

802.15.2™

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

Part 15.2: Coexistence of Wireless Personal Area Networks with Other Wireless Devices Operating in Unlicensed Frequency Bands

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee



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IEEE Computer Society**

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Abstract: This recommended practice addresses the issue of coexistence of wireless local area networks and wireless personal area networks. These wireless networks often operate in the same unlicensed band. This recommended practice describes coexistence mechanisms that can be used to facilitate coexistence of wireless local area networks (i.e., IEEE Std 802.11b™-1999) and wireless personal area networks (i.e., IEEE Std 802.15.1™-2002).

Keywords: coexistence, collaborative, collocated, interference, mechanisms, non-collaborative, WLAN, WPAN

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Introduction

This introduction is not part of IEEE Std 802.15.2-2003, IEEE Recommended Practice for Information Technology—Telecommunications and Information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 15.2: Coexistence of Wireless Personal Area Networks with Other Wireless Devices Operating in Unlicensed Frequency Bands

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Participants

At the time this recommended practice was completed, two (2) working groups participated that had the following membership:

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James D. Allen, Vice-Chair

Ian C. Gifford, Co-Vice-Chair

Patrick Kinney, Secretary

Stephen J. Shellhammer, Chair, 802.15.2

Nada Golmie, Vice-Chair, 802.15.2 and Chair, 802.15.2 MAC

David E. Cypher, Editor-in-Chief, 802.15.2

Arun Arunachalam, Secretary, 802.15.2

Jim Lansford, Chair, 802.15.2 PHY

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Masaaki Akahane
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Arun Arunachalam
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Yasuo Harada
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Laura L. Huckabee

Eran Igler
Katsumi Ishii
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Park Jong-Hun
Jeyhan Karaoguz
Joy H. Kelly
Stuart J. Kerry
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Gunter Kleindl
Bruce P. Kraemer
David G. Leeper
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Jie Liang
Shawn T. Liu
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Fujio Watanabe
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Stephen Wood
Edward G. Woodrow
Hirohisa Yamaguchi
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Harry Worstell, *Vice-Chair*

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Brian Mathews, *Publicity Standing Committee*

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Arnoud Zwemmer
Jim Zyren

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

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Gholamreza Arefi-Anbarani
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Vilas Bhade
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IEEE Recommended Practice for Information technology— Telecommunications and information exchange between systems— Local and metropolitan area networks— Specific requirements

Part 15.2: Coexistence of Wireless Personal Area Networks with Other Wireless Devices Operating in Unlicensed Frequency Bands

1. Overview

This recommended practice addresses the issue of coexistence of wireless personal area networks (WPAN) and wireless local area networks (WLAN). These wireless networks often operate in the same unlicensed frequency band. This recommended practice describes coexistence mechanisms that can be used to facilitate coexistence of WPANs (i.e., IEEE Std 802.15.1™-2002¹) and WLANs (i.e., IEEE Std 802.11b™-1999). The unlicensed frequency bands used by each wireless technology are specified within its respective standard. This recommended practice also describes a computer model of the mutual interference between IEEE Std 802.15.1-2002 and IEEE Std 802.11b-1999 for information.

1.1 Scope

The scope is to develop a recommended practice for an IEEE 802.15™ WPAN that coexists with other selected wireless devices operating in unlicensed frequency bands, to suggest modifications to other IEEE 802.15 standards to enhance coexistence with other selected wireless devices operating in unlicensed frequency bands, and to suggest recommended practices for IEEE Std 802.11™, 1999 Edition devices to facilitate coexistence with IEEE 802.15 devices operating in unlicensed frequency bands.

The scope of this recommended practice is limited to coexistence of IEEE Std 802.15.1-2002 WPANs and IEEE Std 802.11b-1999 WLANs. This recommended practice will cover the IEEE Std 802.11b-1999 direct sequence spread spectrum standard at data rates of 1, 2, 5.5, and 11 Mbit/s. Both IEEE 802.11™ and IEEE 802.15 are continuing to work on additional standards.

¹Information on references can be found in Clause 2.

1.2 Purpose

Usage models exist that presume coexistence of IEEE 802.15 devices with other wireless devices operating in unlicensed frequency bands. The purpose of this recommended practice is to facilitate coexistence of IEEE 802.15 WPAN devices with selected other wireless devices² operating in unlicensed frequency bands. The intended users of this recommended practice include IEEE 802 WLAN developers, as well as designers and consumers of wireless products being developed to operate in unlicensed frequency bands.

This recommended practice includes a computer model of the mutual interference of an IEEE 802.11b WLAN and IEEE 802.15.1 WPAN. This model can be used to predict the impact of the mutual interference between these wireless systems. The model includes many parameters that can be modified to fit various user scenarios.

This recommended practice defines several coexistence mechanisms that can be used to facilitate coexistence of WLAN and WPAN networks. The several coexistence mechanisms defined in this recommended practice are divided into two classes: collaborative and non-collaborative. A collaborative coexistence mechanism can be used when there is a communication link between the WLAN and WPAN networks. This is best implemented when both a WLAN and WPAN device are embedded into the same piece of equipment (e.g., an IEEE 802.11b card and an IEEE 802.15.1 module embedded in the same laptop computer). A non-collaborative coexistence mechanism does not require any communication link between the WLAN and WPAN.

2. References

This recommended practice shall be used in conjunction with the following publications. If the following publications are superseded by an approved revision, the revision shall apply.

IEEE Std 802.11, 1999 Edition (R2003) (ISO/IEC 8802-11: 1999), IEEE Standard for Information Technology—Telecommunications and Information Exchange between Systems—Local and Metropolitan Area Network—Specific Requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.^{3, 4}

IEEE Std 802.11b-1999 (Supplement to ANSI/IEEE Std 802.11, 1999 Edition), Supplement to IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-Speed Physical Layer Extension in the 2.4 GHz Band.

IEEE Std 802.15.1-2002, IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 15.1: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs™).

²The term “selected wireless devices” includes the following: a) Other 802 devices, and b) other wireless devices in the international marketplace operating in the same frequency band as an IEEE 802.15 WPAN. We will limit our scope to dealing with devices that have usage scenarios that assume IEEE 802.15 devices will coexist with these selected and that we are able to obtain technical specification on these selected devices.

³IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>)

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3. Definitions, terms, acronyms, abbreviations, terminology, and variables

For the purposes of this recommended practice, the following subclauses contain the applicable definitions and terms; acronyms and abbreviations; and terminology and variables. *The Authoritative Dictionary of IEEE Standards Terms, Seventh Edition* [B12] should be referenced for terms not defined in this clause.

3.1 Definitions and terms

3.1.1 backward compatible: The ability of one “new” system to interwork with another “old” system. In this case the different set of rules implies that the new set of rules is a modification of the old set of rules. A subset of interworking.

3.1.2 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.

3.1.3 coexistence mechanism: A method for reducing the interference of one system, which is performing a task, on another different wireless system, that is performing its task.

3.1.4 collaborative coexistence mechanism: A coexistence mechanism in which the two systems shall exchange information.

3.1.5 collocation: When two devices’ antennas are positioned less than 0.5 meters apart.

3.1.6 conformance: The ability of a system to follow a single set of rules.

3.1.7 connection-oriented: Data transmission in which the information-transfer phase is preceded by a call-establishment phase and followed by a call-termination phase. (See Weik [B17].)

3.1.8 frequency-hopping: A technique in which the instantaneous carrier frequency of a signal is periodically changed, according to a predetermined code, to other positions within a frequency spectrum that is much wider than that required for normal message transmission. (See Weik [B17].)

3.1.9 interference: In a communication system, extraneous power entering or induced in a channel from natural or man-made sources that might interfere with reception of desired signals or the disturbance caused by the undesired power. (See Weik [B17].)

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

3.1.11 interworking: The ability of two systems to perform a task given that each system implements a different set of rules.

3.1.12 medium sharing element: Defines how IEEE 802.11 traffic and non-IEEE 802.11 traffic share access to the medium.

3.1.13 multipath fading: Fading due to the propagation of an electromagnetic wave over many different paths, dissipating energy and causing distortion, particularly by signal cancellation at the destination because of differences in arrival time due to the different paths. (See Weik [B17].)

3.1.14 non-collaborative coexistence mechanism: A coexistence mechanism in which the two systems shall not exchange information.

3.1.15 operable: The ability of a system to perform the functions as expected.

3.1.16 period of stationarity: The time period over which the parameters defining the transmissions of the devices being modeled do not change.

3.1.17 propagation: The movement or transmission of a wave in a medium or in free space, usually described in terms of phase or group velocity. (See Weik [B17].)

3.1.18 spread spectrum: A communication technique in which the information-modulated signal is transmitted in a bandwidth that is considerably greater than the frequency content of the original information. (See Weik [B17].)

3.1.19 synchronous: Pertaining to events that occur at the same time or at the same rate. (See Weik [B17].)

3.1.20 synchronous connection-oriented link: A point-to-point link between a master and a single slave in the piconet.

3.2 Acronyms and abbreviations

ACL	asynchronous connectionless
ACK	acknowledgement packet
AFH	adaptive frequency-hopping
AP	access point
ARQ	automatic repeat request
AWGN	additive white Gaussian noise
AWMA	alternating wireless medium access
BER	bit error rate
BPF	bandpass filter
BPSK	binary phase shift keying
CCA	clear channel assessment
CCK	complementary code keying
CRC	cyclic redundancy check
CSMA/CA	carrier sense multiple access with collision avoidance
CW	contention window
DBPSK	differential binary phase shift keying
DCF	distributed coordination function
DIFS	distributed (coordination function) interframe space
DQPSK	differential quadrature phase shift keying
DSSS	direct sequence spread spectrum
FCS	frame check sequence
FEC	forward error correction
FH	frequency-hopping
FHSS	frequency-hopping spread spectrum
GFSK	Gaussian frequency shift keying
GLRT	generalized likelihood-ratio test
HEC	header error check
ICR	interference collision ratio
I&D	integrate and dump
LAP	lower address parts
LD	limiter-discriminator
LDI	limiter-discriminator with integrate and dump
LMP	link manager protocol
L2CAP	logical link control and adaptation protocol
MAC	medium access control
MIB	management information base

MLME	MAC sublayer management entity
MPDU	MAC protocol data unit
MSE	medium sharing element
PCF	point coordination function
PER	packet error rate
PHY	physical
PLCP	physical layer convergence protocol
PN	pseudorandom noise (e.g., PN code sequence)
PPDU	physical protocol data unit
PSDU	physical service data unit
PTA	packet traffic arbitration
QoS	quality of service
QPSK	quadrature phase shift keying
RF	radio frequency
RLSL	recursive least-squares lattice
RSSI	received signal strength indication
RX	receive/receiver/receiving
SCO	synchronous connection-oriented
SER	symbol error rate
SINR	signal to interference plus noise ratio ($s/(i+n)$)
SIFS	short interframe space
SIR	signal to interference ratio (s/i)
SNR	signal to noise ratio (s/n)
STA	station
TBTT	target beacon transmit time
TDMA	time-division multiple access
TU	time unit (as defined in IEEE Std 802.11, 1999 Edition)
TX	transmit/transmitter/transmission
UAP	upper address parts
WLAN	wireless local area network
WPAN	wireless personal area network

3.3 Terminology and variables⁵

Packet: Is used consistently through this recommendation to mean “medium access control (MAC) frame” in the context of IEEE 802.11 and “baseband packet” in the context of IEEE 802.15.1.

Packet error rate: The probability of a packet being received with one or more uncorrected bit errors.

⁵The terminology and variables listed in this subclause are only applicable within this recommended practice. Application of these outside of this recommended practice is not applicable. This is why they have their own subclause within this clause.

f_{adp}	next adapted hop-frequency, f_{adp} is an element of S_G or f_{adp} is an element of S_{BK}
f_{hop}	next hop-frequency from the IEEE 802.15.1 hop kernel, f_{hop} is indexed by an element of $[0, ..., 78]$
k_{hop}	index that points to the next hop-frequency
N_B	number of “bad” channels ($N_B = S_B $)
N_{BK}	number of “bad” channels kept in the adapted hopping sequence ($N_{BK} = S_{BK} $)
N_{BR}	number of “bad” channels removed from the adapted hopping sequence ($N_{BR} = S_{BR} $)
N_G	number of “good” channels ($N_G = S_G $)
N_{min}	minimum number of hop channels (typically set by regulatory constraints)
$p(k)$	partition sequence
S	set of all channels = S_G union S_{BK} union $S_{BR} = S_G$ union S_B
S_B	set of “bad” channels (or indices pointing to the “bad” channels)
S_{BK}	set of “bad” channels (or indices) kept in the adapted hopping sequence
$S_{BK}(i)$	i -th channel of S_{BK} , i is an element of $[0, ..., N_{BK} - 1]$
S_{BR}	set of “bad” channels (or indices) removed from the adapted hopping sequence
S_G	set of “good” channels (or indices pointing to the “good” channels)
$S_G(i)$	i -th channel of S_G , i is an element of $[0, ..., N_G - 1]$
T_d	time-out delay
T_S	slot time (i.e., 625μs)

4. General descriptions

This clause describes in general terms 1) the issue that this recommended practice attempts to address; 2) the coexistence mechanisms being recommended to reduce the problem and when to use each coexistence mechanism; 3) the models used to evaluate the effects; and 4) an overview to the structure of this recommended practice.

4.1 Description of the interference problem

Because both IEEE Std 802.11b-1999 and IEEE 802.15.1-2002 specify operations in the same 2.4 GHz unlicensed frequency band, there is mutual interference between the two wireless systems that may result in severe performance degradation. There are many factors that effect the level of interference, namely, the separation between the WLAN and WPAN devices, the amount of data traffic flowing over each of the two wireless networks, the power levels of the various devices, and the data rate of the WLAN. Also, different types of information being sent over the wireless networks have different levels of sensitivity to the interference. For example, a voice link may be more sensitive to interference than a data link being used to transfer a data file. This subclause gives an overview of the mutual interference problem. Subsequent subclauses describe the modeling of the mutual interference and give illustrations of the impact of this mutual interference on both the WLAN and WPAN networks.

There are several versions of IEEE 802.11 physical (PHY) layer. All versions of IEEE 802.11 use a common MAC sublayer. When implementing distributed coordination function (DCF) the 802.11 MAC uses carrier sense multiple access with collision avoidance (CSMA/CA) for medium access control. The scope of this recommended practice is limited to DCF implementations of IEEE 802.11, and does not include point coordination function (PCF) implementations. Initially, 802.11 included both a 1- and 2-Mbit/s frequency-hopping spread spectrum (FHSS) PHY layer, as well as a 1- and 2-Mbit/s direct sequence spread spectrum (DSSS) PHY layer. The FHSS PHY layer uses a 1-MHz channel separation and hops pseudo-randomly over 79 channels. The DSSS PHY layer uses a 22 MHz channel and may support up to three non-overlapping channels in the unlicensed band.

Subsequently, the IEEE 802.11 DSSS PHY layer was extended to include both 5.5 and 11 Mbit/s data rates using complementary code keying (CCK). This high-rate PHY layer is standardized to be named IEEE

802.11b. This high-rate version includes four data rates: 1, 2, 5.5, and 11 Mbit/s. The channel bandwidth of the IEEE 802.11b PHY layer is 22 MHz.

The WPAN covered in this recommended practice is IEEE Std 802.15.1-2002, which is a 1-Mbit/s FHSS system. The IEEE 802.15.1 PHY layer uses the same 79, 1 MHz-wide channels that are used by the FHSS version of IEEE 802.11. IEEE 802.15.1 hops pseudo-randomly at a nominal rate of 1600 hops/second. The IEEE 802.15.1 MAC sublayer supports a master/slave topology referred to as a piconet. The master controls medium access by polling the slaves for data and using scheduled periodic transmission for voice packets.

The following is a brief description of the interference problem for each of the three systems: IEEE 802.11 frequency-hopping (FH), IEEE 802.11b, and IEEE 802.15.1.

4.1.1 IEEE 802.11 FH WLAN in the presence of IEEE 802.15.1 interference

The IEEE 802.11 FH WLAN has the same hopping channels as the IEEE 802.15.1 WPAN. However, the two systems operate at very different hopping rates. IEEE 802.11 FH specifies a hopping rate of greater than 2.5 hops/second, with typical systems operating at 10 hops/second. IEEE 802.15.1 specifies a maximum hopping rate of 1600 hops/second for data transfer. So while IEEE 802.11 FH dwells on a given frequency for approximately 100 ms, IEEE 802.15.1 will have hopped 160 times. So the odds are that IEEE 802.15.1 will hop into the frequency used by IEEE 802.11 FH several times while IEEE 802.11 FH is dwelling on a given channel. IEEE 802.11 FH packets will be corrupted by the IEEE 802.15.1 interference whenever IEEE 802.15.1 hops into the channel used by IEEE 802.11 FH, assuming the IEEE 802.15.1 power level is high enough to corrupt the IEEE 802.11 FH packet at the IEEE 802.11 FH receiver. It is also possible for the IEEE 802.11 FH WLAN packet to be corrupted by the IEEE 802.15.1 interference if the IEEE 802.15.1 packet is sent in an adjacent channel to the IEEE 802.11 FH data. For example, if currently IEEE 802.11 FH is using the 2440 MHz channel then the two adjacent channels are at 2439 and 2441 MHz. Usually, there is only limited attenuation in adjacent channels. It is likely that there will be limited interference if the IEEE 802.15.1 WPAN is greater than one channel away from the current IEEE 802.11 FH channel. Whether an IEEE 802.11 packet is corrupted or not depends on how close the IEEE 802.15.1 unit is to the IEEE 802.11 FH unit, because that effects the interference power level.

The IEEE 802.11 MAC sublayer incorporates automatic repeat request (ARQ) to insure reliable delivery of data across the wireless link. So there is little chance that the data will be lost. The impact of interference on the WLAN is that the delivered data throughput decreases and the network latency increases. The application's requirements determine if these degradations are tolerable.

4.1.2 IEEE 802.11b WLAN in the presence of IEEE 802.15.1 interference

The high-rate IEEE Std 802.11b-1999 defines a frequency-static WLAN that supports four data rates: 1, 2, 5.5, and 11 Mbit/s. Most implementations allow manual or automatic modification of the data rate. The higher rates are desirable for many applications but the distance of transmission using the higher rates is less than that of the lower rates. Many implementations automatically scale the data rate to the highest data rate that is sustainable to each WLAN mobile unit.

The bandwidth of IEEE 802.11b is up to 22 MHz. There is a potential packet collision between a WLAN packet and an IEEE 802.15.1 packet when the WPAN hops into the WLAN passband. Since the bandwidth of the IEEE 802.11b WLAN is 22 MHz, as the IEEE 802.15.1 WPAN hops around the unlicensed band, 22 of the 79 IEEE 802.15.1 channels fall within the WLAN passband.

Because there are four data rates defined within IEEE 802.11b, the temporal duration of the WLAN packets may vary significantly for packets carrying the exact same data. The longer the duration of the WLAN packet, the more likely that it may collide with an interfering WPAN packet.

One of the important issues that effects the level of interference is the WLAN automatic data rate scaling. If it is implemented and enabled, it is possible for the WPAN interference to cause the WLAN to scale to a lower data rate. At a lower data rate the temporal duration of the WLAN packets is increased. This increase in packet duration may lead to an increase in packet collisions with the interfering WPAN packets. In some implementations, this may lead to yet a further decrease in the WLAN data rate. This may result in the WLAN scaling down its data rate to 1 Mbit/s.

The IEEE 802.11 MAC sublayer incorporates ARQ to insure reliable delivery of data across the wireless link. So there is little chance that the data will be lost. The effect this has on the WLAN is that the delivered data throughput decreases and the network latency increases. The application's requirements determine if these degradations are tolerable.

4.1.3 IEEE 802.15.1 in the presence of an IEEE 802.11 FH interferer

Both IEEE 802.15.1 and IEEE 802.11 FH use FHSS by using the same 79 channels. Both FH systems are susceptible to interference on the channel in use and the two adjacent channels. Also, because IEEE 802.15.1 uses short packets the packet error rate (PER) in IEEE 802.15.1 in the presence of IEEE 802.11 FH is not very significant.

IEEE 802.15.1 uses two types of links between the piconet master and the piconet slave. For data transfer IEEE 802.15.1 uses an asynchronous connectionless (ACL) link. The ACL link incorporates ARQ to ensure reliable delivery of data. IEEE 802.15.1 voice communications use a synchronous connection-oriented (SCO) link. On account of the SCO link does not support ARQ, there will be some perceivable degradation in voice quality during periods of IEEE 802.11 FH interference. The detailed model described later quantifies the level of PER. The network throughput would decrease and the network latency would increase for IEEE 802.11 FH interference. A large number of errors on a SCO link can cause voice quality degradation.

4.1.4 IEEE 802.15.1 in the presence of an IEEE 802.11b interferer

IEEE 802.15.1 uses FHSS, while IEEE 802.11b uses DSSS and CCK. The bandwidth of IEEE 802.11b is 22 MHz. 22 of the 79 hopping channels available to IEEE 802.15.1 hops are subject to interference. A FH system is susceptible to interference from the adjacent channels as well. This increases the total number of interference channels from 22 to 24. The detailed model, which is described later, quantifies the level of PER based on these assumptions. The IEEE 802.11b is used because it represents a worse interferer than the IEEE 802.11 FH. The results from this scenario for data transfers are that the network throughput would decrease and the network latency would increase, in the presence of IEEE 802.11b interference. The PER for a SCO link may cause voice quality degradation.

4.2 Overview of the coexistence mechanisms

There are two categories of coexistence mechanisms: collaborative and non-collaborative. Collaborative coexistence mechanisms exchange information between two wireless networks. That is in this case a collaborative coexistence mechanism requires communication between the IEEE 802.11 WLAN and the IEEE 802.15 WPAN. Non-collaborative mechanisms do not exchange information between two wireless networks. These coexistence mechanisms are only applicable after a WLAN or WPAN are established and user data is to be sent. These coexistence mechanisms will not help in the process for establishing a WLAN or WPAN.

Both types of coexistence mechanisms are designed to mitigate interference resulting from the operation of IEEE 802.15.1 devices in the presence of frequency static or slow-hopping WLAN devices (for example IEEE 802.11b). Note that interference due to multiple IEEE 802.15.1 devices is mitigated by frequency-hopping. All collaborative coexistence mechanism described in this recommended practice are intended to be used when at least one WLAN station and WPAN device are collocated within the same physical unit.

When collocated, there needs to be a communication link between the WLAN and WPAN devices within this physical unit, which could be a wired connection between these devices or an integrated solution. The exact implementation of this communication link is outside the scope of this recommended practice.

Non-collaborative coexistence mechanisms are intended to be used when there is no communication link between the WLAN and WPAN.

Table 1 shows the coexistence mechanisms listed in this recommended practice. The “Name” column assigns the name of the coexistence mechanism. The “Type” column lists whether it is collaborative or non-collaborative. The “Clause/Annex” column gives the location within this recommended practice where the description of this mechanism may be found.

Table 1—Listing of the coexistence mechanisms

Name	Type	Clause/Annex
Alternating wireless medium access	collaborative	Clause 5
Packet traffic arbitration	collaborative	Clause 6
Deterministic interference suppression	collaborative	Clause 7
Adaptive interference suppression	non-collaborative	Clause 8
Adaptive packet selection	non-collaborative	Clause 9
Packet scheduling for ACL links	non-collaborative	Clause 10
Packet scheduling for SCO links	non-collaborative	Annex A
Adaptive frequency-hopping	non-collaborative	Annex B

4.2.1 Collaborative coexistence mechanisms

The three collaborative coexistence mechanisms defined in this recommended practice consist of two MAC sublayer techniques (see Clause 5 and Clause 6) and one PHY layer technique (see Clause 7). Both MAC sublayer techniques involve coordinated scheduling of packet transmission between the two wireless (WLAN and WPAN) networks. The PHY layer technique is a programmable notch filter in the IEEE 802.11b receiver to notch out the narrow-band IEEE 802.15.1 interferer. These collaborative mechanisms may be used separately or combined with others to provide a better coexistence mechanism.

The collaborative coexistence mechanism provides coexistence of a WLAN (in particular IEEE 802.11b) and a WPAN (in particular IEEE 802.15.1⁶) by sharing information between collocated IEEE 802.11b and IEEE 802.15.1 radios and locally controlling transmissions to avoid interference. These mechanisms are interoperable with legacy devices that do not include these features.

There are two modes of operation and the mode is chosen depending on the network topology and supported traffic. In the first mode, both IEEE 802.15.1 SCO and ACL traffic are supported where SCO traffic is given higher priority than the ACL traffic in scheduling. The second mode is based on time-division multiple

⁶Although this recommended practice consistently references IEEE 802.15.1, and not Bluetooth®, the mechanism is equally applicable to both IEEE 802.15.1 and Bluetooth®.

access and is used when there is ACL traffic in high piconet density areas. In time-division multiple access (TDMA) mode, the IEEE 802.11b beacon-to-beacon interval is subdivided into two subintervals: one subinterval for IEEE 802.11b and other subinterval for IEEE 802.15.1. Since each radio has its own subinterval, both radios will operate properly, due to total orthogonality. This technique does require an additional feature to restrict when the IEEE 802.15.1 master transmits. The mode to be used is chosen under the command of the access point (AP) management software. Frequency nulling may be used in conjunction with these modes to further reduce interference.

Both alternating wireless medium access (AWMA) and packet traffic arbitration (PTA) may be combined to produce a better coexistence mechanism. This is not described in detail, but in Figure 1 the overall structure of the combined collaborative coexistence mechanisms is shown.

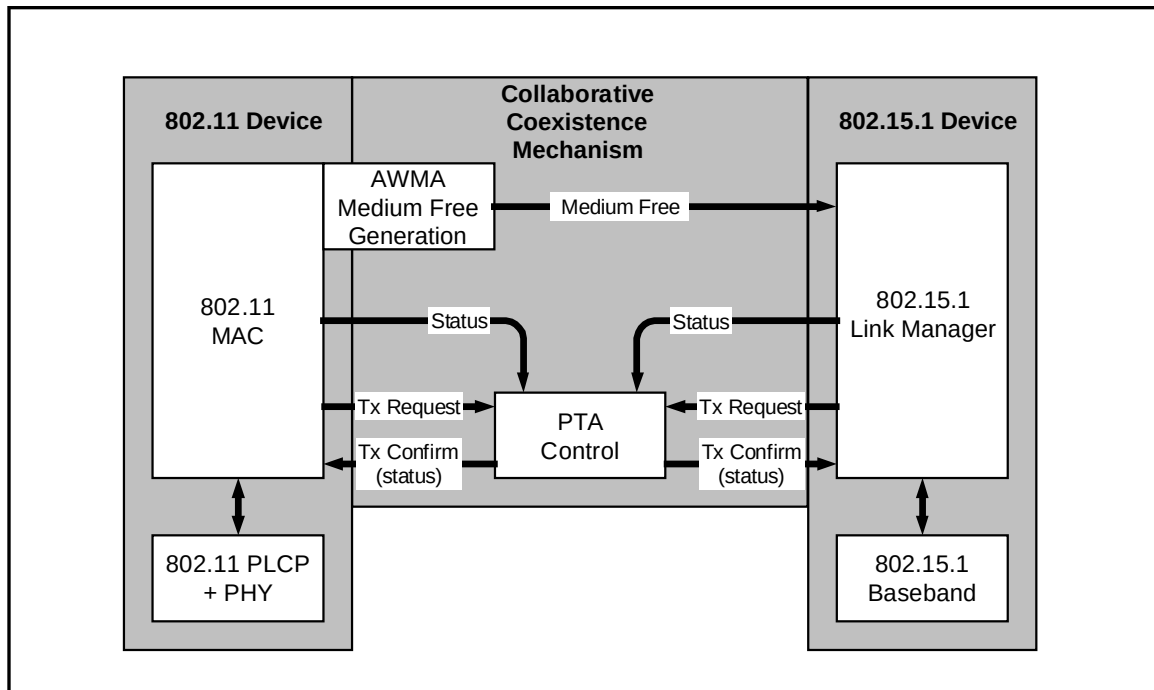


Figure 1—Overall structure of 802.11b / 802.15.1 combined AWMA and PTA collaborative coexistence mechanism

4.2.2 Recommendations on the utilization of collaborative coexistence mechanisms

It is recommended that when it is possible, or necessary, to collocate a WLAN and WPAN device within the same physical unit (e.g., laptop computer), that either the AWMA collaborative coexistence mechanism or the PTA collaborative coexistence mechanism be used. If the PTA mechanism is used it is also recommended that the deterministic interference suppression mechanism be used in concert with the PTA mechanism. While PTA can be used without deterministic interference suppression, the combination of the two mechanisms leads to increased WLAN/WPAN coexistence.

If there is a high density of physical units incorporating both a WLAN and WPAN device in a common area (greater than or equal to three units in a circle of radius 10 meters) and WPAN SCO link (voice link) is not being utilized, then it is recommended that the AWMA mechanism be used. If the density of units incorporating both the WLAN and WPAN devices is low (less than three units in a circle with a radius of 10 meters), or the WPAN SCO link is used, then it is recommended that the PTA mechanism be used in concert with the deterministic interference suppression mechanism.

4.2.3 Non-collaborative coexistence mechanisms

This recommended practice describes several methods (See Clause 8, Clause 9, and Clause 10) that enhance the performance of the IEEE 802.15.1 and IEEE 802.11 networks through the use of adaptive interference suppression of IEEE 802.11b devices, adaptive packet selection, and packet scheduling for ACL links. These methods do not require the collaboration between the IEEE 802.11 devices and the IEEE 802.15.1 devices. Therefore, they belong to the general category of non-collaborative coexistence mechanisms.

Two other methods [packet scheduling for SCO links and adaptive frequency-hopping (AFH) for the IEEE 802.15.1 devices] are provided as information in Annex A and Annex B, respectively.

The key idea for adaptive packet selection and scheduling methods is to adapt the transmission according to channel conditions. For instance, if the channel is dominated by interference from an IEEE 802.11b network, the PER will be mainly due to collisions between IEEE 802.15.1 and IEEE 802.11 systems, instead of bit errors resulting from noise. Packet types that do not include forward error correction (FEC) protection could provide better throughput if combined with intelligent packet scheduling. The foundation for the effectiveness of these types of methods is to be able to figure out the current channel conditions accurately and in a timely manner. Channel estimation may be done in a variety of ways: received signal strength indication (RSSI), header error check (HEC) decoding profile, bit error rate (BER) and PER profile, and an intelligent combination of all of the above (see Clause 11).

There are five non-collaborative mechanisms described in this recommended practice. At least two of these share a common function called channel classification, which is contained in a separate clause under that heading. Three mechanisms are covered under the second item (b) in the following list:

- a) *adaptive interference suppression.* A mechanism based solely on signal processing in the physical layer of the WLAN.
- b) *adaptive packet selection and scheduling.* IEEE 802.15.1 systems utilize various packet types with varying configurations such as packet length and degree of error protection used. By selecting the best packet type according to the channel condition of the upcoming frequency hop, better data throughput and network performance may be obtained. In addition, by carefully scheduling packet transmission so that the IEEE 802.15.1 devices transmit during hops that are outside the WLAN frequencies and refrain from transmitting while in-band, interference to WLAN systems could be avoided/minimized and at the same time increase the throughput of the IEEE 802.15.1 systems.
- c) *adaptive frequency-hopping (AFH).* IEEE 802.15.1 systems frequency hop over 79 channels (in the U.S.) at a nominal rate of 1600 hops/second in connection state, and 3200 hops/second in inquiry and page states. By identifying the channels with interference, it is possible to change the sequence of hops such that those channels with interference (“bad” channels) are avoided. From traffic type and channel condition, a partition sequence is generated as input to the frequency re-mapper, which modifies hopping frequencies to avoid or minimize interference effects.

4.2.4 Recommendations on the utilization of non-collaborative coexistence mechanisms

When it is not possible, or necessary, to collocate a WLAN and WPAN device within the same physical unit, then a non-collaborative coexistence mechanism may be the only practical method. There are possible range limitations under which a non-collaborative mechanism may not be sufficient, however. For example, when an IEEE 802.11b system and an IEEE 802.15.1 system (Class 3) are operated 30 centimeters apart, the IEEE 802.15.1 signal will be considerably above the detection threshold of the WLAN system, even when out of band; thus, non-collaboration schemes relying on channel estimation and interference detection will be unable to prevent interference in these short range situations.⁷

⁷Class 3 IEEE 802.15.1 is 0dBm. Free space path loss at 30 centimeters is 30dB. The IEEE 802.11b specification requires 35dB of attenuation outside of the desired passband, and a minimum detection sensitivity of -76dBm at 11Mbit/s. Even when out of band, the IEEE 802.15.1 signal will be at least 11dB above the detection threshold, which will significantly degrade IEEE 802.11b reception.

The non-collaborative mechanisms considered range from adaptive frequency-hopping to packet scheduling and traffic control. They all use similar techniques for detecting the presence of other devices in the band such as measuring the packet or frame error rate, the signal strength or the signal to interference ratio (often implemented as the RSSI).

For example, each device can maintain a frame error rate measurement per frequency used. FH devices can then infer which frequencies are occupied by other users of the band and thus modify their frequency hopping pattern. They can even choose not to transmit on a certain frequency if that frequency is inferred to be occupied.

MAC sublayer packet selection mechanisms consider encapsulation rules and use the variety of IEEE 802.15.1 packet lengths to avoid overlap in frequency between IEEE 802.11 and IEEE 802.15.1. In other words, the IEEE 802.15.1 scheduler knows to use the packet length of proper duration (1, 3, or 5 slots) in order to skip the so-called “bad” frequency.

It is recommended that AFH be used when appropriate changes to the IEEE Std 802.15.1-2002 hopping sequence have been implemented.

Furthermore, it is recommended that interference aware packet scheduling and traffic control mechanisms be implemented. These mechanisms can be implemented either separately or in combination with other coexistence schemes such as AWMA, PTA, or AFH for additional performance improvements.

It is recommended that adaptive interference suppression be used with all of the above-mentioned mechanisms because it operates at the physical layer; it can also be used by itself. It is recommended that the adaptive interference suppression filter be used when there is sufficient IEEE 802.15.1 interference to noticeably degrade performance and delaying the IEEE 802.11 traffic is not sufficient. Specifically, delay sensitive traffic such as streaming media will benefit from the use of this mechanism.

4.3 Interference model

The coexistence modeling approach used is based on detailed simulation models for the radio frequency (RF) channel and the MAC sublayer that were developed using OPNET Modeler⁸ and the PHY layers that were developed in ANSI C⁹.

The PHY layer models for the IEEE 802.15.1 and IEEE 802.11 transceivers are based on models developed in ANSI C. The MAC sublayer models interface with these PHY layer models, and the integrated MAC and PHY layer simulation models constitute an evaluation framework that is critical to studying the various intricate effects between the MAC sublayer and PHY layer. Although interference is typically associated with the RF channel modeling and measured at the PHY layer, it may significantly impact the performance of higher layers. Changes in the behavior of the MAC sublayer protocol and the associated data traffic distribution impact the interference scenario and the overall system performance.

The physical layer models, source code for the physical layer analytical model, MAC sublayer models, data traffic models, performance metrics, and the coexistence modeling results, are all contained in separate informative annexes (See Annex C, Annex D, Annex E, Annex F, Annex G, and Annex H).

⁸The OPNET Modeler®, a network technology development environment, is a software application provided by OPNET Technologies, Inc.™. More info: <http://www.opnet.com/products/modeler/home.html>. The use of OPNET Technologies product to prepare this recommended practice does not constitute an endorsement of OPNET Modeler® by the IEEE LAN/MAN Standards Committee or by the IEEE.

⁹ANSI X3.159-1989 Standard C (ISO/IEC 9899:1990).

4.4 Overview of the recommended practice

The layout of the recommended practice consists of an individual clause or informative annex for each coexistence mechanism. The collaborative coexistence mechanisms are described first followed by the non-collaborative coexistence mechanisms. A clause devoted to channel classification ends the normative clauses. Finally numerous informative annexes are included that provide other coexistence mechanisms, performance or simulation results supporting a particular coexistence mechanism, and some other background information.

The numerous informative annexes contain: a non-collaborative coexistence mechanism for packet scheduling for SCO links, AFH, performance results for AWMA, PTA, deterministic- and adaptive- interference suppression, the theoretical coexistence models; experimental validation of models; the PHY layer models between IEEE Std 802.11, 1999 Edition and IEEE Std 802.15.1-2002 and their related RF channel models under various characteristics; the MAC sublayer models for IEEE Std 802.11, 1999 Edition and IEEE Std 802.15.1-2002; their related various data traffic models; the performance metrics used to evaluate the results of simulations; the results of the coexistence modeling; and the bibliography.

5. Alternating wireless medium access

AWMA utilizes a portion of the wireless IEEE 802.11 beacon interval for wireless IEEE 802.15 operations. From a timing perspective, the medium assignment alternates between usage following IEEE 802.11 procedures and usage following IEEE 802.15 procedures. Each wireless network restricts their transmissions to the appropriate time segment, which prevents interference between the two wireless networks.

In AWMA, a WLAN radio and a WPAN radio are collocated in the same physical unit. This allows for a wired connection between the WLAN radio and the WPAN radio. This wired communication link is used by the collaborative coexistence mechanism to coordinate access to the wireless medium, between the WLAN and WPAN.

The AWMA mechanism uses the shared clock within all the WLAN-enable devices and thus all WLAN devices connected to the same WLAN AP share common WLAN and WPAN time intervals. Therefore, all devices connected to the same AP restrict their WLAN traffic and WPAN traffic to non-overlapping time intervals. As such, there will be no WLAN/WPAN interference for any devices connected to the same WLAN AP. In the case of multiple APs, typically the APs are not synchronized. In that case there will be some residual interference between WPAN devices synchronized with on WLAN AP and WLAN devices synchronized with another AP. If the WLAN APs are synchronized then this residual interference can also be eliminated. Additional description of this synchronization issue is given in 5.1.

The IEEE 802.11 WLAN AP sends out a beacon at a periodic interval. The beacon period is T_B . AWMA subdivides this interval into two subintervals: one for WLAN traffic and one for WPAN traffic. Figure 2 illustrates the separation of the WLAN beacon interval into two subintervals. The WLAN interval begins at the WLAN target beacon transmit time (TBTT). The length of WLAN subinterval is T_{WLAN} , which is specified in the offset field of the medium sharing element (MSE) in the beacon. The WPAN subinterval begins at the end of the WLAN interval. The length of the WPAN subinterval is T_{WPAN} , which is specified in the duration field of the MSE in the beacon. The combined length of these two subintervals shall not be greater than the beacon period.

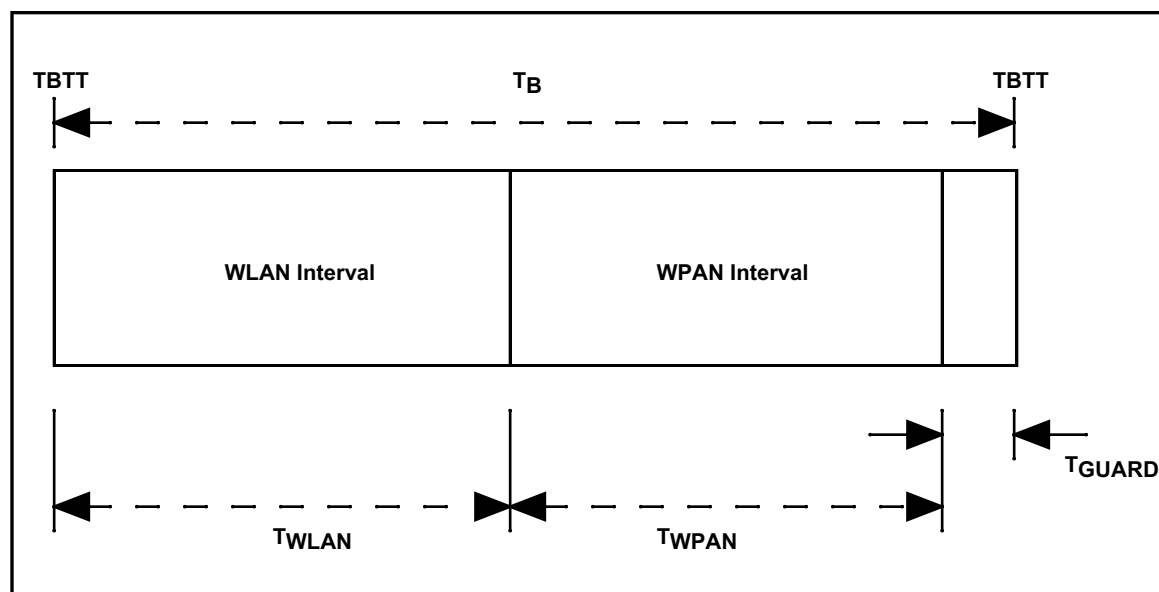


Figure 2—Timing of the WLAN and WPAN subintervals

The MSE in the beacon may also specify a guard band (T_{GUARD}) by setting a non-zero value in the guard field. The purpose of this guard band is to specify an interval immediately preceding the next expected beacon (i.e., TBTT) that is to be free of WPAN traffic. This guard band may be necessary to guarantee that all WPAN traffic has completed by the WLAN beacon time (i.e., before the next beacon needs to be sent).

If the offset field in the MSE of the beacon is greater than the beacon period, no WPAN subinterval shall exist. If the total value of the offset field and the duration field is greater than the beacon time, T_{WPAN} shall end at the next TBTT.

If the guard field in the MSE of the beacon is non-zero, and the beacon period minus the total value of the offset field and the duration field is less than the value of the guard field, T_{WPAN} shall end the value of the guard field prior to the next TBTT.

If the value in the offset field of the MSE is less than the beacon interval but the value of the offset field plus the value of the guard field is equal to or greater than the beacon interval, there shall be no WPAN subinterval.

Table 2 shows the range of values for these timers.

Table 2—Allowed range of values for T_{WPAN} and T_{GUARD}

Value	Minimum (TU)	Maximum (TU)
T_{WPAN}	0	32
T_{GUARD}	0	10

It is recommended to use AWMA whenever there is a high density of devices with collocated WLAN/WPAN radios. The AWMA mechanism not only eliminates interference between the collocated WLAN/WPAN radios, but also the radios in other nearby devices. The AWMA mechanism is also to be used when the WLAN and/or WPAN network bandwidth allocation needs to be deterministically controlled and not dependent on the traffic load of either the WLAN or WPAN.

Annex I provides information on the performance of WLAN and WPAN utilizing AWMA.

5.1 WLAN/WPAN synchronization

AWMA requires that a WLAN node and the WPAN master are collocated in the same physical unit (e.g., both within a single laptop computer). AWMA requires the WLAN node to control the timing of the WLAN and WPAN subintervals. All WLAN nodes connected to the same AP are synchronized, and hence have the same TBTT. As a result all units that implement AWMA have synchronized WLAN and WPAN subintervals. The WLAN node is required to send a physical synchronization signal to the WPAN master, which is in the same physical unit as the WLAN node. That synchronization signal specifies both the WLAN interval and the WPAN interval. This synchronization signal is called the medium free signal. Therefore, the medium is free of WLAN traffic when the medium free signal is true. Figure 3 illustrates the medium free signal.

The AWMA coexistence mechanism prevents interference between IEEE 802.11b and IEEE 802.15.1 by scheduling transmissions so that the WLAN and the WPAN radios do not transmit at the same time. For this mechanism to prevent interference between a WLAN and a WPAN device the two radios must be synchronized. There are three cases to consider in AWMA. They are the following:

- a) The first case is when the WLAN and WPAN radios are collocated in the same physical device. These radios can easily be synchronized because they are in the same physical unit. This synchronization is implemented using the medium free signal sent from the WLAN radio to the collocated WPAN radio.
- b) The second case is any WPAN device in the piconet with the collocated WPAN radio and any WLAN radio connected to the same AP as the collocated WLAN radio. Within the piconet all of the WPAN devices are synchronized to a common clock. Also, all of the WLAN stations attached to the same AP are also synchronized. The two sets of radios (WPAN piconet and the set of WLAN stations connected to the same AP) are all synchronized through the medium free signal sent between the collocated WLAN and WPAN radios. Therefore, in this case interference is also prevented because all these radios are synchronized.
- c) The third case is that of a piconet device with the collocated WPAN and any WLAN station that is connected to a different AP than the collocated WLAN station. In this case the WPAN radio and the WLAN radio are not synchronized because the two APs are not synchronized. This situation can occur at the border between two WLAN cells, one cell covered by one AP and the other cell covered by the other AP. However, this third case can also be addressed by synchronizing the APs. This synchronization can be implemented by sending synchronization messages to the APs over the WLAN distribution medium. The implementation of the synchronization of WLAN APs is outside the scope of this recommended practice because this may be accomplished at higher layers.

An implementation of AWMA does not require synchronization of WLAN APs. If this AP synchronization is not implemented, interference is still prevented for the first two cases. However, the third case of WPAN/WLAN interference is not prevented. The interference in the third case is likely much lower than in the first case because the WLAN and the WPAN are not collocated in the same physical device. Therefore, this limitation with unsynchronized APs is not significant.

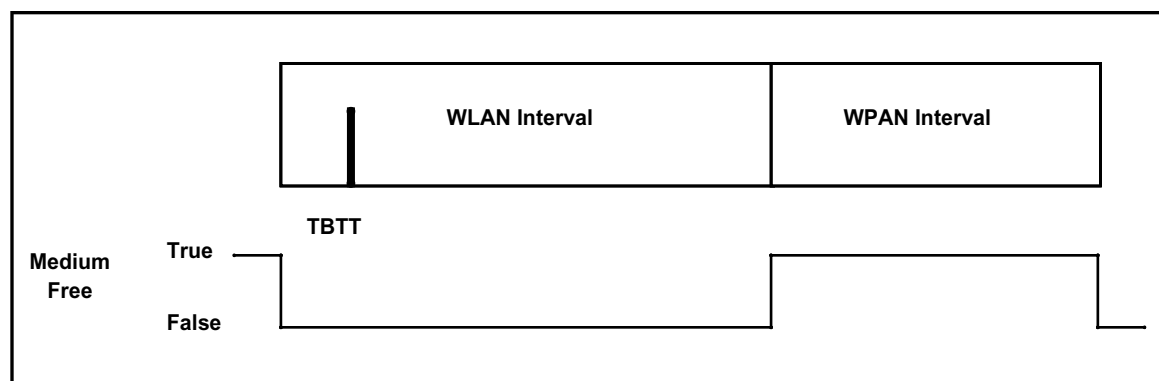


Figure 3—Medium free signal

5.2 Management of AWMA

Management of the AWMA coexistence mechanism is handled over the IEEE 802.11 network utilizing the MSE in the IEEE 802.11 beacon. The description of the time sharing values is given in Clause 5. The format of the MSE beacon element is as shown in Table 3.

It is assumed that a device will be reset after setting any of these new parameters using the MAC sublayer management entity (MLME) primitives and before any of the settings of the new parameters are applied.

Table 3—Medium sharing element format

	Element ID	Element length	Offset (T_{WLAN})	Length (T_{WPAN})	Guard (T_{GUARD})
Octets:	1	1	2	2	2

The Offset, Length, and Guard fields are integer values specifying times in units of TU. Offset contains T_{WLAN} . Length contains T_{WPAN} . Guard contains T_{GUARD} .

5.2.1 MLME-AWMAParameters.request

This primitive sets the value of the AWMA timing parameters: WLANInterval (T_{WLAN}) and WPANInterval (T_{WPAN}).

5.2.2 Semantics of the service primitive

MLME-AWMAParameters.request

```
(
    WLANInterval,
    WPANInterval,
    WGUARDInterval
)
```

The descriptions of these parameters are shown in Table 4.

Table 4—Description of parameters for MLME-AWMAPARAMETERS.request

Name	Type	Valid range	Description
WLANInterval	Integer	>0	The duration (in time units) of the WLAN interval
WPANInterval	Integer	>=0	The duration (in time units) of the WPAN interval
WGUARDInterval	Integer	>=0	The duration (in time units) of the WGUARD interval

The sum of WLANInterval and WPANInterval shall not be greater than the IEEE 802.11 beacon interval.

5.2.2.1 When generated

This primitive is generated by the station management entity to set the AWMA timing parameters.

5.2.2.2 Effect of receipt

This request sets the AWMA timing parameters (T_{WLAN} , T_{WPAN} , and T_{GUARD}) in the station upon receipt of this primitive.

5.2.3 MLME-AWMAPARAMETERS.confirm

This primitive confirms setting the AWMA timing parameters.

5.2.3.1 Semantics of the service primitive

MLME-AWMAPARAMETERS.confirm

```
(
    ResultCode
)
```

The description of this parameter is shown in Table 5.

Table 5—Description of the parameter for MLME-AWMAPARAMETERS.confirm

Name	Type	Valid range	Description
ResultCode	Enumeration	SUCCESS, INVALID_PARAMETERS, NOT_SUPPORTED	Indicates the result of the MLME-AWMAPARAMETERS.request

5.2.3.2 When generated

This primitive is generated by the MLME as a result of the MLME-AWMAPARAMETERS.request to set the AWMA timing parameters. It is not generated until the timing parameters have been set.

5.2.4 MLME-AWMAENABLE.request

This primitive either enables or disables the AWMA coexistence mechanism.

5.2.4.1 Semantics of the service primitive

MLME-AWMAENABLE.request

```
(  
    Enable  
)
```

The description of this parameter is shown in Table 6.

Table 6—Description of the parameter for MLME-AWMAENABLE.request

Name	Type	Valid range	Description
Enable	Boolean	TRUE or FALSE	TRUE enables AWMA operation. FALSE disables AWMA operation.

5.2.4.2 When generated

This primitive is generated by the station management entity to enable (or disable) AWMA operation.

5.2.4.3 Effect of receipt

This request enables or disables AWMA operation in the station upon receipt of this primitive. The AWMA timing parameters are not effected.

5.2.5 MLME-AWMAENABLE.confirm

This primitive confirms enabling or disabling AWMA operation.

5.2.5.1 Semantics of the service primitive

MLME-AWMAENABLE.confirm

```
(  
    ResultCode  
)
```

The description of this parameter is shown in Table 7.

Table 7—Description of the parameter for MLME-AWMAENABLE.confirm

Name	Type	Valid range	Description
ResultCode	Enumeration	SUCCESS, FAILURE, NOT_SUPPORTED	Indicates the result of MLME-AWMAENABLE.request

5.2.5.2 When generated

This primitive is generated by the MLME as a result of the MLME-AWMAENABLE.request to enable or disable AWMA operation. It is not generated until AWMA operation has been either enabled or disabled. A FAILURE is sent if the AWMA timing parameters have not previously been set by a MLME-AWMA-PARAMETERS.request.

5.2.6 Additional management information base definition

To support AWMA the IEEE 802.11 management information base (MIB) needs to be augmented with the following station management attributes.

5.2.6.1 agAWMAgrp

WLANInterval,

WPANInterval,

WGUARDInterval,

Enabled;

5.2.6.2 Station management attribute group templates

AWMAgrp ATTRIBUTE GROUP

GROUP ELEMENTS

WLANInterval,

WPANInterval,

WGUARDInterval,

Enabled;

REGISTERED AS FOLLOWS:

```
{ iso(1) member-body(2) us(840) ieee802dot11(10036) SMT(1) attributeGroup(8) AWMAgrp(1) };
```

5.2.6.3 WLANInterval

WLANInterval ATTRIBUTE

BEHAVIOR DEFINED AS FOLLOWS:

This attribute is the duration of the WLAN interval (in time units) used in AWMA.

REGISTERED AS FOLLOWS:

{ iso(1) member-body(2) us(840) ieee802dot11(10036) SMT(1) attribute(7) StationID(1) };

5.2.6.4 WPANInterval

WPANInterval ATTRIBUTE

BEHAVIOR DEFINED AS FOLLOWS:

This attribute is the duration of the WPAN interval (in time units) used in AWMA.

REGISTERED AS FOLLOWS:

{ iso(1) member-body(2) us(840) ieee802dot11(10036) SMT(1) attribute(7) StationID(1) };

5.2.6.5 WGUARDInterval

WGUARDInterval ATTRIBUTE

BEHAVIOR DEFINED AS FOLLOWS:

This attribute is the duration of the WGUARD interval (in time units) used in AWMA.

REGISTERED AS FOLLOWS:

{ iso(1) member-body(2) us(840) ieee802dot11(10036) SMT(1) attribute(7) StationID(1) };

5.2.6.6 Enabled

Enabled ATTRIBUTE

BEHAVIOR DEFINED AS FOLLOWS:

This attribute indicates whether AWMA is enabled (true) or disabled (false).

REGISTERED AS FOLLOWS:

{ iso(1) member-body(2) us(840) ieee802dot11(10036) SMT(1) attribute(7) StationID(1) };

5.2.7 Frame formats

This subclause contains the modifications (i.e., additions) required in IEEE Std 802.11, 1999 Edition to accommodate these changes for coexistence.

5.2.7.1 Beacon frame format

Add a row and the accompanying note to Table 5 of IEEE Std 802.11b-1999 that is shown here as Table 8 and Note 6.

Table 8—Beacon frame body

Order	Information	Note
49	Media Sharing	6

Note 6—The Media Sharing information element is only present within Beacon frames generated by APs supporting Media Sharing.

5.2.7.2 Probe response frame format

Add a row and accompanying note to Table 12 of IEEE Std 802.11b-1999 that is shown here as Table 9 and Note 11.

Table 9—Probe response frame body

Order	Information	Note
49	Media sharing	11

Note 11—The media sharing information element is only present within Probe response frames generated by APs supporting media sharing.

5.2.7.3 Information elements

Add the following element, Media Sharing, with the value 49, assigned by the Naming Authority, and modify the Reserved value range accordingly in Table 20 (Element IDs) of IEEE Std 802.11b-1999.

5.3 Restriction on WLAN and WPAN transmissions

If AWMA is enabled on a device, then it is required that all WLAN transmissions are restricted to occur during the WLAN subinterval. Similarly, all WPAN transmissions are restricted to the WPAN subinterval. The WLAN mobile units and the WLAN AP all share a common TBTT, so along with shared knowledge of the value of T_{GUARD} and T_{WLAN} , all AWMA enabled WLAN devices shall restrict their transmissions to be within the common WLAN subinterval.

The WPAN device collocated with the WLAN node shall be a WPAN master device. In particular, if the WPAN device conforms to IEEE 802.15.1, then all ACL data transmissions are controlled by the WPAN master. In particular, WPAN slaves may only transmit ACL packets if in the previous time slot the WPAN slave received an ACL packet. Therefore, the WPAN master shall end transmission long enough before the end of the WPAN subinterval so that the longest slave packet allowed (e.g., a five-slot IEEE 802.15.1 packet) will complete its transmission prior to the end of the WPAN interval. Figure 4 illustrates the timing requirement. The value of T_M shall be large enough so as to ensure that the value of T_S is greater than zero.

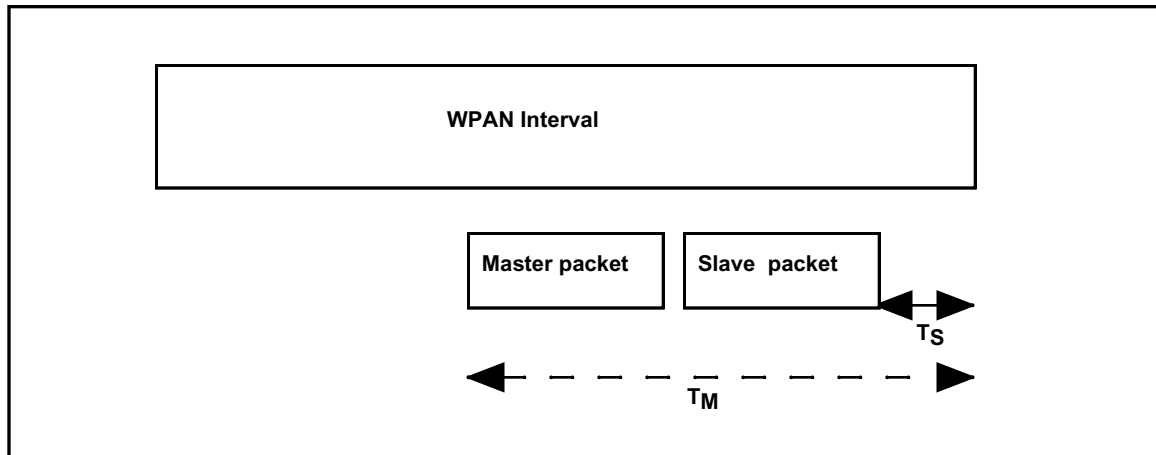


Figure 4—Timing of WPAN packets

IEEE 802.15.1 supports SCO packets, for voice traffic. These packets occur on a regular basis with a fixed period. There are several SCO packet types, depending on the level of FEC. For example, an HV3 link repeats every 6 slots. The first two slots are used for SCO packets and the last four packets may either be used for ACL packets or remain unused time slots. In IEEE 802.15.1 a time slot is $0.625 \mu\text{s}$ and the SCO HV3 period is $3.75 \mu\text{s}$. This is a small fraction of the typical WLAN beacon period. As a result if the WLAN beacon period is subdivided into two subintervals, the WPAN SCO packets may not be restricted to the WPAN interval. As a result the AWMA coexistence mechanism does not support IEEE 802.15.1 SCO links.

The WLAN shall also restrict all WLAN transmission to the WLAN subinterval. Figure 5 illustrates the timing of WLAN traffic. Before a WLAN device may transmit a packet it shall ensure that the value T_S is greater than zero. The WLAN shall calculate T_S as follows:

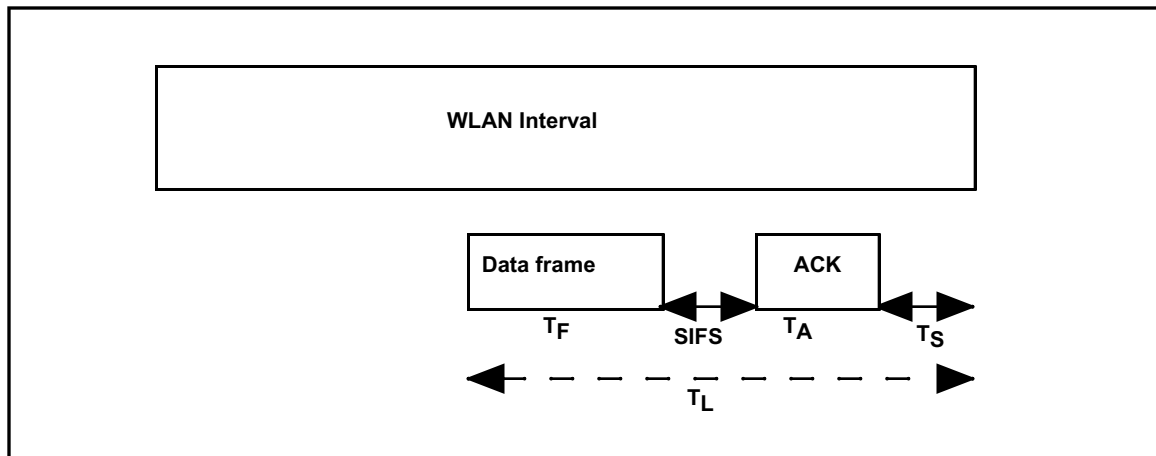


Figure 5—Timing of WLAN packets

$$T_S = T_L - T_F - \text{SIFS} - T_A \quad (1)$$

where

- T_L is the time until the end of the WLAN interval,
- T_F is the length of the frame to be sent,

SIFS is the short interframe space (SIFS) in the WLAN, and
 T_A is the length of the acknowledgement packet (ACK).

As long as T_S is greater than zero, the WLAN may send the frame. If not, it shall defer transmission until the next WLAN subinterval.

6. Packet traffic arbitration

The PTA control entity provides per-packet authorization of all transmissions. In the PTA mechanism, the IEEE 802.11b station (STA) and IEEE 802.15.1 node are collocated. Each attempt to transmit by either the IEEE 802.11b or the IEEE 802.15.1 is submitted to PTA for approval. PTA may deny a transmit request that would result in collision. The PTA mechanism may support IEEE 802.15.1 SCO links.

The PTA mechanism coordinates sharing of the medium dynamically, based on the traffic load of the two wireless networks.

PTA uses its knowledge of the duration of IEEE 802.11b activity and future IEEE 802.15.1 activity of a number of slots into the future to predict collisions. When a collision would occur, PTA prioritizes transmissions based on simple rules that depend on the priorities of the various packets.

It is recommended to use PTA whenever there is a high variability in the WLAN and WPAN traffic load or whenever an IEEE 802.15.1 SCO link needs to be supported. The PTA mechanism uses a dynamic packet scheduling mechanism that automatically adapts to changes in traffic loads over the WLAN and WPAN networks. The PTA mechanism supports IEEE 802.15.1 SCO links while the AWMA mechanism does not.

Annex J contains information on the performance results for PTA and IEEE 802.11b.

6.1 Known physical layer characteristics

The IEEE 802.11b PHY layer operates on a known frequency-static channel. The IEEE 802.15.1 PHY layer hops following a known hopping pattern. At any time, the IEEE 802.15.1 signal may be within or outside the passband of the IEEE 802.11b PHY layer. These are the in-band and out-of-band cases, and they effect the probability of a collision.

The different collision cases are summarized in Table 10.

Table 10—Collision cases as a function of local activities

Local 802.11b activity	Local 802.15.1 activity			
	Transmit		Receive	
	In-band	Out-of-band	In-band	Out-of-band
Transmit	Transmit	None	Transmit-Receive or None	Transmit-Receive or None
Receive	Transmit-Receive or None	Transmit-Receive or None	Receive	None

The different collision types are defined in Table 11.

Table 11—Definition of collision types

Collision type	Definition
Transmit	Both radios are transmitting in-band. One or both of the packets might be received with errors.
Receive	Both radios are receiving in-band. One or both of the packets might be received with errors.
Transmit-Receive	One radio is transmitting and the other is receiving. The locally received packet is received with errors.
None	Simultaneous activity of the two radios does not increase the PER.

In the case of “Transmit-Receive or None” collisions, whether there is a collision or not depends on a number of PHY layer-related parameters that may include: transmit power, received signal strength and the difference between IEEE 802.11b and IEEE 802.15.1 center frequencies.

An implementation predicts the difference between these collision outcomes based on its knowledge of the operating parameters of its PHY layer. So, based on PHY-layer parameters, an implementation predicts whether a collision occurs. The algorithm for predicting packet collisions is outside the scope of this recommended practice.

Implementation constraints may also introduce additional types of “collisions” based on simultaneous conflicting demands for hardware resources. For example, a single-antenna system is unlikely to be able to transmit and receive simultaneously.

6.2 PTA structure

Figure 6 shows the structure of the PTA control entity. Each device has a corresponding control entity to which it submits its transmit requests. This control entity allows or denies the request based on the known state of both radios.

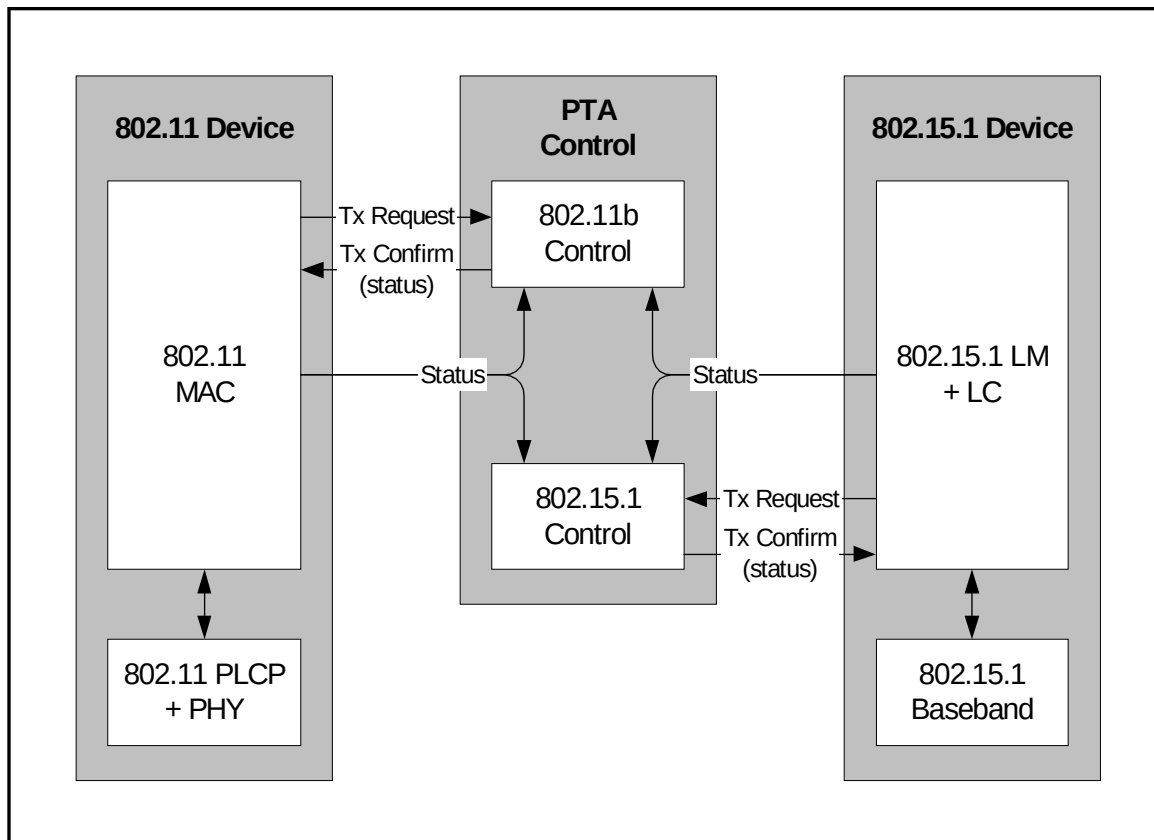


Figure 6—Structure of the PTA entity

6.3 Known 802.11b state

The PTA control assumes that the state defined in Table 12 is available from the IEEE 802.11b MAC.

Table 12—Known 802.11b state

802.11b state item	Definition
Current802.11bState	Indicates the current activity of the 802.11b MAC in terms of current or expected receive and transmit activity. The decision logic described in 6.6 requires that the state variable indicate if 802.11b radio is idle, transmitting, or receiving. Additional states may be exposed through this interface to support local priority policy as described in 6.7.
Channel	Channel number
End Time	Time of the end of the current activity. This may be based on the last duration value received or transmitted in a MAC protocol data unit (MPDU) header.

When a transmit request is made from the IEEE 802.11b MAC, the information described in Table 13 is known.

Table 13—802.11b TX request state

802.11b TX request parameter	Description
Packet type	Type of the MPDU
Duration	On-air duration of the MPDU

6.4 Known 802.15.1 state

The PTA control assumes that the state described in Table 14 is available from the IEEE 802.15.1 MAC.

Table 14—Known 802.15.1 state

802.15.1 state item	Description
Current 802.15.1 state	Describes the current activity of the 802.15.1 baseband in terms of current or expected receive and transmit activity. The decision logic described in 6.6 requires that the state variable indicate if 802.15.1 stack is idle, transmitting, or receiving.
Channel list	List of channels for the current and future slots.
Packet type	Indicates the type of packet predicted for the current and future slots.
Duration	On-air duration of the current packet.
Slot end time	Time at the end of the current slot (i.e., at the next slot edge).

6.5 802.11b control

The purpose of the IEEE 802.11b control entity is to allow or deny transmit requests from the IEEE 802.11b MAC. The TX Request signal is sent when the IEEE 802.11b MAC has determined that it may transmit according to its own protocol (i.e., after any required backoff has completed).

On receipt of a TX Request signal, the IEEE 802.11b control immediately generates a TX Confirm signal containing a status value that is either allowed or denied. Figure 7 defines how the status value is selected.

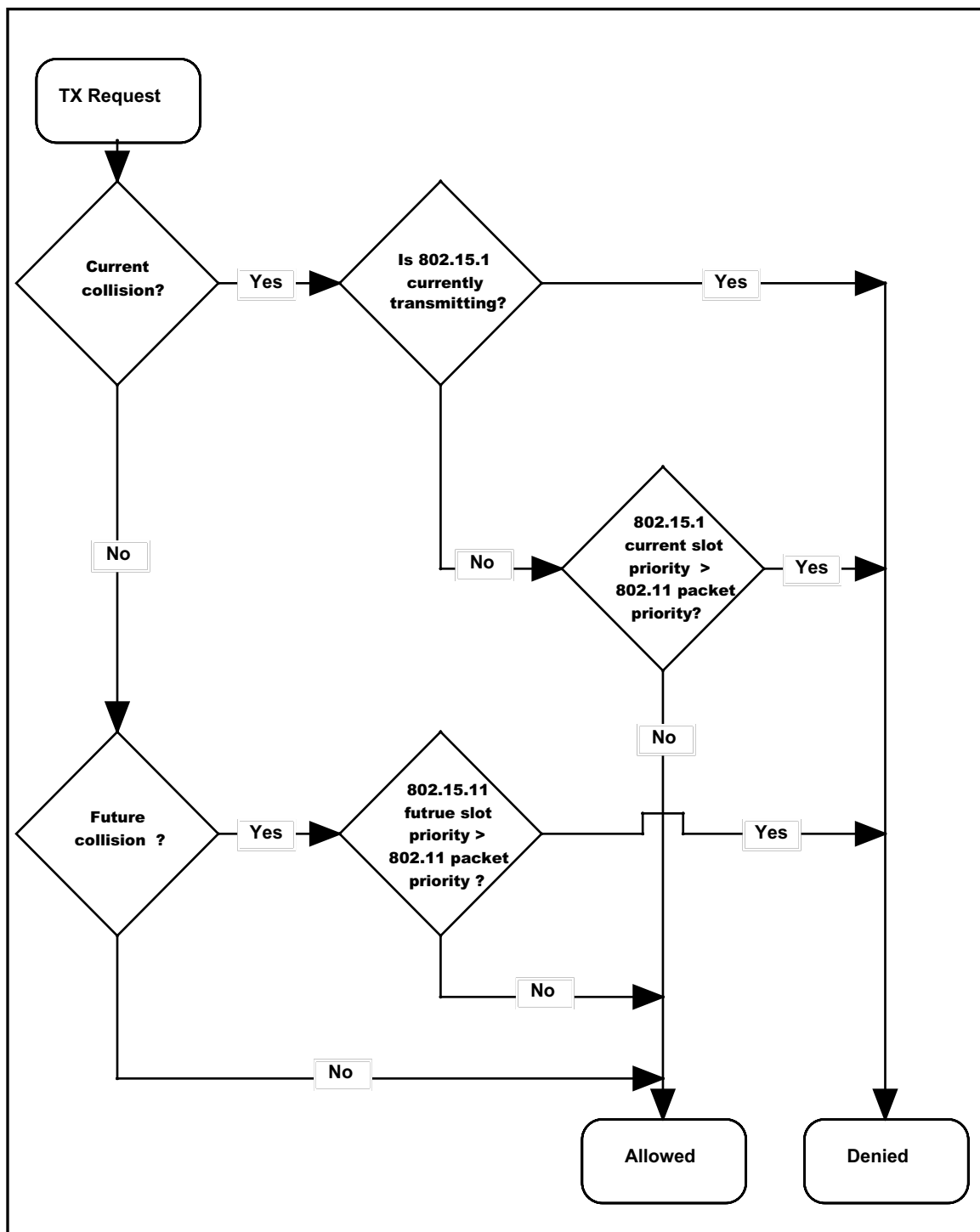


Figure 7—Decision logic for 802.11b TX request

The effect of a denied result on the IEEE 802.11b MAC protocol depends on the access mechanism currently in use. This is defined in Table 15.