

# IEEE Standard for Low-Rate Wireless Networks

## Amendment 1: Enhanced Ultra Wideband (UWB) Physical Layers (PHYs) and Associated Ranging Techniques

IEEE Computer Society

Developed by the  
LAN/MAN Standards Committee

**IEEE Std 802.15.4z™-2020**  
(Amendment to IEEE Std 802.15.4™-2020)

# **IEEE Standard for Low-Rate Wireless Networks**

## **Amendment 1: Enhanced Ultra Wideband (UWB) Physical Layers (PHYs) and Associated Ranging Techniques**

Developed by the

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

Approved 4 June 2020

**IEEE SA Standards Board**

**Abstract:** This amendment enhances the UWB PHYs with additional coding options and improvements to increase the integrity and accuracy of ranging measurements. It also enhances the MAC to support control of time-of-flight ranging procedures and exchange ranging related information between the participating ranging devices.

**Keywords:** amendment, double-sided two-way ranging, DS-TWR, enhanced ranging device, ERDEV, HRP UWB PHY, HRP-ERDEV, IEEE 802.15.4™, IEEE 802.15.4z™, low power, low-rate wireless networks, LRP UWB PHY, LRP-ERDEV, multi-node ranging, precision ranging, ranging device, RDEV, RF, RFID, real time location systems, RTLS, single-sided two-way ranging, SS-TWR, time of flight, TOF, TOF integrity, two-way ranging, TWR, ultra wideband, UWB, wireless specialty networks, WSN

---

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

Copyright © 2020 by The Institute of Electrical and Electronics Engineers, Inc.  
All rights reserved. Published 25 August 2020. 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 978-1-5044-6798-8 STD24237  
Print: ISBN 978-1-5044-6799-5 STDPD24237

*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 <https://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. IEEE Standards are documents developed through scientific, academic, and industry-based technical working groups. Volunteers in IEEE working groups 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 Standards do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. Implementers and users 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.

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. A current 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 <https://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 <https://standards.ieee.org>.

## Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE SA Website at the following URL: <https://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 <https://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 standard was completed, the IEEE 802.15 Working Group had the following membership:

**Robert F. Heile**, *IEEE 802.15 Working Group Chair*  
**Rick Alfvín**, *IEEE 802.15 Working Group Vice-Chair*  
**Patrick W. Kinney**, *IEEE 802.15 Working Group Vice-Chair, IEEE 802.15 Working Group Secretary*  
**James P. K. Gilb**, *IEEE 802.15 Working Group Technical Editor*  
**Benjamin A. Rolfe**, *IEEE 802.15 Working Group Treasurer*

**Tim Harrington**, *IEEE 802.15.4z Task Group Chair*  
**Benjamin A. Rolfe**, *IEEE 802.15.4z Task Group Vice-Chair and Secretary*  
**Billy Verso**, *IEEE 802.15.4z Task Group Technical Editor*

Hendrik Ahlendorf	Roger Hislop	Jaroslaw Niewczas
Koorosh Akhavan	Jay Holcomb	Paul Nikolich
Bernd Baer	Oliver Holland	Philip Orlik
David Barras	Iwao Hosako	Aditya Padaki
Tuncer Baykas	Brima Ibrahim	Clark Palmer
Philip Beecher	Tetsushi Ikegami	Glenn Parsons
Friedbert Berens	Yeong Min Jang	Charles Perkins
Harry Bims	Seongah Jeong	Albert Petrick
Lennert Bober	Seong-Soon Joo	Joe Polland
Monique Brown	Volker Jungnickel	Clinton Powell
Chris Calvert	Juha Juntunen	Demir Rakanovic
Radhakrishna Canchi	S. G. Karthik	Ivan Reede
Jaesang Cha	Paul Kettle	Joerg Robert
Soo-Young Chang	Shoichi Kitazawa	Alessandra Rocha
Matthew Chang	Tero Kivinen	Ren Sakata
Clint Chaplin	Daniel Knobloch	Ruben E. Salazar Cardozo
Sangsung Choi	Ryuji Kohno	Ioannis Sarris
Nathan Clanney	Fumihide Kojima	Peter Sauer
Michael G. Cotton	Ann Krieger	Nikola Serafimovski
Boris Danev	Thomas Kuerner	Daoud Serang
Luc Darmon	Jack Lee	Kunal Shah
Hendricus De Ruijter	Mingyu Lee	Tushar Shah
Brandon Dewberry	Frank Leong	Menashe Shahar
Anthony Fagan	Huan-Bang Li	Stephen Shellhammer
Robert Finch	Zheda Li	Guy Simpson
Michael Gagne	Sang-Kyu Lim	William Smith
Matthew Gillmore	Thomas Lorbach	Frederick Smith
Tim Godfrey	Masood Maqbool	Gary Stuebing
Jianlin Guo	Vinayagam Mariappan	Don Sturek
Joachim Hammerschmidt	Alejandro Marquez	Craig Tedrow
Shinsuke Hara	Gianfranco Miele	Johannes Wechsler
Hiroshi Harada	Apurva Mody	Brian Weis
Chris Hartman	Ayman Naguib	Peter Yee
Christopher Hett	Kathleen Nelson	Shaun Yu

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

Thomas Alexander	Werner Hoelzl	Robert Robinson
David Barras	Brima Ibrahim	Benjamin A. Rolfe
Philip E. Beecher	Raj Jain	Ruben E. Salazar Cardozo
Harry Bims	SangKwon Jeong	Shigenobu Sasaki
Nancy Bravin	Srinivas Kandala	Naotaka Sato
Vern Brethour	S. G. Karthik	Peter Sauer
Demetrio Bucaneg, Jr.	Stuart Kerry	James Schuessler
William Byrd	Yongbum Kim	Kunal Shah
Paul Cardinal	Patrick W. Kinney	Tushar Shah
Juan Carreon	Tero Kivinen	Robert Stacey
Pin Chang	Jarkko Knecht	Dorothy Stanley
Clint Chaplin	Daniel Knobloch	Thomas Starai
Charles Cook	Jan Kruys	Gary Stuebing
Boris Danev	Yasushi Kudoh	Don Sturek
Hendricus De Ruijter	Hyeong Ho Lee	Mark Sturza
Brandon Dewberry	Mingyu Lee	Bo Sun
Igor Dotlic	Wookbong Lee	Mark-Rene Uchida
Edward Eckert	Frank Leong	Aditya V. Padaki
Anthony Fagan	Zheda Li	Dmitri Varsanofiev
Michael Fischer	Yong Liu	Billy Verso
Avraham Freedman	Thomas Lorbach	George Vlantis
James P. K. Gilb	Michael Mc Laughlin	Lisa Ward
Matthew Gillmore	Michael McInnis	Karl Weber
Robert Golshan	Ayman Naguib	Scott Willy
Randall Groves	Nick S. A. Nikjoo	Andreas Wolf
Rainer Hach	Tetsu Nishimura	Chi Xu
Joachim Hammerschmidt	Bansi Patel	Shang-Te Yang
Timothy Harrington	Dev Paul	Kangjin Yoon
Robert F. Heile	Arumugam Paventhan	Yu Yuan
Jerome Henry	Clinton Powell	Oren Yuen
Marco Hernandez	Maximilian Riegel	Sven Zeisberg

When the IEEE SA Standards Board approved this standard on 4 June 2020, it had the following membership:

**Gary Hoffman, *Chair***  
**Jon Walter Rosdahl, *Vice Chair***  
**John D. Kulick, *Past Chair***  
**Konstantinos Karachalios, *Secretary***

Ted Burse	David J. Law	Mehmet Ulema
Doug Edwards	Howard Li	Lei Wang
J. Travis Griffith	Dong Liu	Sha Wei
Grace Gu	Kevin Lu	Philip B. Winston
Guido R. Hiertz	Paul Nikolich	Daidi Zhong
Joseph L. Koepfinger*	Damir Novosel	Jingyi Zhou
	Dorothy Stanley	

\*Member Emeritus

## Introduction

This introduction is not part of IEEE Std 802.15.4z-2020, IEEE Standard for Low-Rate Wireless Networks—Amendment 1: Enhanced Ultra Wideband (UWB) Physical Layers (PHYs) and Associated Ranging Techniques.

This amendment of IEEE Std 802.15.4-2020 specifies enhancements and enhanced modes of operation for the HRP UWB PHY and the LRP UWB PHY and associated ranging techniques in the MAC. The PHY enhancements include facilities to improve the integrity and accuracy of the ranging measurements. The MAC enhancements include specification of information element definitions to facilitate ranging information exchange, and changes to support the PHY enhancements.

These enhancements meet the needs of a wider set of applications where the integrity and accuracy of distance measurement is important.

The standard is widely used in a variety of applications that employ the ranging capabilities enabled by the UWB PHYs specified by IEEE Std 802.15.4-2020. Current users and product manufacturers have identified the need for improved efficiency, integrity, and accuracy of the existing ranging measurement methods in order to expand the usefulness of the standard for applications such as RFID and automotive, in particular, automotive remote control, and similar personal devices. These enhancements are also expected to open up new areas of application.

# Contents

2.	Normative references .....	13
3.	Definitions, acronyms, and abbreviations.....	14
3.1	Definitions .....	14
3.2	Acronyms and abbreviations .....	14
5.	General description .....	15
5.7	Functional overview .....	15
5.7.3	Frame structure .....	15
6.	MAC functional description .....	16
6.2	Channel access.....	16
6.2.11	Beacon-enabled ranging with ERDEV .....	16
6.7	Transmission, reception, and acknowledgment.....	17
6.7.2	Reception and rejection .....	17
6.7.4	Use of acknowledgments and retransmissions .....	17
6.9	Ranging, relative positioning, and localization .....	17
6.9.1	Ranging requirements measurements .....	17
6.9.2	Set-up activities before a ranging exchange .....	25
6.9.3	Finish-up activities after a ranging exchange .....	25
6.9.4	Managing DPS and DCS .....	25
6.9.5	The basic ranging exchange.....	27
6.9.6	Ranging procedures .....	28
6.9.7	Multi-node ranging .....	37
6.9.8	Authenticated challenge-response ranging .....	59
6.9.9	Ranging message non-receipt exchange .....	72
6.9.10	Ranging ancillary information .....	72
6.9.11	Multiple Message Receipt Confirmation.....	73
7.	MAC frame formats.....	74
7.2	General MAC frame format.....	74
7.2.11	FCS field.....	74
7.4	IEs .....	74
7.4.2	Header IEs.....	74
7.4.4	Nested IE.....	75
7.5	MAC commands .....	98
7.5.1	Command ID field .....	98
7.5.31	Ranging Verifier command .....	98
7.5.32	Ranging Prover command .....	99
8.	MAC services .....	100
8.2	MAC management service.....	100
8.2.1	Primitives supported by the MLME-SAP interface.....	100
8.2.5	Communications notification primitives .....	100
8.2.10	Primitives for specifying the receiver enable time .....	100
8.2.15	Primitives for specifying dynamic channel and preamble selection.....	105
8.2.16	Primitives for channel sounding .....	107
8.2.17	Primitives for ranging calibration .....	107

8.2.18	Primitives for Beacon Generation.....	108
8.2.25	RIT data commands .....	108
8.2.27	Primitives for specifying STS parameters .....	109
8.3	MAC data service .....	111
8.3.1	General.....	111
8.3.2	MCPS-DATA.request.....	111
8.3.3	MCPS-DATA.confirm.....	114
8.3.4	MCPS-DATA.indication .....	117
8.3.7	ACRR verifier primitives.....	123
8.3.8	ACRR prover primitives .....	128
8.4	MAC constants and PIB attributes.....	132
8.4.3	MAC PIB attributes .....	132
10.	General PHY requirements .....	133
10.1	General.....	133
10.1.2	Operating frequency range.....	133
10.1.3	Channel assignments.....	133
10.2	General radio specifications.....	134
10.2.8	Clear channel assessment (CCA).....	134
10.3	Ranging capable PHY .....	134
10.3.1	General.....	134
10.3.2	Distance commitment on PSDU .....	134
11.	PHY services .....	136
11.2	PHY constants.....	136
11.3	PHY PIB attributes .....	136
15.	HRP UWB PHY .....	140
15.1	General.....	140
15.2	HRP UWB PPDU format .....	140
15.2.1	General.....	140
15.2.2	PPDU encoding process.....	141
15.2.6	SHR field .....	141
15.2.7	PHR field .....	143
15.2.8	PHY Payload field .....	145
15.2.9	Scrambled timestamp sequence (STS) field .....	145
15.3	Modulation.....	148
15.3.3	FEC .....	148
15.3.4	HRP-ERDEV modulation in HPRF mode.....	149
15.4	RF requirements.....	153
15.4.4	Baseband impulse response .....	153
15.4.6	Chip rate clock and chip carrier alignment.....	154
15.7	HRP-ERDEV parameter sets .....	154
18.	LRP UWB PHY specification .....	157
18.1	Overview.....	157
18.2	LRP UWB PHY symbol structure .....	158
18.2.1	Overview.....	158
18.2.5	Dual-frequency LRP UWB PHY symbol structure.....	159
18.2.6	Variable pulse repetition period (PRP).....	159
18.3	LRP UWB SHR .....	160

18.3.2	LRP UWB SHR preamble .....	160
18.3.3	LRP UWB SHR SFD.....	161
18.5	LRP UWB PSDU.....	162
18.5.1	General.....	162
18.5.2	PSDU in enhanced payload capacity (EPC) mode .....	162
18.6	LRP UWB location enhancing information postamble .....	163
18.7	LRP UWB transmitter specification .....	164
18.7.1	Pulse shape.....	164
18.7.2	Pulse timing .....	164
18.7.3	Transmit PSD mask .....	164
18.8	LRP UWB transmit and receive timing requirements .....	168
18.8.1	Fixed reply time .....	168
18.8.2	Turnaround times .....	168
Annex A (informative) Bibliography .....		169
Annex D (informative) Protocol implementation conformance statement (PICS) proforma.....		170
Annex H (informative) STS generation.....		171

# IEEE Standard for Low-Rate Wireless Networks

## Amendment 1: Enhanced Ultra Wideband (UWB) Physical Layers (PHYs) and Associated Ranging Techniques

(This amendment is based on IEEE Std 802.15.4™-2020.)

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.<sup>1</sup>

---

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