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Contents

Foreword

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In the present document, modal verbs have the following meanings:

shall indicates a mandatory requirement to do something

shall not indicates an interdiction (prohibition) to do something

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should indicates a recommendation to do something

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may indicates permission to do something

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The construction "may not" is ambiguous and is not used in normative elements. The unambiguous constructions "might not" or "shall not" are used instead, depending upon the meaning intended.

can indicates that something is possible

cannot indicates that something is impossible

The constructions "can" and "cannot" are not substitutes for "may" and "need not".

will indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

will not indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

might indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

might not indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

is (or any other verb in the indicative mood) indicates a statement of fact

is not (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

1 Scope

This document specifies the physical layer of Ambient IoT.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP TS 38.211: "NR; Physical channels and modulation".

[3] 3GPP TS 38.391: "Ambient IoT Medium Access Control (MAC) protocol".

[4] 3GPP TS 38.194: "Ambient IoT Base Station (BS) and Carrier-Wave (CW) node radio transmission and reception".

[5] 3GPP TS 38.191: "Ambient IoT device radio transmission and reception".

3 Definitions of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the terms given in TR 21.905 [1] apply. A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [1].

3.2 Symbols

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

Δf	Subcarrier spacing in R2D
I_{bit}	Interval for insertion of a D2R midamble
k_{RE}	Index of a subcarrier relative to a reference in R2D
l_{amble}	Length of a D2R amble sequence
l_{RE}	OFDM symbol index relative to a reference in R2D
M_{chip}	Number of chips to transmit
$M_{\mathrm{chip}}^{\mathrm{symb}}$	Number of chips per OFDM symbol for the R-TAS CAP, PRDCH, R2D postamble and padding
N_{CAP}	Number of bits in the R-TAS CAP
$N_{\mathrm{CP},l_{\mathrm{RE}}}$	Cyclic prefix length in R2D
N_{pad}	Number of padding chips
$N_{\mathrm{RB}}^{\mathrm{min}}$	Minimum number of physical resource blocks to be used in R2D
$N_{\mathrm{RB}}^{\mathrm{R2D}}$	Number of physical resource blocks used in R2D
N_{SFS}	Number of potential small frequency shifts
N_{SIP}	Number of bits in the R-TAS SIP
$N_{\mathrm{sc}}^{\mathrm{RB}}$	Number of subcarriers per resource block in R2D
$N_{\mathrm{TBS}}^{\mathrm{D2R}}$	Size of a D2R transport block

$N_{\mathrm{TBS}}^{\mathrm{R2D}}$	Size of an R2D transport block
n_{PRB}	Physical resource block number in R2D
R_{block}	Block repetition number
R_{SFS}	Small frequency shift factor
$T_{\mathrm{bit}}^{\mathrm{D2R}}$	Duration of a D2R bit for transmission
T_c	Basic time unit for R2D
$T_{\mathrm{chip}}^{\mathrm{D2R}}$	Duration of a D2R chip
$T_{\mathrm{chip}}^{\mathrm{R2D}}$	Duration of a chip for the R-TAS CAP, PRDCH, R2D postamble and padding
$T_{\mathrm{D\to R}}^{\mathrm{min}}$	Minimum timing relationship from D2R to R2D
$T_{\mathrm{R\to D}}$	Timing relationship from R2D to D2R
χ	Chip index relative to a reference
$z_{k_{\mathrm{RE}},l_{\mathrm{RE}}}$	Value of resource element $(k_{\mathrm{RE}}, l_{\mathrm{RE}})$ in R2D
z_χ	Value of chip χ in D2R

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

A-IoT	Ambient IoT
CAP	Clock acquisition part of R-TAS
CRC	Cyclic redundancy check
D2R	Device to reader
DFT-s-OFDM	DFT spread OFDM
IoT	Internet of Things
PDRCH	Physical device-to-reader channel
PRDCH	Physical reader-to-device channel
R-TAS	R2D timing acquisition signal
R2D	Reader to device
SIP	Start indicator part of R-TAS

4 Time and frequency domain structures

4.1 Chips

From the device perspective, a transmission in D2R or a reception in R2D in the time domain consists of M_{chip}^{q} consecutive chips each uniquely identified by the index $\chi^q = 0, 1, \ldots, M_{\mathrm{chip}}^{q} - 1$. χ refers to the chip position in the time domain relative to some reference point. The superscript q is set to $\mathrm{D2R}$ or $\mathrm{R2D}$ respectively, and may be omitted where there is no risk of confusion.

4.2 D2R

D2R transmissions are organised into consecutive chips each of duration $T_{\mathrm{chip}}^{\mathrm{D2R}}$.

D2R chip χ corresponds to the value z_χ.

The constant $\tau = 2 \times 10^6/15000$.

4.3 R2D

4.3.1 General

The size of various fields in the time domain for R2D is expressed in time units $T_c = 1/(480 \times 10^3 \times 4096)$ seconds. The constant $\kappa = 64$.

4.3.2 Time domain

R2D transmissions are organised into OFDM symbols.

There are $M_{\text{chip}}^{\text{symb}}$ consecutive chips each of duration $T_{\text{chip}}^{\text{R2D}} = \frac{1}{\text{M}_{\text{chip}}^{\text{symb}}\Delta f}$ seconds during each OFDM symbol for the R-TAS CAP, PRDCH, the R2D postamble and padding if needed.

There are 4 consecutive chips each of duration $\frac{1}{4\Delta f}$ seconds during each OFDM symbol for the R-TAS SIP.

4.3.3 Physical resources

4.3.3.1 Resource grid

The transmitted signal in each OFDM symbol is described by a resource grid of $N_{\text{RB}}^{\text{R2D}} N_{\text{sc}}^{\text{RB}}$ subcarriers. The frequency location of a subcarrier refers to the centre frequency of that subcarrier.

The subcarrier spacing $\Delta f = 15 \times 10^3$ Hz.

4.3.3.2 Resource elements

Each element in the resource grid is called a resource element and is uniquely identified by the index pair $(k_{\text{RE}}, l_{\text{RE}})$, where $k_{\text{RE}} = 0, 1, \ldots, N_{\text{RB}}^{\text{R2D}} N_{\text{sc}}^{\text{RB}} - 1$ is the index in the frequency domain and $l_{\text{RE}} = 0$ and up refers to the symbol position in the time domain relative to some reference point.

Resource element $(k_{\text{RE}}, l_{\text{RE}})$ corresponds to the value $z_{k_{\text{RE}}, l_{\text{RE}}}$.

For in-band deployment, the starting position of OFDM symbol $l_{\text{RE}} = 0$ is aligned in time with the starting position of an NR OFDM symbol as specified in clause 5.3.1 of TS 38.211 [2].

4.3.3.3 Physical resource blocks

A physical resource block is defined as $N_{\text{sc}}^{\text{RB}} = 12$ consecutive subcarriers in the frequency domain. Physical resource blocks are numbered from 0 to $N_{\text{RB}}^{\text{R2D}} - 1$. The relation between the physical resource block n_{PRB} and subcarrier k_{RE} is:

$$n_{\text{PRB}} = \left\lfloor \frac{k_{\text{RE}}}{N_{\text{sc}}^{\text{RB}}} \right\rfloor.$$

$N_{\text{RB}}^{\text{R2D}} \geq N_{\text{RB}}^{\min}$, where $N_{\text{RB}}^{\min} = 1$ for R-TAS SIP, and as shown in Table 4.3.3.3-1 for PRDCH, R-TAS CAP, R2D postamble and padding transmissions.

Table 4.3.3.3-1: Minimum number of PRBs for PRDCH, R-TAS CAP, R2D postamble and padding transmissions

Number of chips per OFDM symbol $\left(M_{\text{chip}}^{\text{symb}}\right)$	$N_{\text{RB}}^{\min}$
2	1
6	1
12	2
24	3

5 Mapping to physical channels

Table 5-1 specifies the mapping of the D2R and R2D transport channels to their corresponding physical channels.

Table 5-1

TrCH	Physical Channel
D2R-TrCH	PDRCH
R2D-TrCH	PRDCH

6 Physical channels and signals generation

Transport blocks from/to the MAC layer are encoded/decoded to offer transport and control services over the radio transmission link.

6.1 D2R

6.1.1 Overview

A D2R channel corresponds to a set of chips carrying information originating from higher layers. A D2R signal is used by the physical layer, but does not carry information originating from higher layers. The following D2R physical channel and signals are defined:

- Physical device-to-reader channel, PDRCH
- D2R-amble signals consisting of the D2R preamble and D2R midamble

D2R generation has the steps shown in the following figure.

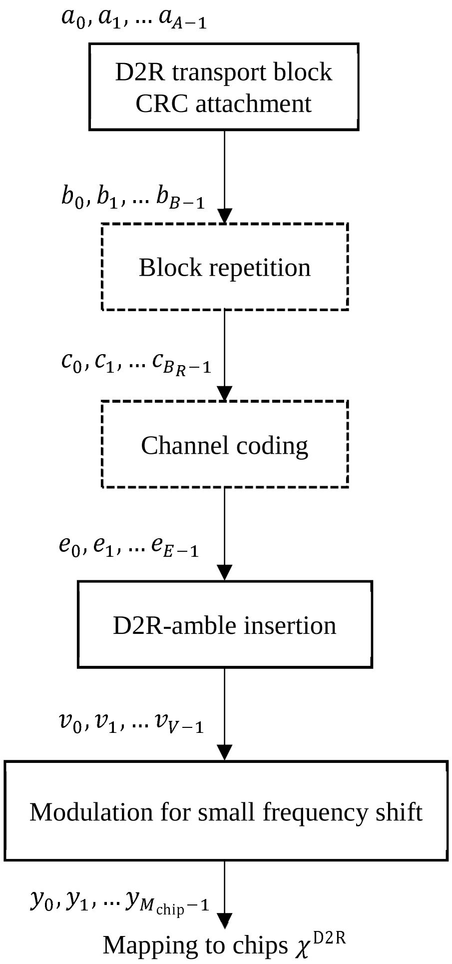

Figure 6.1.1-1: D2R steps

6.1.2 PDRCH

Data arrives to the generation unit in the form of a block of bits from higher layers, termed a D2R transport block.

6.1.2.1 CRC attachment

Error detection is provided for the transport block through a CRC.

The entire transport block shall be used to calculate the CRC parity bits. Denote the bits in a transport block delivered to L1 by $a_0, a_1, \ldots, a_{A-1}$, and the parity bits by $\pi_0, \pi_1, \ldots, \pi_{L-1}$, where A is the payload size and L is the number of parity bits. The lowest order information bit a_0 is mapped to the most significant bit of the transport block as defined in clause 6.1.1 of TS 38.391 [3].

The parity bits shall be computed and attached to the transport block according to clause 8.1, by setting L to 16 bits if $A > 24$; and by setting L to 6 bits otherwise.

The bits after CRC attachment are denoted $b_0, b_1, \ldots, b_{B-1}$, where $B = A + L$.

6.1.2.2 Block repetition

The bits input to the block repetition step are denoted $b_0, b_1, \ldots, b_{B-1}$, where B is the number of bits in the transport block including CRC parity bits.

Block repetition shall be performed so that the bits after repetition are denoted $c_0, c_1, \ldots, c_{B_R-1}$ where $B_R = R_{\text{block}} B$, $R_{\text{block}} \geq 1$ is the block repetition number and:

$$c_{k+KB} = b_k$$
$$k = 0, 1, \ldots, B - 1$$
$$K = 0, 1, \ldots, R_{\text{block}} - 1.$$

6.1.2.3 Channel coding or omission

Only if R_{code} indicates that no channel coding is used, the bits after block repetition are re-denoted $e_0, e_1, \ldots, e_{E-1}$, where $E = B_R$, and the remainder of this clause shall be omitted.

Otherwise, one code block is delivered to the channel coding block. The bits in the code block are denoted $c_0, c_1, \ldots, c_{B_R-1}$ where B_R is the number of bits present after block repetition. The code block shall be encoded according to clause 8.2.

After encoding the bits are denoted $d_0^{(i)}, d_1^{(i)}, \ldots, d_{D-1}^{(i)}$, $i = 0,1,2$, where i is the coded stream index and D is the number of bits in each coded stream, i.e., $D = B_R$.

The sequence of bits $e_0, e_1, \ldots, e_{E-1}$ for transmission, where $E = 3D$, is generated by:

$$e_{3k+i} = d_k^{(i)} \text{ for } k = 0, 1, \ldots, D - 1 \text{ and } i = 0, 1, 2.$$

6.1.3 D2R-amble insertion

The bits of the D2R preamble signal, denoted $p_0, p_1, \ldots, p_{l_{\text{amble}}-1}$, shall be generated according to clause 8.3 by setting $M_{\text{PN}} = l_{\text{amble}}$.

The bits of the D2R midamble signal, denoted $m_0, m_1, \ldots, m_{l_{\text{amble}}-1}$, shall be generated according to clause 8.3 by setting $M_{\text{PN}} = l_{\text{amble}}$.

An assembly of bits denoted $v_0, v_1, \ldots, v_{V-1}$, where

$$V = \begin{cases} E + \left(1 + \left\lceil \frac{E}{I_{\text{bit}}} \right\rceil\right) l_{\text{amble}} & \text{if } I_{\text{add}} \text{ indicates insertion of an additional D2R midamble} \\ E + \left(1 + \left\lfloor \frac{E}{I_{\text{bit}}} \right\rfloor\right) l_{\text{amble}} & \text{otherwise,} \end{cases}$$

is defined on the PDRCH bits e_k, D2R preamble signal bits p_k and D2R midamble signal bits m_k as follows:

- The bits $p_0, p_1, \ldots, p_{l_{\text{amble}}-1}$ of the D2R preamble are arranged into $v_k = p_k$ for $k = 0, 1, \ldots, l_{\text{amble}} - 1$.
- If $E \geq I_{\text{bit}}$, the bits $m_0, m_1, \ldots, m_{l_{\text{amble}}-1}$ of the D2R midamble signal are arranged into v_k according to:

$$v_{k+K(l_{\text{amble}}+I_{\text{bit}})} = m_k$$
$$k = 0, 1, \ldots, l_{\text{amble}} - 1$$
$$K = 1, 2, \ldots, \left\lfloor \frac{E}{I_{\text{bit}}} \right\rfloor.$$

- If I_{add} indicates insertion of an additional D2R midamble, the bits $m_0, m_1, \ldots, m_{l_{\text{amble}}-1}$ of the D2R midamble signal are arranged into $v_{k+V-l_{\text{amble}}} = m_k$ for $k = 0, 1, \ldots, l_{\text{amble}} - 1$.
- The PDRCH bits e_k for $k = 0, 1, \ldots, E - 1$ are arranged into all bits of v which are not occupied by the preamble or a midamble.

6.1.4 Modulation for small frequency shift and mapping to chips

The assembly of bits v shall be modulated for small frequency-shift according to clause 8.4.1.1 or 8.4.2 using a small frequency shift factor R_{SFS}, after which the set of modulated symbols is denoted $y_0, y_1, \ldots, y_{M_{\text{chip}}-1}$. The modulated symbols shall be mapped in sequence starting with y_0 to chips χ in increasing order.

6.1.5 Backscattering

The time-continuous signal $s(t) = z_\chi$, where $t = 0$ at the start of chip $\chi = 0$. The carrier-wave for backscattering at frequency f_0 defined to start at time $t_{\mathrm{CW}} = 0$ is denoted by $w(f_0, t_{\mathrm{CW}})$ as specified in TS 38.194 [4].

The backscattered signal on the carrier wave is given by:

$$s(t)w(f_0, t_{\mathrm{CW}}).$$

6.2 R2D

6.2.1 Overview

An R2D channel corresponds to a set of chips carrying information originating from higher layers. An R2D signal is used by the physical layer, but does not carry information originating from higher layers. The following R2D physical channel and signals are defined:

- Physical reader-to-device channel, PRDCH
- R2D timing acquisition signal, R-TAS, which consists of a start indicator part, SIP, and a clock acquisition part, CAP.
- R2D postamble signal

R2D generation has the steps shown in the following figure.

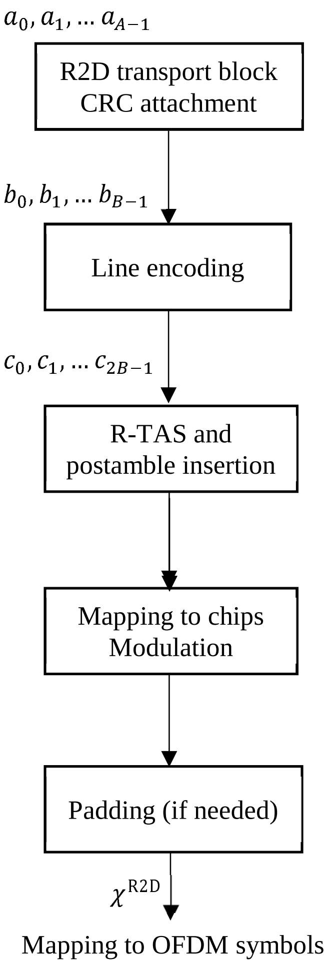

Figure 6.2.1-1: R2D steps

6.2.2 PRDCH

Data arrives to the generation unit in the form of a block of bits from higher layers, termed an R2D transport block.

6.2.2.1 CRC attachment

Error detection is provided for the transport block through a CRC.

The entire transport block is used to calculate the CRC parity bits. Denote the bits in a transport block delivered to L1 by $a_0, a_1, \ldots, a_{A-1}$, and the parity bits by $\pi_0, \pi_1, \ldots, \pi_{L-1}$, where A is the payload size and L is the number of parity bits. The lowest order information bit a_0 is mapped to the most significant bit of the transport block as defined in clause 6.1.1 of TS 38.391 [3].

The parity bits are computed and attached to the transport block according to clause 8.1, by setting L to 16 bits if $A > 24$; and by setting L to 6 bits otherwise.

The bits after CRC attachment are denoted $b_0, b_1, \ldots, b_{B-1}$, where $B = A + L$.

6.2.2.2 Line encoding

The bits input to the line encoding step are denoted $b_0, b_1, \ldots, b_{B-1}$, where B is the number of bits in the transport block including CRC parity bits. The bits are line encoded according to clause 8.5.

After line encoding, the bits corresponding to the line codewords are denoted $c_0, c_1, \ldots, c_{2B-1}$.

6.2.3 Timing acquisition signal

6.2.3.1 Start indicator part

The R-TAS SIP consists of $N_{\mathrm{SIP}} = 8$ bits denoted $S_0, S_1, S_2, S_3, S_4, S_5, S_6, S_7 = 1, 1, 0, 0, 1, 0, 0, 0$.

6.2.3.2 Clock acquisition part

The R-TAS CAP consists of $N_{\mathrm{CAP}} = 4$ bits denoted $A_0, A_1, A_2, A_3 = 1, 0, 1, 0$.

6.2.4 Postamble

The R2D postamble signal consists of 4 bits denoted $P_0, P_1, P_2, P_3 = 1, 1, 1, 1$.

6.2.5 Mapping to chips and modulation

To chips $\chi = 0$ and up are mapped:

- the bits of the R-TAS SIP in sequence starting with S_0 followed by
- the bits of the R-TAS CAP in sequence starting with A_0 followed by
- the bits of PRDCH in sequence starting with c_0 followed by
- the bits of the R2D postamble in sequence starting with P_0,

except if $M_{\mathrm{chip}}^{\mathrm{symb}} = 24$, chips $\chi = \chi', \chi' + 1$ satisfying $(\chi' - N_{\mathrm{SIP}})$ modulo $M_{\mathrm{chip}}^{\mathrm{symb}} = M_{\mathrm{chip}}^{\mathrm{symb}} - 2$ are skipped for the mapping of PRDCH and the R2D postamble, and are instead set to values of 1.

The content of each chip is modulated according to clause 8.4.1.2.

Following the last modulated symbol, the smallest integer $N_{\mathrm{pad}} \geq 0$ padding chips are inserted, if needed, until $\left(M_{\mathrm{chip}}^{\mathrm{R2D}} - N_{\mathrm{SIP}}\right)$ modulo $M_{\mathrm{chip}}^{\mathrm{symb}} = 0$. The padding chips are set to any values which do not result in another R-TAS SIP, and if $M_{\mathrm{chip}}^{\mathrm{symb}} = 24$ values of 1 are mapped to the final two padding chips.

6.2.6 Mapping to OFDM symbols

Chips $\chi = 0, 1, \ldots, N_{\text{SIP}} - 1$ are mapped in sequence to OFDM symbols $l_{\text{RE}} = \lfloor \chi/4 \rfloor$.

Chips $\chi = N_{\text{SIP}}, N_{\text{SIP}} + 1, \ldots, M_{\text{chip}}^{\text{R2D}} - 1$ are mapped in sequence to OFDM symbols $l_{\text{RE}} = \left\lfloor (\chi - N_{\text{SIP}})/M_{\text{chip}}^{\text{symb}} \right\rfloor + 2$ in increasing order.

6.2.7 Baseband signal generation

There is no specified relationship between chip χ mapped to OFDM symbol l_{RE} and the value $z_{k_{\text{RE}},l_{\text{RE}}}$ corresponding to resource element $(k_{\text{RE}}, l_{\text{RE}})$.

The time continuous signal $s_{l_{\text{RE}}}(t)$ for OFDM symbol l_{RE} is defined by:

$$s_{l_{\text{RE}}}(t) = \begin{cases} \bar{s}_{l_{\text{RE}}}(t) & t_{\text{start},l_{\text{RE}}} \le t < t_{\text{start},l_{\text{RE}}} + T_{\text{symb},l_{\text{RE}}} \\ 0 & \text{otherwise} \end{cases}$$

$$\bar{s}_{l_{\text{RE}}}(t) = \sum_{k_{\text{RE}}=0}^{\hat{k}-1} z_{k_{\text{RE}},l_{\text{RE}}} e^{j2\pi\left(k_{\text{RE}} - \hat{k}/2\right)\Delta f\left(t - N_{\text{CP},l_{\text{RE}}} T_{\text{c}} - t_{\text{start},l_{\text{RE}}}\right)}$$

$$T_{\text{symb},l_{\text{RE}}} = \left(N_{\text{u}} + N_{\text{CP},l_{\text{RE}}}\right) T_{\text{c}}$$

where $N_{\text{RB}}^{\text{R2D}} N_{\text{sc}}^{\text{RB}} \ge \hat{k} \ge N_{\text{RB}}^{\text{min}} N_{\text{sc}}^{\text{RB}}$, $t = 0$ at the start of OFDM symbol $l_{\text{RE}} = 0$ and

$$N_{\text{u}} = 2048\kappa$$

$$N_{\text{CP},l_{\text{RE}}} = \begin{cases} 160\kappa & l_{\text{RE}} \text{ modulo } 7 = l_0 \\ 144\kappa & \text{otherwise} \end{cases}$$

where l_0 is a value from $\{0,1,2,3,4,5,6\}$, constant for all OFDM symbols of the generation.

The starting position of OFDM symbol l_{RE} is given by:

$$t_{\text{start},l_{\text{RE}}} = \begin{cases} 0 & l_{\text{RE}} = 0 \\ t_{\text{start},l_{\text{RE}}-1} + T_{\text{symb},l_{\text{RE}}-1} & \text{otherwise.} \end{cases}$$

6.2.8 Modulation and upconversion

Modulation and upconversion to the carrier frequency f_0 of the complex-valued DFT-s-OFDM baseband signal for OFDM symbol l_{RE} assumed to start at $t = 0$ is given by:

$$\text{Re}\left\{ s_{l_{\text{RE}}}(t) \cdot e^{j2\pi f_0\left(t - t_{\text{start},l_{\text{RE}}} - N_{\text{CP},l_{\text{RE}}} T_{\text{c}}\right)} \right\}.$$

7 Physical layer procedures

7.1 D2R related procedures

7.1.1 Device procedure for D2R generation

A device shall generate the D2R transmission using the following parameters provided by higher layers:

- the duration in microseconds of each D2R bit, $T_{\text{bit}}^{\text{D2R}}$
- the block repetition number, R_{block}
- the small frequency shift factor to be used, R_{SFS}
- the interval in bits for D2R midamble insertion, I_{bit}

- sequence length indicator for D2R-ambles, L_{amble}
- the additional D2R midamble insertion indicator, I_{add}
- the channel coding indicator, R_{code}
- the D2R transport block size in bytes, $N_{\text{TBS}}^{\text{D2R}}$

The device shall:

- set $T_{\text{chip}}^{\text{D2R}} = T_{\text{bit}}^{\text{D2R}}/(2 \times R_{\text{SFS}})$
- if L_{amble} indicates a short D2R amble sequence, set $l_{\text{amble}} = 7$; otherwise set $l_{\text{amble}} = 31$.

7.1.2 Device procedure for transmission time determination

A device shall upon receiving a PRDCH intended for the device in an R2D transmission ending in chip $\chi_{\text{end}}^{\text{R2D}} = M_{\text{chip}}^{\text{R2D}} - 1$, perform a corresponding D2R transmission with chip $\chi^{\text{D2R}} = 0$ starting an amount of time $T_{\text{R}\rightarrow\text{D}}$ after the end of chip $\chi^{\text{R2D}} = \chi_{\text{end}}^{\text{R2D}}$ according to the configuration received from higher layers.

If the D2R transmission is for a *Random ID* message (Msg1) or corresponds to a *Random ID Response* message (Msg2)

- the device shall determine the D2R transmission starting time using the following parameters determined by higher layers:
  - the set of $N_{\text{SFS}} \geq 1$ potential small frequency shift factors $R'_{i,\text{SFS}}, i = 1, 2, \ldots, N_{\text{SFS}}$
- T'_{chip} is equal to the largest value among $T_{\text{bit}}^{\text{D2R}}/(2 \times R'_{i,\text{SFS}})$

otherwise

- $T'_{\text{chip}} = T_{\text{chip}}^{\text{D2R}}$.

If the D2R transmission is for a *Random ID* message

- if after chip $\chi^{\text{R2D}} = \chi_{\text{end}}^{\text{R2D}}$ there are potential access occasion(s), as defined in TS 38.391 [3], for the transmission which are earlier in time than the access occasion selected for the transmission
  - the device shall set $T_{\text{R}\rightarrow\text{D}} = 1.25\left(T_{\text{offset}} + M_{\text{chip}}^{\text{D2R}} T_{\text{chip}}^{\text{D2R}}\right)$
- otherwise
  - the device shall set $T_{\text{R}\rightarrow\text{D}} = T_{\text{offset}}$

else if the D2R transmission corresponds to a R2D *Random ID Response* message or to a contention-free random access procedure

- the device shall set $T_{\text{R}\rightarrow\text{D}} = T_{\text{offset}} + \Delta_{\text{code}}$ where Δ_{code} has the value given in Table 7.1.2-1 if R_{code} indicates that channel coding is used, and $T_{\text{R}\rightarrow\text{D}} = T_{\text{offset}}$ if no channel coding is used

Table 7.1.2-1

T'_{chip} [μs]	Δ_{code} [μs]
τ	0
$\tau/2$	
$\tau/4$	
$\tau/8$	
$\tau/16$	
$\tau/32$	τ
$\tau/64$	
$\tau/128$	
$\tau/192$	

otherwise

- the device shall set $T_{\mathrm{R}\rightarrow\mathrm{D}} = T_{\mathrm{offset}} + \Delta_{\mathrm{code}}$ where Δ_{code} has the value given in Table 7.1.2-2 if R_{code} indicates that channel coding is used, and $T_{\mathrm{R}\rightarrow\mathrm{D}} = T_{\mathrm{offset}}$ if no channel coding is used

Table 7.1.2-2

D2R block size [bytes]	Δ_{code} [μs]
$N_{\mathrm{TBS}}^{\mathrm{D2R}} \leq 32$	2τ
$32 < N_{\mathrm{TBS}}^{\mathrm{D2R}} \leq 64$	4τ
$64 < N_{\mathrm{TBS}}^{\mathrm{D2R}} \leq 125$	8τ

where T_{offset} has the value given in Table 7.1.2-3 and $M_{\mathrm{chip}}^{\mathrm{symb}}$ is as determined for the corresponding PRDCH.

Table 7.1.2-3

T'_{chip} [μs]	T_{offset} [μs]
τ	10τ
$\tau/2$	
$\tau/4$	5τ
$\tau/8$	
$\tau/16$	
$\tau/32$	τ
$\tau/64$	τ, if $M_{\mathrm{chip}}^{\mathrm{symb}} = 2$ $\tau/4$, if $M_{\mathrm{chip}}^{\mathrm{symb}} = 6$ or 12 or 24
$\tau/128$	
$\tau/192$	

7.1.3 Device procedure for modulation scheme determination

To determine the modulation scheme for the entire D2R transmission, the device shall:

- if the PDRCH is for transmitting Msg1 or corresponds to a contention-free random access procedure
  - determine according to its implementation to use either OOK modulation or BPSK modulation
- otherwise
  - use the same modulation as determined for transmitting the preceding PDRCH.

7.2 R2D related procedures

7.2.1 Device procedure for R-TAS reception

A device shall, upon determining that a SIP of R-TAS has been received, determine the value of $M_{\mathrm{chip}}^{\mathrm{symb}}$ according to which CAP is received from among those given in Table 4.3.3.3-1.

7.2.2 Device procedure for PRDCH reception

A device shall, upon receiving R-TAS, assume that a PRDCH transmission begins in chip $\chi = \chi_{\mathrm{start}}^{\mathrm{PRDCH}}$, receive the assumed PRDCH and attempt to decode the corresponding R2D transport block, where:

- $\chi_{\mathrm{start}}^{\mathrm{PRDCH}} = N_{\mathrm{SIP}} + N_{\mathrm{CAP}}$
- the device can assume the R2D transport block size is $N_{\mathrm{TBS}}^{\mathrm{R2D}}$ as specified in TS 38.391 [3], if the value is indicated by higher layers.

7.2.3 Monitoring of R2D

A device is not required to monitor R2D:

- when performing D2R transmission
- for a duration $T_{\mathrm{D}\to\mathrm{R}}^{\min}$, as specified in TS 38.191 [5], after the end of chip $\chi^{\mathrm{D2R}} = \chi_{\mathrm{end}}^{\mathrm{D2R}}$ when the device performs a D2R transmission ending in chip $\chi_{\mathrm{end}}^{\mathrm{D2R}} = M_{\mathrm{chip}}^{\mathrm{D2R}} - 1$.

8 Generic functions

8.1 CRC calculation

Denote the input bits to the CRC computation by $a_0, a_1, \dots, a_{A-1}$ and the parity bits by $\pi_0, \pi_1, \dots, \pi_{L-1}$, where A is the size of the input sequence and L is the number of parity bits. The parity bits are generated by one of the following cyclic generator polynomials:

- $g_{CRC16}(D) = [D^{16} + D^{12} + D^5 + 1]$ for a CRC length $L = 16$.
- $g_{CRC6}(D) = [D^6 + D^5 + 1]$ for a CRC length $L = 6$.

The encoding is performed in a systematic form, which means that in GF(2), the polynomial:

$$a_0 D^{A+L-1} + a_1 D^{A+L-2} + \cdots + a_{A-1} D^L + \pi_0 D^{L-1} + \pi_1 D^{L-2} + \cdots + \pi_{L-2} D^1 + \pi_{L-1}$$

yields a remainder equal to 0 when divided by the corresponding CRC generator polynomial.

The bits after CRC attachment are denoted by $b_0, b_1, \dots, b_{B-1}$, where $B = A + L$. The relation between a_k and b_k is:

$b_k = a_k$ for $k = 0,1,2, \dots, A-1$
$b_k = \pi_{k-A}$ for $k = A, A+1, \dots, A+L-1$.

8.2 Channel coding

The bit sequence for a given block input to channel coding is denoted $c_0, c_1, \dots, c_{K-1}$, where K is the number of bits to encode.

A tail biting convolutional code with constraint length 7 and coding rate 1/3 is defined.

The configuration of the convolutional encoder is presented in Figure 8.2-1.

The initial value of the shift register of the encoder shall be set to the values corresponding to the last 6 information bits in the input stream so that the initial and final states of the shift register are the same. Therefore, denoting the shift register of the encoder by $s_0, s_1, s_2, \dots, s_5$, then the initial value of the shift register shall be set to

$$s_i = c_{(K-1-i)}.$$

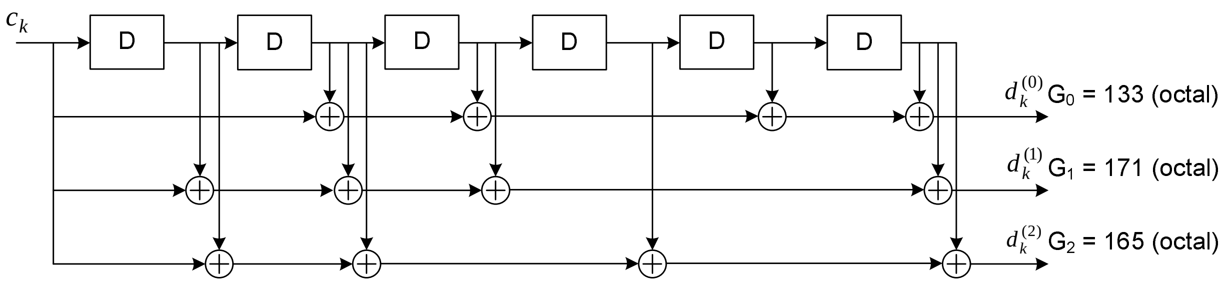

Figure 8.2-1: Rate 1/3 tail biting convolutional encoder

The encoder output streams $d_k^{(0)}$, $d_k^{(1)}$ and $d_k^{(2)}$correspond to the first, second and third parity streams respectively, as shown in Figure 8.2-1.

8.3 Sequence generation

The output pseudo-random m-sequence of length M_{PN} is $x_k, k = 0, 1, \dots M_{\text{PN}} - 1$.

If $M_{\text{PN}} = 7$, the sequence $x = 1, 0, 0, 1, 1, 1, 0$, i.e. in GF(2), $x_{m+3} = x_{m+2} + x_m$, with $x_0 = 1, x_1 = 0, x_2 = 0$.

If $M_{\text{PN}} = 31$, the sequence $x = 0, 1, 0, 0, 1, 0, 0, 0, 0, 1, 0, 1, 0, 1, 1, 1, 0, 1, 1, 0, 0, 0, 1, 1, 1, 1, 1, 0, 0, 1, 1$, i.e. in GF(2), $x_{m+5} = x_{m+3} + x_m$, with $x_0 = 0, x_1 = 1, x_2 = 0, x_3 = 0, x_4 = 1$.

8.4 Modulation mapping

8.4.1 OOK

8.4.1.1 OOK for small frequency shift

In case of OOK modulation for small frequency shift factor R_{SFS}, a single element v_i is mapped to modulation symbols x according to:

$$x_{j+2K} = (2j - 1)v_i + (1 - j)$$
$$j = 0, 1$$
$$K = 0, 1, \dots, R_{\text{SFS}} - 1.$$

8.4.1.2 OOK for R2D

In case of OOK modulation for R2D, each element b_i is mapped to a modulation symbol x_i according to $x_i = b_i$.

8.4.2 BPSK

In case of BPSK modulation for small frequency shift factor R_{SFS}, a single element v_i is mapped to modulation symbols x according to:

$$x_{j+2K} = 2(2j - 1)v_i + (1 - 2j)$$
$$j = 0, 1$$
$$K = 0, 1, \dots, R_{\text{SFS}} - 1.$$

8.5 Line encoding

For line encoding, for a single element v_i the encoder output is a line codeword x_0, x_1 according to:

$$x_j = (2j - 1)v_i + (1 - j), j = 0, 1.$$

Annex A (informative): Change history

Change history							
Date	**Meeting**	**TDoc**	**CR**	**Rev**	**Cat**	**Subject/Comment**	**New version**
2025-05	RAN1#120bis	R1-2503148				First version	0.1.0
2025-06	RAN1#121	R1-2504962				Implementation of further agreements including at RAN1#121, and editor's improvements	0.2.0
2025-06	RAN#108	RP-251010				Submitted to RAN for single-step approval.	1.0.0
2025-06	RAN#108					Further to RAN approval, spec under change control for Rel-19	19.0.0
2025-09	RAN#109	RP-252635	0001	-	F	Corrections to the Ambient IoT physical layer	19.1.0

History

Document history		
V19.1.0	October 2025	Publication