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Partie 15-3: Réseaux multimédias sans fil à haut débit de données

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IEEE Std 802.15.3™-2016
(Revision of
IEEE Std 802.15.3-2003)

IEEE Standard for High Data Rate Wireless Multi-Media Networks

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Approved 15 May 2016
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Abstract: The protocol and compatible interconnection of data and multimedia communication equipment via 2.4 GHz and 60 GHz radio transmissions in a Wireless Personal Area Network (WPAN) using low power and multiple modulation formats to support scalable data rates is defined in this standard. The Medium Access Control (MAC) sublayer protocol supports both isochronous and asynchronous data types.

Keywords: ad hoc network, IEEE 802.15.3™, mobility, mm-wave, radio frequency, wireless

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Introduction

This introduction is not part of IEEE Std 802.15.3-2016, IEEE Standard for High Data Rate Wireless Multi-Media Networks.

IEEE Std 802.15.3-2016 was originally developed to provide superior quality of service (QoS) over relatively medium range wireless links.

The idea of a high-rate addition to the IEEE 802.15 family of standards was first proposed in November 1999 at the IEEE Plenary meeting in Kaua'i, HI. The 802.15.3 task group began its official work at the March 2000 IEEE Plenary meeting in Albuquerque, NM, creating a criteria document and evaluation method. The down-selection of MAC and PHY proposals was completed at the November 2000 IEEE 802 Plenary meeting in Tampa, FL, and the writing of the draft began in December 2000. After working on the draft for one year, the document was ready for the task group ballot process in December 2001. The draft received final working group approval at the November 2002 IEEE Plenary meeting in Kaua'i, HI, and began the sponsor ballot process following the meeting. The draft went through one sponsor ballot and two recirculations before it was submitted to the IEEE Standards Association Standards Board (IEEE-SASB) for approval. The IEEE-SASB approved 802.15.3 as an IEEE standard in June 2003.

IEEE Std 802.15.3-2003 defined an ad-hoc MAC that enabled simple and fast network formation, excellent QoS, strong security with 128-bit AES encryption in CCM mode and methods to coexist with other wireless networks in the band. The PHY operated in the license exempt 2.4 GHz band with data rates of 11 Mb/s to 55 Mb/s at distances of greater than 70 m.

Interest in working on an amendment to fix and enhance IEEE Std 802.15.3 began in the September 2003 meeting in Singapore. A study group was formed at the November 2003 meeting in Albuquerque, which completed a project authorization request that was approved in March 2004. Work progressed quickly, and the first task group letter ballot was successfully completed in March 2005. After one recirculation, the draft began sponsor ballot in August 2005. The ballot was successful, and after a recirculation ballot to validate some minor changes, IEEE Std 802.15.3b was approved by the IEEE Standards Board on 6 December 2005, just over two years after the study group started.

IEEE Std 802.15.3b-2005 fixed mistakes and added enhancements that improve the efficiency of the base standard. Some of the key changes/additions in this amendment are as follows:

— An improved definition of the medium access control (MAC) layer management entity (MLME) service access point (SAP).
— A new acknowledgment (ACK) policy, implied-ACK, which allows polling and a more efficient use of channel time.
— A method for relinquishing time in a channel time allocation (CTA) to allow another device (DEV) time to transmit data.
— The ability to assign device identifiers (DEVIDs) to group addresses to allow multicast connections.
— Faster recovery of network operations when the piconet coordinator (PNC) abruptly disconnects\ with the conditional handover and the next PNC processes.
— Multiple contention periods during a superframe.

In the July 2003 meeting in San Francisco, an interest group was formed to consider a mmWave PHY for the existing standard. 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

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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.

Some of the key features of IEEE Std 802.15.3c-2009 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.
— MAC packet aggregation and the acknowledgment of individual subpackets to reduce retransmission overhead.

The PHY specifices 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.
— Audio/video (AV) mode optimized for the delivery of uncompressed, high-definition video and audio.

In 2015, there were two new projects that wanted to add additional optional PHYs. To support the development of these new amendments, the base standard needed to be revised to create a single document that incorporated the prior two amendments. A PAR was generated in July 2015 at the IEEE Plenary meeting in Waikoloa Village, HI. The PAR was approved by the IEEE SASB in September 2015 and the initial draft was completed soon thereafter (by the same Technical Editor who worked on the previous three documents). After two working group ballots, the sponsor ballot began in December 2015 and completed in February 2016 after two Sponsor ballot recirculations. IEEE Std 802.15.3-2016 was approved by the IEEE-SA Standards Board in May 2016.

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IEEE Standard for High Data Rate Wireless Multi-Media Networks

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1. Overview

1.1 Scope

This standard defines PHY and MAC specifications for high data rate wireless connectivity (typically over 200 Mbps) with fixed, portable, and moving devices. Data rates are high enough to satisfy a set of consumer multimedia industry needs, as well as to support emerging wireless switched point-to-point and high rate close proximity point-to-point applications.

1.2 Purpose

The purpose of this standard is to provide for low complexity, low cost, low power consumption, and high data rate wireless connectivity among devices that support a variety of applications such as a set of consumer multimedia industry needs, wireless switched point-to-point applications in data centers, wireless backhaul/fronthaul intra-device communications, and a wide variety of additional use cases such as rapid large multimedia data downloads and file exchanges between two devices in close proximity, including between mobile devices and stationary devices (kiosks, ticket gates, etc.), and/or wireless data storage devices.

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2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used; therefore, each referenced document is cited in the 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.

ANSI X3.66-1979: Advanced data communication control procedures (ADCCP).[1]

IEEE Std 802®-2014, IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture.[2, 3]

ISO/IEC 646:1991, Information Technology—ISO 7-bit coded character set for information interchange.[4]

NIST FIPS Pub 197: Advanced Encryption Standard (AES), Federal Information Processing Standards Publication 197, US Department of Commerce/N.I.S.T., November 26, 2001.[5]

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3. Definitions, acronyms, and abbreviations

3.1 Definitions

For this standard, the following terms and definitions apply. *The IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[6]

ad hoc network: A network typically created in a spontaneous manner. The principal characteristic of an ad hoc network is its limited temporal and spatial extent.

association: The service used to assign a device identifier to a device to enable communications in a piconet.

channel time allocation: A contiguous period of time in the superframe allocated by the piconet coordinator for communication between specified source and destination.

coexistence: The ability of one system to perform a task in a given shared environment where other systems have an ability to perform their tasks and may or may not be using the same set of rules.

data authentication: Authentication of the sender of the data and provision of data integrity.

data integrity: The assurance that the data has not been modified from its original form.

dBm: Decibels relative to a milliwatt.

device: An entity that implements an IEEE 802.15.3 conformant media access control and physical layer interface to the wireless medium.

device address: The EUI-48 associated with device in an IEEE 802.15.3 piconet.

disassociation: The service that removes an existing association.

frame: Format of aggregated bits that are transmitted together in time.

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

integrity code: A data string generated using a symmetric key that is typically appended to data in order to provide data integrity and source authentication similar to a digital signature.

interoperable: The ability of two systems to perform a given task using a single set of rules.

medium access control command data unit: The unit of data exchanged between two peer medium access control entities using the services of the physical layer to implement the medium access control management protocol.

medium access control protocol data unit: The unit of data exchanged between two peer medium access control entities using the services of the physical layer.

medium access control service data unit: Information that is delivered as a unit between medium access control service access points.

[6] *The IEEE Standards Dictionary Online* is available at http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

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payload protection: The generic term for providing security services on the contents of a data message, including confidentiality, integrity, and authentication.

piconet: A collection of one or more logically associated devices that share a single identifier with a common coordinator.

piconet coordinator: An entity that has device functionality and also provides coordination and other services, e.g., quality of service, synchronization, association, via the wireless medium for associated devices.

quality of service: A collective measure of the level of service (e.g., availability, latency, throughput, error rate) delivered between devices.

secure frame: A command or data frame in which cryptographic techniques are applied to provide encryption or integrity.

secure piconet: A piconet in which cryptographic techniques are implemented to provide security services.

stream: A unidirectional, logical data connection between two devices that may or may not have quality of service requirements associated with it.

superframe: The basic time division of an IEEE 802.15.3 piconet containing a beacon, the channel time allocation period and optionally the contention access period.

symmetric key: A secret key shared between two or more parties that may be used for encryption/decryption or integrity protection/integrity verification.

wireless medium: The medium used to implement the transfer of protocol data units between peer physical layer entities of a wireless personal area network.

3.2 Acronyms and abbreviations

AAS	asymmetric antenna system
ACK	acknowledgment
AES	advanced encryption standard
AS	application specific
ATP	association timeout period
AV	audio/visual
AWGN	additive white Gaussian noise
BBIFS	beam-forming beam-level interframe spacing
BCRD	bidirectional channel time allocation relinquish duration
BcstID	broadcast identifier
BER	bit error rate
BIFS	backoff interframe space
Blk-ACK	block acknowledgment
BPSK	binary phase-shift keying
BSID	beacon source identifier
BSIFS	beam-forming sector-level interframe spacing
BST	beam switching/steering and tracking
CAP	contention access period

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CBC	cipher block chaining
CBC-MAC	cipher block chaining-message authentication code
CCA	clear channel assessment
CCM	counter mode encryption and cipher block chaining message authentication code
CES	channel estimation sequence
CID	Company ID
CMS	common mode signaling
CP	contention period
CRC	cyclic redundancy check
CSMA/CA	carrier sense multiple access with collision avoidance
CTA	channel time allocation
CTAP	channel time allocation period
CWB	continued wake beacon
DAMI	dual alternate mark inversion
DestID	destination identifier
DEV	device
DEVID	device identifier
Dly-ACK	delayed acknowledgment
DME	device management entity
DQPSK	differential quadrature phase-shift keying
DSPS	device synchronized power save
EEP	equal error protection
EIRP	equivalent isotropic radiated power
EPD	Ethertype protocol discrimination
FCS	frame check sequence
FCSL	frame convergence sublayer
FEC	forward error correction
FER	frame error rate
HCS	header check sequence
HR	high rate
HRP	high-rate physical layer
HRPDU	high-rate protocol data unit
HRS	high resolution
HSI	high speed interface
ID	identifier
IE	information element
IFS	interframe space
Imm-ACK	immediate acknowledgment
Imp-ACK	implied acknowledgment
KO	key originator
LAN	local area network
LDPC	low-density parity check
LFSR	linear feedback shift register
LLC	logical link control
LQI	link quality indication
LRP	low-rate physical layer

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LRPDU	low-rate protocol data unit
LSB	least significant bit
MAC	medium access control
MAN	metropolitan area network
MCDU	MAC command data unit
MCS	modulation and coding scheme
McstID	multicast identifier
MCTA	management channel time allocation
MIFS	minimum interframe space
MLME	MAC layer management entity
mmWave	millimeter wave
MPDU	MAC protocol data unit
MPR	mandatory PHY rate
MR	medium rate
MSB	most significant bit
MSC	message sequence chart
MSDU	MAC service data unit
NAK	negative acknowledgment
NbrID	neighbor identifier
NLOS	non-line-of-sight
OFDM	orthogonal frequency-division multiplexing
OOK	on-off keying
OUI	organizationally unique identifier
PAL	protocol adaptation layer
PAN	personal area network
PCES	pilot channel estimation sequence
PCTM	pending channel time map
PDU	protocol data unit
PET	pattern estimation and tracking
PHY	physical layer
PIB	PAN information base
PLME	PHY layer management entity
PN	pseudo noise
PNC	piconet coordinator
PNCID	piconet coordinator identifier
PNID	piconet identifier
PPDU	PHY protocol data unit
PRBS	pseudo-random bit sequence
PRNG	pseudo-random number generator
PS	power save
PSD	power spectral density
PSPS	piconet synchronized power save
PSRC	power source
QAM	quadrature amplitude modulation
QoS	quality of service
QPSK	quadrature phase-shift keying

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QT	quasi-omni training
RF	radio frequency
RIFS	retransmission interframe space
RS	Reed Solomon
RSSI	received signal strength indication
RSSIR	received signal strength indication relative to sensitivity
RX	receive or receiver
SAP	service access point
SAS	symmetric antenna system
SC	single carrier
S-CAP	sub-contention access period
SDU	service data unit
SEC	security
SECID	security identifier
SFC	secure frame counter
SIFS	short interframe space
SINR	signal-to-interference-plus-noise ratio
SNR	signal-to-noise ratio
SPS	synchronous power save
SrcID	source identifier
SSB	single side band
ST	sector training
STP	stream timeout period
TCM	trellis coded modulation
TPC	transmit power control
TSD	transmit switched diversity
TU	time unit
TX	transmit or transmitter
UEP	unequal error protection
WAN	wide area network
WLAN	wireless local area network
WPAN	wireless personal area network

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4. General description

4.1 What is a piconet?

A piconet is a wireless ad hoc data communications system that allows a number of independent data devices (DEVs) to communicate with each other. A piconet is distinguished from other types of data networks in that communications are normally confined to a small area around person or object that typically covers 10 m in all directions and envelops the person or a thing whether stationary or in motion.

This is in contrast to local area network (LAN), metropolitan area network (MAN), and wide area network (WAN), each of which covers a successively larger geographic area, such as a single building or a campus or that would interconnect facilities in different parts of a country or of the world.

4.2 Components of an IEEE 802.15.3 piconet

An IEEE 802.15.3 piconet consists of several components, as shown in Figure 4-1. The basic component is the DEV. One DEV is required to assume the role of the piconet coordinator (PNC) of the piconet. The PNC provides the basic timing for the piconet with the beacon. Additionally, the PNC manages the quality of service (QoS) requirements, power save modes, and access control to the piconet.

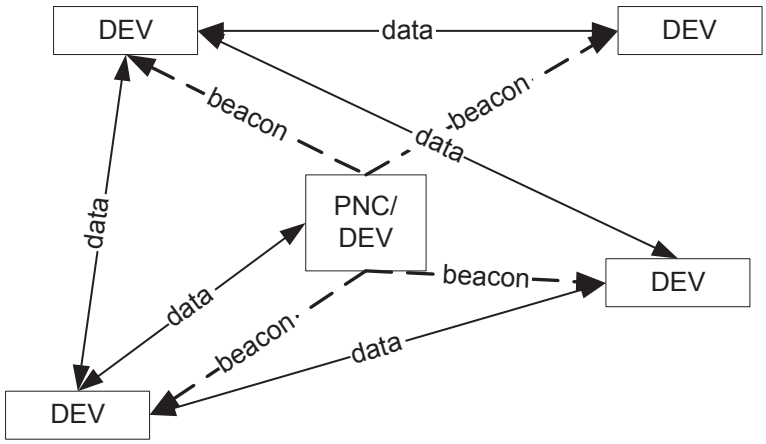

Figure 4-1—IEEE 802.15.3 piconet elements

Because IEEE 802.15.3 piconets form without pre-planning and for only as long as the piconet is needed, this type of operation is referred to as an ad hoc network.

This standard allows a DEV to request the formation of a subordinate piconet. The original piconet is referred to as the parent piconet. The subordinate piconet is referred to as either a child or neighbor piconet, depending on the method the DEV used to associate with the parent PNC. Child and neighbor piconets are also referred to as dependent piconets since they rely on the parent PNC to allocate channel time for the operation of the dependent piconet. An independent piconet is a piconet that does not have any dependent piconets.

4.3 Overview of medium access control (MAC) functionality

IEEE 803.15.3 MAC is designed to support the following goals:

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— Fast connection time
— Ad hoc networks
— Data transport with quality of service (QoS)
— Security
— Dynamic membership
— Efficient data transfer

4.3.1 Coordination

A piconet is formed when an IEEE 802.15.3 DEV that is capable of acting as the PNC begins transmitting beacons. Thus, even if there are no associated DEVs, the PNC sending the beacon is considered to be a piconet.

4.3.1.1 Starting a piconet

To start a piconet, a DEV that is capable of acting as the PNC scans the available channels to find one that is not being used, as described in 7.2.1. If it finds one that is clear, it starts the piconet by simply sending the beacon after making sure that the channel has remained empty for a specified period of time, as described in 7.2.2. If no channels are available, the DEV has the option of attempting to start a dependent piconet, as described in 7.2.7 and 7.2.8 and summarized in 4.3.1.3 and 4.3.1.4. While the process of starting a piconet does not ensure that the "most capable" PNC is initially selected based on the criteria in 7.2.3, the association and handover process does allow the "most capable" DEV to eventually become the PNC of the piconet.

While the PNC is allowed to handover to a dependent PNC, this does not imply that the dependent PNC will merge the two piconets. IEEE Std 802.15.3 does not provide a process for merging two piconets into a single piconet.

4.3.1.2 Handing over control of the piconet

When a DEV associates with an existing piconet, as described in 7.3.1 and 4.3.4, the PNC checks the capabilities of the new DEV to see if it is more capable to be the PNC of the piconet based on the criteria defined in 7.2.3. If the new DEV is more capable and the current security policies allow it, then the PNC has the option of handing over control of the piconet to the DEV that has just joined. This handover process, as described in 7.2.3, maintains all existing time allocations so that there is no interruption in the delivery of data in the piconet. If the PNC is shutting down or wants to leave the piconet, it also uses the handover process to give control to another DEV in the piconet. The handover process also supports the handing over of a dependent PNC, as described in 7.2.6.

4.3.1.3 Creating a child piconet

A child piconet is one that is formed under an established piconet. The established piconet then becomes the parent piconet. The child piconet functionality is useful for either extending the area of coverage of the piconet or shifting some computational or memory requirements to another PNC-capable DEV. It is possible for the parent piconet to have more than one child piconet. In addition, it is also possible for a child PNC to allow a child piconet as a part of its own piconet.

The child piconet uses a distinct piconet identifier (PNID) and acts as an autonomous piconet except that it is dependent on a private channel time allocation (CTA) from the parent piconet. Association and security membership for the child piconet are handled within the child piconet and do not involve the parent PNC.

The child PNC is a member of the parent piconet and thus is able to exchange data with any DEV in the parent piconet. The child PNC is also a member of the child piconet and thus is able to exchange data with any DEV in the child piconet. Only DEVs in a child piconet that are also members of the parent piconet are

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able to communicate directly with DEVs in the parent piconet who are not also members of that child piconet. The use of the child piconet is described in 7.2.7.

4.3.1.4 Creating a neighbor piconet

A neighbor piconet is formed under an established piconet. The established piconet then becomes the parent piconet. The neighbor piconet functionality is a mechanism for sharing the frequency spectrum between different piconets when there are no vacant PHY channels. It is possible for a single piconet to have more than one neighbor piconet or to have both child and neighbor piconets as a part of the parent piconet. In addition, it is possible for the neighbor PNC to allocate a child or neighbor piconets within its own piconet.

The neighbor piconet uses a distinct PNID and is an autonomous piconet except that it is dependent on a private CTA from the parent piconet. Association and security membership for the neighbor piconet are handled within the neighbor piconet and do not involve the parent PNC.

The neighbor PNC is not a member of the parent piconet and thus does not exchange information with any DEV in the parent piconet. The neighbor piconet mechanism is available to other wireless DEVs as a means of sharing the frequency spectrum. Any entity capable of initiating (i.e., requesting status as) an IEEE 802.15.3 neighbor piconet would also be capable of using this as a coexistence method. The use of the neighbor piconet is described in 7.2.8.

4.3.2 Ending a piconet

If the PNC is going to stop operation and there are no other PNC-capable DEVs in the piconet, the PNC places the PNC Shutdown information element (IE), as described in 6.4.5, into the beacon, as described in 7.2.9.1, to notify the members of the piconet.

In the case that the PNC abruptly leaves the piconet without handing over control to another PNC-capable DEV in the piconet, the piconet stops operation. After the association timeout period (ATP) expires, a PNC-capable DEV from the old piconet will be able to start a new piconet using the normal process, as described in 7.2.2.

In the case of dependent piconets, the parent PNC is able to end the dependent piconet via the Disassociation Request command, described in 6.5.1.3, for neighbor piconets, or by using the stream termination procedure, described in 7.5.1.3, for child piconets, as described in 7.2.9.2.

4.3.3 Ending a piconet with a dependent piconet involved

If the parent piconet ends operation, the parent PNC will indicate in the PNC Shutdown IE, as described in 6.4.5, a dependent piconet that will be able to continue to operate. All other dependent piconets will cease operation when the parent piconet ends operation. The dependent PNC that was selected to remain will remove the Parent Piconet IE, as described in 6.4.3, from its Beacon frame, signifying that it is no longer a dependent piconet. In the case where the parent piconet was temporarily disrupted, the parent PNC is able to attempt to join the dependent piconet and potentially receive a transfer of control via PNC handover.

A child piconet ends its piconet with the shutdown procedure and then uses the Channel Time Request command, as described in 6.5.6.1, to terminate the stream and release the resources in the parent piconet. When the child PNC shuts down its piconet, it is not required to leave the parent piconet.

The neighbor piconet uses the Disassociation Request command, as described in 6.5.1.3, to end its relationship with the parent PNC.

When a dependent piconet ends operation it has no effect on the parent piconet except to release resources.

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4.3.4 Association and disassociation

In order to participate in a piconet, a DEV needs to join the piconet using the association process, as described in 7.3.1. Associating with the piconet provides the DEV with an identifier that is unique within that piconet, the DEVID, as described in 6.2.3. The DEVID is used instead of the DEV address to save overhead in the system. The association process optionally provides information about the services available in the piconet as well as the services provided by the DEV, as described in 7.3.2. The association process also provides the PNC with the capabilities of the new DEV to enable the PNC to decide if it wants to hand over control of the piconet to the new DEV, as described in 7.2.3 and 4.3.1.2.

When a new DEV joins the piconet, the PNC broadcasts the information about all of the DEVs in the piconet, as described in 7.3.3, and places information in the beacon about the new DEV. This allows other DEVs in the piconet to become aware of the new DEV as well as giving information to the new DEV about the members of the piconet.

When a DEV wants to leave the piconet or if the PNC wants to remove a DEV from the piconet, the disassociation process, as described in 7.3.4, is used. The DEVID of the disassociated DEV is no longer valid, until reissued by the PNC. However, the PNC is not allowed to reissue the DEVID until a waiting period has expired, as described in 7.3.1.

4.3.5 Security overview

Security is one of the following two modes, as described in 8.2:

a) Mode 0—Open: Security membership is not required and payload protection (either data integrity or data encryption) is not used by the MAC. The PNC is allowed to use a list of DEV addresses to admit or deny entry to the piconet.
b) Mode 1—Secure membership and payload protection: DEVs establish secure membership with the PNC before they have access to the piconet's resources. Data sent in Mode 1 is allowed to use payload protection (data integrity or data encryption with data integrity). Data integrity is required for most of the commands that are sent when in Mode 1.

When security is enabled, i.e., when Mode 1 is being used, DEVs that wish to join the piconet are required to establish secure membership with the PNC. The DEVs are also allowed to establish a secure relationship with other DEVs for secure communications. A DEV has established a secure membership or a secure relationship when it gets a management key for the security relationship. The process of establishing secure membership or a secure relationship is outside of the scope of this standard. The PNC or DEV that generates and distributes the key is called the key originator.

The payload protection protocol, as described in 9.2.2, uses a symmetric key that is generated by the key originator and is securely distributed to DEVs that have established secure membership or a secure relationship with the key originator, as described in 8.4.2. The symmetric key encryption algorithm used is the advanced encryption standard (AES) 128 in counter mode encryption and cipher block chaining-message authentication code (CCM).

4.3.6 The IEEE 802.15.3 superframe

Timing in the IEEE 802.15.3 piconet is based on the superframe, which is illustrated in Figure 4-2. The superframe is composed of the following three parts:

— The beacon, as described in 6.3.1, which is used to set the timing allocations and to communicate management information for the piconet. The beacon consists of the Beacon frame, as described in 6.3.1, as well as any Announce commands sent by the PNC as a beacon extension, as described in 7.6.3.

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— The contention access period (CAP), as described in 7.4.2, which is used to communicate commands and/or asynchronous data if it is present in the superframe.
— The channel time allocation period (CTAP), 7.4.3, which is composed of channel time allocations (CTAs), including management CTAs (MCTAs). CTAs are used for commands, isochronous streams, and asynchronous data connections.

In Figure 4-2 the MCTAs are shown first, but the PNC is allowed to place any number of them at any position in the superframe.

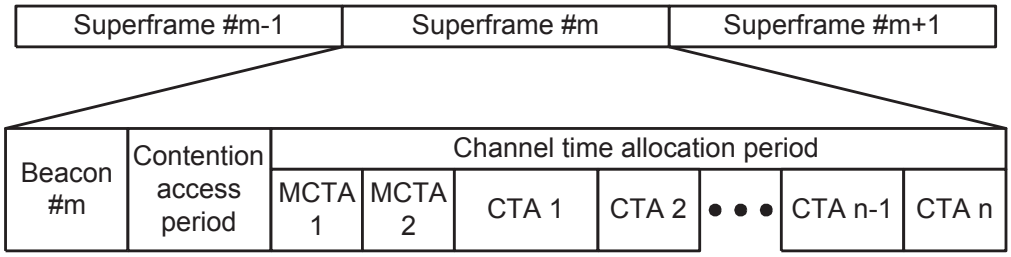

Figure 4-2—IEEE 802.15.3 piconet superframe

The length of the CAP is determined by the PNC and communicated to the DEVs in the piconet via the beacon. However, the PNC is able to replace the functionality provided in the CAP with management CTAs (MCTAs), except in the case of the 2.4 GHz PHY where the PNC is required to allow DEVs to use the CAP, as described in 10.2.10. MCTAs are a type of CTA that is used for communications between the DEVs and the PNC.

The CAP uses carrier sense multiple access/collision avoidance (CSMA/CA) for the medium access, as described in 7.4.2. The CTAP, on the other hand, uses a standard TDMA protocol where the DEVs have specified time windows, as described in 7.4.3.1. MCTAs, as described in 7.4.3.3, are either assigned to a specific source/destination pair and use TDMA for access or they are shared CTAs that are accessed using the slotted aloha protocol, as described in 7.4.3.4.

4.3.7 Channel time management

All data in the IEEE 802.15.3 piconet is exchanged in a peer-to-peer manner. There are three methods for communicating data between DEVs in the piconet, as follows:

a) Sending asynchronous data in the CAP, if present, as described in 7.4.2.
b) Allocating channel time for isochronous streams in the CTAP, as described in 7.5.1.
c) Allocating asynchronous channel time in the CTAP, as described in 7.5.2.

If the CAP is present in the superframe and the PNC allows data in the CAP, DEVs in the piconet are able to use the CAP to send small amounts of data without having to allocate channel time.

If the DEV needs channel time on a regular basis, it makes a request from the PNC for isochronous channel time, as described in 7.5.1.1. If the resources are available, the PNC allocates time in a CTA for the DEV. If the requirements for the data change, then the DEV is able to request a change to the allocation, as described in 7.5.1.2. The source DEV, destination DEV, or the PNC are all allowed to terminate the stream, as described in 7.5.1.3.

For regular CTAs, the PNC is able to change their position within the superframe every superframe. If a DEV misses a beacon, it is unable to use the allocation for a regular CTA. To avoid lost throughput due to

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missed beacons, DEVs are allowed to request a special type of CTA called a pseudo-static CTA, as described in 7.4.3.1. If the DEV is allocated a pseudo-static CTA, it is allowed to use the CTA for up to *mMaxLostBeacons* missed beacons. The PNC is allowed to move the locations of these CTAs, but needs to maintain the time for the old allocation for *mMaxLostBeacons* superframes to avoid collisions, as described in 7.4.3.1.

Asynchronous allocation is slightly different. Rather than requesting recurring channel time, an asynchronous channel time request, as described in 7.5.2.1, is a request for a total amount of time to be used to transfer its data. The PNC is then able to schedule time for this request when available based on the channel time requirements. Unlike an isochronous allocation, only the source DEV or PNC are allowed to terminate an asynchronous allocation, as described in 7.5.2.2.

4.3.8 Data communications between DEVs

In order to handle large data frames from layers above the MAC sublayer, this standard supports the fragmentation and defragmentation of these data frames, as described in 7.7. The ability to fragment data frames is also useful to reduce the frame error rate (FER) of a marginal link by decreasing the frame size. The fragments are numbered with a sequence number for the upper layer frame as well as a sequence number for the fragment itself. The total number of fragments of that data frame is also sent to enable the receiving DEV to allocate the correct amount of internal memory to hold the incoming frame.

If the source DEV wishes to verify the delivery of a frame, then one of the acknowledgment (ACK) policies is used, as described in 7.9. This standard provides for three types of ACKs to enable different applications. The no-ACK policy, as described in 7.9.1, is appropriate for frames that do not require guaranteed delivery, where the retransmitted frame would arrive too late or where an upper layer protocol is handling the ACK and retransmission protocol. The immediate-ACK (Imm-ACK) policy, as described in 7.9.2, provides an ACK process in which each frame is individually ACKed following the reception of the frame. The delayed-ACK (Dly-ACK) policy, as described in 7.9.3, lets the source send multiple frames without the intervening ACKs. Instead, the ACKs of the individual frames are grouped into a single response frame that is sent when requested by the source DEV. The Dly-ACK process decreases the overhead in the Imm-ACK process while allowing the source DEV to verify the delivery of frames to the destination.

If the source DEV does not receive the requested ACK, then it has the option of retransmitting the frame, as described in 7.9.6, or dropping the frame. The decision to retransmit or drop the frame depends on the type of data or command that is being sent, the number of times that the source DEV has attempted sending the frame, the length of time it has spent attempting to send the frame, or other implementation-dependent factors.

4.3.9 Information discovery in the piconet

Since IEEE 802.15.3 piconets are ad hoc in nature, it is important for the DEVs in the piconet to be able to find out information about the services and capabilities of the other DEVs in the piconet at any instant in time. This standard supports four methods for discovering information about other DEVs in the piconet: the PNC Information Request command, as described in 6.5.4.1; the Probe Request command, as described in 6.5.4.5; the Announce command, as described in 6.5.5.2; and the Piconet Services command, as described in 6.5.5.1. In addition, the PNC is able to ask a DEV in the piconet to evaluate the channel conditions in either the current channel or in an alternate channel with the Remote Scan Request command, as described in 6.5.7.3. Any DEV in the piconet is able to ask another DEV about the status of the current channel with the Channel Status Request command, as described in 6.5.7.1.

The PNC Information Request command, as described in 7.10.1, is used to obtain information from the PNC about either a specific DEV in the piconet or all of the DEVs in the piconet. The PNC responds to the request with the PNC Information command, as described in 6.5.4.2, which contains information about the DEV (or DEVs) that was requested by the originator of the command.

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A DEV uses the Probe Request command, 7.10.2, to find out more detailed information about other DEVs in the piconet. This command allows the originating DEV to retrieve some IEs, as defined in 7.10.2, from a target DEV in the piconet.

One of the goals of connecting DEVs in a piconet is to enable them to share services. However, to do this a DEV needs to be able to discover the services that are available in the piconet as well as to advertise its services to other DEVs in the piconet. This standard enables this with the Piconet Services IE, as described in 6.4.16, which optionally is exchanged in the association process, as described in 7.3.1.

The PNC is responsible for determining the channel in which the piconet will operate. Because the DEVs in the piconet are typically at different geographic locations, they provide additional information about interference or other piconets in the area. The Remote Scan Request command, as described in 7.10.5, is used by the PNC to request information about the channel from other DEVs. In response to the PNC's request, the DEV either scans the channels as requested or rejects the request from the PNC if it is not going to perform the scan.

Any DEV in the piconet is able to request information about the quality of the link between itself and another DEV with the Channel Status Request command, as described in 6.5.7.1. This command is used for two purposes. The first is to allow the DEVs to change transmit power, the data rate, or the requested channel time based on the quality of the data connection between the DEVs. The other use is for the PNC to determine if the DEVs in the piconet are having trouble with the channel. This information along with PNC's scanning of the channel and optional remote scan requests assists the PNC in determining if it needs to change the channel that the piconet is currently using.

4.3.10 Dynamic channel selection

The piconet operates in a dynamic environment and under unlicensed operation rules. Thus, it is subject to interference from licensed users, other IEEE 802.15.3 piconets as well as other unlicensed wireless entities in its channels. To enable the piconet to continue operation in this type of environment, the PNC has the capability to dynamically change the channel that the piconet is using without requiring either user intervention or the disruption of services in the piconet. To evaluate the status of the current channel as well as other channels, the PNC is able to use many methods including the following:

— Gathering information about the current channel from other DEVs in the piconet using the Channel Status Request command, as described in 7.10.4.
— Performing a passive scan of the channels, as described in 7.12.1.
— Requesting other DEVs to perform a channel scan using the Remote Scan Request command, as described in 7.10.5.

If the PNC determines that the current channel is unsuitable, it uses the dynamic channel selection procedure, as described in 7.12.1, to move the piconet to the new channel. The configuration of the piconet and the CTAs do not change with a channel change so that the services provided by the piconet are not interrupted by the change.

4.3.11 Power management

This standard provides techniques to allow DEVs to reduce power usage by enabling the DEVs to turn off for one or more superframes. These techniques are as follows:

— Device synchronized power save (DSPS) mode
— Piconet synchronized power save (PSPS) mode
— Asynchronous power save (APS) mode

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DSPS and PSPS are collectively known as synchronized power save (SPS) modes. In the piconet, DEVs operate in one of four power management (PM) modes; ACTIVE mode, DSPS mode, PSPS mode, or APS mode.

PSPS mode, as described in 7.14.1, allows DEVs to sleep at intervals defined by the PNC. The DEV sends a request to the PNC when it wants to enter the PSPS mode. The PNC informs the piconet by setting the DEV's bit in its power save (PS) Status IE in the beacon. The PNC then selects beacons that will be the system wake beacons and indicates the next one in the PS Status IE for the PSPS set. All DEVs in PSPS mode are required to listen to the system wake beacons.

DSPS mode, as described in 7.14.2, is designed to enable groups of DEVs to sleep for multiple superframes but still be able to wake up during the same superframe. DEVs synchronize their sleep patterns by joining a DSPS set that specifies the interval between wake periods for the DEVs and the next time the DEVs will be awake. Besides allowing the DEVs to wake up and exchange traffic at the same time, the use of DSPS sets makes it easy for other DEVs in the piconet to determine exactly when a DSPS DEV will be available to receive traffic.

APS mode, as described in 7.14.3, allows a DEV to conserve power for extended periods until the DEV chooses to listen for a beacon. The only responsibility of a DEV in APS mode is to communicate with the PNC before the end of its ATP in order to preserve its membership in the piconet.

The PNC allocates asynchronous CTAs to a destination DEV that is in either PSPS mode or DSPS mode in the wake superframes for that DEV.

Regardless of the DEV's power management mode, every DEV in the piconet is allowed to power down during parts of the superframe when the DEV is not scheduled to transmit or receive data.

4.3.12 Controlling transmit power in the piconet

The ability to control transmit power in the piconet enables DEVs to minimize interference with other wireless networks that share the same channel as well as to decrease the power usage in some PHY implementations. Two methods are provided by this standard for controlling transmitter power. The first method allows the PNC to set a maximum transmit power for the CAP, beacon, and MCTAs, excluding association MCTAs, as described in 7.12.2.1. Since the link between the PNC and the DEV defines the size of the piconet, controlling the power during these times allows the PNC to reduce transmit power without adversely affecting operation of the piconet.

The second method allows DEVs using a CTA to request either an increase or a decrease in the transmit power of the remote DEV, as described in 7.12.2.2. Thus if two DEVs have a "good" link in a CTA, they are able to reduce their transmitter power to decrease the power usage in some PHY implementations, and to reduce interference to other networks.

4.3.13 Superfame structure using quasi-omni mode

A mmWave piconet operates in either omni mode or quasi-omni mode. The superframe structure for omni mode is illustrated in Figure 4-2. The superframe structure for quasi-omni mode is illustrated in Figure 4-3. In quasi-omni mode, the same Beacon frame is transmitted in different quasi-omni directions in a round-robin way in order to allow mmWave DEVs located in different directional coverage to join the piconet, as described in 7.6.5.

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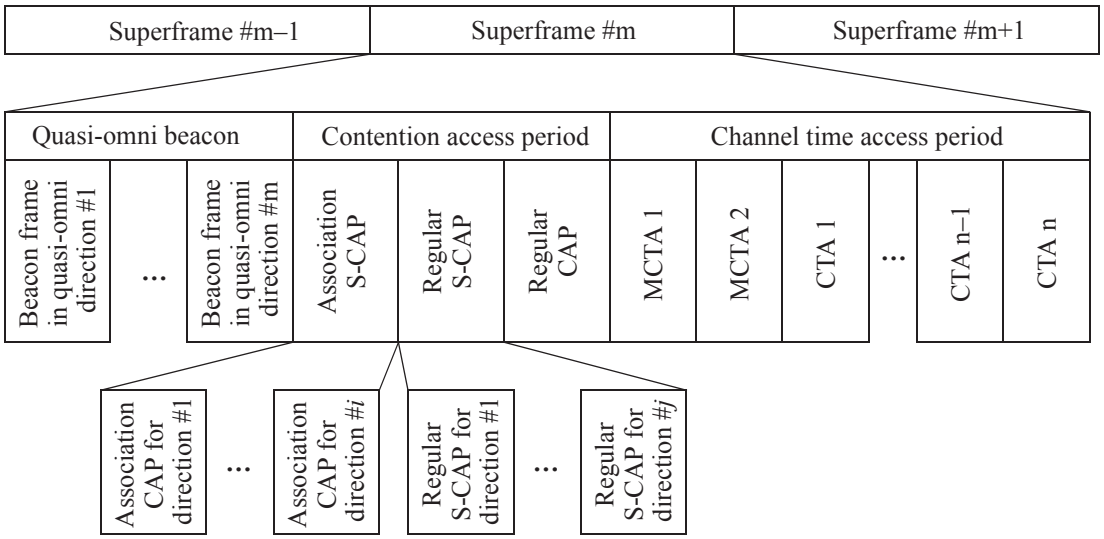

Figure 4-3—Piconet superframe structure in quasi-omni mode

4.3.14 Frame aggregation

Frame aggregation, as described in 7.8, is supported for the purpose of high throughput. Two aggregation methods are provided for mmWave DEVs, one is suitable for normal data and A/V streaming and the other is optimized for low-latency communications.

4.3.15 Beam forming

The beam forming procedure allows a mmWave 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 12.

4.3.16 Channel probing

Channel probing, as described in 7.10.7, is an optional capability that is used by a DEV to determine the best modulation and coding scheme (MCS) to use with the target DEV under current channel condition.

4.3.17 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 only for mmWave DEVs. Three types of UEP are defined, as described in 7.17, for use with the three mmWave PHYs.

4.4 Characteristics of the 2.4 GHz PHY

4.4.1 General characteristics

The 2.4 GHz PHY, Clause 10, uses the 2.4 GHz to 2.4835 GHz band that is available for unlicensed use in much of the world, as described in 10.1. Two channel plans are defined, one with 4 channels for high-density applications and one with 3 channels to enable better coexistence with IEEE Std 802.11b™-1999 [B3][7]

[7]The numbers in brackets correspond to those of the bibliography in Annex A.

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networks, as described in 10.2.3. The PHY also supports 5 data rates, ranging from 11 Mb/s to 55 Mb/s, utilizing, quadrature phase-shift keying (QPSK), differential quadrature phase shift keying (DQPSK), 16-quadrature amplitude modulation (16-QAM), 32-QAM and 64-QAM. The base rate of 22 Mb/s is uncoded, while the 11 Mb/s, 33 Mb/s, 44Mb/s, and 55 Mb/s use trellis coded modulation, 10.3.

For efficiency, the PHY calculates the header check sequence over both the MAC and PHY headers and appends this to the MAC header. The header for all frames is sent at the base rate, 22 Mb/s, to allow all DEVs in the piconet to detect traffic. In the 11 Mb/s mode, the entire MAC and PHY header is repeated at the lower modulation rate to increase the probability of receiving the entire header correctly.

The PHY uses a constant-amplitude, zero-autocorrelation (CAZAC) sequence for the preamble, as described in 10.4.2. This sequence has good properties for obtaining synchronization, timing information, and frequency offset.

The on-air bandwidth is limited to 15 MHz in order to allow more channels as well as to decrease the interference to other systems and to decrease the susceptibility to interference from other systems. The transmitter power is constrained by the limitations of the appropriate regulatory bodies.

The receiver of a compliant system reports both the signal level and, if the higher order modulations are used, an indication of the signal quality. This allows a DEV to determine if errors in the channel are due to poor signal quality or due to interference from other systems.

4.4.2 Coexistence and interoperability

While this standard does not require interoperability with other standards, there were choices made with the 2.4 GHz PHY specification that make it easier to design dual-mode radios. The commonalities that allow interoperable radios are discussed in D.1.

Because the 2.4 GHz PHY operates as an unlicensed system, it needs to share the medium with both licensed and unlicensed users in the band. The IEEE 802.15.3 MAC and the 2.4 GHz PHY offer a variety of techniques to enhance the coexistence with other users in the band. The methods provided by this standard include the following:

— Passive scanning
— Dynamic channel selection
— The ability to request channel quality information
— Link quality and RSSI
— A channel plan that minimizes channel overlap
— Lower transmit power
— Transmit power control
— Neighbor piconet capability

The use of these methods to improve coexistence is described in D.2.

4.5 Characteristics of the mmWave PHY

4.5.1 mmWave PHY characteristics

The mmWave PHY, as described in Clause 11, 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.

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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 11.2.
b) High Speed Interface mode in mmWave PHY (HSI PHY), as described in 11.3.
c) Audio/Visual mode in mmWave PHY (AV PHY), as described in 11.4.

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 11.1.12.

The SC PHY supports data rates up to 5 Gb/s. The SC PHY supports a wide range of modulations, π/2 BPSK, π/2 QPSK, π/2 8-phase shift keying (8-PSK), π/2 16-QAM, 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 11.3, is designed for non-line-of-sight (NLOS) operation and uses OFDM with an FEC based on LDPC.

The AV PHY, as described in 11.4, 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(RS) 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 wireless personal area network (WPAN) will have bidirectional, 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 implementers so that they can best address the different market segments.

4.5.2 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 since 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.

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The complete rules are described in 11.1.

4.6 Conventions

Unless otherwise specified, the term increment or incremented means to increase a value by one.

The editorial conventions in this standard are as follows:

— Frame names (e.g., Beacon frame, MAC Command frame) are capitalized and include the word *frame.*

— Command names (e.g., Association Request command) are capitalized and include the word c*ommand*.

— Field names are capitalized and include the word field, which is not capitalized, e.g., Destination PAN Identifier field. The only exception is in a figure that shows the field, in which the word "field" is not included.

— IE names are capitalized and include the acronym IE (e.g., Capability IE).

— MAC and PHY PIB entries are preceded by a lower case prefix, *mac* or *phy*, respectively, and are capitalized at word boundaries, e.g., "*macDevServicesBroadcast*" and "*phyCurrentChannel*".

— Constants begin with a lower case, italicized "*m*" for MAC related constants and a lower case italicized "*p*" for PHY related constants. Both use the same capitalization and use rules as PIB attributes.

— Service primitives names (e.g., MLME or MCPS) are ALL CAPS, but the .request, .indication, .response, and .confirm in the primitive names are always lower case.

— Primitive parameters are capitalized at word boundaries, e.g., NumberOfPiconets.

— In a PIB attibute, constant or service primitive, acronyms are not capitalized after the first letter, e.g., "*pMinTpcLevel*", "*macDevServicesBroadcast*", or "ScanForBsid.

4.7 Concept of primitives

The services of a layer are the capabilities it offers to the user in the next higher layer or sublayer by building its functions on the services of the next lower layer. This concept is illustrated in Figure 4-4, showing the service hierarchy and the relationship of the two correspondent users and their associated layer (or sublayer) peer protocol entities.

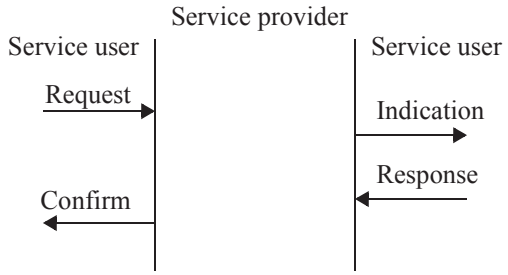

Figure 4-4—Service primitives

The services are specified by describing the information flow between the user and the layer. This information flow is modeled by discrete, instantaneous events, which characterize the provision of a service. Each event consists of passing a service primitive from one layer to the other through a layer SAP associated with an user. Service primitives convey the required information by providing a particular service. These service primitives are an abstraction because they specify only the provided service rather than the means by which it is provided. This definition is independent of any other interface implementation.

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A service is specified by describing the service primitives and parameters that characterize it.

A primitive can be one of the following four generic types:

— *Request:* The request primitive is used to request that a service is initiated.
— *Indication:* The indication primitive is used to indicate to the user an internal event.
— *Response:* The response primitive is used to complete a procedure previously invoked by an indication primitive.
— *Confirm:* The confirm primitive is used to convey the results of one or more associated previous service requests.

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5. Layer management

5.1 Overview of management model

Both MAC and PHY layers conceptually include management entities, called the MAC sublayer management entity and PHY layer management entity (MLME and PLME, respectively). These entities provide the layer management service interfaces for the layer management functions. Figure 5-1 depicts the relationship among the management entities. The protocol adaptation layer (PAL) includes both the FCSL and DME. The reference model depicts the interactions of a single PAL in a single piconet; support for multiple piconets and/or PALs is implementation dependent.

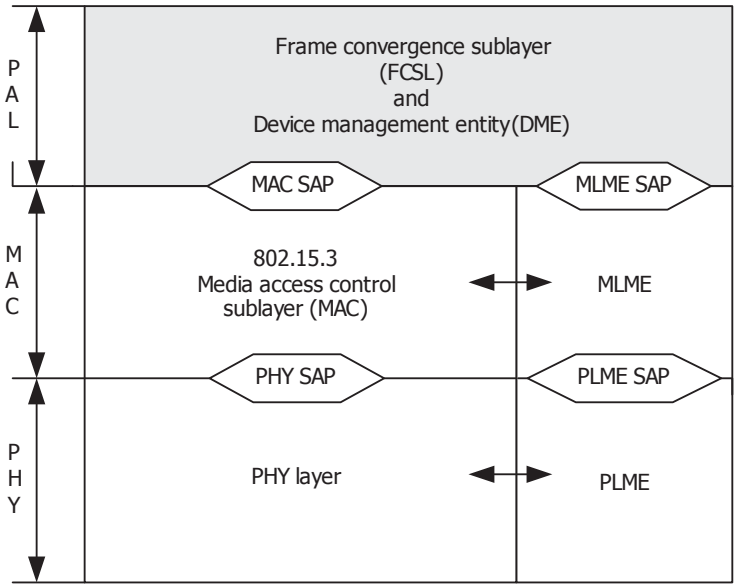

Figure 5-1—The reference model used in this standard

The various entities within this model interact in various ways. Certain of these interactions are defined explicitly within this standard, via a service access point (SAP) across which defined primitives are exchanged. Other interactions are not defined explicitly within this standard, such as the interface between the MAC and the MLME or the interface between the PHY and the PLME. The specific manner in which these MAC and PHY interfaces are integrated into the overall MAC and PHY layers are not specified within this standard.

The various SAPs within this model are the following:

a) PAL SAP (not shown)
b) MAC SAP
c) MLME SAP

The PHY SAP and PLME SAP are not defined in this standard as they are rarely, if ever, exposed in a typical implementation. The PHY management objects and attributes are accessed through the MLME SAP with the generic management primitives defined in 5.2.

The MAC SAP is described further in Annex B.

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