

IEEE Standard for Medium Frequency (less than 12 MHz) Power Line Communications for Smart Grid Applications

IEEE Communications Society

Sponsored by the
Power Line Communication Standards Committee

IEEE Standard for Medium Frequency (less than 12 MHz) Power Line Communications for Smart Grid Applications

Sponsor

**Power Line Communication Standards Committee
of the
IEEE Communications Society**

Approved 7 May 2018

IEEE-Standards Board

Abstract: Physical (PHY) and media access control (MAC) layers of the medium frequency band (less than 12 MHz) broadband power line communication technology for smart grid applications (SGPLC) based on orthogonal frequency division multiplexing (OFDM) are specified in this standard. The necessary security requirements that assure communication privacy and allow use for mission critical and security sensitive services and applications are addressed in this standard. The coexistence with other technologies based on IEEE Std 1901™-2010 also are addressed. The approach that is geared towards achieving an extended communication range with medium speeds in comparison with the existing power line communication technologies operating in similar frequency bands is defined in this standard.

Keywords: BPL, broadband power line, coexistence, FFT, IEEE 1901™, IEEE 1901.1™, IEEE 1901.2™, MAC, medium frequency, OFDM, orthogonal frequency division multiplexing, PHY, PLC, power line communication, security, smart grid

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 14 May 2018. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 978-1-5044-4820-8 STD23080
Print: ISBN 978-1-5044-4821-5 STDPD23080

*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. 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 Xplore 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 this IEEE standard was completed, the IEEE P1901.1 Working Group had the following membership:

Oleg Logvinov, *Chair*

Scott Willy, *Vice Chair*

Liheng Chen	Jiaofeng Li	Harris Tzou
Peijin Cong	Chunyan Li	Xiaohui Wang
Shuo Dai	Xiangru Lin	Xueliang Wang
Wei Dai	Li-Cheng Lin	Jing Xiangkun
Xu Dechao	Qingyang Liu	Hu Xiaojing
Haitao Dong	Dan Liu	Shuang Xiong
Lingqiang Fan	Lei Liu	Guan Yan
Wei Gao	Yixuan Lv	Sunny Yang
Pan Guo	Eugen Mayer	Bucai Ye
Yue Han	MengHsin Ou	Wu Yifan
Dai Hongguang	Bingbing Peng	Xu Youshi
Zhang Hongxing	Tomasz Piasecki	Hui Yu
Jianqiang Hou	Yi Qu	Zhang Yungang
Xudong Hou	Davide Righini	Nauman Ahmad Zaffar
Jeng-Shiann Jiang	Markus Rindchen	Xuming Zhang
Li JianQi	David Ruiz	Hailong Zhang
Xin Jin	Garba Sanusi	Bo Zhao
Zou Keshu	Ernst Siegler	Ming Zhao
Ferris Lee	Kuichao Song	Yunlong Zhong
Xiuyan Li	Yu Sun	Jia Zhou
	Andrea Tonello	

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

James D. Allen	Werner Hoelzl	Markus Rindchen
Niranth Amogh	Noriyuki Ikeuchi	Charles Rogers
Demetrio Bucaneg Jr.	Li Jiaofeng	Benjamin Rolfe
William Byrd	Xiangkun Jing	Daniel Sabin
Xin Chang	Thomas Kurihara	Yu Sun
De Chen	Benjamin Lanz	Jun Wang
Shan Chen	Ferris Lee	Xueliang Wang
Peijin Cong	Xiuyan Li	Lisa Ward
Shuo Dai	Dan Liu	Scott Willy
Wei Dai	Qingyang Liu	Yifan Wu
Lingqiang Fan	Xiaohui Liu	Hongxing Zhang
Randall Groves	Oleg Logvinov	Bo Zhao
Pan Guo	Yixuan Lv	Yunlong Zhong
Yue Han	Eugen Mayer	Jia Zhou
	Tomasz Piasecki	

When the IEEE-Standards Board approved this standard on 11 May 2018, it had the following membership:

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

Ted Burse
Guido R. Hiertz
Christel Hunter
Joseph L. Koepfinger*
Thomas Koshy
Hung Ling
Dong Liu

Xiaohui Liu
Kevin Lu
Daleep Mohla
Andrew Myles
Paul Nikolich
Ronald C. Petersen
Annette D. Reilly

Robby Robson
Dorothy Stanley
Mehmet Ulema
Phil Wennblom
Philip Winston
Howard Wolfman
Jingyi Zhou

*Member Emeritus

Introduction

This introduction is not part of IEEE Std 1901.1-2018, IEEE Standard for Medium Frequency (less than 12 MHz) Power Line Communications for Smart Grid Applications.

This standard specifies physical (PHY) and media access control (MAC) layers of the medium frequency band (less than 12 MHz) broadband power line communication technology for smart grid applications (SGPLC) based on orthogonal frequency division multiplexing (OFDM). The standard addresses the necessary security requirements that assure communication privacy and allow use for mission critical and security sensitive services and applications. It also addresses the coexistence with other technologies based on IEEE Std 1901™. This standard also defines the approach that is geared towards achieving an extended communication range with medium speeds in comparison with the existing power line communication technologies operating in similar frequency bands.

Contents

1. Scope.....	20
2. Normative references	20
3. Definitions, acronyms, and abbreviations	21
3.1 Definitions.....	21
3.2 Acronyms and abbreviations	21
4. General description	24
4.1 Introduction	24
4.2 Device roles.....	24
4.3 Network topology.....	25
4.4 Reference model.....	26
5. Network management sub-layer.....	27
5.1 Management packet format	27
5.2 Single network.....	60
5.3 Multi-network	64
5.4 Network maintenance.....	64
6. MAC sub-layer.....	70
6.1 Frame format	70
6.2 MAC sub-layer functions	93
7. Data link layer service.....	112
7.1 Overview	112
7.2 Data transmission service at the data link layer	113
7.3 Data management service at the data link layer	114
8. Physical layer	119
8.1 General requirements and definitions	119
8.2 Physical layer services.....	150
9. PHY requirements	153
9.1 Transmitter electrical specifications	153
9.2 Performance requirements.....	153
9.3 Amplitude map	154
10. Security	155
10.1 Framework	155
10.2 Security methods.....	155
10.3 Device-based security network (DSN) data confidentiality protocol.....	155
10.4 Shared key DSNA.....	158
10.5 Key provisioning.....	160
10.6 Generation of AES encryption keys and nonces	162
11. Coexistence	162
11.1 Multi-network coexistence and coordination.....	162
11.2 Coexistence between non-interoperable protocols	167
Annex A (informative) Whitelist management.....	182
Annex B (informative) Testing frame.....	183

Annex C (informative) Bridging behavior	184
Annex D (informative) Adaptation of IPv4/IPv6.....	185
Annex E (informative) EMC mitigation toolkit.....	188
Annex F (informative) Bibliography.....	190

List of Figures

Figure 1—Example of broadband carrier communication network topology	25
Figure 2—Example of a topology for multiple broadband carrier communication networks.....	25
Figure 3—Protocol stack for a broadband carrier communication network	26
Figure 4—Exchange of management packets	63
Figure 5—MMeAssocGatherInd packet	64
Figure 6—Network topology	67
Figure 7—Format of a MAC frame	71
Figure 8—Format of an MPDU.....	74
Figure 9—Single-frame transmission with no SACK frame	79
Figure 10—Single-frame transmission with a SACK frame	79
Figure 11—PB format for an MPDU.....	83
Figure 12—PB format for a beacon MPDU	85
Figure 13—Timeslot allocation.....	93
Figure 14—Beacon timeslot allocation.....	95
Figure 15—TDMA timeslot allocation	96
Figure 16—CSMA timeslot allocation	96
Figure 17—Timeslot allocation.....	98
Figure 18—BIFS.....	100
Figure 19—CIFS (1)	101
Figure 20—CIFS (2)	101
Figure 21—RIFS.....	101
Figure 22—EIFS	102
Figure 23—Inter-frame space measurement	102
Figure 24—Inter-frame space measurement for RTS/CTS frames.....	103
Figure 25—Format of a MAC frame	104
Figure 26—Long MPDU generation.....	105
Figure 27—Short MPDU generation.....	105
Figure 28—MAC frame reassembly	106
Figure 29—Packet filtering	107

Figure 30—Unicast SOF transmission	108
Figure 31—SOF frame broadcast locally	109
Figure 32—SOF frame broadcast on the entire network by proxy	110
Figure 33—SOF frame transmit on the branch.....	111
Figure 34—Data link layer services	112
Figure 35—Physical layer architecture	120
Figure 36—Physical layer frame format	120
Figure 37—OFDM symbol timing.....	121
Figure 38—Frame control FEC processing.....	121
Figure 39—Payload FEC processing	123
Figure 40—Architecture of the turbo convolutional encoder.....	124
Figure 41—ENC1/ENC2 encoding architecture.....	125
Figure 42—Scrambling process	128
Figure 43—ROBO interleaving parameters.....	131
Figure 44—ROBO outputting.....	135
Figure 45—Preamble data format	137
Figure 46—Illustration of pilot symbol insertion	143
Figure 47—Physical layer service reference model	150
Figure 48—MAC frame fragmentation and MPDU generation	157
Figure 49—MAC DSNA CBC mode encryption process.....	157
Figure 50—MAC DSNA CBC mode decryption process.....	158
Figure 51—NMK provisioning procedure	160
Figure 52—NEK provisioning procedure	161
Figure 53—NEK re-provisioning procedure.....	161
Figure 54—NEK update missing, NEK re-provisioning.....	162
Figure 55—Multi-network bandwidth coordination	164
Figure 56—Bandwidth negotiation request.....	164
Figure 57—Bandwidth negotiation principle 1	165
Figure 58—Bandwidth negotiation principle 2	165
Figure 59—Bandwidth negotiation principle 3	166
Figure 60—Timing of the ISP signal	168

Figure 61—Sync points (single-phase ac main)	172
Figure 62—Sync points (three-phase ac main).....	172
Figure 63—ISP time window and ISP fields concept	173
Figure 64—Periodicity of ISP windows	174
Figure 65—ISP fields	175
Figure 66—Composition of an ISP field: ISP signal and two ISP margins (silence periods)	177
Figure 67—Leakage signal level.....	181

List of Tables

Table 1—Fields in the management packet header.....	27
Table 2—Management packet types (MMTYPE).....	27
Table 3—Fields in MMeAssocReq packets.....	28
Table 4—Values of the Phase field.....	29
Table 5—Values of the Product Type field.....	29
Table 6—Values of the MAC Type field.....	30
Table 7—Subfields in the STA Version field.....	30
Table 8—Values of the System Start Reason field.....	30
Table 9—Values of the Version Date field.....	31
Table 10—Values of the Proxy Type field.....	31
Table 11—Fields in MMeAssocCnf packets.....	32
Table 12—Values of the Result field.....	32
Table 13—Values of some thresholds in the Result field.....	33
Table 14—Values of the TEI field.....	33
Table 15—Subfields in the Route Info field.....	34
Table 16—Subordinate STA list.....	34
Table 17—Fields in MMeAssocGatherInd packets.....	36
Table 18—Values of the Result field.....	36
Table 19—Subfields in the STA Information field.....	37
Table 20—Fields in MMeChangeProxyReq packets.....	37
Table 21—Values of the Proxy Type field.....	38
Table 22—Values of the Reason field.....	38
Table 23—Fields in MMeChangeProxyCnf packets.....	39
Table 24—Value of the Result field.....	39
Table 25—Subordinate STA list.....	40
Table 26—Fields in MMeChangeProxyBitMapCnf packets.....	41
Table 27—Value of the Result field.....	41
Table 28—Fields in MMeLeaveInd packets.....	42
Table 29—Values of the Reason field.....	42

Table 30—Subfields in the Leave STA MAC field	43
Table 31—Fields in MMeHeartBeatCheck packets	43
Table 32—Fields in MMeDiscoverNodeList packets	44
Table 33—Values of the Role field	45
Table 34—Subfields in the Up Route Entry Information field	46
Table 35—Values of the Route Type subfield	46
Table 36—Subfields in the Received Discovery Information field	47
Table 37—Fields in MMeSuccessRateReport packets	47
Table 38—Subfields in the Communication Rate Information field	48
Table 39—Fields in the MMeNetworkConflictReport packet	48
Table 40—Subfields in the Neighboring Network Entry field	49
Table 41—Fields in the MMeZeroCrossNTBCollectionReq packet	49
Table 42—Values of the Collection Mode field	50
Table 43—Values of the Collection Period field	50
Table 44—Fields of the MMeZeroCrossNTBReport packet	50
Table 45—Subfields of the Difference NTB Phase field	51
Table 46—Fields in MMeLBDAtCnf packets	52
Table 49—Fields of MMeSetKeyRequest	53
Table 50—Values of Key Type field	53
Table 51—Fields of MMeSetKeyConfirm	54
Table 52—Values of Result field	54
Table 53—Fields of MMeGetKeyRequest	55
Table 54—Fields of MMeGetKeyConfirm	56
Table 55—Values of Result field	56
Table 56—Fields of MMeAuthrzRequest	56
Table 57—Fields of MMeAuthrzConfirm	57
Table 58—Fields of MMeEncryptedPIInd	58
Table 59—Values of Payload Type	58
Table 60—Values of PEKS	58
Table 61—Fields in MMeSetAmpMapReq packet	59
Table 62—Fields in MMeSetAmpMapCnf packet	60

Table 63—Values of Response field	60
Table 64—Fields in MMeNetworkDiagnosisReport packets	60
Table 65—Definitions of the cyclic shift phase	63
Table 66—Routing entries of the CCO	67
Table 67—Routing entries of STA1	68
Table 68—Routing entries of STA2	68
Table 69—Period parameters	69
Table 70—Fields in a MAC frame header	71
Table 71—Values of the Version field	71
Table 72—Values of the Send Type field	71
Table 73—Values of the MSDU Type field	72
Table 74—MAC Frame Type field	73
Table 75—Subfields in the Relay Variant field	73
Table 76—Values of Proxy Main Path Flag field	74
Table 77—Values of the Broadcast Direction field	74
Table 78—Subfields in the FC field	75
Table 79—Values of the Delimiter Type field	75
Table 80—Values of the Network Type field	75
Table 81—Values of the Version field	76
Table 82—Variant fields in a beacon frame	76
Table 83—Values of the Phase Line field	77
Table 84—Variant fields in a SOF	77
Table 85—Values of the LID field	78
Table 86—Values of the Encryption Key Select field	78
Table 87—Values of the Broadcast Flag field	79
Table 88—Values of the Resend Flag field	79
Table 89—Variant fields in an SACK frame	80
Table 90—Variant fields in an inter-network coordinate frame	81
Table 91—Variant fields in an RTS/CTS frame	82
Table 92—Values of the MNBF field	82
Table 93—RTSF interpretation	83

Table 94—PBH format.....	84
Table 95—Subfields in the beacon frame payload field.....	85
Table 96—Values of the BT field.....	86
Table 97—Values of the Networking Flag field.....	86
Table 98—Values of the Start Associate field	86
Table 99—Values of the Beacon Evaluation Flag field.....	86
Table 100—Subfields in the BMI field	87
Table 101—Values of the NBE field.....	87
Table 102—Values of the BEHDR field	87
Table 103—Value of the BELEN field	88
Table 104—Subfields in the STA Capability List field	88
Table 105—Timeslot allocation list.....	89
Table 106—Subfields in the Non Central Beacon Information field.....	90
Table 107—Subfields in the CSMA Slot Information field	90
Table 108—Subfields in the Bind CSMA Slot Information field.....	91
Table 109—Route parameter list.....	91
Table 110—Frequency change list	91
Table 111—VCS timer value and channel status transition	99
Table 112—Inter-frame space values	102
Table 113—Data transmission service primitives at the data link layer.....	113
Table 114—MSDU transmit primitive	113
Table 115—MSDU receive primitive.....	113
Table 116—Data management service primitives at the data link layer	114
Table 117—Network topology query primitive.....	114
Table 118—Network topology report primitive	115
Table 119—Single network topology entry report primitive	115
Table 120—Network NID query primitive.....	115
Table 121—NID report primitive.....	116
Table 122—NID configuration primitive	116
Table 123—Neighbor network query primitive.....	116
Table 124—Neighbor network report primitive	117

Table 125—Single network topology entry report primitive	117
Table 126—Whitelist query primitive	117
Table 127—Whitelist report primitive	118
Table 128—Whitelist configuration primitive.....	118
Table 129—OFDM symbols	121
Table 130—Diversity copier for frame control.....	122
Table 131—Turbo interleaving parameter settings.....	125
Table 132—S lookup table for PB16	126
Table 133—S lookup table for PB72	126
Table 134—S lookup table for PB136	126
Table 135—S lookup table for PB520	127
Table 136—Puncturing model for the bit rate of 1/2.....	127
Table 137—Puncturing model for the bit rate of 16/18.....	127
Table 138—Channel interleaving parameter settings.....	129
Table 139—Nibble shift rules.....	129
Table 140—ROBO basic modes.....	129
Table 141—ROBO extended modes	130
Table 142—Relation between N_{Inter} and N_{Copy}	131
Table 143—Modulation capacity	136
Table 144—Constellation point mapping table	136
Table 145—Bit-to-I/Q mapping table.....	137
Table 147—Power normalization factors.....	137
Table 146—Phase angle reference values for frame control and payload mapping.....	138
Table 149—Value of the PilotStepSize field.....	143
Table 148—Preamble phase table	145
Table 150—Communication frequency bands	150
Table 151—Relative power of the preamble, frame control, and payload	150
Table 152—Signal transmission start state primitive	151
Table 153—Signal transmission completion state primitive	151
Table 154—Signal receiving start state primitive.....	151
Table 155—Frame control receiving completion primitive.....	151

Table 156—Payload receiving completion primitive	152
Table 157—Noise power primitive	152
Table 158—Signal attenuation primitive.....	152
Table 159—SNR/Average SNR primitive.....	152
Table 160—Estimated clock deviation primitive	153
Table 161—SNR requirements for basic TMI modes.....	154
Table 162—Power reduction for the amplitude map entry	154
Table 163—Fields of the IV	156
Table 164—Parameters of ISP signal	169
Table 165—ISP signal carrier frequencies	170
Table 166—ISP signal phase vector reference.....	171
Table 167—ISP signal phase vector offsets.....	171
Table 168—Meaning of the IEEE 1901.1 ISP window fields.....	175
Table 169—Meaning of the IH-C1 window fields.....	175
Table 170—Meaning of the IH-C2 window fields.....	176
Table 171—Meaning of the IH-G window fields	176
Table D.1—Selection from IETF RFC 6282 [B8]	186

IEEE Standard for Medium Frequency (less than 12 MHz) Power Line Communications for Smart Grid Applications

1. Scope

This standard specifies physical (PHY) and media access control (MAC) layers of the medium frequency band (less than 12 MHz) broadband power line communication technology for smart grid applications (SGPLC) based on orthogonal frequency division multiplexing (OFDM) (e.g., FTT and/or wavelet OFDM). This standard coexists with IEEE Std 1901™-2010, IEEE Std 1901.2™-2013 [B1], and IEEE Std 1901.2a™-2015 [B2].^{1,2} The standard addresses the necessary security requirements that assure communication privacy and allow use for mission critical and security sensitive services and applications. This standard also defines the approach that is geared towards achieving an extended communication range in comparison with the existing power line communication technologies operating in similar frequency bands.

2. Normative references

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

FIPS 197, Advanced Encryption Standard (AES), 2001.³

IEEE Std 802™-2001, IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture.^{4,5}

IEEE Std 1901™-2010, IEEE Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications.

¹Information on references can be found in [Clause 2](#).

²The numbers in brackets correspond to those of the bibliography in [Annex F](#).

³FIPS publications are available from the National Technical Information Service, U.S. Department of Commerce (<http://www.ntis.org/>).

⁴The IEEE standards or products referred to in [Clause 2](#) are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

⁵IEEE publications are available from the Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).