor [dB]
1	0	0	8.6
2	560	-18.2	5.1
3	1180	-25.5	7.8

Table C-6 Table UH (Urban) is applicable within 67.3MHz-108MHz.

Group	Delay [ns]	Power [dB]	K-Factor [dB]
1	0	0	4.81
2	520	-4.4	1.61
3	990	-8.9	1.73
4	1510	-11.5	2.12

Table C-7 Table UM (Urban) is applicable within 47.4MHz-67.3MHz.

Group	Delay [ns]	Power [dB]	K-Factor [dB]
1	0	0	5.58
2	550	-6.6	2.90
3	1070	-10.9	3.42
4	1600	-13.6	6.06

Table C-8 Table UL (Urban) is applicable within 30MHz-47.4MHz.

Group	Delay [ns]	Power [dB]	K-Factor [dB]
1	0	0	6.57
2	510	-5.2	3.86
3	970	-9.2	1.82
4	1430	-12.1	3.01

Table C-9 Table LH (Littoral) is Applicable within 67.3MHz-108MHz.

Group	Delay [ns]	Power [dB]	K-Factor [dB]
1	0	0	2.5
2	950	-14.9	2.4
3	1740	-18.7	5.2

Table C-10 Table LM (Littoral) is applicable within 47.4MHz-67.3MHz.

Group	Delay [ns]	Power [dB]	K-Factor [dB]
1	0	0	8.8
2	1250	-15.6	7.4
3	2010	-21.5	9.6

Table C-11 Table LL (Littoral) is applicable within 30MHz-47.4MHz.

Group	Delay [ns]	Power [dB]	K-Factor [dB]
1	0	0	10.4
2	1070	-16.9	3.9
3	2260	-21.0	7.8

Table C-12 Table SH (Suburban) is applicable within 67.3MHz-108MHz.

Group	Delay [ns]	Power [dB]	K-Factor [dB]
1	0	0	2.6
2	760	-12.7	-0.26
3	1360	-18.0	2.2

Table C-13 Table SM (Suburban) is applicable within 47.4MHz-67.3MHz.

Group	Delay [ns]	Power [dB]	K-Factor [dB]
1	0	0	5.4
2	770	-14.1	6.6
3	1310	-18.9	6.2

Table C-14 Table SL: (Suburban) is applicable within 30MHz-47.4MHz.

Group	Delay [ns]	Power [dB]	K-Factor [dB]
1	0	0	5.4
2	910	-15.0	3.2
3	1480	-18.9	4.5

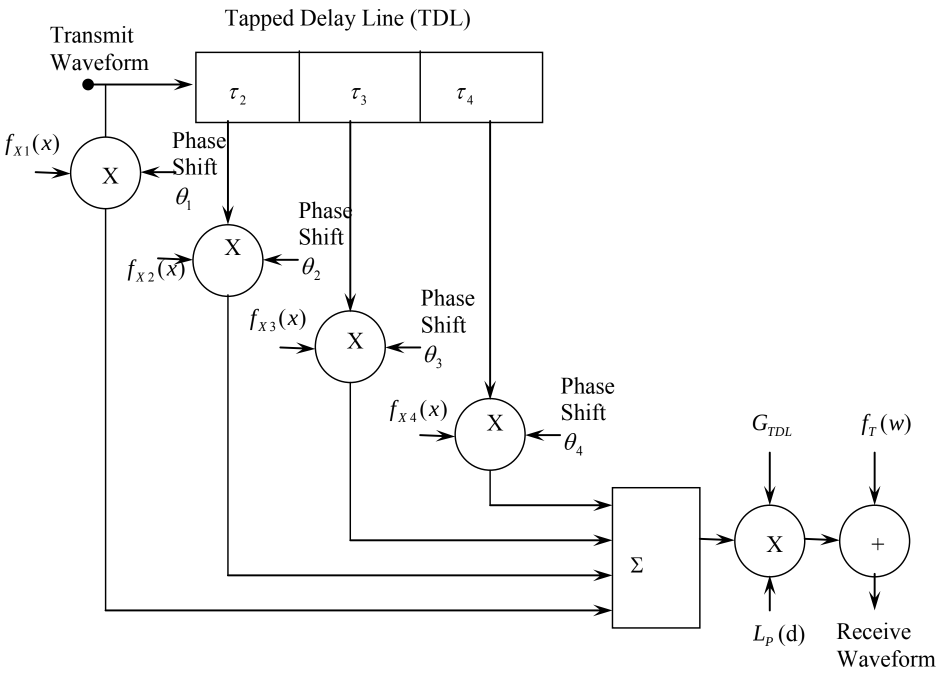

Figure C-1 Tapped-delay line model of VHF channel simulator for burst communications, for slow fading.

ANNEX D SPECIFICATION OF TOLERANCES

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D.1 Tolerances

Table D-1 gives specifications on the tolerances of quantities involved in generating the NBWF(Land) which are advised to be followed in order that transceivers have sufficient properties to host the CPM modulation. Radios must operate in either or both of the anticipated bands of operation: VHF (30.0MHz - 107.975MHz [N3]) and UHF (225.0MHz – 399.975MHz [N4]).

Table D-1 Tolerances specified for generation of physical layer NBWF.

Variable	Tolerance	Comment
Timing granularity	Min. 4 samples per symbol of highest baud rate	Affects quality of Tx waveform.
Group Delay Variation of Receiver	1.5us	The effect of receiver filtering (RF and IF) should have group delay not in excess of stated Tolerance.
Phase Noise	-75dBc/Hz beyond 1kHz from carrier	Gives sufficient SNR margin for all modes of operation

ANNEX E PROCEDURE FOR MEASURING AND ASSESSING CONFORMANCE TO SPECTRAL OCCUPANCY REQUIREMENTS

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E.1 Useful Definitions

When describing the duration of the different parts of the TDMA bursts, it is useful to make use of defined terminology.

1) BASEBAND

In the process of modulation, the frequency band occupied by the aggregate of the transmitted signals when first used to modulate a carrier.

2) CARRIER (See also [ACP])

A electromagnetic wave suitable for modulation by the intelligence to be transmitted over a communication system.

3) FREQUENCY TOLERANCE (See also [ACP])

The maximum permissible departure by the centre frequency of the frequency band occupied by an emission from the assigned frequency, or by the characteristic frequency of an emission from the reference frequency.

4) MODULATION (See also [ACP])

The process of varying one or more characteristics of the carrier wave in accordance with the instantaneous value of the signal to be transmitted. See CARRIER.

5) NECESSARY BANDWITH (See also [ITU2])

For a given class of emission, the width of the frequency band which is just sufficient to ensure the transmission of information at the rate and with the quality required under specified conditions.

6) OUT-OF-BAND (OOB) EMISSION (See also [ITU2])

Emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions. Any unwanted emission which falls at frequencies separated from the centre frequency of the emission by less than 250% of the necessary bandwidth will generally be considered out-of-band emission.

7) SPURIOUS EMISSION (See also [ITU2])

Emission on a frequency or frequencies which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions.

8) SQUELCH (See also [ACP])

A term indicating the ability of a radio receiver to suppress an audio frequency output in the absence of an input signal having predetermined characteristics.

9) RECEIVER ATTACK TIME

The time interval from the application of a step input RF signal (for all signal levels within the receiver input range) to the receiver input until the receiver output amplitude reaches 90 per cent of its steady-state value. This time delay includes the time for the receiver to un-squelch, if applicable.

10) TRANSMITTER ATTACK TIME

The time interval from keying-on a transmitter until the transmitter RF signal amplitude has increased to 90 per cent of its steady-state value. This delay excludes any necessary time for automatic antenna tuning.

11) TRANSMITTER RELEASE TIME

The time interval from keying-off a transmitter until the transmitted RF signal amplitude has decreased to 10 per cent of its key-on steady-state value.

12) UNITS dBc AND dBsd

Definitions of dBc and dBsd are available in (Section 1, [ITU2]).

13) POWER AMPLIFIER CATEGORIES

Power amplifiers used for low power operation (may be used for handheld applications) are governed differently than those for high power operation (manpack and vehicular applications).

Table E-1 Nomenclature used for Power Output Categories

Nomenclature	Power Range of “Max Output CW Power”
Low “L”	Less than 10W (TBC)
High “H”	Greater than 10W (TBC)

14) REGIONS OF BURST

Figure E-1 shows the time domain representation of a TDMA burst transmission, where the ramp-up and ramp down regions of the burst are denoted. The function defining the ramp-up and ramp-down regions of the burst are not specified, since optimal approaches will depend on the switching transients of the power amplifiers, and how these phase and amplitude transients impact spurious emissions.

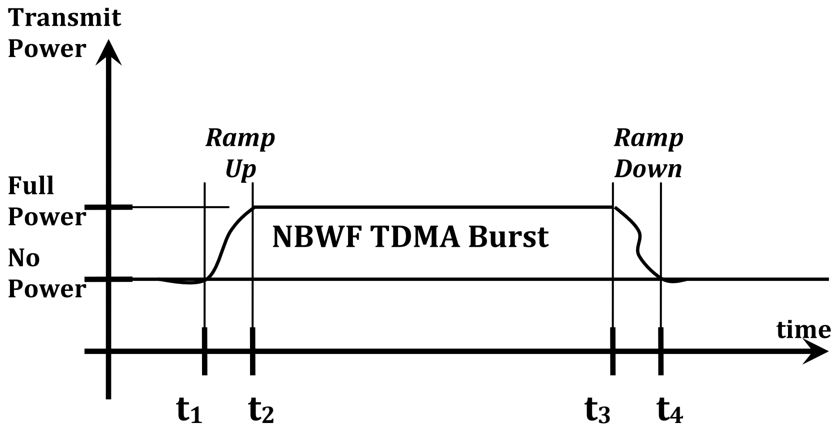

Figure E-1 Definition of "Ramp Up" and Ramp "Down" durations of the TDMA emission for Narrowband Waveform.

Elements of the burst in Figure E-1 are named as in Table E-2 [ETSI]:

Table E-2 Nomenclature used for Power Output Categories

Nomenclature	Time Interval During Burst Transmission
"Ramp Up"	Between t_1 and t_2
"Ramp Down"	Between t_3 and t_4
"Useful Part of Burst"	Between t_2 and t_3

15) EMISSION MODES

Table E-3 sums up NBWF emission modes.

Table E-3 NBWF Emission Modes

Narrowband Waveform Modes	Necessary Bandwidth	Channel Spacing "CS"
NR, N1, N2, N3, N4	25kHz	25kHz
N5, N6	50kHz	50kHz

E.2 Specifications of NBWF radio performance

1) FREQUENCY RANGE

The frequency range shall be from 30MHz to 107.975MHz.

It is desirable that it extends to 399.975MHz.

2) TUNING

Equipment shall tune to integral multiples of 500Hz, starting at 30MHz.

3) FREQUENCY ACCURACY [N3], [N4]

The radio frequency accuracy, including tolerance and long-term stability but not any effects due to Doppler shift, shall be within the ranges of Table E-4 where in the context of the Narrowband Waveform specification, VHF and UHF specifically refer to those frequency ranges identified in Annex D.

Table E-4 Frequency accuracy

Band	Frequency Range	Frequency Accuracy
VHF	30.0MHz - 107.975MHz [N3]	± 500Hz
UHF	225.0MHz – 399.975MHz [N4]	± 2kHz

4) FREQUENCY RESPONSE

The recommended receiver IF selectivity characteristics are as stated in Table E-5 with passband fluctuation of less than 0.15dB.

Table E-5 Recommended IF selectivity

CS	Receiver IF Selectivity
25kHz	-3dB Bandwidth at ± 20kHz, -60dB Bandwidth at ± 45kHz, -100dB Bandwidth at ± 1MHz
50kHz	-3dB Bandwidth at ± 20kHz, -60dB Bandwidth at ± 50kHz, -100dB Bandwidth at ± 1MHz

.

5) MODE OF OPERATION

Equipment shall be capable of operating in the single-frequency simplex mode.

6) SWITCHING TIME

The NBWF transmitter and receiver should meet these requirements;

a) Transmitter attack-time shall not be more than 0.2ms

b) Transmitter release-time shall not be more than 1ms

c) Receiver attack-time shall not be more than 1ms.

7) SPECIFICATIONS FOR OUT OF BAND EMISSIONS

The emissions measured during the Useful Part of the Burst shall have spectral occupancy properties constrained by the Necessary Bandwidth and the Emission Mask, and these limits apply to frequencies up to 250% of the channel spacing (CS) from the carrier.

8) NECESSARY BANDWIDTH

99% of the total mean radiated power shall be contained within a bandwidth of 25kHz for modes with CS of 25kHz, and within 50kHz for modes with CS of 50kHz.

9) EMISSIONS MASK

The spectrum emissions mask for the out of band region of the Narrowband Waveform emissions is defined by the sequence of points in Table E-6.

The graphical representation of this mask is found in (Figure 42, ANNEX 12, [ITU2]).

Table E-6 Emission Mask for Narrowband Waveform (taken from (TABLE 28, ANNEX 12, [ITU2]))

Frequency Offset (CS %)	Attenuation (dBsd)
0	0
50	0
65	25
150	25
150	40
250	40

Following guidance in [ITU2], Annex 12, it is advised that for measurement purposes the resolution bandwidth should be around 1% of the necessary bandwidth, and “the 0dBsd reference level is taken as the maximum value of the power spectral density inside the occupied bandwidth.”

10) UNWANTED EMISSIONS DURING RAMP UP and RAMP DOWN INTERVALS

Peak power measurements shall be done at frequency offsets from the carrier, covering at least the transition “ramp-up” and “ramp-down” regions of the waveform burst.

The maximum hold level of -45dBc for power amplifier level “L”, and -50dBc for power amplifier level “H” at frequency offset 50kHz from the carrier shall not be exceeded.

11) UNWANTED EMISSIONS FAR FROM CARRIER

Unwanted emissions are measured at frequencies greater than 250%CS from the carrier (that is, greater than 62.5kHz for 25kHz necessary bandwidth, and greater than 125kHz for 50kHz necessary bandwidth) in the frequency range 30MHz through 500MHz.

12) DISCRETE COMPONENTS

The maximum allowed power for each discrete spurious component emission shall be less than-36dBm, measured in a 100kHz bandwidth in the frequency range 30MHz through 500MHz (following Sect. 6.4.2.3 in [ETSI]).

13) WIDEBAND NOISE

Unwanted emissions far from the carrier are not to exceed the values indicated in Table E-7 for carrier frequencies within 30MHz and 500MHz.

All levels in Table E-7 are expressed in dBc relative to the actual transmitted power level and are in line with [N3] and [N4], and are measured in bandwidth of the channel spacing CS of the emitted waveform (25kHz for N1, N2, N3, N4, NR or 50kHz for N5, N6), at the listed offsets from the carrier frequency (following Sect. 6.4.2.3 in [ETSI]).

Table E-7 Levels that unwanted emissions are not to exceed, for 25kHz CS (top) and 50KHz CS (bottom).

Frequency Offset Range from Carrier for 25kHz CS	Low Power “L” Power Amplifier	High Power “H” Power Amplifier
62.5kHz – 250kHz	-60dBc	-60dBc
250kHz – 500kHz	-80dBc	-80dBc
500kHz and greater	-100dBc	-100dBc

Frequency Offset Range from Carrier for 50kHz CS	Low Power “L” Power Amplifier	High Power “H” Power Amplifier
125kHz – 500kHz	-60dBc	-60dBc
500kHz – 1000kHz	-80dBc	-80dBc
1000kHz and greater	-100dBc	-100dBc

ANNEX F PARAMETERS FOR NBWF(LAND)

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F.1 Introduction

The technical specifications for use of the NBWF PHY for Land and helicopter (i.e. for land support) operations (known as NBWF(Land)) are made in this Annex. Table F.1 provides a highlight of the parameters required for construction of the waveform PHY preamble. Table F.2 defines the modulation and coding modes. Table F.2 lists hard numerical parameters, and other parameters derived from the hard numbers. Relationships governing these calculations are provided.

F.2 Specifications

Table F.1: Parameters for NBWF(Land) modes for generating on-air CPM preamble and header.

Field	Duration (# symbols)	Comment
P	45	CW signal segment, in terms of number of N1 baud periods. Used for Modes N1 through N4, and short message use of NR.
SOM	63	Unique PN sequence. Same CPM Modulation as data Mode N1. Used for Modes N1 through N4 and short message use of NR.
PAR	48	12 bits encoded with rate 1/4 block code. Same CPM Modulation as data Mode N1.
P_R	115	CW duration in terms of NR baud periods for robust operation
SOM_R	200	SOM duration in terms of NR baud periods for robust operation

Table F.2: Parameters for NBWF(Land) modes for generating on-air PHY CPM modulation.

Waveform Modes	User Data Rates (kbps)	L	Mc	h	Pulse Shape	Code Rate	Symbol Rate(ksps)	Nominal 99% BW (kHz)
N1	**20**	2	2	1/2	REC	2/3	30	25
N2	**31.5**	2	2	1/4	REC	3/4	42	25
N3	**64**	3	2	1/6	REC	4/5	80	25
N4	**82**	3	2	1/9	REC	6/7	96	25
N5	**40**	2	2	1/2	REC	2/3	60	50
N6	**63**	2	2	1/4	REC	3/4	84	50
NR	**10**	2	2	1/2	REC	1/3	30	25

Table F.3: Summary of NBWF modes with filtering parameters (F_p corner frequency and F_S stopband frequency) for optional Tx and Rx filtering.

Waveform Modes	Tx Filter (kHz)		Rx Filter (kHz)	
	F_p	F_s	F_p	F_s
N1	10	12.5	10	12.5
N2	10	12.5	10	12.5
N3	15	20	15	20
N4	17.5	22.5	17.5	22.5
N5	20	25	20	25
N6	20	25	20	25
NR	10	12.5	10	12.5

Table F.4: Global parameters applicable to NBWF(Land).

Variable Name	Value for NBWF(Land)	Comment
T_S	22.5ms	Fundamental time unit corresponds to TDMA slot in the NBWF(Land) MAC layer.
T_{AGC}	0.3ms	AGC time
T_G	2.0ms	Guard Time
T_{PROP}	0.2ms	Propagation Delay (max.)
T_{TXRX}	0.2ms	Tx/Rx switch time, includes TGC
N_P	45	Optimized for NBWF(Land)
T_P	N_P x T_{N1} + T_{AGC} = 1.5ms + 0.3ms = 1.8ms	CW including time for driving AGC
N_{SOM}	63	Optimized for NBWF(Land)
T_{SOM}	N_{SOM} x T_{N1} = 2.1ms	Duration SOM
N_{PR}	115	Robust mode optimized for NBWF(Land)
N_{SOMR}	200	Robust mode optimized for NBWF(Land)
T_{SOMR}	N_{SOMR} x T_{NR} = 6.67ms	
R_{N1}	30000 sps	Baud rate Mode N1
R_{N2}	42000 sps	Baud rate Mode N2
R_{N3}	80000 sps	Baud rate Mode N3
R_{N4}	96000 sps	Baud rate Mode N4
R_{N5}	60000 sps	Baud rate Mode N5
R_{N6}	84000 sps	Baud rate Mode N6
R_{NR}	30000 sps	Baud rate Mode NR
T_{N1}	$1/R_{N1}$	Baud period Mode N1
T_{N2}	$1/R_{N2}$	Baud period Mode N2
T_{N3}	$1/R_{N3}$	Baud period Mode N3
T_{N4}	$1/R_{N4}$	Baud period Mode N4
T_{N5}	$1/R_{N5}$	Baud period Mode N5
T_{N6}	$1/R_{N6}$	Baud period Mode N6
T_{NR}	$1/R_{NR}$	Baud period Mode NR
CR_{N1}	2/3	Code Rate N1
CR_{N2}	¾	Code Rate N2
CR_{N3}	4/5	Code Rate N3
CR_{N4}	6/7	Code Rate N4
CR_{N5}	2/3	Code Rate N5
CR_{N6}	¾	Code Rate N6
CR_{NR}	1/3	Code Rate NR
N_{TAIL}	9	Number tail bits transmitted for $(13,15,17)_8$ convolutional code for modes N1, N2, N3, N4, N5, N6, NR in each interleaver.

T_{TAIL1}	$N_{TAIL}T_{N1}$	Duration occupied by tail bits in mode N1
T_{TAIL2}	$N_{TAIL}T_{N2}$	Duration occupied by tail bits in mode N2
T_{TAIL3}	$N_{TAIL}T_{N3}$	Duration occupied by tail bits in mode N3
T_{TAIL4}	$N_{TAIL}T_{N4}$	Duration occupied by tail bits in mode N4
T_{TAIL5}	$N_{TAIL}T_{N5}$	Duration occupied by tail bits in mode N5
T_{TAIL6}	$N_{TAIL}T_{N6}$	Duration occupied by tail bits in mode N6
SOM	[(MSB)1000011000101001 1110100011100100 1011011101100110 101011111100000 (LSB)]	
SOM_S		
EOM	[0_{MSB}110 1111 1011 1001 1010 0001 1010 0011_{LSB}]	
EQU_{25}	[1_{MSD} -1 -1 1 -1 1 1 -1 -1 1 1 1 1 1 -3 -1_{LSD}]	
EQU_{50}	[1_{MSD} -1 -1 -1 -1 -1 1 1 -1 -1 -1 -1 1 -1 1 -1 -1 -1 1 1 1 1 -1 -1 1 -1 -1 -1 1 -1 1 1 -1 -1 1 1 1 -1 1 -1 1 -1 -1 1 1 1 1 1 -1 1 -1 -1 -1 -1 1 1 1 -1 -1 -1 1 -1 -1 -1_{LSD}]	
N_{EOM}	32	Number of bits in EOM
N_{PAR}	48	12 Par information bits coded using rate ¼ Double Golay block code gives N_{PAR}
T_{PAR}	N_{PAR} x T_{N1} = 1.6ms	Duration of PAR Header
N_{TR1}	2	Number of transitions bits for modes N1, N2, N5 and N6
N_{TR2}	3	Number of transitions bits for modes N3, N4
T_{TR1}	N_{TR1} x T_{N1} =0.07ms	Duration of transition region for N1
T_{TR2}	N_{TR1} x T_{N2} = 0.05ms	Duration of transition region for N2
T_{TR3}	N_{TR2} x T_{N3} = 0.04ms	Duration of transition region for N3
T_{TR4}	N_{TR2} x T_{N4} = 0.03ms	Duration of transition region for N4

T_{TR5}	N_{TR1} x T_{N5} = 0.03ms	Duration of transition region for N5
T_{TR6}	N_{TR1} x T_{N6} = 0.02ms	Duration of transition region for N6
N_{EQ25}	16	Equalizer training field sequence length 25KHzKHz modes
N_{EQ50}	64	Equalizer training field sequence length 50KHzKHz modes
$T_{EQ25} = N_{EQ25}$ x T_{N1}		Time duration equalizer training field 25KHzKHz modes
$T_{EQ50} = N_{EQ50}$ x T_{N5}		Time duration equalizer training field 50KHzKHz modes
$Size(IA)_{N1}$ $Size(IA)_{N2}$ $Size(IA)_{N3}$ $Size(IA)_{N4}$ $Size(IA)_{N5}$ $Size(IA)_{N6}$	345 445 684 758 570 701	Size Interleaver IA for N1 Size Interleaver IA for N2 Size Interleaver IA for N3 Size Interleaver IA for N4 Size Interleaver IA for N5 Size Interleaver IA for N6
$Size(IB)_{N1}$ $Size(IB)_{N2}$ $Size(IB)_{N3}$ $Size(IB)_{N4}$ $Size(IB)_{N5}$ $Size(IB)_{N6}$	435 609 1164 1395 873 1221	Size Interleaver IB for N1 Size Interleaver IB for N2 Size Interleaver IB for N3 Size Interleaver IB for N4 Size Interleaver IB for N5 Size Interleaver IB for N6
$Size(IE)_{N1}$ $Size(IE)_{N2}$ $Size(IE)_{N3}$ $Size(IE)_{N4}$ $Size(IE)_{N5}$ $Size(IE)_{N6}$	519 669 1024 1136 837 1029	Size Interleaver IE for N1 Size Interleaver IE for N2 Size Interleaver IE for N3 Size Interleaver IE for N4 Size Interleaver IE for N5 Size Interleaver IE for N6
$Size(IF)_{N1}$ $Size(IF)_{N2}$ $Size(IF)_{N3}$ $Size(IF)_{N4}$ $Size(IF)_{N5}$ $Size(IF)_{N6}$	657 917 1754 2102 1284 1797	Size Interleaver IF for N1 Size Interleaver IF for N2 Size Interleaver IF for N3 Size Interleaver IF for N4 Size Interleaver IF for N5 Size Interleaver IF for N6
Size(IG) T_{IG}	204 Size(IG) x T_{NR} + N_{TAIL}	Interleaver IG for Short Message, fixed payload IG Duration within short message
N_{SHORT}	65	Preset Payload Short Message

Table F-5 Service primitive parameter specification

Parameter	Min. value	Max. value	Resolution	
			Should	Shall
PWR	0 dBm	60 dBm	≤ 1 dB	≤ 5 dB
RSSI	-130 dBm	20 dBm	≤ 1 dB	≤ 5 dB
BGNOISE	-130 dBm	20 dBm	≤ 1 dB	≤ 5 dB
SLENGTH	10.0	100.0	-	-
MAXSLOT	2	10	-	-

ANNEX G NSPICS TO THE NBWF PHYSICAL LAYER

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G.1 INTRODUCTION

1. Guidance, notations and instructions for completing the NPICS proforma can be found in Annex B of this document.

G.2 NPICS

1. Section 2.1 applies to implementation of the PHY Layer of the NBWF in order to be interoperable at the Interoperability Point 1 (IOP1) and be part of a NBWF compliant network, as defined in this document.
2. Non-supported mandatory capabilities are to be identified in the NPICS, with an explanation of why the implementation is non-conformant. Such information shall be provided as exception information.

G.2.1 Identification of the Implementation and General Statement of Conformance

G.2.1.1 Implementation Identification

Nation/Supplier	
Contact point for queries about the NPICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification – e.g., name(s) and version(s) of machines and/or operating systems; system names	

Notes:

Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirement for full identification.
The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, and Model).

G.2.1.2 General Statement of Conformance

Identification of protocol specification	AComP-5631 (A)(1) Narrowband Waveform for VHF/UHF Radios - Physical Layer and Propagation Models
Identification of amendments and corrigenda to this NPICS proforma which have been completed as part of this NPICS	Am. : Corr. : Am. : Corr. : Am. : Corr. : Am. : Corr. :
Have any Exception items been required? (The answer Yes means that the implementation does not conform to the NBWF specification)	No [ ] Yes [ ]

Date of Statement	

G.2.1.3 Item References

1. Items in the NPICS proforma are identified by mnemonic item references. NPICS items dealing with related functions are identified by item references sharing the same initial letter or letter-pair (in capitals).
2. The following is a list of those initial letters, listed in the order in which they occur in the NPICS proforma:
   a. TDMA : TDMA NBWF Optimized operation and General TDMA
   b. TIME : Physical layer response time and time accuracy
   c. PDU : Physical Layer Data Unit construction
   d. PAR : Par elements
   e. BURST : Burst mode formats for data transmission
   f. WAVE : Waveform requirements
   g. CODE : Waveform coding
   h. FILT : Transmission filtering
   i. RAD : Radio requirements

Entries in the References field of the NPICS tables apply to paragraphs, tables, or figures in this AComP.

G.2.1.4 NPICS for NBWF Physical Layer

Base Standard Features				
Item	**Protocol**	**Reference**	**Status**	**Support**
TDMA1	Is the PHY layer used for NBWF Optimized TDMA Operation?	AComP-5631, Section 2	O	Yes [ ] No [ ]
TIME1	Does the implementation meet the timing requirement stated?	AComP-5631, Section 2.3.4.3	TDMA1: M	Yes [ ]
TIME2	Does the implementation meet the timing requirement stated?	AComP-5631, Section 2.3.5.7	TDMA1: M	Yes [ ]
TIME3	Does the implementation meet the performance requirement for Class 1?	AComP-5631, Section 2.3.5.12	TDMA1: M	Yes [ ]
TIME4	Does the implementation meet the performance requirement for Class 2?	AComP-5631, Section 2.3.5.12	O	Yes [ ] No [ ]
PDU1	Does the implementation support the PDU structure depicted?	AComP-5631, Section 2.4.1	M	Yes [ ]
PDU2	Does the implementation meet requirements to Exitation field?	AComP-5631, Section 3.2	M	Yes [ ]
PDU3	Does the implementation meet requirements to Aquisition field?	AComP-5631, Section 3.3	M	Yes [ ]
PDU4	Does the implementation meet requirements to SOM field?	AComP-5631, Section 3.4	M	Yes [ ]
PDU5	Is the SOM field implemented using N1 as required?	AComP-5631, Section 3.4	M	Yes [ ]
PDU6	Does the implementation send Equilizer Training field for 25kHz?	AComP-5631, Section 3.5	O	Yes [ ] No [ ]
PDU7	Does the implementation send Equilizer Training field for 50kHz?	AComP-5631, Section 3.5	O	Yes [ ] No [ ]
PDU8	Does the implementation meet requirements to the PAR field?	AComP-5631, Section 3.6	TDMA1:M	Yes [ ]
PDU9	Does the implementation meet requirements to the generation of preamble and header?	AComP-5631, Annex F, Table F-1	M	Yes [ ]

PDU11	Does the relevant1signalled Service Primitives meet the specifications in values and resolution?	AComP-5631, Annex F, Table F-5	O	Yes [ ] No[ ]
PAR1	Is the Mode field supported?	AComP-5631, Section 3.6.1	PDU8:M	Yes [ ]
PAR2	Is the Slot Merge field supported?	AComP-5631, Section 3.6.2	PDU8:M	Yes [ ]
PAR3	Is the Processing field supported?	AComP-5631, Section 3.6.3	PDU8:M	Yes [ ]
PAR4	Is the Full/Half slot field supported?	AComP-5631, Section 3.6.4	PDU8:M	Yes [ ]
PAR5	Is the EOM field supported?	AComP-5631, Section 3.6.5	PDU8:M	Yes [ ]
PAR6	Is the Frame Check field supported?	AComP-5631, Section 3.6.6	PDU8:M	Yes [ ]
PAR7	Is the Par Header protected as specified?	AComP-5631, Section 3.6.7	PDU8:M	Yes [ ]
PAR8	Is the Transition bits used as specified?	AComP-5631, Section 3.6.8	PDU8:M	Yes [ ]
BURST1	Does the implementation support Single Slot Burst formats with Processing time with interleaver IA?	AComP-5631, Section 4.2	TDMA1:M	Yes [ ]
BURST2	Does the implementation support Single Slot Burst formats without FCS?	AComP-5631, Section 4.2	O	Yes [ ] No [ ]
BURST3	Does the implementation support Single Slot Burst formats with FCS and no processing time with interleaver IB?	AComP-5631, Section 4.2	TDMA1:M	Yes [ ]
BURST4	Does the implementation support Single Slot Burst formats without FCS and no processing time?	AComP-5631, Section 4.2	O	Yes [ ] No [ ]
BURST5	Does the implementation support merged slot bursts tailored for NBWF optimized TDMA?	AComP-5631, Section 4.2	TDMA1:M	Yes [ ]
BURST6	Does the implementation support merged burst slot for gereralized TDMA for FCS protection?	AComP-5631, Section 4.2	O	Yes [ ] No [ ]

BURST7	Does the implementation support burst format for Continuous Transmission?	AComP-5631, Section 4.4	O	Yes [ ] No [ ]
BURST8	Does the implementation support Short Burst format for signalling?	AComP-5631, Section 4.5	O	Yes [ ] No [ ]
BURST9	Does the implementation support Robust Mode burst ?	AComP-5631, Section 4.6	O	Yes [ ] No [ ]
WAVE1	Does the radio support Mode NR	AComP-5631, Annex F, Table F-2	O	Yes [ ] No [ ]
WAVE2	Does the radio support Mode N1	AComP-5631, Annex F, Table F-2	O	Yes [ ] No [ ]
WAVE3	Does the radio support Mode N2	AComP-5631, Annex F, Table F-2	O	Yes [ ] No [ ]
WAVE4	Does the radio support Mode N3	AComP-5631, Annex F, Table F-2	O	Yes [ ] No [ ]
WAVE5	Does the radio support Mode N4	AComP-5631, Annex F, Table F-2	O	Yes [ ] No [ ]
WAVE6	Does the radio support Mode N5	AComP-5631, Annex F, Table F-2	O	Yes [ ] No [ ]
WAVE7	Does the radio support Mode N6	AComP-5631, Annex F, Table F-2	O	Yes [ ] No [ ]
WAVE8	For implemented Modes, are parameters as stated?	AComP-5631, Annex F, Table F-4	WAVE1-8: M	Yes [ ]
CODE1	Is Outer Convolutional coder used as specified?	AComP-5631, Section 5.3	M	Yes[ ]
CODE2	Is Outer Convolutional coder terminiated as specified?	AComP-5631, Section 5.3.1	M	Yes[ ]
CODE3	Are interleavers implemented and used as specified?	AComP-5631, Section 5.4	M	Yes[ ]
CODE4	Is CPM moduation implemented as specified?	AComP-5631, Section 5.6	M	Yes[ ]
CODE5	Is CPM moduation implemented as specified?	AComP-5631, Section 5.6	M	Yes[ ]
FILT1	Is TX filtering applied?	AComP-5631, Section 5.6 and Annex F, Table F-3	O	Yes [ ] No [ ]
FILT2	Is RX filtering applied?	AComP-5631, Section 5.6 and Annex F, Table F-3	O	Yes [ ] No [ ]

RAD1	Does the radio meet requirements to timing granularity?	AComP-5631, Annex D, Table D-1	M	Yes [ ]
RAD2	Does the radio meet requirements to Receiver Group delay variation?	AComP-5631, Annex D, Table D-1	M	Yes [ ]
RAD3	Does the radio meet requirements to Phase Noise?	AComP-5631, Annex D, Table D-1	M	Yes [ ]
RAD4	Does the radio operate in 30-107.975MHz range	AComP-5631, Annex E, E.2 1)	O	Yes [ ] No[ ]
RAD5	Does the radio operate in 225-399.975MHz range	AComP-5631, Annex E, E.2 1)	O	Yes [ ] No [ ]
RAD6	Does the radio tune in integral multiples of 500Hz?	AComP-5631, Annex E, E.2 2)	O	Yes [ ] No [ ]
RAD7	Does the radio tune in 12.5kHz steps to operate in both 25kHz and 50kHz bandwidth?	AComP-5631, Section 5.2	O	Yes [ ] No [ ]
RAD8	Does the radio tune in 25kHz steps to operate in 25kHz bandwidth?	AComP-5631, Section 5.2	O	Yes [ ] No [ ]
RAD9	Does the radio detect 25kHz vs 50 kHz bandwidth transmissions?	AComP-5631, Section 5.2	O	Yes [ ] No [ ]
RAD10	Does the radio meet the frequency accuracy in 30-107.975 MHz range?	AComP-5631, Annex E, E.2 3) Table E-4	M	Yes [ ]
RAD11	Does the radio meet the frequency accuracy in 225.000-399.975 MHz range?	AComP-5631, Annex E, E.2 3) Table E-4	RAD4:M	Yes [ ]
RAD12	Is the frequency selectivity in 25 kHz bandwidth met?	AComP-5631, Annex E, E.2 4) Table E-5	O	Yes [ ] No [ ]
RAD13	Is the frequency selectivity in 50 kHz bandwidth met?	AComP-5631, Annex E, E.2 4) Table E-5	O	Yes [ ] No [ ]
RAD14	Does the radio operate in single frequency simplex mode?	AComP-5631, Annex E, E.2 5) Table E-5	M	Yes [ ]
RAD 15	Does the radio meet the requirement to TX attack time?	AComP-5631, Annex E, E.2 6)	O	Yes [ ] No [ ]
RAD16	Does the radio meet the requirement to TX release time?	AComP-5631, Annex E, E.2 6)	O	Yes [ ] No [ ]
RAD17	Does the radio meet the requirement to Receiver attack time?	AComP-5631, Annex E, E.2 6)	O	Yes [ ] No [ ]

RAD18	Does the radio meet the requiremets to out of band emissions?	AComP-5631, Annex E, E.2 7)	O	Yes [ ] No [ ]
RAD19	Does the radio meet the requirement to mean radiated power in bandwidth in 25kHz mode?	AComP-5631, Annex E, E.2 8)	O	Yes [ ] No [ ]
RAD20	Does the radio meet the requirement to mean radiated power in bandwidth in 50kHz mode?	AComP-5631, Annex E, E.2 8)	O	Yes [ ] No [ ]
RAD21	Does the radio meet the requirement to emission mask for Out of band region?	AComP-5631, Annex E, E.2 9) Table E-6	O	Yes [ ] No [ ]
RAD22	Does the radio meet the requirement to emission mask during ramp-up and ramp-down for PA level L?	AComP-5631, Annex E, E.2 10)	O	Yes [ ] No [ ]
RAD23	Does the radio meet the requirement to emission mask during ramp-up and ramp-down for PA level H?	AComP-5631, Annex E, E.2 10)	O	Yes [ ] No [ ]
RAD24	Does the radio meet the requirement to unwanted emissions far from carrier for 25kHz operation?	AComP-5631, Annex E, E.2 11)	O	Yes [ ] No [ ]
RAD25	Does the radio meet the requirement to unwanted emissions far from carrier for 50kHz operation?	AComP-5631, Annex E, E.2 11)	O	Yes [ ] No [ ]
RAD26	Does the radio meet the requirement to discrete transmitted components?	AComP-5631, Annex E, E.2 12)	O	Yes [ ] No [ ]
RAD27	Does the radio meet the requirement to unwanted transmissions in 25kHz operation for Low Power radios?	AComP-5631, Annex E, E.2 13), Table E-7	O	Yes [ ] No [ ]
RAD28	Does the radio meet the requirement to unwanted transmissions in 25kHz operation for High Power radios?	AComP-5631, Annex E, E.2 13), Table E-7	O	Yes [ ] No [ ]
RAD29	Does the radio meet the requirement to unwanted transmissions in 50kHz operation for Low Power radios?	AComP-5631, Annex E, E.2 13), Table E-7	O	Yes [ ] No [ ]

RAD30	Does the radio meet the requirement to unwanted transmissions in 50kHz operation for High Power radios?	AComP-5631, Annex E, E.2 13), Table E-7	O	Yes [ ] No [ ]

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