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Short Range Devices;
Low Throughput Networks (LTN);
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Part 1: Lfour and DD-UNB protocol families

Reference

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

The present document is part 1 of a multi-part deliverable, covering protocols for radio interface A of Short Range Devices (SRD) in Low Throughput Networks (LTN), as identified below:

Part 1: "Lfour and DD-UNB protocol families";

Part 2: "TS-UNB protocol".

The present document is a revision of ETSI TS 103 357 (V1.1.1) [i.8], where section and annexes related to TS-UNB protocol have been removed.

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

"**must**" and "**must not**" are **NOT** allowed in ETSI deliverables except when used in direct citation.

1 Scope

The present document, which is part 1 of a multi-part deliverable, specifies radio protocols for two LTN protocol families:

- Lfour; and
- DD-UNB.

It contains an implementable description of the physical and MAC/link layers of these two protocols, and a section on implementation commonalities between the three LTN families.

NOTE 1: ETSI TR 103 249 [i.5] describes LTN use cases and system characteristics.

NOTE 2: ETSI TS 103 358 [i.6] specifies the architecture of LTN systems.

NOTE 3: Based on the above documents, radio technologies have been developed with a focus on different subsets of applications, where the optimal balance of technical parameters differs.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at https://docbox.etsi.org/Reference/.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are necessary for the application of the present document.

[1] ISO/IEC 29192-2:2019 : "Information technology -- Security techniques -- Lightweight cryptography -- Part 2: Block ciphers".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ERC Recommendation 70-03 (Tromsø 1997 and subsequent amendments): "Relating to the use of short range devices (SRD)", Recommendation adopted by the Frequency Management, Regulatory Affairs and Spectrum Engineering Working Groups, Version of 21 October 2016.

[i.2] ETSI EN 300 220-1 (V2.4.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW; Part 1: Technical characteristics and test methods".

[i.3] CFR Title 47 Part 15 section 15.247: "Operation within the bands 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz".

[i.4] ARIB STD-T108: "920 MHz-Band Telemeter, Telecontrol and data transmission radio equipment", Version 1.0 of February 14th 2012.

[i.5] ETSI TR 103 249 (V1.1.1): "Low Throughput Network (LTN); Use Cases and System Characteristics".

[i.6] ETSI TS 103 358 (V1.1.1): "Short range devices; Low Throughput Networks (LTN) Architecture; LTN Architecture".

[i.7] ETSI TS 103 357-2: "Short Range Devices; Low Throughput Networks (LTN); Protocols for radio interface A; Part 2: TS-UNB protocol".

[i.8] ETSI TS103 357 (V1.1.1) (06-2018), “Short Range Devices; Low Throughput Networks (LTN); Protocols for radio interface A”.

3 Definitions of terms, symbols, and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

CLEFIA: lightweight block cipher

NOTE: As defined in ISO/IEC 29192-2 [1].

data-burst: sequence of consecutive radio bursts transmitted by an LTN entity

network element: node in the DD-UNB system

NOTE: A network element can refer to an EP, RP, OEP, BS, or SC.

orphan end-point: EP which is connected through a relay point

radio-burst: radio transmission over the air which starts with a ramp up, finishes with a ramp down and which has a continuous centre frequency and constant transmission power (apart from modulation)

radio-frame: area in time and frequency plane containing all radio bursts belonging to one packet

sub-packet: fragment of a packet after telegram splitting

subframe: portion of the basic 24 s frame which is allocated to a specific link, direction and content (i.e. A or A"-interface with DL, UL data or UL Ack)

superframe: set of 64 consecutive frames

3.2 Symbols

For the purposes of the present document, the following symbols apply:

$\Delta f_{slowchirp}$	Frequency difference between the start and end of secondary modulated PPDU as a result of chirp
ΔT	Symbol duration
$BW_{UL\text{-}Ch}$	Bandwidth of UL channel used by EP in band of operation
dB	decibel
f_c	Channel centre frequency
f_h	Frequency of high tone
f_l	Frequency of low tone
n_b	Number of PSDU data bytes

$N_{repetitions}$	Number of repetitions of a PPDU
P_{TX}	Transmission power
T_0	Start time of the radio frame transmission
T_{PPDU}	PPDU duration in seconds
T_{tx-gap}	Repetition gap between PPDUs in seconds

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AC	Acknowledge Codeword
AES	Advanced Encryption Standard
BC	Broadcast
BCH	Bose–Chaudhuri–Hocquenghem code
BFSK	Binary Frequency Shift Keying
BPSK	Binary Phase Shift Keying
BS	Base Station
BSGP	Base-System Group
BSID	Base Station Identifier
BW	Bandwidth
CC	Control Codeword
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
DAPCH	Downlink Acknowledge Physical Channel
DBPCH	Downlink Broadcast Physical Channel
DC	Duty Cycle
DCPCH	Downlink Control Physical Channel
DD-UNB	Dynamic Downlink Ultra Narrowband
DL	Downlink
DLL	Data Link Layer
DMPCH	Downlink Multicast Physical Channel
DSP	Digital Signal Processing
DSPCH	Downlink Sync Physical Channel
DWPCH	Downlink Wakeup Physical Channel
DXPCH	Downlink Connection Physical Channel
EP	End-Point
EPID	End-Point Identifier
EUI	Extended Unique Identifier
FEC	Forward Error Correction
FMAC	Frequency Medium Access Control
FSK	Frequency Shift Keying
GMSK	Gaussian Minimum Shift Keying
GP	Grid Position
GPS	Global Positioning System
GPSW	GPS Weeks
GPSWS	GPS Week-Seconds
IC	Integrated Circuit
ID	Identifier
LAPCH	Local Acknowledge Physical Channel
LBPCH	Local Downlink Broadcast Physical Channel
LBT	Listen Before Talk
LCPCH	Local Control Physical Channel
LDPC	Low Density Parity Check
LFSR	Linear Feedback Shift Register
LMPCH	Local Multicast Physical Channel
LSB	Least Significant Bit
LSPCH	Local Sync Physical Channel
LTN	Low Throughput Network
LWPCH	Local Wakeup Physical Channel
LXPCH	Local Connection Physical Channel

MAC	Medium Access Control
MC	Multicast
MCL	Minimum Coupling Loss
MPDU	MAC Protocol Data Unit
MSB	Most Significant Bit
MSDU	MAC Service Data Unit
OEP	Orphan End-Point
OFB	Output Feedback
OSI	Open System Interconnection
P	Power
PA	Power Amplifier
PDU	Protocol Data Unit
PHY	Physical layer
PLL	Phase Locked Loop
PPDU	PHY Protocol Data Unit
PRN	Pseudo-Random Number
PSDU	PHY Service Data Unit
RF	Radio Frequency
RFS	Random Frequency Selection
ROS	Relay Outstation
RP	Relay Point
RSSI	Received Signal Strength Indication
SC	Service Centre
SCC	Strong Control Codeword
SDU	Service Data Unit
SE	Secure Element
SFEC	Strong Forward Error Correction
SRD	Short Range Device
SSID	Short System Identifier
SXC	Strong Connection Codeword
Sym	Symbols
Sync	Synchronization
TCXO	Temperature Compensated Crystal Oscillator
TDD	Time Division Duplex
TS	Telegram Splitting
TS-UNB	Telegram Splitting Ultra Narrow Band
UAPCH	Uplink Acknowledge Physical Channel
UDPCH	Uplink Data Physical Channel
UL	Uplink
UNB	Ultra Narrowband
WAC	Weak Acknowledge Codeword
WMC	Weak Multicast Codeword
WU	Wakeup
XC	Connection Codeword
XOR	logic eXclusive OR

4 General description

A LTN system according to the architecture document shall support one or more of the three protocol families described in the present document and in ETSI TS 103 357-2 [i.7]. The protocol families are designed to operate effectively in sub-GHz frequency bands. The protocol description offers particular mechanism to allow the operation of the LTN system under different national or regional radio spectrum regulations (e.g. [i.1], [i.2], [i.3] and [i.4]).

5 Lfour family

5.1 Overview

If a LTN System supports LFour family, the following protocol description shall apply. The Lfour LTN family is a low power, wideband technology and supports star network topology in radio access network. The Lfour air interface description applies to A-interface between Class Z EP and one or more BSs.

The Lfour LTN family has several key characteristics:

- Uni-directional link aiming to achieve the lowest power consumption with simple architecture.
- Three different modes of operation to choose from depending on likelihood of interference, regulation, and sensitivity requirements.
- Ability to coherently add re-transmitted packet(s) to enhance transmission range and/or combat with interference.
- LDPC forward error coding to achieve best sensitivity and mobility performance.

The three modes of operation are differentiated by modulation type and bandwidth as per the parameters in Table 5-1.

Table 5-1: Modes of operation

	Mode A	Mode B	Mode C
Modulation Type	Chirp modulated BPSK	BPSK	BPSK
Symbol Rate	26 MHz/4 096 = ~6,35 kSym/s	26 MHz/512 = ~50,8 kSym/s	26 MHz/256 = ~101,6 kSym/s
Occupied BW	160 kHz	50,8 kHz	101,6 kHz
Check Sum	CRC24	CRC24	CRC24
FEC	Rate=1/4 LDPC	Rate=1/4 LDPC	Rate=1/4 LDPC
T_{PPDU}	2 496/Sym rate = ~393,2 ms	9 616/Sym rate = ~189,4 ms	9 616/Sym rate = ~94,7 ms
Re-transmission	Yes (Coherent)	Yes (Coherent)	Yes (Coherent)
MCL	> 155 dB	> 150,6 dB	> 150,6 dB

Uplink transmissions are triggered by EPs and resultant data packets can be received by one or more BS(s). The system supports two sizes of MSDUs, 128 bits and 64 bits denoted by Type 1 and Type 2 respectively. The symbol rate of modulated PPDU bits is derived from 26 MHz TCXO which is used in Lfour transmitter design.

An overview of MAC and PHY layer functions and PDU formats is shown in Figure 5-1.

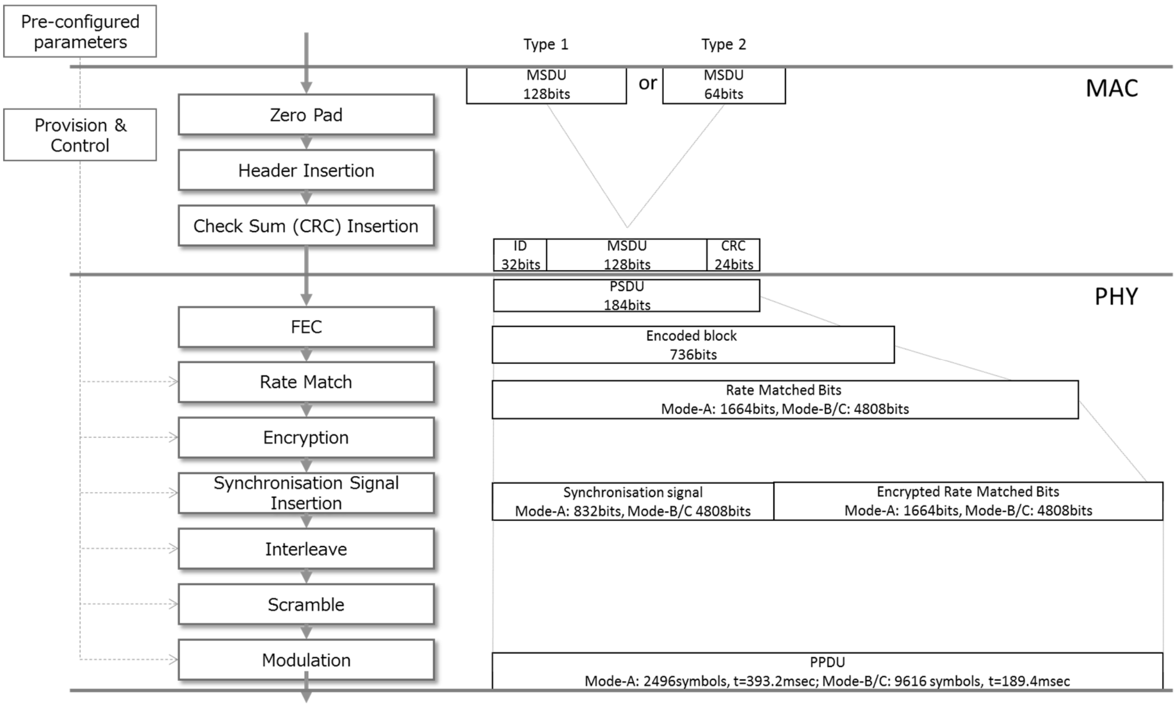

Figure 5-1: Overview of MAC and PHY flow and PDU format

Lfour system makes use of time, frequency and code space domains for multiple access to accommodate large number of devices requesting service in a coverage area as shown in Figure 5-2 and Figure 5-3. Lfour may use auxiliary time synchronization methods (e.g. GPS) to reduce the complexity of the receiver in BS.

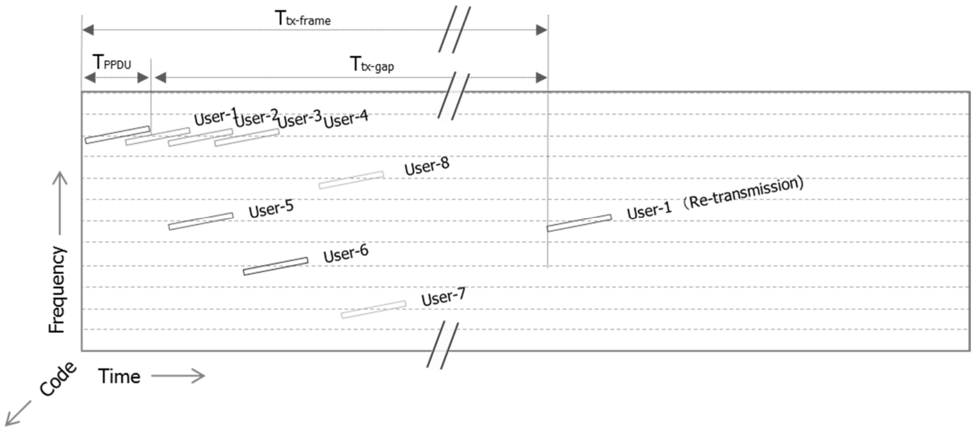

Figure 5-2: Multi-user Access Overview for Mode A Operation

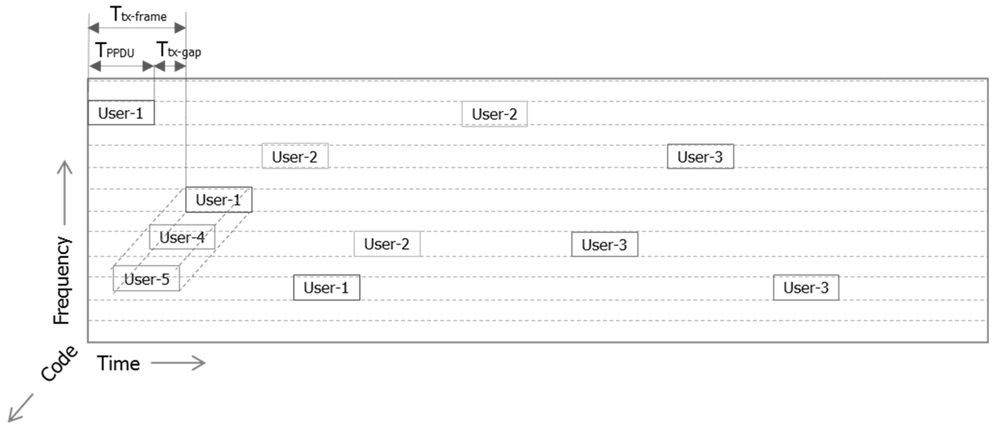

Figure 5-3: Multi-user Access Overview for Mode B/C Operation

5.2 MAC layer description

5.2.1 Overview

MAC sub-layer specification applies to UL only as Lfour is an UL system.

The MAC sub-layer for LTN air-interface provides following services:

- Passing and Receiving User Plane Data to and from higher layer entity.
- Assembling and Disassembling of MSDU.
- Assembling and Disassembling of MAC Header Information.
- Assembling and Disassembling of CRC.
- Passing and Receiving MPDU to and from PHY layer.
- Provision of re-transmission parameters.
- Provision of Encryption parameters.
- Provision of PHY parameters.

Figure 5-4 denotes MAC services for an EP transmitter. Reverse procedure applies at corresponding BS receiver.

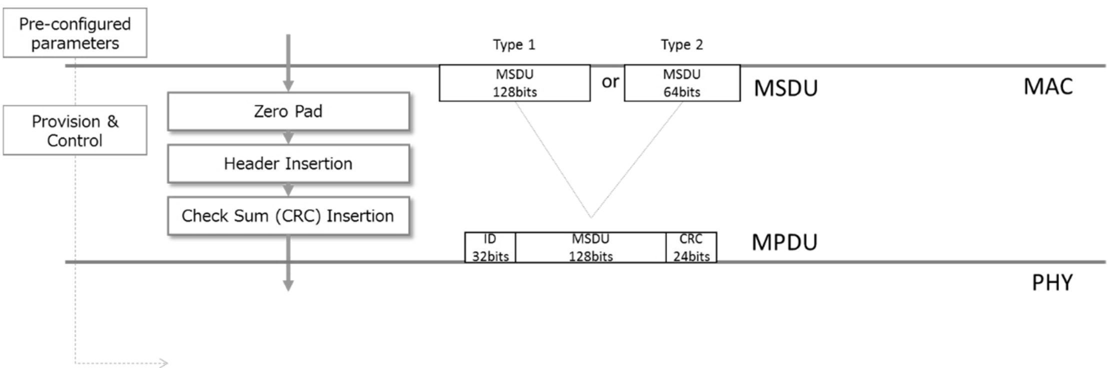

Figure 5-4: MAC Functional Overview

5.2.2 MAC format in UL

MPDU shall be of fixed length of 184-bit and composed as shown in Figure 5-5. MSDU lengths of 128-bit (Type 1) and 64-bit (Type 2) shall be supported.

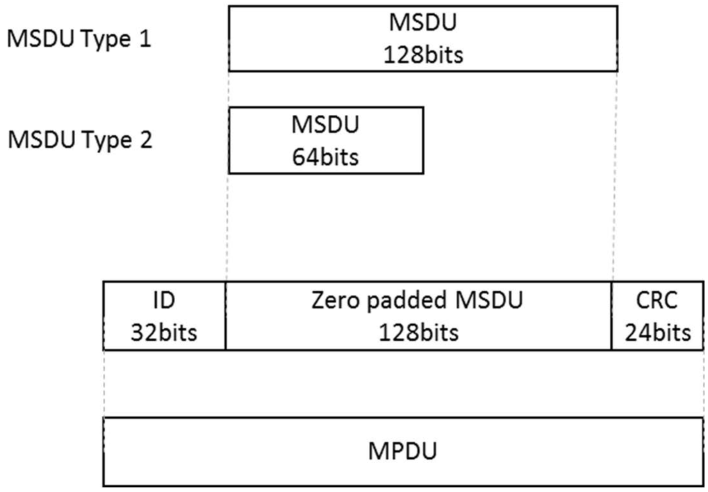

Figure 5-5: MPDU format

5.2.3 MAC function in UL

5.2.3.1 Assembling of MSDU

A 128-bit fixed length MSDU shall be formed from byte aligned MSDU of size less than or equal to 128-bits. If MSDU payload size is less than 128-bits, then it shall be padded with zero (0) to form 128-bit MSDU. The payload size is pre-configured for an EP and known to the BS(s).

5.2.3.2 Assembling of Header Field

A 32-bit header comprising entirely of address field shall be concatenated to the start of zero-padded MSDU payload.

5.2.3.3 Insertion of Check Sum

24-bit CRC shall be generated using following polynomial and initial state set to all one's (0xFFFFFF).

$$p(x) = x[24] + x[23] + x[18] + x[17] + x[14] + x[11] + x[10] + x[7] + x[6] + x[5] + x[4] + x[3] + x[1] + 1$$

The CRC shall be concatenated to the end of zero-padded MSDU payload.

5.2.3.4 Provisioning of PHY Parameter

5.2.3.4.1 PHY Mode

The PHY Mode of operation for an EP shall be set to one of Mode A, B, or C. This is pre-configured for the EP and known to the BS(s).

5.2.3.4.2 Repetitions

The value of $N_{repetition}$ shall be provided and set as below. This value is pre-configured for an EP and known to the BS(s).

$$0 \leq N_{repetition} \leq 31$$

5.2.3.4.3 Encryption Parameters

The parameters for encryption control and operation shall be provided as in Table 5-2. These parameters are pre-configured for an EP and known to the BS(s).

Table 5-2: Encryption Parameters

	Parameter provided to PHY
Type	AES128 or ISO/IEC 29192-2 [1] CLEFIA
Key	128-bit sequence
Pseudo random number	128-bit sequence
Control	MSDU Type, PHY Mode, Encryption_on

5.2.3.4.4 PHY Parameters

Parameters used in pseudo-random code generation for synchronization and scrambling shall be provided. These parameters are pre-configured for an EP and known to the BS(s).

5.2.3.4.5 Operation Band

Operational frequency band(s) for EP UL operation shall be provided. This parameter is preconfigured for an EP and known to the BS(s).

5.2.3.4.6 Channel Access

Parameters used to access channel for EP UL operation shall be provided. These parameters are pre-provisioned for an EP and known to BS(s).

Table 5-3: Channel Access Parameters

Parameter	Value	Description
Access Type (N_{Access})	0-7 (integer)	0: Access Type is Duty-Cycle (DC) 1-6: Access Type is Listen-Before-Talk (LBT) and integer value represents number of channel assessment attempts (if channel not found clear) before Abort 7: Reserved
Transmission Type	0-255 (integer)	0: Asynchronous 1: Synchronous Pattern-1 2-255: Reserved

5.2.3.4.7 Transmission Frame

Parameters used to calculate time of transmission for initial and repetition PPDUs as defined in Table 5-4 shall be provided. These parameters are pre-provisioned for an EP and known to BS(s).

Table 5-4: Transmission Frame Parameters

Parameter	Value	Description
Frame Duration ($T_{tx\text{-}frame}$)	0-15 (integer)	0: 5 s (Mode A), 0,3 s (Mode B), 0,2 s (Mode C) 1-15: Reserved
Slot Duration ($T_{tx\text{-}slot}$)	0-15 (integer)	0: 8 ms (Mode A), 10 ms (Mode B), 8 ms (Mode C) 1-15: Reserved
UL Data Slots	0-15 (Integer)	0: 570 (Mode A), 10 (Mode B), 12 (Mode C) 1-15: Reserved
NOTE: Frame parameters vary according to PHY Mode; therefore each parameter value corresponds to three different settings. Only one setting shall apply depending on PHY Mode.		

5.2.4 MAC procedures

5.2.4.1 Overview

As Lfour is an UL-only system, medium access is defined for EP, but not for BS. While MAC processing is the same for each PHY Mode, operational parameters related to time and frequency are dependent on the following pre-provisioned parameters:

- PHY Mode, see clause 5.2.3.4.1.
- Operation Band see clause 5.2.3.4.5.
- Channel Access see clause 5.2.3.4.6.

5.2.4.2 End-point Operation

5.2.4.2.1 Overview

The EP operation for channel access shall apply to initial transmission and repetition of PPDUs and comprises of frequency selection, time selection and channel assessment procedures respectively.

5.2.4.2.2 Repetition Procedure

An EP shall make $N_{repetitions}$ repetitions of a PPDU following its initial transmission, value of which is defined in clause 5.2.3.4.2.

5.2.4.2.3 Frequency Selection Procedure

Upon initiating the transmission of initial PPDU or repetition PPDU, frequency selection shall be performed by EP in two step procedure:

Step 1: Centre frequency

Channel Centre frequency (f_c) shall be determined as follows:

- If "Transmission Type" is set to "0", then f_c shall be centre frequency of randomly selected channel from available set of channels in the "Operation Band" as defined in clause 5.2.3.4.5.
- If "Transmission Type" is set to "1", then f_c shall be centre frequency of the channel corresponding to initial or repetition PPDU using procedure specified in clause 5.3.4.2.

Step 2: Transmit frequency

PPDU transmit frequency shall be determined as follows:

- If PHY Mode as defined in clause 5.2.3.4.1 is Mode A:
  - Transmit frequency shall be $f_c - \Delta f_{slowchirp}/2$ and sweep upward toward $f_c + \Delta f_{slowchirp}/2$ across PPDU as per chirp parameters defined in clause 5.3.3.7.3.
  - Frequency error shall be less than or equal to ±100 Hz.
- If PHY Mode as defined in clause 5.2.3.4.1 is Mode B or Mode C:
  - Transmit frequency shall be (f_c) and remain constant over PPDU.
  - Frequency error shall be less than or equal to ±100 Hz.

5.2.4.2.4 Transmission Start Time Selection Procedure

The transmission start time t_0 of initial PPDU shall be determined based on pre-configured Channel Access Parameters in Table 5-3.

If "Transmission Type" is set to "0", transmission time t_0 shall be selected at random.

If "Transmission Type" is set to "1", transmission start time selection shall be performed by an EP in two step procedure.

Step 1: Time slot based on "Transmission Frame" parameters defined in clause 5.2.3.4.7.

A time-slot t_{slot} referenced by index GP derived using procedure in clause 5.3.4.2 shall be selected.

Step 2: Transmission start time

Transmission start time t_0 of initial PPDU shall be aligned to the start of t_{slot} with permissible error of ±300 μs.

The transmission start time of a repetition PPDU shall be after a fixed time interval $T_{tx\text{-}frame}$ calculated from the start of previous transmission ($PPDU_0$ or $PPDU_i$, where i = 1, 2, …, $N_{repetition}$-1). The value of $T_{tx\text{-}frame}$ shall be as defined in Table 5-4.

Additionally, an EP shall comply with duty cycle parameters applicable to "Operation Band" defined in clause 5.4.2 if Channel Access Parameter "Access Type" is set to "0".

5.2.4.2.5 Channel Assessment Procedure

Channel assessment procedure shall apply to initial and repetition PPDU if Channel Access Parameter "Access Type" in Table 5-3 is set to a value between 1 and 6. A flow chart depicting steps is shown in Figure 5-6.

Assume counter i = 1:

- Carrier Sense:
  - Presence of signal shall be assessed over UL channel of operation $BW_{UL\text{-}Ch}$ for duration of at least t_{listen} prior to transmission. Back-off procedure shall be applied if a signal of strength more than $SS_{threshold}$ is detected at the EP receiver antenna input. Otherwise, transmission of PPDU shall be executed.
- Back-off:
  - If maximum attempts of carrier sense as defined in Table 5-3 has not been reached, then following steps shall be carried out.
  - Select new centre frequency $f_c(i) = f_c(i) + \Delta f$ (wrap around if exceeds the upper channel) where $\Delta f = 2 \times BW_{UL\text{-}Ch}$.
  - Select new transmission time $t(i) = t(i) + t_{back\text{-}off}$
  - Increment counter value "i" by 1.
- Abort:
  - Abort transmission if channel is found busy after "Access Type" attempts at carrier sense.

The values of t_{listen}, $t_{back\text{-}off}$ and $SS_{threshold}$ shall be set so as to comply with regulation as applies to "Operation Band".

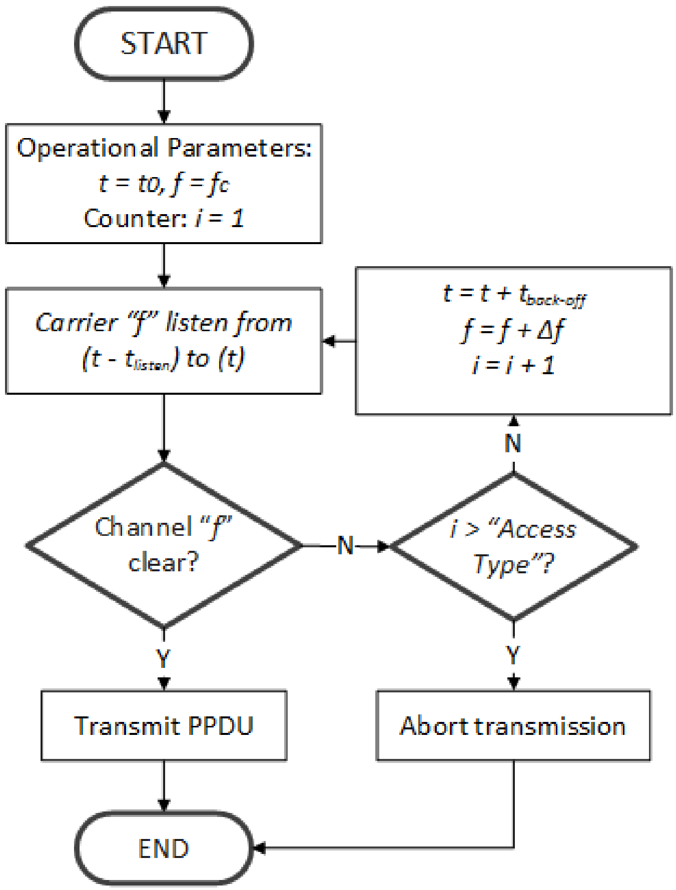

Figure 5-6: LBT procedure

5.3 PHY layer description

5.3.1 Overview

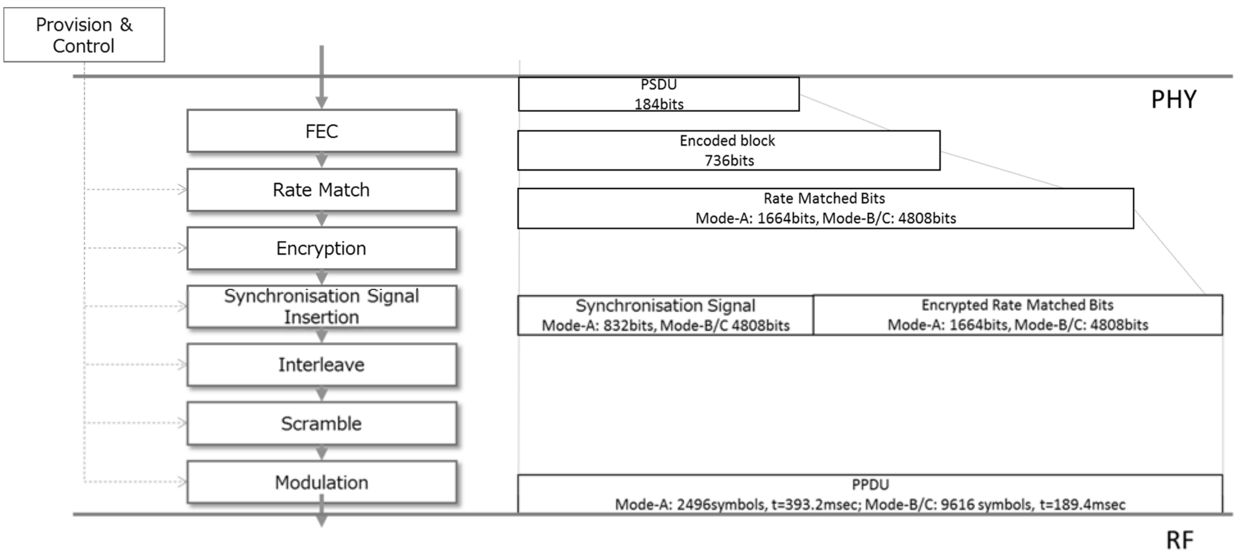

Figure 5-7: PHY Functional Overview

5.3.2 PHY format in UL

A PHY PDU or PPDU shall be of fixed size dependant on PHY Mode defined in clause 5.2.3.4.1 as shown in Table 5-5 and comprises of interleaved synchronization signal and coded payload bits as illustrated in Figure 5-7.

Table 5-5: PPDU Size

PHY Mode	PPDU Size (number of bits)
Mode A	2 496
Mode B	9 616
Mode C	9 616

5.3.3 PHY function in UL

5.3.3.1 Forward Error Correction

All PSDUs shall be coded for forward error correction with LDPC parameters in Table 5-6 as per the description below.

Table 5-6: LDPC Parameters

Code rate	1/4
K_{ldpc}	184
N_{ldpc}	736
M_{ldpc}	552

LDPC code with rate R=1/4 shall be applied to form Coded Block size of $L_{codedblock}$=4 × $L_{codeblock}$ where $L_{codeblock}$= SizeMPDU, i.e. 184-bit.

Input: 184 bits (128 + 32 + 24), denoted as $i_0, i_1, \ldots, i_{K_{ldpc}-1}$ with K_{ldpc} = 184
Output: 736 code bits, denoted as $\lambda_0, \lambda_1, \ldots, \lambda_{N_{ldpc}-1} = i_0, i_1, \ldots, i_{K_{ldpc}-1}, p_0, p_1, p_2, \ldots, p_{M_{ldpc}-1}$, with N_{ldpc} = 736 and M_{ldpc} = 552.

A systematic binary LDPC code with quasi-cyclic structure (information part) and dual staircase (parity part) shall be used, i.e. parities shall be accumulated (see below). Encoding shall be performed as follows:

- First:
  - K_{ldpc} = 184 parities shall equal information bits: $\lambda_k = i_k,\ for\ k = 0,1, \ldots, K_{ldpc} - 1$
- Initialize:
  - $p_0 = p_1 = p_2 = \cdots = p_{M_{ldpc}-1} = 0$
- Accumulate the first information bit, i_0, at parity bit addresses specified in the first row of Table 5-7. For example, (all additions are in GF(2)):
  - $p_1 = p_1 \oplus i_0$ $p_7 = p_7 \oplus i_0$
  - $p_{90} = p_{90} \oplus i_0$ $p_{172} = p_{172} \oplus i_0$
  - $p_{209} = p_{209} \oplus i_0$ $p_{359} = p_{359} \oplus i_0$
  - $p_{401} = p_{401} \oplus i_0$ $p_{420} = p_{420} \oplus i_0$
  - $p_{483} = p_{483} \oplus i_0$ $p_{487} = p_{487} \oplus i_0$

- For the next 7 information bits, i_m, m =1, 2, ..., 7, accumulate i_m at parity bit addresses $[x + (m \bmod 8)\times Q_{ldpc}] \bmod M_{ldpc}$, where x denotes the address of the parity bit accumulator corresponding to the first bit i_0, and Q_{ldpc} = 69. So for example for information bit i_1, the following operations are performed:

  - $p_{70} = p_{70} \oplus i_1$ $p_{76} = p_{76} \oplus i_1$
  - $p_{159} = p_{159} \oplus i_1$ $p_{241} = p_{241} \oplus i_1$
  - $p_{278} = p_{278} \oplus i_1$ $p_{428} = p_{428} \oplus i_1$
  - $p_{470} = p_{470} \oplus i_1$ $p_{489} = p_{489} \oplus i_1$
  - $p_0 = p_0 \oplus i_1$ $p_4 = p_4 \oplus i_1$

- For the 9th information bit i_8, the addresses of the parity bit accumulators are given in the second row of Table 5-7. In a similar manner the addresses of the parity bit accumulators for the following 7 information bits i_m, m = 9, 10, ..., 15 are obtained using the formula $[x + (m \bmod 8)\times Q_{ldpc}] \bmod M_{ldpc}$, where x denotes the address of the parity bit accumulator corresponding to the information bit i_8, i.e. the entries in the second row of Table 5-7.

- In a similar manner, for every group of 8 new information bits, a new row from the Table 5-7 is used to find the addresses of the parity bit accumulators.

After all of the information bits are exhausted, the final parity bits shall be obtained by accumulation as follows:

- Sequentially perform the following operations starting with i = 1:

  - $p_i = p_i \oplus p_{i-1}$ $for\ i = 1, 2, ..., M_{ldpc} - 1$

- Final content of p_i , i = 0, 1,.., M_{ldpc} -1 is equal to the parity bit p_i.

Table 5-7: Parity bit addresses for LDPC code

Row and col index	1	2	3	4	5	6	7	8	9	10
1	1	7	90	172	209	359	401	420	483	487
2	57	164	192	197	284	307	174	356	408	425
3	22	50	191	379	385	396	427	445	480	543
4	32	49	71	234	255	286	297	312	537	550
5	30	70	88	111	176	201	283	322	419	499
6	86	94	177	193	266	368	373	389	475	529
7	134	223	242	254	285	319	403	496	503	534
8	18	84	106	165	170	199	321	355	386	410
9	129	158	226	269	288	316	397	413	444	549
10	33	113	133	194	256	305	318	380	507	
11	317	354	402							
12	53	64	374							
13	83	314	378							
14	162	259	280							
15	166	281	486							
16	185	439	489							
17	119	156	224							
18	26	62	244							
19	8	246	482							
20	15	72	91							
21	43	69	390							
22	127	186	506							
23	55	81	412							

5.3.3.2 Rate Matching

The output from FEC, coded block of size $L_{codedblock}$, shall follow the Rate matching procedure based on parameters defined in Table 5-8 and as per steps illustrated in Figure 5-8 and described below.

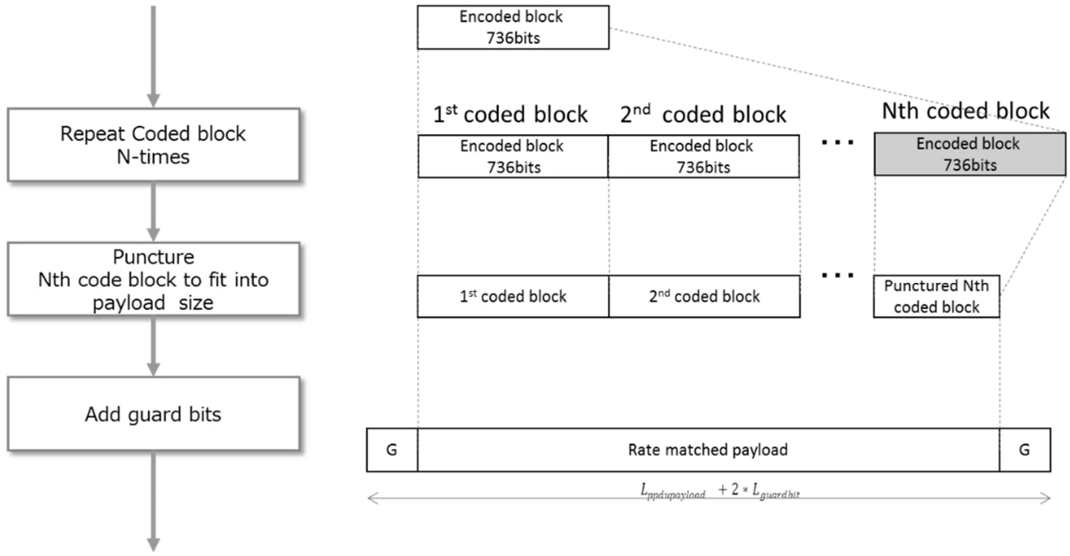

Figure 5-8: Rate match procedure

Table 5-8: Rate match parameters

Size (bits)	Mode A	Mode B	Mode C
$L_{codedblock}$	736		
$L_{ppdupayload}$	1 656	4 800	
$N_{ratematch}$	3	7	
$L_{guardbit}$	4		

Output from FEC shall be repeated $N_{ratematch}$ times, where:

$$N_{ratematch} = Ceil(\frac{L_{ppdupayload}}{L_{codedblock}})$$

Excessive bits shall be removed to match PPDU payload size $L_{ppdupayload}$ by applying puncturing to N^{th} coded block as described below.

For PHY Mode A, puncturing shall be performed such that only every 4th bit of coded block remains. This is depicted in Figure 5-9.

For PHY Mode B and PHY Mode C, puncturing shall be performed in steps:

- Remove 1^{st} 184 bits from coded block N.
- Partition remaining block into 24 sub-blocks of length 23 bits each.
- Apply puncturing such that only 16 out of 23 bit remains from each sub-block.

This is depicted in Figure 5-10.

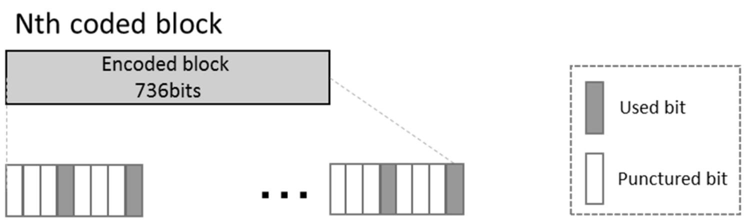

Figure 5-9: Puncturing for PHY Mode A

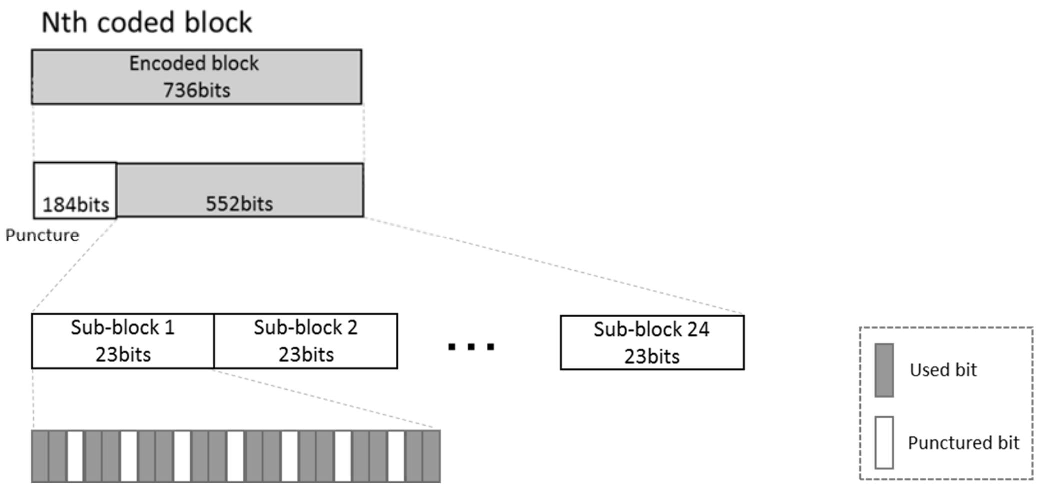

Figure 5-10: Puncturing for PHY Mode B and C

The last step of rate matching procedure concatenates header and trailer guard bit filed with length $L_{guardbit}$ as defined in Table 5-8. The content of guard bit shall be set to all zeros (0b0).

$$L_{guardbit} \equiv Number\ of\ guard\ bits\ to\ be\ concatenated.$$

5.3.3.3 Encryption

Encryption code generated from 128-bit key shall be applied to PPDU payload. Encryption is based on AES128 or ISO/IEC 29192-2 [1] CLEFIA set through Encryption parameters described in clause 5.2.3.4.3 and operates under counter mode. Encryption scheme is shown in Figure 5-11. A 128-bit Pseudo random number, 128-bit key, and parameters needed for control shall be provided by MAC layer as described in clauses 5.2.3.4.3 and 5.2.3.4.4.

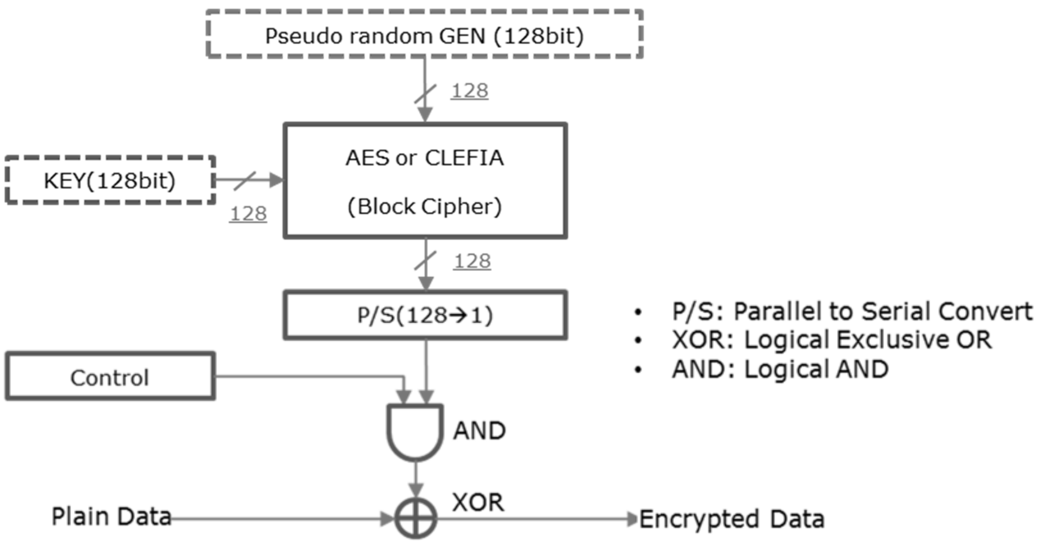

Figure 5-11: AES and CLEFIA encryption

Sequence of control signal shall be generated according to PHY Mode (A, B, or C) and MSDU Type (1 or 2) as illustrated in Figure 5-12 and Figure 5-13.

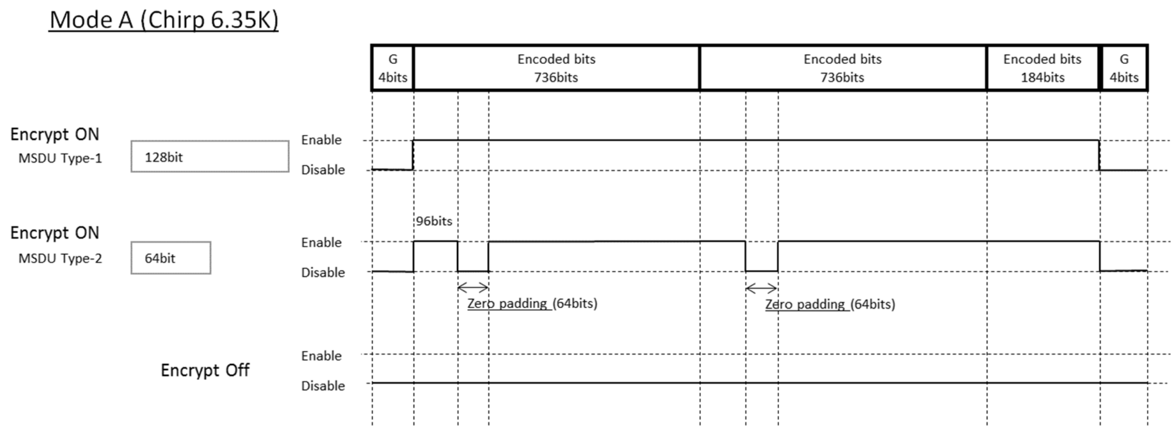

Figure 5-12: Output of control signal for PHY Mode A

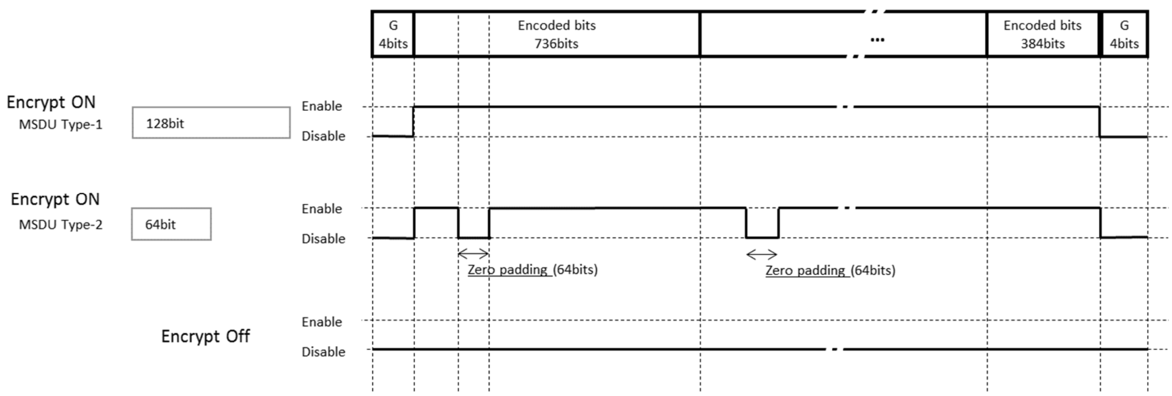

Figure 5-13: Output of control signal for PHY Mode B and C

5.3.3.4 Synchronization Signal Insertion

The rate matched PPDU payload including the guard bits shall be concatenated with a synchronization signal of length L_{sync} where:

$$L_{sync} = 832 \text{ bits (Mode A) and } 4\,808 \text{ bits (Mode B and C)}$$

Synchronization signal shall be a truncated gold code with polynomials as follows:

M-Sequence 1: p1(x) = x[25] + x[3] + 1

M-Sequence 2: p2(x) = x[25] + x[3] + x[2] + x[1] + 1

This is shown in Figure 5-14.

Initial state of generator polynomials shall be set to a value as per clause 5.2.3.4.4. The states of polynomials shall be initialized to the value of PPDU.

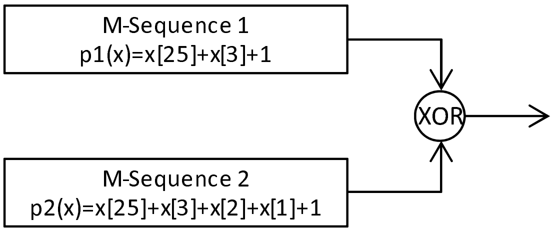

Figure 5-14: Synchronization Signal Generator

5.3.3.5 Interleaving

5.3.3.5.1 Mode A Interleaver

The input to interleaver comprises of:

- 832 synchronization signal bits denoted by $b_{s0}, b_{s1} \ldots b_{s831}$
- 8 guard bits denoted by $b_{g0}, b_{g1} \ldots b_{g7}$
- 1 656 encoded bits denoted by $b_{e0}, b_{e1} \ldots b_{e1655}$

The interleaver shall follow below procedure:

- First two synchronization signal bits are each followed by two guard bits in order, i.e. $b_{s0}\ b_{g0}\ b_{g1}\ b_{s1}\ b_{g2}\ b_{g3}$
- The next 828 synchronization signal bits are each followed by two encoded bits in order, i.e. $b_{s2}\ b_{e0}\ b_{e1}\ b_{s3}\ b_{e2}\ b_{e3} \ldots\ b_{s828}\ b_{e1652}\ b_{e1653}\ b_{s829}\ b_{e1654}\ b_{e1655}$
- The last two synchronization signal bits are each followed by two guard bits in order, i.e. $b_{s830}\ b_{g4}\ b_{g5}\ b_{s831}\ b_{g6}\ b_{g7}$

The resultant interleaving pattern is illustrated in Figure 5-15.

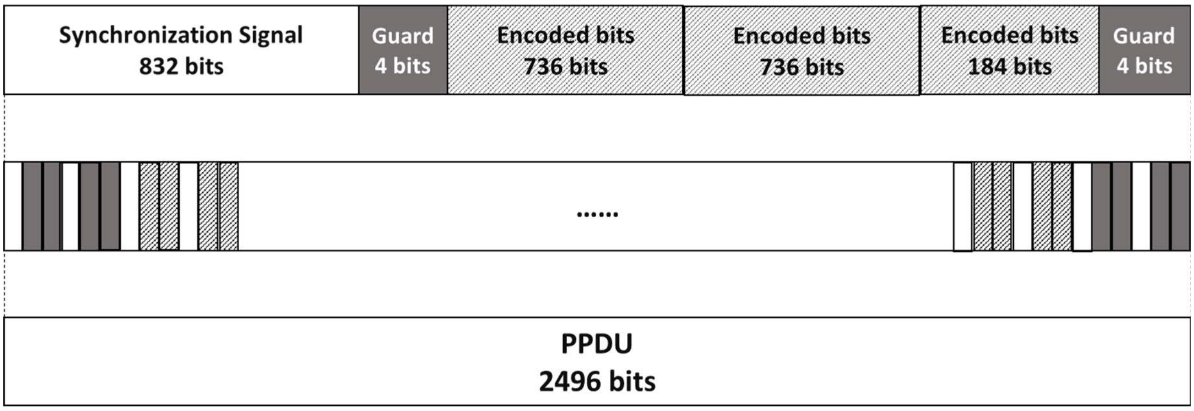

Figure 5-15: Interleave pattern, Mode A

5.3.3.5.2 Mode B and C Interleaver

The input to interleaver comprises of:

- 4 808 synchronization signal bits denoted by b_{s0}, b_{s1}…b_{s4807}
- 8 guard bits denoted by b_{g0}, b_{g1}…b_{g7}
- 4 800 encoded bits denoted by b_{e0}, b_{e1}…b_{e4799}

The interleaver shall follow below procedure:

- First four synchronization signal bits are each followed by one guard bit in order, i.e. b_{s0} b_{g0} b_{s1} b_{g1} …b_{s3} b_{g3}
- The next 4 800 synchronization signal bits are each followed by one encoded bit in order, i.e. b_{s4} b_{e0} b_{s5} b_{e1} …. b_{s4803} b_{e4799}
- The last four synchronization signal bits are each followed by one guard bit in order, i.e. b_{s4804} b_{g4} b_{s4805} b_{g5} …b_{s4807} b_{g7}

The resultant interleaving pattern is illustrated in Figure 5-16.

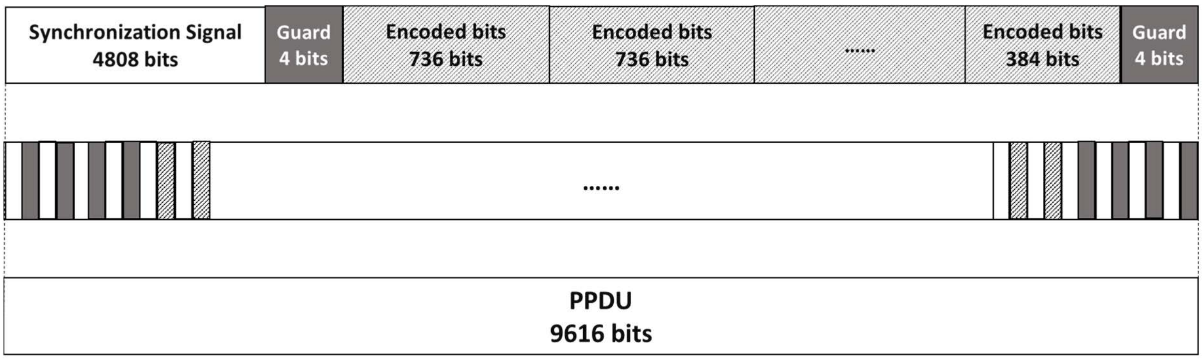

Figure 5-16: Interleave pattern, Mode B and Mode C

5.3.3.6 Scrambling

Scrambling shall be applied over PPDU with M-sequence generator shown as below and illustrated in Figure 5-17.

$$x[24]+x[23]+x[18]+x[17]+x[14]+x[11]+x[10]+x[7]+x[6]+x[5]+x[4]+x[3]+x+1$$

Initial state of generator polynomial shall be set to a value as per clause 5.2.3.4.4. The state of polynomial shall be initialized to value of PPDU.

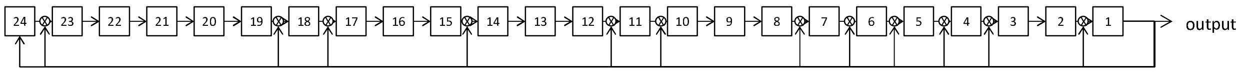

Figure 5-17: Scramble code generator

5.3.3.7 Modulation

5.3.3.7.1 Introduction

Modulation procedure shall comprise of primary and secondary modulation stages and applied according to PHY Mode defined in clause 5.2.3.4.1.

5.3.3.7.2 Primary Modulation

π/2-shift BPSK modulation shall be applied to scrambled PPDU, as shown in Figure 5-18, and based on bit mapping and phase assignment according to Table 5-9 and Table 5-10.

The modulated PPDU thus generated is ready for transmission on air for PHY Modes B and C.

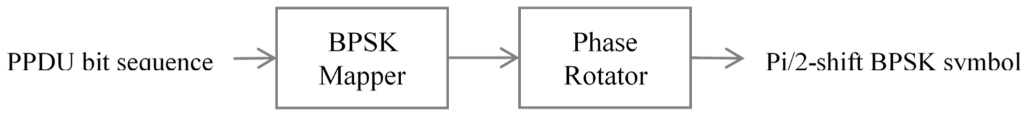

Figure 5-18: Primary Modulation

Table 5-9: BPSK Mapper

Bit	Modulated Symbol, (I, Q)
0	(-1, 0)
1	(+1, 0)

Table 5-10: Phase Rotator

b[n], Mod(n,4)	Radian
0	+π × (0/2)
1	+π × (1/2)
2	+π × (2/2)
3	+π × (3/2)

5.3.3.7.3 Secondary Modulation

If PHY Mode is set to Mode A in clause 5.2.3.4.1, then secondary modulation shall be applied to primary modulated PPDU.

Secondary modulation shall be a linear chirp sequence derived from chirp rate β = 387,430 kHz/s and applied over π/2-shift BPSK modulated signal.

The resultant sweep frequency is defined as:

$$\Delta f_{slowchirp} = \beta \times T_{PPDU}$$

The value of T_{PPDU} is defined in Table 5-1.

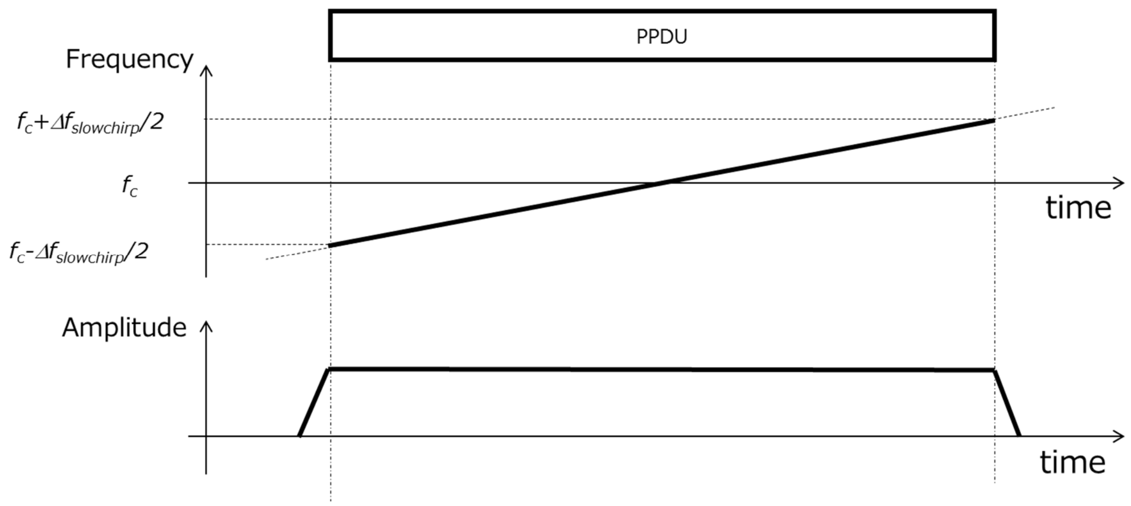

Figure 5-19: Chirp Modulation

5.3.4 PHY Procedures

5.3.4.1 Overview

The UL physical layer uses randomization in time and frequency for PPDU transmissions to achieve high system capacity. Channel Access parameters defined in clause 5.2.3.4.6 determines if transmission is asynchronous or synchronous. While time synchronization may be achieved using various methods, "Synchronous Pattern-1" relies on GPS time. "Transmission Type" parameter in Table 5-4 has reserved values to allow other synchronous patterns and methods in future.

5.3.4.2 Synchronous Pattern-1

5.3.4.2.1 Frame structure

If "Transmission Type" in Table 5-3 is set to "1", then transmission of PPDUs shall be carried out by EPs in a synchronous manner according to procedure specified in this clause.

In time domain, a frame structure is employed as per parameters "Frame Duration" and "Slot Duration" in Table 5-4. A resultant frame with a grid structure is illustrated in Figure 5-20 for Mode A. For example, a 5 s frame with 8 ms slot duration leads to 625 slots. Each such slot is indexed using parameter called Grid Position (GP). All or some of the slots within frame may be used for UL data transmission. This is determined by parameter "UL Data Slots" in Table 5-4.

Similar frame structure is employed for Modes B and C using parameters in Table 5-4.

The start of a PPDU transmission shall be aligned to start of one of the available data slots which is selected together with a transmit frequency according to hopping procedure specified in clause 5.3.4.2.2.

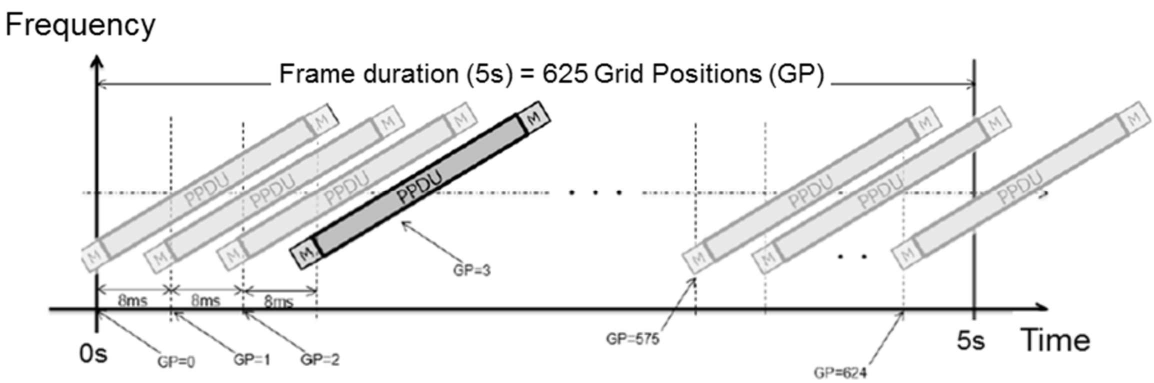

Figure 5-20: Lfour Transmission Frame Example - Mode A

5.3.4.2.2 Time and frequency hopping

Lfour enabled EPs shall perform frequency hopping for initial and repetition PPDUs and time-slot hopping within defined frame for initial PPDU as a function of following parameters:

- FH_RNG denotes available number of channels in the "Operation Band" as defined in clause 5.2.3.4.5.
- GP_RNG denotes available number of grid positions indicated by parameter "UL Data Slots" in Table 5-4.
- TXID denotes 32-bit address used as MAC header as defined in clause 5.2.3.2.
- GPSTIME denotes 32-bit GPS time of transmission composed of 12-bit MSBs of GPS weeks (GPSW) followed by 20-bit LSBs of GPS Week-Seconds (GPSWS).

  Where:

  - GPSW = floor(AccumulatedSeconds / 60 × 60 × 24 × 7);
  - GPSWS = modulo(AccumulatedSeconds, 60 × 60 × 24 × 7); and
  - AccumulatedSeconds is duration in seconds since date 1980/1/6 00:00:00.

The frequency channel index (CH) and GP shall be determined for initial and repetition PPDUs using following steps:

- Calculate size of pseudo-random seed PRN_BW as:

$$PRN\_BW = ceil(\log_2(MPATH))$$

Where:

$$MPATH = GP\_RNG \times (FH\_RNG \wedge (N_{repetitions}+1))$$

- Calculate scaling factor α as:

$$\alpha = ceil(\,(MPATH / (POWER2 - 1)) \times 64) / 64$$

Where:

POWER2 = 2 ^ (PRN_BW)

- Calculate seed $MSEED_{raw}$ of size "PRN_BW" bits using procedure specified in clause 5.3.4.2.3.
- Derive candidate $MSEED_{cand}$ as follows:

$$MSEED_{cand} = floor(MSEED_{raw} \times \alpha)$$

- If $MSEED_{cand}$ < MPATH, then MSEED = $MSEED_{cand}$; else, repeat process to derive $MSEED_{cand}$ from regenerated $MSEED_{raw}$ until $MSEED_{cand}$ < MPATH or up to four attempts, whichever condition is satisfied first.
- If $MSEED_{cand}$ < MPATH, then MSEED = $MSEED_{cand}$; else MSEED = $MSEED_{cand}$/2.
- Derive GP using divmod moderator as follows:

$$Divmod(MSEED, GP\_RNG) = \{GP, QUO[0]\}$$

  The GP shall be used for transmission start time of initial PPDU and repeated PPDUs.

- Derive CH_0, $CH_1 \ldots CH_n$ where $n=N_{repetitions}$ using divmod operator iteratively as follows:

$$Divmod(QUO[0], FH\_RNG) = \{CH_0, QUO[1]\},$$

$$Divmod(QUO[1], FH\_RNG) = \{CH_1, QUO[2]\} \text{ and so on up to:}$$

$$Divmod(QUO[n], FH\_RNG) = \{CH_n, QUO[1]\}$$

The CH_0 shall be used for transmission frequency of initial PPDU and $CH_1 \ldots CH_n$ for that of repeated PPDUs respectively.

This process is illustrated in Figure 5-21.

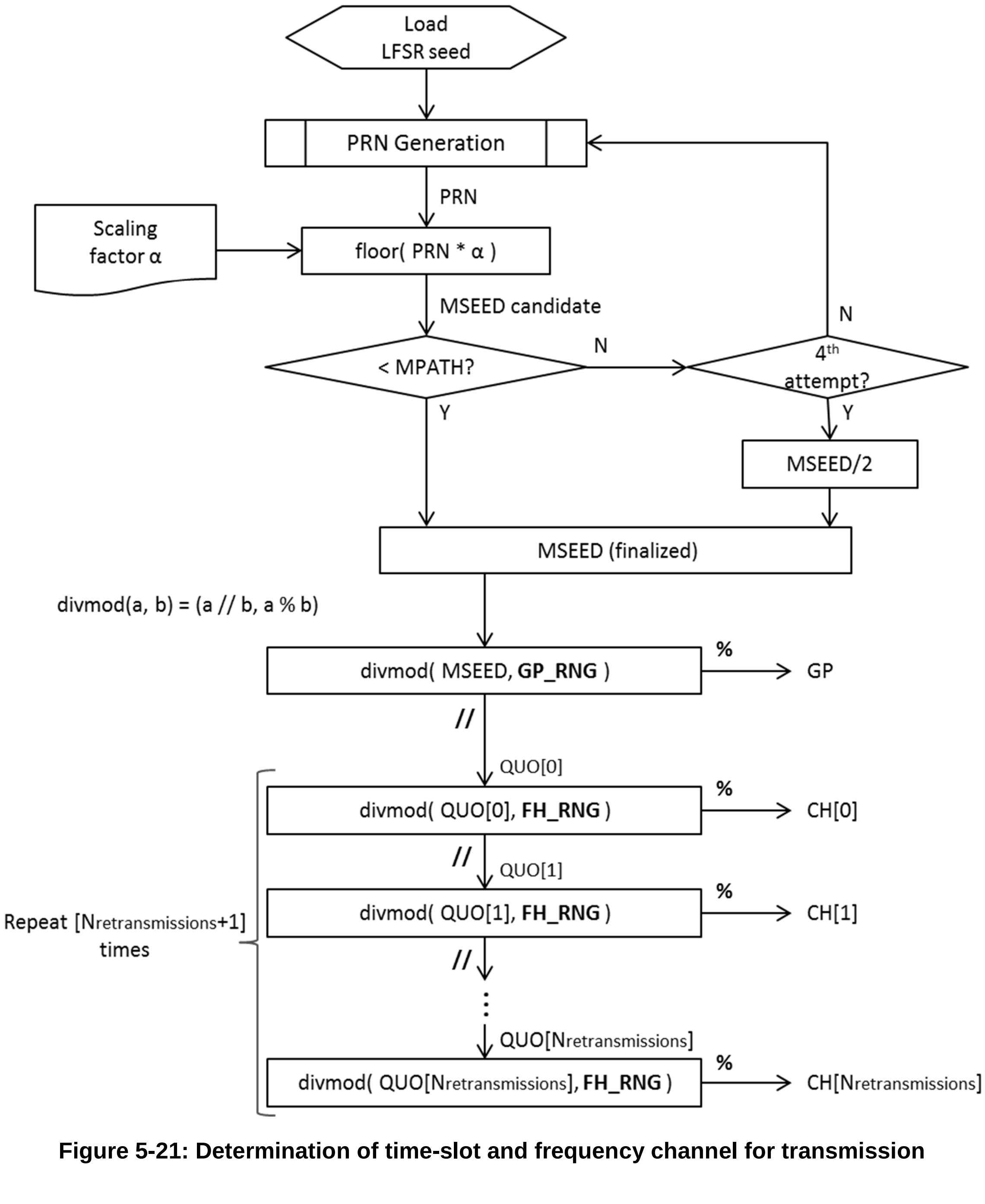

Figure 5-21: Determination of time-slot and frequency channel for transmission

5.3.4.2.3 Pseudo-random seed generation

A PRN generator comprises of two LFSRs, LFSR1 and LFSR2 respectively, where:

LFSR1 uses 32-bit shift register initialized to polynomial TXID as defined in clause 5.3.4.2.2 and with polynomial P(x) in its feedback path:

$$P(x) = x[32] + x[7] + x[5] + x[3] + x[2] + x[1] + 1$$

LFSR2 uses 32-bit shift register initialized to polynomial GPSTIME as defined in clause 5.3.4.2.2 and with polynomial Q(x) in its feedback path:

$$Q(x) = x[32] + x[30] + x[17] + x[12] + x[3] + x[1] + 1$$

A bit-wise XOR is performed on outputs of LFSR1 and LFSR2 to generate unique PRN seeds denoted by "$MSEED_{raw}$" of size "PRN_BW" iteratively.

This process is illustrated in Figure 5-22.

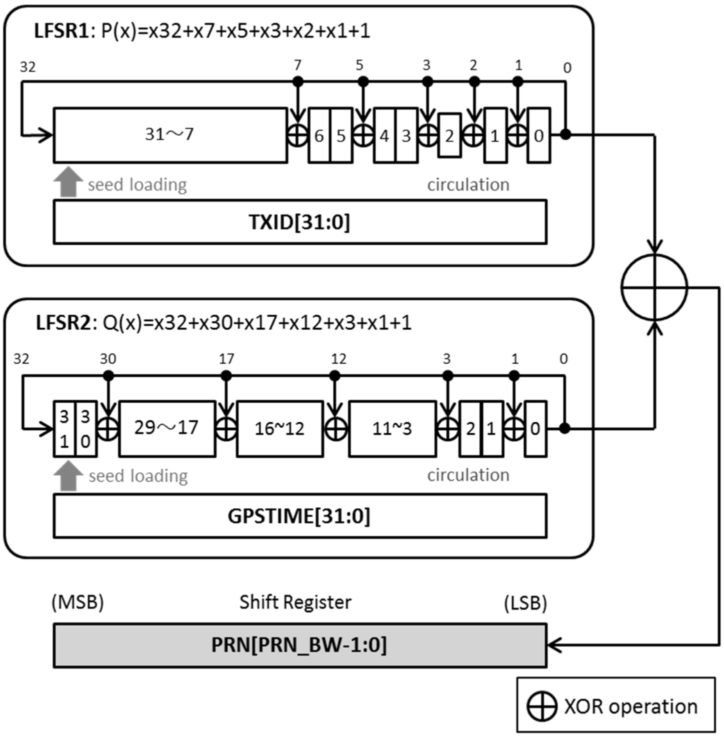

Figure 5-22: PRN Generator for Synchronous Pattern-1

5.4 Radio characteristics

5.4.1 Overview

Lfour enabled EP shall be configured to comply with the regional harmonized or global regulations applicable to spectrum of use. An EP may be configured to operate in more than one, i.e. non-contiguous frequency bands.

5.4.2 Band-plan

Lfour UL operation requires frequency spectrum of at least 200 kHz for Access Type "0" and at least 600 kHz for Access Type values "1..6", where Access Type refers to parameter defined in clause 5.2.3.4.6.

If total bandwidth of Operation Band(s) defined in clause 5.2.3.4.5 is more than 200 kHz, then the band(s) are split evenly in channels of 200 kHz each and frequency of operation f_c, shall be defined at centre frequency of each channel. A channel of operation is denoted by $BW_{UL\text{-}Ch}$. This channelization shall apply to all PHY modes.

6 Dynamic Downlink Ultra Narrow Band (DD-UNB) family

6.1 System overview

6.1.1 System elements

6.1.1.1 Architecture

A LTN system running DD-UNB protocol comprises a Service Centre (SC), a number of Base Stations (BSs), and many End-Points (EPs). Some EP may not be in the coverage area of a BS (referred to as Orphaned End-Points or OEP). OEP can be connected to the network using a relay link through another EP (called Relay Point or RP).

LTN systems are based on the architecture described in ETSI TS 103 358 [i.6] (Low Throughput Networks (LTN) Architecture). In the case of the DD-UNB system the A-interface protocol supports communication over the A-interface, i.e. between a Base Station (BS) and an End-Point (EP); the same protocol provides communication between BS and RP over the A"-interface (typically an EP can be configured to act also as a RP).

The A"-interface is the DD-UNB air interface for the bidirectional relay link between OEP and RP.

The B-interface is the backhaul access network interface (e.g. over cellular) used for communication between BS and SC; backhaul link protocol is out of the scope of the present document.

6.1.1.2 Service Centre

The present document describes a DD-UNB system with a single SC. It is possible to have multiple linked Service Centres to increase capacity for very large systems, but such an arrangement is implementation-specific and out of scope of the present document.

6.1.1.3 Base station

A DD-UNB BS includes a transmitter and a receiver. The receiver typically has an analogue bandwidth greater than 15 kHz and Digital Signal Processing (DSP) which can receive multiple concurrent DD-UNB signals on different frequencies within that bandwidth. The transmitter typically operates at higher power levels (500 mW erp) than EP with a higher gain antenna. The downlink data rate is 8 times that of the uplink.

BSs are connected to the Service Centre using backhaul transmission links (over B interface).

6.1.1.4 End-points

An EP can receive a single DL transmission or transmit a single UL signal on a single frequency at any one time; this can be on the A or A"-interface.

The A"-interface is used by an EP to communicate with a BS via another EP acting as a Relay Point (RP). The DD-UNB system is not designed to operate as a multi-hop mesh system and allows only one such "extra" hop for each connection.

6.1.2 Protocol Overview

6.1.2.1 Introduction

The DD-UNB protocol is based on the OSI reference model. A typical implementation of DD-UNB is illustrated in Figure 6-1 (for downlink). Physical layer (PHY) and Medium Access Control (part of layer 2 - Data Link Layer (DLL)) are described in the present document. The remainder of DLL and higher layers are implementation-dependent.

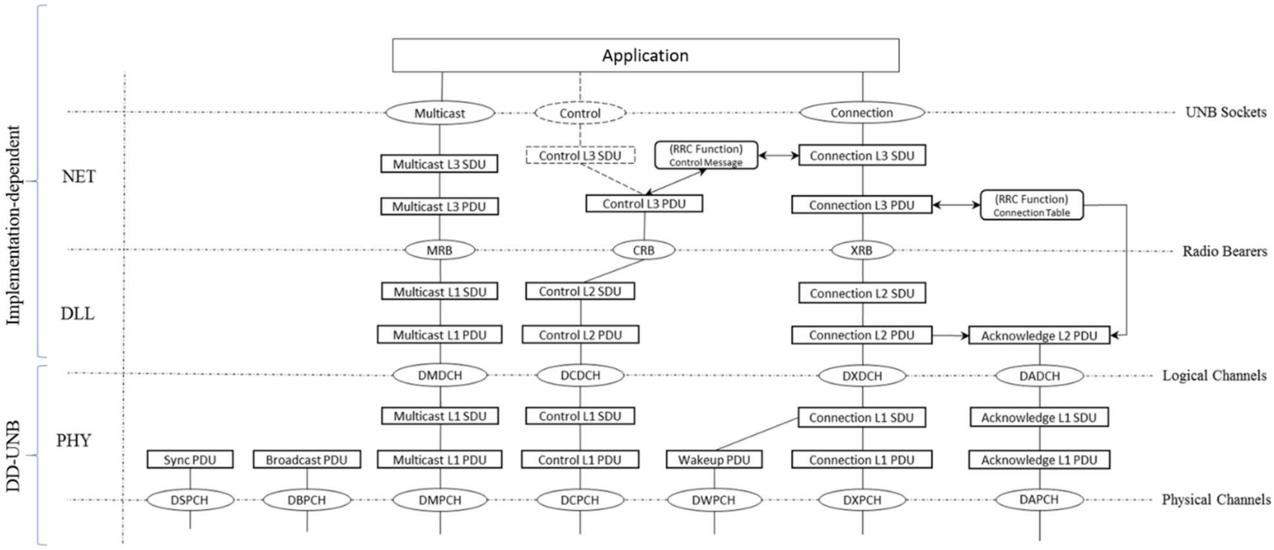

Figure 6-1: DD-UNB Protocol Layers (Downlink) in example implementation

DD-UNB is designed as an efficient means of meeting, within severely constrained resources, the requirements of applications served by LTN systems, and provides a means of transferring 14-byte application messages between a service centre and end-points. While the basic OSI layering model is used, the inherently-limited resources and the benefits of reducing overheads result in the removal of some opacity between the layers of the DD-UNB system. This applies particularly to addressing where a single addressing scheme is assumed at all layers of the DD-UNB protocol. Layers use common sets of parameters as much as possible, for example the "block number" associated with each connection data unit at layer 3 is also used by lower layers to reduce overhead.

The Medium Access Control (MAC) is treated as part of DLL and used only in uplink direction.

6.1.2.2 Protocol Termination Points

The present document specifies behaviour of PHY and MAC. A typical implementation of DD-UNB provides functionality at higher layers and this clause describes how protocols at those layers might be terminated to provide support for typical applications.

Figure 6-2 describes the A-interface protocol DL termination points.

NOTE: All Layer 3 downlink services initiated from SC are supported (Figure 6-2 (a)). In addition, Multicast service may be initiated from BS (Figure 6-2 (b)) where this meets application needs.

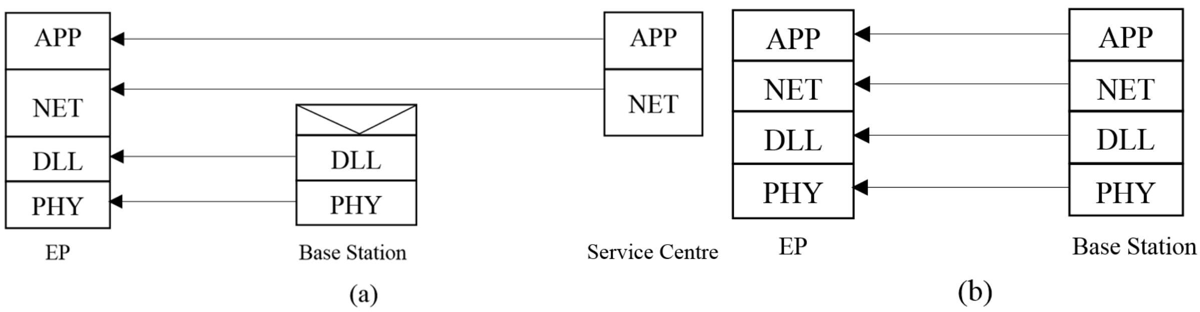

Figure 6-2: Protocol Termination (A-interface Downlink)

A-interface protocol UL termination points are shown in Figure 6-3.

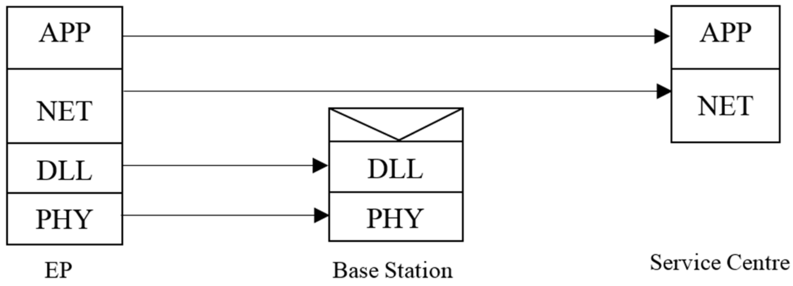

Figure 6-3: Protocol Termination (A-interface Uplink)

In cases where a relay node is used, Figure 6-4 and Figure 6-5 illustrate protocol termination points in A" downlink. All Layer 3 A" downlink services are initiated from SC; Multicast service may also be initiated from BS.

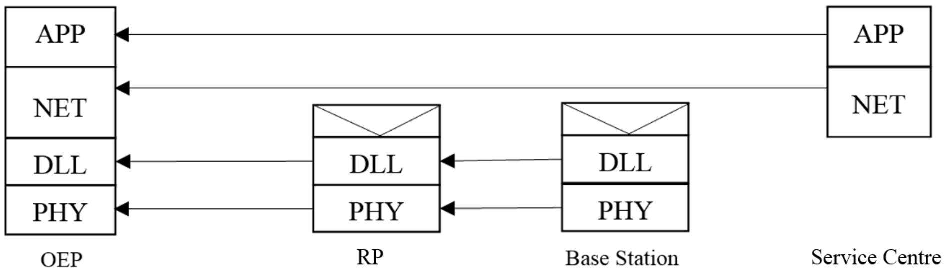

Figure 6-4: Protocol Termination (A" Downlink - SC initiated App)

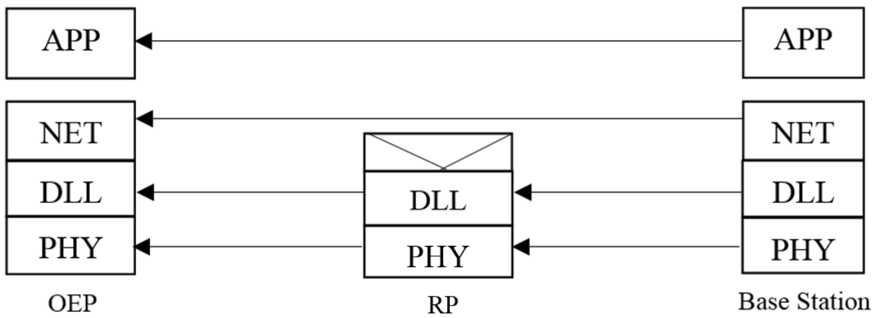

Figure 6-5: Protocol Termination (A" Downlink - BS initiated App)

Figure 6-6 illustrates protocol termination points for A" uplink.

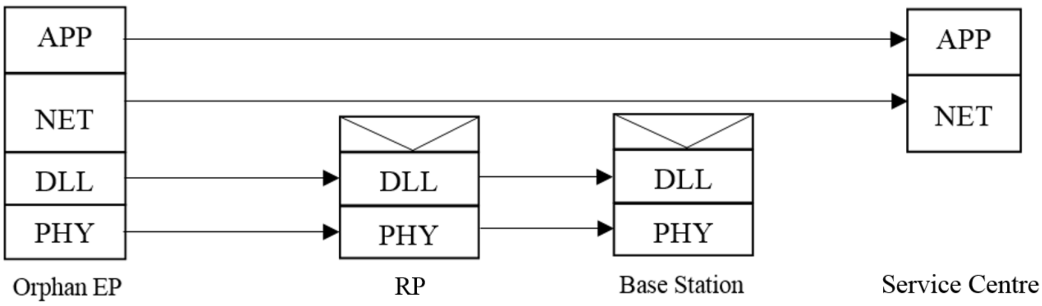

Figure 6-6: Protocol Termination (A"-interface Uplink)

6.1.2.3 System Addressing and Identities

Several address types are used by DD-UNB protocol to address different entities in each system:

- A unique 10 bit Short System ID (SSID) is used to identify the system.
- End-Point ID (EPID) is a unique 32 bit BSGP allocated for each EP in the system.
- Base Station ID (BSID) is a unique 13 bit identifier allocated for each BS in the system.
- Connection ID (ConID) is a 14 bit identifier which is unique for each connection within a cell but may be reused in other cells. ConID value 0x0 is reserved for use in A" UL management (see clause 6.3.2.3 and Table 6-6).

In addition, a EUI-64 identifier is used for globally-unique identification of End-points.

6.1.3 Upper Layer Principles

DD-UNB provides the L1 / MAC mechanisms to support the implementation of a guaranteed delivery mechanism for streams of Data PDUs (or a definite indication of failure and, in this case, an indication of which blocks have been delivered). Acknowledge PDUs can be used by both L2 and L3 to provide acknowledgement, repetition and flow control for connections on a hop-by-hop and end-to-end basis respectively. Layers above L1/MAC are implementation-dependent.

Connection-oriented links are anticipated to dominate communications between application entities in a DD-UNB system.

In order to identify each EP uniquely, a 32 bit EP identifier is used (about 4 billion differs). Since a typical system would have a much smaller EP population, DD-UNB uses connection identifiers, reducing overheads.

Connections are made between specific "ports" of application entities. Up to 16 ports can be associated with one EP. A RP can relay as many connections as required although there will typically be implementation restrictions.

Connections are managed with Control PDUs, which can be sent connectionless, and if necessary routed through a multi-hop path using only the information which they themselves contain. Control PDUs are resent if lost.

6.1.4 Layer 3 (NET) Overview

Layer 3 is implementation-dependent. In a DD-UNB implementation many connections are typically "semi-permanent":

- a connection is set up when an EP begins operation and not removed unless one or both ends of the connection cease operation. However this is not mandated.

6.1.5 Layer 2 (DLL) Overview

6.1.5.1 Overview

DD-UNB Layer 1 is designed to support a range of Layer 2 implementations, but the present document details the MAC sub-layer employed in DD-UNB.

DD-UNB Layer 2 is also designed to support message encryption and authentication of application messages, although other approaches to encryption may be implemented if required for certain applications.

6.1.5.2 MAC Sublayer

Medium Access Control (MAC) is considered as a DLL sublayer.

Medium access in the downlink and A" downlink is based upon the spectrum access rules including regulatory duty cycle limitation. However, in the Uplink and A" Uplink there is potential for multiple EP to transmit simultaneously, therefore MAC is employed to manage UL transmission collision. The MAC procedure (based on slotted ALOHA in time) is described in clause 6.3.2.

6.1.6 Layer 1 (PHY) Overview

6.1.6.1 Frequency use

A-interface Downlink and Uplink frequencies may or may not be the same; regulatory constraints suggest they will typically be different. Frequency planning may be employed to manage interference between cells.

A"-interface Downlink and Uplink transmissions are intended for reception by EP (i.e. by OEP, and by EP configured to act as a RP respectively) and therefore frequencies used should reflect EP receiver implementation. Therefore A"-interface typically uses a frequency close to that of the A-interface Downlink.

Frequency hopping is optional. In a hopping system the BS (and RP on A"-interface) transmissions hop in a pre-determined pattern, with one timeslot per hop.

6.1.6.2 A-interface Downlink and Uplink timing

The UL and DL physical layer operates using TDD with a frame of 60 timeslots, each of length 400 ms. A frame comprises Downlink, Uplink and Uplink Acknowledge subframes, as illustrated in Figure 6-7. The allocation of timeslots to these subframes is variable and is broadcast by the BS for each frame. For relay operation a variable-length A"-interface subframe (during the A-interface UL subframe) is assigned for traffic between the RP and the OEP.

The frame number is a 6-bit number that cycles modulo 64, giving a "superframe" of 64 frames.

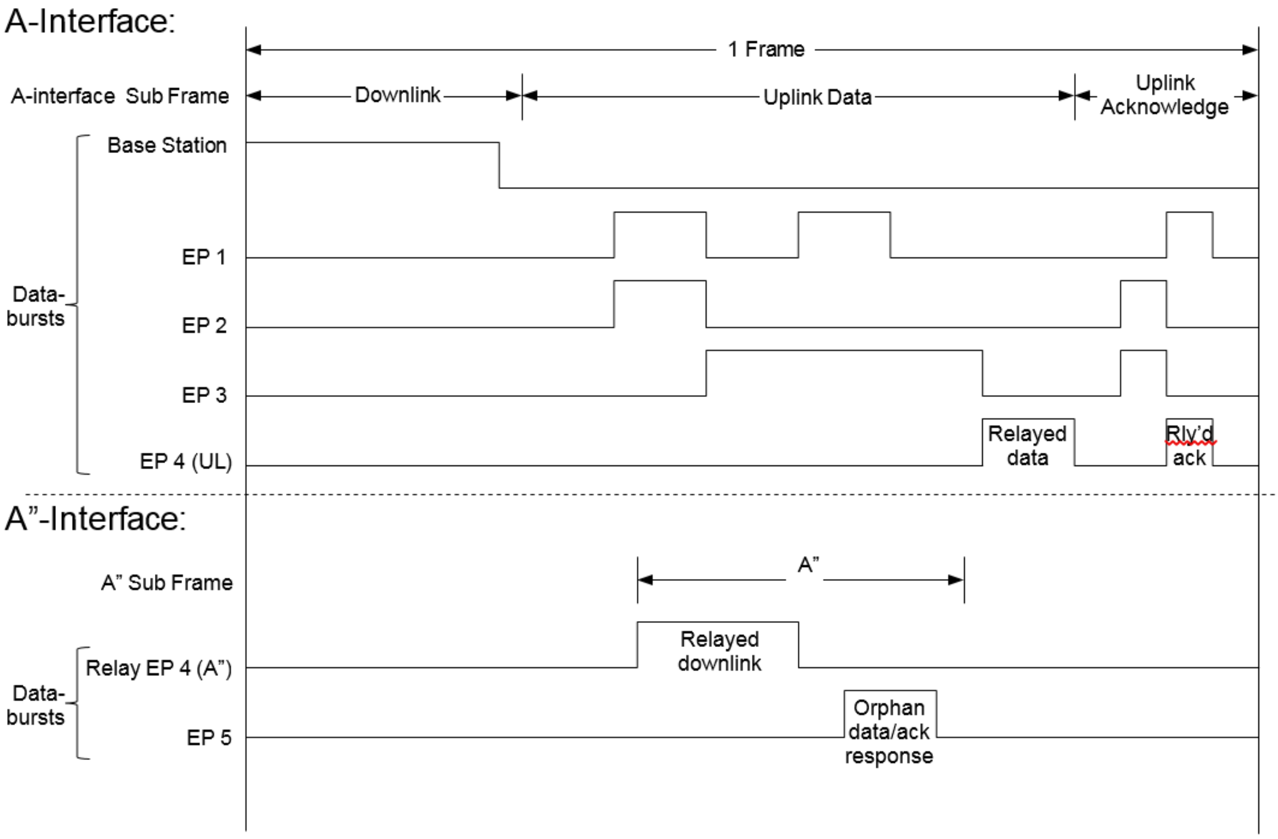

Figure 6-7: Example Frame and Subframe Timings

The downlink data-burst accommodates the L1 PDUs from the following physical channels (if present) in the order listed:

- A "Sync channel" used to synchronize EP with the frame and, if used, the frequency hopping sequence. Sync channel does not carry any upper-layer SDU.
- A "Broadcast channel" defines the format of the downlink data-burst that is to follow. Broadcast channel carries no upper-layer SDU.

- A "Multicast channel" carries Multicast data addressed to all EP in the cell.
- A "Control channel" carries signalling information mainly used in the set-up and control of layer 3 connections and other procedures.
- A "Wakeup channel" carries the connection identifiers for those connections for which Connection PDUs are being sent in the current frame.
- An "Acknowledge channel" carries acknowledgments for the UL Connection (Data) PDUs previously received.
- A "Connection channel" carries Connection (Data) PDUs destined for individual connections, as indicated in the Wakeup channel.

This order allows EP for which there is no connection data to switch off as soon as possible during the data-burst to preserve power.

L1 PDUs are typically BCH codewords of differing strength reflecting differing importance of error-free reception and the use, or not, of acknowledgement.

A-interface UL protocol implements Slotted Aloha MAC: each EP transmits its UL data and UL Acknowledge data-bursts with random (slotted) timing within the appropriate subframes. UL data and UL Acknowledge data-bursts are sent on a random frequency within the allocation.

6.1.6.3 A"-Interface (Relay Operation) timing

An EP which cannot successfully receive a base station is called an Orphan EP (OEP). An OEP may communicate with a BS via a Relay EP (RP) if the radio path permits; EP to RP communication uses the A"-interface. In normal circumstances OEP are avoided by careful deployment planning, however relay operation provides an option in exceptional circumstances. One or more OEP may be served by a RP. Enabling EP to act as RP is part of system planning and configuration activity.

The RP retransmits any required part of a DL data-burst on the A"-interface in a format similar to that of the DL. Transmissions from OEP (i.e. A" Uplink) then follow in the same A" subframe. A MAC procedure is employed in A" uplink which is described in clause 6.3.2.3. Transmissions in both directions on the A"-interface take place at the same data rate as the main downlink.

6.1.6.4 Frequency and Time Synchronization

An EP typically has a low-stability frequency reference. It establishes and maintains frequency and time synchronization by receiving and decoding transmissions from a BS.

6.2 Network Layer

The DD-UNB Layer 3 is implementation-dependent.

6.3 Data Link Layer

6.3.1 DLL introduction

The DD-UNB DLL is implementation-dependent and a range of DLL implementations can be used to take advantage of the features supported by the DD-UNB PHY, in particular the logical channels provided. However MAC sub-layer functionality is closely related to the PHY constraints of UNB (and DD-UNB specifics) and shall be implemented as described in the present document.

6.3.2 MAC sub-layer

6.3.2.1 MAC on A-interface UL - Data Subframe

6.3.2.1.1 General

The A-interface UL protocol MAC procedure is based on the "Aloha" approach randomized in both time (slotted Aloha) and frequency. The MAC procedure randomizes the timing of the transmission of data-bursts subject to avoiding unnecessary delays in sending data and subject to constraints arising from selected frame formats.

6.3.2.1.2 UL throttle

The BS shall transmit (as part of its broadcast channel, see Table 6-7) a number between 0 and 7 related to the degree of overall uplink congestion it is experiencing. This number is called "uplink throttle value". If the uplink throttle value is not zero, then independently for each current or attempted connection (i.e. each active port) an EP shall generate in each frame a random number "Rand" between 1 and 127 (inclusive) and shall only transmit, in that frame, UL data-bursts related to that port if the following condition is met:

$$Rand \geq 128 - 2^{(7-uplink\ throttle\ value)}$$

This allows the BS to influence the population of EPs transmitting, providing a measure of UL medium access control. Any data-bursts not transmitted shall be deferred to the following frame (and the same process repeated if applicable).

6.3.2.1.3 Time domain

The random selection of timing of UL transmissions is strongly influenced by current physical layer configuration (including frame format) and constraints on the handling of data-bursts to be transmitted.

A number of UL transmission time windows are available to an EP in the UL Data subframe, each is of 8 timeslots duration (starting with the first timeslot of the UL Data subframe). UL data-bursts occupy 1 or 2 such windows (see clause 6.4.3.3.3). The number of such windows available in an UL subframe is defined by the selected frame format; however in the case of a RP some of the windows may be assigned to the A" UL subframe and thus be unavailable to the A-interface UL.

UL data-bursts for transmission in a given frame shall be assigned randomly for transmission in available windows (subject also to the constraints of clause 6.4.3.3.3), the seed for the randomization shall be assigned randomly to each EP/RP. Any data-bursts which cannot be accommodated shall be deferred to the following frame.

6.3.2.1.4 Frequency domain

If an EP has one or more data-bursts to send during the UL subframe, MAC shall select, at random and independently for each data-burst, a UL sub-channel on which to transmit the data-burst (a value FMAC is provided to PHY, see clause 6.3.2.2.3); an exception is described in clause 6.4.3.3.3 for strongly-coded PDUs.

6.3.2.2 MAC on A-interface UL - Ack Subframe

6.3.2.2.1 General

The A-interface UL protocol MAC procedure is based on the "Aloha" approach randomized in both time (slotted Aloha) and frequency.

6.3.2.2.2 Time domain

The random selection of timing of UL transmissions is strongly influenced by current physical layer configuration (including frame format) and constraints on the handling of data-bursts to be transmitted.

A number of UL transmission time windows are available to an EP in the UL Ack subframe, each is of 4 timeslots duration (starting with the first timeslot of the UL Ack subframe). Each UL data-burst occupies one such window (see clause 6.4.3.3.4). The number of such windows available in an UL subframe is defined by the selected frame format.

UL data-bursts for transmission in a given frame shall be assigned randomly for transmission in available windows, the seed for the randomization shall be assigned randomly to each EP/RP. Any data-bursts which cannot be accommodated shall be deferred to the following frame.

6.3.2.2.3 Frequency domain

If an EP has one or more data-bursts to send during the UL Ack subframe, MAC shall select, at random and independently for each data-burst, a UL sub-channel on which to transmit the data-burst (a value FMAC is provided to PHY, see clause 6.3.2).

6.3.2.3 MAC on A"-interface UL

6.3.2.3.1 General

The DD-UNB A" UL supports randomization in the time domain but not the frequency domain.

In the A"-interface DL for each frame, an RP shall indicate to attached OEP (see clause 6.4.2.3) that the current A"-interface subframe is either "open" or "closed":

- In an open A"-interface subframe any attached OEP may transmit.
- In a closed A"-interface subframe the RP indicates that a particular OEP, and only that OEP, may transmit during the current subframe. Closed frames are mainly intended for the transmission of data and Ack PDUs, although Control PDUs may also be sent.
- An OEP may request a closed subframe by sending an uplink data-burst to the ROS containing only a Sync PDU (see Table 6-6).

6.3.2.3.2 Time domain

The MAC in an open A" UL subframe is based on slotted Aloha principles in the time domain.

A number of timeslots are available to an OEP in the UL A" subframe (Table 6-3). Transmission of an A" UL data-burst shall start at the beginning of a timeslot, the timeslot shall be chosen randomly from those which permit completion of the transmission of the full data-burst within the current subframe. The seed for the randomization shall be assigned randomly to each EP/RP.

6.3.3 Encryption and Authentication

DD-UNB supports UL and DL encryption of application messages on the A and A"-interfaces.

Encryption is applied between SC and EP (or OEP). Each EP shall be pre-provisioned with a pair of randomly-selected secret 256-bit keys (one for each of UL and DL), the mechanism for this is implementation-dependent; the keys shall be stored with a level of physical security and/or obfuscation appropriate to the application.

Each 14-byte application message (content field in L2 SDU) shall be encrypted before being passed to layer 1 in Connection L1 SDU (Table 6-16). The encryption algorithm used is AES 256 operating in OFB mode (Figure 6-8). Each 14-byte content field presented as a L2 SDU is first encrypted in the SC (for DL data) or the EP (for UL data); decryption is carried out at the corresponding point in the other entity. The key used is the private key stored in both SC and EP for the applicable direction. The initialization vector shall be determined when a L3 connection is established between SC and EP based on parameters related to the connection and known by both ends of the connection (e.g. connection identifiers, connection initialization parameters); choice of specific parameters will depend upon implementation-dependent upper-layer protocol elements and shall provide sufficient entropy to ensure adequate message privacy and an adequately low risk of vulnerability to replay attacks. Output Feedback Mode operation continues for the life of the connection. Note that in both encryption and decryption the block cipher is an encryption operation.

Authentication of application messages is provided by the insertion of implementation- and application-dependent known-text by the application in the originating entity and recovery of that text in the destination application.

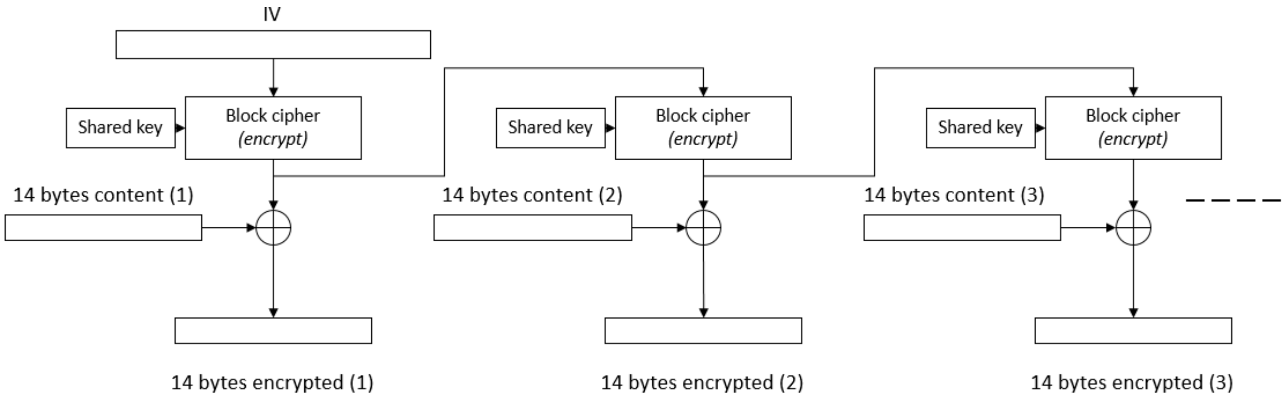

Figure 6-8: Encryption operation

6.4 Physical Layer

6.4.1 PHY Format

6.4.1.1 Timing and Frame Formats

6.4.1.1.1 Introduction

The A-interface and A"-interface PHY use Time Domain Duplex (TDD). The basic element in the time structure of the DD-UNB system is the timeslot, which has a fixed length of 0,4 seconds. A frame comprises 60 timeslots numbered from timeslot number 0. A superframe comprises 64 frames numbered from frame 0.

Each DD-UNB data-burst shall comprise a sequence of (one or more) radio-bursts in consecutive timeslots; its duration is determined by the number and length of the relevant PDUs to be transmitted.

Each radio-burst is divided into an active period (384 ms) and a guard period (16 ms), the latter is provided at the end of each timeslot and is the period during which frequency changes can take place to support optional frequency hopping as described in clause 6.5.1. Transmit power shall be reduced between radio-bursts as described in clause 6.5.3. Data is transmitted during the active part of each timeslot. When all data in a data-burst has been transmitted, transmission of the data-burst shall cease.

Each frame is divided into variable-length subframes allocated to carry specific Physical channels (see clause 6.4.1.2); the order of subframes is as shown in Table 6-1. Data-bursts shall be transmitted as determined by the MAC layer in the indicated subframe. In the DL a DD-UNB BS shall transmit no more than one data-burst in each subframe of a given frame; transmission of each DL data-burst starts in the first timeslot of the related subframe. In the UL more than one data-burst may be transmitted under the control of the MAC procedure (see clause 6.3.2.3).

If the assigned frame format means a given subframe cannot accommodate all the PDUs to be transmitted, remaining PDUs shall be transmitted in the next such subframe available (i.e. in the next frame).

Table 6-1: Subframe types

A-interface	Used for
DL subframe	DL Physical Channels
UL data subframe	Uplink Data Physical Channel (UDPCH)
UL Acknowledge subframe	Uplink Acknowledge Physical Channel (UAPCH)
A"-interface	**Used for**
A" DL subframe	Local Downlink Physical Channels
A" UL data/ack subframe	Local Uplink Physical Channels

The valid frame formats for the DD-UNB system are listed in Table 6-2 and Table 6-3. Figure 6-9 shows an example frame timing for A-interface format 0 and A"-interface format 1.

The start of the A" subframe within the frame is fixed (starting in timeslot 19) for all frame formats.

Timeslot 55 is reserved (no transmissions shall be made on any interface) in all frame formats.

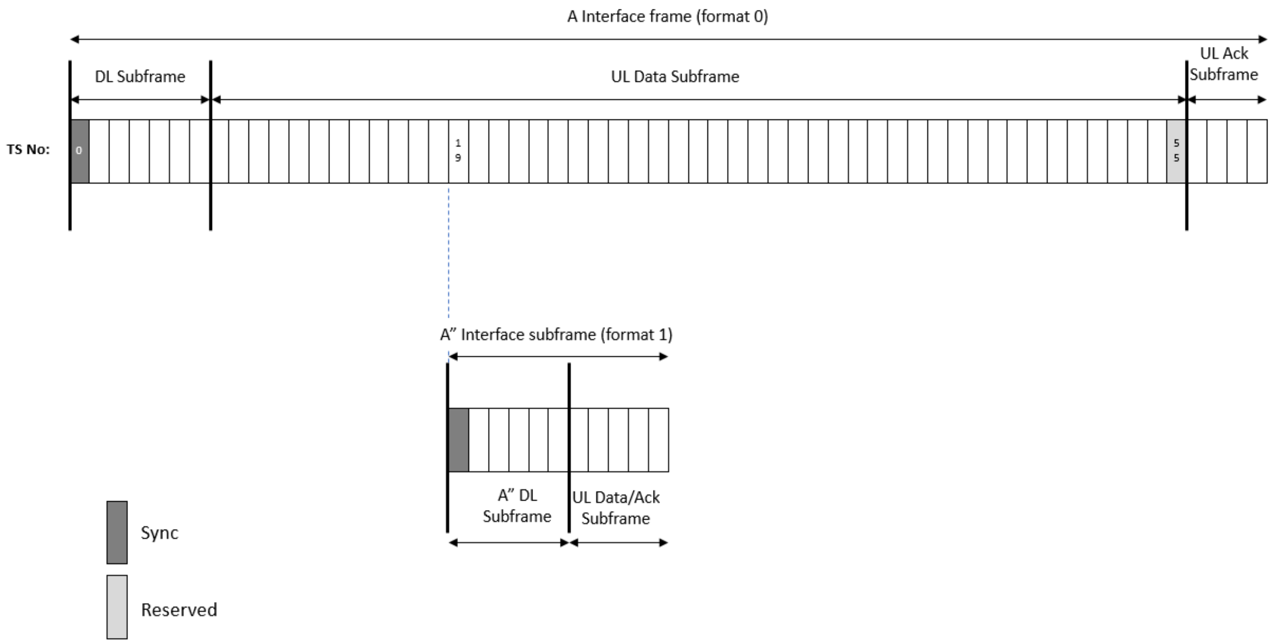

Figure 6-9: Example Frame Structure

6.4.1.1.2 A-interface Frame Formats

There are 8 frame formats defined for the A-interface of a DD-UNB system, the number of timeslots in each subframe are shown in Table 6-2; the timeslots are allocated to subframes within the frame in the order shown. The choice of A-interface frame format shall be made by the BS on a per-frame basis and should take into account the traffic expected by the BS.

The example in Figure 6-9 includes A-interface format 0.

Table 6-2: A-interface Frame Formats - No. of timeslots in each subframe

Frame Format Index	DL		Noise Measurement	UL Data	UL Ack
	Synchronization	Other DL			
0	1	6	0	48	4
1	1	10	0	40	8
2	1	14	0	40	4
3	1	18	0	32	8
4	1	6	12	32	8
5	1	10	8	32	8
6	1	14	4	32	8
7	1	17	1	32	8
8-15	Reserved				

6.4.1.1.3 A"-interface Subframe Formats

There are 5 frame formats defined for the A"-interface of a DD-UNB system, the number of timeslots in each subframe is shown in Table 6-3; timeslots are allocated to subframes within the A"-interface subframe in the order shown. The choice of A"-interface format shall be made by the RP on a per-frame basis and should take into account the traffic expected by the RP.

The example in Figure 6-9 includes A"-interface format 1.

Table 6-3: A"-interface Subframe Formats

Frame Format Index	DL		UL Data/Ack
	Synchronization	Other DL	
0	1	1	5
1	1	5	5
2	1	9	5
3	1	13	5
4	1	17	5
5-14	Reserved		

6.4.1.1.4 Synchronization and Frame Offset

BS in a DD-UNB system may be synchronized to a common timing of timeslot 0 of frame 0 (i.e. start of a superframe) with a maximum error of ±8 ms; such synchronization allows management of inter-BS interference. The method of maintaining synchronization is implementation-dependent.

As described in Table 6-2, the DD-UNB DL is active in the first part of each frame. In order to distribute DL transmissions from multiple synchronized BS more evenly in time, an optional frame offset may be applied to the timing in a specific cell: the value of offset shall be 0, 20 or 40 timeslots. The timing offset used in a cell is signalled in the Downlink Sync pre-coding block as Frame Offset.

6.4.1.1.5 Battery saving

6.4.1.1.5.1 Battery saving in DD-UNB

DD-UNB supports three classes of EP operation. Class(es) supported by a specific EP are implementation-dependent as below. In battery-save mode an EP/RP does not support air-interface activity; it shall exit battery-save mode in time to operate as described below.

Further battery-saving mechanisms are possible, including different EP to be active in different frames/superframes in Class B (to support a greater number of battery-saving EP); these mechanisms are for further study.

All battery-saving classes are applicable only after an EP has established a connection with a BS.

6.4.1.1.5.2 Class C

An EP operating in Class C listens in every frame for BS and/or RP DL transmissions. It may enter battery-save mode (i.e. stop A-interface reception) as soon as it has received any data intended for it or has received an indication that there is no such data in the current frame (clause 6.4.2.4).

A RP may also support Class C, but shall complete any activity required on the A"-interface before entering battery-save mode.

6.4.1.1.5.3 Class B

An EP/RP operating in Class B operates as specified for Class A except that the air interface is only active in frame 0 of each superframe, unless the result of activity in frame 0 indicates a requirement for ongoing activity in subsequent frame(s). As soon as such activity is completed the EP/RP may enter battery-save mode.

Management of Class B battery-saving is implementation-dependent and requires that the associated BS is aware of any EP/RP in Class B operation and schedules DL activity accordingly.

6.4.1.1.5.4 Class A

An EP in Class A operation is normally inactive on the air interface; however it may maintain an implementation-dependent level of synchronization with the DD-UNB network. If the application in the EP determines that an A-interface transmission is required the EP shall re-establish full synchronization with its associated BS and initiate UL communication in the normal way. The EP shall then continue to monitor (and respond to) the A-interface in Class C for one superframe cycle (including the frame corresponding to that in which the EP transmission was initiated) after which it may re-enter battery save mode if such ongoing activity has been completed.

Management of Class A battery-saving is implementation-dependent and requires that the associated BS and/or any application is aware of any EP/RP in Class A operation to ensure DL activity is timed accordingly.

6.4.1.2 Physical Channels

For the Downlink and A" downlink, each logical channel transferring data from higher layers corresponds to a physical channel, with three additional physical channels: the Sync Physical Channel, the Broadcast Physical Channel and the Wakeup Physical Channel.

For the Uplink, two of the logical channels (the Uplink DLL Control channel and the Uplink DLL Connection Channel) are multiplexed into one physical channel (Uplink Physical Data Channel).

DL physical channels are:

- Downlink Sync Physical Channel (DSPCH): carries Sync PDUs that are generated at BS physical layer (i.e. there is no Sync SDU required).
- Downlink Broadcast Physical Channel (DBPCH): carries Broadcast PDUs that are generated at BS physical layer (i.e. there is no Broadcast SDU required).
- Downlink Multicast Physical Channel (DMPCH): carries Multicast L1 PDUs, which BS physical layer has received via Multicast L1 SDUs, to all EP in the cell.
- Downlink Control Physical Channel (DCPCH): carries Control L1 PDUs which BS physical layer has received via Control L1 SDUs, targeted to a specific EP for a specific connection.
- Downlink Wakeup Physical Channel (DWPCH): carries Wakeup PDUs that are generated at BS L1 (i.e. there is no Wakeup SDU required) which it extracts from connection data information.
- Downlink Acknowledge Physical Channel (DAPCH): carries Acknowledge L1 PDUs which BS physical layer has received from upper layers via Acknowledge SDUs, confirming associated uplink Data PDUs sent in previous frame, were received successfully.
- Downlink Connection Physical Channel (DXPCH): carries Connection L1 PDUs which BS physical layer has received via Connection L1 SDUs, targeted to a specific EP for a specific connection, that are being transported along the established connection.

UL physical channels are:

- Uplink Data Physical Channel (UDPCH): carries data PDUs which EP physical layer has received via either Control L1 SDUs or Connection L1 SDUs.
- Uplink Acknowledge Physical Channel (UAPCH): carries Acknowledge L1 PDUs which EP physical layer has received in upper layers' Acknowledge SDUs. These confirm that associated downlink Connection PDUs sent in this frame, and destined to this EP for a specific connection, were received successfully.

A" physical channels are:

- Local Sync Physical Channel (LSPCH) which is the A" equivalent of DSPCH.
- Local Downlink Broadcast Physical Channel (LBPCH) which is the A" equivalent of DBPCH.
- Local Multicast Physical Channel (LMPCH) which is the A"-interface equivalent of DMPCH.
- Local Control Physical Channel (LCPCH) which is the A"-interface equivalent of DCPCH.

- Local Wakeup Physical Channel (LWPCH) which is the A"-interface equivalent of DWPCH.
- Local Acknowledge Physical Channel (LAPCH) which is the A"-interface equivalent of DAPCH.
- Local Connection Physical Channel (LXPCH) which is the A"-interface equivalent of DXPCH.
- Local Uplink Descriptor Physical Channel (LUDSPCH) which is the A"-interface Uplink equivalent of DSPCH and DBPCH combined.
- Local Uplink Control Physical Channel (LUCPCH) which is the A"-interface Uplink equivalent of DCPCH.
- Local Uplink Wakeup Physical Channel (LUWPCH) which is the A"-interface Uplink equivalent of DWPCH.
- Local Uplink Acknowledge Physical Channel (LUAPCH) which is the A"-interface Uplink equivalent of DAPCH.
- Local Uplink Connection Physical Channel (LUXPCH) which is the A"-interface Uplink equivalent of DXPCH.

6.4.2 L1 PDUs and SDUs

6.4.2.1 Overview

Figure 6-10 shows how information is passed to/from Physical layer (downlink example), using L1 PDUs and SDUs.

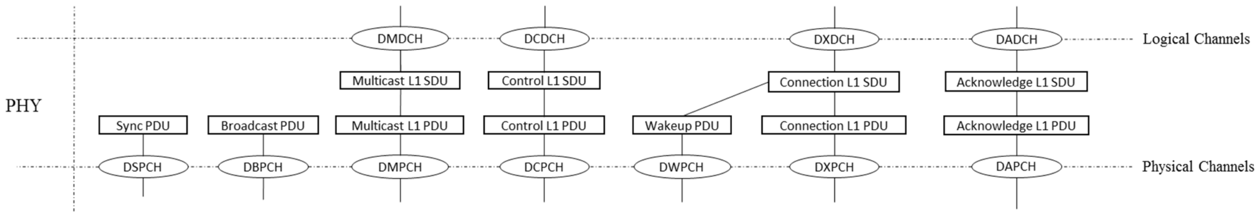

Figure 6-10: PHY PDUs and SDUs (Downlink)

L1 PDUs and SDUs shall be constructed as described below.

6.4.2.2 Sync PDU

Sync PDU is created at L1 and is formed by combining an uncoded Sync Header with a Sync Codeword (i.e. SC codeword, see Table 6-26 and Table 6-28) which is the result of BCH coding of Sync pre-coding block.

Sync Header is defined as follows:

Table 6-4: Sync Header

Type	Preamble Sequence	Sync Word
Downlink/ A" Downlink	"0101… 0101" (48 bits) followed by "1010… 1010" (16 bits)	"0xB0E2" (16 bits)
A" Uplink		"0x470D" (16 bits)
Uplink/ Uplink Ack	(0 bits)	"0xB8D0" (16 bits) When used for sending normal data/control and Ack
		"0x0B1D" (16 bits) When used for sending strongly-coded (double) data/control

For A-interface downlink and A" downlink, the Sync pre-coding block has a length of 49 bits, see Table 6-5.

Table 6-5: Downlink and A"-interface Downlink Sync pre-coding block

Field	Length (bits)	Notes
SSID	10	Short system ID
BSID	13	Base Station ID
Frame Offset	2	0x0: Frame timing in this cell synchronized with system reference time 0x1: Frame timing in this cell delayed 20 timeslots from system reference time 0x2: Frame timing in this cell delayed 40 timeslots from system reference time
DL Hopping flag	1	0x0 = single DL frequency used 0x1 = DL hopping used
Hop Phase Offset	5	If DL Hopping Flag = 0x0: Reserved (set to 0) If DL Hopping Flag = 0x1: Value to be added to index used to look up centre frequency in each timeslot
Frame Number	6	(0 - 63) frame number
Slot Number	8	Timeslot number of slot in which this PDU is transmitted
Frame Format	4	Frame format index

For A" uplink, the Sync pre-coding block is called "A" UL Descriptor" (and the codeword used is called DC, see Table 6-28). It has a length of 49 bits and contains Sync and other information describing the current A" UL data-burst, see Table 6-6.

Table 6-6: A" Uplink Sync pre-coding block (A" UL Descriptor)

Field	Length (bits)	Notes
Reserved	3	Reserved field (set to 0)
NumStrongCntlCw	2	Number of Strong Control PDUs
SSID	10	Short system ID
BSID	13	Base Station ID
ConID	14	Request closed frame for connection ID (0x0 means no request)
NumCntlCw	3	Number of Control PDUs
NumWakeupCw	2	Number of Wakeup PDUs
NumAckCw	2	Number of Ack PDUs

In A-interface Uplink, Sync PDU does not exist; the Sync header (16 bits, see Table 6-4) is transmitted at the beginning of each UL or UL Acknowledge data-burst and indicates the strength of the coding used for the rest of the data-burst. For other links, length of Sync PDU is 192 bits.

6.4.2.3 Broadcast PDU

Broadcast PDU contains information describing the structure of the DL data-burst. The Broadcast PDU has different formats for the downlink and A" downlink.

The Broadcast PDU is a broadcast codeword of length 175 bits.

For the A-interface downlink, the Broadcast pre-coding block has length 51 bits, see Table 6-7.

Table 6-7: A-interface Downlink Broadcast pre-coding block

Field	Length (bits)	Notes
Reserved	1	Reserved field (set to 0)
Multicast Repeat	1	Multicast repeat flag
NumWeakAckCw	3	Number of Weak Ack PDUs
UL frequency	6	UL_Chan_Freq (note)
Reserved	6	Reserved field (set to 0)
UL throttle	3	UL throttle value
BC BSGP	4	Broadcasted BSGP
Reserved	2	Reserved field (set to 0)
NumStrongCntlCw	5	Number of Strong Control PDUs
NumMulticastCw	4	Number of Multicast PDUs
NumCntlCw	5	Number of Control PDUs
NumWakeupCw	5	Number of Wakeup PDUs
NumAckCw	5	Number of Ack PDUs
Fast reconnect	1	0 = use normal reconnection, 1 = use fast reconnection (see "Fast Find" in clause 6.4.4.1)
NOTE: This field contains the value n which defines the UL_Chan_Freq selected for the cell, see clause 6.5.2.3.		

For A" downlink, the Broadcast pre-coding block is of length 51 bits, see Table 6-8.

Table 6-8: A" Downlink Broadcast pre-coding block

Field	Length (bits)	Notes
Reserved	8	Reserved field (set to 0)
Multicast Repeat	1	Multicast repeat flag
NumStrongCntlCw	5	Number of Strong Control PDUs
Tx Power	2	A" Transmit Power level
Reservation protocol	1	0 = do not use reservation (MAC) protocol
ConID	14	A" reserved connection ID (0x0 means not reserved i.e. "Open")
NumMulticastCw	4	Number of Multicast PDUs
NumCntlCw	5	Number of Control PDUs
NumWakeupCw	5	Number of Wakeup PDUs
NumAckCw	5	Number of Ack PDUs
Fast reconnect	1	0 = use slow reconnection, 1 = use fast reconnection (see "Fast Find" in clause 6.4.4.1)

6.4.2.4 Wakeup PDU

Each Wakeup PDU contains 2 wakeup messages. Each wakeup message is 18 bits long which is evaluated and filled at physical layer, according to what is going to be transmitted on the data channel so that relevant EP stay up and anticipate, whereas others go to sleep and save power.

Each wakeup message contains 14 bits Connection ID which is extracted from Connection L1 SDU. Wakeup PDU is a Codeword which is the result of BCH coding of wakeup pre-coding block (i.e. WU codeword in Table 6-26 and Table 6-28). Wakeup PDU is 175 bits long.

The Wakeup pre-coding block is 51 bits long, see Table 6-9.

Table 6-9: Wakeup pre-coding block

<table>
<tr><th>Field</th><th>Length (bits)</th><th colspan="3">Content</th></tr>
<tr><td>Reserved</td><td>15</td><td colspan="3">Reserved field (set to 0)</td></tr>
<tr><td rowspan="4">Wakeup message 1</td><td rowspan="4">18</td><td>Field</td><td>Length (bits)</td><td>Notes</td></tr>
<tr><td>High Interference</td><td>1</td><td>SFEC Flag
indicating strong coding is used or not</td></tr>
<tr><td>Blkcount</td><td>3</td><td>Number of Connection PDUs to be sent this frame</td></tr>
<tr><td>ConID</td><td>14</td><td>1st Connection ID</td></tr>
<tr><td rowspan="4">Wakeup message 2</td><td rowspan="4">18</td><td>Field</td><td>Length (bits)</td><td>Notes</td></tr>
<tr><td>High Interference</td><td>1</td><td>SFEC Flag
indicating strong coding is used or not</td></tr>
<tr><td>Blkcount</td><td>3</td><td>Number of Connection PDUs to be sent this frame</td></tr>
<tr><td>ConID</td><td>14</td><td>2nd Connection ID or 0x0 if no further messages indicated</td></tr>
</table>

6.4.2.5 Multicast L1 SDU and PDU

Multicast L1 SDU can have two different lengths (51 bits and 139 bits).

The Multicast Short L1 pre-coding block is identical to the Multicast Short L1 SDU and therefore is 51 bits.

The Multicast Long L1 pre-coding block is described in Table 6-10.

Table 6-10: Multicast Long L1 pre-coding block

Field	Length (bits)	Notes
Reserved	4	Reserved field (set to 0)
Content	139	Multicast Long L1 SDU

In both cases, Multicast L1 PDU is a codeword which is the result of BCH coding of that pre-coding block.

In creating Multicast L1 PDU, the BCH code used on Long pre-coding block is WMC codeword (see Table 6-26 and Table 6-28). The stronger MC codeword is used on Short pre-coding block. The resulting Multicast L1 PDU is 175 bits long in both cases.

There is a strong transmission mode for multicast messages, which is activated if the multicast repeat flag (see Table 6-7 and Table 6-8) is set to (1)). If strong transmission mode for multicast is used, once all Multicast PDUs have been transmitted (the "first set") they are transmitted again, in the same order, immediately following the first set and in the same A/A" DL data-burst. The decoding mechanism of such repeated transmissions is implementation-dependent.

6.4.2.6 Control L1 SDU and PDU

6.4.2.6.1 Overview

The Control L1 SDU is always 135 bits long with the format shown in Table 6-11.

Table 6-11: Control L1 SDU

Field	Length (bits)	Notes
SSID	10	Short System ID.
Direction	1	0 = towards Service Centre. 1 = away from Service Centre.
L2 BSID	13	If Direction = 1: L2 BSID identifies the BS sending towards destination EP, or identifies the RP sending towards destination OEP (as applicable). L2 EPID identifies the destination EP, or identifies the receiving RP which will forward the SDU to the destination OEP (as applicable). If Direction = 0: L2 BSID identifies the BS connecting the source EP to SC, or identifies the RP connecting the source OEP towards SC (as applicable). L2 EPID identifies the source EP, or the RP connecting the source OEP (as applicable).
L2 EPID	32	
L3 BSID	13	L3 BSID is typically "0" (i.e. SC). L3 EPID identifies the final source/destination EP (or OEP).
L3 EPID	32	
Control Msg Type	6	Taken from Control L2 SDU. 0 - 63 (note 1).
Port	4	Taken from Control L2 SDU.
Content	24	Control L2 SDU payload (3 bytes) (note 2).
NOTE 1: Control Msg Type is a field which may be used by higher layers to indicate the type of control message conveyed in this SDU (e.g. connect, disconnect). NOTE 2: Content is a field which may be used by higher layers to provide further data associated with the specified type of control message.		

Control L1 PDU is a codeword which is the result of BCH coding of that Control pre-coding block.

6.4.2.6.2 A-interface Downlink and A"-interface

On A-interface DL and A"-interface the pre-coding block is shown in Table 6-12.

Table 6-12: Downlink/A" Control L1 pre-coding block

Field	Length (bits)	Notes
Reserved	1	Reserved field (set to 0)
Content	135	Control L1 SDU

In this case Control L1 PDU is 168 bits if normal coding (i.e. CC codeword, see Table 6-26 and Table 6-28) is used, and 252 bits if strong coding (i.e. SCC codeword, see Table 6-26 and Table 6-28) is used.

6.4.2.6.3 A-interface Uplink

In UL there is only one physical channel (UDPCH) to carry both control and connection data, the corresponding PDU is called Data L1 PDU. For normal coding strength see Table 6-13.

Table 6-13: Uplink Data L1 pre-coding block - normal strength coding

Field	Length (bits)	Notes
Content Type	1	= 0 for Control
Content	135	Control L1 SDU

The resulting Data L1 PDU after coding is 176 bits long (i.e. CC codeword in Table 6-27).

In circumstances where Uplink faces high interference, an entity may use double codeword format Data PDUs see Table 6-14 and Table 6-15.

Table 6-14: Uplink Data L1 pre-coding block, first half

Field	Length (bits)	Notes
Flag	1	= 0 for first half
content	75	First 75 bits out of 136 from Table 6-13

Table 6-15: Uplink Data L1 pre-coding block, second half

Field	Length (bits)	Notes
Flag	1	= 1 for second half
CRC	14	CRC calculated across all data in the Control L1 SDU
content	61	Last 61 bits out of 136 from Table 6-13

The two resulting strongly coded Data L1 PDUs (176 bits each, see SCC codeword in Table 6-27) carrying a single Control L1 SDU shall be transmitted consecutively (sent as one UL data-burst, occupying 16 timeslots).

The CRC shall be the bitwise inverse of that calculated according to the following polynomial:

$$x_{14} + x_{10} + x_6 + x_1 + x_0$$

Initialization value: 0x3fff

6.4.2.7 Connection L1 SDU and PDU

6.4.2.7.1 Connection L1 SDU

Connection L1 SDU is 131 bits long as described in Table 6-16.

Table 6-16: Connection L1 SDU

Field	Length (bits)	Notes
ConID	14	Connection ID
BlkNum	5	PDU block number allocated by layer 3
Content	112	payload (14 bytes)

6.4.2.7.2 A-interface Downlink and A"-interface

PHY extracts Connection ID (14 bits) from the Connection L1 SDU and puts it in Wakeup PDU as explained in clause 6.4.2.4. The Connection L1 pre-coding block is shown in Table 6-17.

Table 6-17: A-interface Downlink/A" Connection L1 pre-coding block

Field	Length (bits)	Notes
Reserved	7	Reserved field (set to 0)
Content	117	Connection L1 SDU without its Connection ID field

PHY creates the Connection L1 PDU which is simply a codeword as the result of BCH coding of the pre-coding block.

Connection L1 PDU can be 168 bits long if normal coding (i.e. XC codeword, see Table 6-26 and Table 6-28) is used, or 252 bits long if strong coding (i.e. SXC codeword, see Table 6-26 and Table 6-28) is used. Connection L1 PDUs for the same connection in the same data-burst shall be transmitted in order and consecutively.

6.4.2.7.3 A-interface Uplink

In this case, the pre-coding block contains Connection L1 SDU (including its ConID field) plus 5 bits header added by PHY, so the pre-coding block is 136 bits.

Table 6-18: Uplink Data L1 pre-coding block - normal strength coding

Field	Length (bits)	Notes
Content Type	1	=1 for Connection (i.e. data)
XC BSGP	4	BSGP used for UL data
Content	131	Connection L1 SDU for uplink

NOTE: For details of the XC BSGP field, refer to clause 6.4.4.9.

The resulting L1 Data PDU after coding is 176 bits long (i.e. XC codeword in Table 6-27).

In a high interference situation, an entity may use double codeword format Data PDUs (e.g. SXC codeword, see Table 6-27), in the way described in clause 6.4.3.5. PHY creates two L1 Data PDUs as the result of BCH coding of the first half and second half of the pre-coding block, carrying a single Connection L1 SDU, which shall be transmitted consecutively (in one data-burst, occupying 16 timeslots).

Note that EP may transmit more than one UL data-burst in a single frame.

Data L1 PDUs for the same connection shall be transmitted in order. Received Data L1 PDUs with incorrect (out of sequence) numbers may be discarded.

6.4.2.8 Acknowledge L1 SDU

6.4.2.8.1 Ack Message Format

Acknowledge L1 SDU comprises a number of Ack messages declaring Connection PDUs that are successfully received on the opposite (Up/Down)link, plus some L1-specific control parameters.

The format of an Ack message is described in Table 6-19.

Table 6-19: Ack Message Format

Field	Length (bits)	Notes
ConID	14	Connection ID
Ack type	2	The type of acknowledge, see Table 6-20
BlkNum	5	the block number of acknowledged uplink Data PDU, interpretation depends on the Ack type

The Ack type field is defined in Table 6-20.

Table 6-20: Ack Types

Type	Value	Interpretation
L2,L3 combined	0	Combined L2 and L3 Acknowledged, hence the same block number
L2 only	1	Acknowledge at L2 only, block number is for L2
L3 only	2	Acknowledge at L3 only, block number is for L3
L3 ack confirm	3	Confirmation of L3 acknowledge, block number is for the last correctly received L3 Ack block number

6.4.2.8.2 Acknowledge on A"-interface and A-interface DL

For downlink, A" downlink and A" uplink, Acknowledge L1 SDU can have two different lengths, see Table 6-21 and Table 6-22. PHY adds some L1 control fields and creates long Ack L1 pre-coding block (143 bits) or short Ack L1 pre-coding block (51 bits), which are then coded using the WAC or AC codeword respectively. The resulting Acknowledge L1 PDU is always 175 bits long.

Long Acknowledge L1 SDU is 126 bits long, and has the format described in Table 6-21.

Table 6-21: Long Acknowledge L1 SDU (Downlink)

Field	Number of fields	Length of each field (bits)	Notes
Ack messages	6	21	6 Ack messages, see Table 6-19

Short Acknowledge L1 SDU is 42 bits long, and has the format described in Table 6-22.

Table 6-22: Short Acknowledge L1 SDU (A-interface Downlink/A")

Field	Number of fields	Length of each field (bits)	Notes
Ack messages	2	21	2 Ack messages, see Table 6-19

Long Acknowledge L1 pre-coding block is described in Table 6-23.

Table 6-23: Long Ack L1 pre-coding block (A-interface Downlink/A"-interface)

<table>
<tr><th>Field</th><th>Number of fields</th><th>Length of each field (bits)</th><th colspan="3">Content of each field</th></tr>
<tr><td>Reserved</td><td>1</td><td>5</td><td colspan="3">Reserved field (set to 0)</td></tr>
<tr><td rowspan="4">Ack messages
+
L1 Control parameters</td><td rowspan="4">6</td><td rowspan="4">23</td><td>Field</td><td>Length (bits)</td><td>Notes</td></tr>
<tr><td>One Ack message (extracted from Ack L1 SDU)</td><td>21</td><td>See Table 6-19</td></tr>
<tr><td>Too Loud
Note 1</td><td>1</td><td>UL power control flag (significant on A-interface DL only).
=1 EP should lower its transmit power.
=0 EP should increase its transmit power.
Reserved on A" (set to 0)</td></tr>
<tr><td>High Interference
Note 2</td><td>1</td><td>UL high interference flag (significant on A-interface DL only).
=1 means the EP should transmit (or continue to) in High Interference mode (i.e. using double codewords).
=0 means it should transmit in Normal mode.
Reserved on A" (set to 0)</td></tr>
<tr><td colspan="6">NOTE 1: Setting of Too Loud flag is implementation-dependent and typically reflects RSSI at BS. Power limits shall be observed.
NOTE 2: Decision to set High Interference flag is implementation-dependent.</td></tr>
</table>

Short Acknowledge L1 pre-coding block is 51 bits long, see Table 6-24.

Table 6-24: Short Ack L1 pre-coding block (Downlink/A")

<table>
<tr><th>Field</th><th>Number of fields</th><th>Length of each field (bits)</th><th colspan="3">Content of each field</th></tr>
<tr><td>Reserved</td><td>1</td><td>5</td><td colspan="3">Reserved field (set to 0)</td></tr>
<tr><td rowspan="4">Ack message
+
L1 Control parameters</td><td rowspan="4">2</td><td rowspan="4">23</td><td>Field</td><td>Length (bits)</td><td>Notes</td></tr>
<tr><td>One Ack message (extracted from Ack L1 SDU)</td><td>21</td><td rowspan="3">As indicated in Table 6-23</td></tr>
<tr><td>Too Loud</td><td>1</td></tr>
<tr><td>High Interference</td><td>1</td></tr>
</table>

6.4.2.8.3 Acknowledge on A-interface UL

For A-interface uplink, Acknowledge L1 SDU is always 21 bits long. PHY creates Uplink Ack L1 pre-coding block which is 31 bits long as Table 6-25.

Table 6-25: Uplink Ack L1 pre-coding block

Field	Length (bits)	Notes
Reserved	1	Reserved field (set to (0))
AC BSGP	4	BSGP used for UL Ack
Reserved	4	Reserved field (set to (0))
High Interference	1	DL high interference flag (significant on A-interface UL only). =1 means the BS should transmit (or continue to) in High Interference mode (i.e. using double codewords). =0 means BS should transmit in Normal mode. Reserved on A" (set to (0))
Ack message	21	See Table 6-19

The BCH code used on uplink Ack L1 pre-coding block is AC codeword which results in Acknowledge L1 PDU which is 80 bits long.

6.4.3 PHY Functions

6.4.3.1 Channel Processing

Figure 6-11 illustrates the channel processing applied in the physical layer for the A-interface Downlink transmission.

L2 PDUs are passed to the PHY through logical channels (which is then called L1 SDU). L1 SDUs are passed as described in clause 6.4.2 as pre-coding blocks to PHY channel coding function which performs BCH coding on them according to the information type, pre-coding block size and coding strength (see Figure 6-11 for downlink example).

The resulting BCH codewords are named as Sync Codeword (SC), Broadcast Codeword (BC), Multicast Codeword (MC), Weak Multicast Codeword (WMC), Control Codeword (CC), Strong Control Codeword (SCC), Wake Up (WU), Acknowledge Codeword (AC), Weak Acknowledge Codeword (WAC), Connection data Codeword (XC), and Strong Connection data Codeword (SXC). Details of each BCH codeword format is provided in clause 6.4.3.2.

PHY shall treat these BCH codewords as L1 PDUs without any modification (except Sync PDU as below) and pass them through relevant physical channels.

The Sync PDU shall be formed by concatenating the uncoded Sync header with the Sync Codeword (SC).

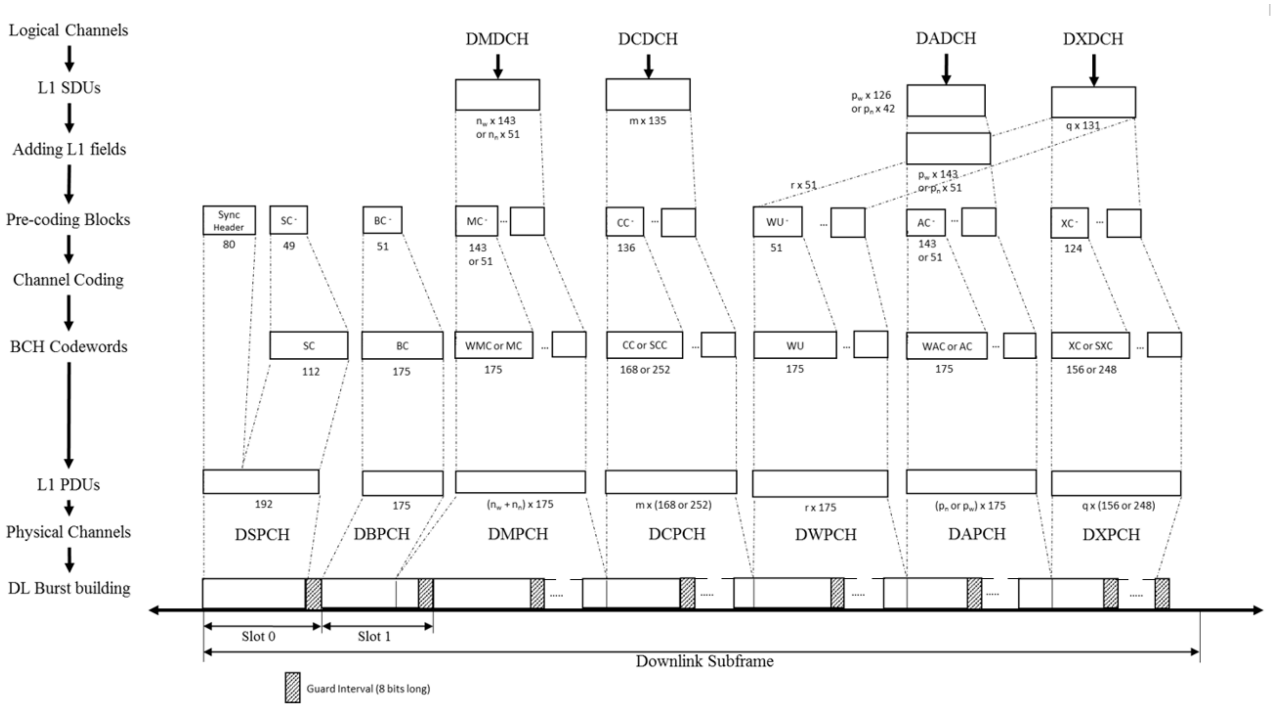

Figure 6-11: PHY Channel Processing in A-interface Downlink

Figure 6-12 illustrates the channel processing applied in the physical layer for the A-interface Uplink transmission. Selection of the slot "U" in which transmission of the burst starts is described in clause 6.4.4.6.

Normal or strong coding may be used as shown in Figure 6-12.

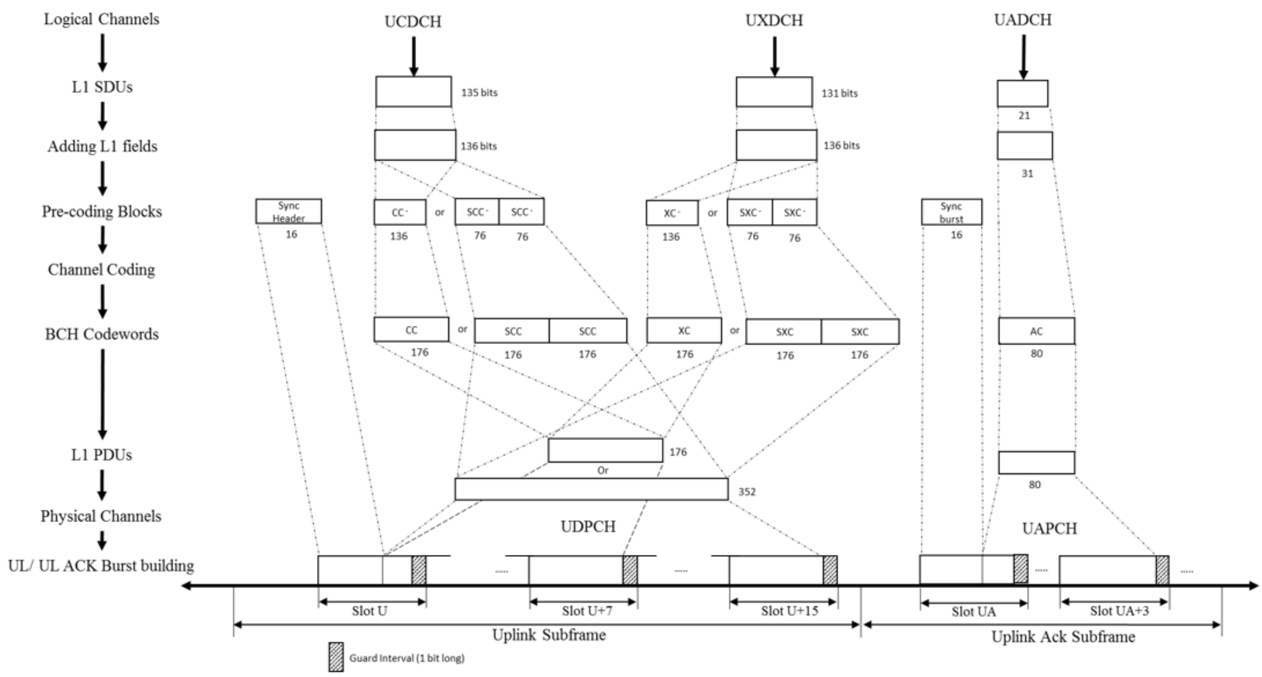

Figure 6-12: Channel processing and example scheduling in A-interface Uplink / Uplink Ack

Figure 6-13 and Figure 6-14 illustrate the channel processing applied in the physical layer for the A" Downlink and Uplink transmission respectively.

A" channel processing for both uplink and downlink is similar to that of normal downlink but with the introduction of Descriptor Codeword (DC) replacing SC and BC.

Selection of the slot "LU" or "LA" in which transmission of the A" UL data-burst starts is described in clause 6.4.4.6.

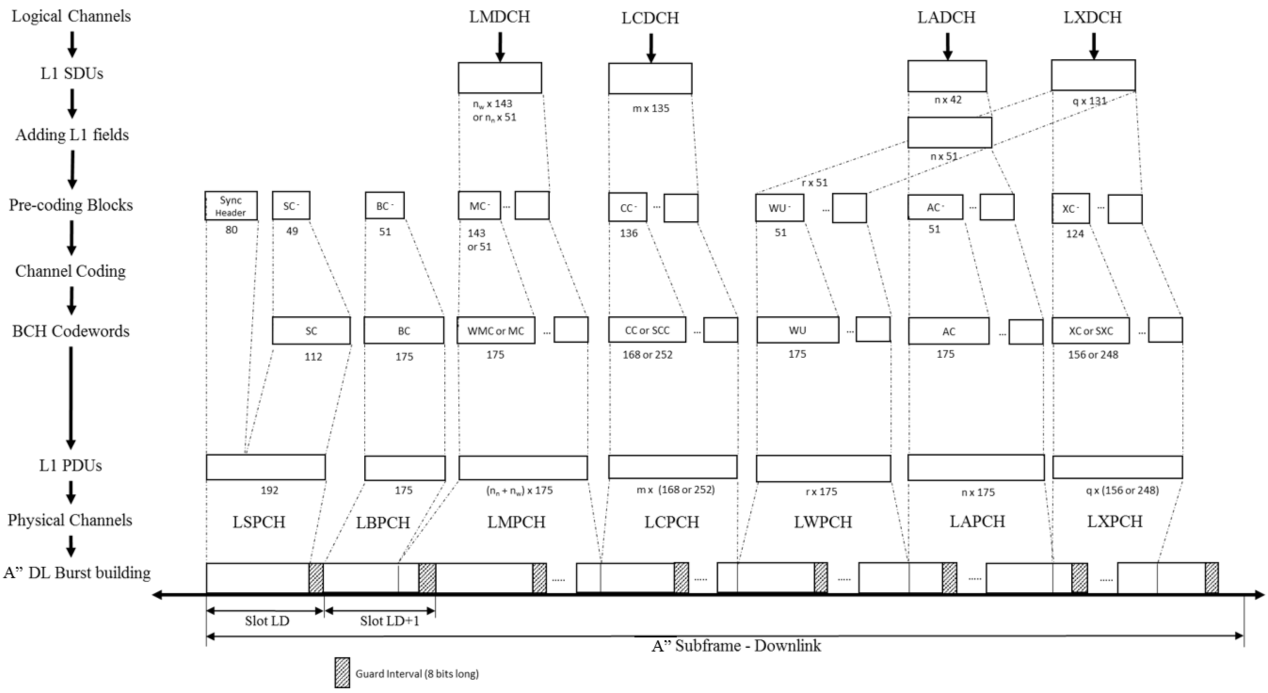

Figure 6-13: Channel processing in A" Downlink

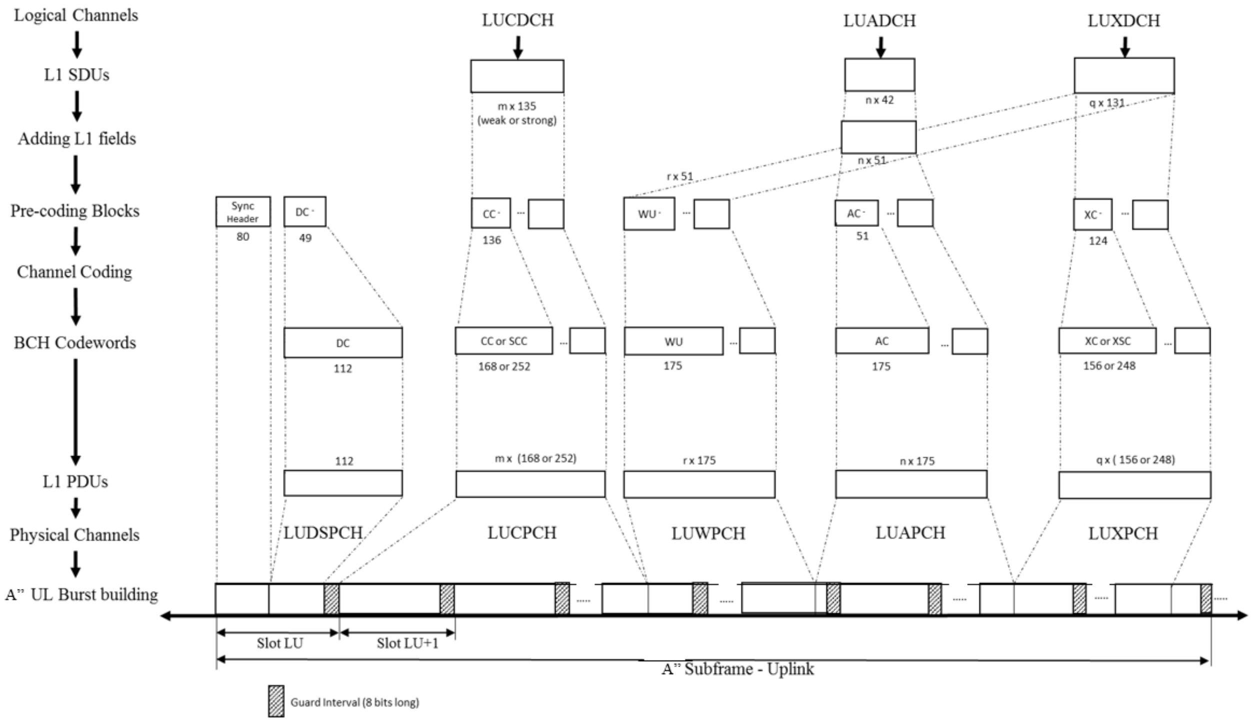

Figure 6-14: Channel processing in A" Uplink

6.4.3.2 Channel Coding

All data transmitted by either Base Station or End-point shall be encoded using shortened BCH cyclic codes as described in Table 6-26, Table 6-27 and Table 6-28.

Table 6-26: Downlink Codewords

Code Type	Base Code		Shortened Form		Properties		DL BCH Codewords
	n	k	n'	k'	rate	t (used)	
DL Strong 2	127	64	112	49	49/112	10(10)	SC
DL Strong 1	255	131	175	51	51/175	18(18)	BC MC WU AC
DL Strong 3	255	139	252	136	136/252	15(10)	SCC
DL Strong 4	255	131	248	124	124/248	18(13)	XSC
DL Weak 1	255	223	168	136	136/168	4(2)	CC
DL Weak 3	255	223	175	143	143/175	4(2)	WAC WMC
DL Weak 2	255	223	156	124	124/156	4(2)	XC

Table 6-27: Uplink Codewords

Code Type	Base Code		Shortened Form		Properties		UL BCH Codewords
	n	k	n'	k'	rate	t (used)	
UL Short	127	78	80	31	31/80	7(6)	AC
UL Long	255	215	176	136	136/176	5(3)	CC XC
DL Long Strong	255	155	176	76	76/176	13(13)	SCC SXC

Table 6-28: A" Codewords

Code Type	Base Code		Shortened Form		Properties		A" BCH Codewords
	n	k	n'	k'	rate	t (used)	
DL Strong 2	127	64	112	49	49/112	10(10)	SC DC
DL Strong 1	255	131	175	51	51/175	18(18)	BC MC WU AC
DL Strong 3	255	139	252	136	136/252	15(10)	SCC
DL Strong 4	255	131	248	124	124/248	18(13)	SXC
DL Weak 1	255	223	168	136	136/168	4(2)	CC
DL Weak 3	255	223	175	143	143/175	4(2)	WMC
DL Weak 2	255	223	156	124	124/156	4(2)	XC

6.4.3.3 Data-Burst Building

6.4.3.3.1 Introduction

In the DD-UNB system, a data-burst typically occupies multiple timeslots. Data-bursts of different types are used for A-interface (Downlink, Uplink and Uplink Ack) and A"-interface (Downlink and Uplink). The transmission of data-bursts is generally determined by application requirements and those of other protocol layers.

6.4.3.3.2 A-interface DL

Each A-interface DL data-burst shall comprise, in the order shown, a concatenation of:

- A Sync PDU (a Sync header of 80 bits followed by 112 bits SC codeword and then a guard period) which fits exactly into one timeslot (0,4 second).
- A single BC which carries the details of the sequence of codewords that follows it.
- Zero or more WMC/MC codewords.

- Zero or more CC/SCC codewords.
- Zero or more WU codewords.
- Zero or more WAC/AC codewords.
- Zero or more XC/SXC codewords, in the order indicated by the contents of WU PDU transmitted in the current frame.
- The content of the data-burst shall be consistent with the DL subframe duration as indicated by the current frame format.
- A BS shall transmit a single such data-burst in each frame, see Figure 6-11.

6.4.3.3.3 A-interface UL Data

Each A-interface UL Data data-burst shall comprise a Sync header of 16 bits (see Table 6-4) followed by a CC/XC codeword (176 bits) or a double SCC/XCC codeword (352 bits), occupying 8 or 16 timeslots. A resulting 16-slot data-burst shall be divided into a first and second sequential (but not necessarily contiguous) 8-slot data-bursts for separate scheduling by MAC for the purpose of fitting it into timeslots available (given the constraints of the current frame and subframe formats).

Zero or more UL Data data-bursts may be transmitted by an EP/RP in each UL subframe, see Figure 6-12, subject to frame and subframe format constraints.

6.4.3.3.4 A-interface UL Ack

Each A-interface Uplink Ack data-burst shall comprise a Sync header of 16 bits (see Table 6-4) followed by a single AC codeword (80 bits), occupying 4 timeslots.

Zero or more UL Ack data-bursts may be transmitted by an EP/RP in each UL subframe, see Figure 6-12, subject to frame and subframe format constraints. Timing is determined by MAC.

6.4.3.3.5 A"-interface DL

Each A"-interface DL data-burst shall comprise, in the order shown, a concatenation of:

- A Sync PDU (a Sync header of 80 bits followed by 112 bits SC codeword and then a guard period) which fits exactly into one timeslot (0,4 second).
- A single BC which carries the details of the sequence of codewords that follows it.
- Zero or more WMC/MC codewords.
- Zero or more CC/SCC codewords.
- Zero or more WU codewords.
- Zero or more WAC/AC codewords.
- Zero or more XC/SXC codewords, in the order indicated by the contents of WU PDU transmitted in the current frame.
- The content of the data-burst shall be consistent with the current A"-interface subframe format.
- A RP shall transmit a single such data-burst in each A"-interface DL subframe, see Figure 6-13.

6.4.3.3.6 A"-interface UL Data data-burst

Each A"-interface UL data-burst shall comprise, in the order shown, a concatenation of:

- A Sync PDU (a Sync header of 80 bits followed by 112 bits DC codeword and then a guard period) which fits exactly into one timeslot (0,4 second).

- Zero or more CC/SCC codewords.
- Zero or more WU codewords.
- Zero or more WAC/AC codewords.
- Zero or more XC/SXC codewords, in the order indicated by the contents of WU PDU transmitted in the current frame.
- The content of the data-burst shall be consistent with the current A"-interface subframe format.

An OEP shall transmit no more than one such data-burst in each A"-interface UL subframe, see Figure 6-14, subject to frame and subframe format constraints.

In a closed A" UL subframe, transmission starts in the first available timeslot.

In an open A" UL subframe, timing is determined by MAC.

6.4.3.3.7 A"-interface UL Ack data-burst

A"-interface Uplink Ack data-burst shall always start with a specific Sync header of 16 bits (as in Table 6-4). The remainder of the data-burst consists of a single AC codeword (80 bits).

A RP shall transmit no more than one such data-burst in each A"-interface UL subframe, subject to frame and subframe format constraints.

In a closed A" UL subframe, transmission shall start in the first available timeslot.

In an open A" UL subframe, timing is determined by MAC.

6.4.3.3.8 Bit order

Each pre-coding block shall be packed with the last entry in its pre-coding block table in the least significant location of the PDU (without changing bit order) and then each preceding entry shall be added in more significant locations (in the same bit order). The packed and coded PDU is transmitted least significant bit, of least significant byte, first.

Figure 6-15 is an example for the Sync PDU (clause 6.4.2.2).

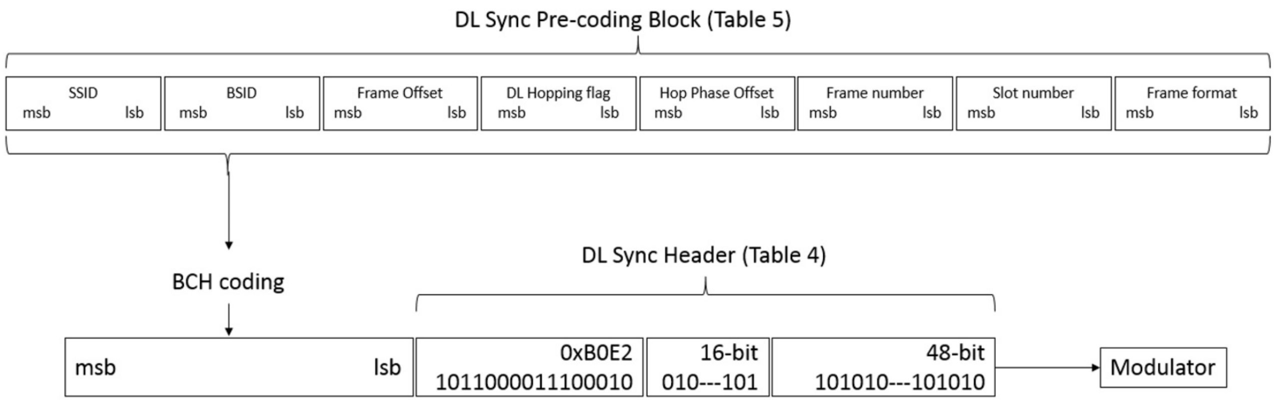

Figure 6-15: Example bit order - Sync PDU

6.4.3.4 Power Control

Power control is used in A-interface Uplink transmission by EP. Provision is made in PHY to control transmit power level using "Too Loud" flag. When the received RSSI at the BS is higher than an implementation-dependent defined threshold, BS may indicate "Too Loud" (see Table 6-23) in which case the EP shall reduce its transmit power by 2 dB from its current level when it next transmits. If "Too Loud" is not indicated, the EP shall increase its transmit power by 2 dB from its current level when it next transmits (up to its maximum level).

If the EP is in high interference mode (and is therefore sending double codeword format Data PDUs) (see clause 6.4.2.6), it shall ignore the "Too Loud" flag and set the transmit power level to its maximum level.

6.4.3.5 High Interference Mode

As described in the present document, strong and weak coding is available for a range of PDUs. The choice of coding scheme shall be made by the related entity and shall be signalled as described (e.g. Table 6-9). Choice of algorithm by which to determine whether to use High Interference Mode is implementation dependent, however specified control mechanisms shall be supported (see Table 6-23, Table 6-24, Table 6-25 and clause 6.4.3.4).

6.4.4 PHY Procedures

6.4.4.1 Synchronization and Frequency Scanning

Layer 1 supports frequency scanning and synchronization processes to detect available BS and RP. This process is implementation-dependent.

6.4.4.2 Base Selection

The process by which an EP selects a BS / RP with which to attempt connection is implementation-dependent.

6.4.4.3 Transmit Duty-Cycle Control

DD-UNB implementations are typically subject to regulatory limits on transmitter duty cycle. It is an implementation issue to ensure such limits are not exceeded.

6.4.4.4 A-interface Downlink Transmission Control - Frame Structure

Before the start of each frame, BS shall determine the frame format to use for that frame as described in clause 6.4.1.1. This process is implementation-dependent. Transmission of DL data-bursts shall commence in the first timeslot allocated to the related subframe, see Table 6-1.

6.4.4.5 A"-interface Downlink Transmission Control - Subframe Structure

Before the start of each A"-interface subframe, RP shall determine the format to use for that subframe as described in clause 6.4.1.1. This process is implementation-dependent.

6.4.4.6 Uplink Transmission Control

BS transmissions are the reference for both the time and the frequency of EP and RP transmissions. No allowance for propagation delays is required in the timing of uplink transmissions.

6.4.4.7 PHY Measurements

PHY measurements are implementation-dependent and may include:

- the average power (RSSI) of the Sync Word in a data-burst;
- the number of corrected bits in each received codeword; or
- other measurements.

Such measurements may be used to support "too loud" indication (clause 6.4.3.4).

6.4.4.8 Noise Measurement

Some A-interface frame formats allocate "noise measurement" timeslots during which no system elements transmit. These may be used to measure noise and/or interference levels; such measurements, and the use of the results, are implementation-dependent.

6.4.4.9 Base-System Group (BSGP)

To enable the BS to distinguish reception of a local EP's (intended) transmissions from distant EP's (unintended) transmissions (in the case that block numbers coincide), "Uplink Connection Base-System Group" (XC BSGP) is included in each Data L1 PDU on the A-interface UL, see Table 6-18.

XC BSGP (see Table 6-18) has the same value as BC BSGP (see Table 6-7) which is broadcast in every frame. Received Uplink Data PDUs at the BS side with incorrect XC BSGP shall be ignored.

Similarly, AC BSGP (see Table 6-25) is used to prevent the same problem happening for Uplink Acknowledgements. AC BSGP has the same value as BC BSGP which is broadcast in every frame. Received Uplink Ack PDUs at the BS side with incorrect AC BSGP shall be ignored.

6.5 Radio characteristics

6.5.1 Frequency Structure - Radio Mode 0

Clause 6.5.1 and any subclauses describe DD-UNB operation in Radio Mode 0; other modes are for further study.

Table 6-29: Radio Mode definition

Radio Mode	Downlink / A"			Uplink		
	Bit-rate (bps)	Symbol-rate (Hz)	Deviation Δf (Hz)	Bit-rate (bps)	Symbol-rate (Hz)	Deviation Δf (Hz)
0	500	500	±250	62,5	62,5	±250
Other	Reserved					

Frequency domain separation of uplink and downlink transmissions may be used for network planning purposes and/or to reflect regulatory constraints, but this is not essential to achieve full-duplex operation.

The operating frequency band(s) to be used for DL and UL, and whether to use frequency hopping for the DL and A"-interface, are selected when a system is planned and shall be known to all entities; the selection is applicable to both A and A"-interfaces. The spectrum used for each interface in a given direction shall be contiguous. In a non-hopping system each cell operates on one of N planned DL and UL channels (UL/DL_Chan_Freq(n), n $\in$ {0, … , N-1}; the spacing of the centre frequencies of these channels within the respective operating band is 15 kHz in the UL and 25 kHz in the DL (Figure 6-16).

If DL hopping, the frequencies in the hop set (selected within the DL band as described above for a non-hopping system) shall be arranged in pseudorandom order in a Frequency Hopping Sequence, each element of which defines a DL centre frequency. The Physical Layer maintains a Frequency Hopping Index that shall be initialized (see below) for timeslot 0 of each frame and incremented for each subsequent timeslot within the frame, modulo the size of the table, and used to look up the DL frequency to be used in the timeslot. The initial value in each frame shall be determined by the Hop Phase Offset selected when a system is planned and allows nearby cells to reduce or avoid the simultaneous use of the same DL frequency by the use of different Hop Phase Offset values. The Hop Phase Offset shall be signalled in the DL Sync PDU to enable an EP to ascertain system time (see Table 6-5).

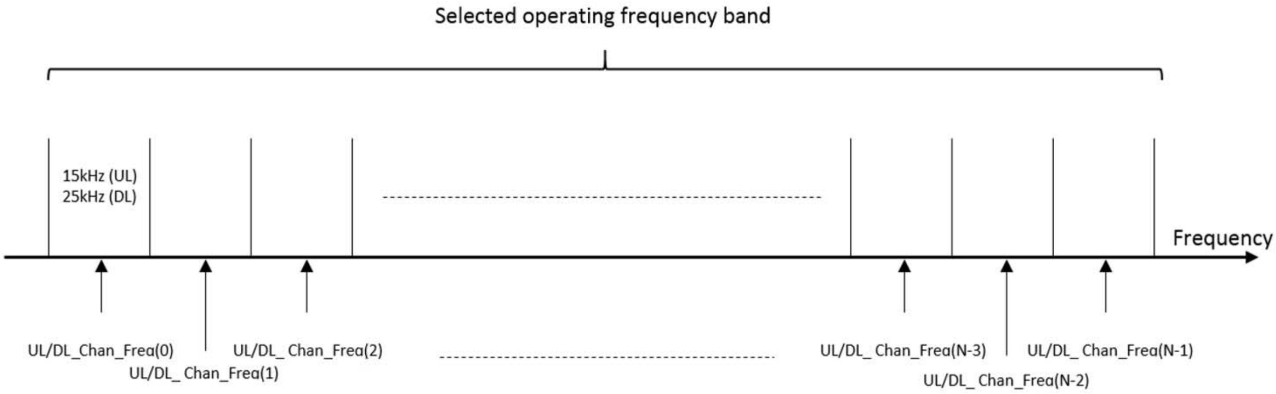

Figure 6-16: Channel numbering

6.5.2 Modulation - Radio Mode 0

6.5.2.1 General

Clause 6.5.2 and subclauses describe DD-UNB operation in Radio Mode 0; other modes are for further study and may, for example, include the generation of more than one modulated carrier within the identified channel on one or more interfaces or alternative modulation schemes.

The DD-UNB modulation uses Binary Frequency Shift Keying (BFSK) for UL on A"-interface and for DL on both A-interface and A"-interface. It uses a combination of BFSK and Random Frequency Selection (RFS) for UL on A-interface. Use of Continuous Phase FSK is mandatory for the base station but optional for the End-point. BS transmit frequencies are determined in network planning.

In Radio Mode 0, in all interfaces, the information bits are represented by two tones offset in frequency by Δf = 250 Hz from a selected carrier frequency. A "1" corresponds to transmission of the higher frequency tone (f_h).

6.5.2.2 A-interface DL and A"-interface (UL and DL) modulation

Within the selected 25 kHz channel a number of nominal carrier frequencies spaced at 500 Hz intervals are identified (as FDM_f_c(n)) as depicted in Figure 6-17. For Radio Mode 0 A-interface DL a modulated carrier is generated at FDM_f_c(10) or FDM_f_c(40); the choice between these values of FDM_f_c is made in network planning.

For A"-interface (UL and DL) FDM_f_c(25) is used.

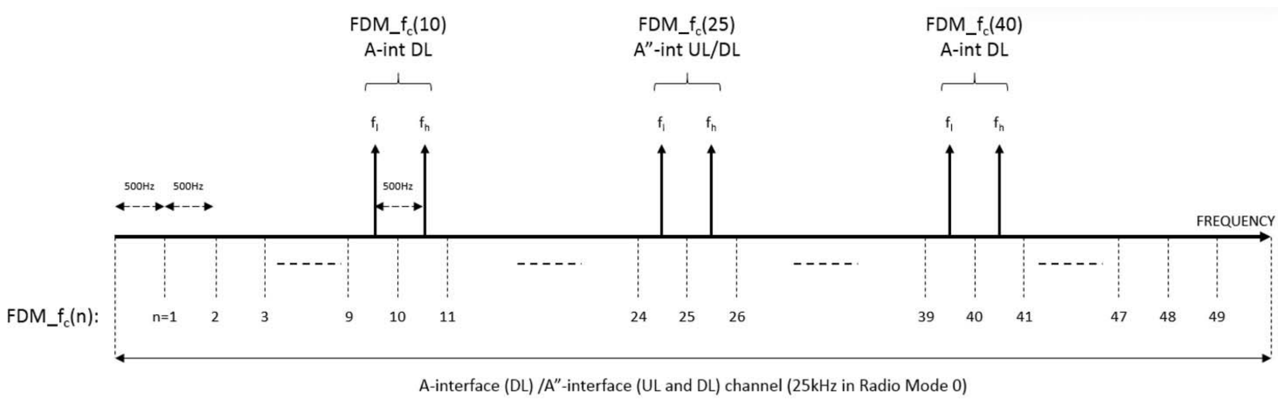

Figure 6-17: A-interface (DL) and A"-interface (UL and DL) frequencies

In Radio Mode 0 a DL (A and A") receiver shall receive any signal or signals within the selected 25 kHz channel. Such a receiver typically employs digital techniques to filter and demodulate those signals.

6.5.2.3 A-interface UL modulation

Uplink modulation is implemented based on a combination of BFSK and Random Frequency Selection (RFS).

In Radio Mode 0 the UL operating channel width is 15 kHz. Each EP/RP shall perform RFS independently for each data-burst (except as described in clause 6.4.3.3.3 for strongly-coded PDUs where each pair of data-bursts shall be transmitted on the same frequency) and shall choose its BFSK centre frequency (RFS_f_c) within the UL channel (see Figure 6-18) as determined by MAC, such that:

$$RFS\_f_c = UL\_Chan\_Freq - (RFS\_range / 2) + (F_{MAC} \times F_{gran})$$

and where:

- UL_Chan_Freq is the centre frequency of the UL channel (see Table 6-7).
- RFS_range is the difference between the lowest and highest permitted values of RFS_f_c (14 kHz for Radio Mode 0).
- F_{MAC} is an integer value generated by MAC (value from 0 to (RFS_range/ F_{gran})).
- F_{gran} is the granularity of RFS selection (implementation dependent).

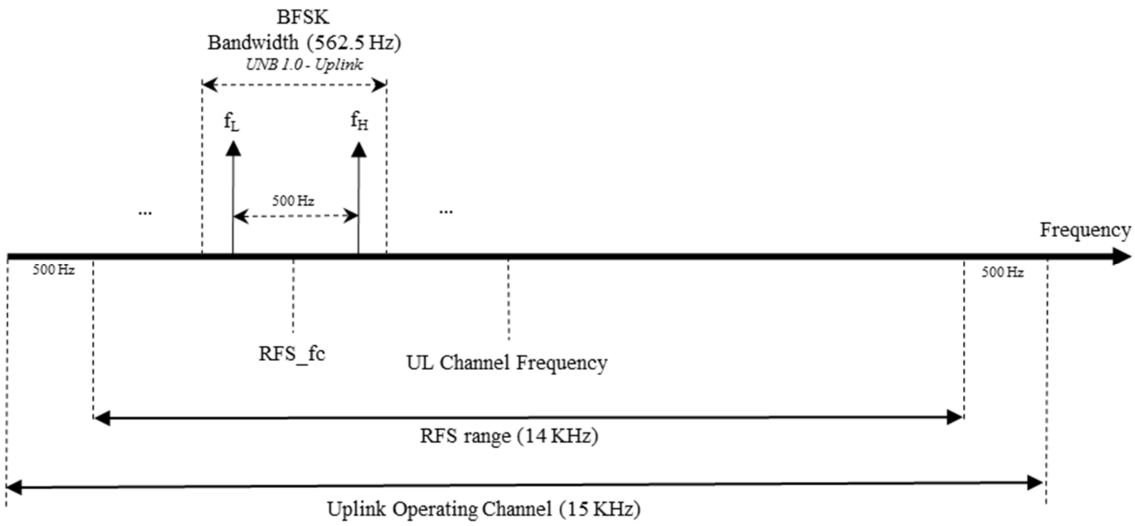

Figure 6-18: A-interface UL modulation

6.5.3 Radio-Burst Power Ramping

A guard period of 16 ms is provided for power-ramping and optional frequency hopping between radio-bursts; when transmitting, transmit power shall be reduced during the guard period in all entities (whether or not frequency-hopping). Transmit power shall rise or fall by ≥60 dB within 500 µs of the start or end (respectively) of the radio-burst, any frequency changes shall take place when the power is at that reduced level. The power shall be within ±1 dB of the average radio-burst transmit power for the active part of the radio-burst (see Figure 6-19). Any emissions arising from such ramping and frequency changes shall be within regulatory limits.

During the guard period a sequence of alternating "1"s and "0"s at the bit rate, beginning with a "1", is inserted in the modulation bit-stream.

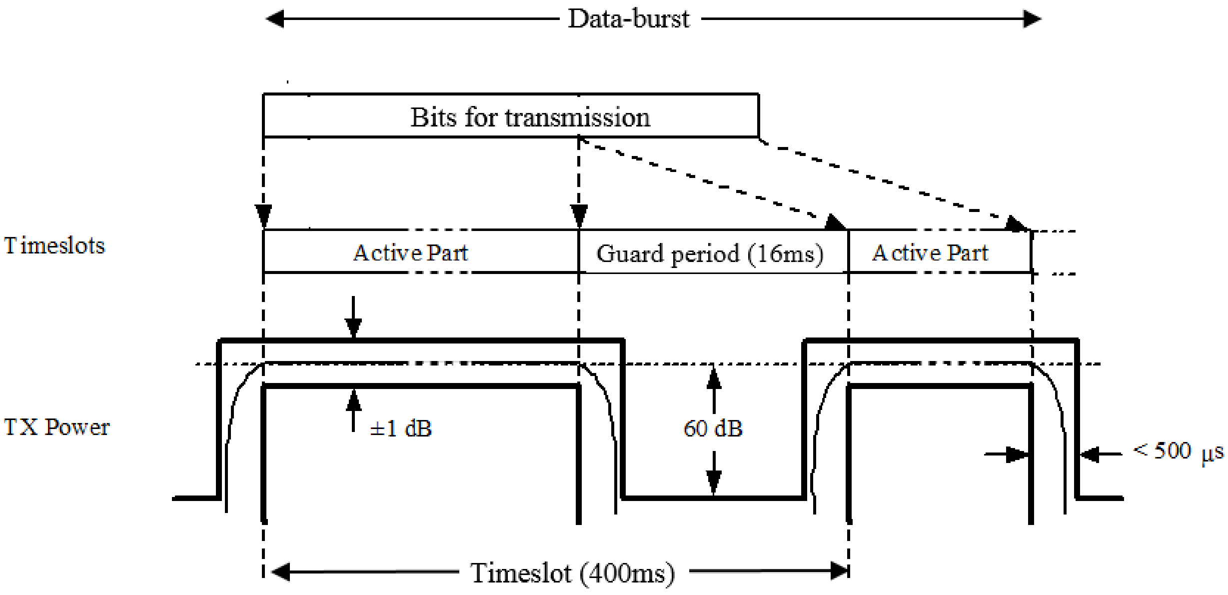

Figure 6-19: Power Ramping and Frequency Switching

Annex A (informative): Generic end-point system block diagram

A.1 Overview

The BS and the RP are network elements that are specific to each family.

To maximize the economy of scale, this clause proposes an example of a generic EP transceiver implementation that supports all LTN families.

Figure A-1 shows an example implementation of an EP.

The EP can be designed with sensors and/or control/data ports for external sensors.

The EP can be designed with or without a host CPU - for instance, the microcontroller embedded in the transceiver may have sufficient functionality and performance to undertake the role of host CPU for some applications.

The EP can additionally have a Secure Element (SE) to hold secret data for payload encryption for example. While it is possible to embed the SE into the transceiver IC, an external SE is likely to provide more flexibility and potentially offers a more future-proof design.

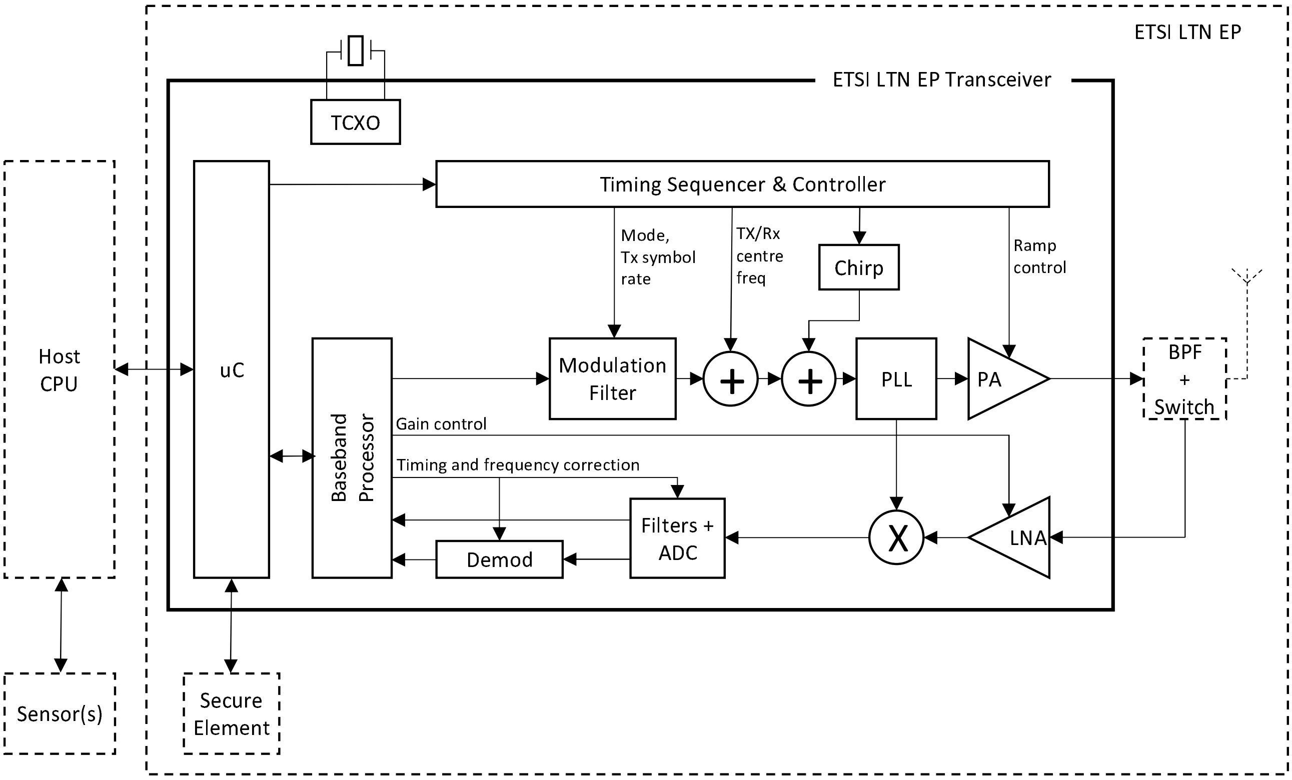

Figure A-1: System overview of EP

The following clauses provide some implementation detail about some of the key blocks within the EP transceiver.

A.2 µC

A microcontroller that is optimized for small size and low-power consumption while being able to handle functions such as; manipulation of payload data, communication with the SE and the set up the Timing Sequencer & Controller.

A.3 Baseband Processor

The uplink functions are; CRC calculation, FEC, Interleaving, Encryption.

The downlink functions are; Decryption, de-interleaving, error correction (convolutional, LDPC), CRC check.

A hardware DSP function is likely to provide the optimal trade-off of size, power consumption and cost.

A.4 TCXO

It is possible to use a 26 MHz reference clock for all families. However, with detailed analysis, a more suitable clock frequency may be found that will ease the design of the sequencers, state machines, modulator and demodulator.

The TCXO is likely to be a function integrated into the transceiver IC.

A.5 Timing Sequencer and Controller

This block is likely to be a collection of Finite State Machines and sequencers implemented in hardware. The configuration will be undertaken by software running on the microcontroller. Functions will include; set modulation/demodulation mode, set the Tx and Rx symbol rate, set the Tx and Rx centre frequency, chirp control and PA ramp control.

A.6 Modulation Filter

Modulation function is provided by a configurable filter supporting the following modulations; BPSK, Pi/2 BPSK, BFSK and GMSK.

A.7 PLL

A fractional-N type PLL with performance to meet the local RF requirements is used.

A single PLL design is shown in Figure A-1, however a dual-PLL design (one for Tx and one for Rx) may offer performance advantages.

A.8 Power Amplifier

A suitable Power Amplifier (PA) is provided for the desired frequency band of operation and the regulations that are in force locally.

A.9 Demodulator

The demodulator could be implemented using a matched filter.

A.10 Summary

An implementation example has been shown for a generic EP transceiver that can support all three families that make up LTN. Based on knowledge of the requirements of the families and the use-cases for LTN, some high-level guidance has been included for some of the blocks to aid the design trade-offs, particularly between performance and cost. Other approaches can be followed in implementing each of these functional blocks.

Annex B (informative): Change history

Date	Version	Information about changes
06/2018	1.1.1	Publication
06/2024	2.1.1	Publication as new part 1

History

Document history		
V1.1.1	June 2018	Publication as ETSI TS 103 357
V2.1.1	June 2024	Publication