

IEEE Standard for Low-Rate Wireless Networks

Amendment 6: Enabling Spectrum Resource Measurement Capability

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

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

IEEE Std 802.15.4s™-2018
(Amendment to
IEEE Std 802.15.4™-2015
as amended by IEEE Std 802.15.4n™-2016,
IEEE Std 802.15.4q™-2016, IEEE Std 802.15.4u™-2016,
IEEE Std 802.15.4t™-2017, IEEE Std 802.15.4v™-2017, and
IEEE Std 802.15.4-2015/Cor 1-2018)

IEEE Std 802.15.4s™-2018
(Amendment to
IEEE Std 802.15.4™-2015
as amended by IEEE Std 802.15.4n™-2016,
IEEE Std 802.15.4q™-2016, IEEE Std 802.15.4u™-2016,
IEEE Std 802.15.4t™-2017, IEEE Std 802.15.4v™-2017, and
IEEE Std 802.15.4™-2015/Cor 1-2018)

IEEE Standard for Low-Rate Wireless Networks

Amendment 6: Enabling Spectrum Resource Measurement Capability

Sponsor

LAN/MAN Standards Committee
of the
IEEE Computer Society

Approved 15 February 2018

IEEE-SA Standards Board

Abstract: Definitions of MAC related functions to enable spectrum resource management are addressed in this amendment to IEEE Std 802.15.4™. It specifies the following:

- Spectrum resource measurements and network performance metrics, such as packet error ratio, delay, etc.
- Information elements and data structures to capture these measurements,
- Procedures for collecting and exchanging spectrum resource measurement information with higher layers or other devices.

Keywords: IEEE 802.15.4™, spectrum resource measurement, transmit power control

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

Copyright © 2018 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 27 June 2018. Printed in the United States of America.

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

PDF: ISBN 978-1-5044-4794-2 STD23063
Print: ISBN 978-1-5044-4795-9 STDPD23063

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.

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page, appear in all standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.” They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/IPR/disclaimers.html>.

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents (standards, recommended practices, and guides), both full-use and trial-use, are developed within IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (“IEEE-SA”) Standards Board. IEEE (“the Institute”) develops its standards through a consensus development process, approved by the American National Standards Institute (“ANSI”), which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and participate without compensation from IEEE. 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.

IEEE does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims all warranties (express, implied and statutory) not included in this or any other document relating to the standard, including, but not limited to, the warranties of: merchantability; fitness for a particular purpose; non-infringement; and quality, accuracy, effectiveness, currency, or completeness of material. In addition, IEEE disclaims any and all conditions relating to: results; and workmanlike effort. IEEE standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

Use of an IEEE standard is wholly voluntary. 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.

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.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

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 or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, or 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 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. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in revisions to an IEEE standard is welcome to join the relevant IEEE working group.

Comments on standards should be submitted to the following address:

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

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document 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

IEEE draft and approved standards are copyrighted by IEEE under U.S. and international copyright laws. They are made available by IEEE and are adopted 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 these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate fee, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, 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.

Updating of IEEE Standards documents

Users of IEEE Standards documents 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.

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 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://ieeexplore.ieee.org/> or contact IEEE at the address listed previously. For more information about the IEEE-SA or IEEE's standards development process, visit the IEEE-SA Website at <http://standards.ieee.org>.

Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE-SA Website 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 at <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 the draft of this standard was sent to sponsor ballot, the IEEE P802.15 Working Group had the following voting members:

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*

Shoichi Kitazawa, *Task Group 15.4s Chair and Technical Editor*
Hidetoshi Yokota, *Task Group 15.4s Vice Chair, Secretary, and Lead Technical Editor*

Mounir Achir	Timothy Harrington	Jinesh P. Nair
Keiji Akiyama	James Hartman	Chiu Ngo
Philip Beecher	Marco Hernandez	Paul Nikolich
Frederik Beer	Ken Hiraga	John Notor
Chandrashekhar P. S. Bhat	Iwao Hosako	Hiroyo Ogawa
Kiran Bynam	Yeong Min Jang	Taejoon Park
Edgar Callaway	Seong-Soon Joo	Glenn Parsons
Chris Calvert	Akifumi Kasamatsu	Charles Perkins
Radhakrishna Canchi	Shuzo Kato	Albert Petrick
Kapseok Chang	Toyoyuki Kato	Verotiana Rabarijaona
Soo-Young Chang	Jeritt Kent	Ivan Reede
Clint Chaplin	Jaehwan Kim	Richard Roberts
Stephen Chasko	Youngsoo Kim	Benjamin A. Rolfe
Paul Chilton	Shoichi Kitazawa	Ruben E. Salazar Cardozo
Sangsung Choi	Tero Kivinen	Noriyuki Sato
Hendricus de Ruijter	Ryuji Kohno	Norihiko Sekine
Guido Dolmans	Fumihide Kojima	Kunal Shah
Igor Dotlic	Thomas Kuerner	Stephen Shellhammer
Stefan Drude	Byung-Jae Kwak	Shusaku Shimada
Dietmar Eggert	Jae Seung Lee	Gary Stuebing
Shahriar Emami	Myung Lee	Don Sturek
Andrew Estrada	Sangjae Lee	Mineo Takai
David Evans	Huan-Bang Li	Kou Togashi
George Flammer	Qing Li	Billy Verso
Kiyoshi Fukui	Michael Lynch	Gabriel Villardi
Matthew Gillmore	Itaru Maekawa	Brian Weis
Tim Godfrey	Hiroyuki Matsumura	Makoto Yaita
Elad Gottlib	Michael McLaughlin	Peter Yee
Jussi Haapola	Michael McInnis	Yu Zeng
Rainer Hach	Robert Moskowitz	Chunhui (Allan) Zhu

Major contributions were received from the following individuals:

Masa Ariyoshi	Shoichi Kitazawa	Shusaku Shimada
Chris Calvert	Mitsuru Iwaoka	Mineo Takai
James P.K. Gilb	Benjamin A. Rolfe	Hidetoshi Yokota

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

Tomoko Adachi	Sergiu Iordanescu	Venkatesha Prasad
Thomas Alexander	Akio Iso	Maximilian Riegel
James D. Allen	Atsushi Ito	Robert Robinson
Nobumitsu Amachi	Raj Jain	Benjamin Rolfe
Lai King Anna Tee	SangKwon Jeong	M. K. Sajeev
Michael Bahr	Ritesh Kalle	Naotaka Sato
Harry Bims	Piotr Karocki	Noriyuki Sato
Nancy Bravin	Stuart Kerry	Kunal Shah
Vern Brethour	Yongbum Kim	Daniel Smith
Demetrio Bucane Jr.	Tero Kivinen	Dorothy Stanley
William Byrd	Yasushi Kudoh	Thomas Starai
Edgar Callaway	Hyeong Ho Lee	Walter Struppler
Juan Carreon	James Lepp	Gary Stuebing
Suresh Channarasappa	Huan-Bang Li	Mark Sturza
Keith Chow	Elvis Maculuba	Bo Sun
Hendricus De Ruijter	Jeffery Masters	Lorenzo Vangelista
Sourav Dutta	Michael McInnis	Dmitri Varsanofiev
Richard Edgar	Richard Mellitz	Billy Verso
Avraham Freedman	Michael Montemurro	George Vlantis
Tim Godfrey	Rick Murphy	Khurram Waheed
Eric W. Gray	John Notor	Lisa Ward
Randall Groves	Satoshi Oyama	Scott Willy
Marco Hernandez	Bansi Patel	Andreas Wolf
Werner Hoelzl	Arumugam Paventhan	Oren Yuen
Rita Horner	Dalibor Pokrajac	
Noriyuki Ikeuchi	Clinton Powell	

When the IEEE-SA Standards Board approved this standard on 15 February 2018, it had the following membership:

Jean-Philippe Faure, *Chair*
Vacant Position, *Vice Chair*
John D. Kulick, *Past Chair*
Konstantinos Karachalios, *Secretary*

Ted Burse	Hung Ling	Robby Robson
Guido R. Hiertz	Xiaohui Liu	Dorothy Stanley
Gary Hoffman	Kevin Lu	Mehmet Ulema
Cristel Hunter	Deleep Mohla	Phil Wennblom
Michael Janezic	Andrew Myles	Philip Winston
Joseph L. Koepfinger*	Paul Nikolich	Howard Wolfman
Thomas Koshy	Ronald C. Peterson	Jingy Zhou
	Annette D. Reilly	

*Member Emeritus

Introduction

This introduction is not part of IEEE Std 802.15.4s-2018, IEEE Standard for Low-Rate Wireless Networks—Amendment 6: Enabling Spectrum Resource Measurement Capability.

This amendment to IEEE Std 802.15.4-2015 enhances the functionalities to realize spectrum resource measurement and management for IEEE Std 802.15.4 physical layer (PHY) and medium access control layer (MAC). The standardized management mechanism enables individual PAN devices to coordinate with each other and operate more efficiently where devices are densely deployed in shared license exempt frequency bands and heavy interference could limit the overall performance. To this end, this amendment specifies the framework, PIB attributes, MLME primitives and MAC commands for exchanging information on spectrum resource usage, which includes the following:

- Spectrum resource measurements and network performance metrics.
- Information elements and data structures to capture these measurements.
- Procedures for collecting and exchanging spectrum resource measurement information with higher layers or other devices.

This amendment builds on popularity of IEEE Std 802.15.4-2015 to enhance performance of existing deployment and increases opportunities for applications of IEEE Std 802.15.4-2015 based system in new ways.

Contents

3. Definitions, acronyms, and abbreviations.....	12
3.2 Acronyms and abbreviations	12
5. General description	12
5.7 Functional overview	12
5.7.7 Enabling spectrum resource measurement capability.....	12
6. MAC functional descriptions.....	13
6.17 Spectrum resource measurement (SRM)	13
6.17.1 SRM performance metrics	14
6.17.1.1 Energy detection (ED)	14
6.17.1.2 Percentage of time of failed transmissions	14
6.17.1.3 Percentage of time of deferred transmissions	15
6.17.1.4 Retry Histogram.....	15
6.17.1.5 Channel utilization	16
6.17.1.6 Received channel power indicator (RCPI)	16
6.17.1.7 Received Signal Noise Indicator (RSNI).....	17
6.17.1.8 Received signal strength indicator (RSSI).....	18
6.17.1.9 Noise Histogram	18
6.17.1.10 Average access delay	19
6.17.1.11 MAC performance metrics specific MAC PIB attributes.....	19
6.17.2 SRM functionality.....	19
6.17.2.1 Signaling.....	20
6.17.2.2 Transmit power control.....	20
6.17.2.3 SRM Request/Response.....	20
6.17.2.4 SRM Report	21
6.17.2.5 SRM Information	22
6.17.2.6 MAC performance metrics specific MAC PIB attributes.....	22
7. MAC frame formats.....	23
7.4 IEs	23
7.4.4 Nested IEs	23
7.4.4.1 Format of Nested IE.....	23
7.4.4.32 SRM IE	23
7.4.4.33 Scope-based Performance Metric	25
7.4.4.34 Example of Signal quality related IEs	25
7.5 MAC commands	26
7.5.1 Command ID field	26
7.5.27 SRM Request command	27
7.5.28 SRM Response command.....	28
7.5.29 SRM Report command	29
7.5.30 SRM Information command	30
8. MAC services	31
8.2 MAC management services	31
8.2.1 Primitives supported by the MLME-SAP interface.....	31

8.2.26 Primitives for SRM.....	31
8.2.26.1 MLME-SRM.request.....	31
8.2.26.2 MLME-SRM.indication.....	33
8.2.26.3 MLME-SRM.response.....	34
8.2.26.4 MLME-SRM.confirm.....	36
8.2.27 MLME-SRM-REPORT.....	36
8.2.27.1 MLME-SRM-REPORT.request.....	36
8.2.27.2 MLME-SRM-REPORT.indication.....	38
8.2.27.3 MLME-SRM-REPORT.confirm.....	39
8.2.28 MLME-SRM-INFORMATION.....	40
8.2.28.1 MLME-SRM-INFORMATION.request.....	40
8.2.28.2 MLME-SRM-INFORMATION.indication.....	42
8.2.28.3 MLME-SRM-INFORMATION.confirm.....	42
8.4 MAC constants and PIB attributes.....	43
8.4.2 MAC PIB attributes.....	43
8.4.2.1 General MAC PIB attributes for functional organization.....	43
8.4.2.9 SRM specific MAC PIB attributes.....	43
10. General PHY requirements.....	45
10.1 General requirements and definitions.....	45
10.1.5 Transmit power.....	45
11. PHY services.....	45
11.3 PHY PIB attributes.....	45
22. Sun O-QPSK.....	46
22.3 Modulation and coding for SUN O-QPSK.....	46
22.3.10 MDSSS bit-to-chip mapping.....	46
Annex D (informative) Protocol implementation conformance statement (PICS) proforma.....	48
D.7 PICS proforma tables.....	48
D.7.3 Major capabilities for the MAC sublayer.....	48
D.7.3.1 MAC sublayer functions.....	48
D.7.3.2 MAC frames.....	48
D.7.3.3 MAC IEs.....	49

IEEE Standard for Low-Rate Wireless Networks

Amendment 6: Enabling Spectrum Resource Measurement Capability

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.

3. Definitions, acronyms, and abbreviations

3.2 Acronyms and abbreviations

Replace definition for TPC with new definition as follows:

TPC transmit power control

Insert the following acronyms alphabetically into 3.2 as follows:

ANPI average noise power indicator

IPI idle power indicator

RCPI received channel power indicator

RSNI received signal noise indicator

SRM spectrum resource measurement

TBPC turbo product code

5. General description

5.7 Functional overview

Insert new subclause 5.7.7 after 5.7.6 as follows:

5.7.7 Enabling spectrum resource measurement capability

SRM enables devices to gather a variety of data for evaluating radio link performance, which contributes to the selection of the best available PAN for joining and efficient radio spectrum usage for the selected PAN. As shown in Figure 5-10, the device obtains radio link characteristics by local measurements or via exchange of information with other devices via reporting messages all the way to the PAN coordinator. The PAN coordinator is also able to disseminate information to the devices in the PAN, such as the maximum transmit power, by which the receiving devices can set their radio parameters in a unified manner. SRM data is also made available to the upper protocol layers, which is able to use it for controlling the lower layer or their applications.

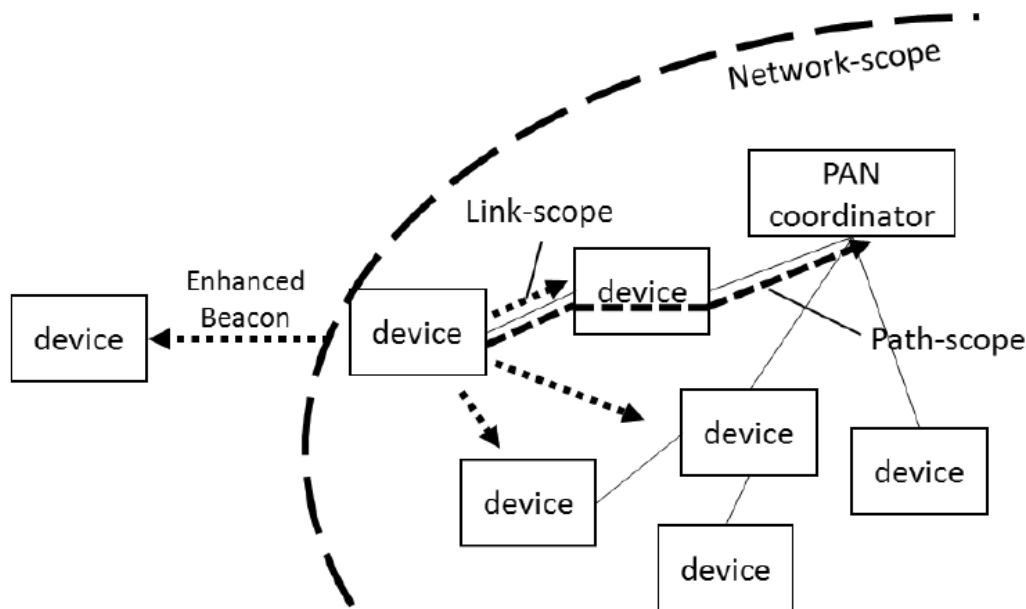


Figure 5-10—Scope-based forwarding control

The measurement of SRM metrics are conducted only when the device is capable of doing it. In the case of LE transmission and reception, for example, even if the requesting device requests the peer device to measure SRM metrics for a specific duration of time, the requested device can do it only when the receiver is enabled.

In the case of TSCH, there are three modes of measurement operation.

- Full measurement: the device conducts the measurement for a specified duration of time regardless of the channel.
- Channel-specific measurement: the device conducts the measurement only when it is on the specified channel within the hopping sequence. The device puts the measured data together and calculates the performance metrics. The obtained result is the characteristics of the specified channel.
- Link-specific measurement: the device conducts the measurement only when it is on a specific link, which is represented by *macLinkHandle* defined in Table 8-85. The device puts the measure data together and calculates the performance metrics. The obtained result is the characteristics of the specified link.

6. MAC functional descriptions

Insert new subclause 6.17 after 6.16 as follows:

6.17 Spectrum resource measurement (SRM)

SRM specifies the following functions and procedures in order to effectively operate wireless systems that could have heavy interferences within or outside the network:

- Spectrum resource measurements and network performance metrics, such as packet error ratio, delay, etc.
- Information elements and data structures to capture these measurements
- Procedures for collecting and exchanging spectrum resource measurement information with higher layers or other devices and for transmit power control (TPC)

6.17.1 SRM performance metrics

6.17.1.1 Energy detection (ED)

ED capability is included in the fundamental features for PHY technologies as described in 10.2.5. In the case that SRM capabilities is supported, the scaling of ED data shall abide by the following rule.

- The minimum and maximum values of ED are 0x0 and 0xf, respectively.

This range covers twice the range of 40 dB with the accuracy of 6 dB.

6.17.1.2 Percentage of time of failed transmissions

The percentage of time of failed transmissions feature is intended for use by a higher layer, or by a common network manager existing in a multiple wireless network environment, to aid in the estimation of propagation quality of specific links as part of a channel selection algorithm.

The output of the feature is a value for the PIB attribute *macTxFailTime*, which shall be calculated with the following equation:

$$macTxFailTime = \frac{\sum tx\ fail\ time[j]}{\sum attempted\ time[i]}$$

macTxFailTime is linearly scaled with 0xff representing 100%.

In this equation, *tx fail time* [j] is the time period starting at the first bit of the MPDU and stopping at the end of the last retry time out. The value of j is determined by the number of the failed transmissions within the Measurement time as depicted in Figure 6-79, where the first attempt on the left hand side is successful and not counted as *tx fail time* [j] and the second attempt on the right hand side is unsuccessful so that it is counted as *tx fail time* [j]. Also, *attempted time* [i] is the time when the first frame is attempted to be transmitted to the time when either it is successfully transmitted and acknowledged or it is failed to transmit by reaching *macMaxFrameRetries* times. Measurement time is defined as the duration of the requested measurement specified by the SRM Duration in Figure 7-136. By considering only the attempted time within the measurement time, the time between any two consecutive attempts, which is idle, is excluded. The accuracy for the time used in this equation shall be $\pm 100\ \mu\text{s}$.

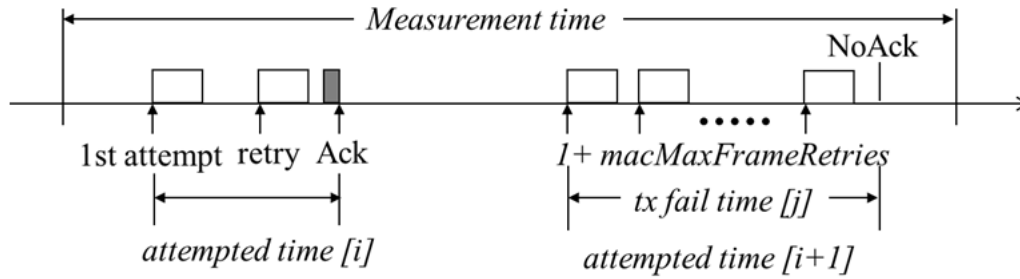


Figure 6-79—maxTxFailTime

6.17.1.3 Percentage of time of deferred transmissions

The percentage of time of deferred transmissions feature is intended for use by a higher layer, or by a common network manager existing in a multiple wireless network environment, to aid in the estimation of congestion with coexisting LR-WPAN, WLAN, or other networks as part of a channel selection algorithm. The output of the feature is a value for the PIB attribute *macDeferredTxTime*, which shall be calculated with the following equation:

$$macDeferredTxTime = \frac{\sum \text{deferred period } [j]}{\sum \text{attempted time } [i]}$$

In this equation, *deferred period [j]* is the total duration of all back-off periods of all packets sent during the Measurement Time as depicted in Figure 6-80. Also, *attempted time [i]* is the time when the first frame is attempted to be transmitted to the time when it is successfully transmitted and acknowledged. Measurement time is defined as the duration of the requested measurement specified by the SRM Duration in Figure 7-136. By considering only the attempted time within the measurement time, the time between any two consecutive attempts, which is idle, is excluded. The accuracy for the time used in this equation shall be $\pm 100 \mu\text{s}$.

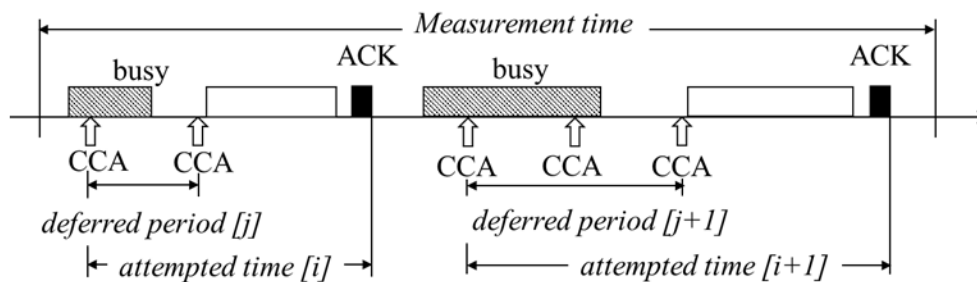


Figure 6-80—macDeferredTxTime

6.17.1.4 Retry Histogram

Retry Histogram is intended for use by the next higher layer or a common network manager existing in multiple wireless network environment, in order to optimize the utilization of spectrum resource.

Retry histogram is the histogram of the number of retries for one transmission during the measurement time. The bins range from 0 to *macMaxFrameRetries*. Retry number=0 means that the transmission is successful without retry. Retry number=*macMaxFrameRetries* means that the transmission is failed and it is regarded