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STANDARD

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IEEE
8802-15-4

Second edition
2018-03

**Information technology —
Telecommunications and information
exchange between systems — Local
and metropolitan area networks —
Specific requirements —**

**Part 15-4:
Wireless medium access control
(MAC) and physical layer (PHY)
specifications for low-rate wireless
personal area networks (WPANs)**

*Technologies de l'information — Télécommunications et échange
d'information entre systèmes — Réseaux locaux et métropolitains —
Exigences spécifiques —*

*Partie 15-4: Spécifications du contrôle d'accès du milieu sans fil
(MAC) et de la couche physique (PHY) pour les réseaux personnels
sans fil de faible débit (WPAN)*



Reference number
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Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

Institute of Electrical and Electronics Engineers, Inc
3 Park Avenue, New York
NY 10016-5997, USA

stds.ipr@ieee.org
www.ieee.org

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This second edition cancels and replaces the first edition (ISO/IEC/IEEE 8802-15-4:2010), which has been technically revised.

A list of all parts in the ISO/IEC/IEEE 8802 series can be found on the ISO website.

IEEE Std 802.15.4™-2015

(Revision of
IEEE Std 802.15.4-2011)

IEEE Standard for Low-Rate Wireless Networks

Sponsor

**LAN/MAN Standards Committee
of the
IEEE Computer Society**

Approved 5 December 2015

IEEE-SA Standards Board

Abstract: The protocol and compatible interconnection for data communication devices using low-data-rate, low-power, and low-complexity short-range radio frequency (RF) transmissions in a wireless personal area network (WPAN) are defined in this standard. A variety of physical layers (PHYs) have been defined that cover a wide variety of frequency bands.

Keywords: ad hoc network, IEEE 802.15.4™, low data rate, low power, LR-WPAN, mobility, PAN, personal area network, radio frequency, RF, short range, wireless, wireless personal area network, WPAN

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

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Elad Gottlib	Hiroyuki Matsumura	Peter Yee
Jussi Haapola	Michael McLaughlin	Yu Zeng
Rainer Hach	Michael McInnis	Chunhui (Allan) Zhu
	Kenichi Mori	

Major contributions in the revision process were received from the following individuals:

Philip Beecher	Jeritt Kent	Benjamin A. Rolfe
Monique Brown	Patrick W. Kinney	Ruben E. Salazar Cardozo
Edgar Callaway	Tero Kivinen	Cristina Seibert
Soo-Young Chang	Amarjeet Kumar	Kunal Shal
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Major contributions were received from the following individuals:

Tony Adamson
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 David Avery
 Venkat Bahl
 Daniel Bailey
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Tracy Wright
Hirohisa Yamaguchi
Kamya Yekeh Yazdandoost

Su-Khiong Yong
Zhan Yu
Serdar Yurdakul
Mahmoud Zadeh
Bin Zhen

Major contributions in the revision process were received from the following individuals:

Jon Adams
Helmut P. Adamski
Jonathan Avey
Jon Beniston
Bernd Grohmann
José A. Gutierrez
Jesper Holm
ZhiJian Hu
Phil A. Jamieson
Yuen-Sam Kwok

Colin Lanzl
Myung Lee
Zhongding Lei
Liang Li
Yong Liu
Frederick Martin
Frank Poegel
Matthias Scheide
D. C. Seward

Huai-Rong Shao
Mark Shea
Stephen J. Shellhammer
Mark A. Tillinghast
Johannes Van Leeuwen
Richard Wilson
Ping Xiong
Bing Xu
ChenYang Yang
Chunhui Zhu

The following members of the IEEE P802.15 Working Group participated in the development of the second revision, IEEE Std 802.15.4-2011:

Robert F. Heile, Chair
Rick Alfvin, Co-Vice Chair
Patrick W. Kinney, Co-Vice Chair
James P. K. Gilb, Working Group Technical Editor
Patrick W. Kinney, Secretary

James P. K. Gilb, Task Group 4i Chair and Technical Editor

Emad Afifi
Gahng-Seop Ahn
Roberto Aiello
Arthur Astrin
Taehan Bae
Michael Bahr
John Barr
Anuj Batra
Tuncer Baykas
Philip E. Beecher
Ashutosh Bhatia
Ghulam Bhatti
Gary Birk
Mathew Boytim
Peter David Bradley
Nancy Bravin
David Britz
Monique B. Brown
Sverre Brubk
Brian Buchanan
John Buffington
Kiran Bynam
Brent Cain
Edgar H. Callaway
Chris Calvert

Ruben E. Salazar Cardozo
Douglas Castor
Jaesang Cha
Russell Chandler
Kuo-Hsin Chang
Soo-Young Chang
Clint Chaplin
Hind Chebbo
Chang-Soon Choi
Sangsung Choi
Ciaran Connell
David Cypher
Matthew Dahl
David Davenport
Mark Dawkins
Hendricus de Ruijter
Upkar Dhaliwal
Gang Ding
Paul Dixon
Guido Dolmans
Igor Dotlic
Michael Dow
Dietmar Eggert
David Evans
Charles Farlow

John Farserotu
Jeffrey Fischbeck
Mike Fischer
George Flammer
Ryosuke Fujiwara
Noriyasu Fukatsu
Kiyoshi Fukui
John Geiger
Gregory Gillooly
Tim Godfrey
Paul Gorday
Elad Gottlieb
Robert Hall
Shinsuke Hara
Hiroshi Harada
Timothy Harrington
Rodney Hemminger
Marco Hernandez
Garth Hillman
Jin-Meng Ho
Wei Hong
Srinath Hosur
David Howard
Jung-Hwan Hwang
Taeho Hwang

Ichirou Ida	Robert Moskowitz	Steve Shearer
Tetsushi Ikegami	Hamilton Moy	Stephen Shellhammer
Akio Iso	Peter Murray	Shusaku Shimada
Yeong Min Jang	Theodore Myers	Chang Sub Shin
Adrian Jennings	Chiu Ngo	Cheol Ho Shin
Wuncheol Jeong	Paul Nikolic	Michael Sim
Steven Jillings	Hirohito Nishiyama	Jonathan Simon
Noh-Gyoung Kang	David Olson	Jaeseung Son
Tae-Gyu Kang	Okundu Omeni	Paul Stadnik
Shuzo Kato	Ryoji Ono	René Struik
Tatsuya Kato	Laurent Ouvry	Chin-Sean Sum
Jeritt Kent	James Pace	Hui-Hsia Sung
Prithpal Khakuria	Hyung-Il Park	Gu Sungi
Dae Ho Kim	Jahng Park	Kenichi Takizawa
Dong-Sun Kim	Seung-Hoon Park	Hirokazu Tanaka
Dukhyun Kim	Taejoon Park	Larry Taylor
Jaehwan Kim	Ranjeet Patro	Mark Thompson
Jeffrey King	Al Petrick	James Tomcik
Ryuji Kohno	Dalibor Pokrajac	Ichihiko Toyoda
Fumihide Kojima	Daniel Popa	David Tracey
Bruce Kraemer	Stephen Pope	Khanh Tran
Raymond Krasinski	Clinton C. Powell	Jerry Upton
Masahiro Kuroda	Richard Powell	Jana van Greunen
John Lampe	Chang-Woo Pyo	Hartman van Wyk
Zhou Lan	Mohammad Rahman	Michel Veillette
Khanh Le	Sridhar Rajagopal	Billy Verso
Cheolhyo Lee	Jayaram Ramasastry	Bhupender Virk
Hyungsoo Lee	Marc Reed	Joachim Walewski
Myung Lee	Ivan Reede	Junyi Wang
Daniel Lewis	Richard Roberts	Quan Wang
Huan-Bang Li	Craig Rodine	Xiang Wang
Liang Li	June Chul Roh	Andy Ward
Sang-Kyu Lim	Benjamin A. Rolfe	Scott Weikel
Jeremy Link	Seung-Moon Ryu	Nicholas West
Mike Lynch	Didier Sagan	Mark Wilbur
Robert Mason	Kentaro Sakamoto	Ludwig Winkel
Tomokuni Matsumura	Will San Filippo	Eun Tae Won
Jeff McCullough	H. Sanderford	Alan Chi Wai Wong
Michael McGillan	Kamran Sayrafian	Tao Xing
Michael D. McInnis	Timothy Schmidl	Wen-Bin Yang
Michael McLaughlin	Michael Schmidt	Yang Yang
Charles Millet	Jean Schwoerer	Kazuyuki Yasukawa
Siamak Mirnezami	Cristina Seibert	Kamya Yazdandoost
Rishi Mohindra	Neal Seidl	Kaoru Yokoo
Emmanuel Monnerie	Kunal Shah	Mu Zhao
Rajendra Moorti		Bin Zhen

Major contributions in the revision process were received from the following individuals:

Philip E. Beecher	Clint Chaplin	Clinton C. Powell
Vern Brethour	James P. K. Gilb	Benjamin A. Rolfe
Monique B. Brown	Patrick W. Kinney	Timothy Schmidl
Edgar H. Callaway	Michael D. McInnis	René Struik
Kuor-Hsin Chang		Billy Verso

Introduction

This introduction is not part of IEEE Std 802.15.4™-2015, IEEE Standard for Low-Rate Wireless Networks.

This is the third revision of IEEE Std 802.15.4. From the beginning, the goal of the IEEE P802.15 Working Group was to produce a standard that enabled very low-cost, low-power communications. The initial standard, IEEE Std 802.15.4-2003, defined two optional physical layers (PHYs), operating in different frequency bands with a simple and effective medium access control (MAC).

In 2006, the standard was revised and added two more PHY options. The MAC remained backward compatible, but the revision added MAC frames with an increased version number and a variety of MAC enhancements, including the following:

- Support for a shared time base with a data time stamping mechanism
- Support for beacon scheduling
- Synchronization of broadcast messages in beacon-enabled personal area networks (PANs)
- Improved MAC layer security

In 2011, the standard was revised to include the three amendments approved subsequent to the 2006 revision. This effort added four more PHY options along with the MAC capability to support ranging. Additionally, the organization of the standard was changed so that each PHY would have a separate clause, and the MAC clause was split into functional description, interface specification, and security specification.

The current revision of the standard was created to roll in the amendments approved subsequent to the 2011 revision: six PHY amendments and one MAC amendment, with corrigenda and clarifications. The features added by the amendments include the following:

- Enhanced frame formats maintaining backward compatibility
- Information Elements (IEs)
- Channel agility
- Extended superframe options
- Low-energy mechanisms
- An enhanced acknowledgment frame that can carry data and can be secured
- Prioritized channel access
- A variety of new PHY modulation, coding, and band options to support a wide variety of application needs including radio frequency identification (RFID), smart utility networks (SUNs), television white space (TVWS) operation, low-energy critical infrastructure monitoring (LECIM), and rail communications and control (RCC).

Much of the corrigenda and clarifications were collected from requests from individuals after the revision in 2011. Major corrigenda items included changes to the security text to correct errors and clarify the text, removal of the encrypt only mode, addition of security policy checks for the IEs, corrections regarding personal area network identifier (PAN ID) compression behavior to eliminate ambiguous specification, and changes to the IEs subclauses to include more information necessary for users of this standard.

The Project Authorization Request (PAR) for IEEE Std 802.15.4-2015 was first proposed in July 2013 and was approved in October 2013 by IEEE's New Standards Committee (NesCom). After three working group ballots and two sponsor ballots, the final standard was approved in December 2015, just over two years from start to finish.

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IEEE Standard for Low-Rate Wireless Networks

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1. Overview

1.1 Scope

This standard defines the physical layer (PHY) and medium access control (MAC) sublayer specifications for low-data-rate wireless connectivity with fixed, portable, and moving devices with no battery or very limited battery consumption requirements. In addition, the standard provides modes that allow for precision ranging. PHYs are defined for devices operating various license-free bands in a variety of geographic regions.

1.2 Purpose

The standard provides for ultra low complexity, ultra low cost, ultra low power consumption, and low data rate wireless connectivity among inexpensive devices. In addition, one of the alternate PHYs provides precision ranging capability that is accurate to one meter. Multiple PHYs are defined to support a variety of frequency bands.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI X3.66-1979, Advanced Data Communication Control Procedures.¹

Code of Federal Regulations, Title 47: Telecommunication, Part 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 (47 CFR, Part 90, Subpart S).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 (47 CFR, Part 90, Subpart Y).

FIPS Pub 197, Advanced Encryption Standard (AES).³

IEEE Std 802[®]-2014, IEEE Standards for Local and Metropolitan Area Networks: Overview and Architecture.^{4, 5}

IETF RFC 6225, Dynamic Host Configuration Protocol Options for Coordinate-Based Location Configuration Information, Internet Engineering Task Force.⁶

¹ANSI publications are available from the American National Standards Institute (<http://www.ansi.org/>)

²CFR publications are available from the U.S. Government Printing Office (<http://www.gpo.gov/>).

³FIPS publications are available from the National Technical Information Service (NTIS) (<http://www.ntis.org/>).

⁴IEEE publications are available from The Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

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⁶IETF RFCs are available from the Internet Engineering Task Force (<http://www.ietf.org/>).

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary* should be consulted for terms not defined in this clause.⁷

association: The service used to establish membership for a device in a network.

authentication tag: Information that allows the verification of authenticity of a message.

channel hopping: Periodically switching the channel using a sequence known to both sending and receiving devices where the entire frame is sent on a single channel.

channel offset: A number used in the channel calculation of a slotted channel hopping system to allow for different channels to be used in the same slot.

chirp: Linear frequency sweep (frequency may either increase or decrease).

dependent device: A device that operates without direct Internet access to the television white space (TVWS) database and depends on another device for channel availability information.

encryption: The transformation of a message into a new representation so that privileged information is required to recover the original representation.

fragment: An individual subset of a MAC protocol data unit.

frame: The format of aggregated bits from a medium access control sublayer entity that are transmitted together in time.

group key: A key that is known only to a set of devices.

independent device: A device that has direct access to the television white space (TVWS) database via the Internet.

key: Privileged information that may be used, for example, to protect information from disclosure to, and/or undetectable modification by, parties that do not have access to this privileged information.

keying material: The combination of a key and associated security information (e.g., a nonce value).

link key: A secret key that is shared between precisely two devices.

mobile device: A device whose location in the network may change during use.

nonce: A nonrepeating value, such as an increasing counter, a sufficiently long random string, or a time stamp.

packet: The formatted, aggregated bits that are transmitted together in time across the physical medium.

payload data: The contents of a data message that is being transmitted.

⁷*IEEE Standards Dictionary* subscription is available at
http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

radio frequency identification (RFID): The use of electromagnetic or inductive coupling in the radio frequency (RF) portion of the spectrum to communicate to or from a tag through a variety of modulation and encoding schemes to uniquely read the identity of an RF tag.

slotframe: A collection of timeslots repeating in time, analogous to a superframe in that it defines periods of communication opportunities.

smart utility network (SUN): a principally outdoor, low data rate wireless network that supports two-way communications among sensing, measurement, and control devices in the smart grid.

symmetric key: A secret key that is shared between two or more parties that may be used for encryption/decryption or integrity protection/integrity verification, depending on its intended use.

timeslot: A defined period of time during which a frame and an acknowledgment may be exchanged between devices.

transaction: The exchange of related, consecutive frames between two peer medium access control (MAC) entities, required for a successful transmission of a MAC command frame or Data frame.

3.2 Acronyms and abbreviations

Ack	acknowledgment
AES	advanced encryption standard
AIFS	acknowledgment interframe spacing
AR	acknowledgment request
ASK	amplitude shift keying
ASN	absolute slot number
ATI	allowed transmission interval
BCH	Bose Chaudhuri Hocquenghem
BDE	bit differential encoding
BLE	battery life extension
BOP	beacon only period
BPM	burst position modulation
BPSK	binary phase-shift keying
BSN	beacon sequence number
CAP	contention access period
CBC-MAC	cipher block chaining message authentication code
CCA	clear channel assessment
CCM	counter mode encryption and cipher block chaining message authentication code
CCM*	extension of counter mode encryption and cipher block chaining message authentication code
CFP	contention-free period
CID	company identifier
CP	cyclic prefix
CoU	chirp on ultra-wide band
CRC	cyclic redundancy check
CS	continuous spectrum
CSK	chirp-shift keying
CSL	coordinated sampled listing

CSM	common signaling mode
CSMA-CA	carrier sense multiple access with collision avoidance
CSS	chirp spread spectrum
DA	device announcement
DAA	detect and avoid
DBS	dedicated beacon slot
DEMUX	de-multiplexer
DFT	discrete Fourier transform
DPS	dynamic preamble selection
DPSK	differential phase-shift keying
DQCSK	differential quadrature chirp-shift keying
DQPSK	differential quadrature phase-shift keying
DSME	deterministic and synchronous multi-channel extension
DSN	data sequence number
DSSS	direct sequence spread spectrum
EBSN	enhanced beacon sequence number
ED	energy detection (also in 6.2.8, extended duration)
EIRP	effective isotropic radiated power
Enh-Ack	enhanced acknowledgment
ESDU	encapsulated service data unit
EUI-64	64-bit extended unique identifier
EVM	error-vector magnitude
FCC	Federal Communications Commission
FCS	frame check sequence
FEC	forward error correction
FFD	full-function device
FICS	fragment integrity check sequence
FoM	figure of merit
Frak	fragment acknowledgment
FSCD	fragment sequence context description
FSK	frequency shift keying
GDB	geolocation database
GFSK	Gaussian frequency-shift keying
GMSK	Gaussian-filtered minimum shift keying
GTS	guaranteed time slot
HCS	header check sequence
HRP	high rate pulse repetition frequency
ID	identifier
IDFT	inverse discrete Fourier transform
IE	information element
IFS	interframe space or spacing
Imm-Ack	immediate acknowledgment
ISR	interference-to-signal ratio
I-RIT	implicit receiver initiated transmission
LBT	listen before talk
LCP	linear combination of pulses

LE	low energy
LECIM	low-energy, critical infrastructure monitoring
LEIP	location enhancing information postamble
LFSR	linear feedback shift register
LIFS	long interframe spacing
LMR	land mobile radio
LRP	low rate pulse repetition frequency
LQI	link quality indication
LR-WPAN	low-rate wireless personal area network
LSB	least significant bit
LTF	long training field
MAC	medium access control
MBAN	medical body area network
MCPS	MAC common part sublayer
MCPS-SAP	MAC common part sublayer service access point
MCS	modulation and coding scheme
MD	multi-superframe duration
MDSSS	multiplexed direct sequence spread spectrum
MFR	MAC footer
MHR	MAC header
MIC	message integrity code
MLME	MAC sublayer management entity
MLME-SAP	MAC sublayer management entity service access point
MPM	multi-PHY management
MSB	most significant bit
MSK	minimum shift keying
MPDU	MAC protocol data unit
MPSK	m-ary phase shift keying
MSDU	MAC service data unit
NRNSC	nonrecursive and nonsystematic code
OOK	on-off keying
O-QPSK	offset quadrature phase-shift keying
OUI	organizationally unique identifier
OVSF	orthogonal variable spreading factor
PAN	personal area network
PC	personal computer
PCA	priority channel access
PD	physical layer data
PD-SAP	physical layer data service access point
PER	packet error rate
P-FSK	position-based frequency shift keying
PHR	PHY header
PHY	physical layer
PIB	personal area network information base
PICS	protocol implementation conformance statement
PLME	physical layer management entity

PLME-SAP	physical layer management entity service access point
PN	pseudo-random noise
PPDU	PHY protocol data unit
PPM	pulse position modulation
PRBS	pseudo-random binary sequence
PRF	pulse repetition frequency
PSD	power spectral density
PSDU	PHY service data unit
PSSS	parallel sequence spread spectrum
QAM	quadrature amplitude modulation
QPSK	quadrature phase-shift keying
RCC	rail communications and control
RCCN	rail communications and control network
RDEV	ranging-capable device
RF	radio frequency
RFD	reduced-function device
RFD-RX	reduced function device—receive only
RFD-TX	reduced function device—transmit only
RFID	radio frequency identification
RFRAME	ranging frame
RIT	receiver initiated transmission
RIV	remainder initialization value
RMARKER	ranging marker
RSC	recursive and systematic code
RSSI	receive signal strength indicator
RX	receive or receiver
SAB	slot allocation bitmap
SD	superframe duration
SF	spreading factor
SFD	start-of-frame delimiter
SHR	synchronization header
SIFS	short interframe spacing
SNR	signal-to-noise ratio
SPC	super PAN coordinator
STF	short training field
SUN	smart utility network
TID	transaction identifier
TMCTP	TVWS multichannel cluster tree PAN
TPC	turbo product code
TRLE	time-slot relaying based link extension
TSCH	timeslotted channel hopping
TVWS	television white space
TX	transmit or transmitter
UWB	ultra-wide band
WPAN	wireless personal area network

4. Format conventions

4.1 General

Throughout this standard, unless otherwise stated, data structures exposed in interfaces are represented using the conventions and formats defined in this clause.

NOTE—It is important to note that interfaces are depicted in this standard as bit serial by convention but may be implemented in other forms, e.g., 4- or 8-bit parallel.⁸

Within the PHY, data structures are passed to the reference modulator input in bit-serial convention. PHY specific coding may change the bit-order and encode multiple information bits into symbols. Hence the over-the-air interface may express the data structure content in a manner different than the conventions defined here.

After all applicable expansion, the size of a MAC frame shall be less than the maximum PSDU size supported by the PHY in use.

4.2 Fields

The general format of a data structure is shown in Figure 4-1. Each field is represented by a column in the figure giving the size of the field and the name and/or type of the datum encoded in the field. The convention of a data structure is recursive in that a field may contain a data structure which is in turn composed of fields.

Octets: 2	Bits: 0–5	6–7	...
Field Name/Type (Number datum)	Field Name/Type (Bit string datum)	Field Name/Type (Bit string datum)	...

Figure 4-1—General data structure format

The form <Octets: n > means the field is n octets long. The form <Bits: n > or <Bits: m – n > means bit number n or bits m to n of the data structure. The terms octet and bit may also be written as octets or bits. In a figure, if a field length appears without either Octets or Bits, then the preceding units apply.

The form <Octets: $n/m/l$ > means the field can be n , m or l octets long.

Fields are concatenated into larger data structures, e.g., Figure 4-1 represents a data structure with 3 fields of length 2 octets, 6 bits and 2 bits for a total size of 3 octets.

Order of representation is strict with the leftmost field as shown in any figure occurring before the next field to its right. The second field from the left occurs before the third field and so on.

Significance, as expressed in the terms LSB and MSB, only applies to numbers as defined in 4.3. All other fields are treated as strings.

The convention of 'processing a data structure' or 'transmitting a data structure' mean treatment of the content of the data structure in the order defined in the following subclauses.

⁸Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

4.3 Numbers

Numbers are represented in decimal (nnn), binary (0bnnn), or hexadecimal (0xnnn) notation with the number of digits indicated. For example, 0b001 is a 3 digit binary number of value 1 and 0x001 is a 3 digit hexadecimal number of value 1. Numbers encoded in fields may be signed or unsigned integers. Other formats (e.g., a field containing a floating point number) are stated in the field definition where applicable.

When represented in fields, numbers are expressed with LSB leftmost and MSB rightmost as shown in Figure 4-2 for an n -bit unsigned integer. (Note that this is the inverse of the number representations 0bnnn and 0xnnn and of common number representations used in mathematical notations.) For example, the number 0x47 would be represented in an 8-bit field as 1110 0010.

Bit:0	...	7	Bits 8–($n-2$)	$n-1$
LSB	...	–	Subsequent octets	MSB

Figure 4-2—General number field format

Numbers of size greater than 1 octet occur with the octet containing the least significant bits first (leftmost) followed by octets containing bits of increasing significance to the right.

Unless otherwise stated in the definition of a field, a number in a field shall be formatted as an unsigned integer.

4.4 Strings

A string of length k bits is represented as a bit sequence numbered from 0 to $k-1$. Bit 0 occurs first and is represented as the leftmost bit of a string field. Bit 1 occurs to the right of bit 0 and so on until bit ($k-1$). This is illustrated in Figure 4-3.

Bits:0	...	7	Bits 8–($k-1$)
String bit 0	...	String bit 7	String bits 8 to $k-1$

Figure 4-3—General string field format

A string of length greater than 1 octet is represented by the octet containing the lowest numbered bits first and leftmost, followed by octets containing increasing bit numbers to the right.

4.5 Reserved fields and values

Each bit within any Reserved field shall be set to zero on transmission and shall be ignored on reception.

No decision should be made on the contents of any Reserved field or field containing a reserved value.

5. General description

5.1 Introduction

A low-rate wireless personal area network (LR-WPAN) is a simple, low-cost communication network that allows wireless connectivity in applications with limited power and relaxed throughput requirements. The main objectives of an LR-WPAN are ease of installation, reliable data transfer, extremely low cost, and a reasonable battery life, while maintaining a simple and flexible protocol.

This standard defines multiple PHYs operating in a variety of frequency bands, as described in 10.1.1.

Two different device types can participate in an IEEE 802.15.4 network: a full-function device (FFD) and a reduced-function device (RFD). An FFD is a device that is capable of serving as a personal area network (PAN) coordinator or a coordinator, as defined in 6.1. An RFD is a device that is not capable of serving as either a PAN coordinator or a coordinator. An RFD is intended for applications that are extremely simple, such as a light switch or a passive infrared sensor; it does not have the need to send large amounts of data and only associates with a single FFD at a time. Consequently, the RFD can be implemented using minimal resources and memory capacity.

Supplemental information for different industrial domains is described in “Applications of IEEE Std 802.15.4” [B3].⁹

5.2 Special application spaces

Although this standard is intended address many diverse application spaces, some application spaces have unique requirements which required specific elements added to this standard. These elements are described in this subclause.

5.2.1 Smart utility network (SUN)

SUNs enable multiple applications to operate over shared network resources, providing monitoring and control of a utility system. SUN devices are designed to operate in very large-scale, low-power wireless applications and often require using the maximum transmit power available under applicable regulations, in order to provide long-range, point-to-point connections. Frequently, SUNs are required to cover geographically widespread areas containing a large number of outdoor devices. In these cases, SUN devices are able to employ mesh or peer-to-peer multihop techniques to communicate with an access point.

5.2.2 Rail communications and control (RCC)

RCC refers to a wireless information exchange and sensor or control communications deployed in areas such as the following:

- 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

RCC devices are intended to support mobile rail vehicle communications at high speeds with data rates that enable connections at distances of over 50 km. The RCC PHYs are designed to take advantage of relatively small amounts of spectrum where spectrum is costly or scarce.

⁹The numbers in brackets correspond to the numbers of the bibliography in Annex A.

5.2.3 Television white space (TVWS)

TVWS operation has the requirement to determine which TVWS frequency allocations are available for use at a given time and geographic location. TVWS devices need to have access to TVWS channel availability information, for example, via a central database that is accessed over the Internet. A TVWS device that has no connection to the Internet must depend upon another TVWS device that has access to the TVWS database via the Internet to acquire channel availability information.

5.2.4 Radio frequency identification (RFID)

Active RFID devices are used to identify and often locate people or objects in industrial or commercial environments. Typical applications include asset management, inventory management, process control and automation, safety and accountability.

In its simplest form an active RFID system comprises a number of transmit-only tags that periodically transmit a packet containing a unique ID and a small amount of data. The packet is received by one or more readers that may simply register the tag as present, may employ further processing to determine the location of the tag, or forward data to an application server. More complex active RFID systems might employ two-way communications with the tag for control, communication, and coordination.

5.2.5 Low-energy, critical infrastructure monitoring (LECIM)

The LECIM portions of this standard are designed to implement a minimal network infrastructure that enables the collection of scheduled and event data from a large number of non-mains powered end points that are widely dispersed, or are in challenging propagation environments. To facilitate low energy operation necessary for multi-year battery life, MAC protocols that minimize network maintenance traffic and device wake durations have been defined.

5.2.6 Medical body area network (MBAN) services

Some countries have allocated spectrum for MBAN services on a secondary basis such that MBAN devices are required to protect all primary users and accept possible interference from those users. MBAN devices operating within this allocated spectrum conform to a set of rules which restrict use of the band to only medical, non-voice use under direction of a healthcare practitioner, among other requirements. When a primary user is making use of a portion of the band, MBAN devices vacate that portion of the band. Use of the band by the primary user is, in general, scheduled well in advance allowing MBAN users to share the band in an orderly manner.

5.3 Components of the IEEE 802.15.4 WPAN

A system conforming to this standard consists of several components. The most basic is the device. A device has a single radio interface that implements an IEEE Std 802.15.4 MAC and PHY. Two or more devices communicating on the same physical channel constitute a wireless personal area network (WPAN). A WPAN includes at least one FFD, operating as the PAN coordinator.

5.4 Multi-PHY management (MPM) of the SUN WPAN

Multiple, different SUN PHYs can operate in the same location and within the same frequency band. In order to mitigate interference, an MPM scheme is specified for SUNs to facilitate inter-PHY coexistence. For this purpose, the MPM scheme facilitates interoperability and negotiation among potential coordinators with different PHYs by permitting a potential coordinator to detect an operating network during its discovery phase using the common signaling mode (CSM) appropriate to the band being used. The MPM

procedure can be used in conjunction with the clear channel assessment (CCA) mechanism to provide coexistence.

5.5 Network topologies

Depending on the application requirements, an IEEE 802.15.4 LR-WPAN operates in either of two topologies: the star topology or the peer-to-peer topology. Both are shown in Figure 5-1. In the star topology, the communication is established between devices and a single central controller, called the PAN coordinator. A device typically has some associated application and is either the initiation point or the termination point for network communications. The PAN coordinator is the primary controller of the PAN. All devices operating on a network of either topology have unique addresses, referred to as extended addresses. In addition, a device can be assigned a short address during the association process. A device will use either the extended address or the short address for communication within the PAN. The transmission of the extended and short address fields is optional for RFD-TX devices. The PAN coordinator will often be mains powered, while the devices will likely be battery powered. Applications that benefit from a star topology include home automation, personal computer (PC) peripherals, games, and personal health care.

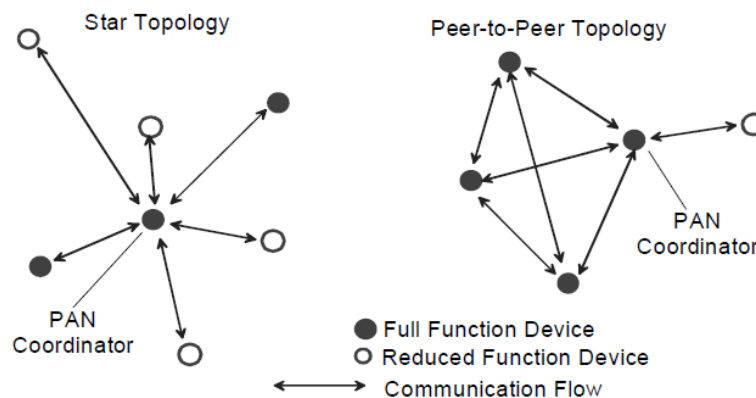


Figure 5-1—Star and peer-to-peer topology examples

The peer-to-peer topology also has a PAN coordinator; however, it differs from the star topology in that any device is able to communicate with any other device as long as they are in range of one another. Peer-to-peer topology allows more complex network formations to be implemented, such as mesh networking topology. Applications such as industrial control and monitoring, wireless sensor networks, asset and inventory tracking, intelligent agriculture, and security would benefit from such a network topology. A peer-to-peer network allows multiple hops to route messages from any device to any other device on the network. Such functions can be added at the higher layer, but they are not part of this standard.

Each independent PAN selects a unique identifier. This PAN identifier (ID) allows communication between devices within a network using short addresses and enables transmissions between devices across independent networks. The mechanism by which identifiers are chosen is outside the scope of this standard.

The network formation is performed by the higher layer, which is not part of this standard.

5.5.1 Star network formation

The basic structure of a star network is illustrated in Figure 5-1. After an FFD is activated, it can establish its own network and become the PAN coordinator. All star networks operate independently from all other star networks currently in operation. This is achieved by choosing a PAN ID that is not currently used by any other network within the radio communications range. Once the PAN ID is chosen, the PAN coordinator