

**IEEE Standard for
Local and metropolitan area networks—**

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

Amendment 5: Physical Layer Specifications for Low Energy, Critical Infrastructure Monitoring Networks

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 802.15.4k™-2013
(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,
and IEEE Std 802.15.4j™-2013)

IEEE Std 802.15.4k™-2013
(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,
and IEEE Std 802.15.4j™-2013)

**IEEE Standard for
Local and metropolitan area networks—**

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

Amendment 5: Physical Layer Specifications for Low Energy, Critical Infrastructure Monitoring Networks

Sponsor

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

Approved 14 June 2013

IEEE-SA Standards Board

Abstract: Two PHYs (DSSS and FSK) that support critical infrastructure monitoring applications are provided in this amendment to IEEE Std 802.15.4TM-2011. In addition, only those MAC modifications needed to support the implementation of the two PHYs are described in this amendment.

Keywords: IEEE 802.15.4TM, IEEE 802.15.4kTM, low data rate, low power, LR-WPAN, PAN, personal area network, radio frequency, RF, wireless personal area network, WPAN

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

Copyright © 2013 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 14 August 2013. Printed in the United States of America.

IEEE and IEEE 802 are registered trademarks in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

Print: ISBN 978-0-7381-8445-6 STD98250
PDF: ISBN 978-0-7381-8446-3 STDPD98250

IEEE prohibits discrimination, harassment, and bullying.

For more information, visit <http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html>.

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Notice and Disclaimer of Liability Concerning the Use of IEEE Documents: IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE SA) Standards Board. IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

Use of an IEEE Standard is wholly voluntary. IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon any IEEE Standard document.

IEEE does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained in its standards is free from patent infringement. IEEE Standards documents are supplied “AS IS.”

The existence of an IEEE standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE standard is subjected to review at least every ten years. When a document is more than ten years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

Translations: The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE should be considered the approved IEEE standard.

Official Statements: A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered the official position of IEEE or any of its committees and shall not be considered to be, nor be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

Comments on Standards: Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE. However, IEEE does not provide consulting information or advice pertaining to IEEE Standards documents. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important to ensure that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to comments or questions except in those cases where the matter has previously been addressed. Any person who would like to participate in evaluating comments or revisions to an IEEE standard is welcome to join the relevant IEEE working group at <http://standards.ieee.org/develop/wg/>.

Comments on standards should be submitted to the following address:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854-4141
USA

Photocopies: Authorization to photocopy portions of any individual standard for internal or personal use is granted by The Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Notice to users

Laws and regulations

Users of these documents should consult all applicable laws and regulations. Compliance with the provisions of this standard does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

This document is copyrighted by the IEEE. It is made available for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making this document available for use and adoption by public authorities and private users, the IEEE does not waive any rights in copyright to this document.

Updating of IEEE documents

Users of IEEE standards should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect. In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE-SA Website at <http://standards.ieee.org/index.html>, or contact the IEEE at the address listed previously. For more information about the IEEE Standards Association or the IEEE standards development process, visit the IEEE-SA Website at <http://standards.ieee.org/index.html>.

Errata

Errata, if any, for this and all other standards can be accessed at the following URL: <http://standards.ieee.org/findstds/errata/index.html>. Users are encouraged to check this URL for errata periodically.

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE-SA Website <http://standards.ieee.org/about/sasb/patcom/patents.html>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

Participants

At the time this draft standard was completed, the IEEE P802.15 Working Group had the following membership:

Robert F. Heile, *Chair*

Rick Alfvin, *Co-Vice Chair*

Patrick W. Kinney, *Co-Vice Chair, Secretary*

James P. K. Gilb, *Technical Editor*

Benjamin A. Rolfe, *Treasurer*

Patrick W. Kinney, *Task Group 4k Chair*

Benjamin A. Rolfe, *Task Group 4k Vice Chair, Task Group 4k Secretary*

Monique B. Brown, *Task Group 4k Technical Editor*

Jon Adams
Rick Alfvin
Moshaddique Ameen
Arthur Astrin
Tuncer Baykas
Philip Beecher
Monique B. Brown
Kiran Bynam
Edgar Callaway
Chris Calvert
Radhakrishna Canchi
Ruben Salazar Cardozo
Kuor-Hsin Chang
Soo-Young Chang
Clint Chaplin
Minho Cheong
Paul Chilton
Sangsung Choi
Jinyoung Chun
Hendricus De Ruijter
Igor Dotlic
Jia Dong Du
Shahriar Emami
David Evans
John Farserotu
Stanislav Filin
George Flammer
Ryuhei Funada
James P. K. Gilb
Matthew Gillmore
Elad Gottlib
Jussi Haapola
Shinsuke Hara
Hiroshi Harada
Robert F. Heile
Marco Hernandez
Jin-Meng Ho
Iwao Hosako
David Howard
Jung-Hwan Hwang
Tetsushi Ikegami
Takuya Inoko

Young-Ae Jeon
Wuncheol Jeong
Steven Jillings
Sungeun Jin
Matthew Johnson
Seong-Soon Joo
Akifumi Kasamatsu
Shuzo Kato
Jeritt Kent
Jinkyong Kim
Suhwook Kim
Youngsoo Kim
Patrick W. Kinney
Shoichi Kitazawa
Tero Kivinen
Ryuji Kohno
Fumihide Kojima
Bruce Kraemer
Raymond Krasinski
Thomas Kuerner
Kyung Sup Kwak
Khanh Tuan Le
Donghun Lee
Jae Seung Lee
Myung Lee
Feng Li
Huan-Bang Li
Liang Li
Qing Li
Yong Li
Lu Liru
Michael Lynch
Michael McInnis
Charles Millet
Kenichi Mori
Robert Moskowitz
Ken Naganuma
Chiu Ngo
Paul Nikolich
John Notor
Mi-Kyung Oh
Yoshihiro Ohba

David Olson
Giwon Park
Seung-Hoon Park
Taejoon Park
Albert Petrick
Daniel Popa
Clinton Powell
Richard Powell
Sebastian Priebe
Jayaram Ramasastry
Ivan Reede
Richard Roberts
Benjamin A. Rolfe
Kiseon Ryu
Shigenobu Sasaki
Naotaka Sato
Noriyuki Sato
Jean Schwoerer
Cristina Seibert
Kunal Shah
Huairong Shao
Stephen Shellhammer
Jie Shen
Shusaku Shimada
Chang Sub Shin
Cheol Ho Shin
Chin-Sean Sum
Hirokazu Tanaka
Dalton Victor
Gabriel Villardi
Khurram Waheed
Xiang Wang
Tao Xing
Ping Ping Xu
Yang Yang
Kaoru Yokoo
Chanho Yoon
Eldad Zeira
Mu Zhao
Mingtuo Zhou
Chunhui Zhu

Major contributions were received from the following individuals:

Moshaddique Ameen
Tuncer Baykas
Monique B. Brown
Edgar Callaway
Sangsung Choi
Sourav Dey
James P. K. Gilb
Jussi Haapola
David Howard
Wuncheol Jeong

Steven Jillings
Matthew Johnson
Seong-Soon Joo
Shuzo Kato
Patrick W. Kinney
Kyung Sup Kwak
Qing Li
Ted Myers
Mi-Kyung Oh

Kwang-Roh Park
Benjamin A. Rolfe
Jean Schwoerer
Cristina Seibert
Jie Shen
Shusaka Shimada
Xiang Wang
Tao Xing
Yang Yang
Betty Zhao

The following members of the balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

Emad Afifi
Nobumitsu Amachi
Butch Anton
Arthur Astrin
Stefan Aust
Michael Bahr
Tuncer Baykas
Riccardo Brama
Nancy Bravin
Vern Brethour
Monique B. Brown
William Byrd
Brent Cain
Edgar Callaway
Radhakrishna Canchi
Juan Carreon
Dave Cavalcanti
Keith Chow
Charles Cook
Steven Crowley
Hendricus De Ruijter
Wael William Diab
Patrick Diamond
Sourav Dutta
Peter Ecclesine
Richard Eckard
Edward Eckert
Richard Edgar
David Evans
Avraham Freedman
Ali Ghandour
James P. K. Gilb
Tim Godfrey
Randall Groves
Michael Gundlach
Chris Guy
Jussi Haapola
Rainer Hach
Marco Hernandez
Werner Hoelzl

David Howard
Heqing Huang
Tetsushi Ikegami
Noriyuki Ikeuchi
Akio Iso
Atsushi Ito
Mitsuru Iwaoka
Raj Jain
Oyvind Janbu
Steven Jillings
Tal Kaitz
Shinkyō Kaku
Masahiko Kaneko
Chol Kang
Piotr Karocki
Stuart Kerry
Yongbum Kim
Patrick W. Kinney
Bruce Kraemer
Raymond Krasinski
Yasushi Kudoh
Thomas Kurihara
John Lampe
Jeremy Landt
Arthur H Light
Lu Liru
HaiTao Liu
William Lumpkins
Greg Luri
Michael Lynch
Elvis Maculuba
Ahmad Mahinfallah
Michael McInnis
David Mitton
Kenichi Mori
Ronald Murias
Peter Murray
Michael S. Newman
John Notor
Mi-Kyung Oh

Seung-Hoon Park
Dalibor Pokrajac
Clinton Powell
Richard Powell
Venkatesha Prasad
Ivan Reede
Robert Robinson
Benjamin A. Rolfe
Randall Safier
Shigenobu Sasaki
Naotaka Sato
Peter Saunderson
Bartien Sayogo
Cristina Seibert
Kunal Shah
Jie Shen
Shusaku Shimada
Manikantan Srinivasan
Thomas Starai
Rene Struik
Walter Struppler
Chandrasekaran
Subramaniam
Jun Ichi Takada
Ha Nguyen Tran
Dmitri Varsanofiev
Prabodh Varshney
John Vergis
Jane Verner
George Vlantis
Xiang Wang
Hung-Yu Wei
Ludwig Winkel
Andreas Wolf
Chun Yu Charles Wong
Tao Xing
Yang Yang
Oren Yuen
Janusz Zalewski
Daidi Zhong

When the IEEE-SA Standards Board approved this amendment on 14 June 2013, it had the following membership:

John Kulick, *Chair*
David J. Law, *Vice Chair*
Richard H. Hulett, *Past Chair*
Konstantinos Karachalios, *Secretary*

Masayuki Ariyoshi
Peter Balma
Farooq Bari
Ted Burse
Wael William Diab
Stephen Dukes
Jean-Philippe Faure
Alexander Gelman

Mark Halpin
Gary Hoffman
Paul Houzé
Jim Hughes
Michael Janezic
Joseph L. Koepfinger*
David J. Law
Oleg Logvinov

Ron Petersen
Gary Robinson
Jon Walter Rosdahl
Adrian Stephens
Peter Sutherland
Yatin Trivedi
Phil Winston
Yu Yuan

*Member Emeritus

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

Richard DeBlasio, *DOE Representative*
Michael Janezic, *NIST Representative*

Patrick Gibbons
IEEE Standards Program Manager, Document Development

Lisa Perry
IEEE Standards Program Manager, Technical Program Development

Introduction

This introduction is not part of IEEE Std 802.15.4k-2013, IEEE Standard for Local and metropolitan area networks—Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)—Amendment 5: Physical Layer Specifications for Low Energy, Critical Infrastructure Monitoring Networks.

This amendment specifies alternate PHYs in addition to those of IEEE Std 802.15.4-2011. In addition to the new PHYs, the amendment also defines those MAC modifications needed to support their implementation.

Contents

3.	Definitions, acronyms, and abbreviations.....	2
3.1	Definitions	2
3.2	Acronyms and abbreviations	2
4.	General description	3
4.3	Network topologies.....	3
4.3.1	Star network formation	3
4.5	Functional overview	3
4.5.1	Superframe structure.....	3
4.5.4	Improving probability of successful delivery	3
5.	MAC protocol	6
5.1	MAC functional description	6
5.1.1	Channel access	6
5.1.6	Transmission, reception, and acknowledgment.....	10
5.1.8	Ranging	11
5.1.8a	PHY parameter change notification procedure.....	11
5.1.10	Deterministic and synchronous multi-channel extension (DSME)	12
5.1.11	LE-transmission, reception, and acknowledgment	14
5.2	MAC frame formats.....	17
5.2.1	General MAC frame format.....	17
5.2.2	Format of individual frame types.....	18
5.2.4	Information element.....	18
5.3	MAC command frames.....	31
5.3.11	DSME-commands.....	31
5.4	MPDU fragmentation	36
5.4.1	MPDU fragmentation and reassembly.....	36
5.4.2	Fragment acknowledgment and retransmission.....	38
6.	MAC services	41
6.2	MAC management service.....	41
6.2.2	Association primitives	41
6.2.4	Communications notification primitives	44
6.2.21	Primitives for DSME	44
6.2.22	Operating parameter change primitives.....	46
6.3	MAC data service	50
6.3.1	MCPS-DATA.request.....	50
6.3.2	MCPS-DATA.confirm.....	50
6.4	MAC constants and PIB attributes.....	51
6.4.1	MAC constants	51
6.4.2	MAC PIB attributes	51
6.4.3	Calculating PHY dependent MAC PIB values	54
8.	General PHY requirements	58
8.1	General requirements and definitions	58
8.1.1	Operating frequency range.....	58
8.1.2	Channel assignments.....	61
8.1.7	Receiver sensitivity definitions.....	64

8.2	General radio specifications.....	64
8.2.1	TX-to-RX turnaround time	64
8.2.2	RX-to-TX turnaround time	64
9.	PHY services	65
9.2	PHY constants.....	65
9.3	PHY PIB attributes	65
9.4	PHY PIB attribute values for <i>phyMaxFrameDuration</i> and <i>phySHRDuration</i>	68
19.	LECIM PHYs	70
19.1	DSSS PHY specification	70
19.1.1	PPDU format for DSSS	70
19.1.2	Modulation and spreading	71
19.1.3	DSSS PHY RF requirements	79
19.2	FSK PHY specification.....	81
19.2.1	PPDU format for FSK.....	81
19.2.2	Modulation and coding for FSK	82
19.2.3	Data whitening for FSK.....	88
19.2.4	FSK PHY RF requirements	89
	Annex A (informative) Bibliography	91
	Annex D (informative) Protocol implementation conformance statement (PICS) proforma.....	92
D.2	Abbreviations and special symbols.....	92
D.7	PICS proforma tables.....	92
D.7.1	Functional device types	92
D.7.2	Major capabilities for the PHY	93
D.7.2.2	Radio frequency (RF).....	93
D.7.3	Major capabilities for the MAC sublayer	95
D.7.3.1	MAC sublayer functions	95
	Annex Q (informative) Low energy, critical infrastructure monitoring systems	96
Q.1	Introduction.....	96
Q.1.1	LECIM characteristics	96
Q.1.2	Use case examples	97
Q.1.2.1	Oil and gas pipeline monitoring.....	97
Q.1.2.2	Water leak detection.....	97
Q.1.2.3	Soil monitoring.....	98
Q.1.2.4	Inventory control - event driven with query	98
Q.1.2.5	Building monitoring - time and event driven data with query	98
Q.1.3	LECIM behaviors	99
Q.1.3.1	Commissioning	99
Q.1.3.2	Low energy.....	100
Q.1.3.3	Coverage extension	100
Q.1.3.4	Device sensitivity and interference robustness	100
Q.2	Functionality added.....	101
Q.2.1	DSSS.....	101
Q.2.2	FSK	101
Q.2.3	Fragmentation	101
Q.2.4	Frame priority	103

Q.2.5	TRLE	103
Q.2.6	PIB attributes	103
Q.2.7	IEs	104
Q.2.8	PHY parameter changes for fragment sequence exchange.....	104
Annex R (informative) ample results from 384 bit LECIM DSSS PHY blocked interleaver		106
R.1	Introduction.....	106
Annex S (normative) Time-slot relaying based link extension (TRLE).....		109
S.1	General	109
S.2	Link extension for a beacon-enabled PAN	109
S.3	Link extension for the non-TRLE PAN.....	110
S.3.1	TRLE PAN relay association and disassociation	110
S.3.2	Frame filtering in relaying mode	111
S.3.3	One-hop relaying	111
S.4	Link extension for the TRLE-enabled PAN	112
S.4.1	TRLE-enabled PAN.....	112
S.4.2	Starting a TRLE-enabled PAN	113
S.4.3	TRLE relaying path formation.....	114
S.4.4	Multi-hop relaying	116
S.4.5	TRLE path maintenance	118
S.4.6	Multiple grades of link access	120
S.5	MAC services for the TRLE-enabled PAN	120
S.5.1	TRLE information elements	120
S.5.1.1	TRLE Descriptor IE	120
S.5.2	TRLE commands	121
S.5.2.1	TRLE-Management request command	121
S.5.2.2	TRLE-Management response command.....	123
S.5.3	Primitives for managing the TRLE-enabled PAN	125
S.5.3.1	MLME-TRLE-MANAGEMENT.request.....	125
S.5.3.2	MLME-TRLE-MANAGEMENT.indication	128
S.5.3.3	MLME-TRLE-MANAGEMENT.response	129
S.5.3.4	MLME-TRLE-MANAGEMENT.confirm.....	131
S.5.4	TRLE specific MAC PIB attributes.....	135

IEEE Standard for Local and metropolitan area networks—

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

Amendment 5: Physical Layer Specifications for Low Energy, Critical Infrastructure Monitoring Networks

IMPORTANT NOTICE: IEEE Standards documents are not intended to ensure safety, health, or environmental protection, or ensure against interference with or from other devices or networks. Implementers of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.

This IEEE document is made available for use subject to important notices and legal disclaimers. These notices and disclaimers appear in all publications containing this document and may be found under the heading “Important Notice” or “Important Notices and Disclaimers Concerning IEEE Documents.” They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/IPR/disclaimers.html>.

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 ~~strike through~~ (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

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

3. Definitions, acronyms, and abbreviations

3.1 Definitions

Insert the following definitions alphabetically into 3.1:

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

3.2 Acronyms and abbreviations

Insert the following acronyms alphabetically into 3.2:

CDMA	code division multiple access
CIC	central inventory control
CLON	co-located orthogonal network
FVS	fragment validation sequence
I-ACK	fragment incremental acknowledgment
I-RIT	implicit receiver initiated transmission
LECIM	low energy, critical infrastructure monitoring
OVSF	orthogonal variable spreading factor
PCA	priority channel access
P-FSK	position-based frequency shift keying
P-GFSK	position-based Gaussian frequency shift keying
RIV	remainder initialization value
RZ Time	rendezvous time
SF	spreading factor
TID	transaction identifier
TRLE	time-slot relaying based link extension

4. General description

4.3 Network topologies

4.3.1 Star network formation

Insert the following paragraph at the end of 4.3.1:

Low energy critical infrastructure monitoring (LECIM) networks primarily operate in a star topology. LECIM networks are typically asymmetric in energy supply and capability, having a PAN coordinator that is mains powered (or otherwise provided a substantial power source) and energy and/or cost constrained devices. The PAN coordinator typically monitors the channel more often than a device. A device sleeps unless it has a data frame to send.

4.5 Functional overview

4.5.1 Superframe structure

4.5.1.1 General

Insert the following item at the end of the list in 4.5.1.1:

- Support for priority channel access (PCA) in the contention access period (CAP) of the superframe structure, as described in 5.1.1.4.5 and 5.1.1.4a

4.5.4 Improving probability of successful delivery

Insert the following new subclause (4.5.4.1a) after 4.5.4.1:

4.5.4.1a CSMA-CA used with PCA

When a critical event occurs in a nonbeacon-enabled PAN, PCA is achieved by use of the PCA backoff algorithm described in 5.1.1.4.5. The PCA backoff algorithm, on average, provides a shorter backoff duration for PCA than for normal access. In addition, the PCA conducts a clear channel assessment (CCA) at regular intervals, even if it is assessed to be busy, in order to gain immediate access to the channel once it is assessed to be idle.

When a critical event occurs in a beacon-enabled PAN, fixed-size CAP time allocations are dedicated in a superframe for PCA. Priority frame transmission may commence in the priority allocations and continue through the duration of the CAP. Priority frames access the channel using the PCA backoff algorithm.

4.5.4.2 ALOHA mechanism

Insert following paragraph after the last paragraph of 4.5.4.2:

When using slotted ALOHA with PCA (5.1.1.4a), PCA allocations of more than four consecutive backoff slot durations are introduced in the CAP of the superframe. The first such allocation dedicated for PCA traffic occurs immediately after the beacon. The backoff slot length is PHY dependent and accommodates, at minimum, the transmission of a single MAC protocol data unit (MPDU) fragment.

Insert the following new subclause after 4.5.4.2:

4.5.4.2a MPDU fragmentation

MPDU fragmentation operates on the MHR and MSDU portions of the MPDU and adapts the MAC frame structure to the specific PHY and PHY operating mode. To reduce over-the-air overhead, MAC header information is compressed or suppressed in the over-the-air exchange, by establishing a fragment sequence (transaction) context. The combination of the information in the fragment and the fragment sequence context provides identification of the individual fragment, the sequence to which it belongs, and where the fragment fits into the sequence. Each fragment carries an incremental validity check sequence for detecting errors; therefore, the MFR is not transmitted. Each fragment is validated and, when all valid fragments are received, the MPDU is reconstructed. A schematic view of the fragmentation process is shown in Figure 6a.

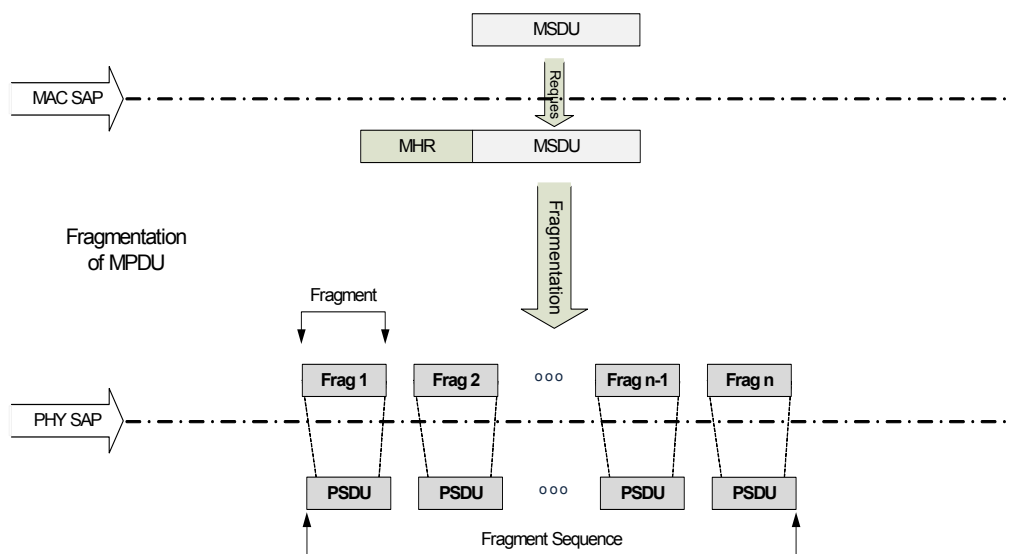


Figure 6a—Schematic view of MPDU fragmentation

Each fragment is individually acknowledged and retransmitted, if required. Retransmission of only the missed fragments reduces air time and improves reliability.

4.5.4.3 Frame acknowledgment

Insert the following new subclause (4.5.4.3a) after 4.5.4.3:

4.5.4.3a Fragment incremental acknowledgment (I-ACK)

The I-ACK is used during the fragment sequence transfer to determine which fragments have been received successfully and which fragments need to be retransmitted. An I-ACK includes the status of one or more fragments. The format of the I-ACK is given in 5.4.2.1.2.

4.5.4.4 Data verification

Insert the following paragraph at the end of 4.5.4.4:

To accommodate individual fragment acknowledgements, a fragment validation sequence (FVS) is included with each fragment. The recipient uses the FVS and fragment number to determine which fragments of the sequence have been received correctly and which are missing. The FVS is described in 5.4.1.2.

5. MAC protocol

5.1 MAC functional description

5.1.1 Channel access

5.1.1.4 CSMA-CA algorithm

Insert the following new subclause (5.1.1.4.5) after 5.1.1.4.4:

5.1.1.4.5 CSMA-CA with PCA

An MSDU or MSDU fragment in which the `CriticalEventMessage` parameter in the `MCPS-DATA.request` primitive is `TRUE` is referred to as a critical event message. The CSMA-CA with PCA backoff algorithm is used before the transmission of a critical event message during the CAP.

In a beacon-enabled PAN when PCA is enabled (*macPriorityChannelAccess* is true), the LECIM PCA Allocation Specification payload IE shall be included in enhanced beacon frames that are sent at every beacon interval.

In a beacon-enabled PAN, the MAC sublayer employs the slotted version of the CSMA-CA with PCA backoff algorithm, as shown in Figure 11c, for transmissions in the CAP of the superframe. Conversely, in a nonbeacon-enabled PAN or if a beacon could not be located in a beacon-enabled PAN, the MAC sublayer may transmit using the unslotted version of the CSMA-CA with PCA backoff algorithm, as shown in Figure 11d.

The variable *NB* is not used in CSMA-CA with PCA backoff algorithm. The PCA backoff algorithm is used during the transmission of a priority message: the backoff exponent *BE* is initialized to the value of *macMinBE* – 1 or 1, whichever is larger, prior to the first transmission attempt, and *BE* remains constant for subsequent retransmissions. The MAC sublayer is responsible for maintaining a variable called *Total backoffs (TB)*, which indicates the number of remaining backoff periods since the start of the CSMA-CA with PCA backoff algorithm. *TB* is initialized to a random value between 0 and $2^{BE} - 1$. The PCA backoff algorithm follows a persistent CSMA mechanism, meaning that the device continues to monitor the channel and decrements *TB* by one any time the channel is sensed idle in a backoff period, in order to gain access to the channel in a timely manner. The slotted PCA backoff algorithm is illustrated in Figure 11c and the unslotted PCA backoff algorithm is illustrated in Figure 11d within the dashed line rectangles, respectively.

In the slotted CSMA-CA with a PCA backoff algorithm, the MAC sublayer shall ensure that, after the persistent random backoff, the remaining CSMA-CA operations can be undertaken and the entire transaction can be transmitted before the end of the CAP. If *TB* is greater than the remaining number of backoff periods in the CAP, the MAC sublayer pauses the *TB* countdown at the end of the CAP and resumes it at the start of the CAP in the next superframe. If *TB* is less than or equal to the remaining number of backoff periods in the CAP, the MAC sublayer applies the PCA backoff algorithm one CCA attempt further and then again evaluates whether there is sufficient time to proceed. The MAC sublayer may proceed if the remaining CSMA-CA algorithm steps, the frame transmission, and any acknowledgment can be completed before the end of the CAP. If there is not sufficient time to proceed, the MAC sublayer waits until the start of the CAP in the next superframe before continuing to apply the PCA backoff algorithm.

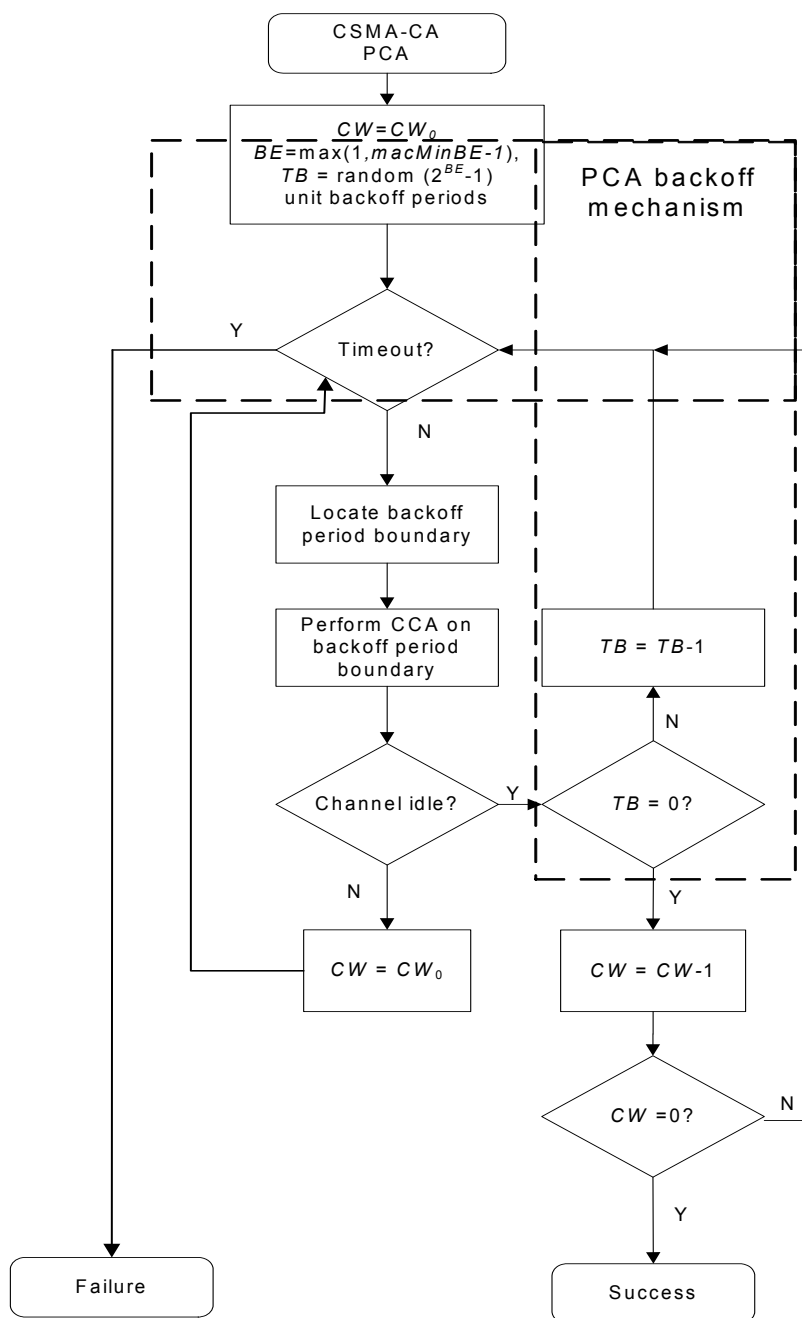


Figure 11c—Algorithm for slotted CSMA-CA with PCA

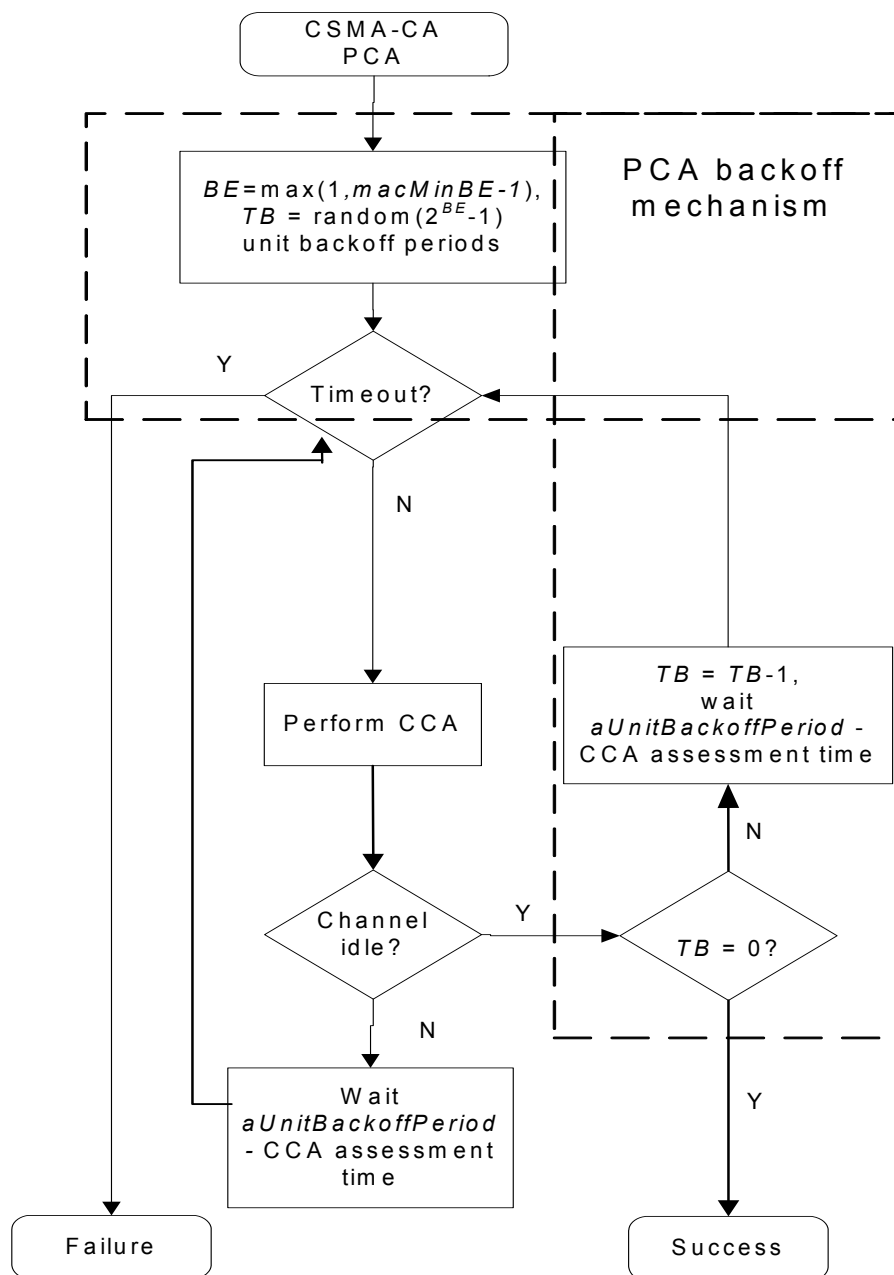


Figure 11d—Algorithm for unslotted CSMA-CA with PCA

When operating a LECIM PHY in a nonbeacon-enabled PAN using unslotted CSMA-CA, the critical event message transmission may be initiated at any time, and the PCA backoff algorithm follows Figure 11d.

In a beacon-enabled PAN, the length of a PCA allocation shall be at least 880 symbol durations. When *macPriorityChannelAccess* is TRUE, the minimum number of PCA allocations in a superframe is defined by the MAC personal area network information base (PIB) attributes *macPCAAllocationSuperRate*, *macPCAAllocationRate*, and *macCritMsgDelayTol*. The relations of the parameters are illustrated in Table 0.0a.

Table 0.0a—PCA MAC PIB attribute relations

Value of <i>macPCAAllocationSuperRate</i>	Superframe duration (SD)	<i>macPCAAllocationRate</i>
FALSE	$SD \leq \frac{macCritMsgDelayTol}{3}$	Maximum value $\left\lfloor \frac{macCritMsgDelayTol}{3 \times SD} \right\rfloor$
TRUE	$\frac{macCritMsgDelayTol}{3} < SD \leq macCritMsgDelayTol$	Minimum value 1
TRUE	$SD > macCritMsgDelayTol$	Minimum value $\left\lceil \frac{SD}{macCritMsgDelayTol} \right\rceil$

In Table 0.0a, $\lfloor \cdot \rfloor$ indicates the closest integer less than or equal to its argument and $\lceil \cdot \rceil$ indicates the closest integer larger than or equal to its argument. When *macPCAAllocationSuperRate* is FALSE, *macPCAAllocationRate* is interpreted as a substrate, and it indicates the maximum number of consecutive superframes for which only one PCA allocation is required. In this case, the PCA allocations need only occur within the superframes having *macBSN* that are integer divisible by the *macPCAAllocationRate* value. When $SD \leq macCritMsgDelayTol/3$, *macPCAAllocationSuperRate* shall be set to FALSE; otherwise, it shall be set to TRUE. When *macPCAAllocationSuperRate* is TRUE, *macPCAAllocationRate* indicates the minimum number of PCA allocations required per superframe.

If there are multiple PCA allocations per superframe, the first allocation occurs at the start of the CAP. The remaining PCA allocations are distributed throughout the superframe, but no PCA allocation shall occur outside the CAP.

When a critical event message transmission is initiated within the CAP during a time that is not a PCA allocation, CSMA-CA, as defined in 5.1.1.4, with the previously described PCA backoff algorithm may be used.

If DSME is utilized with *macCAPReductionFlag* set to TRUE and the multi-superframe duration (MD) is longer than *macCritMsgDelayTol*, then *macPriorityChannelAccess* shall be set to FALSE.

When *macPriorityChannelAccess* is TRUE, a PCA allocation shall not occur if the CAP length duration is less than *aMinCAPLength* plus the time required for a single PCA allocation.

5.1.1.4a LECIM ALOHA PCA

When PCA is in use with CCA Mode 4 (ALOHA), PCA is achieved using a modified version of the PCA backoff algorithm described in 5.1.1.4.5. Instead of one backoff period being equal to *aUnitBackoffPeriod*, a backoff period is defined as *macLECIMALohaUnitBackoffPeriod*.

When MPDU fragmentation is in use, the value of *macLECIMALohaUnitBackoffPeriod* should be long enough to accommodate the transmission of a single MPDU fragment with the associated interframe spacing (IFS) period and an I-ACK frame. When MPDU fragmentation is not in use, the value of *macLECIMALohaUnitBackoffPeriod* should be long enough to accommodate the transmission of a maximum-sized MPDU with the associated IFS and an ACK frame.

When CCA Mode 4 (ALOHA) with the PCA backoff algorithm is used in a beacon-enabled PAN, the process illustrated in Figure 11c is modified as follows: *CW* is initialized to 1. The algorithm advances directly from the state “Locate backoff period boundary” to the state “TB = 0?”

When CCA Mode 4 (ALOHA) with the PCA backoff algorithm is used in a nonbeacon-enabled PAN, the process illustrated in Figure 11d is modified as follows: when the state “Timeout?” returns “N,” the algorithm advances directly to the state “TB = 0?”

When *macPriorityChannelAccess* is set as TRUE, each PCA allocation shall be at least four consecutive *macLECIMALohaUnitBackoffPeriod* in duration. The first PCA allocation shall begin at the start of the CAP. The number of PCA allocations per superframe is described by Table 0.0a.

A PCA allocation cannot occur if the CAP length duration is less than *aMinCAPLength* plus the time required for a single PCA.

5.1.6 Transmission, reception, and acknowledgment

Insert the following sentence at the end of the first paragraph:

Additional processing is performed when MPDU fragmentation is in use, as described in 5.4.

5.1.6.1 Transmission

Change the sixth paragraph in 5.1.6.1:

If the frame is to be transmitted on a beacon-enabled PAN, the transmitting device shall attempt to find the beacon before transmitting. If the beacon is not being tracked, as described in 5.1.1.4, and hence the device does not know where the beacon will appear, it shall enable its receiver and search for at most $[aBaseSuperframeDuration \times (2^n + 1)]$, where n is the value of *macBeaconOrder*, in order to find the beacon. If the beacon is not found after this time, the device shall transmit the frame following the successful application of the unslotted version of the CSMA-CA algorithm, as described in 5.1.1.4. Once the beacon has been found, either after a search or due to its being tracked, the frame shall be transmitted in the appropriate portion of the superframe. Transmissions in the CAP shall follow a successful application of the slotted version of the CSMA-CA algorithm, as described in 5.1.1.4, and transmissions in a GTS shall not use CSMA-CA. When the LECIM DSSS PHY is in use in a beacon-enabled PAN, transmissions after the beacon shall commence *phyLECIMDSSSPPDUTxAt* following the reception of the last symbol of the beacon frame.

5.1.6.2 Reception and rejection

Insert the following new paragraph before the first paragraph of 5.1.6.2:

When MPDU fragmentation is in use, see 5.4.2.1 for a description of fragment acknowledgement.

5.1.6.4 Use of acknowledgments and retransmissions

5.1.6.4.2 Acknowledgment

Change the second paragraph of 5.1.6.4.2 as indicated:

The transmission of an acknowledgment frame in a nonbeacon-enabled PAN or in the CFP shall commence t_{ack} ~~macSIFSPeriod~~ after the reception of the last symbol of the data or MAC command frame. The transmission of an acknowledgment frame in the CAP shall commence either t_{ack} ~~macSIFSPeriod~~ after the reception of the last symbol of the data or MAC command frame or at a backoff period boundary. In the latter case, the transmission of an acknowledgment frame shall commence between t_{ack} ~~macSIFSPeriod~~ and $(t_{ack}$ ~~macSIFSPeriod~~ + $aUnitBackoffPeriod$) after the reception of the last symbol of the data or MAC command frame. The value of t_{ack} is 1 ms for the SUN PHYs and LECIM PHYs. The value of t_{ack} is equal to $macSIFSPeriod$ for all other PHYs.

5.1.8 Ranging

5.1.8.4 The ranging exchange

Insert the following new subclauses (5.1.8a-5.1.8a.2) after 5.1.8.4:

5.1.8a PHY parameter change notification procedure

This procedure is initiated through the MLME-PHY-OP-SWITCH.request primitive, as described in 6.2.22.1, in order to notify one or more peer devices of the intention to switch operating band, channel, or other PHY-specific operating parameters.

5.1.8a.1 Signaling using beacon frames

This method is initiated by the reception of the MLME-PHY-OP-SWITCH.request primitive with the SignalMethod parameter value set to USE_BEACON. The method requires that the enhanced beacon feature is supported and that the device is the PAN coordinator using enhanced beacon frames. If these conditions are not met, the device shall respond with the MLME-PHY-OP-SWITCH.confirm primitive having the appropriate status parameter value indicating the reason for the request failure.

A PHY Parameter Change IE, as defined in 5.2.4.23, shall be generated and inserted in the next outgoing enhanced beacon frame. The Effective Time of Change field of the IE shall be set to the value of the TargetTime parameter of the MLME-PHY-OP-SWITCH.request primitive. The Notification Time field shall be updated with the local time of the device each time it is transmitted. An Operating Mode Description IE (5.2.4.29) shall be generated according to the values in the PHYParameterList and inserted in the same enhanced beacon frame following the PHY Parameter Change IE.

If the value of the RepeatCount parameter of the MLME-PHY-OP-SWITCH.request primitive is nonzero, then the generated IEs shall be included in each enhanced beacon frame subsequently generated until the repeat count is exhausted or until the value in the TargetTime parameter has elapsed. If the RepeatCount parameter is zero, the generated IEs shall be included in only the next enhanced beacon frame.

5.1.8a.2 Signaling using multipurpose frames

This method is initiated by the reception of the MLME-PHY-OP-SWITCH.request primitive with the SignalMethod parameter value set to USE_MP. The method requires that the multipurpose frame (5.2.2.6) is supported. If this condition is not met, the device shall respond with the MLME-PHY-OP-SWITCH.confirm primitive having the appropriate status parameter value.

The device shall generate a PHY Op Mode Switch frame, which is a multipurpose frame containing a PHY Parameter Change IE and an Operating Mode Description IE. The addressing fields shall be set according to the DeviceAddrMode and DeviceAddr parameter values in the MLME-PHY-OP-SWITCH.request primitive. If the DeviceAddress parameter contains the broadcast address, then only the PAN ID addressing field shall be included, and it shall be set to the broadcast PAN ID. The PHY Parameter Change IE and an Operating Mode Description IE shall be generated using the TargetTime, RepeatCount, and PHYParameterList parameters, as described in 5.1.8a.1.

For a directed PHY Op Mode Switch frame, the frame shall be generated with the acknowledgment request (AR) field in the MHR set to request an acknowledgment and transmitted according to 5.1.6.

If the RepeatCount parameter value is greater than zero, the MLME shall repeat transmission of the frame after a delay equal to the value of the RepeatInterval parameter until the RepeatCount parameter value is exhausted. The Notification Time field shall be updated with the local time of the device each time it is transmitted.

When the TxIndirect parameter is set to TRUE, the PHY Op Mode Switch frame shall be sent using indirect transmission, as described in 5.1.5.

5.1.10 Deterministic and synchronous multi-channel extension (DSME)

5.1.10.1 DSME multi-superframe structure

Insert the following new paragraphs and Figure 34ga after the last paragraph of 5.1.10.1:

When *macExtendedDSMEenabled* is TRUE, the Extended DSME PAN Descriptor IE shall be included in enhanced beacon frames that are sent every beacon interval in an Extended DSME-enabled PAN.

When *macExtendedDSMEenabled* is TRUE, the values of the multi-superframe order, MO, the superframe order, SO, and the beacon order, BO, are related as follows:

$$SO \leq MO \leq [BO + \text{len}(\text{BSN})]$$

where

$\text{len}(\text{BSN})$ is 8 when the enhanced beacon frame contains the Sequence Number field and 0 when the Sequence Number field is not present.

Because the value of MO can be larger than that of BO, there may be multiple beacon intervals BIs within an MD. An example of a multi-superframe structure with the value of MO larger than that of BO is shown in Figure 34ga.

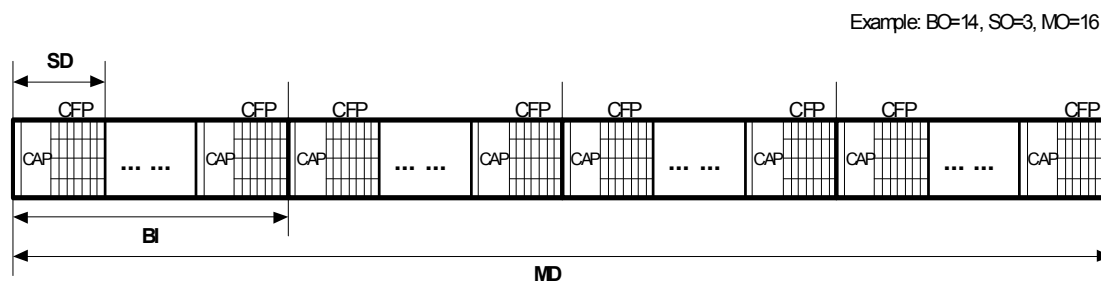


Figure 34ga—Example of DSME multi-superframe structure (MO>BO)

5.1.10.5 DSME-GTS allocation and management

5.1.10.5.1 DSME-GTS allocation

Insert the following paragraph at the end of 5.1.10.5.1:

Devices in a DSME-enabled PAN may be allocated DSME-GTSs during the association procedure. If *macExtendedDSMEenabled* is TRUE and a device is instructed to associate with the PAN through the MLME-ASSOCIATE.request primitive having the DSMEAssociationType parameter set to one, the device requests DSME-GTS allocation by sending a DSME-Association request command to a coordinator with the Extended DSME-GTS Allocation field present, as described in 5.3.11.2.5. On receipt of the DSME-Association request command, the MAC sublayer of the coordinator informs the next higher layer that DSME-GTS allocation is being requested through the MLME-ASSOCIATE.indication primitive with the DSMEAssociationType parameter set to one. The next higher layer of the coordinator instructs the MAC sublayer to reply to the request for DSME-GTS allocation through the MLME-ASSOCIATE.response primitive. Then, the MAC sublayer of the coordinator sends a DSME-Association response command to the device containing the DSME-GTS allocation information described in 5.3.11.3. On receipt of the DSME-Association response command, the MAC sublayer of the device allocates a DSME-GTS and reports the results to the next higher layer.

5.1.10.5.3 DSME-GTS expiration

Insert the following two rows at the end of Table 1a:

Table 1a—Allocation counter table (*macDSMEACT*) description

Attribute	Type	Range	Description
Allocation Order	Integer	0x00–0x08	As defined in 5.3.11.3.6. If $MO \leq BO$, the value of <i>macAllocationOrder</i> shall be set to zero.
BI Index	Integer	0x00–0xff	As defined in 5.3.11.3.7.

5.1.11 LE-transmission, reception, and acknowledgment

Insert the following new subclause (5.1.11.0) before 5.1.11.1:

5.1.11.0 LE transmission, reception, and acknowledgment with positive handshake

When *macLEHSEnabled* is set to TRUE in the coordinator and the device, the data transmission, reception, and acknowledgment process illustrated in Figure 34na shall be used.

If the device received an acknowledgment frame from the coordinator indicating that the coordinator has a pending frame, the device shall send a data request command to the coordinator and wait for the corresponding data frame from the coordinator.

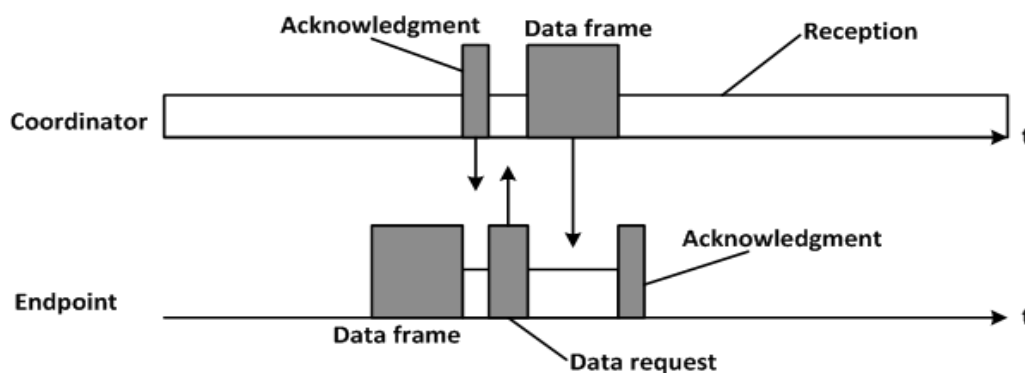


Figure 34na—LE transmission with positive handshake

If the acknowledgment is not received as expected, retransmission shall be performed as defined in 5.1.6.4.3. If, after sending the acknowledgment with the Frame Pending field set, the Data Request command is not received, the coordinator waits for a retransmission and, if received, repeats the acknowledgment with the Frame Pending field set.

5.1.11.1.2 CSL idle listening

Change 5.1.11.1.2 as indicated:

During idle listening, the CSL coordinator performs a channel sample every *macCSLPeriod* time. If no energy is detected on the channel, the channel sample does not detect energy on the channel, the CSL coordinator disables the receiver until the next channel sample time; and then performs the next channel sample. If the channel sample receives contains a wake-up frame, the CSL coordinator checks the destination address in the wake-up frame. Acknowledgment and Retransmissions follow the same process are performed as defined described in 5.1.6.4.3, with the additional requirement except that for each transmission, follows the process above described in this subclause is used. If the destination address of the wakeup frame matches *macShortAddress*, the CSL coordinator checks whether the wake-up frame contains the Wake-up Interval field. If the wake-up frame does not contain the Wake-up Interval field, the CSL coordinator disables the receiver until the Rendezvous Time (RZ Time) in the wake-up frame and then enables the receiver to receive the payload data frame. Otherwise, If the wake-up frame does contain the Wake-up Interval field, and its value is nonzero, the CSL coordinator disables the receiver and transmits the data request frame with the AR field in the payload data frame set to one. Then the CSL coordinator waits

for up to *macEnhAckWaitDuration*, as defined in Table 52j, for the enhanced acknowledgment frame. If the enhanced acknowledgment frame is received, the RZ Time is updated using the contents of the enhanced acknowledgment frame, and the receiver remains on for up to *macMaxFrameTotalWaitTime*, in order to receive the payload data frame.

When the wake-up frame contains the Wake-up Interval field with a nonzero value, the transmission, reception, and acknowledgment operation is as illustrated in Figure 34oa.

If the destination address of the wake-up frame does not match *macShortAddress*, the CSL coordinator disables the receiver until RZ Time plus the transmission time of the maximum length payload frame and the secure acknowledgment frame, and then resumes channel sampling.

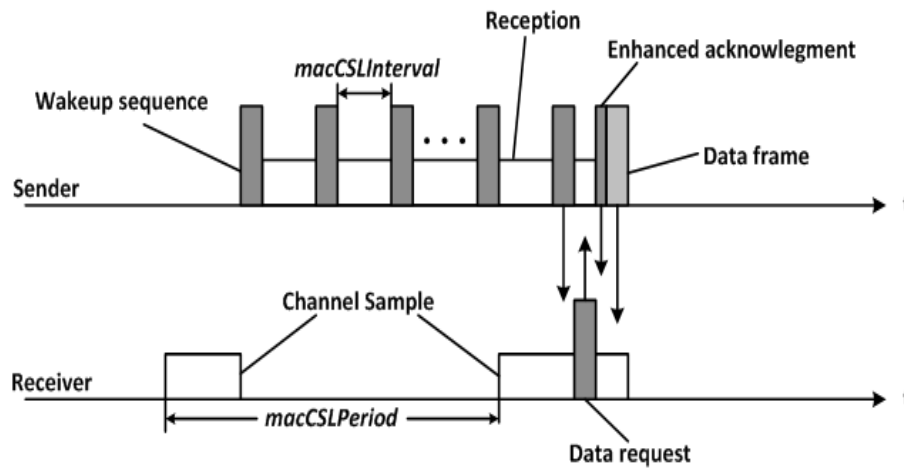


Figure 34oa—CSL operations when the wake-up frame interval is nonzero

5.1.11.1.3 CSL transmission

Change the first paragraph of 5.1.11.1.3 as indicated:

Each CSL transmission of a payload frame is preceded with a sequence of ~~back-to-back~~ wake-up frames (wake-up sequence).

5.1.11.1.4 Unicast transmission

Change 5.1.11.1.4 as indicated:

In unicast transmissions, the wake-up sequence length ~~can~~ may be long or short based on the following two cases:

Unsynchronized transmission: This is the case when the MAC sublayer does not know the CSL phase and period of the destination device. In this case, the maximum wake-up sequence length is *macCSLMaxPeriod*.

Synchronized transmission: This is the case when the MAC sublayer knows the CSL phase and period of the destination device. In this case, the wake-up sequence length is only the guard time against clock drift based on the last time when CSL phase and period updated about the destination device.

If the next higher layer has multiple frames to transmit to the same destination, it ~~can~~ may set the Frame Pending field in the Frame Control field ~~frame pending bit~~ to one in all but the last frame, in order to maximize the throughput.

CSL unicast transmission is performed in the following steps by the MAC sublayer:

- a) Perform CSMA-CA to acquire the channel.
- b) If the previous acknowledged payload frame to the destination has the ~~Frame Pending~~ bitfield set and is within *macCSLFramePendingWaitT* (defined in Table 52j), go to ~~step c)~~ Step e.
- c) If it is a synchronized transmission, wait until the destination device's next channel sample.
- d) For the duration of wake-up sequence length (short or long)
 - 1) Construct wake-up frame with the destination short address and remaining time to payload frame transmission (at the end of wake-up sequence).
 - 2) Transmit wake-up frame.
 - 3) If *macCSLInterval* is not equal to zero, wait for up to *macCSLInterval* for the data request frame from the corresponding destination device. If the data request frame is received, then stop the transmission of the wake-up sequence, perform a CSMA-CA to acquire the channel, and transmit an enhanced acknowledgment frame with the RZ Time updated to zero.
- e) Transmit payload frame.
- f) Wait for up to *macEnhAckWaitDuration* (defined in Table 52j) ~~symbol time~~ for the enhanced acknowledgment frame if the ~~Acknowledge Request AR~~ field in the payload frame is set to one.
- g) If the enhanced acknowledgment frame is received, update CSL phase and period information about the destination device from the Acknowledgment CSL Sync field.
- h) If the enhanced acknowledgment frame is not received, start retransmission process.

Retransmissions follow the same process as defined in 5.1.6.4.3 except that each transmission follows the process above.

5.1.11.1.5 Broadcast transmission

Change the first paragraph of 5.1.11.1.5 as indicated:

Broadcast transmission is the same as unicast transmission except for the following conditions:

- It is always unsynchronized transmission.
- The destination address ~~in~~ of the wake-up frames is set to 0xffff.
- If *macCSLInterval* is nonzero, the CSL coordinator will stop sending the wake-up sequence only after either receiving data request frames from all of the destination devices or when the *macCSLMaxPeriod* expires.
- Optionally includes LE CSL IE.

Insert the following new subclause (5.1.11.3) after 5.1.11.2.4:

5.1.11.3 Implicit receiver initiated transmission (I-RIT)

I-RIT is a low energy mode for nonbeacon-enabled PANs. I-RIT is designed to be used by end devices, such as sensors, that primarily transmit information to a coordinator but have no way of determining when they should make use of conventional RIT.

In order to enable I-RIT in an end device, the PIB attribute *macIRITEnabled* is set to TRUE. When an end device has I-RIT enabled, the device shall enable its receiver *macIRITOffsetInterval* after the last bit of its transmitted frame for a period of *macIRITListenDuration*, in order to allow the receipt of a frame from the coordinator. The values of *macCSLPeriod* and *macIRITOffsetInterval* shall be ignored when *macIRITEnabled* is TRUE. Transmission and reception in I-RIT mode is illustrated in Figure 34sb.

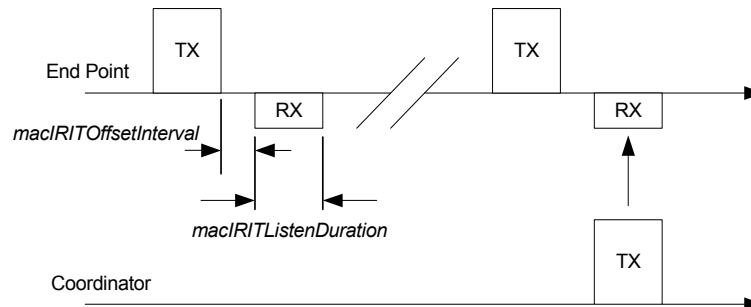


Figure 34sb—I-RIT transmission

5.2 MAC frame formats

5.2.1 General MAC frame format

5.2.1.1 Frame Control field

5.2.1.1.1 Frame Type field

Change the first paragraph of 5.2.1.1.1 and Table 2 as indicated:

The Frame Type field shall be set as defined in Table 2. If the Frame Type value indicates a fragment (i.e., 110), then the frame format shall not be as illustrated in Figure 35 but shall instead be as defined in 5.4.1.2.

5.2.1.1.3 Frame Pending field

Change the fourth paragraph of 5.2.1.1.3 as indicated:

When operating in low-energy (LE) CSL mode, the frame pending bit may be set to one to indicate that the transmitting device has ~~back-to-back~~ pending frames to send to the same recipient and expects the recipient to keep the radio on until the frame pending bit is reset to zero.

Table 2—Values of the Frame Type field

Frame Type value	Description
000	Beacon
001	Data
010	Acknowledgment
011	MAC command
100	LLDN
101	Multipurpose
<u>110</u>	<u>Fragment</u>
~~110~~ –111	Reserved

5.2.2 Format of individual frame types

5.2.2.1 Beacon frame format

5.2.2.1.1a Information Elements field

Insert the following new row at the end of Table 3b, and update the column heading as indicated:

Table 3b—EBR IEs per enabled attribute

Attribute Request Identifier	PIB attribute	IE type	IEs to include
0	<i>macTRLEenabled</i>	Header	TRLE Descriptor (S.5.1.1)

5.2.2.8 LE-multipurpose Wake-up frame

5.2.2.8.1 General

Replace Figure 48m with the following new figure:

Octets: 2	1	2	2	4/6	2
Frame Control	Sequence Number	Destination PAN ID	Destination Address	RZ Time Header IE	IE List Terminator

Figure 48m—Multipurpose Wake-up frame

5.2.4 Information element

5.2.4.2 Header information elements

Change Table 4b (the entire table is not shown) as indicated:

Table 4b—Element IDs, Header IEs

Element ID	Content length	Name	Description
0x1d	2	RZ Time	As defined in 5.2.4.10
0x21		Extended DSME PAN Descriptor	As defined in 5.2.4.9a
0x22		MPDU Fragment Sequence Context Description	As defined in 5.2.4.25
0x23		Simplified Superframe Specification	As defined in 5.2.4.26
0x24		Simplified GTS Specification	As defined in 5.2.4.27
0x25		LECIM Capabilities	As defined in 5.2.4.28
0x26		TRLE Descriptor	As defined in S.5.1.1
0x27-0x7d	—	Reserved	—

5.2.4.5 MLME information elements

Change Table 4d (the entire table is not shown) as indicated:

Table 4d—Sub-ID allocation for short form

Sub-ID value	Content length	Name	Description
0x27		PCA Info	Description of the LECIM PCA allocation parameters in use, as described in 5.2.4.21a.
0x28		DSSS Operating Mode	Description of the operating mode parameters for the DSSS LECIM PHY, as defined in 5.2.4.29.1.
0x29		FSK Operating Mode	Description of the operating mode parameters for the FSK LECIM PHY, as defined in 5.2.4.29.2.
0x2a-0x3f	—	Reserved	—

5.2.4.7 LE CSL IE

Replace Figure 48t with the following new figure.i:

Octets: 2	2	2
CSL Phase	CSL Period	RZ Time

Figure 48t—Format of the LE CSL IE

Insert the following new paragraph at the end of 5.2.4.7

The RZ Time field is only present in the transmitted IE when *macCSLInterval* is nonzero. The RZ Time field is the expected length of time, in units of 10 symbols, between the end of the transmission of the wake-up frame and the beginning of the transmission of the payload frame. When the CSL receives a data request frame from the corresponding destination device, the MAC sublayer shall send enhanced acknowledgements with the RZ Time field updated to zero.

5.2.4.9.5 Group ACK specification

Insert the following new subclause (5.2.4.9a) after 5.2.4.9.5:

5.2.4.9a Extended DSME PAN descriptor IE

The format of the Extended DSME PAN Descriptor element shall be as illustrated in Figure 48ab.

Octets: 2	variable	2	8	variable	variable	0/1	variable
Superframe Specification	Pending Address	Extended DSME Superframe Specification	Time Synchronization Specification	Beacon Bitmap	Channel Hopping Specification	Hopping Sequence Length	Hopping Sequence

Figure 48ab—Format of Extended DSME PAN Descriptor IE

The Superframe Specification field is described in 5.2.2.1.2.

The Pending Address field is described in 5.2.2.1.6.

The Extended DSME Superframe Specification field shall be formatted as illustrated in Figure 48ac.

Bits: 0–7	8	9	10	11	12	13–15
MO	Channel Diversity Mode	Reserved	CAP Reduction Flag	Deferred Beacon Flag	Hopping Sequence List Flag	Reserved

Figure 48ac—Format of the Extended DSME Superframe Specification field

The MO, Channel Diversity Mode, CAP Reduction Flag, and Deferred Beacon Flag fields of the Extended DSME Superframe Specification field are described in 5.2.4.9.1.

The Hopping Sequence List Flag field of the Extended DSME Superframe Specification field shall be set to one if an association request command is received before the enhanced beacon transmission and the Hopping Sequence ID of one is used in the DSME-enabled PAN.

The Time Synchronization Specification field is described in 5.2.4.9.2.

The Beacon Bitmap field is described in 5.2.4.9.3.

The Channel Hopping Specification field is described in 5.2.4.9.4. This field is present only in the channel hopping mode (i.e., the value of the Channel Diversity Mode field in the DSME Superframe Specification is set to one).

The Hopping Sequence Length field is described in 5.3.11.3.4. This field is present only if the Hopping Sequence List Flag field of the Extended DSME Superframe Specification field is one.

The Hopping Sequence field is described in 5.3.11.3.5. This field is present only if the Hopping Sequence List Flag field of the Extended DSME Superframe Specification field is one.

5.2.4.10 Rendezvous Time IE

Change 5.2.4.10 as indicated:

The Rendezvous Time (RZ Time) IE is used in the LE Wake-up frame and shall be formatted as illustrated in Figure 48aaa.

<u>Octets: 2</u>	<u>2</u>
<u>RZ Time</u>	<u>Wake-up Interval</u>

Figure 48aaa—Format of the RZ Time IE

~~The Rendezvous Time (RZ Time) IE is 2 octets.~~ The RZ Time field is the expected length of time in units of 10 symbols between the end of the transmission of the wake-up frame and the beginning of the transmission of the payload frame. The RZ Time field shall be set by the next higher layer when requesting the MAC sublayer to transmit. The last wake-up frame in a wake-up sequence shall have RZ Time field set to the value zero.

The Wake-up Interval field is only present in the transmitted IE when *macCSLInterval* is nonzero. The Wake-up Interval field is the length of the interval between two successive LE wake-up frames in the wake-up sequence, in units of 10 symbols. The Wake-up Interval field shall be set to *macCSLInterval* when requesting the MAC sublayer to transmit.

5.2.4.21 Unmanaged ID space IEs

Insert the following new subclause(5.2.4.21a) after 5.2.4.21:

5.2.4.21a LECIM PCA Allocation Specification IE

The LECIM PCA Allocation Specification IE shall be formatted as shown in Figure 48ttb.

Bit: 0	1	2–15	16–23
PCA Used	Super-rate	Delay Tolerance	Allocation Rate

Figure 48ttb—Format of LECIM PCA Allocation Specification IE

The PCA Used field is set according to the MAC PIB attribute *macPriorityChannelAccess*, with a value of zero indicating *macPriorityChannelAccess* is FALSE and a value of one indicating *macPriorityChannelAccess* is TRUE.

The Super-rate field is set according to the MAC PIB attribute *macPCAAllocationSuperRate* with a value of zero indicating *macPCAAllocationSuperRate* is FALSE and a value of one indicating *macPCAAllocationSuperRate* is TRUE.

The Delay Tolerance field describes the delay tolerance of a critical event message, encoded as an integer in units of $60.0/(2^{14} - 1)$ seconds.

The Allocation Rate field is set according to the MAC PIB attribute *macPCAAllocationRate*, and in conjunction with *macPCAAllocationSuperRate*, it provides the rate at which PCA allocations are made, as described in 5.1.1.4.5.

5.2.4.24 O-QPSK PHY Operating Mode Description IE

Insert the following new subclauses (5.2.4.25–5.2.4.29.2) after 5.2.4.24:

5.2.4.25 MPDU Fragment Sequence Context Description IE

The MPDU Fragment Sequence Context IE contains a description of an MPDU being fragmented and associates this information with a unique fragmentation transaction identifier (TID). The format of the MPDU Fragment Sequence Context Description IE is given in Figure 48ww.

Octets: 2						2		
Bits: 1	1	5	6	2	1	10	6	
Fragment Tx Option	Secure Fragment	Reserved	TID	I-ACK Policy	TID Extension	MPDU Size / Success Threshold	Addressing Information	...

	0/1/3/5	variable	0/4		0/2
			26	6	
...	TID Extension Parameters	Addressing	MPDU Counter	Reserved	PHY-dependent Parameters

Figure 48ww—Format of the MPDU Fragment Sequence Context Description IE

5.2.4.25.1 Fragment Tx Option field

When *macExtendedDSMEEnabled* is set to TRUE, the Fragment Tx Option field indicates whether subsequent transmissions or retransmissions of fragments occur in the next available CAP or in the next DSME-GTS allocated, if the transmission of fragments is not completed in a DSME-GTS. Subsequent fragments shall be transmitted or retransmitted in the next available CAP if the field is set to zero.

Subsequent fragments shall be transmitted or retransmitted in the next DSME-GTS allocated if the field is set to one.

5.2.4.25.2 Secure Fragment field

The Secure Fragment field is used to indicate whether the fragments in this transaction will be sent with authentication. When set, the MPDU Counter field shall be present in this IE, and the fragment validation field shall be set to the MIC, as described in 7.4. The field shall be set to one when *macMPDUFragSecure* is set to TRUE.

5.2.4.25.3 TID field

A TID field value of zero indicates that the TID field will not be present in the fragments that follow. When the TID field value is nonzero, the value identifies the fragment sequence. It associates the context information with each fragment in the transaction. The specific method for generating the TID is implementation dependent and should assure that the current value is different from the preceding value.

5.2.4.25.4 I-ACK Policy field

The I-ACK Policy field shall be set to one of the following values given in Table 4t.

Table 4t—I-ACK Policy field values

I-ACK Policy field value	MPDU Size/Success Threshold field	I-ACK policy description
0	Number of octets in the MPDU	An I-ACK shall be sent upon reception of each fragment
1	Number of octets in the MPDU	ACK/NACK based on time: An I-ACK shall be generated if <i>macIACKprogressTimeout</i> has elapsed since the reception of the fragment context frame or the last received fragment, whichever is later.
2	Number of octets in the MPDU	ACK “last outstanding” fragment: An I-ACK shall be generated only when the last expected fragment is received, or if <i>macIACKprogressTimeout</i> has elapsed since the last received fragment.
3	Number of valid fragments required to be received in order to declare the transaction successful	ACK after specified number of known good fragments received: The I-ACK shall be generated after the successful reception of at least the number of fragments specified in the MPDU Size/Success Threshold field have been received and validated.

5.2.4.25.5 TID Extension field

The TID Extension field shall be set to one to indicate that the TID Extension Parameters field is present. Otherwise, the TID Extension Parameters field is absent.

5.2.4.25.6 MPDU Size/Success Threshold field

The MPDU Size/Success Threshold field is described in Table 4t.

5.2.4.25.7 Addressing Information field

The Addressing Information field describes the content of the addressing fields that follow. The fragment context frame description may contain any combination of source PAN ID, destination PAN ID, source address, and destination address in any of the allowable addressing modes defined by this standard. Figure 48xx illustrates the format of this field.

Bit: 0	1	2–3	4–5
Source PAN ID Present	Destination PAN ID Present	Source Address Mode	Destination Address Mode

Figure 48xx—Addressing Information field format

The setting of the Addressing Information field shall be determined by the PAN ID and addressing mode fields of the MPDU being fragmented.

The Source and Destination PAN ID Present fields shall be set respectively if a source and/or destination PAN ID is included in the Addressing field. The Source Address Mode field indicates the presence and format of a source address included in the Addressing field; the Source Address Mode field shall be set to one of the values given in Table 3. The Destination Address Mode field shall indicate the presence and format of a destination address included in the Addressing field, and the Destination Address Mode field shall be set to one of the values given in Table 3.

5.2.4.25.8 TID Extension Parameters field

The TID Extension Parameters field is present only when the TID Extension field is set. When present, the field shall be encoded as shown in Figure 48yy. The TID Extension Parameters field may be used to enhance unique identification of the transaction by reducing the probability that the TID will be decoded and recognized by devices other than the intended device.

Bits: 1	7	16 or 32
FVS RIV Present	FVS Offset Value	FVS RIV

Figure 48yy—TID Extension Parameters field format

The FVS Remainder Initialization Value (RIV) Present field shall be set to one to indicate that the FVS RIV field is present. It shall be set to zero otherwise.

The FVS Offset Value field indicates whether the location of the FVS value is offset within the PHY service data unit (PSDU), and the field contains the value of the offset in octets. A value of zero indicates that no offset was used, (i.e., the FVS value is located at the end of the PSDU). A value greater than zero indicates that the FVS value is offset within the PSDU; the offset value is counted back from the last octet of the PSDU. If the FVS offset feature is not supported by a receiving device, the receiving device shall ignore any fragment or I-ACK received with this field set to a value greater than zero.

The FVS RIV field is only present if the value used as the initial remainder in the CRC calculation is not equal to the default initialization value for the remainder given in 5.2.1.9. In a transmitting device, this field is used to signal that an alternate CRC RIV was used when generating the fragment or I-ACK. In a receiving

device, when a FVS RIV value other than zero is present, the CRC calculation initial value shall be set to the FVS RIV field contents. The length of the field is determined by the current value of *macFragmentFVSType*.

In order to allow for alternative coordination methods, the TID extension methods for FVS offset and FVS RIV may be determined by the *macFVSoffset* and *macFVSRIV* PIB attributes and not signaled in the MPDU Fragment Sequence Context Description IE. In the event that an MPDU Fragment Sequence Context Description IE is received with a value different than what is set in the PIB, the received values shall be used for that transaction.

5.2.4.25.9 Addressing field

The Addressing field contains source and/or destination addressing information associated with the MPDU being fragmented. The format is illustrated in Figure 48zz.

Octets: 0/16	0/16	0/8/16/64	0/8/16/64
Source PAN ID	Destination PAN ID	Source Address	Destination Address

Figure 48zz—Addressing field format

The content of this field shall be set according to the addresses contained in the MHR of the MPDU being fragmented. Addresses may be elided to fit into the PSDU size of the PHY in use; algorithms for address suppression are implementation-dependent.

5.2.4.25.10 MPDU Counter field

The MPDU Counter field shall be present when the Secure Fragment field is set to one (*macMPDUFragSecure* is set to TRUE). The MAC shall maintain a counter that is incremented with each MPDU fragmentation transaction, initiated such that the counter value is not repeated, as described in 7.4.2.

5.2.4.25.11 PHY-dependent Parameters field

The value of the PHY-dependent Parameters field depends upon the PHY being used. The possible values are implementation dependent. For the LECIM FSK PHY defined in 19.2, this field is 2 octets in length and contains the fragment size used for the transaction. This field is not used by the LECIM DSSS PHY.

5.2.4.26 Simplified Superframe Specification IE

The Simplified Superframe Specification IE may be used to define a basic superframe in a format that can be transmitted in the smallest single PSDU provided for by the LECIM PHYs, such that it may be transmitted unfragmented. The Simplified Superframe Specification IE shall be formatted as shown in Figure 48aaa.

Octets: 2	2	2
Timestamp	Superframe Specification	CFP Specification

Figure 48aaa—Format of the Simplified Superframe Specification IE

The Timestamp field shall be incremented between transmissions; the initial value, resolution (LSB value), and accuracy are implementation dependent.

The Superframe Specification field is as defined in 5.2.2.1.2.

The Contention-Free Period (CFP) Specification field determines the size and position of the CFP and CAP within the superframe. The CFP Specification field shall be encoded as shown in Figure 48aab.

Bits: 0–3	4–7	8–11	12	13–15
Number of GTSSs	First CFP Slot in Superframe	Last CFP Slot in Superframe	GTS Permit	Reserved

Figure 48aab—CFP Specification field format

Each GTS contains an equal number of superframe slots. The Number of GTSSs field is set according to the number of GTSSs allocated by the coordinator. The value of the First CFP Slot in Superframe field is equal to the slot number in which the CFP begins. The value of the Last CFP Slot in Superframe field is equal to the slot number in which the CFP ends.

The GTS Permit field shall be set to one if *macGTSPermit* is equal to TRUE, indicating that the coordinator is accepting GTS requests. Otherwise, the field shall be set to zero.

5.2.4.27 Simplified GTS Specification IE

The Simplified GTS Specification IE, shown in Figure 48aac, and the Simplified Superframe Specification IE, shown in Figure 48aaa, indicate devices that have been allocated a GTS.

Octets: 1	Variable
GTS Directions	GTS Device Address List

Figure 48aac—Format of the Simplified GTS Specification IE

The GTS Directions field is defined in Figure 43 of 5.2.2.1.4.

The GTS Device Address List field contains one address for each GTS defined as indicated in the Number of GTSSs field in the Simplified Superframe Specification IE. Each GTS device address list entry is a short (i.e., 16-bit) address assigned to the device that has been granted the GTS. If a GTS has not been allocated, the address list entry for that slot shall contain the value 0xffff.

5.2.4.28 LECIM Capabilities IE

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

Octets: 2	2	0/2	0/2
PHY Type and Bands Supported	LECIM PHY Features Supported	Lowest 2.4 GHz Channel	Highest 2.4 GHz Channel

Figure 48aad—Format of the LECIM Capabilities IE

In the PHY Type and Bands Supported field, bit 0 indicates the PHY type supported, which is the PHY type being described by the IE. A value of one indicates that LECIM FSK is described; a value of zero indicates that LECIM DSSS is described. Bits 1–11 indicate support for different bands. A value of one indicates that a band is supported; a value of zero indicates that a band is not supported. The device shall indicate as supported only those bands that are implemented and defined for the indicated PHY type. The encoding for the field is shown in Table 4u.

Table 4u—LECIM PHY Type and Bands Supported field encoding

Bit number	Description
0	PHY type described: 0 = LECIM DSSS 1 = LECIM FSK
1	Band 169 supported
2	Band 433 supported
3	Band 470 supported
4	Band 780 supported
5	Band 863 supported
6	Band 915 supported
7	Band 917 supported
8	Band 920 supported
9	Band 921 supported
10	Band 922 supported
11	Band 2450 supported
12–15	Reserved

When the PHY Type and Bands Supported field indicates a LECIM DSSS PHY, the LECIM PHY Features Supported field shall be encoded as shown in Table 4v. Bit 0 and bit 1 indicate support for different modulation schemes. A value of one indicates that the modulation scheme is supported; a value of zero indicates that the modulation scheme is not supported. Bits 2–5 indicate that maximum spreading factor is supported. The valid value range is between 16 and 32768 and is calculated by:

$$2^{(\text{bits } 2-5)_{10}}$$

Bits 6–8 indicate support for different PSDU sizes. A value of one indicates that the PSDU size is supported; a value of zero indicates that PSDU size is not supported.

Table 4v—LECIM PHY Features Supported field encoding for DSSS

Bit number	Description
0	BPSK modulation supported
1	O-QPSK modulation supported
2–5	Maximum spreading factor supported; see Table 71 for the definition of <i>phyLECI MDSSSPDSUSpreadingFactor</i> .
6	16 octet PSDU supported
7	24 octet PSDU supported
8	32 octet PSDU supported
9	OVSF supported
10–15	Reserved

When the PHY Type and Bands Supported field indicates a LECIM FSK PHY, the LECIM PHY Features Supported field shall be encoded as shown in Table 4w. A value of one indicates that the feature is supported; a value of zero indicates that the feature is not supported.

Table 4w—LECIM PHY Features Supported field encoding for FSK

Bit number	Description
0	Positional modulation supported
1	Symbol rate 37.5 ksps supported, 200 kHz channel spacing ^a
2	Symbol rate 25 ksps supported, 200 kHz channel spacing ^a
3	Symbol rate 12.5 ksps supported, 200 kHz channel spacing ^a
4	Symbol rate 37.5 ksps supported, 100 kHz channel spacing ^a
5	Symbol rate 25 ksps supported, 100 kHz channel spacing ^a
6	Symbol rate 12.5 ksps supported, 100 kHz channel spacing ^a
7	FEC supported
8	Interleaving supported
9	Scrambling supported
10	SF 2 supported
11	SF 4 supported
12	SF 8 supported
13	SF 16 supported

Table 4w—LECIM PHY Features Supported field encoding for FSK (*continued*)

Bit number	Description
14	Alternating SF pattern supported
15	Non-alternating SF pattern supported

^aDefined in 19.2.2.

The Lowest 2.4 GHz Channel and the Highest 2.4 GHz Channel fields specify the range of channels within the 2.4 GHz band supported. These fields shall only be present when the PHY Type and Bands Supported field indicates support for the 2.4 GHz band. The range includes all of the channels starting from the channel number specified in the Lowest 2.4 GHz Channel field to the channel number specified in the Highest 2.4 GHz Channel field, inclusive.

5.2.4.29 Operating Mode Description IEs

5.2.4.29.1 DSSS Operating Mode Description IE

The DSSS Operating Mode Description IE content shall be encoded as shown in Table 4x.

Table 4x—Operating Mode Information field encoding for DSSS

Bit number	Description
0–3	Operating band selected. The bands are defined as the integers greater than 0 corresponding to the bit numbers given in Table 4u. Not all entries are valid. Values not corresponding to a band ID in Table 4u are reserved.
4–12	Channel number, as defined in 8.1.2.
13	Modulation selection: 0 = BPSK 1 = O-QPSK
14–16	Chip rate in kchip/s: 0 = invalid 1 = 100 2 = 200 3 = 400 4 = 600 5 = 800 6 = 1000 7 = 2000
17	Channel spacing, as specified in Table 68l. 0 = 0.1 MHz 1 = 0.2 MHz
18–19	PSDU size: 00 = invalid 01 = 16 octets 10 = 24 octets 11 = 32 octets

Table 4x—Operating Mode Information field encoding for DSSS (*continued*)

Bit number	Description
20	Preamble present: 0 = not present 1 = present
21	Start-of-frame delimiter (SFD) present: 0 = not present 1 = present
22–25	Spreading factor; see Table 71 for the definition of <i>phyLECMDSPPSDUSpreadingFactor</i> .
26–29	OVSF spreading factor: 0000 = OVSF not applied 0001 = SF of 2 0010 = SF of 4 0011 = SF of 8 0100 = SF of 16 0101 = SF of 32 0110 = SF of 64 0111 = SF of 128 1000 = SF of 256
30–53	Gold code LFSR2 initialization value, as specified in 19.1.2.6.1.
54–63	Reserved

5.2.4.29.2 FSK Operating Mode Description IE

The FSK Operating Mode Description IE content shall be encoded as shown in Table 4y.

Table 4y—Operating Mode Information field encoding for FSK

Bit number	Description
0–3	Operating band selected. The bands are defined as the integers greater than 0 corresponding to the bit numbers given in Table 4u. Not all entries are valid. Values not corresponding to a band ID in Table 4u are reserved.
4–12	Channel number, as defined in 8.1.2.
13	Position modulation utilized.
14–15	Symbol rate: 0 = 37.5 ksps 1 = 25 ksps 2 = 12.5 ksps
16	Channel spacing: 0 = channel spacing for indicated operating band is 200 kHz 1 = channel spacing for indicated operating band is 100 kHz
17	FEC enabled: 0 = not enabled 1 = enabled

Table 4y—Operating Mode Information field encoding for FSK (*continued*)

Bit number	Description
18	Interleaving enabled: 0 = not enabled 1 = enabled
19	Scrambler enabled: 0 = not enabled 1 = enabled
20	Spreading enabled: 0 = not enabled 1 = enabled
21–22	Spreading factor (see definition of <i>phyLECIMDSSSPSDUSpreadingFactor</i>): 0 = SF of 2 1 = SF of 4 2 = SF of 8 3 = SF of 16
23	Spreading pattern: 0 = non-alternating 1 = alternating
24–31	Reserved

5.3 MAC command frames

Change Table 5 (the entire table is not shown) as indicated:

Table 5—MAC command frames

Command frame identifier	Command name	RFD		Subclause
		Tx	Rx	
<u>0x0a</u>	<u>TRLE-Management request</u>	<u>X</u>	<u>X</u>	<u>S.5.2.1</u>
<u>0x0b</u>	<u>TRLE-Management response</u>	<u>X</u>	<u>X</u>	<u>S.5.2.2</u>
~~0x0c– 0xff 0x21–0x3f~~	Reserved			—
~~0x44–0x5f~~	Reserved			—
~~0x61–0x62~~	Reserved			—
~~0x64–0xff~~	Reserved			—

5.3.11 DSME-commands

5.3.11.2 DSME-Association request command

Replace Figure 59g with the following figure:.