IEEE Standard for Local and metropolitan area networks—

Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)

Amendment 7: Physical Layer for Rail Communications and Control (RCC)

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

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3 Park Avenue
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USA

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(Amendment to
IEEE Std 802.15.4™-2011
as amended by IEEE Std 802.15.4e™-2012,
IEEE Std 802.15.4f™-2012,
IEEE Std 802.15.4g™-2012,
IEEE Std 802.15.4j™-2013,
IEEE Std 802.14.3k™-2013, and
IEEE Std 802.15.4m™-2014)

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Approved 27 March 2014

IEEE-SA Standards Board

Abstract: This amendment to IEEE Std 802.15.4™-2011 specifies a PHY for use in equipment intended to address rail transportation industry needs and to meet US positive train control (PTC) regulatory requirements and similar regulatory requirements in other parts of the world. In addition, the amendment describes only those MAC changes needed to support this PHY.

Keywords: CBTC, communications-based train control, IEEE 802.15.4p™, low data rate, low power, LR-WPAN, PAN, personal area network, positive train control, PTC, radio frequency, rail communications and control, RCC, RF, wireless personal area network, WPAN

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Introduction

This introduction is not part of IEEE Std 802.15.4p™-2013, IEEE Standard for Local and metropolitan area networks—Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)—Amendment 7: Physical Layer for Rail Communications and Control (RCC).

This amendment specifies alternate PHYs, in addition to those of IEEE Std 802.15.4™-2011, and any MAC modifications needed to support their implementation.

The new PHYs are to be used in equipment intended to address rail transportation industry needs and to meet US positive train control (PTC) regulatory requirements and similar regulatory requirements in other parts of the world. The new RCC PHYs are:

— PHYs operating at multiple over-the-air data rates in support of land mobile radio (LMR) for use in RCC applications. The following five modulation schemes are available for use: Gaussian minimum shift keying (GMSK), continuous four-level frequency modulation (C4FM), quadrature phase-shift keying (QPSK), Pi/4 differential quadrature phase-shift keying (DQPSK), and direct sequence spread spectrum (DSSS) employing differential phase-shift keying (DPSK).

DSSS binary phase-shift keying (BPSK) PHY operating at multiple over-the-air data rates for use in RCC applications.

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IEEE Standard for
Local and metropolitan area networks—

Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)

Amendment 7: Physical Layer for Rail Communications and Control (RCC)

NOTE—The editing instructions contained in this amendment define how to merge the material contained therein into the existing base standard and its amendments to form the comprehensive standard.

The editing instructions are shown in ***bold italic***. Four editing instructions are used: change, delete, insert, and replace. ***Change*** is used to make corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using ~~strikethrough~~ (to remove old material) and underscore (to add new material). ***Delete*** removes existing material. ***Insert*** adds new material without disturbing the existing material. Deletions and insertions may require renumbering. If so, renumbering instructions are given in the editing instruction. ***Replace*** is used to make changes in figures or equations by removing the existing figure or equation and replacing it with a new one. Editing instructions, change markings, and this NOTE will not be carried over into future editions because the changes will be incorporated into the base standard.[1]

[1]Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

2. Normative references

Insert the following new reference alphabetically into Clause 2:

Code of Federal Regulations, Title 47 Part 90 (47 CFR 90), Private Land Mobile Radio Services, Subpart S—Regulations Governing Licensing and Use of Frequencies in the 806–824, 851–869, 896–901, and 935–940 MHz Bands.[2]

Code of Federal Regulations, Title 47: Telecommunication, Part 90—Private Land Mobile Radio Services, Subpart Y—Regulations Governing Licensing and Use of Frequencies in the 4940–4990 MHz Band.

[2]CFR publications are available from the U.S. Government Printing Office, 732 N. Capitol Street, NW, Washington, DC 20401, USA (http://www.gpo.gov/).

3. Definitions, acronyms, and abbreviations

3.1 Definitions

Insert the following definitions alphabetically into 3.1:

communications-based train control (CBTC): A rail signal and control system that does not depend on track circuits to detect trains or to communicate commands between the train and the wayside.

3.2 Acronyms and abbreviations

Insert the following acronyms alphabetically into 3.2:

C4FM	continuous four-level frequency modulation
CBTC	communications-based train control
DPSK	differential phase-shift keying
DQPSK	differential quadrature phase-shift keying
GMSK	Gaussian-filtered minimum shift keying
LMR	land mobile radio
PTC	positive train control
QPSK	quadrature phase-shift keying
RCC	rail communications and control
RCCN	rail communications and control network

5. MAC protocol

5.1 MAC functional description

5.1.1 Channel access

Insert the following new subclause (5.1.1.6a) after 5.1.1.6:

5.1.1.6a RCCN superframe structure

Support for the RCCN superframe structure is optional for an RCC device. For typical usage, see U.4.

The RCCN superframe structure is shown in Figure 11i. The duration of an RCCN superframe slot is

$$(k + 1) \times aRCCNBaseSlotDuration$$

where k is the value of the Slot Size Multiplier field of the RCCN descriptor IE, as described in 5.2.4.36.

The superframe begins with an enhanced beacon containing the RCCN descriptor IE. The management downlink slots are used by the RCCN PAN coordinator to send frames to RCCN endpoints, while the management uplink slots are used by RCCN endpoints to send frames to the RCCN PAN coordinator. Channel access in the management uplink slots is performed using slotted CSMA-CA. Following the uplink slots is the CAP, in which communication between any devices in the RCCN may occur; channel access is gained using slotted CSMA-CA, optionally with PCA, as described in 5.1.1.4.5. Following the CAP is a CFP containing one or more GTSs allocated by the RCCN PAN coordinator.

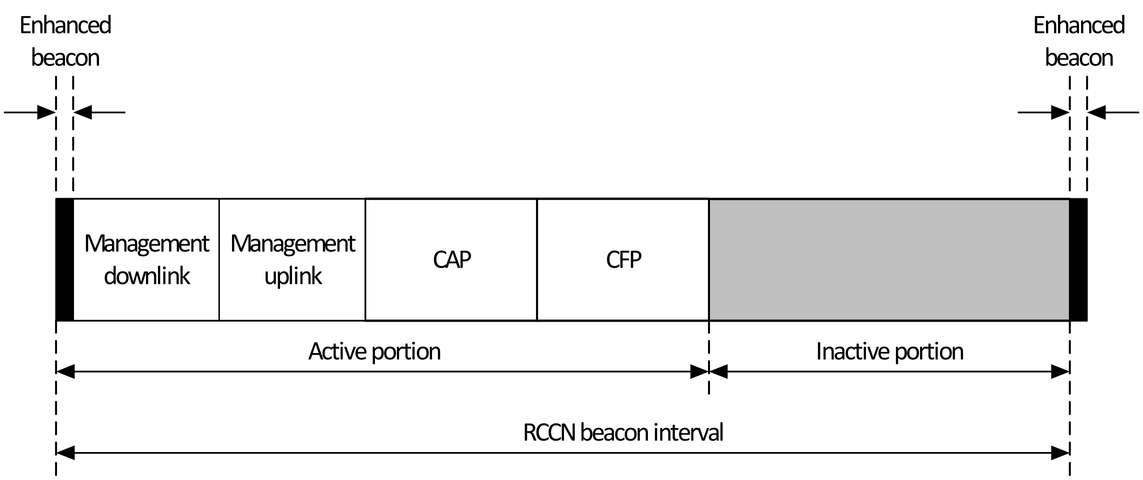

Figure 11i—RCCN superframe structure

5.1.11 LE transmission, reception, and acknowledgment

5.1.11.1 Coordinated sampled listening (CSL)

5.1.11.1.4 Unicast transmission

Change step f) in paragraph three as indicated:

f) Wait for ~~up to~~ at most *macEnhAckWaitDuration* (defined in ~~Table 52j~~Table 52) ~~symbol time~~ for the enhanced acknowledgment frame if the Acknowledge Request field in the payload frame is set to one.

5.2 MAC frame formats

5.2.4 Information element

5.2.4.2 Header information elements

Insert the following new rows at the end of Table 4b as indicated:

Table 4b—Element IDs, Header IEs

Element ID	Name	Description
0x27	RCC capabilities	As defined in 5.2.4.28a.
0x28	RCCN descriptor	As defined in 5.2.4.36.
0x29	Global time	As defined in 5.2.4.37.

5.2.4.5 MLME information elements

Insert the following new row at the end of Table 4d as indicated:

Table 4d—Sub-ID allocation for short form

Sub-ID value	Name	Description
0x36	RCC PHY operating mode	Description of the operating mode parameters for the RCC PHY used, as defined in 5.2.4.29.3.

5.2.4.28a RCC capabilities IE

The following IE declares the RCC capabilities supported by a device. The presence of this IE in a transmitted frame indicates that the coordinator supports an RCC PHY. The IE content shall be as shown in Figure 48aae.

Octets: 2	2	2
RCC Frequency Bands Supported	RCC PHY and Modulation Supported	RCC DSSS DPSK Modulation Supported Feature

Figure 48aae —Format of the RCC capabilities IE

Table 4wa contains the RCC Frequency Bands Supported field encoding, Table 4wb contains the RCC PHY and Modulation Supported field encoding, and Table 4wc contains the RCC DSSS DPSK Modulation Supported Feature field encoding.

Table 4wa—RCC Frequency Bands Supported field encoding

Bit number	Description
0	161 MHz band supported
1	216 MHz band supported
2	217 MHz band supported
3	220 MHz band supported
4	450 MHz band supported
5	770 MHz band supported
6	800 MHz band supported
7	806 MHz band supported
8	896 MHz band supported
9	915 MHz band supported
10	928 MHz band supported
11	2450 MHz band supported
12	4965 MHz band supported
13	5800 MHz band supported
14–15	Reserved

Table 4wb—RCC PHY and Modulation Supported field encoding

Bit number	Description
0	LMR PHY GMSK 9.6 kbps supported
1	LMR PHY GMSK 19.2 kbps supported
2	LMR PHY C4FM 9.6 kbps supported
3	LMR PHY C4FM 19.2 kbps supported
4	LMR PHY C4FM 38.4 kbps supported
5	LMR PHY QPSK 16 kbps supported
6	LMR PHY QPSK 32 kbps supported
7	LMR PHY Pi/4 DQPSK 16 kbps supported
8	LMR PHY Pi/4 DQPSK 32 kbps supported
9	LMR PHY Pi/4 DQPSK 36 kbps supported
10	LMR PHY DSSS DPSK supported

Table 4wb—RCC PHY and Modulation Supported field encoding *(continued)*

Bit number	Description
11	DSSS BPSK PHY supported
12–15	Reserved

Table 4wc—RCC DSSS DPSK Modulation Supported Feature field encoding

Bit number	Description
0	300 kcps chip rate supported
1	600 kcps chip rate supported
2	800 kcps chip rate supported
3	1 Mcps chip rate supported
4	1.6 Mcps chip rate supported
5	2 Mcps chip rate supported
6	3 Mcps chip rate supported
7	4 Mcps chip rate supported
8	11-chip spreading sequence supported
9	15-chip spreading sequence supported
10	20-chip spreading sequence supported
11	40-chip spreading sequence supported
12	DSSS DBPSK supported
13	DSSS DQPSK supported
14–15	Reserved

5.2.4.29 Operating Mode Description IEs

5.2.4.29.3 RCC PHY Operating Mode Description IE

The RCC PHY Operating Mode Description IE content shall be encoded as shown in Table 4z.

Table 4z—Operating Mode Information field encoding for RCC PHY

Bit number	Description
0–13	Channel number; see 8.1.2.14.
14–18	The operating band selected. The bands are defined as the integers greater than zero that correspond to the bit numbers given in Table 4wa.
19–22	The PHY and modulation selection, as defined in Table 4wb.

Table 4z—Operating Mode Information field encoding for RCC PHY *(continued)*

Bit number	Description
23–25	Chip rate selection for LMR PHY DSSS DPSK. Otherwise, reserved. 0 = 300 kcps 1 = 600 kcps 2 = 800 kcps 3 = 1 Mcps 4 = 1.6 Mcps 5 = 2 Mcps 6 = 3 Mcps 7 = 4 Mcps
26–27	Spreading sequence selection for LMR PHY DSSS DPSK. Otherwise, reserved. 0 = 11-chip 1 = 15-chip 2 = 20-chip 3 = 40-chip
28–31	Reserved

Insert the following new subclauses (5.2.4.36–5.2.4.37) after 5.2.4.35:

5.2.4.36 RCCN descriptor IE

The RCCN descriptor IE is included in enhanced beacons to signal that an RCCN PAN is present and to describe the superframe configuration in use. The RCCN descriptor IE format is given in Figure 48nae.

Octet: 1		**2**	**1**	**1**	**1**	**1**	
Bits: 0–3	**4–7**						
Version	Reserved	Slot Size Multiplier	Management Downlink Slots	Management Uplink Slots	CAP Slots	CFP Slots	...

	Octet: 1	**1**	**variable**	**1**	**variable**
...	Inactive Portion Duration	Network ID Length	Network ID	Device Type	Capabilities

Figure 48nae—Format of the RCCN descriptor IE

The Version field indicates the version of the RCCN descriptor IE and shall be set to zero for this version of the standard.

The Slot Size Multiplier field is used to calculate the superframe slot duration, as given in 5.1.1.6a.

The Management Downlink Slots field indicates the number of superframe slots allocated to the PAN coordinator for the purpose of sending frames to RCCN endpoints.

The Management Uplink Slots field indicates the number of superframe slots allocated to RCCN endpoints for the purposed of sending frames to the RCCN PAN coordinator.

The CAP Slots field indicates the number of superframe slots allocated to the CAP.

The CFP Slots field indicates the number of superframe slots allocated to the CFP.

The Inactive Portion Duration field specifies the length of the inactive portion of the superframe structure. The inactive portion is specified in units of superframe slot duration.

The Network ID Length field indicates the length of the Network ID field.

The Network ID field contains a set of octets which contains a network-specific identification. The value of the field shall be set to *macRCCNNetID*.

The Device Type field contains an application-specific device type indication. The definition of device types is out of the scope of this standard.

The Capabilities field contains information that is implementation specific.

5.2.4.37 Global time IE

The Global time IE is encoded as shown in Figure 48naf.

Octet: 4
Global Time

Figure 48naf— Format of the Global time IE

The Global time IE is used to distribute a network-wide time reference. The presence of this IE indicates that the transmitting device has a reference to global time, e.g., GPS reference time. The IE consists of a Global Time field that contains the number of seconds elapsed since 00:00:00 UTC, January 1,1970.

6. MAC services

6.4 MAC constants and PIB attributes

6.4.1 MAC constants

Insert the following new row at the end of Table 51:

Table 51—MAC sublayer constants

Constant	Description	Value
aRCCNBaseSlotDuration	The number of symbols forming an RCCN superframe slot.	60

6.4.3 Calculating PHY dependent MAC PIB values

6.4.3.2 General MAC PIB attributes for functional organization

Change the first paragraph of 6.4.3.2 as indicated, and insert the following new rows at the end of Table 52a:

Table 52a provides the General MAC PIB attributes for functional organization. Attributes marked with a dagger (†) are read-only attributes (i.e., attribute can only be set by the MAC sublayer), which can be read by the next higher layer using the MLME-GET.request primitive. All other attributes can be read or written by the next higher layer using the MLME-GET.request or MLME-SET.request primitives, respectively.

Table 52a—General MAC PIB attributes for functional organization

Attribute	Type	Range	Description	Default
macRCCNEnabled	Boolean	TRUE or FALSE	An indication of whether the device is using functionality specific to an RCCN. If TRUE, the device is using this functionality. If FALSE, it is not.	Implementation specific
macRCCNNumTimeSlots	Integer	0–254	The number of timeslots within a superframe, excluding the timeslot for beacon frame and management timeslots.	48
macRCCNNumMgmtTS	Integer	0–254	The number of management timeslots.	4
macRCCNNumGtsTS	Integer	0–254	The number of GTS timeslots.	24
macRCCNNetID	Set of octets	variable	A set of octets which contains a network specific identification.	0

Table 52a—General MAC PIB attributes for functional organization

Attribute	Type	Range	Description	Default
macRCCNDevType	Enumeration	RCCPANC, MOBILE, or FIXED	Indicates the type of RCCN device. It may be one of the following device types: a PAN coordinator, a mobile device that is not a PAN coordinator, or a fixed device that is not a PAN coordinator. This attribute is only valid when operating in an RCCN network.	Implementation specific
macRCCNCap†	Set of octets	variable	The PHY capabilities supported.	Implementation specific

8. General PHY requirements

8.1 General requirements and definitions

Insert the following items at the end of the second bulleted list in 8.1:

— **RCC LMR PHYs:** PHYs operating at multiple over-the-air data rates in support of land mobile radio (LMR) for use in rail communications and control (RCC) applications, as defined in 21.2. The five available modulation schemes are: Gaussian minimum shift keying (GMSK), continuous four-level frequency modulation (C4FM), quadrature phase-shift keying (QPSK), Pi/4 differential quadrature phase-shift keying (DQPSK), and direct sequence spread spectrum (DSSS) employing differential phase-shift keying (DPSK).

— **RCC DSSS BPSK PHY:** a DSSS binary phase-shift keying (BPSK) PHY operating at multiple over-the-air data rates for use in RCC applications, as defined in 21.3.

8.1.1 Operating frequency range

Change the first paragraph of 8.1.1 as indicated, and insert the new table (Table 66c):

~~A compliant device shall operate in one or several frequency bands summarized in Table 66, Table 66a and Table 66b.~~ Table 66a shows frequency bands for devices supporting the LECIM DSSS PHY, and Table 66b shows frequency bands for devices supporting the LECIM FSK PHY. Table 66c shows frequency bands for devices supporting the RCC PHYs.

Table 66c—Frequency bands and data rates for RCC PHYs

<table>
<tr><th>Band identifier</th><th>Frequency range (MHz)</th><th>Modulation and bit rate</th></tr>
<tr><td>161</td><td>160.170–161.580</td><td rowspan="4">LMR PHY GMSK: 9.6/19.2 kbps
LMR PHY C4FM: 9.6/19.2/38.4 kbps
LMR PHY QPSK: 16/32 kbps
LMR PHY Pi/4 DQPSK: 16/32/36 kbps</td></tr>
<tr><td>216</td><td>216–217</td></tr>
<tr><td>217</td><td>217–220</td></tr>
<tr><td>220</td><td>220–222</td></tr>
<tr><td>450</td><td>450–470</td><td>LMR PHY GMSK: 9.6/19.2 kbps
LMR PHY C4FM: 9.6/19.2/38.4 kbps
LMR PHY QPSK: 16/32 kbps
LMR PHY Pi/4 DQPSK: 16/32/36 kbps</td></tr>
<tr><td>770</td><td>769–775</td><td rowspan="3">LMR PHY GMSK: 9.6/19.2 kbps
LMR PHY C4FM: 9.6/19.2/38.4 kbps
LMR PHY QPSK: 16/32 kbps
LMR PHY Pi/4 DQPSK: 16/32/36 kbps</td></tr>
<tr><td>800</td><td>799–805</td></tr>
<tr><td>806</td><td>806–821
851–866</td></tr>
</table>

Table 66c—Frequency bands and data rates for RCC PHYs *(continued)*

Band identifier	Frequency range (MHz)	Modulation and bit rate
896	896–901 935–940	LMR PHY GMSK: 9.6/19.2 kbps LMR PHY C4FM: 9.6/19.2/38.4 kbps LMR PHY QPSK: 16/32 kbps LMR PHY Pi/4 DQPSK: 16/32/36 kbps
915	902–928	LMR PHY GMSK: 9.6/19.2 kbps LMR PHY C4FM: 9.6/19.2/38.4 kbps LMR PHY QPSK: 16/32 kbps LMR PHY Pi/4 DQPSK: 16/32/36 kbps LMR PHY DSSS DPSK DSSS BPSK PHY
928	928–960	LMR PHY GMSK: 9.6/19.2 kbps LMR PHY C4FM: 9.6/19.2/38.4 kbps LMR PHY QPSK: 16/32 kbps LMR PHY Pi/4 DQPSK: 16/32/36 kbps
2450	2400–2483.5	DSSS BPSK PHY
4965	4940–4990	LMR PHY DSSS DPSK DSSS BPSK PHY
5800	5725–5850	LMR PHY DSSS DPSK DSSS BPSK PHY

8.1.2 Channel assignments

8.1.2.2 Channel numbering for 868 MHz, 915 MHz, and 2450 MHz bands

Change the first paragraph of 8.1.2.2 as indicated:

This subclause does not apply to the SUN PHY, ~~or~~ LECIM PHY, or RCC PHY specifications. For explanations of channel numbering for the SUN PHYs and LECIM PHYs, see 8.1.2.9 and 8.1.2.12, respectively. For an explanation of channel numbering for the RCC PHYs, see 8.1.2.14.

Insert the following new subclause (8.1.2.14) after 8.1.2.13:

8.1.2.14 Channel numbering for RCC PHYs

A channel page value of 13 indicates an RCC PHY.

Local regulations shall be used to define channel numbering where indicated in Table 68m. For all other bands, the channel center frequency, *ChanCenterFreq*, for an RCC PHY shall be derived as follows:

$$ChanCenterFreq = ChanCenterFreq_0 + NumChan \times ChanSpacing$$

where

ChanCenterFreq$_0$ is the first channel center frequency in MHz
ChanSpacing is the separation between adjacent channels in MHz
NumChan is the channel number from 0 to *TotalNumChan*–1
TotalNumChan is the total number of channels for the available frequency band

The parameters *ChanSpacing*, *TotalNumChan*, and *ChanCenterFreq*$_0$ for each frequency band is specified in Table 68m. The information in the table applies to all RCC modulation schemes.

Table 68m—Total number of channels and first channel center frequencies for RCC PHYs

Band identifier	*ChanSpacing* (MHz)	*TotalNumChan*	*ChanCenterFreq*$_0$ (MHz)
161	0.0075	187	160.1775
216	0.00625	159	216.00625
217	0.00625	479	217.00625
220	0.005	400	220.0025
450	0.00625	3199	450.00625
770	0.00625	960	769.003125
800	0.00625	960	799.003125
806	As defined in US CFR Title 47 (FCC), Part 90, Subpart S, section 90.613		
896	As defined in US CFR Title 47 (FCC), Part 90, Subpart S, section 90.613		
915	0.500	51	902.500
928	0.00625	5119	928.0125
2450	0.2	416	2400.2
4965	As defined in US CFR Title 47 (FCC), Part 90, Subpart Y, section 90.1213		
5800	0.5	249	5725.5

8.1.3 Minimum LIFS and SIFS periods

Change the first paragraph of 8.1.3 as indicated:

For all PHYs other than the UWB and RCC PHYs, the minimum LIFS period and SIFS period are:[3]

— *macLIFSPeriod* – 40 symbols
— *macSIFSPeriod* – 12 symbols

[3]For the MR-OFDM PHY, the MAC symbol duration is defined in 5.1.

Insert the following new paragraph after the first paragraph of 8.1.3:

For the RCC PHYs, the minimum LIFS period and SIFS period are:

— *macLIFSPeriod* – 5 symbols

— *macSIFSPeriod* – 5 symbols

8.2 General radio specifications

8.2.7 Clear channel assessment (CCA)

Change the third paragraph of 8.2.7 as indicated:

The PHY PIB attribute *phyCCAMode*, as described in 9.3, shall indicate the appropriate operation mode. The CCA parameters are subject to the following criteria:

a) Except for the MR-O-QPSK PHY, the ED threshold shall correspond to a received signal power of at most 10 dB greater than the specified receiver sensitivity for that PHY. For the MR-O-QPSK PHY, the ED threshold shall comply with the specification in 16.3.4.13.

b) Except for the 920 MHz band PHYs, ~~and~~ the 950 MHz band PHYs, and the RCC PHYs, the CCA detection time shall be equal to *aCCATime*, as defined in Table 70. For the 920 MHz band, ~~and~~ the 950 MHz band PHYs, and the RCC PHYs, *phyCCADuration* symbol periods shall be used.

9. PHY services

9.2 PHY constants

Change Table 70 (the entire table is not shown) as indicated:

Table 70—PHY constants

Constant	Description	Value
aMaxPHYPacketSize	The maximum PSDU size (in octets) the PHY shall be able to receive.	2047 for SUN, ~~and~~ LECIM FSK, and RCC LMR PHYs. For LECIM DSSS PHY, this is not a constant; refer to *phyLECIMDSSSPSDUSize*. 127 for all other PHYs

9.3 PHY PIB attributes

Change Table 71 (the entire table is not shown) as indicated:

Table 71—PHY PIB attributes

Attribute	Type	Range	Description
phyCCADuration	Integer	~~0~~5–1000	The duration for CCA, specified in symbols. This attribute shall only be implemented with PHYs operating in the 920 MHz band and the 950 MHz band, and with the RCC PHYs.
phyLMRCodingRate	Enumeration	1/2, 2/3, 3/4, 7/8, 1	Controls which puncturing pattern is used for the PSDU, as described in 21.2.2. If the attribute value is one, then FEC shall not be applied.

Insert after Clause 20 the following new clause (Clause 21):

21. RCC PHYs

21.1 General

This clause specifies the PHYs necessary to support RCC applications. An RCC device shall support the LMR PHY with GMSK modulation and a data rate of 9.6 kbps.

21.2 LMR PHY specification

21.2.1 PPDU format

The LMR PHY PPDU shall be formatted as illustrated in Figure 154.

The synchronization header (SHR), PHY header (PHR), and PHY payload components are treated as bit strings of length n, numbered b_0 on the left and b_{n-1} on the right. When transmitted, they are processed b_0 first to b_{n-1} last, without regard to their content or structure.

Bits: 32/64	23			0/6	variable			0/3
	Data FEC Type (4 bits)	Data Length (11 bits)	CRC (8 bits)	PHR FEC Tail	PSDU (variable)	Payload FEC Tail (0/6 bits)	PAD (variable)	
SHR	PHR				PHY payload			Tail

Figure 154—Format of the RCC PPDU

21.2.1.1 SHR

The SHR shall be selected from the list of values shown in Table 72. The SHR shall be transmitted starting from the left-most bit.

Table 72—SHR values for RCC LMR PHY

Modulation	SHR value for FEC coded PHR	SHR value for FEC uncoded PHR
GMSK 9.6/19.2 kbps	1111 1000 0011 1000 1001 0000 1110 1101	0000 0111 1100 0111 0110 1111 0001 0010
C4FM 9.6/19.2/38.4 kbps	0101 0101 0111 1111 1111 01 0101 1111 1101 1111 0111 11 1111 0101 0111 0101 1101	1111 1111 1101 0101 0101 11 1111 0101 0111 0101 1101 01 0101 1111 1101 1111 0111
QPSK 16/32 Kbps	1100 1100 1100 1100 1100 11 1111 0000 0011 0000 1100 00 0000 1111 1100 1111 0011	1100 1100 1100 1100 1100 11 1111 0000 0011 0000 1100 11 1111 0000 0011 0000 1100

Table 72—SHR values for RCC LMR PHY *(continued)*

Modulation	SHR value for FEC coded PHR	SHR value for FEC uncoded PHR
Pi/4 DQPSK 16/32/36 Kbps	0101 0101 0111 1111 1111 01 0101 1111 1101 1111 0111 11 1111 0101 0111 0101 1101	1111 1111 1101 0101 0101 11 1111 0101 0111 0101 1101 01 0101 1111 1101 1111 0111
DSSS DBPSK	1010 1010 1011 1000 1001 0000 1110 1101	10 1010 1011 1000 1001 0111 0001 0010
DSSS DQPSK	1100 1100 1100 1100 1100 11 1111 0000 0011 0000 1100 00 0000 1111 1100 1111 0011	1100 1100 1100 1100 1100 11 1111 0000 0011 0000 1100 11 1111 0000 0011 0000 1100

21.2.1.2 PHR

The Data FEC Type field indicates how the PSDU is encoded. The field shall have one of the values given in Table 73, transmitted leftmost bit first as shown, and shall be set according to the value of *phyLMRCodingRate*. See 21.2.2 for more information on coding.

Table 73—Data FEC Type field for RCC LMR PHY

Data FEC Type field value	Coding rate
0000	1 (no FEC)
0001	7/8
0010	3/4
0011	2/3
0100	1/2
0101–1111	Reserved

The Data Length field specifies the total number of octets contained in the PSDU. The MSB shall be transmitted first.

The Data FEC Type and Data Length fields shall be protected with an 8-bit CRC. The polynomial and the details of its calculation are given in 18.2.1.3. The block diagram shown in Figure 155 is provided as a reference to aid in implementation. The protected bits shall be processed in transmit order, and the CRC field shall be transmitted with the highest term first. All CRC calculations shall be made prior to data whitening.

When FEC is applied to the PHR, the PHR FEC Tail field shall have a length of 6 bits (i.e., six FEC tail bits are appended after the CRC field to aid in FEC decoding). When the PHY header is not FEC protected, the PHR FEC Tail field shall have length zero (i.e., no tail bits are appended).

21.2.1.3 PHY payload

The Payload FEC Tail field shall be present only if the PSDU is FEC protected, as indicated by the Data FEC Type field.

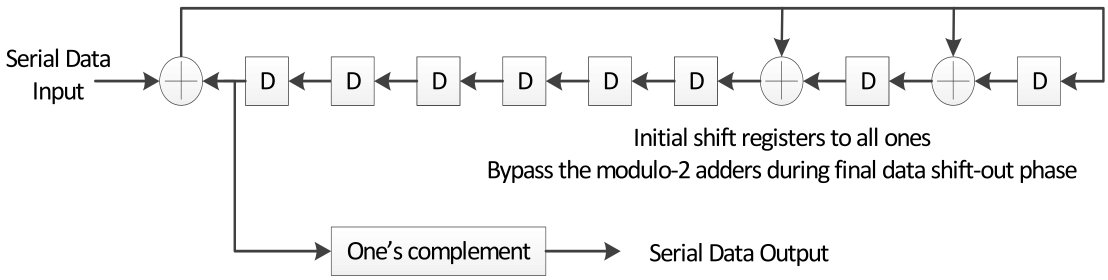

Figure 155—CRC-8 implementation for RCC LMR PHY

The length of the PAD field depends on the selected coding rate. The total number of bits contained in the PSDU, Payload FEC Tail, and PAD fields shall be an integer multiple of the interleaver block size.

21.2.1.4 Tail bits

Three extra zero bits shall be appended at the end of the packet if GMSK modulation is used.

21.2.2 Forward error correction (FEC)

FEC protection of the PHR shall be supported. When FEC is enabled, the rate ½ code shall be used.

FEC protection of the PHY payload shall be supported. The PSDU shall be coded using one of the values contained in Table 73, corresponding to the desired data rate. The convolutional encoder shall use generator polynomials $g_0 = 133_8$ and $g_1 = 171_8$ for rate ½, as shown in Figure 156. Higher rates are achieved by puncturing, according to Figure 11i.

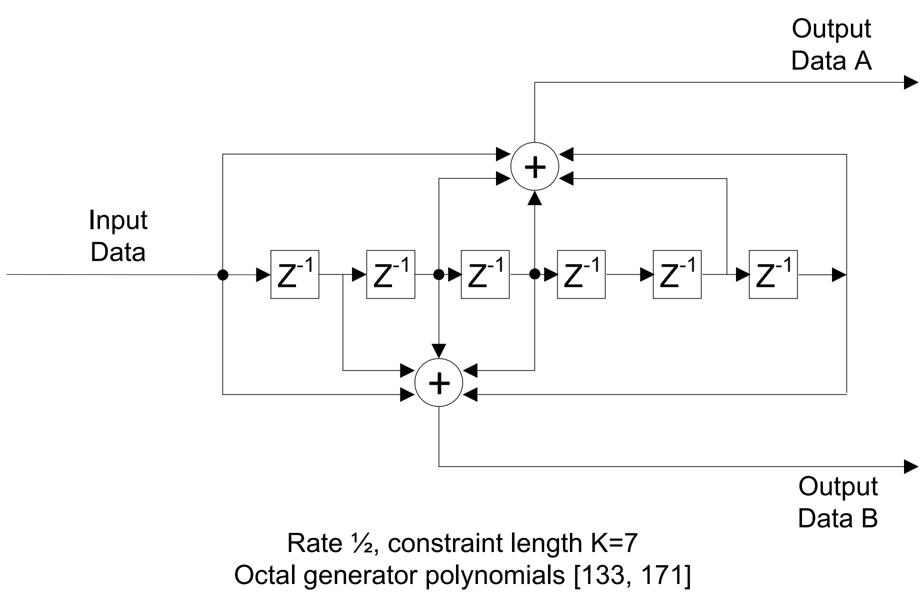

Figure 156—Convolutional encoder for RCC LMR PHY

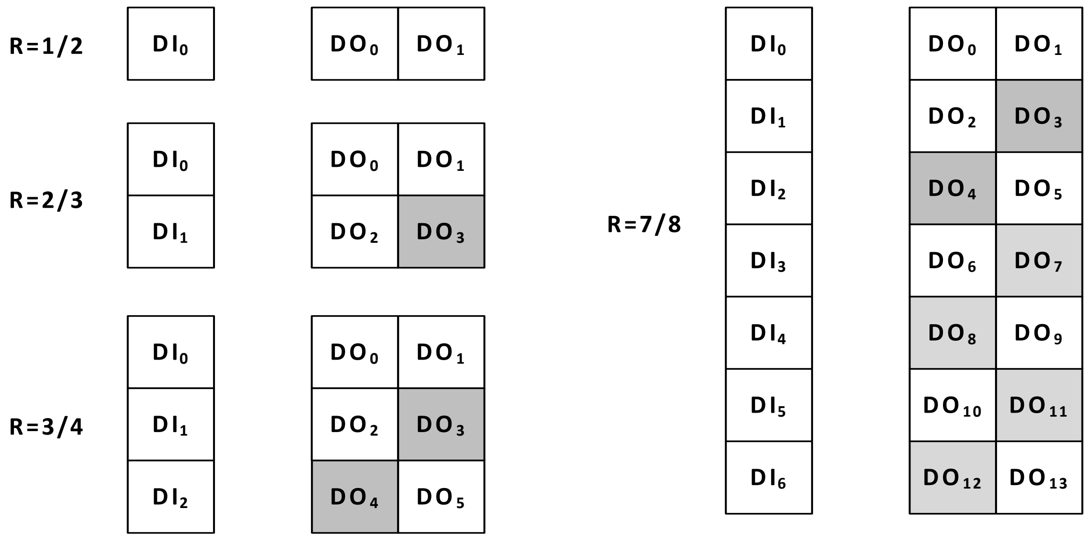

Figure 157—FEC puncturing pattern for RCC LMR PHY

21.2.3 Interleaver

Interleaving of the PHY payload shall be supported. Interleaving shall be enabled when FEC is enabled. Interleaving shall be disabled when FEC is disabled.

The process of interleaving is illustrated in Figure 158.

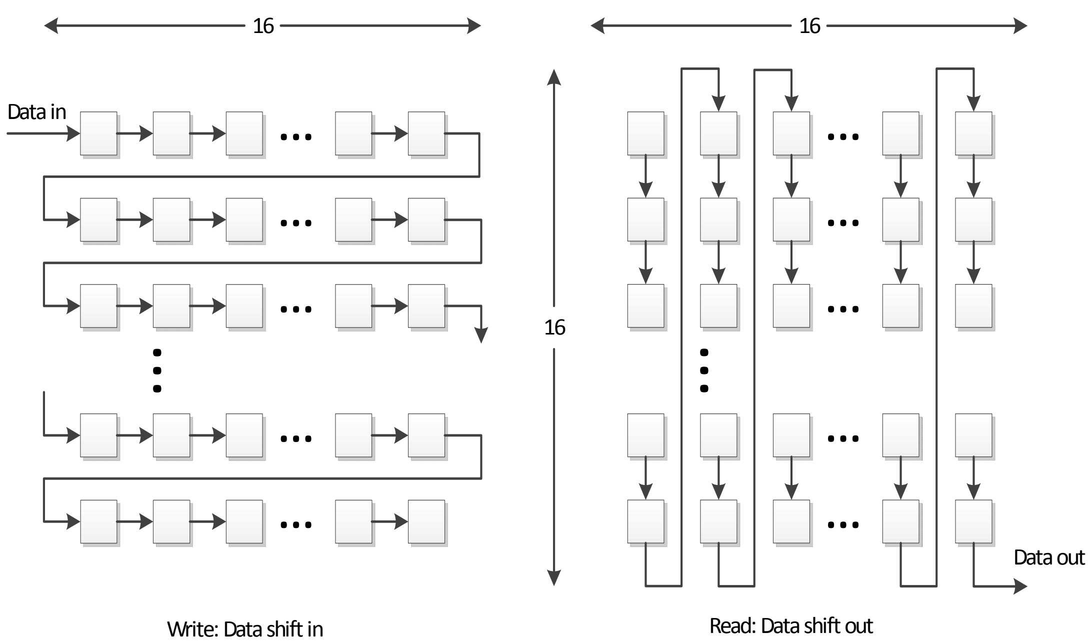

Figure 158—Interleaver for RCC LMR PHY

21.2.4 Data whitening

Data whitening shall be applied to the PHR and PHY payload, as described in 16.1.3.

The PN9 sequence generator shall not be reset between the PHR and the PSDU.

21.2.5 Modulation

This subclause describes the modulation schemes possible with the LMR PHY.

21.2.5.1 GMSK

The bit sequences are modulated onto the carrier using GMSK, where the Gaussian filter BT is nominally 0.3. A bit value of one is transmitted by shifting the frequency higher than the channel center frequency, and a bit value of zero is transmitted by shifting the frequency lower than the channel center frequency.

The nominal frequency deviation shall be 1/4 of the symbol rate. The deviation shall be between 25% and 130% of the nominal deviation. For the sequence 0101, the deviation shall be between 25% and 110% of the nominal deviation. For the sequence 00001111, the deviation shall be between 80% and 130% of the nominal deviation. The excursions for the zero crossings for all trajectories of the eye diagram shall be constrained to within ±12.5% of the symbol time.

21.2.5.2 C4FM

C4FM is a four-level frequency modulation with continuous phase. Figure 159 shows a typical C4FM modulator in a digital implementation. This functional block diagram serves as a reference for specifying the LMR PHY with C4FM modulation.

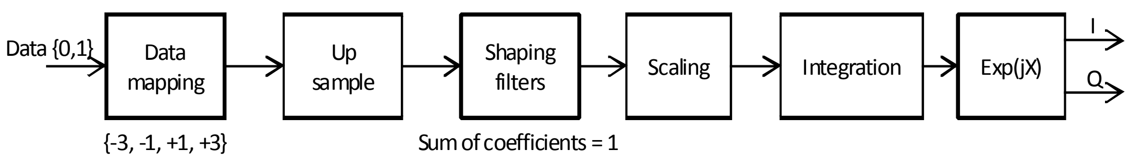

Figure 159—Typical C4FM modulator for RCC LMR PHY

The shaping filters consists of a Nyquist raised cosine filter cascaded with an inverse-sinc filter. The frequency response of the Nyquist raised cosine filter *H(f)* is given by:

$$|H(f)| = 1, \qquad \text{for } |f| < \text{symbol rate} \times 0.4$$

$$|H(f)| = 0.5 + 0.5\cos\left[\frac{2 \times \pi \times f}{\text{symbol rate} \times 0.4}\right], \qquad \text{for } (\text{symbol rate} \times 0.4) < |f| < (\text{symbol rate} \times 0.6)$$

$$|H(f)| = 0, \qquad \text{for } (|f| > \text{symbol rate} \times 0.6)$$

The amplitude response of the inverse-sinc filter *P(f)* is given by:

$$|P(f)| = \left[\frac{\left(\frac{\pi \times f}{\text{symbol rate}}\right)}{\left(\frac{\sin(\pi \times f)}{\text{symbol rate}}\right)}\right], \quad \text{for } |f| < (\text{symbol rate} \times 0.6)$$

The response of *P(f)* for $|f| > \text{symbol rate} \times 0.6$ is not specified for frequencies above $\text{symbol rate} \times 0.6$, since these frequencies are cut off by *H(f)*.

The data mapping and frequency deviation, f_{dev}, are indicated in Table 136 of 18.1.2.2. The value of f_{dev} is $f_{dev} = 3/8 \times \text{symbol rate}$.

The modulation quality is as specified in 18.1.2.3, with the exception that it is measured after the square root raised cosine filter in the receiver.

21.2.5.3 QPSK

Figure 160 shows a typical QPSK modulator in a digital implementation. This functional block diagram serves as a reference for specifying the LMR PHY with QPSK modulation. The bit-to-symbol mapping shall be encoded according to Table 74. The default pulse shaping filter shall be equivalent to a root cosine filter with a roll-off factor of 0.25.

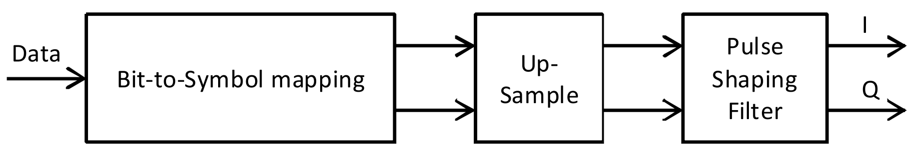

Figure 160—Typical QPSK modulator for RCC LMR PHY

Table 74—QPSK encoding values for RCC LMR PHY

Data $\{b_1, b_0\}$	Phase
01	$+3/4 \times \pi$
00	$+1/4 \times \pi$
10	$-1/4 \times \pi$
11	$-3/4 \times \pi$

21.2.5.4 Pi/4 DQPSK

Figure 161 shows a typical Pi/4 DQPSK modulator in a digital implementation. This functional block diagram is provided as a reference for specifying the LMR PHY using Pi/4 DQPSK modulation. The bit-to-symbol mapping and differential encoding shall be encoded according to Table 75. The default pulse shaping filter shall be a root raised cosine filter with a roll-off factor of 0.25.

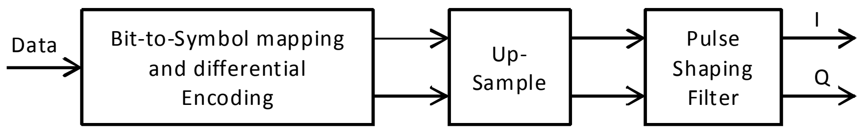

Figure 161—Typical Pi/4 DQPSK modulator for RCC LMR PHY

Table 75—Pi/4 DQPSK encoding values for RCC LMR PHY

Data $\{b_1, b_0\}$	Phase change
01	$+3/4 \times \pi$
00	$+1/4 \times \pi$
10	$-1/4 \times \pi$
11	$-3/4 \times \pi$

21.2.5.5 DSSS DPSK

The modulation for DSSS DPSK is either DSSS DBPSK or DSSS DQPSK.

The functional block diagram shown in Figure 162 is provided as a reference for specifying the DSSS DPSK modulation and spreading functions.

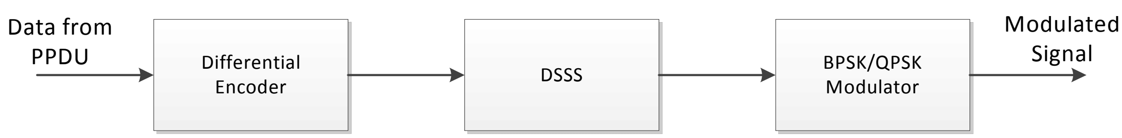

Figure 162—DSSS DPSK modulation and spreading

The bit-to-symbol mapping and differential encoding for DSSS DBPSK shall be encoded according to Table 76.

Table 76—DSSS DBPSK encoding table

Data	Phase change
0	0
1	π

The bit-to-symbol mapping and differential encoding for DSSS DQPSK shall be encoded according to Table 77.

Table 77—DSSS DQPSK encoding table

Dibit pattern (d_0,d_1)[a]	Phase change
00	0
01	$\frac{\pi}{2}$
11	π
10	$-\frac{\pi}{2}$

[a]Bit d_0 is transmitted first in time.

The spreading sequences are specified in Table 78. The leftmost chip shall be transmitted first in time.

Table 78—DSSS DPSK spreading sequences

Spreading sequence length	Spreading sequence
11	111 0001 0010
15	101 1111 0100 0110
20	1010 1000 0011 0110 0111
40	1010 0011 1001 0010 1101 1101 1001 1010 1011 1111

The chip rates are specified in Table 79.

Table 79—DSSS DPSK chip rates

DSSS DPSK chip rates
300 kcps
600 kcps
800 kcps
1 Mcps
1.6 Mcps
2 Mcps

Table 79—DSSS DPSK chip rates *(continued)*

DSSS DPSK chip rates
3 Mcps
4 Mcps

21.2.6 Reference modulator diagram

The functional block diagram in Figure 163 serves as a reference for specifying the LMR PHY data flow processing functions. Data whitening shall be applied over the PHR and PHY payload continuously. The six FEC tail bits shall be replaced by six non-scrambled zeros prior to FEC encoding. When FEC is enabled, FEC processing for the PHR and PHY payload shall be performed separately.

All fields in the PPDU shall use the same symbol rate and modulation.

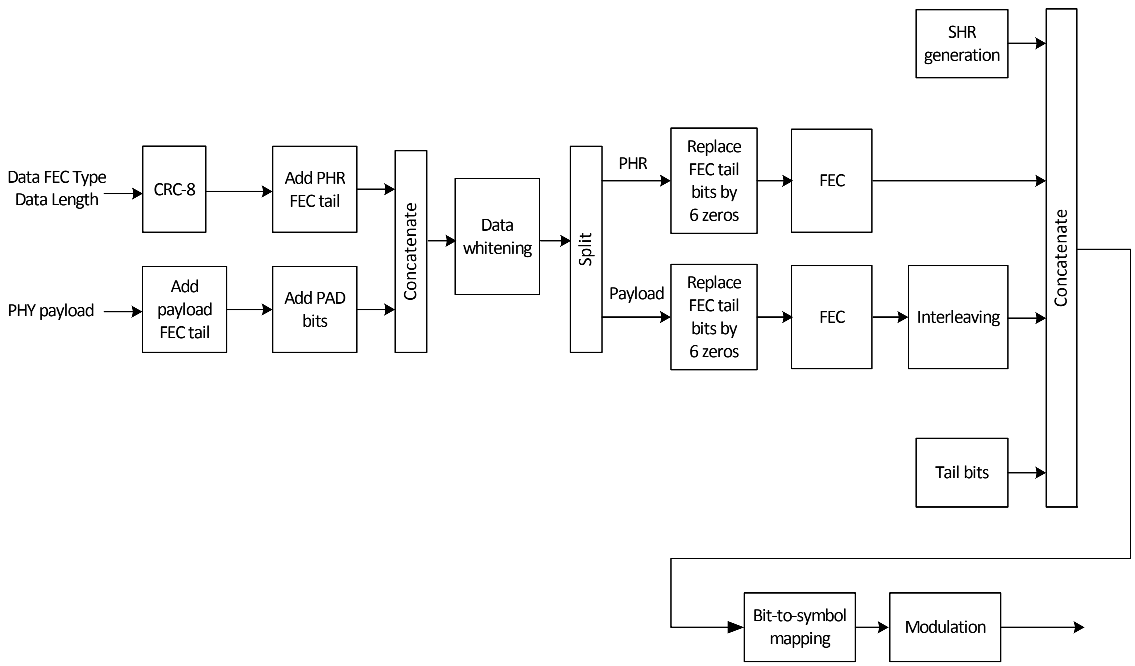

Figure 163—RCC LMR PHY reference modulator diagram

21.2.7 LMR PHY RF requirements

21.2.7.1 Transmitter symbol rate tolerance

The transmitter symbol rate error shall be less than or equal to ± 5 ppm.

21.2.7.2 Channel switching time

The channel switching time shall be less than or equal to 500 μs.

21.2.7.3 Transmit power spectral density (PSD) mask

The LMR PHY transmit spectral mask shall conform with local regulations.

21.2.7.4 Error vector magnitude

When the LMR PHY is using either QPSK or Pi/4 DQPSK modulation, it shall have EVM values of less than 35% when measured for 1000 symbols using the measurement process defined in 8.2.3.

21.2.7.5 Transmit power

The maximum transmit power is limited by local regulatory bodies.

21.2.7.6 Receiver sensitivity

Receiver sensitivity is implementation specific, however, the method for measuring receiver sensitivity is described in 8.1.7.

21.2.7.7 Receiver interference rejection

The minimum receiver interference rejection is implementation specific.

21.2.7.8 Receiver maximum input level of desired signal

The receiver maximum input level is implementation specific.

21.2.7.9 TX-to-RX turnaround time

The TX-to-RX turnaround time shall be less than or equal to 5 symbols.

21.2.7.10 RX-to-TX turnaround time

The RX-to-TX turnaround time shall be less than or equal to 5 symbols.

21.2.7.11 Receiver energy detection (ED)

The LMR PHY shall provide the receiver ED measurement, as described in 8.2.5.

21.2.7.12 Link quality indicator (LQI)

The LMR PHY shall provide the LQI measurement, as described in 8.2.6.

21.2.7.13 Clear channel assessment (CCA)

The LMR PHY shall use one of the CCA methods described in 8.2.7.

21.3 DSSS BPSK PHY specification

The DSSS BPSK PHY shall employ the BPSK PHY specified in Clause 11, with the exception that the bit-to-chip mapping is changed as shown in Table 80.

Table 80—DSSS BPSK PHY bit-to-chip mapping

Input bit	Chip values (c_0, c_1,..., c_{14})
0	1 1 0 1 0 1 0 1 1 0 0 1 0 0 0
1	0 0 1 0 1 0 1 0 0 1 1 0 1 1 1

Annex A

(informative)

Bibliography

Insert the following new references alphanumerically in Annex A:

[B37] Doong, M., "Link Analysis Example," IEEE 802.15 Working Group for Wireless Personal Area Networks (WPAN), Doc. IEEE 15-13-0600-00-004p, Oct. 2013.

[B38] IEEE Std 1474.1™-2004, IEEE Standard for Communications-Based Train Control (CBTC) Performance and Functional Requirements.[4, 5]

[4]The IEEE standard or product referred to in this annex is a trademark of The Institute of Electrical and Electronics Engineers, Inc.
[5]This publication is available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

Annex D

(informative)

Protocol implementation conformance statement (PICS) proforma[6]

Subclause D.2 is reproduced here to assist the reader in understanding the abbreviations and special symbols in this annex. No changes are made to D.2.

D.2 Abbreviations and special symbols

Notations for requirement status:

M Mandatory
O Optional
O.n Optional, but support of at least one of the group of options labeled O.n is required.
N/A Not applicable
X Prohibited
"item": Conditional, status dependent upon the support marked for the "item"

For example, FD1: O.1 indicates that the status is optional but at least one of the features described in FD1 and FD2 is required to be implemented, if this implementation is to follow the standard to which this PICS proforma is part.

D.7 PICS proforma tables

D.7.2 Major capabilities for the PHY

D.7.2.1a PHY packet

Change Table D.2a as indicated:

Table D.2a—PHY packet

Item number	Item description	Reference	Status	Support		
				N/A	Yes	No
PLP1	PSDU size up to 2047 octets	9.2	~~FD6~~ FD8, FD9, RF21.1, RF21.2, RF21.3, RF21.4, RF21.5: M			

[6]Copyright release for PICS proformas: Users of this standard may freely reproduce the PICS proforma in this annex so that it can be used for its intended purpose and may further publish the completed PICS.

D.7.2.2 Radio frequency (RF)

Insert the following new rows at the end of Table D.3:

Table D.3—Radio frequency (RF)

Item number	Item description	Reference	Status	Support		
				N/A	Yes	No
RF21	RCC PHYs	Table 66c, Clause 21 RCC PHYs	O.3			
RF21.1	RCC LMR GMSK	21.2.5.1	M			
RF21.2	RCC LMR C4FM	21.2.5.2	O			
RF21.3	RCC LMR QPSK	21.2.5.3	O			
RF21.4	RCC LMR Pi/4 DQPSK	21.2.5.4	O			
RF21.5	RCC LMR DSSS DPSK	21.2.5.5	O			
RF21.6	DSSS BPSK	21.3	O			
RF22	RCC LMR GMSK data rate	Table 66c	O.3			
RF22.1	9.6 kbps	Table 66c	M			
RF22.1	19.2 kbps	Table 66c	O			

D.7.3 Major capabilities for the MAC sublayer

D.7.3.1 MAC sublayer functions

Insert the following new rows at the end of Table D.5:

Table D.5—MAC sublayer functions

Item number	Item description	Reference	Status	Support		
				N/A	Yes	No
MLF36	RCC capability		O			
MLF36.1	RCCN superframe structure	5.1.1.6a	MLF36: M			
MLF36.2	RCCN IEs	5.2.4.28a, 5.2.4.29.3, 5.2.4.36, 5.2.4.37	MLF36: M			

Insert after Annex T the following new annex (Annex U):

Annex U

(informative)

Rail communications and control (RCC) systems

U.1 General description

For the purposes of this standard, an RCC system refers to a wireless communications system used for rail vehicle data communications between the rail vehicle and fixed infrastructure. This standard applies to information exchange and sensor or control communications.

Portions of RCC systems are deployed as:

— A wireless link between trains, locomotives, or other mobile rolling stock to fixed trackside or network infrastructure

— A link between connected fixed, remote trackside infrastructure and fixed network infrastructure

— A link between vehicles in the same train or between two or more trains

This standard is capable of supporting fixed-to-fixed, fixed-to-mobile, and mobile-to-mobile communications.

RCC PHYs are designed in such a manner that ranges of over 50 km are practical, subject to propagation path loss, transmitter output power, carrier frequency, data rate, and antenna placement/height above average terrain. RCC PHYs are intended to support mobile rail vehicle communications at speeds up to 600 km/h and data rates from 9.6 kbps to nearly 1 Mbps. The PHYs are designed to take advantage of relatively small amounts of spectrum where spectrum is costly or scarce, with the ability to operate in channel widths from 12.5 kHz (licensed spectrum) to nearly 2 MHz (license-exempt spectrum).

U.2 Introduction to communications-based train control (CBTC)

As defined by IEEE Std 1474.1-2004 [B38], a CBTC system is a "continuous, automatic train control system utilizing high-resolution train location determination, independent of track circuits; continuous, high-capacity, bidirectional train-to-wayside data communications; and trainborne and wayside processors capable of implementing Automatic Train Protection (ATP) functions, as well as optional Automatic Train Operation (ATO) and Automatic Train Supervision (ATS) functions." This standard provides the bidirectional train-to-wayside data communications function. Many of the largest metropolitan rail transit systems in the world use CBTC.

This standard provides a bi-directional wireless communications link that can be used for CBTC systems, and has the flexibility to employ either licensed or license-exempt frequency bands to provide flexibility and robustness.

U.3 Example: positive train control (PTC)

In 2008, the United States Congress enacted a law called the Rail Safety Improvement Act of 2008, in order to improve rail safety. The law uses the phrase “positive train control system” to describe a safety system designed to prevent train-to-train collisions, over-speed derailments, incursions into established work zone limits, and the movement of a train through a switch left in the wrong position. The law does not specify implementation of such a system.

As interpreted by the US Federal Railroad Administration, a PTC system includes four components:

— Equipment deployed on the locomotive/train
— Equipment deployed trackside
— Network access points deployed at or near trackside that are connected to systems operating at a remotely located control center
— A bi-directional wireless data link that connects all these elements

PTC systems are integrated command, control, communications, and information systems for controlling train movements with safety, security, precision, and efficiency. PTC systems will improve railroad safety by significantly reducing the probability of collisions between trains, casualties to roadway workers and damage to their equipment, and overspeed accidents.

PTC systems are composed of digital data link communications networks, continuous and accurate positioning systems such as National Differential GPS, on-board computers with digitized maps on locomotives and maintenance-of-way equipment, in-cab displays, throttle-brake interfaces on locomotives, wayside interface units at switches and wayside detectors, and control center computers and displays. PTC systems also interface with tactical and strategic traffic planners, work order reporting systems, and locomotive health reporting systems. PTC systems issue movement authorities to train and maintenance-of way crews, track the location of the trains and maintenance-of-way vehicles, have the ability to automatically enforce movement authorities, and continually update operating data systems with information on the location of trains, locomotives, cars, and crews. A remote intervention capability of a PTC system permits the control center to stop a train should the locomotive crew be incapacitated.

A number of radio frequency bands currently used or planned for rail and rail transit communications are included in this standard. Also included are modulation modes and error-correction techniques that enhance functionality for low-data rate rail and rail transit communications.

U.4 RCC network

A typical RCC network (RCCN) concurrently supports both star and peer-to-peer topologies in order to allow communication between the control center and various endpoints, as depicted in Figure 11i.

An RCCN base station is a fixed device that provides gateway access to the backhaul network. RCCN endpoints are mobile (e.g., a locomotive) or fixed (e.g., a wayside device). Communication between the fixed endpoints and mobile endpoints are either through a base station or directly peer-to-peer. A base station is not always in range of the endpoints.

When a base station is available, it acts as an RCCN PAN coordinator, transmitting a periodic beacon and defining an RCCN superframe, as described in 5.1.1.6a.

When an RCCN endpoint is not receiving beacons from an RCCN PAN coordinator, the RCCN endpoints communicate directly using contention access.

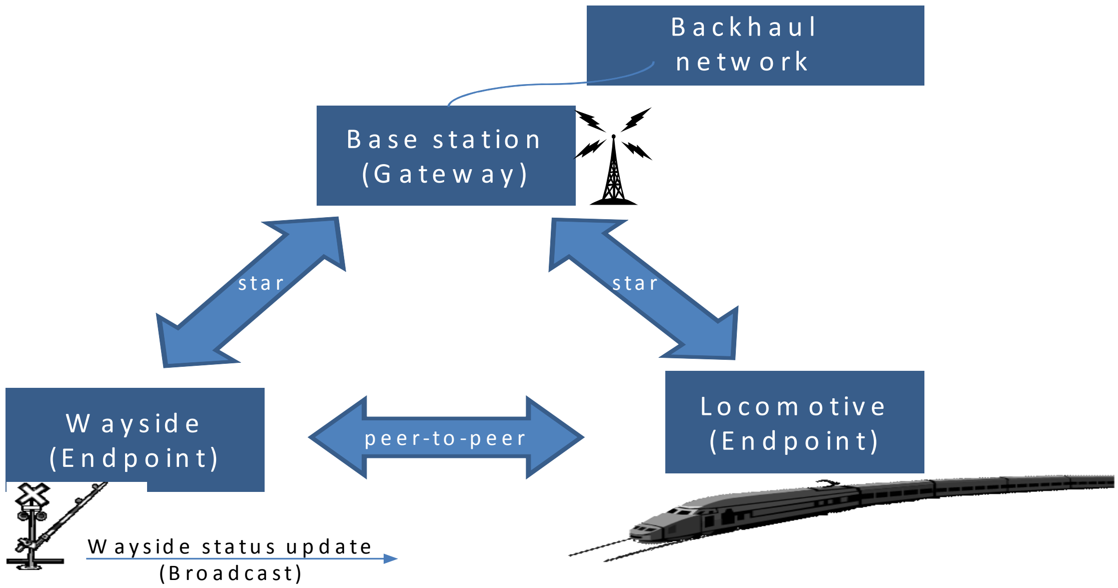

Figure U.1—A typical RCCN