



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

**Part 15.3: Wireless Medium Access Control
(MAC) and Physical Layer (PHY)
Specifications for High Rate Wireless
Personal Area Networks (WPANs)**

**Amendment 2: Millimeter-wave-based
Alternative Physical Layer Extension**

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

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

12 October 2009

IEEE Std 802.15.3cTM-2009
(Amendment to
IEEE Std 802.15.3TM-2003)

IEEE Std 802.15.3c™-2009

(Amendment to
IEEE Std 802.15.3™-2003)

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

**Part 15.3: Wireless Medium Access Control
(MAC) and Physical Layer (PHY)
Specifications for High Rate Wireless
Personal Area Networks (WPANs)**

**Amendment 2: Millimeter-wave-based
Alternative Physical Layer Extension**

Sponsor

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

Approved 11 September 2009

IEEE-SA Standards Board

Abstract: This amendment defines an alternative physical layer (PHY) for IEEE Std 802.15.3-2003. Three PHY modes have been defined that enable data rates in excess of 5 Gb/s using the 60 GHz band. A beam-forming protocol has been defined to improve the range of communicating devices. Aggregation and block acknowledgment have been defined to improve the medium access control (MAC) efficiency at the high data rates provided for by the PHY.

Keywords: 60 GHz, aggregation, beam forming, block acknowledgment, millimeter wave, uncompressed video, wireless personal area network, WPAN

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

Copyright © 2009 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 12 October 2009. 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 978-0-7381-6050-4 STD95963
Print: ISBN 978-0-7381-6051-1 STDPD95963

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.

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The 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 the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the 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. The 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 this, or any other IEEE Standard document.

The IEEE does not warrant or represent the accuracy or content of the material contained herein, 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 herein 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 five years for revision or reaffirmation, or every ten years for stabilization. When a document is more than five years old and has not been reaffirmed, or more than ten years old and has not been stabilized, 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 this document available, the IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is the IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEEE Standards document, should rely upon the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received 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 interpretation requests except in those cases where the matter has previously received formal consideration. 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 interpretation of the 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, explanation, or interpretation of the IEEE. Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Recommendations to change the status of a stabilized standard should include a rationale as to why a revision or withdrawal is required.

Comments and recommendations on standards, and requests for interpretations should be addressed to:

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

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.

Introduction

This introduction is not part of IEEE Std 802.15.3c-2009, IEEE Standard for Information technology Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPANs)—Amendment 2: Millimeter-wave-based Alternative Physical Layer Extension.

IEEE Std 802.15.3c-2009 is an amendment to IEEE Std 802.15.3-2003 (reaffirmed in 2008) that defines an alternative physical layer operating in the millimeter wave band along with the necessary MAC changes to support this PHY. Some of the key features and additions are as follows:

- Operation in the 60 GHz band.
- New data rates, with the highest greater than 5 Gb/s.
- Beamforming negotiation for the transmitter to increase the communication range.
- The ability to aggregate incoming data into single packets for improve MAC efficiency.
- Acknowledgment of individual subpackets in a packet to reduce retransmission overhead.

The PHY specifies three modes and one common mode. The three PHY modes are as follows:

- Single carrier (SC) mode optimized for low power and low complexity.
- High-speed interface (HSI) mode optimized for low-latency bidirectional data transfer.
- Qudio/video (AV) mode optimized for the delivery of uncompressed, high-defintion video and audio.

Also defined as a part of the alternate PHY is common-mode signaling, which is a PHY mode that allows devices using different PHY modes to communicate.

Interest in developing a millimeter wave alternative PHY began in the July 2003 meeting in San Francisco with the formation of an interest group. A study group was formally created in the March 2004 IEEE 802 plenary meeting in Orlando and developed a project authorization request that was approved in March 2005. The first meeting as a task group was in May 2005 in Cairns, Australia and the group worked steadily developing channel models and evaluation documents. The PHY modes were selected in November 2007 at the Atlanta meeting and draft progressed rapidly, entering working group letter ballot in June 2008. After three working group recirculation ballots, sponsor ballot started in March 2009. A total of three sponsor recirculation ballots were held, leading to approval of IEEE Std 802.15.3c-2009 by the IEEE-SA Standards Board on 11 September 2009.

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 Standards Association website at <http://ieeexplore.ieee.org/xpl/standards.jsp>, 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>.

Errata

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

Interpretations

Current interpretations can be accessed at the following URL: <http://standards.ieee.org/reading/ieee/interp/index.html>.

Patents

Attention is called to the possibility that implementation of this amendment may require use of subject matter covered by patent rights. By publication of this amendment, no position is taken with respect to the existence or validity of any patent rights in connection therewith. 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 Patent 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 amendment 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 amendment was submitted to the IEEE-SA for approval, the IEEE 802.15 Working Group had the following membership:

Robert F. Heile, *Chair*
Richard Alfvén, *Vice-Chair*
Patrick Kinney, *Vice-Chair*
James P. K. Gilb, *Technical Editor*

Reed Fisher, *IEEE 802.15.3c Chair*
Shu Kato, *IEEE 802.15.3c Vice-Chair*
Abbie Matthew, *IEEE 802.15.3c Vice-Chair*
Tuncer Baykas, *IEEE 802.15.3c Secretary*
Chin-Sean Sum, *IEEE 802.15.3c Secretary*
James P. K. Gilb, *IEEE 802.15.3c Technical Editor*

Tuncer Baykas, *IEEE 802.15.3c Assistant Editor*
Brian Gaffney, *IEEE 802.15.3c Assistant Editor*
Zhou Lan, *IEEE 802.15.3c Assistant Editor*
Chin-Sean Sum, *IEEE 802.15.3c Assistant Editor*
Chiu Ngo, *IEEE 802.15.3c Assistant Editor*

Gahng-Seop Ahn
Xizhi An
Takashi Arita
Arthur Astrin
Taehan Bae
Michael Bahr
Jay Bain
Vered Bar
John Barr
Anuj Batra
Phil Beecher
Ghulam Bhatti
Bruce Bosco
Nancy Bravin
Sverre Brubk
John Buffington
Kiran Bynam
Philippe Chambelin
Kuor-Hsin Chang
Soo-Young Chang
Clint Chaplin
Hind Chebbo
Chihong Cho
Sangsung Choi
Chia Chin Chong
Ciaran Connell
David Davenport
Hendricus De Ruijter
Gang Ding
Paul Dixon
Guido Dolmans
Igor Dotlic
Christophe Dugas
Dietmar Eggert
Amal Ekbal
Jason Ellis
Frederick Enns
Robert Fanfelle
Charles Farlow

John Farserotu
Will Filippo
George Flammer
Noriyasu Fukatsu
Kiyoshi Fukui
Shigeru Fukunaga
Ryuhei Funada
Uhlend Goebel
Paul Gorday
Vivek Gupta
Shinsuke Hara
Hiroshi Harada
David Hart
Marco Hernandez
Jin-Meng Ho
Seungeun Hong
Wei Hong
Srinath Hosur
David Howard
Jung-Hwan Hwang
Ichirou Ida
Tetsushi Ikegami
Akio Iso
Wuncheol Jeong
Zhanfeng Jia
Seong-Soon Joo
Chol Su Kang
Noh-Gyoung Kang
Sungweon Kang
Tae-Gyu Kang
Yasunao Katayama
Yasutaka Kawamoto
Jeritt Kent
Dae Ho Kim
Jaehwan Kim
Kyeongpyo Kim
Yongsun Kim
Ryuji Kohno
Fumihide Kojima

Keitarou Kondou
Bruce Kraemer
Kyung Sup Kwak
Hyoungjin Kwon
Hyukchoon Kwon
Youngmi Kwon
Ismail Lakkis
John Lampe
Khanh Le
Myung Lee
Daniel Lewis
Huan-Bang Li
Liang Li
Sheung Li
Sang-Kyu Lim
Noam Livneh
Frederick Martin
Jeff McCullough
Michael Mcinnis
Michael McLaughlin
Klaus Meyer
Dino Miniutti
Emmanuel Monnerie
Rajendra Moorti
Theodore Myers
Yukimasa Nagai
Ken Naganuma
Tatsuo Nakagawa
Chiu Ngo
Paul Nikolich
Hirohito Nishiyama
Makoto Noda
Dominic O'Brien
Okundu Omeni
Ryoji Ono
Laurent Ouvry
Satoshi Oyama
James Pace
Hyung-Il Park

Jahng Park
Seung-Hoon Park
Tae Rim Park
Taejoon Park
Maulin Patel
Ranjeet Patro
Al Petrick
Frank Poegel
Stephen Pope
Clinton Powell
Jim Raab
Mohammad Rahman
Sridhar Rajagopal
Jayaram Ramasastry
Arthur Redfern
Ivan Reede
Edward Reuss
Richard Roberts
June Chul Roh
Benjamin Rolfe
John Rouse
Olivier Rousseaux

Seung-Moon Ryu
Didier Sagan
Zafer Sahinoglu
Katsuyoshi Sato
Hirokazu Sawada
Kamran Sayrafian
Donald Schultz
Jean Schwoerer
Cristina Seibert
Huairong Shao
Stephen Shellhammer
Nobuhiko Shibagaki
Shusaku Shimada
Chang Sub Shin
Jaeseung Son
Myunghee Son
Marinus Struik
Shuji Suzuki
Kazuaki Takahashi
Kenichi Takizawa
James Taylor
James Tomcik

Ichihiko Toyoda
Jason Trachewsky
Sana Ullah
Masahiro Umehira
Jana van Greunen
Joachim Walewski
Chao-Chun Wang
Junyi Wang
Qin Wang
Scott Weikel
Magnus Wiklund
Ludwig Winkel
Eun Tae Won
Pyo Chang Woo
Hiroyuki Yamagishi
Wen-Bin Yang
Kamya Yazdandoost
Kaoru Yokoo
Su Yong
Yang Moon Yoon
Mu Zhao
Bin Zhen

Major technical contributions were received from the following individuals:

Vered Bar
Tuncer Baykas
Troy Beukema
André Bourdoux
Bruce Bosco
Chang-Soon Choi
Ryuhei Funada
Brian Gaffney
Ian Gifford
James P. K. Gilb
Eckhard Grass
Hiroshi Harada
Tian-Wei Huang
Kyoichi Iigusa
Akio Iso
Yasunao Katayama
Shuzu Kato
Seongsoo Kim
Ryota Kimura

Fumihide Kojima
Keitarou Kondou
Edwin Chang Yeul Kwon
Zhiguo Lai
Ismail Lakkis
Zhou Lan
Ming Lei
Wei Li
Nadine Malhouroux-Gaffet
Abbie Matthew
Michael McLaughlin
Hiroyuki Nakase
Chiu Ngo
Yoshinori Nishiguchi
Makoto Noda
Hiroyo Ogawa
Jisung Oh
Pascal Pagani
Chang-woo Pyo

Yu Zhan Raymond
Mohammad Azizur Rahman
Rick Roberts
Katsuyoshi Sato
Hirokazu Sawada
Alireza Seyedi
Harkirat Singh
Huai-Rong Shao
Masashi Shinagawa
Yozo Shoji
Stan Skafidas
Chin-Sean Sum
Ichihiko Toyoda
Masahiro Umehira
Alberto Valdes-Garcia
Junyi Wang
Pengfei Xia
Sandra Xiang Ping Qin
Hiroyouki Yamagishi
Su-Khiong Yong

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

Richard Alfvén	Akio Iso	Okundu Omeni
Butch Anton	Atsushi Ito	Chris Osterloh
Yoshio Aoki	Stephen Jackson	Satoshi Oyama
Taehan Bae	Raj Jain	James R. Parker
Jay Bain	Jaehyuk Jang	Eldad Perahia
Vered Bar	Bobby Jose	Venkatesha Prasad
John Barr	Woochul Jung	Mohammad Rahman
Tuncer Baykas	Tal Kaitz	Jayaram Ramasastry
Stephen Bennett	Naveen Kakani	Ivan Reede
H. Stephen Berger	Shinkyō Kaku	Robert Robinson
Harry Bims	Hyunjeong Kang	Benjamin Rolfe
Bruce Bosco	Noh-Gyoung Kang	Jaeyoung Ryu
Nancy S. Bravin	Haideh Karkhanechi	Randall Safier
Vern Brethour	Assaf Kasher	Osman Sakr
William Byrd	Yasunao Katayama	John Santhoff
James Carlo	Isao Katsuno	Shigenobu Sasaki
Juan Carreon	Stuart J. Kerry	Katsuyoshi Sato
Clint Chaplin	Jaehwa Kim	Hirokazu Sawada
Wei-Peng Chen	Sangbum Kim	Bartien Sayogo
Jaeweon Cho	Yongbum Kim	Cheng Shan
Hokyu Choi	Youngdoo Kim	Huairong Shao
Keith Chow	Youngsoo Kim	Jaejeong Shim
Charles Cook	Patrick Kinney	Changyong Shin
Todor Cooklev	Cees Klik	Gil Shultz
Joseph Decuir	Fumihide Kojima	Harkirat Singh
Yohannes Demessie	Keitarou Kondou	Jaeseung Son
Russell Dietz	Bruce Kraemer	Guocong Song
Thomas Dineen	Shoji Kuriki	Amjad Soomro
John Dorsey	Edwin Kwon	Thomas Starai
Paul Eastman	Zhou Lan	Walter Struppler
Richard Eckard	Jeremy Landt	Mark Sturza
Darwin Engwer	Michael McLaughlin	Chin-Sean Sum
Stanislav Filin	Insun Lee	Jun Ichi Takada
Michael Fischer	Jae Min Lee	David Thompson
Reed Fisher	Jeong Ho Lee	Geoffrey Thompson
C. Fitzgerald	Myung Lee	Karim Nassiri Toussi
Mark Forbes	Tae Hoon Lee	Ichihiko Toyoda
Dengwei Fu	John LeMoncheck	Solomon Trainin
Kiyoshi Fukui	Jan-Ray Liao	Masahiro Umehira
Shigeru Fukunaga	Arthur Light	Alberto Valdes-Garcia
Ryuhei Funada	Chiwoo Lim	Dmitri Varsanofiev
Devon Gayle	Hyoung-Kyu Lim	Prabodh Varshney
Theodore Georgantas	Jianhan Liu	Junyi Wang
James P. K. Gilb	Noam Livneh	Stanley Wang
Jeffrey Gilbert	Steve Lo	Fujio Watanabe
Uhland Goebel	William Lumpkins	Robert Wiser
Michael Gordon	John Marshall	Andreas Wolf
Randall Groves	David Mazzaresé	Pyo Chang Woo
Xiang Guan	Patrick Mcelwee	Harry Worstell
C. Guy	Apurva Mody	Xuyong Wu
Christopher Hansen	Hiroyuki Nakase	Hiroyuki Yamagishi
Hiroshi Harada	Michael S. Newman	James Yee
Robert F. Heile	Chiu Ngo	Su Khiong Yong
Marco Hernandez	Makoto Noda	Oren Yuen
Keang Ho	John Notor	Chunhui Zhu
Oliver Hoffmann	Satoshi Obara	
Robert Huang	Knut Odman	
Chan-Soo Hwang	Jisung Oh	

When the IEEE-SA Standards Board approved this standard on 11 September 2009, it had the following membership:

Robert M. Grow, *Chair*
Thomas Prevost, *Vice Chair*
Steve M. Mills, *Past Chair*
Judith Gorman, *Secretary*

John Barr
Karen Bartleson
Victor Berman
Ted Burse
Richard DeBlasio
Andy Drozd
Mark Epstein

Alexander Gelman
Jim Hughes
Richard H. Hulett
Young Kyun Kim
Joseph L. Koepfinger*
John Kulick

David J. Law
Ted Olsen
Glenn Parsons
Ronald C. Petersen
Narayanan Ramachandran
Jon Walter Rosdahl
Sam Sciacca

*Member Emeritus

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

Howard L. Wolfman, TAB Representative
Michael Janezic, NIST Representative
Satish Aggarwal, NRC Representative

Don Messina
IEEE Standards Program Manager, Document Development

Kathryn Cush
IEEE Standards Program Manager, Technical Program Development

Contents

3.	Definitions	2
4.	Acronyms and abbreviations	2
5.	General description	3
5.3	Overview of MAC functionality	3
5.3.12	Superframe structure using quasi-omni mode.....	3
5.3.13	Frame aggregation	4
5.3.14	Beam forming	4
5.3.15	Channel probing.....	4
5.3.16	Unequal error protection (UEP).....	4
5.5	Characteristics of the mmWave PHY	4
5.5.1	mmWave PHY characteristics	4
5.5.2	Piconets using mmWave PHY modes	5
6.	Layer management.....	6
6.3	MLME SAP interface	6
6.3.2	Scanning for piconets.....	6
6.3.3	Starting a piconet	6
6.3.18	Transmit switched diversity.....	7
6.5	MAC management.....	8
6.5.1	MAC PIB PNC group	8
6.5.2	MAC PIB characteristics group.....	9
6.6	MAC SAP	9
6.6.4	MAC-ISOCH-DATA.request	10
6.6.5	MAC-ISOCH-DATA.indication.....	10
7.	MAC frame format	11
7.2	General frame format	11
7.2.1	Frame control	11
7.2.4	Fragmentation control	12
7.2.5	Stream index	12
7.2.6	MAC header validation.....	13
7.2.8	SC and HSI aggregated frame format	13
7.2.9	AV aggregated frame format	19
7.3.6	Sync frame	26
7.4	Information elements	26
7.4.6	Piconet parameter change	27
7.4.11	Capability	27
7.4.22	Synchronization	32
7.4.23	Transmit switched diversity.....	34
7.4.24	UEP specific	35
7.4.25	IFS.....	35
7.4.26	CTA relinquish duration	36
7.4.27	Feedback	36
7.4.28	Mapping.....	37
7.4.29	BST clustering	38
7.4.30	Pattern estimation and tracking (PET) clustering	39
7.4.31	Beam PET	40
7.4.32	HRS beam PET	40

7.4.33	PET amplitude	41
7.4.34	PET phase	41
7.4.35	Sync frame frequency	42
7.4.36	Directional peer.....	42
7.5	MAC command types	43
7.5.1	Association and disassociation commands	43
7.5.4	Information request commands	43
7.5.6	Channel time allocation request, modification, and termination commands.....	43
8.	MAC functional description	44
8.1	Introduction.....	44
8.2	Starting, maintaining, and stopping piconets.....	44
8.2.1	Scanning through channels	44
8.2.3	PNC handover.....	44
8.4	Channel access.....	45
8.4.1	Interframe space (IFS)	45
8.4.2	Carrier sense multiple access with collision avoidance (CSMA/CA).....	45
8.4.3	Channel time allocation period channel access	45
8.5	Channel time management.....	45
8.5.1	Isochronous stream management.....	45
8.6	Synchronization	45
8.6.2	Beacon generation.....	45
8.6.6	Superframe support for directional PHYs	46
8.7a	Aggregation	50
8.7a.1	Standard aggregation	50
8.7a.2	Low-latency aggregation	52
8.8	Acknowledgment and retransmission.....	53
8.8.3b	Block ACK	53
8.9	Peer discovery.....	55
8.9.7	Channel probing.....	55
8.12	Multi-rate support	55
8.15	MAC sublayer parameters	55
8.16	UEP	57
8.17	Sync frame transmission and virtually dependent piconet	57
10.	Security specifications	58
10.2	Symmetric cryptography building blocks.....	58
10.2.4	Nonce value	58
12.	PHY specification for millimeter wave	58
12.1	General requirements.....	58
12.1.1	Regulatory information.....	59
12.1.2	RF power measurements.....	60
12.1.3	Unwanted emissions	60
12.1.4	Operating temperature range	60
12.1.5	RF channelization	60
12.1.6	Transmit PSD mask	60
12.1.7	Error vector magnitude calculation.....	60
12.1.8	Common PHY management for mmWave PHY modes	62
12.1.9	Requirements for mmWave PNCs.....	64
12.1.10	CP operation	64
12.1.11	mmWave PHY mode usage in CTA.....	65

12.1.12	Common Mode Signaling (CMS).....	65
12.1.13	mmWave PHY PIB.....	69
12.2	Single Carrier Mode of mmWave PHY.....	70
12.2.1	PHY operating specifications of SC PHY	71
12.2.2	Modulation, forward error correction and spreading.....	71
12.2.3	SC PHY frame format.....	86
12.2.4	Transmitter specifications.....	92
12.2.5	Receiver specifications	93
12.2.6	PHY layer timing.....	94
12.2.7	PHY management for SC PHY	95
12.2.8	Optional OOK/DAMI modes.....	95
12.3	High Speed Interface mode of mmWave PHY.....	96
12.3.1	General operating specifications.....	97
12.3.2	HSI PHY modulation, forward error correction, and spreading.....	97
12.3.3	HSI PHY frame format	109
12.3.4	Transmitter specifications.....	113
12.3.5	Receiver specifications	114
12.3.6	HSI PHY management.....	115
12.4	Audio/Visual mode of mmWave PHY	116
12.4.1	General requirements.....	117
12.4.2	AV PHY modulation and forward error correction	120
12.4.3	AV PHY frame formats	134
12.4.4	AV PHY transmitter requirements	141
12.4.5	AV PHY Receiver characteristics.....	143
12.4.6	Preambles and training symbols	143
13.	Beam forming	147
13.1	Introduction.....	147
13.2	Beam forming terminology.....	148
13.2.1	Quasi-omni patterns.....	149
13.2.2	Sectors.....	149
13.2.3	Beams.....	149
13.2.4	Clusters	150
13.3	Beam forming codebooks	151
13.3.1	Beam forming codebooks	153
13.4	Beam forming reference model	153
13.5	Beam forming protocol.....	155
13.5.1	Two-level training mechanism	156
13.5.2	Beam tracking	167
13.6	On-demand beam forming	169
13.7	Pro-active beam forming	169
13.8	Transmit switched diversity.....	169
Annex A	(normative) Frame convergence sublayer.....	171
Annex D	(normative) Protocol implementation conformance statement (PICS) proforma.....	179
Annex D1	(informative)Implementation considerations.....	181
Annex D2	(normative) Optional OOK/DAMI Modes	183

IEEE Standard for
Information technology—
Telecommunications and information
exchange between systems—
Local and metropolitan area networks—
Specific requirements

Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPANs)

Amendment 2: Millimeter-wave-based Alternative Physical Layer Extension

IMPORTANT NOTICE: This standard is not intended to ensure safety, security, health, or environmental protection in all circumstances. Implementers of the standard are responsible for determining appropriate safety, security, environmental, and health practices or regulatory requirements.

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. 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

Insert the following definitions in alphabetical order:

3.45 beacon: A broadcast frame sent by the piconet coordinator operating in either omni mode or quasi-omni mode for piconet synchronization and management.

3.46 dBm: Decibels relative to a milliwatt.

3.47 guard interval: A time period placed at the front of a symbol for inter-symbol interference avoidance.

4. Acronyms and abbreviations

Insert the following acronyms in alphabetical order:

AAS	asymmetric antenna system
AV	audio/visual
BBIFS	beam-forming beam-level interframe spacing
BCRD	bidirectional channel time allocation relinquish duration
Blk-ACK	block acknowledgment
BPSK	binary phase-shift keying
BSIFS	beam-forming sector-level interframe spacing
BST	beam switching/steering and tracking
CE	channel estimation
CES	channel estimation sequence
CMS	common mode signaling
DAMI	dual alternate mark inversion
EEP	equal error protection
EIRP	equivalent isotropic radiated power
GI	guard interval
GMSK	Gaussian filtered minimum shift keying
HR	high rate
HRP	high-rate physical layer
HRPDU	high-rate protocol data unit
HRS	high resolution
HSI	high-speed interface
LDPC	low-density parity check
LFSR	linear feedback shift register
LR	low rate
LRP	low-rate physical layer
LRPDU	low-rate protocol data unit
MCS	modulation and coding scheme
MPR	mandatory PHY rate
MR	medium rate
mmWave	millimeter wave
MSK	minimum shift keying
NLOS	non line of sight

OFDM	orthogonal frequency-division multiplexing
OOK	on-off keying
PCES	pilot channel estimation sequence
PET	pattern estimation and tracking
PRBS	pseudo-random bit stream
PSD	power spectral density
QT	quasi-omni training
RS	Reed Solomon
SAS	symmetric antenna system
SC	single carrier
S-CAP	sub-contention access period
SINR	signal to interference plus noise ratio
SSB	single side band
ST	sector training
SYNC	synchronization
TSD	transmit switched diversity
UEP	unequal error protection

5. General description

5.3 Overview of MAC functionality

After 5.3.11, insert the following new subclauses:

5.3.12 Superframe structure using quasi-omni mode

A mmWave WPAN operates in either omni mode or quasi-omni mode. The superframe structure for omni mode is illustrated in Figure 2. The superframe structure for quasi-omni mode is illustrated in Figure 2a. In quasi-omni mode, the same beacon frame is transmitted in different quasi-omni directions in a round-robin way in order to allow devices (DEVs) located in different directional coverage to join the piconet, as described in 8.6.6.

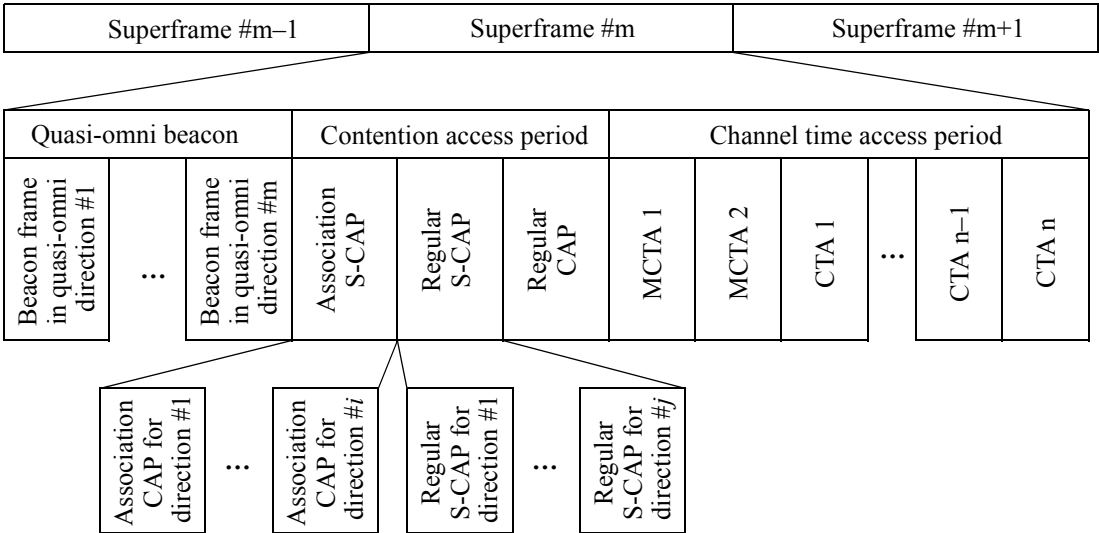


Figure 2a—Piconet superframe structure in quasi-omni mode

5.3.13 Frame aggregation

Frame aggregation, as described in 8.7a, is supported for the purpose of high throughput. With the high data rate provided by the mmWave PHY, throughput increases if the payload length is increased. Two aggregation methods are provided, one is suitable for normal data and A/V streaming and the other is optimized for low-latency communications.

5.3.14 Beam forming

The beam forming procedure allows a DEV that is capable of beam forming to increase the antenna gain for supporting high data rate transmission. The beam forming procedures are described in Clause 13.

5.3.15 Channel probing

Channel probing, as described in 8.9.7, is an optional capability that is used by a DEV to determine the best MCS to use with the target DEV under current channel condition.

5.3.16 Unequal error protection (UEP)

For flexible error protection that accounts for data that has more emphasis on the msbs than the lsbs, e.g., video, UEP is provided as an option. Three types of UEP are defined, as described in 8.16, for use with the three mmWave PHYs.

After 5.4, insert the following subclause as 5.5:

5.5 Characteristics of the mmWave PHY

5.5.1 mmWave PHY characteristics

The mmWave PHY, as described in Clause 12, is defined for the frequency band of 57.0–66.0 GHz, as allocated by the regulatory agencies in Europe, Japan, Canada, and the United States as well as any other areas where the regulatory bodies have allocated this band. While four channels are defined for the PHY, regulatory requirements allow fewer in some regions.

A total of three PHYs are defined for the mmWave PHY. They are as follows:

- a) Single Carrier mode in mmWave PHY (SC PHY), as described in 12.2.
- b) High Speed Interface mode in mmWave PHY (HSI PHY), as described in 12.3.
- c) Audio/Visual mode in mmWave PHY (AV PHY), as described in 12.4.

For DEVs that implement the mmWave PHY, at least one of the three PHYs is required. In addition, to promote coexistence and interoperability, a common mode signaling (CMS) is defined based on a low data rate SC PHY mode, as described in 12.1.12.

The SC PHY supports a variety of modulation and coding schemes (MCSs) that support up to 5 Gb/s. The SC PHY supports a wide range of modulations, $\pi/2$ BPSK, $\pi/2$ QPSK, $\pi/2$ 8-PSK, $\pi/2$ 16-QAM, pre-coded MSK, pre-coded GMSK, on-off keying (OOK), and dual alternate mark inversion (DAMI). The coding schemes included are Reed-Solomon (RS) coding with low-complexity implementation and low-density parity check (LDPC) coding with high error-correcting capability. Code spreading using either linear feedback shift register (LFSR) code or Golay sequence is also applied to increase robustness of the system.

The HSI PHY, as described in 12.3, is designed for NLOS operation and uses OFDM with an FEC based on LDPC.

The AV PHY, as described in 12.4, is designed for NLOS operation and the transport of uncompressed, high definition video and audio. It uses OFDM modulation with convolutional inner code and a Reed Solomon outer code. The AV mode supports omni-directional coverage via the low-rate PHY (LRP) for the purpose of setting up high-throughput connections using the high-rate PHY (HRP).

Different PHYs are a result of demands of different market segments, which were based on the development of the usage models for this standard. For example one usage model is for kiosk applications. This usage model requires 1.5 Gb/s at a 1 m range. The SC-PHY can provide such a data rate at that short range with less complexity thus lower cost than an OFDM PHY. Another usage model required the streaming of uncompressed video. Due to the nature of uncompressed video signals a special PHY, the AV PHY, was selected to provide high throughput. A third usage model involves an ad-hoc system to connect computers and devices around a conference table. In this usage model, all of the devices in the WPAN will have bi-directional, NLOS high speed, low-latency communication, which is provided for by the HSI PHY. Mandatory data rates of all those PHYs are selected according to specific usage models. In addition, higher data rates are provided to give options to the implementors so that they can best address the different market segments.

5.5.2 Piconets using mmWave PHY modes

When a mmWave PHY PNC capable DEV starts a piconet, the type of piconet it starts depends on the PHY modes that are supported. For example, if the PNC capable DEV supports only the AV PHY mode, it would start an AV piconet in which the beacon is sent with the AV PHY mode and the contention periods (CPs) would use the AV PHY mode. The AV PNC would also send the sync frame to improve coexistence with other piconets. DEVs that support only the AV PHY mode are able to find and join the piconet using the AV PHY mode.

The same process is used for a mmWave PHY PNC capable DEV that supports only HSI PHY mode or SC PHY mode, with the exception that an SC PHY mode PNC does not need to send a sync frame as its beacon is sent in CMS mode already.

If a PNC capable DEV supports more than one mmWave PHY mode, then it is able to select the type of piconet it starts, potentially starting more than one piconet, each with a different PHY mode, with the additional piconets as dependent piconets. Alternatively, the multi-mode PNC is able to have a single piconet in which DEVs use any MCS in a CTA that is supported by both of the DEVs.

The complete rules are described in 12.1.

6. Layer management

6.3 MLME SAP interface

Insert the following row in Table 3 as shown. The other rows are not changed and are not shown.

Table 3—Summary of MLME primitives

Name	Request	Confirm	Indication	Response
<u>MLME-TXDIV</u>	<u>6.3.18.1</u>	<u>6.3.18.2</u>	=	=

6.3.2 Scanning for piconets

Insert the following row to Table 3c in 6.3.2 as shown. All other rows are unchanged and are not shown.

Table 3c—Elements of PiconetDescription

Name	Type	Valid range	Description
<u>PHYMode</u>	<u>Enumeration</u>	<u>2.4_GHZ.</u> <u>SC_MMWAVE.</u> <u>HSI_MMWAVE.</u> <u>AV_MMWAVE</u>	<u>The PHY mode that is being used in the piconet that was found.</u>

6.3.3 Starting a piconet

Insert the following row to Table 3e in 6.3.3 as shown. All other rows are unchanged and are not shown.

Table 3e—MLME-START primitive parameters

Name	Type	Valid range	Description
<u>PHYMode</u>	<u>Enumeration</u>	<u>2.4_GHZ.</u> <u>SC_MMWAVE.</u> <u>HSI_MMWAVE.</u> <u>AV_MMWAVE</u>	<u>The PHY that will be used for the beacons and the CP(s) in the piconet that will be started.</u>

6.3.3.1 MLME-START.request

Change the primitive definition in 6.3.3.1 as follows:

```
MLME-START.request      (
                          BSIDLength,
                          BSID,
                          SECMODE,
                          MinDepSuperframePercent,
                          DesiredDepSuperframePercent,
                          PHYMode
                          )
```

Insert the following subclause after 6.3.17 from IEEE Std 802.15.3b as 6.3.18:

6.3.18 Transmit switched diversity

These primitives are used to exchange the transmit switched diversity capability between a source and a destination, as described in 13.8. The parameters used for these primitives are defined in Table 3x.

Table 3x—MLME-TXDIV primitive parameters

Name	Type	Valid range	Description
TrgtID	Integer	Any valid DEVID, as defined in 7.2.3	Specifies the DEVID of the target DEV for exchanging transmit Switched Diversity information.
OrigID	Integer	Any valid DEVID, as defined in 7.2.3	The DEVID of the DEV that initiated the MLME request.
SupportedNumAntennas	Integer	0–15	The number of antennas supported by the DEV.
Timeout	Integer	0–65535	The time in milliseconds allowed for the primitive to complete.
TXDiversityThresholdType	Enumeration	LQI type, as defined in 7.4.11.	Specifies the type of LQI measurement to use.
TXDiversityTheshold	Integer	Any valid LQI value, as defined in 7.4.27.	Specifies the value of the threshold for antenna switching.
AntennaIndex	Integer	0–15	Specifies antenna index to be used.
ResultCode	Enumeration	SUCCESS, FAILURE	Indicates the result of the MLME request.
ReasonCode	Enumeration	NOT_SUPPORTED, OTHER	Indicates the reason for a ResultCode of FAILURE.

6.3.18.1 MLME-TXDIV.request

This primitive is used to request to use transmit switched diversity. The semantics of this primitive are as follows:

```
MLME-TXDIV.request      (  
    TrgtID,  
    TXDiversityThresholdType,  
    TXDiversityTheshold,  
    Timeout  
)
```

The primitive parameters are defined in Table 3x.

6.3.18.2 MLME-TXDIV.confirm

This primitive is used to report the result of the request for transmit switched diversity. The semantics of this primitive are as follows:

```
MLME-TXDIV.confirm      (  
    AntennaIndex,  
    ResultCode,  
    ReasonCode  
)
```

The primitive parameters are defined in Table 3x.

6.5 MAC management

6.5.1 MAC PIB PNC group

Change and insert the following rows in Table 33 as shown. The other rows are unchanged and are not shown.

Table 33—MAC PIB PNC group parameters

Managed object	Octets	Definition	Access
<u>MACPIB_CAPStartTime</u>	<u>2</u>	<u>The time at which the CAP starts when quasi-omni beacons are used.</u>	<u>Read only</u>

6.5.2 MAC PIB characteristics group

Insert the following new row in Table 34 as shown. The other rows are unchanged and are not shown.

Table 34—MAC PIB characteristics group parameters

Managed object	Octets	Definition	Access
<u>MACPIB_CTARelinquishDuration</u>	<u>2</u>	<u>The CTA Relinquish Duration field value sent in the CTA Relinquish Duration IE</u>	<u>Read/write</u>

6.6 MAC SAP

Insert the following new rows to Table 36 as shown. The other rows are unchanged and are not shown.

Table 35—MAC-ISOCH-DATA and MAC-ASYNC-DATA primitive parameters

Name	Type	Range	Description
<u>UncompressedVideo</u>	<u>Boolean</u>	<u>TRUE, FALSE</u>	<u>Set to TRUE if the Data parameter contains uncompressed video data.</u>
<u>UEPAllowed</u>	<u>Boolean</u>	<u>TRUE, FALSE</u>	<u>Indicates if UEP is allowed for the transmission of the data.</u>
<u>ErrorsFreeData</u>	<u>Boolean</u>	<u>TRUE, FALSE</u>	<u>Indicates if the Data parameter that was received contains errors or is free from errors.</u>
<u>InterlacedFieldIndication</u>	<u>Enumeration</u>	<u>TOP_FIELD, BOTTOM_FIELD, NOT_INTERLACED</u>	<u>If UncompressedVideo is TRUE, the parameter indicates if the pixels belong to the top or bottom field of an interlaced image or that the image is not interlaced.</u>
<u>VideoFrameNumber</u>	<u>Integer</u>	<u>As defined in 7.2.9.1.4</u>	<u>If UncompressedVideo is TRUE, the parameter contains a sequential numbering of the video frames that are being transferred.</u>
<u>HPosition</u>	<u>Integer</u>	<u>As defined in 7.2.9.1.4</u>	<u>If UncompressedVideo is TRUE, the parameter contains the horizontal position of the first pixel in the MSDU.</u>
<u>VPosition</u>	<u>Integer</u>	<u>As defined in 7.2.9.1.4</u>	<u>If UncompressedVideo is TRUE, the parameter contains the vertical position of the first pixel in the MSDU.</u>

Insert the following paragraph to the end of 6.6:

The parameters InterlacedFieldIndication, VideoFrameNumber, HPosition, and VPosition are used by the AV PHY in the Video Subheader field, as described in 7.2.9.1.4. These fields are sent in the MAC header because it has lower error rate than the subframes carrying video data. For uncompressed video applications, video data that is in error can still be displayed, but only if the position of the pixel data is known.

6.6.4 MAC-ISOCH-DATA.request

Change the primitive definition as shown:

```
MAC-ISOCH-DATA.request      (  
    RequestID,  
    StreamIndex,  
    TransmitTimeout,  
    MaxRetries,  
    SNAPHeaderPresent,  
    ACKRequested,  
    ConfirmRequested,  
    Length,  
    Data,  
    DataType,  
    UEPAllowed,  
    InterlacedFieldIndication,  
    VideoFrameNumber,  
    HPosition,  
    VPosition  
)
```

6.6.5 MAC-ISOCH-DATA.indication

Change the primitive definition as shown:

```
MAC-ISOCH-DATA.indication   (  
    TrgtID,  
    OrigID,  
    StreamIndex,  
    SNAPHeaderPresent,  
    Length,  
    Data,  
    DataType,  
    ErrorFreeData,  
    InterlacedFieldIndication,  
    VideoFrameNumber,  
    HPosition,  
    VPosition  
)
```

Insert the following paragraph after the primitive definition in 6.6.5:

Data identified as video by the source DEV may be passed by the destination DEV to the higher layers even if the data was received in error. The error status of the data passed up by this primitive is indicated in the ErrorFreeData parameter.

7. MAC frame format

7.2 General frame format

Change the second paragraph in 7.2 as shown:

The figures in this subclause are a representation of the MAC header and MAC frame body. The HCS is not shown since this is calculated and verified by the PHY. The MAC frame shall be formatted as illustrated in Figure 6. The maximum size of the MAC frame body, pMaxFrameBodySize, is a PHY dependent parameter that includes the frame payload and FCS, but not the PHY preamble, PHY header, MAC header, MAC subheader, or MAC Header validation. ~~For the 2.4 GHz PHY, this parameter is defined in 11.2.8.1. The parameter pMaxFrameBodySize is defined in the following:~~

- 11.2.8.1 for the 2.4 GHz PHY
- 12.2.7.1 for the SC PHY mode
- 12.3.6.3 for the HSI PHY mode
- 12.4.1.3.1 for the AV PHY mode

7.2.1 Frame control

Replace Figure 9 with the following:

bits: b15	b14	b13	b12	b11	b10	b9	b8-b7	b6	b5-b3	b2-b0
Reserved	Blk-ACK	CTA relinquish	Imp-ACK NACK	Imp-ACK request	More data	Retry	ACK policy	SEC	Frame type	Protocol version

Figure 9—Frame control field format

7.2.1.2 Frame type

Change Table 39 as follows. The other rows are kept unchanged.

Table 39—Valid frame type values (numeric values in this table are shown in binary)

Type value b5 b4 b3	Frame type description	Subclause
<u>110</u>	<u>Sync frame</u>	<u>7.3.6</u>
~~110-111~~	Reserved	—

Change the title of 7.2.1.4 as follows:

7.2.1.4 ACK policy, ~~and~~ implied ACK (Imp-ACK) request and Blk-ACK

Change the first paragraph as shown:

The ACK Policy field, ~~and~~ Imp-ACK Request field, ~~and~~ Blk-ACK field are used to indicate the type of acknowledgment procedure that the addressed recipient is required or allowed to perform. The use of the ACK procedures is described in 8.8. The allowed values of the ACK Policy field, ~~and~~ the Imp-ACK Request

field, and the Blk-ACK field are defined in Table 40. The ACK policy of a frame is determined by the combination of the ACK Policy field, ~~and~~ the Imp-ACK Request field, and Blk-ACK field.

Delete Table 40 and insert the following table in its place:

Table 40—Valid ACK policy field type values

Blk-ACK field b14	Imp-ACK request field b11	ACK policy field b8 b7	ACK policy type	Description
0	0	00	No ACK	The recipient(s) does not acknowledge the transmission, and the sender treats the transmission as successful without regard for the result, as described 8.8.1
0	0	01	Immediate ACK (Imm-ACK)	The addressed recipient returns an Imm-ACK frame after successful reception, as described in 8.8.2.
0	0	10	Delayed ACK (Dly-ACK)	The addressed recipient keeps track of the frames received with this policy until requested to respond with a Dly-ACK frame, as described in 8.8.3.
0	0	11	Dly-ACK request	The addressed recipient returns either an Imm-ACK or a Dly-ACK frame after successful reception, as described in 8.8.3.
0	1	01	Imp-ACK	The addressed recipient returns an Imm-ACK frame, a data frame, or a command frame after successful reception, as described in 8.8.4.
1	0	01	Blk-ACK	The addressed recipient returns a frame with the MAC sub-header including the Blk-ACK Bitmap field after successful reception of the MAC header, as described in 8.8.3b.

7.2.4 Fragmentation control

Change the second paragraph in 7.2.4 as shown:

The three octets that compose the Fragmentation Control field may be used for reporting PHY-dependent receive status information to the transmitting DEV in Imm-ACK, ~~and Dly-ACK, and data frames with ACK policy set to Blk-ACK.~~ If the source DEV is not reporting PHY-dependent receive status information in an Imm-ACK or Dly-ACK frame, it shall set the fragmentation field of the frame to all zeros, i.e., 0x000000. All other values are PHY-dependent. The receive status for the 2.4 GHz PHY is defined in 11.7. The receive status for the mmWave PHYs is defined in 12.1.8.3.

7.2.5 Stream index

Change the dashed list in 7.2.5 as shown:

The Stream Index field reserved values are as follows:

- 0x00 reserved for asynchronous data
- 0xFB reserved for beam forming starting from sector level training
- 0xFC reserved for beam forming starting from beam level training
- 0xFD reserved for MCTA traffic
- 0xFE reserved for unassigned streams
- 0xFF reserved for future use

7.2.6 MAC header validation

Change the paragraph in 7.2.6 as shown:

When the PHY receives a frame it validates the received frame’s MAC header before passing the MAC header and its associated MAC frame body to the MAC. The protection mechanism used to ~~validate~~ validate the MAC header is PHY dependent. In addition, the bit order and the length of the protection mechanism, pLengthHCS, are also PHY dependent. ~~For the 2.4 GHz PHY, the~~ The MAC header protection mechanism is defined in the following: 11.2.9.

- 11.2.9 for the 2.4 GHz PHY
- 12.2.3.2.2 for the SC PHY mode
- 12.3.3.4 for the HSI PHY mode
- 12.4.1.4 for the AV PHY mode

After 7.2.7, insert the following subclauses as 7.2.8 and 7.2.9:

7.2.8 SC and HSI aggregated frame format

Figure 10a illustrates the SC and HSI aggregated frame format.



Figure 10a—SC and HSI aggregated frame format

The MAC frame body and MAC subheader for standard and low-latency aggregation are defined in 7.2.8.1 and 7.2.8.2.

7.2.8.1 Standard aggregation format

7.2.8.1.1 Non-secure standard aggregation format

To use standard aggregation, the Aggregation field and Low-latency Mode field in PHY header shall be set as described in 12.2.3.2.1.

The MAC subheader for standard aggregation shall be formatted as illustrated in Figure 10b.

octet: 1	5	...	5	2
RX buffer size	Subheader 8	...	Subheader 1	Blk-ACK bitmap

Figure 10b—MAC subheader format for standard aggregation

The Blk-ACK Bitmap field shall be formatted as illustrated in Figure 10c.

bits:8	8
ACK or lsb ACK	ACK or msb ACK

Figure 10c—Blk-ACK bitmap field format

In EEP mode, the ACK or msb ACK field is a bitmap that indicates if a subframe was correctly received. The bit position zero, which is the first bit from right in Figure 10c, corresponds to the first subframe of the frame that is being ACKed. If a subframe was correctly received, then the bit for that subframe is set to one and shall be set to zero otherwise. The ACK or lsb ACK field shall be set to the same value as the ACK or msb ACK field.

To use UEP mode, the UEP field in PHY header shall be set as described in 12.2.3.2.1. In UEP mode, the ACK or msb ACK field is a bitmap that indicates if the msbs of a subframe were correctly received. The bit position zero, which is the first bit from right in Figure 10c, corresponds to the first subframe of the frame that is being ACKed. If the msbs of the subframe were correctly received, then the bit for that subframe is set to one and shall be set to zero otherwise. The ACK or lsb ACK field is a bitmap that indicates if the lsbs of a subframe were correctly received. The bit position zero of the ACK or lsb ACK field corresponds to the first subframe of the frame that is being ACKed. If the lsbs of the subframe were correctly received, then the bit for that subframe is set to one and shall be set to zero otherwise.

The Subheader field shall be formatted as illustrated in Figure 10d.

bits: 1	1	7	9	1	2	11	1	1	1	5
Reserved	Last fragment	Fragment number	MSDU number	Skewed constellation	Subframe information	Subframe length	Resolution indication	Retry	FCS present	MCS information

Figure 10d—Subheader field format

In UEP mode, the MCS Information field shall be set to the UEP MCS (as defined in 12.2.2.9 for SC PHY and 12.3.2.1 for HSI PHY) that is used for the subframe.

In EEP mode, the MCS Information field shall be set to zero. All the subframes use the MCS indicated in the PHY header.

The FCS Present field shall be set to one if the subframe uses an FCS and shall be set to zero otherwise. The FCS is optional for subframes for the cases in which the upper layer will handle checking the data integrity. If the FCS present field is set to zero, then the subframe is considered correctly received only if the PHY header, MAC header, and MAC subheader were all correctly received.

The Retry field shall be set to one if the subframe is a retransmission and shall be set to zero otherwise.

The Resolution Indication field shall be set to zero if the resolution of the Subframe Length field is 1 octet and shall be set to one if the resolution is 512 octets.

The Subframe Length field is used to determine the length of the subframe before coding, not including the FCS. If the resolution of the Subframe Length field is 1 octet, then this field contains the length of the subframe in octets. If the resolution of the Subframe Length field is 512 octets, then the length of the

subframe in octets is 512 times the value of this field. If the Subframe length field is set to zero, the corresponding subframe is not present in the aggregated data frame.

The Subframe Information field indicates if the subframe contains msb, lsb, or msb and lsb combined data. Valid values for the Subframe Information field are as follows:

- 0 → The subframe contains only msb data
- 1 → The subframe contains only lsb data
- 2 → The subframe contains msb and lsb data
- 3 → Reserved

The Skewed Constellation field shall be set to one if a skewed constellation is used in the subframe and shall be set to zero otherwise.

The MSDU Number field indicates the MSDU number of the subframe. Each subframe that contains a fragment from the same MSDU shall have the same MSDU number.

The Fragment Number field indicates the fragment sequence number of the subframe within the current MSDU, if the subframe contains a MSDU fragment. This field shall be set to zero if the corresponding subframe contains an unfragmented MSDU.

The Last Fragment bit shall be set to one if the subframe contains the last fragment of the MSDU and shall be set to zero otherwise.

The RX Buffer Size field indicates the free buffer space at the target DEV as a multiple of the preferred fragment size, as defined in 7.4.11.

The MAC frame body for standard aggregation shall be formatted as illustrated in Figure 10e.

octets: 4 or 8	variable	...	4 or 8	variable
FCS or combined FCS	Subframe payload <i>n</i>	...	FCS or combined FCS	Subframe payload 1

Figure 10e—MAC frame body format for standard aggregation

The maximum number of subframes that are aggregated in one frame shall be mMaxSubframeSize, as defined in 8.15.

In EEP mode, the subframe contains the FCS field, as defined in 7.2.7.6. In UEP mode, the subframe contains the Combined FCS field, as defined in Figure 10ag. The Subframe Payload field includes an LLC/ SNAP header as the first octets in the payload, as defined in A.1.

7.2.8.1.2 Secure standard aggregation format

The secure MAC subheader for standard aggregation shall be formatted as illustrated in Figure 10f.

octet: 1	5	...	5	2	5
RX buffer size	Subheader 8	...	Subheader 1	Blk-ACK bitmap	Security header

Figure 10f—Secure MAC subheader format for standard aggregation

The Security header shall be formatted as illustrated in Figure 10g.

octets: 1	2	2
Subframe security	SFC	SECID

Figure 10g—Security header format

The SECID field is used to identify the key set that is used to encrypt and/or authenticate the data in the frame, as defined in 7.2.7.2.

The SFC field contains a counter that is used to ensure the uniqueness of the nonce of a secure frame, as defined in 7.2.7.3.

The Subframe Security field contains a bitmap that indicate if a subframe applies security or not. The bit position zero, which is the first bit from right in Figure 10g, corresponds to the first subframe. The bit shall be set to one if the subframe applies security and shall be set to zero otherwise.

The secure MAC frame body for standard aggregation shall be formatted as illustrated in Figure 10h.

octets: 4 or 8	8	variable	...	4 or 8	8	variable
FCS or combined FCS	Integrity code	Subframe payload n	...	FCS or combined FCS	Integrity code	Subframe payload1

Figure 10h—Secure MAC frame body format for standard aggregation

The Integrity Code field is used to cryptographically protect the integrity of the header and payload as defined in 7.2.7.5.

7.2.8.2 Low-latency aggregation formats

7.2.8.2.1 Non-secure low-latency aggregation format

To use low-latency aggregation mode, the Aggregation field and the Low-latency Mode field in PHY header shall be set as described in 12.2.3.2.1.

The MAC subheader for low-latency aggregation shall be formatted as illustrated in Figure 10i.

octets: 64	2	2	1	1
Blk-ACK bitmap	MSDU response number	MSDU request number	RX buffer size	UEP

Figure 10i—MAC subheader field format for low-latency aggregation

The UEP field shall be formatted as illustrated in Figure 10j.

bits: 3	5
Reserved	UEP MCS

Figure 10j—UEP field format

In EEP mode, the UEP MCS field shall be set to zero and all subframes use the MCS indicated in the PHY header.

In UEP mode, the UEP MCS field indicates the MCS used for UEP mode for the subframes, as defined in 12.2.2.9.

The RX Buffer size field indicates the free buffer space at the destination DEV as a multiple of the preferred fragment size, as defined in 7.4.11.

The MSDU Request Number field and the MSDU Response Number field shall be formatted as illustrated in Figure 10k.

bits: 7	9
Reserved	MSDU sequence number

Figure 10k—MSDU request/response number field format

The MSDU Sequence Number field is used as the basis for the Blk-ACK bitmap.

The MSDU Request Number field indicates the most recent MSDU sequence number acknowledged at the transmitter.

The MSDU Response Number field indicates the first MSDU sequence number of the transmitted Blk-ACK bitmap-field. The MSDU Response Number field is used to generate the offset for the Blk-ACK bitmap field. The MSDU Response Number field shall be a copy from the received MSDU Request Number, upon reception of a valid MAC Subheader.

For EEP mode the Blk-ACK Bitmap field shall be formatted as illustrated in Figure 10l.

bits: 256	1	...	1	1
Reserved	Subframe ACK #256	...	Subframe ACK #2	Subframe ACK #1

Figure 10l—EEP mode Blk-ACK bitmap field format

The Subframe ACK field is an offset from the MSDU sequence number of the received MSDU Response Number field. It shall be set to one if the corresponding subframe was correctly received and shall be set to zero otherwise.

For UEP mode the Blk-ACK Bitmap field shall be formatted as illustrated in Figure 10m.

bit: 1	1	...	1	1	1	1
Subframe lsb ACK #256	Subframe msb ACK #256	...	Subframe lsb ACK #2	Subframe msb ACK #2	Subframe lsb ACK #1	Subframe msb ACK #1

Figure 10m—UEP mode Blk-ACK bitmap field format

The Subframe msb ACK field shall be set to one if the msbs of the corresponding subframe were correctly received and shall be set to zero otherwise.

The Subframe lsb ACK field shall be set to one if the lsbs of the corresponding subframe were correctly received and shall be set to zero otherwise.

The MAC frame body for low-latency aggregation shall be formatted as illustrated in Figure 10n.

octets: 4 or 8	variable	3	...	4 or 8	variable	3
FCS or combined FCS	Subframe payload n	MSDU subheader n	...	FCS or combined FCS	Subframe payload 1	MSDU subheader 1

Figure 10n—MAC frame body format for low-latency aggregation

The maximum number of subframes that are be aggregated in one frame shall be $mMaxSubframeSize$, as defined in 8.15.

The MSDU Subheader field shall be formatted as illustrated in Figure 10o.

bits: 8	1	6	9
MSDU subheader HCS	Reserved	Subframe length	MSDU number

Figure 10o—MSDU subheader format

The MSDU Number field indicates the sequence number of the MSDU that is aggregated in the subframe. The MSDU number is unique in a window of 256 MSDUs, allowing retransmission of an out-of-order MSDU over several frames.

Subframe Length field contains the length of each subframe in unit of four octets. This field may be set to zero to allow idle transmission of data if data is not present at the FCSL. The HCS field shall be inverted in the case of a zero length MSDU, so that the MSDU HCS check fails.

The MSDU subheader HCS is an 8 bit CRC defined as the ones-complement of the remainder of the division of the 16 bits of the header by the polynomial $x^8 + x^2 + x + 1$. A serial implementation is illustrated in Figure 10p.

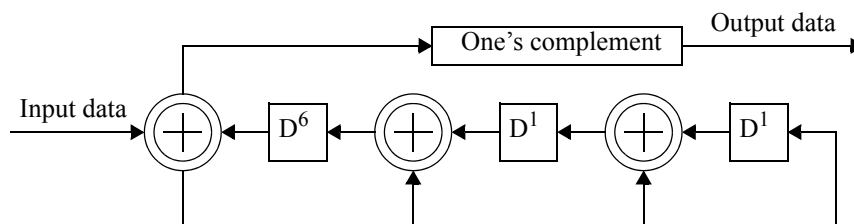


Figure 10p—HCS implementation example for MSDU subheader

In EEP mode, the subframe contains the FCS field, as defined in 7.2.7.6. In UEP mode, the subframe contains the Combined FCS field, as defined in Figure 10ag.

7.2.8.2.2 Secure low-latency aggregation format

The Secure MAC subheader for low-latency aggregation shall be formatted as illustrated in Figure 10q.

octets: 32/64	2	2	1	1	2	2
Blk-ACK bitmap	MSDU response number	MSDU request number	RX buffer size	UEP	SFC	SECID

Figure 10q—Secure MAC subheader field format for low-latency aggregation

The SECID field is used to identify the key set that is used to encrypt and/or authenticate the data in the frame, as defined in 7.2.7.2.

The SFC field contains a counter that is used to ensure the uniqueness of the nonce of a secure frame, as defined in 7.2.7.3.

The secure MAC frame body for low-latency aggregation shall be formatted as illustrated in Figure 10r.

octets: 4 or 8	8	variable	3	...	4 or 8	8	variable	3
FCS or combined FCS	Integrity code	Subframe payload 1	Secure MSDU subheader n	...	FCS or combined FCS	Integrity code	Subframe payload 1	Secure MSDU subheader n

Figure 10r—Secure MAC frame body format for low-latency aggregation

The Secure MSDU Subheader field shall be formatted as illustrated in Figure 10s.

bits: 8	1	6	9
MSDU subheader HCS	Subframe security	Subframe length	MSDU number

Figure 10s—Secure MSDU subheader format

The Subframe Security bit shall be set to one if the subframe applies security and shall be set to zero otherwise.

The Integrity Code field is used to cryptographically protect the integrity of the header and payload as defined in 7.2.7.5.

7.2.9 AV aggregated frame format

The AV aggregated frame format is optimized to carry uncompressed audio and video in an efficient manner. The AV aggregated frame format is used instead of the standard aggregation or low-latency aggregation formats.

Figure 10t illustrates the AV aggregated MAC frame body format.

MAC frame body				
Subframe 7	Subframe 6	...	Subframe 2	Subframe 1

Figure 10t—AV aggregated MAC frame body format

The collection of subframes in a single frame is referred to as the Frame Body field. The Frame Body field of a MAC frame may have one to seven, inclusive, subframes of varying sizes.

7.2.9.1 Extended MAC header format

The Extended MAC header is used to describe the contents of an AV aggregated frame, which typically is used to transport uncompressed audio and video.

The HRP Extended MAC Header shall be formatted as illustrated in Figure 10u.

octets: 16	24	5	5	2	10
Reserved	Video header	Security header	MAC extension header	Extended control header	MAC header

Figure 10u—HRP Extended MAC header format

The LRP Extended MAC Header shall be formatted as illustrated in Figure 10v.

octets: 5	5	2	10
Security header	MAC extension header	Extended control header	MAC header

Figure 10v—LRP extended MAC header format

The MAC extension header, Security header, and Video header are present in LRP frames only if their corresponding control bits are set in the Extended control header.

The Extended MAC header for HRP frames shall have the space for the MAC extension Header, Security header, and Video header. Therefore, the HRP MAC header always has a fixed size.

7.2.9.1.1 Extended Control header

The Extended Control header field shall be formatted as illustrated in Figure 10w.

bits: 7	3	1	1	1	3
Reserved	Frame type	Video header present	Security header present	MAC extension header present	Frame class

Figure 10w—Extended Control header

Valid values for the Frame Class field are given in Table 40a.

Table 40a—Frame class field values

Field value	Frame class
0b000	Regular
0b0001	AV aggregated
0b010	Omni-ACK
0b011	Beacon
0b100–0b111	Reserved

Regular frames have a single payload field without MAC level aggregation while AV aggregated frames have one or more subframes as a part of the frame.

The MAC Extension Header Present field shall be set to one if the MAC Extension Header is in the Extended MAC Header field and shall be set to zero otherwise.

The Security Header Present field shall be set to one if the Security header is in the Extended MAC Header field and shall be set to zero otherwise.

The Video Header Present field shall be set to one if the Video Header is in the Extended MAC Header field and shall be set to zero otherwise.

For HRP frames, the MAC Extension Header Present field, Security Header Present field and Video Header Present field indicate the validity of the associated field. Because the HRP header is a fixed length, space for these fields is always present in the Extended MAC Header field. If a header in the HRP MAC header is present but not valid, it may be set to any value and shall be ignored upon reception. For LRP frames, unused headers, as indicated by the appropriate header present bit, are not present in the MAC header.

The Frame Type field is only defined for regular frame class, it shall be set to zero in other frames. AV aggregated frames use the Type field in the MAC Extension Header field while the Omni-ACK and Beacon frames do not require the Frame Type field. Valid values for the Frame Type field are as follows:

- 0 → MAC commands
- 1 → Data
- 2 → Audio
- 3–7 → Reserved

7.2.9.1.2 MAC Extension header

The MAC Extension Header field is illustrated in Figure 10x.

bits: 8	4	4	...	4
ACK groups	Reserved	Type 7	...	Type 1

Figure 10x—MAC extension header format

The Type field indicates the type of data that is contained in the subframe. Valid values for the Type field are as follows:

- 0x0 → MAC commands
- 0x1 → Data
- 0x2 → Audio
- 0x3 → Video
- 0x4–0xF → Reserved

The ACK Groups field shall be formatted as illustrated in Figure 10y.

bits: 1	1	...	1	1
lsb FCS	Subframe 7	...	Subframe 1	Subframe 1

Figure 10y—ACK groups field format

The bit for a subframe shall be set to one if the subframe is in the same ACK group as the previous (i.e., lower numbered subframe). Otherwise, it is the first subframe in an ACK group and its bit shall be set to zero. The first bit, corresponding to subframe 1, shall always be set to zero as it is always the start an ACK group. No more than 5 ACK groups shall be defined, therefore, the number of bits set to zero among the subframe bits shall not exceed five.

The lsb FCS field shall be set to one if the lsb FCS is part of the calculation to determine if a subframe was correctly received, as defined in 8.1. It shall be set to zero if the lsb FCS is ignored in determining if a subframe was correctly received. The setting of this field applies only to those subframes that are sent with a UEP HRP mode. For all other subframes, the lsb FCS field shall be set to zero.

7.2.9.1.3 Security header

The Security header shall be formatted as illustrated in Figure 10z.

octets: 2	3
SFC	Security control

Figure 10z—Security header format

The Security Control field shall be formatted as illustrated in Figure 10aa.

bits: 2	...	2	2	8
Subframe 1 security	...	Subframe 7 security	Reserved	SECID

Figure 10aa—Security Control field format

The SECID field is used to identify the key set that is used to encrypt and/or authenticate the data in the frame, as defined in 7.2.7.2.

The Subframe Security field indicates the type of security that is applied to a subframe. Valid values are as follows:

- 0b00 → No security applied
- 0b01 → Encryption and integrity code
- 0b10–0b11 → Reserved

The SFC field is defined in 7.2.7.3. The SFC shall be incremented for each subframe in the frame, even if security is not applied to the subframe.

7.2.9.1.4 Video header

The Video Header shall be formatted as illustrated in Figure 10ab.

octets: 4	5	5	5	5
Reserved	Video control 4	Video control 3	Video control 2	Video control 1

Figure 10ab—Format of the Video header

Unless otherwise stated, the numbers for all of the fields begin with zero, e.g., the first video frame is number zero, then number one, etc. One of the first video subframes in the first frame sent in a stream should have the Video Frame Number field, the H-position field, and V-position field set to zero.

The Video Subheader is included as part of the MAC header because the error rate for the MAC header is lower than that of the subframes.

The Video Control field shall be formatted as illustrated in Figure 10ac.

bits: 4	3	1	16	16
Reserved	Video frame number	Interlaced field indication	H-position	V-position

Figure 10ac—Video control field format

The Interlaced Field Indication field shall be set to one if the video subframes carry pixels for the bottom field. It shall be set to zero if the video subframes carry pixels for the top field or if the video subframes carry pixels for non-interlaced video modes.

The Video Frame Number field contains a counter that keeps track of the video frame to which the pixels in the subframe belong. The video frame number is calculated follows:

- For progressive video, the Video Frame Number field shall be incremented sequentially. After reaching the max value of 0x7, the next value shall be zero. All frames belonging to the same video frame have identical Video Frame Number values.
- For interlaced video, the Video Frame Number field shall be incremented in a step of two. Thus, each video frame has two frame numbers. All frames belonging to the first field have even Video Frame Numbers and all frames belonging to the second field have odd Video Frame Numbers. For example, for the first uncompressed video frame, the frames belonging to the first field have a Video Frame Number set to zero, and the frames belonging to the second field have a Video Frame Number set to one. Therefore, the same video frame has two Video Frame Numbers.

The H-position field contains the horizontal position of the first pixel in the subframe where zero is on the left side of the screen.

The V-position field contains the vertical position of the first pixel in the subframe where zero corresponds to the top of the screen. For interlaced formats, the V-position of the lines range from 0-539 independent of status as even or odd frame number.

7.2.9.2 Subframe format

The subframes with Type Video in the MAC frame shall be formatted as illustrated in Figure 10ad.

octets: 8	variable
Combined FCS	Subframe payload

Figure 10ad—Subframe format

Subframes other than those with Type Video shall be formatted as illustrated in Figure 10ae.

octets: 4	variable
FCS	Subframe payload

Figure 10ae—LRP data subframe format

The Subframe Payload field includes an LLC/SNAP header as the first octets in the payload, as defined in A.1, followed by the data to be transmitted. If the subframe has an integrity code, as indicated by the

Subframe Security field, then Subframe Payload field shall be formatted as illustrated in Figure 10af, where the Payload Data field includes an LLC SNAP header as the first octets in the payload, as defined in A.1.

octets: 8	variable
Integrity code	Payload data

Figure 10af—Subframe payload with integrity code

The Integrity Code field is defined in 7.2.7.5.

The Combined FCS field shall be formatted as illustrated in Figure 10ag.

bits:4	4	4	...	4	4	4	4	...	4	4	4
msb FCS 4	lsb FCS 4	msb FCS 3	...	lsb FCS 2	msb FCS 1	lsb FCS 1	msb FCS 8	...	lsb FCS 6	msb FCS 5	lsb FCS 5

Figure 10ag—Combined FCS field format

The lsb FCS field contains the FCS, as defined in 7.2.7.6, calculated over the four lsbs of each octet in the Subframe Payload field. The lsb FCS field occupies the lsbs of the Combined FCS field.

The msb FCS field contains the FCS, as defined in 7.2.7.6, calculated over the four msbs of each, if present, and Subframe Payload field. The msb FCS field occupies the msbs of the Combined FCS field.

The FCS field contains the FCS, as defined in 7.2.7.6, calculated over Subframe Payload field.

Subframes with frame type other than data do not support aggregation or fragmentation.

Subframes with frame type data support the aggregation of MSDUs or the fragmentation of MSDUs in their payloads. The format of a Subframe Payload field for a subframe with Frame Type data is illustrated in Figure 10ah.

octets: variable	...	variable	variable
Sub-payload N	...	Sub-payload 2	Sub-payload 1

Figure 10ah—Subframe payload field with aggregation

Each sub-payload field shall be formatted as shown in Figure 10ai.

bits: variable	1	1	10	20
MSDU	First fragment	Last fragment	Sequence number	Length

Figure 10ai—Sub-payload field format

The Length field indicate the length of the MSDU field in octets.

The Sequence Number field is incremented for each fragment, regardless if it is of the same or different MSDU.

The fragment fields shall be set as indicated in Table 40b

Table 40b—Fragment field settings

Fragment type	Last fragment field	First fragment field
First fragment	0	1
Last fragment	1	0
Middle fragment	0	0
Complete MSDU	1	1

The MSDU field for subframes with frame type data shall be formatted as defined in 7.3.5.

7.2.9.3 AV aggregated

The AV aggregated frame shall be formatted as illustrated in Figure 10aj. The AV aggregated frame shall not be used for LRP frames.

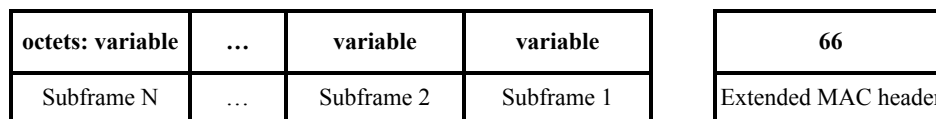


Figure 10aj—AV aggregated frame format

The AV aggregated frame has one to seven, inclusive, subframes. The subframe format is defined in 7.2.9.2.

7.2.9.4 Regular

The HRP regular frame shall be formatted as illustrated in Figure 10ak.

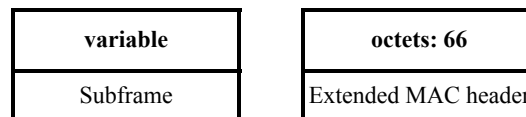


Figure 10ak—HRP regular frame format

The LRP regular frame shall be formatted as illustrated in Figure 10al.

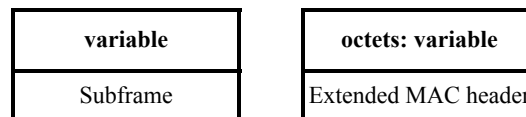


Figure 10al—LRP regular frame format

The subframe format is defined in 7.2.9.2.

7.2.9.5 Directional ACK

The Directional ACK frame format is defined in 12.4.3.8. The Directional ACK frame is used to acknowledge HRP frames and beam formed LRP frames. The ACK policy for a directional ACK shall be Imm-ACK. The directional ACK shall be only used with the AV PHY HRP frames

After 7.3.5, insert the following subclause as 7.3.6:

7.3.6 Sync frame

The Sync frame shall be formatted as illustrated in Figure 23a.

octets: 4	4	...	4	4	10
FCS	CTA block-n	...	CTA block-1	Synchronization parameters	MAC header

Figure 23a—Sync frame format

The Synchronization Parameters field shall be formatted as illustrated in Figure 23b.

octets: 2	2
Frame start time	Superframe duration

Figure 23b—Synchronization parameters field format

The Superframe Duration field indicates the duration of the current superframe, as described in 7.3.1.1.

The Frame Start Time field indicates the time stamp for the Sync frame, which is the start time of the preamble of a Sync frame, measured from the start of the superframe.

The CTA Block field shall be formatted as illustrated in Figure 23c.

octets: 2	2
CTA duration	CTA location

Figure 23c—CTA block field format

The CTA Location field indicates the start time of the allocation, measured from the start of the superframe, as described in 7.3.1.1.

The CTA Duration field specifies the duration of the CTA, as described in 7.3.1.1.

7.4 Information elements

Change and insert the following rows in Table 48 as shown. The other rows are not changed and are not shown.

Table 48—Information elements

Element ID hex value	Element	Subclause	Present in beacon
0x14	<u>Synchronization</u>	7.4.22	<u>As needed</u>
0x15	<u>Transmit switched diversity</u>	7.4.23	<u>As needed</u>
0x16	<u>UEP specific</u>	7.4.24	<u>As needed</u>
0x17	<u>IFS</u>	7.4.25	<u>As needed</u>
0x18	<u>CTA relinquish duration</u>	7.4.26	<u>As needed</u>

Table 48—Information elements (continued)

Element ID hex value	Element	Subclause	Present in beacon
<u>0x19</u>	<u>Feedback</u>	<u>7.4.27</u>	<u>As needed</u>
<u>0x1A</u>	<u>Mapping</u>	<u>7.4.28</u>	<u>As needed</u>
<u>0x1B</u>	<u>BST clustering</u>	<u>7.4.29</u>	<u>As needed</u>
<u>0x1C</u>	<u>Pattern estimation and tracking (PET) clustering</u>	<u>7.4.30</u>	<u>As needed</u>
<u>0x1D</u>	<u>Beam PET</u>	<u>7.4.31</u>	<u>As needed</u>
<u>0x1E</u>	<u>HRS beam PET</u>	<u>7.4.32</u>	<u>As needed</u>
<u>0x1F</u>	<u>PET amplitude</u>	<u>7.4.33</u>	<u>As needed</u>
<u>0x20</u>	<u>PET phase</u>	<u>7.4.34</u>	<u>As needed</u>
<u>0x21</u>	<u>Sync frame frequency</u>	<u>7.4.35</u>	<u>As needed</u>
<u>0x22</u>	<u>Directional peer</u>	<u>7.4.36</u>	<u>As needed</u>
<u>0x423–0xFF</u>	Reserved		

7.4.6 Piconet parameter change

Change Table 49 as shown. The other rows are not changed and are not shown.

Table 49—Description of field contents for change type values

Change type	Interpretation	Field to decode	Description of field contents
4	CHANNEL	New channel index	The channel index of the PHY channel that the piconet will begin using the beacon that has the beacon number equal to the Change Beacon Number field. The mapping of the channel number is PHY dependent. For the 2.4 GHz PHY the mapping is defined in 11.2.3. <u>For the SC PHY and HSI PHY the mapping is defined in 12.1.5. For the AV PHY the mapping is defined in 12.4.1.1.</u>

7.4.11 Capability

After Figure 38, insert the following paragraphs and Figure 38a:

For the mmWave PHYs, the Capability IE shall be formatted as illustrated in Figure 38a.

octets: 13	1	1
Overall capabilities	Length	Element ID

Figure 38a—Capability information element format for mmWave PHYs

After Figure 39, insert the following paragraphs and Figure 39a:

For the mmWave PHYs, the overall Capabilities field shall be formatted as illustrated in Figure 39a.

octets: 3	6	4
Beam forming capabilities	DEV capabilities	PNC capabilities

Figure 39a—Overall capabilities field format for mmWave PHYs

After Figure 42, insert the following paragraphs and Figure 42a:

For the mmWave PHYs, the DEV Capabilities field shall be formatted as illustrated in Figure 42a.

bits: b7	b6	b5	b4	b3	b2	b1	b0
Supported MCSs							
bits: b15	b14	b13	b12	b11	b10	b9	b8
Imp-ACK	Dly-ACK	Listen to Multicast	Listen to Source	Always AWAKE	Preferred fragment size		
bits: b23	b22	b21	b20	b19	b18	b17	b16
Blk-ACK	DAMI capable	OOK capable	AV capable	HSI capable	SC capable	STP	CTA relinquish
bits: b31	b30	b29	b28	b27	b26	b25	b24
TSD support	HRP TX capable	HRP RX capable	UEP type			UEP capable	
bits: b39	b38	b37	b36	b35	b34	b33	b32
PCES capability	Pilot word capability	Supported aggregation		Supported IFS			
bits: b47	b46	b45	b44	b43	b42	b41	b40
Reserved							Sync frame capable

Figure 42a—DEV capabilities field format for mmWave PHYs

Change the fourteenth and fifteenth paragraphs as shown:

The Supported Data Rates or Supported MCSs field is a PHY dependent mapping that indicates the data rates that the DEV is capable of using. For the 2.4 GHz PHY, this field is the Supported Data Rates field, it shall be formatted as illustrated in Figure 42, and the mapping of a field value to a set of data rates is defined

in Table 89. For the mmWave PHYs, this field is the Supported MCSs field, it shall be formatted as illustrated in Figure 42a, and the mapping of a field value to a set of MCSs is defined in 12.1.8.1.

The Preferred Fragment Size field is a PHY dependent mapping that indicates the maximum MAC frame size preferred to be received by the DEV when fragmentation is used. For the 2.4 GHz PHY, this field shall be formatted as illustrated in Figure 42 and the mapping of a field of value to a preferred fragment size is defined in Table 90. For the mmWave PHYs, this field shall be formatted as illustrated in Figure 42a and the mapping of a field value to a preferred fragment size is defined in 12.1.8.2.

After the last paragraph, insert the following paragraphs, tables, and figures.

For the mmWave PHYs, the SC Capable field shall be set to one if the DEV supports the SC PHY, as defined in 12.2. It shall be set to zero otherwise.

The HSI Capable field shall be set to one if the DEV supports the HSI PHY, as defined in 12.3, and shall be set to zero otherwise.

The AV Capable field shall be set to one if the DEV supports the AV PHY, as defined in 12.4, and shall be set to zero otherwise.

The OOK Capable field shall be set to one if the DEV supports the OOK mode, as defined in Annex D2, and shall be set to zero otherwise.

The DAMI Capable field shall be set to one if the DEV supports the DAMI mode, as defined in Annex D2, and shall be set to zero otherwise.

The Blk-ACK field shall be set to one if the DEV is capable of performing Blk-ACK as defined in 8.8.3b. Otherwise the field shall be set to zero.

The UEP Capable field indicates if the DEV supports UEP in the PHY. The valid values of the UEP Capable field are given in Table 49a.

Table 49a—UEP capable field values

Value	UEP support
0	No UEP
1	SC UEP
2	HSI UEP
3	AV UEP

The UEP Type field indicates the type of UEP that is supported based on the value of the UEP capable field. The valid values of the UEP Type field are given in Table 49b.

The HRP RX Capable field shall be set to one if the DEV supports HRP RX for the AV PHY, as defined in 12.4, and shall be set to zero otherwise.

The HRP TX Capable field shall be set to one if the DEV supports HRP TX for the AV PHY, as defined in 12.4, and shall be set to zero otherwise.

Table 49b—UEP type field values

Value	PHY UEP type of mmWave PHYs
0	No UEP support
1	UEP type 1 using different FECs (SC PHY)
2	UEP type 2 using different MCSs (SC PHY)
3	UEP type 3 using different MCSs (All PHYs)
4	UEP type 3 using skewed constellation (All PHYs)
5	UEP type 3 using different MCSs and skewed constellation (SC and HSI PHYs)
6	All UEP types (SC PHY)
7	Reserved

The TSD Support field shall be set to one if the DEV is capable of transmit switched diversity (TSD) as defined in 13.8, it shall be set to zero otherwise.

The Supported IFS field indicates the minimum value of the IFS supported by a DEV. The valid values of the field are given in Table 49c.

Table 49c—Supported IFS encoding

Field value	SIFS and MIFS duration
0	0.2 μ s
1	0.4 μ s
2	0.6 μ s
3	0.8 μ s
4	1.0 μ s
5	2.0 μ s
6	2.5 μ s
7–15	Reserved

The minimum allowed IFS for either SIFS or MIFS may also be constrained by the PHY mode in use. A source DEV may use the shortest SIFS or MIFS supported by the destination DEV. The SIFS and MIFS used may be different.

The Supported Aggregation field indicates the type of aggregation that is supported by the DEV. The valid values for the Supported Aggregation field are as follows:

- 0 → No aggregation support
- 1 → Standard aggregation support
- 2 → Low-latency aggregation support
- 3 → Standard and low-latency aggregation support

The Pilot Word Capability field shall be set to one if the DEV supports a pilot word of length 8. It shall be set to zero otherwise.

The PCES Capability field shall be set to one if the DEV supports the use of PCES and shall be set to zero otherwise.

The Sync Frame Capable field shall be set to one if the DEV supports Sync frame transmission, as defined in 8.17, and shall be set to zero otherwise.

The Beam Forming Capabilities field shall be formatted as illustrated in Figure 42b.

bits:6	2	2	1	3	4	4	2
Reserved	Number RX quasi-omni directions	Number TX quasi-omni directions	PET	Antenna type	Number RX sectors	Number TX sectors	LQI type

Figure 42b—Beam forming capabilities field format

The LQI Type field indicate the type of LQI used in beam forming procedure. Valid values of the LQI type fields are

- 0 → RSSI_r
- 1 → SNR
- 2 → SINR
- 3 → Reserved

The Number TX Sectors field indicates the number of TX sectors supported by the DEV.

The Number RX Sectors field indicates the number of RX sectors supported by the DEV.

The Antenna Type field indicate the supported antenna type of the DEV. Valid values of the Antenna Type field are as follows:

- 0 → No beam forming capability
- 1 → Beam forming antenna capable
- 2–7 → Reserved

The PET field shall be set to one if the DEV supports pattern estimation and tracking and shall be set to zero otherwise.

The Number TX Quasi-omni Directions field indicates the number of TX quasi-omni directions supported by the DEV.

The Number of RX Quasi-omni Directions field indicates the number of RX quasi-omni directions supported by the DEV.

Insert the following subclauses as 7.4.22 through 7.4.35:

7.4.22 Synchronization

The Synchronization IE shall be formatted as illustrated in Figure 48e. The Synchronization IE shall be supported by DEVs that support the SC PHY or HSI PHY.

octets: 5	5	1	4	1	1
Regular S-CAP info	Association S-CAP info	Section indications	Quasi-omni beacon info	Length	Element ID

Figure 48e—Synchronization information element format

The Quasi-omni Beacon Info field shall be formatted as illustrated in Figure 48f.

bits: 6	4	3	3	16
Reserved	PNC directional antenna capabilities	Number beacon frames	Beacon index	Beacon offset time

Figure 48f—Quasi-omni beacon info field format

The Beacon Offset Time field contains the time in microseconds that is the start of this beacon frame delayed from the start of the superframe.

The Beacon Index field indicates the index of the current beacon frame.

The Number Beacon Frames field indicates the number of beacon frames that will be sent as part of the quasi-omni beacon.

The PNC Directional Antenna Capabilities field shall be formatted as illustrated in Figure 48g.

bits: 1	1	1	1
BST support	Sectors only	PNC beam forming capable	Antenna symmetry

Figure 48g—PNC directional capabilities field format

The Antenna Symmetry field shall be set to one if the PNC has a symmetric antenna system (SAS) and shall be set to zero otherwise, i.e., the PNC has an asymmetric antenna system (AAS).

The PNC Beam Forming Capable bit shall be set to one if the PNC is capable of beam forming and shall be set to zero otherwise.

The Sectors Only field shall be set to one if the PNC supports only sectorized antenna and shall be set to zero otherwise.

The BST Support field shall be set to one if the PNC supports beam switching/steering and tracking, as described in Clause 13, and shall be set to zero otherwise.

The Section Indication field shall be formatted as illustrated in Figure 48h.

bits: 4	1	1	1	1
Reserved	Regular S-CAP present	Association S-CAP present	Sector training present	PNC quasi-omni tracking present

Figure 48h—Section indication field format

The PNC Quasi-Omni Tracking Present field shall be set to one if the PNC quasi-omni tracking section exists in the beacon and shall be set to zero otherwise.

The Sector Training Present field shall be set to one if the sector training section exists in the beacon and shall be set to zero otherwise.

The Association S-CAP Present field shall be set to one if association S-CAP sections exist in the CAP and shall be set to zero otherwise.

The Regular S-CAP Present field shall be set to one if regular S-CAP sections exist in the CAP and shall be set to zero otherwise.

The Association S-CAP info field shall be formatted as illustrated in Figure 48i.

bits: 2	2	2	2	16	16
Reserved	First PNC quasi-omni RX index	Number association S-CAPs in superframe	Total number association S-CAPs	S-CAP duration	Association S-CAP start time

Figure 48i—Association S-CAP info field format

The Association S-CAP Start Time field specifies the start time offset of the association S-CAPs from the start of the superframe in microseconds.

The S-CAP Duration field specifies the duration of the association S-CAP, as described in 8.6.6.2, in microseconds.

The Total Number of Association S-CAPs is the same as the total number of PNC quasi-omni RX directions.

The Number of Association S-CAPs in Superframe field specifies the number of association S-CAPs in the current superframe.

The First PNC Quasi-Omni RX Index field specifies the PNC's quasi-omni RX index that will be used in the first association S-CAP in the current superframe.

The Regular S-CAP info field shall be formatted as illustrated in Figure 48j.

bits: 2	2	2	2	16	16
Reserved	First PNC quasi-omni RX index	Number regular S-CAPs in superframe	Total number regular S-CAPs	S-CAP duration	Regular S-CAP start time

Figure 48j—Regular S-CAP info field format

The Regular S-CAP Start Time field specifies the start time offset of the regular S-CAP from the start of the superframe in microseconds.

The S-CAP Duration field specifies the duration of the regular S-CAPs in microseconds.

The Total Number of Regular S-CAPs field is set to be the same as the total number of PNC quasi-omni RX directions.

The Number of Regular S-CAPs field in Superframe field specifies the number of regular S-CAPs in the current superframe.

The First PNC Quasi-Omni RX Index field specifies the PNC's quasi-omni RX index that will be used in the first regular S-CAP in the current superframe.

7.4.23 Transmit switched diversity

The Transmit Switched Diversity IE is used for information exchange in TSD procedure as described 13.8. The Transmit Switched Diversity IE shall be formatted as illustrated in Figure 48k.

octets: 1	1	1	1	1	1
Transmit direction index	TSD feedback period	Number of transmit directions	Mode	Length	Element ID

Figure 48k—Transmit switched diversity information element format

The Mode field is encoded as indicated in Table 49d.

Table 49d—Mode field encoding

Field value	Mode	Description
0	Announce	Announce TSD IE sent from PNC to DEV
1	Request to switch	DEV requests PNC to switch to the next transmit direction
2	Request to stay	DEV requests PNC to stay at the current transmit direction
3	Response	In response of a request
4-255	Reserved	

The Number Of Transmit Directions field indicates the number of TX directions supported by the PNC.

The TSD Feedback Period field indicates the time interval between the TSD IEs sent from the DEV to the PNC for feedback.

The Transmit Direction Index field indicates the index of the transmit direction of the PNC. A field value of zero indicates that the PNC shall select one of the transmit directions that was not used previously.