

IEEE P802.15
Wireless Personal Area Networks

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Title	Power save proposal		
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Re:	[Power save mechanism in TG3-MAC]		
Abstract	[This contribution is a proposal for power save mechanisms to be used in TG3 MAC]		
Purpose	[power save mechanisms to be used in TG3 MAC.]		
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Overview of the Power save proposal

In this paper there are two power save states that are proposed, Snooze state and Sleep state. The Snooze state is completely controlled by the DEV and Sleep state needs coordination from the PNC as the DEV needs to be in sync with the ongoing within the piconet. The Sleep states is requested by the DEV and permitted/rejected by the PNC. When Sleep state for a DEV is permitted, the PNC must indicate the “traffic pending” state for the DEV in the Power-Save-Information-element in its Beacons. Using this information, the DEVs enter a sleep-cycle at the end of which if the traffic is pending at the PNC, the DEVs send “Active-state-indication” command to the PNC so that the PNC can start sending the buffered frames to the DEV. Since the PNC is involved, the mechanism apply equally well to buffering multicast and broadcast frames for the DEV.

MAC Frame Formats

7.1.x Power save information element

Octets: 1	1	2	2	-----	2
Element ID	Length = (n * 2)	TIB-1	TIB-2	TIB-n

Figure 1—Power save information element

The Power save information element shall be present only in Beacons . This element consists of multiple, 2-octet wide traffic-indication blocks (TIB), and the TIBs shall be arranged in an increasing order of the start-DEV address contained in them. The contents of a TIB is illustrated in Figure 2.

Octets: 1	1
Start DEV address	“traffic pending” indication. LS bit of the octet is the indication corresponding to “start-DEV-address”

Figure 2—Traffic Indication Block (TIB)

The TIB consist of Start-DEV-address and an octet of “traffic-indication”. A ‘1’ in any of the bit positions in traffic-indication octet means that some traffic is pending for the DEV whose allocated address is the sum of the start-DEV-address contained in the first octet of the TIB and the position of the current bit. Hence the least significant bit (b0) in traffic-indication octet indicates whether there is any traffic is pending at PNC for the DEV whose address is mentioned as the start-DEV-address in the current TIB. Absence of a TIB containing “traffic pending” indication for a DEV shall mean that there is no traffic pending for that DEV at the PNC.

Command types

NOTE: Alternatively, it is possible to make the response by the PNC (permit/reject) as the immediate response to the sleep-state-req by the DEV.

1.2.x1 Sleep time request

A DEV that is associated with a PNC indicating its intention to use sleep state during the association state shall use this command to obtain permission to enter sleep state. The command structure is illustrated in Figure 3.

octets: 2	2	2
Command Type	Length (= 2)	Requested sleep state duration (in TU)

Figure 3—Sleep time request command format

The requested sleep state duration is the length of time that the PNC is being requested to buffer the frames for the requesting DEV.

1.2.x2 Sleep time permit

PNC shall use this command to permit a requesting DEV to enter sleep state. The requesting DEV shall enter the sleep state only after it has successfully acknowledged this command from the PNC. The command structure is illustrated in Figure 4.

octets: 2	2	2
Command Type	Length (= 2)	Max sleep state duration (in TU)

Figure 4—Sleep time permit command format

The max sleep state duration is the length of time that the PNC is agreeing to buffer the frames for the requesting DEV.

1.2.x3 Sleep time reject

PNC shall use this command to reject a requesting DEV to enter sleep state. The requesting DEV shall not enter the sleep state if it receives this command from the PNC. The command structure is illustrated in Figure 5.

octets: 2	2	1	1
Command Type	Length (= 2)	reserved	Reason code

Figure 5—Sleep time reject command format

The max sleep state duration is the length of time that the PNC is agreeing to buffer the frames for the requesting DEV.

- 0 -> No resources available
- 1 -> Channel change is in progress
- 2 -> PNC hand over is in progress
- 3 -> Pending buffered frames from previous sleep state
- 4-> Unknown reason
- 5-255-> Reserved

1.2.x4 Active state indication

A DEV that was permitted to enter sleep state by the PNC uses this command to indicate its intention to be back in active state. After successfully acknowledging this frame, the PNC shall stop buffering frames for the requesting DEV and start delivering the currently buffered frames to this DEV. The command structure is illustrated in Figure 6.

octets: 2	2
Command Type	Length (= 0)

Figure 6—Active state indication command format

NOTE: This command in reality can be any command (even just a NULL command frame) from the DEV to the PNC

8.x Description of Power save modes and operation

There are three states in power management (PM) at MAC, (a) Active state (b) Snooze state and (c) Sleep state. The PS bit in capability field shall be set to 1 if the DEV is planning to use sleep state during an association state.

NOTE: Snooze state is same as the RPS in doc#262r0 and Sleep state is same as the EPS in doc #262r0 as the basic descriptions of these states were drawn from doc#292r1 and 293r1.

The DEV shall remain awake as long it is in active state.

In Snooze state, the DEV shall be awake at the beacon tx time and for the entire CAP. During CFP the DEV uses the channel time allocation received in Beacon or channel time grant command to decide when to be awake. Each DEV shall be awake at all GTSs in which its address is listed as either the source or the source DEV-address. All DEVs, except those in sleep state, shall be awake at all GTSs for which the destination DEV-address is Broadcast DEV-address. The rest of the time during the superframe the DEV is free to snooze and not transmit or receive any frame on the channel. Each DEV is free to use snooze state and save power in any superframe only if it has correctly received beacon frame for that superframe.

In Sleep state, the DEV may not receive or be able to transmit for several superframes at a time. The PNC is required to buffer all the frames to the sleeping DEV and all the broadcast frames received during the sleep state of the DEV and make them available to the DEV when it is awake. PNC is also responsible for indicating the “traffic pending” information in the beacon using Power-save-information element described above. The PNC needs to check its local buffers meant for the repeat service to decide if the “traffic-indication” for a DEV needs to be set in the outgoing Beacon. Before going to Sleep state, the DEV shall inform the same to PNC its intention to go to sleep state using “Sleep State Request” command and wait for PNC to respond. Only after the reception of “Sleep state permit” command from PNC, shall the DEV is allowed to shut itself off for a maximum sleep time duration as indicated by the PNC in “Sleep state permit” command. Note that the DEV must awake sufficient time before the expiration of that maximum sleep time in order to inform the

1 PNC that the DEV is awake. If the DEV did not successfully indicate its awake state to PNC within the expi-
2 ration of that maximum sleep time, the PNC shall disassociate the DEV from its piconet. If the DEV
3 receives “Sleep state reject” command from the PNC instead of “Sleep state permit” command, the DEV
4 shall not go to sleep state and wait for atleast one more beacon interal before attempting to send another
5 “Sleep state request” command to PNC. But the device is free to use snooze state following the rules to enter
6 snooze state described above. In addition to simply using the sleep state request and permit commands for
7 the power save operation, the DEVs can adopt a sleep cycle that is described in Figure 8 below. The DEVs
8 can wakeup at periodic intervals, receive a beacon and check the power-save-information element in the
9 received beacon to decide one of the following

10
11 (a) Go back to sleep immediately if there is no traffic pending indication for the DEV and if the max-
12 imum sleep time has not expired. However the DEV must wakeup before the maximum sleep time
13 permitted by the PNC expire.

14
15 (b) Send another sleep state request, if there is no traffic pending indication for the DEV but the
16 maximum sleep time is close to being expired.

17
18 (c) Send “active-state-indication” to PNC and expect the frames from PNC if there is traffic pending
19 indication for the DEV

20
21 When the DEV wakes up from sleep, it shall remain awake until atleast one beacon is correctly received so
22 as to detect the CAP correctly.

23
24 The PNC shall set the repeater bit to 1 in all the frames it is relaying to a DEV that is awake from sleep state.
25 Since the PNC is buffering broadcast frames and transmitting them when the DEV is awake, it is possible
26 for any DEV in the piconet to receive the same broadcast frames multiple times with or without repeater bit
27 set. Hence each DEV shall use duplication detection mechanism described in 8.6.6 to reject all the multiply
28 received broadcast frames.

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30 The sequence chart in Figure 7 show the sequence of frames/commands exchanged between DEV and PNC
31 for sleep-state management.

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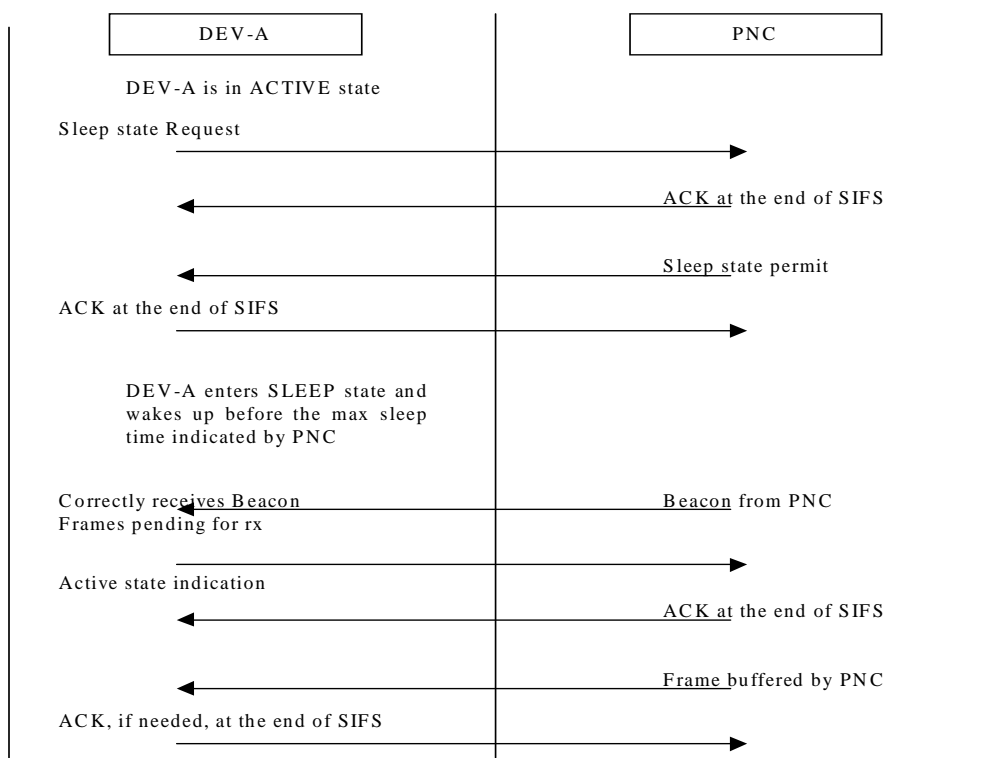


Figure 7—Message sequence chart for entering sleep state and buffered data reception at a DEV

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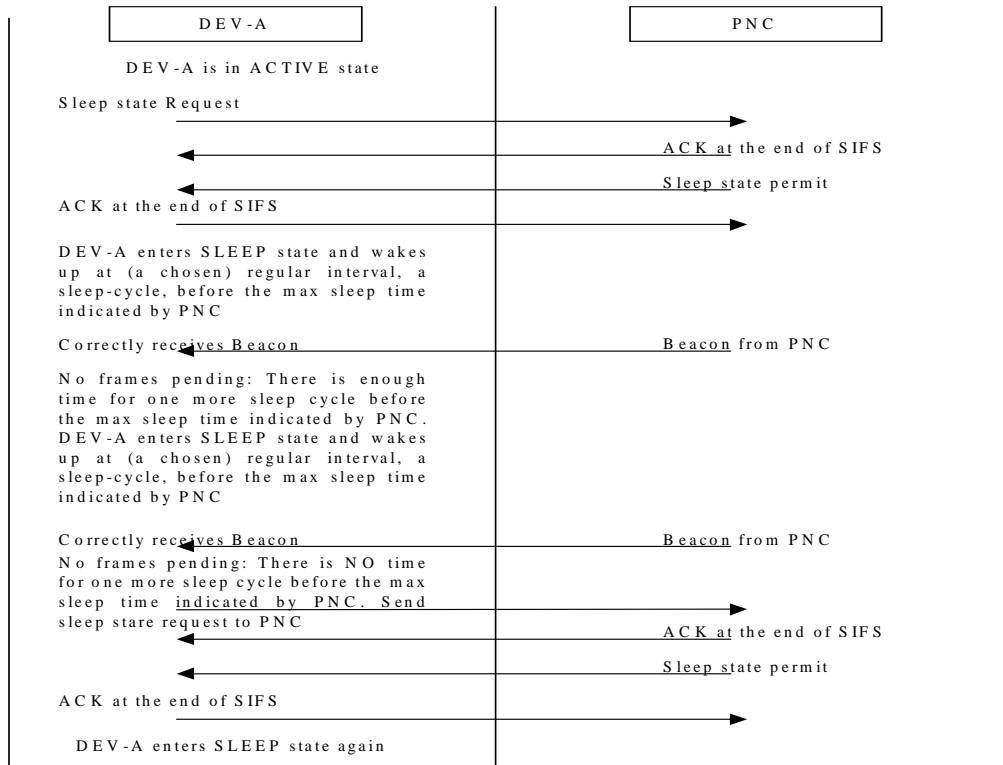


Figure 8—Message sequence chart for entering sleep state and buffered data reception at a DEV

7. MAC Frame Formats

This clause specifies the format of the MAC frames. All DEVs shall be able to validate every received frame, either error free or in error, using the frame check sequence (FCS). In addition, every DEV shall be able to construct a subset of the command frames for transmission, and to decode another (potentially different) subset of the command frames upon validation following reception. The particular subsets of these commands that a DEV shall construct and decode are determined by the functional capabilities supported by that particular DEV.

7.1 Overview

Each MAC frame consists of the following basic components:

- a) A MAC header, which comprises frame control, address and sequence number information, and, optionally, traffic category information.
- b) A fixed length header check sequence (HCS), which contains the CRC parity bits for frame header that includes the PHY header and the MAC header.
- c) A variable length frame body, which contains information specific to the frame type and subtype.
- d) A frame check sequence (FCS) which contains an IEEE 32-bit cyclic redundancy code (CRC).

7.1.1 Conventions

The MAC frames in the MAC sub-layer are described as a sequence of fields in specific order. Each figure in Clause 7 depicts the fields/sub-fields as they appear in the MAC frame and in the order in which they are passed to the PHY, from left to right where the left-most bit is transmitted first in time.

In the figures, all bits within fields are numbered, from 0 to k , where the length of the field is $k+1$ bits. The octet boundaries within a field are obtained by taking the bit-numbers of the field modulo 8. Octets within numeric fields that are longer than a single octet are depicted in increasing order of significance, from lowest numbered bit to highest numbered bit. The octets in fields longer than a single octet are sent to the PHY in order from the octet containing the lowest numbered bits to the octet containing the highest numbered bits.

Any field containing a CRC is an exception to this convention and is transmitted commencing with the coefficient of the highest-order term.

Values specified in decimal are coded in natural binary unless otherwise stated.

Without further qualification, “reception” by the MAC sub-layer implies that the frame contents are valid and that the protocol version is supported. However, “reception” implies nothing about frame addressing, nor whether the frame type or other fields in the MAC header are meaningful to the MAC entity that has received the frame.

Unless otherwise stated, any reserved field or sub-field shall be set to 0 upon transmission and shall be ignored on reception.

Reserved values in non-reserved fields and sub-fields shall not be transmitted by conformant DEVs. However, a DEV conformant to an older revision of this standard may receive frames with what it considers to be reserved values in non-reserved fields and sub-fields. These fields, along with other fields in the same frame whose interpretation is directly dependent thereon, shall be ignored on reception.

7.2 General frame format

The MAC frame format comprises a set of fields that occur in a fixed order in all frames. The general MAC frame format shall be formatted as illustrated in Figure 11. Each field is defined in 7.2.1. The maximum size of a MAC frame, aMaxFrameSize, is a PHY dependent parameter that includes the frame body and FCS, but not the PHY preamble, header, MAC header or HCS. For the 2.4 GHz PHY, this parameter is defined in 11.2.7.

octets: 2	2	1	1	2	2	2	variable	0-4
Frame control	PNID	Destination address (DA)	Source address (SA)	Stream control	Sequence number	HCS	Frame body	FCS
MAC Header								

Figure 11—MAC Frame format

The number of octets in the frame body shall range from 0 to aMaxFrameSize-4, inclusive.

7.2.1 Frame control field

The frame control field consists of the following sub-fields: protocol version, ACK policy, frame type, pad octet, frag-start, frag-end, retry, Del-ACK request, SECurity and repeater. The format of the frame control field shall be formatted as illustrated in Figure 12.

bits: 0-1	2-3	4-6	7	8	9	11	12	13	14	15
protocol version	ACK policy	frame type	pad octet	frag-start	frag-end	retry	Del-ACK request	reserved	SEC	repeater

Figure 12—Frame control field

7.2.1.1 Protocol version field

The protocol version field is two bits in length and is invariant in size and placement across all revisions of the 802.15.3 standard. For this revision of the standard the value of the protocol version is 0. All other values are reserved. The revision level will be incremented only when a fundamental incompatibility exists between a new revision and the prior revision of the standard. A DEV that receives a frame with a higher revision level than it supports will discard the frame without indication to the sending DEV.

7.2.1.2 ACK policy field

The ACK policy field is 2 bits in length and is used to indicate the kind of acknowledgement procedure that the addressed recipient is required to perform. The use of the ACK policies is described in 8.8. The allowed values for the ACK policy field are:

- 0: No acknowledgement: The recipient(s) shall not acknowledge the transmission, and the sender treats the transmission as successful without regard for the actual result. The use of this policy is defined in 8.8.1.

- 1: Immediate acknowledgement (Imm-ACK) required: The addressed recipient returns an ACK frame after successful reception, according to the procedures defined in 8.8.2.
- 2: Delayed acknowledgement (Del-ACK): The addressed recipient uses the delayed-ACK command, defined in 7.5.9.1, to convey the acknowledgement according to the procedures defined in 8.8.3.
- 3: Implied acknowledgement: The intended recipient is allowed to send either an Imm-ACK or any other frame to the source-DEV of this frame as described in 8.8.4.

7.2.1.3 Frame type field

The frame type field is three bits in length. Table 59 lists the valid frame type values and their description. The format and the usage of each of the individual frame types is defined in 7.3.

**Table 59—Valid frame type values
(numeric values in this Table are shown in binary)**

Type value b2 b1 b0	Frame type description
000	Beacon
001	Immediate acknowledgement (ACK)
010	Command
111	Data
011-110	Reserved

7.2.1.4 Pad octet field

The pad octet field is one bit in length and shall be set to 1 in all data frames where the number of data octets is an odd number and the data payload has been padded by an extra octet to maintain word aligned frames. It shall be set to zero otherwise.

7.2.1.5 Frag-start field

The frag-start field is one bit in length and is set to 1 in all data or command frames, that is the start of the current MSDU/MCDU. It is set to 0 in all other frames.

7.2.1.6 Frag-end field

The frag-end field is one bit in length and is set to 1 in all data or command frames, that is the end of the current MSDU/MCDU. It is set to 0 in all other frames.

7.2.1.7 Retry field

The retry field is one bit in length and is set to 1 in any data or command frame that is a retransmission of an earlier frame. It is set to 0 in all other frames. A receiving DEV uses this indication to aid in the process of eliminating duplicate frames.

7.2.1.8 Del-ACK request field

The Del-ACK request field is one bit in length and is valid only in the data frames of a stream that is currently employing the delayed ACK mechanism. When this bit is set, the source DEV of the stream is requesting the destination DEV to expedite the delivery of the delayed-ACK command.

7.2.1.9 SEC field

The SEC field is one bit in length. When the SEC bit is set to 1, the frame body is encrypted using the currently assigned data encryption key for the piconet.

7.2.1.10 Repeater field

The repeater field is one bit in length and is set to 1 if the frame is being repeated by the PNC as part of the repeater service between two DEVs in the same piconet. It is set to 0 in all other frames.

7.2.2 Piconet ID (PNID)

The PNID is a unique identification for the piconet. The PNID remains constant during the current instantiation of the piconet and may be persistent for multiple sequential instantiations of the piconet by the same PNC.

7.2.3 Address fields

There are two address fields in the MAC frame format and each of these fields is 8 bits in length. These fields are used to indicate the destination address (DA) and the source address (SA). An address for a DEV is assigned by the PNC during the association of the DEV. The address of a DEV is unique to an associated DEV within a piconet. The following addresses are reserved.

- The address value 0 is reserved for the PNC, for coordinator related transmissions and receptions
- The address value of all-ones (0xFF) is reserved for broadcast frames
- The address value of 0xFE is reserved for use by all new clients during their association until a unique address is allocated to each one of those new clients by the PNC.
- The address value of 0xFD is reserved for multicast frames
- The address values of 0xFA, 0xFB or 0xFC are reserved for neighbor piconets

7.2.4 Stream control

The stream control field is 16 bits in length and is used to uniquely identify a data stream. This field is valid only for data frames. This field is set to zero, and ignored upon reception, in all other frame types.

bits 0:7	8	9:11	12:15
Stream index	Stream type	Priority	Reserved

Figure 13—Stream control field

This field contains three sub-fields, stream index, stream type and priority.

The stream index field is an 8-bit field with the value of zero reserved for non-stream data. The DEVs use the rest of the values of the stream index as dynamically assigned by the PNC during the setup of the data stream. The PNC allocates a unique value of stream index for each stream in the piconet.

The stream type shall be set to '1' for streams requiring isochronous services and shall be set to '0' otherwise.

The priority field indicates the priority of the stream and is defined in A.3.

Any frame that does not belong to an established stream and does not need a stream connection is a non-stream data frame. Any non-stream data frame is transmitted with the stream index value of zero. The use of a stream connection for asynchronous or isochronous data is up to the DEV.

7.2.5 Sequence number field

The sequence number field is a 16-bit value indicating the sequence number of the current MPDU.

For data frames, the DEVs maintain one modulo-65536 counter associated with the stream index of each of the data stream that they source. The sequence number for a stream with a given stream index is assigned from the counter associated with that stream index.

The sequence numbers for all command frames shall be assigned from a single modulo-65536 counter.

The sequence number for Imm-ACK frames and the beacon frame shall be set to 0.

Each sequence number counter is started at 0 and incremented by 1 at the end of frame for which the sequence number is assigned.

7.2.6 Header check sequence

The header check sequence (HCS) is PHY dependent and is generated by the PHY before transmission and checked by the PHY during reception. The HCS for the 2.4 GHz PHY is defined in 11.2.8.

7.2.7 Frame body field

The frame body is a variable length field and contains information specific to individual frame types. The minimum frame body is zero octets. The maximum length frame body is aMaxFrameSize-4 octets, including the security information, if any.

7.2.8 FCS field

The FCS field is a 32 bit field that contains a 32-bit CRC. The FCS is calculated over all of the frame body field, including, if present, the stuffed octet, 7.3, which is referred to here as the calculation field.

If the frame body has zero length (as in an immediate ACK frame) the FCS shall not be sent.

The FCS is calculated using the following standard generator polynomial of degree 32:

$$G(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$$

The FCS is the one's complement (modulo 2) of the sum of the following:

- 1) The remainder of $x^k x (x^{31} + x^{30} + x^{29} + \dots + x^2 + x + 1)$ divided (modulo 2) by $G(x)$, where k is the number of bits in the calculation field, and
- 2) The remainder after multiplication of the contents (treated as a polynomial) of the calculation field by x^{32} and then division by $G(x)$.

The FCS field is transmitted commencing with the coefficient of the highest order term.

As a typical implementation, at the transmitter, the initial remainder of the division is preset to all ones and is then modified by division of the calculation fields by the generator polynomial $G(x)$. The ones complement of this remainder is transmitted, with the high order bit first, as the FCS field.

At the receiver, the initial remainder is preset to all ones and the serial incoming bits of the calculation fields and FCS, when divided by $G(x)$ results in the absence of transmission errors, in a unique non-zero remainder value. The unique remainder value is the polynomial:

$$x^{31} + x^{30} + x^{26} + x^{25} + x^{24} + x^{18} + x^{15} + x^{14} + x^{12} + x^{11} + x^{10} + x^8 + x^6 + x^5 + x^4 + x^3 + x + 1$$

7.3 Format of individual frame types

There are four defined frame types. The commands within command frame are defined so that a DEV may perform multiple transactions in one shot with a low overhead of just one frame transaction.

All frames shall have a length that is an even number of octets. While encoding, if the frame is not an even number of octets, an extra octet with an all-zero value shall be placed after the last valid octet of the frame, before the FCS, to achieve an even number of octets. The length field of the frame shall the number of octets, including the stuffed octet in its count. While decoding, the pad octet field is used to know the number of octets that belong to the command. If the pad octet field is set, then the last octet prior to the FCS shall be ignored.

Note that the FCS calculation includes the stuffed octet.

7.3.1 Beacon frame format

The contents of the beacon frame body are shown in Table 60. The individual information elements in the beacon frame are described in 7.4. The information elements in the beacon frame may appear in any order in the beacon and DEVs may ignore any elements in the beacon which are not listed in Table 60.

Table 60—Beacon frame body

Information element	Sub-clause	Note	Present in beacon
Device identifier	7.4.1	IEEE 802 address of the PNC	In every beacon
Piconet synchronization parameters	7.4.2	Beacon number and other time duration elements	In every beacon
Piconet maximum transmit power	7.4.9	Sets the max TX power level in the piconet	As needed
Channel change	7.4.5	During change to new channel	As needed
Channel time allocation	7.4.10	All the channel time allocation in the current superframe	As needed
Traffic indication map	<TBD>	Traffic indication map for currently sleeping DEVs	As needed
Device identifier of parent PNC (if child or neighbor piconet)	7.4.1	IEEE 802 address of the parent PNC	As needed

The frame control fields and the stream control field of the beacon frame shall be set according to the values in Table 61.

Table 61—Frame control field settings for beacon frame

Header field	Setting on transmission	Interpretation on reception
ACK Policy	0	Ignored
Frame type	Beacon value in Table 59	Decoded
Frag-start	0	Ignored
Frag-end	0	Ignored
Retry	0	Ignored
Del-ACK Request	0	Ignored
SEC	0	Ignored
Repeater	0	Ignored
Stream control	0x00	Ignored

The DA in the beacon frame header is broadcast address. The SA is the PNC address, defined in 7.2.3.

7.3.2 Immediate acknowledgement (ACK) frame format

The frame control fields and the stream control field of the immediate-ACK frame are given in Table 62

Table 62—Frame control field settings of the immediate ACK frame

Header field	Setting on transmission	Interpretation on reception
ACK Policy	0	Ignored
Frame type	Immediate-ACK value in Table 59	Decoded
Frag-start	0	Ignored
Frag-end	0	Ignored
Retry	0	Ignored
Del-ACK Request	0	Ignored
SEC	0	Ignored
Repeater	0	Ignored
Stream control	0x00	Ignored

The SA of the ACK frame is copied from the DA field of the immediately previous directed frame that requires immediate acknowledgement. Similarly the DA of the ACK frame is copied from the SA field of the immediately previous directed frame that requires immediate acknowledgement.

7.3.3 Command frame format

The command frame shall only be sent in either a slot that is allocated for communication between the PNC and the DEV or during the CAP.

The command frame body consists of one or more command blocks as shown in Figure 14. Each command block consists of a 2-octet command type field, a 2-octet length field and a variable length command payload as shown in Figure 15. The command types are described in sub-clause 7.5.

octets: 12	$(2+2+L_1)$	$(2+2+L_2)$...	$(2+2+L_n)$	4
MAC frame header	Command block-1	Command block-2	...	Command block-n	FCS

Figure 14—Command frame format

octets: 2	2	L_x
Command type	Length (= L_x)	Command payload

Figure 15—Command block format

The stream control field in the command frame header shall be set to 0x00 and shall be ignored upon reception.

The command blocks shall always start on a 2-octet boundary within the frame body. While encoding, if the command payload is not aligned to 2-octet boundary, an extra octet with an all-zero value shall be placed after the last valid octet of the command payload to achieve the 2-octet alignment. However, the length field shall contain only the number of valid octets and hence shall exclude the stuffed octet from its count. While decoding, the length field is used to determine the number of octets that belong to the payload of the command. If the value of the length field is an odd number, then the octet following the last valid octet of the payload shall be ignored before considering the next command block.

A command data unit (MCDU) may also be transmitted in fragments, as described in 8.7.

7.3.4 Data frame format

The frame format of data frame is as shown in Figure 16.

octets: 12	variable	0 or 4
MAC frame header	Data	FCS

Figure 16—Data frame format

The length of the data field is 0 to aMaxFrameSize-4, inclusive.

Note that the FCS is not sent for 0 length frames, as defined in 7.2.8

7.4 Information elements

The information elements are listed in Table 63. Individual elements are described in the following sub-clauses.

Table 63—Information elements

Element ID hex value	Element	Sub-clause
0x00	Device identifier	7.4.1
0x01	Piconet synchronization parameters	7.4.2
0x02	Capability information	7.4.3
0x03	Maximum supported time slots	7.4.4
0x04	Channel change	7.4.5
0x05	Supported rates	7.4.6
0x06	Security parameters	7.4.7
0x07	Transmit power parameters	7.4.8
0x08	Transmit power change	7.5.5.1
0x09	Piconet maximum transmit power	7.4.9
0x0A	Channel time allocation	7.4.10
0x0B	Max CTAs	7.4.11
0x0C	DEV GTS status	7.4.12
0x0D	Power management parameters Traffic indication map	7.4.13
0x0E	Application specific information	7.4.14
0x0F-0xFF	Reserved	

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The format of an individual information element is shown in Figure 17. The first octet is the information element ID and the second octet is the length (L_n) of the payload of the information element in octets. The following L_n octets are the payload for the information element. These elements may appear in any order in the frames that are allowed include more than one of these elements.

The information elements shall always start on a 2-octet boundary within frame body. While encoding, if the information element is not aligned to a 2-octet boundary, an extra octet with an all-zero value shall be placed after the last valid octet of that information element to achieve the 2-octet alignment. However, the length field in the information element shall contain only the number of valid octets and hence shall exclude the stuffed octet from its count. While decoding, the length field is used to know the number of octets that belong to the information element. If the value of the length field is an odd number, then the octet following the last valid octet of the information element shall be ignored before considering the next information element.

octets: 1	1	L_n
Element ID	Length (= L_n)	data

Figure 17—Information element format

7.4.1 Device identifier

The format of the device identifier element shall be formatted as illustrated in Figure 18.

octets: 1	1	6
Element ID	Length (=6)	Device ID

Figure 18—Device identifier element

The device ID is the 48-bit (6 octets) IEEE 802 address of the DEV that is sending the frame. The lsb of the address is sent first, i.e. the lsb of the address follows the msb of the length field.

7.4.2 Piconet synchronization parameters

The format of the piconet synchronization parameter element shall be formatted as illustrated in Figure 19

octets: 1	1	4	2	2	2	1	1
Element ID	Length (=12)	Beacon number	Superframe duration	CFP duration	CAP MaxBurstDuration	Key number	Piconet mode

Figure 19—Piconet synchronization parameters element.

The beacon number is a 32 bit counter which is incremented in each beacon.

The superframe duration is the duration of the current superframe. The resolution of this field is 8 μ s and therefore has a range of [0-524280] μ s. However the valid range of this field is [aMinSuperframeDuration, aMaxSuperframeDuration].

The CFP duration is the time allocated to the CFP within the superframe. The resolution of this field is 8 μ s which gives a range of [0-524280] μ s. The duration of the CAP is computed as the difference between the superframe duration and the CFP duration. The same value is used as the time offset for the start of the CFP from the start of beacon transmission.

The MaxBurstDuration in the CAP is the duration of the longest allowed burst during the CAP of the current superframe. The resolution of this field is 8 μ s and so the range is [0-524280] μ s.

The key number is used to identify the current data encryption key (DEK) for the piconet. The PNC increments this number as a rollover counter every time it changes the DEK. If the piconet does not use data encryption, this field shall be set zero.

The piconet mode indicates 2 types of information: 1) what type of information is allowed to be sent in the CAP of the current superframe and 2) the current security requirements. The encoding of this octet shall be formatted as illustrated in Figure 20.

bits: b0	b1	b2	b3	b4-b5	b6-b7
Data	Commands (except association)	Association commands	EPS	SEC mode	Reserved

Figure 20—Piconet mode field

If a bit is set for data, commands, association or EPS, i.e. its value is 1, then that type of data or command is allowed to be sent in the CAP of the current superframe. Otherwise, that type of frame is not allowed to be sent in the CAP. The use of this command is described in 8.4.2.

The SEC mode indicates the current security settings in the piconet. The field is encoded as follows (b5, the msb, is listed first, b4, the lsb, last):

- 0b00: neither authentication nor data encryption are required.
- 0b01: authentication is required.
- 0b11: both authentication and data encryption are required

Note that 0b10, i.e. having the data encryption but not authentication, is a disallowed state.

7.4.3 Capability information

The capability information element shall be formatted as illustrated in Figure 21 and the capability field shall be formatted as illustrated in Figure 22. The bits in the capability field shall not change while the DEV is associated in a piconet. For the PNC, the bits in the capability field shall not change while it is the PNC of

the current piconet. Bits b11-b15 are arranged in order of preference for PNC selection, with the highest preference (AC) corresponding to the MSb.

octets: 1	1	2
Element ID	Length (=2)	Capability field

Figure 21—Capability information element format

bits: b0-b5	b6-b9	b10	b11	b12	b13	b14	b15
Supported data rates	Reserved	Neighbor PNC	PSAVE	PSRC	SEC	PNC-Des-Mode	AC

Figure 22—Capability field format

The supported data rates element is a PHY dependent mapping of the optional data rates to a 5 bit field that indicates which of the optional data rates are supported by a DEV. For the 2.4 GHz PHY, this mapping is defined in Table 94.

The neighbor piconet bit shall be set to 1 if the DEV is intends to be a neighbor PNC, 8.2.6, in the current piconet and shall be set to 0 otherwise.

The PSAVE bit shall be set to 1 if the DEV is planning to use EPS state as a part of power management. Otherwise the PS bit shall be set to 0. The PNC shall always set this bit to 0 in its capability field.

The PSRC field shall be set to 1 if the DEV is receiving power from the alternating current mains and shall be set to 0 otherwise.

The SEC bit shall be set to 1 if the DEV is capable of supporting encryption for its data streams. Otherwise SEC bit shall be set to 0.

The PNC-Des-Mode is the designated mode of the DEV as currently set. This bit shall be set to 1 if the DEV is in the PNC mode. Otherwise this bit shall be set to 0.

The AC bit shall be set to 1 if the DEV is capable of being a PNC in the piconet. Otherwise AC bit shall be set to 0.

7.4.4 Maximum supported time slots

The maximum supported time slots element shall be formatted as illustrated in Figure 23.

octets: 1	1	1	1
Element ID	Length (=2)	Reserved	Max number of time slots supported

Figure 23—Maximum supported time slot elements

The Max number of time slots supported indicates the maximum number of time slots that may be allocated to the DEV that is sending this element in any superframe.

7.4.5 Channel change

The channel change element shall be formatted as illustrated in Figure 24.

octets: 1	1	1	1
Element ID	Length (=2)	New channel index	Channel change time-out (in Kμs)

Figure 24—Channel change element

The new channel index indicates the channel to which the PNC is intending to move the piconet. The values of this field are PHY dependent. For the 2.4 GHz PHY, the valid channels are defined in 11.2.3.

The channel change time-out is the time within which the DEVs shall expect beacon from PNC in the new channel. This time duration is indicated in Kμs.

7.4.6 Supported rates

The supported rates element specifies the rates in the operational rate set and are conveyed to MAC through MLME-ASSOCIATE and MLME-START primitives. The supported rates element shall be formatted as illustrated in Figure 25.

octets: 1	1	(1 – 8)
Element ID	Length (=1 – 8)	Supported Rates

Figure 25—Supported rates element

The information field is encoded as 1 to 8 octets where each octet describes a single supported rate. The encoding is PHY dependent. For the 2.4 GHz PHY, the encoding is defined in 11.7

7.4.7 Security parameters

The security parameters element is used to communicate the security parameters used in a piconet. The security parameters element shall be formatted as illustrated in Figure 26.

octets: 1	1	2	variable
Element ID	Length (=2+variable)	OID length	OID

Figure 26—Security parameters element

The OID length is the length in octets of the OID field.

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The OID field specifies a cipher suite according to IEEE P1363: Standard Specifications for Public-Key Cryptography.

7.4.8 Transmit power parameters

The transmit power parameters element shall be formatted as illustrated in Figure 27. The element is used to communicate the TPC capabilities of a DEV.

octets: 1	1	1	1	1
Element ID	Length (=2)	TX power level	TX power step size	Current TX power

Figure 27—Transmit power parameters element

The TX power level is a one octet field that is the number of levels supported by a DEV.

The TX step size is a one octet field that is the TX power level step size in 1 dB resolution, e.g. a number 4 in this field means that the DEV has nominally 4 dB steps.

If a DEV does not support TPC, it shall set the TX power level and TX power step size fields to 0.

The current TX power is DEVs estimate of its transmitter power measured at the antenna interface. The value is in dBm encoded in 2s complement format. For example, a +2 dBm TX power level is encoded as 0x02 while a -2 dBm TX power level is encoded as 0xFE.

7.4.9 Piconet maximum transmit power

The piconet maximum transmit power elements shall be formatted as illustrated in Figure 28. This element is used to communicate the transmit power control (TPC) capabilities of a DEV.

octets: 1	1	1	1
Element ID	Length (=2)	Max TX power level	Reserved

Figure 28—Piconet maximum transmit power element

The max TX power level element is a one octet field that indicates maximum TX power level allowed by the PNC in the piconet. The value is in dBm encoded in 2s complement format. For example, a +2 dBm TX power level is encoded as 0x02 while a -2 dBm TX power level is encoded as 0xFE.

7.4.10 Channel time allocation

The channel time allocation (CTA) element shall be formatted as illustrated in Figure 29. Since the length parameter supports only 255 octets of payload allowed in any one information element, the PNC may split the CTA information into more than one information element entry in the beacon. The receiving DEV shall

assemble all the CTA elements in a received beacon frame before its analysis. The PNC shall place the CTA-blocks in the increasing order of their allocated channel time to ease their reassembly.

octets: 1	1	6	6	...	6
Element ID	Length = (n * 6)	CTA block-1	CTA block-2	...	CTA block-n

Figure 29—Channel time allocation element

Each CTA element consists of multiple, 6-octet wide CTA blocks, which shall be formatted as illustrated in Figure 30.

octets: 1	1	1	1	2
Source DEV address	Destination DEV address	Stream index	CTA-control	Slot Start time or SFNext

Figure 30—Channel time allocation block

The source DEV address indicates the DEV to whom the channel time is being allocated.

The destination DEV address indicates the DEV to whom the source DEV may send the frames. If this is a broadcast address, then the source DEV shall send broadcast frames only during that time slot.

For a child PNC, the source DEV and destination DEV addresses shall both be the AD-AD of the DEV that is the child piconet’s PNC.

For a neighbor piconet, the source and destination addresses shall both be the AD-AD assigned by the parent PNC for the neighbor piconet and shall be one of the reserved neighbor piconet addresses, 7.2.3.

The stream index is the number assigned by the PNC that indicates the stream associated with the channel time.

The CTA control field shall be formatted as illustrated in Figure 31.

bits: b0	b1	b2	b3-b7
Time-beacon	CTA type	Key change	Reserved

Figure 31—CTA control block

The time beacon bit of the CTA Control field shall be set by the PNC to indicate how the two octets of the slot location field are interpreted. The bit shall be set to 0 if the slot location field is to be interpreted as the slot start time. It shall be set to 1 if the slot location field is to be interpreted as the SFNext.

The SFNext field is defined for both ACTIVE CTA elements and EPS CTA elements. For ACTIVE CTA, the field contains the least significant two octets of a beacon number corresponding to next superframe in

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which an actual time slot will be allocated. For EPS CTA, it is equal to the least significant two octets of EPSNext, which corresponds to the next WAKE superframe.

The CTA type specifies whether the source DEV and destination DEV are in ACTIVE mode or EPS mode. The bit shall be set to 0 if they are in ACTIVE mode and shall be set to 1 if they are in EPS mode.

The key change bit is reserved for possible security implementation with TBD meaning.

The slot location field is interpreted as either the slot start time field or the SFNext field, depending on the value of the time beacon bit. The use of this field is summarized in Table 64.

Table 64—Summary of slot location field usage

Type of activity for destination DEV	Slot location octets	Time beacon bit value	CTA type bit value
ACTIVE CTA, GTS present in this superframe	Slot start time	0	0
ACTIVE CTA, no GTS in this superframe	SFNext	1	0
EPS CTA, AWAKE superframe	Slot start time	0	1
EPS CTA, no GTS, just WAKE	Slot start time = 0	0	1
EPS CTA, Momentary EPS CTA GTS	Slot start time	0	1
EPS CTA, not a WAKE superframe	SFNext	1	1

Slot Start time field contains the start time of the allocated slot. The value of this field is always an offset from the start of superframe and hence the start of transmission of beacon frame from the PNC. The resolution of this field is 8 μs and so the range is [0-524280] μs.

The end of each GTS slot is the start time of the next GTS slot minus the guard time indicated in the beacon.

7.4.11 Max CTAs

The max CTAs element shall be formatted as illustrated in Figure 32.

octets: 1	1	2	2
Element ID	Length (=4)	MaxAssignedCTAs	MaxProcessedCTAs

Figure 32—Max CTAs information element

The MaxAssignedCTAs field describes the maximum number of GTS slots that may be assigned to a DEV when the DEV is either the source or destination. The destination address may include group or multicast destinations.

The MaxProcessedCTAs field specifies the maximum number of CTAs that the DEV is able to process.

7.4.12 DEV GTS status

The DEV GTS status element shall be formatted as illustrated in Figure 33. This element is a 256 bit bitmap where each bit corresponds to an AD-AD. The DEV GTS status element may only be sent by the PNC in the beacon. The purpose of this information element is to enable a DEV to know if any GTSs where it is either the SA or DA have changed since the last beacon. If any of the GTSs for a given DEV has changed since the last beacon, the bit corresponding to the AD-AD for that DEV shall be set to a one. If none of the GTSs for that DEV have changed since the last beacon, the bit corresponding to the AD-AD for that DEV shall be set to zero. If a broadcast GTS has changed since the last beacon, only the broadcast GTS bit shall be set, and not all bits in the bitmap

octets: 1	1	8
Element ID	Length (=8)	(lsb) DEV GTS status bitmap (msb)

Figure 33—DEV GTS status information element

If a DEV correctly received beacon *n*, it does not need to process the CTAs in beacon *n+1* if it's DEV GTS status bit and the broadcast GTS status bit in beacon *n+1* are set to zero. If either it's DEV GTS status bit or the broadcast GTS status bit is set to one, then the DEV needs to process the CTAs in that beacon.

7.4.13 Power management parameters

~~The power management parameters element shall be formatted as illustrated in Figure 34. The purpose of this information element is to communicate the EPS information to the requesting DEV.~~

octets: 1	1	1	1	1	...	1
Element ID	Length (=2+n)	EPS info	EPS set 1	EPS set 2	...	EPS set n

Figure 34—Power management parameters element

~~The EPS set(s) are a listing of the numbers assigned by the PNC to all of the EPS set(s) to which the DEV belongs.~~

~~The EPS info field shall be formatted as illustrated in Figure 35.~~

bits: b0-b1	b2	b3-b7
PowerManagementMode	EPS status	Reserved

Figure 35—EPS info field

~~PowerManagementMode indicates the power management mode of the DEV. If the device uses EPS power management at any time during a session, this field is set to 2. If the DEV will only use RPS power management, this field is set to 1. If the DEV will not use any power management, the field will be set to 0. This field is the result of information provided to the DEV and PNC by the DEV host for use in this session.~~

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1 ~~EPS status indicates the current operation (EPS or ACTIVE) for an EPS DEV and has meaning for a DEV~~
 2 ~~with PowerManagementMode set = 2. A value of 1 is set if the DEV is currently in EPS mode. A value of 0~~
 3 ~~is set if the DEV is currently in ACTIVE mode.~~

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 5 **7.4.13 Traffic indication map (TIM) Information element**

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octets: 1	1	1	variable (1-32)
Element ID	Length	Start AD-AD	Traffic indication map (TIM)

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 14
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 16
 17 The TIM field is a bit map of 1 to 32 octets, with each bit when set to 1 indicating that there is traffic indicat-
 18 ing for a DEV whose AD-AD is equal to start AD-AD plus the bit position in the map.

19
 20 The bit corresponding to BC address (0xFF) indicates that there is broadcast frame(s) or GTS-request(s) is
 21 pending.

22
 23 The bit corresponding to MC address (0xFD) indicates that there is broadcast frame(s) or GTS-request(s) is
 24 pending.

25
 26 The bit corresponding the AD-AD of zero is reserved. Bits corresponding to ther reserved values of AD-AD
 27 are reserved. All the reserved bit positions shall be set to zero upon transmission by PNC and shall be
 28 ignored upon reception.

29
 30 **7.4.14 Application specific information**

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 32 The application specific information element (ASIE) shall be formatted as illustrated in Figure 37. The pur-
 33 pose of this information element is to allow custom information for enhanced operation that is outside of the
 34 scope of this standard.

35
 36
 37

octets: 1	1	1	variable
Element ID	Length	AD-AD	Application specific data

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 39
 40
 41 **Figure 37—Application specific information element**

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 43 The AD-AD is set by the PNC as the index of the application specific capable device that will make use of
 44 this information element.

45
 46 The application specific data is specified by the PNC. Its use by the application specific capable device is
 47 beyond the scope of this standard.

48
 49 More than one application specific information element (ASIE) may be placed in any beacon by the PNC.
 50 All ASIEs shall be the last information elements in the beacon. The ASIE shall only be used by the PNC
 51 after negotiating the application specific capability with a DEV using a standard a GTS or CFP message
 52 exchange. The negotiation of the application specific capability between the DEV and the PNC is beyond
 53

the scope of this specification. The use of the application specific data field of the information element is beyond the scope of this specification.

7.5 Command types

The command types are listed in Table 65. The individual commands are described in the following sub-clauses. No command frame shall be transmitted to or by an unassociated DEV within a piconet.

Table 65—Command types

Command type hex value	Command name	Sub-clause
0x0000	Delayed-ACK command	7.5.9.1
0x0001	Transmission sequence sync command	7.5.9.2
0x0002	Channel time request command	7.5.10.1
0x0003	Channel time grant command	7.5.10.2
0x0004	Probe request command	7.5.4.1
0x0005	Probe response command	7.5.4.2
0x0006	Repeater services request command	7.5.6.1
0x0007	Repeater service grant command	7.5.6.2
0x0008	Repeater service reject command	7.5.6.3
0x0009	Channel status request command	7.5.4.3
0x000A	Channel status response command	7.5.4.4
0x000B	Alternate PNC announcement command	7.5.1.1
0x000C	Alternate PNC pullout command	7.5.1.2
0x000D	New PNC announcement command	7.5.1.3
0x000E	PNC handover command	7.5.1.4
0x000F	Device information request command	7.5.8.1
0x0010	Device information response command	7.5.8.2
0x0011	Stream management command	7.5.10.3
0x0012	Association request command	7.5.2.1
0x0013	Association response command	7.5.2.2
0x0014	Disassociation request command	7.5.2.3
0x0015	EPS action request command	7.5.7.1
0x0016	EPS action response command	7.5.7.2
0x0017	DEV to PNC PS information command	7.5.7.3
0x0018	Switch to ACTIVE CTA mode command	7.5.7.4
0x0019	Switch to EPS CTA mode command	7.5.7.5

Table 65—Command types

Command type hex value	Command name	Sub-clause
0x001A	Momentary EPS CTA command	7.5.7.6
0x001B	Child or neighbor information response command	7.5.8.3
0x001C	Authentication request command	7.5.3.1
0x001D	Authentication response command	7.5.3.2
0x001E	Challenge request command	7.5.3.3
0x001F	Challenge response command	7.5.3.4
0x0020	Request key request command	7.5.3.5
0x0021	Request key response command	7.5.3.6
0x0022	Distribute key request command	7.5.3.7
0x0023	Deauthenticate request command	7.5.3.8
0x0024-0xFFFF	Reserved	

The commands shall always start on a 2-octet boundary within frame body. While encoding, if a command is not aligned to a 2-octet boundary, an extra octet with an all-zero value shall be placed after the last valid octet of that command to achieve the 2-octet alignment. However, the length field in the command shall contain only the number of valid octets and hence shall exclude the stuffed octet from its count. While decoding, the length field is used to know the number of octets that belong to the command. If the value of the length field is an odd number, then the octet following the last valid octet of the command shall be ignored before considering the next command.

7.5.1 PNC selection and handover commands

The PNC selection commands are used at the formation of a piconet to choose the PNC. There are three types of PNC selection commands, the alternate PNC announcement, alternate PNC pullout and new PNC announcement.

The ACK policy shall be set to request immediate acknowledgement when sent as a directed frame. Otherwise the ACK-policy bits shall be set to zero.

The frag-start, frag-end, retry, Del-ACK request, SEC and Repeater sub-fields in the frame control field of the MAC header of this frame shall be set to zeros and shall be ignored upon reception.

The DA is set to broadcast or a directed address. When sent as a directed frame, the intended recipient shall send an immediate acknowledgement frame if the frame is received correctly. The stream control and sequence number fields shall be set to zero and shall be ignored upon reception.

The PNC selection commands use the same configuration of the frame body and shall be formatted as illustrated in Figure 38.

octets: 2	2	2	1	1	1	1	6	2
Command Type	Length (=14)	Capability	Reserved	Max number GTS	Repeater memory	TX power level	Device ID	CSTimeout

Figure 38—PNC selection frame body

The capability field shall be formatted as illustrated in Figure 22 and is described in 7.4.3. This frame shall not be transmitted with the AC bit in the capability field set to 0.

The max number of GTS indicates how many GTSs the DEV is capable of allocating as a PNC.

The repeater memory field indicates the total memory (in Mbytes) that is available to the DEV to perform repeater service.

The TX power level indicates the maximum transmit power that is possible for the DEV. The power level is in dBm, encoded in 2s complement notation. For example, if a DEV was capable of 14 dBm TX power, the field would take on the value 0x0E while if the DEV was capable of -4 dBm TX power, the field would take on the value 0xFC.

The device ID is the 48-bit IEEE 802 address of the sender of this frame.

The CSTimeout is the time within which the other DEVs are expected to participate in the PNC selection process. This time duration is indicated in K μ s. A late joining, new DEV may extend this time via its frame which shall be adopted by all the currently participating DEVs.

7.5.1.1 Alternate PNC announcement command

This action type is used by all ACs to announce their capabilities that make them suitable for the responsibilities of PNC in the piconet.

7.5.1.2 Alternate PNC pullout command

An AC uses this action type to pullout of the multi-AC announcement session if it has received an announcement from another AC that is better suited to be the PNC in the piconet. The fields in the PNC selection frame body are compared for elimination of an AC from contest or pulling out of the multi-AC announcement. This process is described in 8.2.3.

7.5.1.3 New PNC announcement command

An AC uses this action type to announce itself as the winning PNC in a multi-AC announcement session if it is better suited as PNC in the piconet.

At the end of a PNC hand over, the new PNC of the piconet uses the PNC selection frame with this action type to signal the end of PNC hand over.

The CSTimeout in this frame indicates the time offset before which the first beacon from the winning AC shall be expected by the rest of the DEVs in the channel.

7.5.1.4 PNC handover command

The PNC shall use this command to hand over its responsibility to an associated DEV that is capable of being a PNC. The command structure shall be formatted as illustrated in Figure 39.

octets: 2	2	2	2	6	6	2
Command Type	Length (= 18)	Number of DEVs	Superframe duration	PNC device ID	AC device ID	Hand over time-out

Figure 39—PNC handover command format

The number of DEVs field indicates the total number of DEVs that are currently associated with the PNC.

The superframe duration is defined in sub-clause 7.4.2.

The PNC device ID is the device ID of the current PNC of the piconet.

The AC device ID is the device ID of the AC that is chosen to be the new PNC of the piconet.

The hand over time-out is the time by which the new PNC is expected to obtain the DEV information from the current PNC and start the beaconing process. The resolution of this field is 8 μs and therefore has a range of [0-524280] μs. The indicated time-out shall be with reference to the start of transmission of immediately previous beacon from the current PNC.

7.5.2 Association and disassociation

7.5.2.1 Association request command

Only a DEV that wishes to associate with the PNC of an already existing piconet shall send this command.

The ACK policy shall always be set to request immediate acknowledgement.

The frag-start, frag-end, retry, Del-ACK request, SEC and Repeater sub-fields in frame control field of the MAC header in this command shall be set to zeros and shall be ignored upon reception.

The DA shall always be set to all-zero address, meant to indicate the PNCs address. The SA shall always be set 0xFE to indicate the association-address.

The PNID values is set to the PNID of the piconet to which the DEV is attempting to associate.

The structure of the frame body for an association request command shall be formatted as illustrated in Figure 40.

octets: 2	2	6	2	2
Command type	Length	Device ID	Capability	ATP

Figure 40—Association request command format

The device ID field is the 48-bit IEEE 802 address of the DEV involved in the association.

The capability field is same as illustrated in Figure 22. This field describes the capabilities of the DEV.

The ATP (association time-out period) is the time-out, in ms, during which if the frames from PNC meant for the current DEV are not received at the DEV, the DEV disassociates and tries to associate again. Similarly, if PNC did not receive any frame originating from the current DEV within this time-out duration, the PNC may disassociate the DEV and expect the DEV to associate again.

7.5.2.2 Association response command

Only the PNC of an already existing piconet shall send this command and shall send the command only to a DEV that is currently trying to associate. The structure of the frame body for an association response command shall be formatted as illustrated in Figure 41.

octets: 2	2	6	1	1	2
Command type	Length	Device ID	Reason Code	AD-AD	ATP

Figure 41—Association response command format

The ACK policy shall always be set to zero and shall be ignored upon reception.

The frag-start, frag-end, retry, Del-ACK request, SEC and Repeater sub-fields in frame control field of the MAC header of this command shall be set to zeros and shall be ignored upon reception.

The SA shall always be set to an all-zero address which is the PNCs address. The DA shall always be set to 0xFE to indicate the association-address. Hence this command shall not be ACKed.

The device ID field is the 48-bit IEEE 802 address of the DEV involved in the association. When the PNC sends this command to the DEV, the PNC uses the field from the previously received association request from that DEV. Two or more DEVs trying for association at the same time distinguish the response command from the PNC by comparing their device ID to the device ID in the response command. If there is a match, the DEV uses the AD-AD as its address for all its future communications.

The AD-AD field is filled with the address allocated to the DEV if the association is successful. The address shall be in the valid range of addresses. The DEV shall start using that address as its address in the piconet during all its future communications until it is disassociated and hence required to associate again. If this field contains the association-address (0xFE), the DEV is not allowed to associate for the reason mentioned in the reason code. For the association of a neighbor PNC, the AD-AD shall be one of the reserved neighbor piconet IDs, 7.2.3.

The valid reason codes are:

- 0 -> Success
- 1 -> Already serving maximum number of DEVs
- 2 -> Lack of available bandwidth to serve the DEV
- 3 -> Channel is too severe to serve the DEV
- 4 -> PNC is turning off with no AC in the piconet
- 5 -> DEV wishes to disassociate
- 6 -> Channel change is in progress

- 7 -> PNC hand over is in progress
- 9-255 -> reserved

The ATP is the finalized value for the time-out period. This value may be different from that requested by the DEV in its association request command if the PNC is not able to support the value requested.

7.5.2.3 Disassociation request command

Either the PNC or an associated DEV may send the disassociation request command. The structure of the command shall be formatted as illustrated in Figure 42

octets: 2	2	6	1	1
Command type	Length (=8)	Device ID	Reason code	Reserved

Figure 42—Disassociation request command format

The device ID is the 48 bit IEEE 802 address of the DEV that is being disassociated.

The valid reason codes are:

- 0 -> DEV state has expired (Need to re-associate)
- 1 -> Channel is severe to serve the DEV
- 2 -> DEV is overshooting its allocated channel time
- 3 -> PNC is turning off with no AC in the piconet
- 4 -> DEV wishes to disassociate
- 5-> DEV authentication failed
- 6-255 -> reserved

7.5.3 Authentication and security commands

This set of commands is used to establish security and privacy functions between DEVs and a PNC in the piconet. In all cases involving the establishment and maintenance of security and privacy in the piconet, the PNC is defined as hosting the Piconet Security Manager (PSM) function in the piconet. Identically, the PNC, which is defined as hosting the PSM, shall always operate as the active security manager in a piconet.

7.5.3.1 Authentication request command

An associated DEV uses this command to request authentication within a piconet from the PNC.

The ACK policy shall be set to request immediate acknowledgement. The Del-ACK request, SEC and Repeater sub-fields in frame control field of the MAC header in this command shall be set to zeros and shall be ignored upon reception.

The authentication request command frame structure shall be formatted as illustrated in Figure 43

octets: 2	2	2	Variable
Command type	Length	PublicKeyObjectLength	DEVPublicKeyObject

Figure 43—Authentication request command format

The DEVPublicKeyObject may be simply a public key, a public-key certificate or some other construct that communicates public-key related information.

The PublicKeyObjectLength is the length in octets of the variable length DEVPublicKeyObject.

7.5.3.2 Authentication response command

The authentication response command is used by the PNC to respond to an authentication request command from the DEV.

The ACK policy shall be set to request immediate acknowledgement. The Del-ACK request, SEC and repeater sub-fields in frame control field of the MAC header in this command shall be set to 0 and shall be ignored upon reception.

The authentication response command frame structure shall be formatted as illustrated in Figure 51

octets: 2	2	2	Variable	1
Command type	Length	AuthenticationInfoLength	AuthenticationInfo	ResultCode

Figure 44—Authentication response command format

The AuthenticationInfoLength is the length in octets of the AuthenticationInfo parameter.

The AuthenticationInfo parameter is variable in length, as specified by the active cipher suite. The format of the information contained in the AuthenticationInfo parameter is also defined by the active cipher suite.

The ResultCode shall be set to 1 if the PNC accepts the DEV for authentication, and shall be set to 0 otherwise.

7.5.3.3 Challenge request command

The challenge request command is used to initiate a public key challenge from the PNC to an associated DEV. It includes a public key challenge that is dependent on the cipher suite that is being used and the public key of the PNC.

The ACK policy shall always be set to request immediate acknowledgement. The Del-ACK request, SEC and repeater sub-fields in frame control field of the MAC header in this command shall be set to 0 and shall be ignored upon reception.

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The challenge request command frame structure shall be formatted as illustrated in Figure 51

octets: 2	2	2	Variable	2
Command type	Length	PublicKeyChallengeLength	PublicKeyChallenge	AuthenticateFailureTimeout

The PublicKeyChallengeLength is the length in octets of the PublicKeyChallenge parameter.

The PublicKeyChallenge parameter is variable in length, as specified by the active cipher suite. The format of the information contained in the PublicKeyChallenge parameter is also defined by the active cipher suite

The AuthenticateFailureTimeout parameter is the maximum wait time in ms until the challenge request command issued by the DEV to the PNC is no longer valid.

7.5.3.4 Challenge response command

The challenge response command is used by an associated DEV to respond to a public key challenge from the PNC. It includes a public key proof that is dependent on the cipher suite that is being used.

The ACK policy shall always be set to request immediate acknowledgement. The Del-ACK request, SEC and repeater sub-fields in frame control field of the MAC header in this command shall be set to 0 and shall be ignored upon reception.

The challenge response command frame structure shall be formatted as illustrated in Figure 51

octets: 2	2	2	Variable
Command type	Length	PublicKeyProofLength	PublicKeyProof

Figure 46—Challenge response command format

The PublicKeyProofLength specifies the length in octets of the PublicKeyProof parameter.

The PublicKeyProof parameter is variable in length, as specified by the active cipher suite. The format of the information contained in the PublicKeyProof parameter is also defined by the active cipher suite.

7.5.3.5 Request key request command

The request key request command is used by an associated DEV to request the transmission of a key from the PNC.

The ACK policy shall always be set to request immediate acknowledgement. The Del-ACK request, SEC and repeater sub-fields in frame control field of the MAC header in this command shall be set to 0 and shall be ignored upon reception.

The request key request command frame structure shall be formatted as illustrated in Figure 51

octets: 2	2	1	1
Command type	Length (=2)	KeyPurpose	KeyRequestTime-out

The KeyPurpose specifies the purpose for which the key is intended to be used, as enumerated in the cipher suite list.

The KeyRequestTimeout parameter is the maximum wait time in ms until the request key request command issued by the DEV to the PNC is no longer valid.

7.5.3.6 Request key response command

The request key response command is used by the PNC to respond to an associated and authenticated DEV with either an encrypted version of the requested key or an indication that the key request was denied.

The request key response command frame structure shall be formatted as illustrated in Figure 51

octets: 2	2	1	1	2	Variable
Command type	Length	KeyPurpose	ReasonCode	EncryptedKeyObjectLength	EncryptedKeyObject

The KeyPurpose specifies the purpose for which the key is intended to be used, as enumerated in the cipher suite list.

The EncryptedKeyObjectLength is the length in octets of the EncryptedKeyObject.

The EncryptedKeyObject is a variable length object specified by the active cipher suite. The EncryptedKeyObject contains payload data key that may be encrypted using a public key or a symmetric private key, in a format defined by the active cipher suite.

The ReasonCode shall be set to 1 if the PNC accepts the request key request command from the DEV and shall be set to 0 otherwise.

7.5.3.7 Distribute key request command

The distribute key request command is used by the PNC to send a key to a specific DEV.

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The distribute key request command frame structure shall be formatted as illustrated in Figure 51

octets: 2	2	1	2	Variable	2
Command type	Length	KeyPurpose	EncryptedKey ObjectLength	EncryptedKeyObject	DistributeKey FailureTimeout

Figure 49—Distribute key request command format

The KeyPurpose specifies the purpose for which the key is intended to be used, as enumerated in the cipher suite list.

The EncryptedKeyObjectLength is the length in octets of the EncryptedKeyObject.

The EncryptedKeyObject is a variable length object specified by the active cipher suite. The EncryptedKey-Object contains payload data key that may be encrypted using a public key or a symmetric private key, in a format defined by the active cipher suite.

The DistributeKeyFailureTimeout parameter is the maximum wait time in ms until the distribute key request command issued by the PNC to the DEV is no longer valid.

7.5.3.8 Deauthenticate request command

The deauthenticate request command is used by the PNC to revoke the authentication of an authenticated and associated DEV.

The deauthenticate request command frame structure shall be formatted as illustrated in Figure 51

octets: 2	2
Command type	Length (=1)

Figure 50—Deauthenticate request command format

7.5.4 Information request commands

This set of commands is used to retrieve information from another DEV in the piconet. The probe commands deal with the information elements while the channel status commands return the remote DEVs view of the channel.

7.5.4.1 Probe request command

The probe request command is used either to request information about a DEV or to see if a DEV is still present in the piconet. This command may be exchanged between any two DEVs in the piconet. The individual information elements used in this frame are described in 7.4. The stream control field in the probe

request frame header shall be set to 0x00 and shall be ignored upon reception. The probe request command frame structure shall be formatted as illustrated in Figure 51

octets: 2	2	2	Variable
Command type	Length	Information request	Information elements

Figure 51—Probe request command format

The least significant 15 bits of the information request field is a bitmap to indicate the information requested of the destination of DEV. The sender sets a value of '1' in a bit to request the information element that corresponds to the bit position. Otherwise the sender sets the bit to '0'. The bit position for an information element is same as the value of the element-ID for that information element. That is, the bit position of 'n' in information request field corresponds the information element whose element ID, Table 63, is 'n'. An all-zero value in this field means that the source DEV is not expecting any probe information from the destination DEV, but is providing the information about itself to the destination DEV in the elements following this field. In this case, the destination DEV only ACKs the frame if it is received correctly and does not respond with a probe response command.

The most significant bit of information request field indicates that the rest of the bits in the field are not bit maps, instead they are binary coded to indicate the element ID of the information element that is being requested by the sender of this command from its intended recipient.

The information elements field is a list of the information elements described in 7.4. The elements themselves may be placed in any order and all the elements need not be present.

7.5.4.2 Probe response command

The probe response command is used to respond to an information request. This command may be exchanged between any two DEVs in the piconet. The individual elements used in this frame are described in 7.4. The stream control field in the probe request frame header shall be set to 0x00 and shall be ignored upon reception. The probe response command frame structure shall be formatted as illustrated in Figure 52

octets: 2	2	2	Variable
Command type	Length	Information Request	Information elements

Figure 52—Probe response command format

The information request field is defined in 7.5.4.1

The information elements field is defined in 7.5.4.1.

7.5.4.3 Channel status request command

The structure of the command shall be formatted as illustrated in Figure 53. This command may be sent by any DEV in the piconet to an other DEV in the piconet, including the PNC, to request the current channel condition as experienced at the requested DEV.

octets: 2	2
Command type	Length (=0)

Figure 53—Channel status request command format

7.5.4.4 Channel status response command

The structure of the command shall be formatted as illustrated in Figure 54. This command is sent by a DEV in response to the DEV that is requesting the channel status to let the requesting DEV know the current channel condition at the responding DEV.

octets: 2	2	2	2	2	2	2
Command type	Length (=10)	Measurement window size	TX frames count	RX frames count	RX error frames count	RX frames loss count

Figure 54—Channel status response command format

The measurement window size is the time duration, in $K\mu s$, during which the measurements were carried out.

The TX frames count is the total number of frames, not including Imm-ACK frames, that were transmitted by the sender of this command to the destination of this command.

The RX frames count is the total number of frames, not including Imm-ACK frames, that were correctly received by the sender of this command. Only the directed frames intended for this DEV are included.

The RX error frames count is the total number of frames, not including Imm-ACK frames, that were received in error by the sender of this command. A frame is considered to have been received in error if the header passes the HCS calculation but the frame body fails the FCS calculation.

The RX frame loss count is the total number of frames, not including Imm-ACK frames, that were detected as not having been received at the first attempt of their transmission. Only the expected, but not received, directed frames intended for this DEV are included. Loss of frame(s) for a given stream index is detected when the stream sequence number in a received frame corresponding to that stream is not one more than the sequence number indicated in the last received frame corresponding to the same stream. The difference between the new stream sequence number and the last stream sequence number received reduced by one gives the number of frames lost. These numbers are accumulated for all streams at a DEV and sent as receive frame loss count. The frames received with retry bit set are excluded from this calculation as it is not possible to determine the number of attempts made by the sending DEV before the frame is successfully received by the destination DEV.

7.5.5 Transmitter power

This group of commands is used to control the transmit power of DEVs.

7.5.5.1 Transmit power change

The transmit power control element shall be formatted as illustrated in Figure 55. This element is used to request a change in the transmit power of a DEV.

octets: 1	1	1
Element ID	Length (=1)	TX power change

Figure 55—Transmit power control (TPC) element

The TX power change field contains the requested TX power level change in dB at the destination DEV in 2s complement format. For example, a +2 db change in the TX power level is 0x02 while a -2 dB TX power level change is encoded as 0xFE.

7.5.6 Repeater service

This group of commands is used to request, grant or reject repeater service from the PNC.

7.5.6.1 Repeater services request command

The repeater services request shall only be sent by an associated DEV on the piconet and shall not be sent by the PNC. The structure of the command shall be formatted as illustrated in Figure 56.

octets: 2	2	6	12	12	...	12
Command type	Length (6 + (n * 12))	Destination device ID	CTRB for stream-1	CTRB for stream-2	...	CTRB for stream-n

Figure 56—Repeater services request/response command format

The destination device ID is the 48-bit IEEE 802 address of the DEV associated with the link for which the sender of this command is requesting repeater service by the PNC. If the destination device ID is a broadcast address, the request is for all links from/to the sender of the command. The format of channel time for a given stream shall be formatted as illustrated in Figure 76. The list of channel times includes all the link(s) originating from the sender of this command to the DEV(s) indicated by destination device ID.

7.5.6.2 Repeater service grant command

The repeater service grant command shall be sent only by the PNC. The command structure is the same as the repeater service request command, illustrated in Figure 56.

The destination device ID is that of the second DEV that is associated with the link for which the repeater service is granted. The format of channel time for a given stream shall be formatted as illustrated in Figure 76. The channel time fields indicate the total channel time for an indicated stream that has been allo-

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1 cated by the PNC for repeater service. If the DEV sends more frames than those that are able to be accom-
 2 modated in this allocated channel time, the extra frames are buffered and repeated whenever the channel
 3 time next becomes available.

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 5 **7.5.6.3 Repeater service reject command**

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 7 Either the PNC or the DEV that originally requested repeater-service may send the repeater service reject
 8 command. The structure of the command shall be formatted as illustrated in Figure 57.

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octets: 2	2	6	1
Command type	Length (=7)	Destination device ID	Reason code

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15 **Figure 57—Repeater service reject command format**

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 18 When PNC sends this command, the repeater service is being terminated between the DA of the frame con-
 19 taining this command and the DEV indicated in the destination device ID field.

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 21 When a member DEV sends this command, the repeater service is being rejected for the link between the SA
 22 and DA of the frame containing this frame. The destination device ID field contains the IEEE 48-bit address
 23 of the DA.

24
 25 The reason codes indicate the result of the repeater service request. Valid reason codes are:

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- 0 -> reserved
 - 1 -> already serving maximum number of DEVs
 - 2 -> lack of available bandwidth to serve the DEV
 - 3 -> channel is too severe to serve the DEV
 - 4 -> PNC is turning off with no AC in the piconet
 - 5 -> channel change is in progress
 - 6-> PNC hand over is in progress
 - 7-255 -> reserved
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36 **7.5.7 Power management commands**

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 38 **7.5.7.1 EPS action request command**

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 40 ~~The EPS action request command shall be formatted as illustrated in Figure 58. This command is used to~~
 41 ~~create and maintain EPS sets as well as EPS set membership. When an EPS set is confirmed as created, the~~
 42 ~~PNC shall begin keeping the time base specified for that EPS set.~~

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octets: 2	2	1	1	2	4
Command type	Length (=2 to 8)	Action type	EPS set value	EPSTime	EPSNext

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50 **Figure 58—EPS action request/response command format**

The value of the action type determines the length of the command since the EPSTime and EPSNext fields may be left out for certain action types. The valid request types and the corresponding values for EPS set, EPSTime and EPSNext are given in Table 66.

Table 66—EPS action request command entries

Action type	Action type value	EPS set value	EPSTime and EPSNext
Release request	0	Value required	Not present
New request	1	Set to 0	Required
Place in set	2	Value required	Not present
Information request	3	Value required	Not present
Reserved	4-255		

The EPS set value is a octet that is assigned by the PNC to a group of DEVs that share the same EPSTime and EPSNext.

The EPSTime has a range of 0 to 65,535 ms. A value of zero indicates that the DEV is waking for each superframe. Depending on the value of superframe duration parameter, values of EPSTime that are less than the current value of superframe duration indicate that the DEV wakes for each superframe. Since the wake time is bounded by superframe beacon location, the beacon start point immediately preceding the completion of EPSTime shall be the wake point.

EPSNext is a beacon number as defined in piconet synchronization parameters element, 7.4.2. EPSNext informs the PNC or DEVs when the next EPSTime will occur. For this command, the value of EPSNext is taken from the EPSSync parameter in the MLME_POWERMGT.request primitive. The current beacon number when that primitive is received by the SME is used to calculate the beacon number for the next EPSTime event and inserts that beacon number as EPSNext when building the EPS action request command.

7.5.7.2 EPS action response command

The EPS action request command shall be formatted as illustrated in Figure 58. This command is used to create and maintain EPS sets as well as EPS set membership. When an EPS set is confirmed as created, the PNC shall begin keeping the time base specified for that EPS set.

The definitions of the EPS set value, EPSTime and EPSNext fields in the command are the same as for the EPS action request, 7.5.7.1.

The value of the action type determines the length of the command since the EPSTime and EPSNext fields may be left out for certain action types. The valid action types for an EPS action response and the corresponding values for EPS set, EPSTime and EPSNext are given in Table 67.

7.5.7.3 DEV to PNC PS information command

The structure of this command shall be formatted as illustrated in Figure 59. Each DEV in the piconet using either EPS or RPS modes shall inform the PNC via this command. The mode is provided as is the priority information. The command may be sent at any time but it shall be sent prior to the channel time request

Table 67—EPS action response command entries

Action type	Action type value	EPS set value	EPSTime and EPSNext
Release confirm	0	Value released	Not present
New confirm	1	New value provided	Not present
Place in set confirm	2	Value of set place	Not present
Return information on the EPS set response	3	Value required	Part of reply
Incorrect command length	4	Set to 0	Not present
Already a member	5	Set to 0	Not present
EPS set does not exist	6	Set to 0	Not present
Cannot create new set	7	Set to 0	Not present
Illegal command	8	Set to 0	Not present
Reserved	9-255		

command that this should apply to. The command may be repeated during the association of the DEV in the piconet if DEV requirements change.

octets: 2	2	1	1
Command type	Length (=2)	PowerManagementMode	PowerManagementPriority

Figure 59—DEV to PNC PS information command format

The PowerManagementMode value shall be 1 for RPS mode and 2 for EPS mode for the DEV sending the message. All other values are reserved.

PowerManagementPriority value shall be 1 for low priority, 2 for medium priority, and 3 for high priority. PowerManagementPriority is an indication of battery sensitivity. It is used by the PNC to allocate CTA locations. A PowerManagementPriority value of high indicates a very battery sensitive device requiring optimal CTA locations. All other values are reserved.

7.5.7.4 Switch to ACTIVE CTA mode command

The structure of this command shall be formatted as illustrated in Figure 60. The switch to ACTIVE CTA mode command is sent by a DEV that wishes to send and receive data after being asleep in EPS mode. The purpose of this command is to instruct the PNC to use the previously determined Channel time request for ACTIVE mode. Additional destination DEV addresses operating with same EPS set may be appended to

this command. Optionally, the sending device may send a zero length command to the PNC for self wake only.

octets: 2	2	0-n
Command type	Length (=n)	Destination DEV addresses

Figure 60—Switch to ACTIVE CTA mode command format

The destination DEV addresses are the AD ADs of the DEVs that will switch from EPS to ACTIVE mode.

7.5.7.5 Switch to EPS CTA mode command

The structure of the command is indicated in Figure 61. To indicate to the PNC, the Switch to EPS CTA mode command is initiated by the originating DEV. The use is to instruct the PNC to use the previously determined channel time request for EPS mode. Additional destination DEV addresses operating with same EPS set may be appended to this command. Optionally, the sending device may send a zero length command to the PNC for self sleep only.

octets: 2	2	0-n
Command type	Length (=n)	Destination DEV addresses

Figure 61—Switch to EPS CTA mode command format

The destination DEV addresses are the AD ADs of the DEVs that will switch from ACTIVE to EPS mode.

7.5.7.6 Momentary EPS CTA command

The structure of the command shall be as illustrated in Figure 62. This command instructs the PNC to use the EPS CTR slot size in the EPS CTA of the next WAKE beacon. This substitution is only in effect for one EPS superframe. If the WAKE beacon already has an EPS slot, there is no change to the CTA, and if the EPS CTA scheduled was a null CTA, then the null CTA shall be replaced with a non zero CTA, the length specified by the EPS CTR for that DEV.

octets: 2	2
Command type	Length (=0)

Figure 62—Momentary EPS CTA command format

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7.5.7.1 Sleep time request

A DEV that is associated with a PNC indicating its intention to use EPS state during the association state shall use this command to obtain permission to enter EPS state. The command structure is illustrated in Figure 63.

octets: 2	2	2
Command Type	Length (= 2)	Requested EPS state duration (in TU)

Figure 63—Sleep time request command format

The requested EPS state duration is the length of time that the DEV is wishing to sleep.

7.5.7.2 Sleep time permit

PNC shall use this command to permit a requesting DEV to enter EPS state. The requesting DEV shall enter the EPS state only after it has successfully acknowledged this command from the PNC. The command structure is illustrated in Figure 64.

octets: 2	2	2
Command Type	Length (= 2)	Max EPS state dura- tion (in TU)

Figure 64—Sleep time permit command format

The max EPS state duration is the length of time that the PNC is agreeing to allow the DEV to sleep.

7.5.7.3 Sleep time reject

PNC shall use this command to reject a requesting DEV to enter EPS state. The requesting DEV shall not enter the EPS state if it receives this command from the PNC. The command structure is illustrated in Figure 65.

octets: 2	2	1	1
Command Type	Length (= 2)	reserved	Reason code

Figure 65—Sleep time reject command format

Allowed reason codes to reject the EPS state for a DEV are listed below.

- 0 -> No resources available
- 1 -> Channel change is in progress
- 2 -> PNC hand over is in progress

- 3 -> Pending buffered frames or a GTS-request from previous EPS state
- 4 -> BC/MC traffic or GTS-request for BC/MC traffic pending
- 5-> Unknown reason
- 6-255-> Reserved

7.5.8 Device information

This group of commands is used to request and provide information about any or all of the currently associated DEVs.

7.5.8.1 Device information request command

Only a DEV shall send the device information request command. The structure of the command shall be formatted as illustrated in Figure 66.

octets: 2	2	6
Command type	Length (=6)	Queried device ID

Figure 66—Device information request command format

The queried device ID is the device ID of the DEV whose information is being requested from the PNC. If this field has a broadcast address, then the DEV is requesting the entire list at the PNC.

7.5.8.2 Device information response command

Only a PNC sends the device information response command. This command may be sent either as a response to the device information request by a DEV or it may be sent unsolicited. This command may be sent in a directed command frame to a DEV or it may be sent in a broadcast command frame meant for all DEVs in the piconet.

octets: 2	2	2	Variable	Variable	---	Variable
Command type	Length	Number of records (= m)	Record for DEV-1	Record for DEV-2	...	Record for DEV-m

Figure 67—Device information response command format

The record field shall be formatted as illustrated in Figure 68.

octets: 1	1	6	2	2	12	12	...	12
AD-AD	EPS info	Device ID	Capability field	Number of TX slots (= n)	CTRB for stream-1	CTRB for stream-2	...	CTRB for stream-n

Figure 68—Format of a record in device information response command

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The AD-AD is the address assigned to the DEV. This field is an all-zero value for the record corresponding to the PNC.

~~The EPS info field shall be formatted as illustrated in Figure 35 and is defined in 7.4.13.~~

The device ID is for the DEV whose allocations are given in the record.

The capability field shall be formatted as illustrated in Figure 22 and is defined in 7.4.3.

The number of TX slots is the number of allocated transmission slots for the DEV within each superframe.

The CTRB is the channel time request block for a given stream which shall be formatted as illustrated in Figure 76.

7.5.8.3 Child or neighbor information response command

This command, following the same response rules as the device information response command, defined in 7.5.8.2, uses the structure illustrated in Figure 69.

octets: 2	2	12	12	...	12
Command type	Length (=n*12)	Record for child or neighbor PNC	Record for child or neighbor PNC	...	Record for child or neighbor PNC

Figure 69—Child or neighbor information response command format

The record field shall be formatted as illustrated in Figure 70.

octets: 1	1	6	1	1	2
Type ID	Stream index	Neighbor PNC Device ID	Duration between time slots	Minimum requested channel time in a time slot	Requested channel time per time slot

Figure 70—Child or neighbor PNC information response record

The type ID shall be 0x01 for a child piconet and 0x02 for a neighbor piconet.

The duration between transmissions indicates the requested frequency of time slots that needs to be allocated for the DEV. The resolution of this field is $K\mu\text{s}$.

The minimum requested channel time is the minimum duration of the time that is acceptable at the requesting DEV in any time slot. The resolution of this field is 32 ms and so the range of this field is [0-8160] μs .

The requested channel time is the time required at the DEV in every time slot for transmission of the indicated stream. Hence this field represents the time required for the given stream and not necessarily for the entire superframe. The resolution of the channel time field is 8 μs and so the range of requested time is range [0-524280] μs .

7.5.9 Retransmission

This group of commands is used in the retransmission process for frames in connected streams.

7.5.9.1 Delayed-ACK command

Only the DEV that is receiving a unicast stream addressed to it shall send a delayed-ACK command. The command structure shall be formatted as illustrated in Figure 71.

octets: 2	2	9	9	...	9
Command type	Length (=9*n)	Record for stream-1	Record for stream-2	...	Record for stream-n

Figure 71—Delayed-ACK command format

The record for a stream shall be formatted as illustrated in Figure 72.

octets: 1	2	2	4
stream index	Start Sequence Number	End Sequence Number	RX status bitmap

Figure 72—Format of a record in delayed-ACK command

The stream index field is a 1-octet field that identifies stream of the MPDUs being acknowledged by this record. There may be more than one record with the same stream index in a given delayed-ACK command frame, if more than 32 frames from that stream require acknowledgement and/or negative acknowledgement.

The start sequence number is a 2-octet field that contains the sequence number of the first frame reported in the RX status bitmap.

The end sequence number is a 2-octet field that contains the sequence number of the last frame reported in the RX status bitmap.

The RX status bitmap is a 4-octet field in which each bit indicates the reception status of a frame within the specified stream. The RX status bitmap bit number 0 indicates the reception status of the frame with the sequence number contained in the start sequence number field and subsequent bits indicate the reception status of frames with the next 31 sequentially ascending sequence numbers. RX status bitmap bits set to 1 indicate frames that have been received successfully, whereas bits set to 0 indicate frames that have not yet been successfully received (and which may not have been sent).

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7.5.9.2 Transmission sequence sync command

Only the DEV that is transmitting a unicast stream addressed to some other DEV in the piconet shall send a transmission sequence sync command. The command structure shall be formatted as illustrated in Figure 73.

octets: 2	2	3	3	...	3
Command type	Length = 4 * m	Record for stream-1	Record for stream-2	...	Record for stream-m

Figure 73—Transmission sequence sync command format

The record for a stream shall be formatted as illustrated in Figure 74.

octets: 1	2
Stream index	Start sequence number

Figure 74—Format of a record in transmission sequence sync command

The stream index is a 2-octet field that identifies stream that is being re-synchronized between the sending and receiving DEVs.

The start sequence number is a 2-octet field that contains the sequence number of the first frame that shall be expected after this command frame.

7.5.10 Request and modify GTS allocations

This group of commands is used for the request and grant of time slots within the CFP.

7.5.10.1 Channel time request command

The channel time request command structure shall be formatted as illustrated in Figure 75. Each block of 9 octets corresponds to channel time requested for a particular stream. The DEV that sends this command is

the originator and is seeking to allocate channel time to communicate with the target DEV. The format of a channel time request block for a given stream shall be formatted as illustrated in Figure 76.

octets: 2	2	12	12	...	12
Command type	Length (n * 10) +pad	Channel time request block for stream-1	Channel time request block for stream-2	...	Channel time request block for stream-n

Figure 75—Channel time request command format

octets: 1	1	1	1	2	2	2	2
Target AD-AD	CTRB type	EPS set	Stream index	Allocation period	Minimum GTS time	Desired GTS time	Maximum allocation delay

Figure 76—Channel time request block for a particular stream

The target AD-AD is the AD-AD of the DEV for which the originator DEV is requesting a channel time for communication.

~~CTRB type indicates whether the CTA requested is for ACTIVE mode channel time or EPS mode channel time. The PNC shall maintain separate ACTIVE mode type CTAs and EPS mode type CTAs. Values of 0, or 1 are used for making ACTIVE mode channel time requests, and the value of 2 is used for making EPS mode channel time requests. All other values of CTRB type are reserved. CTA management is discussed in 8.13.3.5.~~

~~For a device without EPS capability a value of 0 shall be used for an ACTIVE mode channel time request. For an EPS capable device, a value of 0 or 1, shall be used for an ACTIVE mode channel time request and a value of 2 shall be used for an EPS mode channel time request.~~

~~The difference between using a 0 and a 1 CTRB type is the persistence of the CTR. The values 0 and 1 are used to tell the PNC whether it should delete this CTR when the switch to EPS mode command is received by the PNC. A 0 indicates that the PNC shall delete this CTR and de-allocate the associated channel time, and a 1 indicates that the PNC shall retain the CTR, and if possible, return the channel time to the DEV when the PNC it the device returns to ACTIVE mode from EPS mode.~~

~~The CTRB type value of 2 is used to create an EPS channel time request. The PNC shall create and retain this EPS CTR based on this request.~~

~~The EPS set is the one for which this channel time is requested if the CTRB type indicates that this is for an EPS mode CTA. The DEV that sends this command shall be a member of EPS set before it sends this request for an EPS mode CTA. The use of this field for EPS CTRs is described in 8.13.3.4~~

~~The stream index indicates the stream for which the channel time is being requested or modified. This field is defined in 7.2.4.~~

~~The allocation period has different meanings depending on the value of the CTRB type field.~~

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If the CTRB type field indicates that this request is for an EPS mode channel time request, then the allocation period is an integer, N, ranging from 1-65535 that indicates what fraction, 1/N, of the EPS slots require this allocation. A zero value is not allowed for this field and shall cause the command to be ignored by the recipient.

Otherwise, the allocation period is for an ACTIVE mode CTA and defined as the block of time that the DEV is using to calculate the other parameters in this block. The resolution of this field is 1 ms and so the range of this field is [0-65535] ms.

The minimum GTS time is the minimum duration of the time that is acceptable at the requesting DEV in any time slot. The resolution of this field is 8 μs and so the range of this field is [0-524280] μs.

The desired GTS time is the amount of time that the DEV would prefer to have allocated. The resolution of this field is 8 μs and so the range of this field is [0-524280] μs.

The maximum allocation delay defines the allowable time jitter in the allocation of the GTSs with respect to the allocation period. The value 0xFFFF indicates that the DEV has no jitter requirements for the GTS. The resolution of the channel time field is 8 μs and so the range of requested time is [0-524272] μs.

The relationship of the allocation period, minimum GTS time, desired GTS time and maximum allocation delay is discussed in B.2.

7.5.10.2 Channel time grant command

This command lists the channel time allocations granted or rejected to the addressed DEV in response to a channel time request command. The format of a channel time grant command shall be formatted as illustrated in Figure 77.

octets: 2	2	6	1	6	1	...	6	1
Command type	Length (= n*7)	CTA element 1	Grant status 1	CTA element 2	Grant status 2	...	CTA element n	Grant status n

Figure 77—Channel time grant command format

The CTA element is defined in 7.4.10.

The grant status field format shall be formatted as illustrated in Figure 78.

bits: b0-b15	b16-b9	b20-b23
SFNext	Reason code	Reserved

Figure 78—Grant status field format

The reason code field is defined in 7.5.10.3.

The SFNext indicates the start time of the next GTS. The definition of this field is the same as that of the slot start time in 7.4.10.

The channel time allocations that have been announced in the immediately preceding beacon at the beginning of the CFP shall not be changed using this command.

7.5.10.3 Stream management command

The stream management command is used for setting up, tearing down and negotiating parameters of a stream in the piconet. This command may be used by the DEVs that are involved in transmitting or receiving a unicast stream and by the PNC of the piconet.

octets: 2	2	1	1	1	1	2	20
Command type	Length (=26)	Stream request identifier	Originator AD-AD	Target AD-AD	Max Frames (Del-ACK)	Control Information	Stream QoS parameters

Figure 79—Stream management command format

The stream request index is a 1-octet field containing the unique identifier that is generated by the DEV that originates the stream connection request (see the action type below). This chosen identifier is always used in conjunction with the allocated address of the requester. This identifier shall remain constant in the entire frame exchange sequence regarding the connection of the intended stream.

The originator AD-AD is the allocated address of the DEV that is the originator of the stream management command.

The target AD-AD is the allocated address of the DEV that is the target of the stream management command.

The max frames field specifies the maximum number of frames that are able to be outstanding when the ACK policy for the stream is Del-ACK.

The control information field shall be formatted as illustrated in Figure 80.

bits b0:b1	b2:b3	b4:b6	b7	b8:b11	b12	b13-b15
Action Type	ACK Policy	Security	Direction	Reason code	GTS type	Reserved

Figure 80—Control information field in the stream management command

The action type is a 2-bit field with the following values.

- A value of '0' indicates that this is a request for stream connection. This request is sent from the DEV that originates the stream management request to the PNC.
- A value of '1' indicates that this is a forwarded request frame sent from the PNC to the target of the stream. This command contains the QoS-parameters set by the PNC, except for the retransmission window.
- A value of '2' indicates that this is a response to the stream connection. This is sent from the target DEV to the PNC. The target DEV may modify the QoS-parameters to smaller values in the response.
- A value of '3' indicates that this is a confirmation of the acceptance of the stream connection. This request is sent by the PNC to the originator DEV to complete the stream connection.

- 1 — A value of “4” indicates that the frame is sent by one of the DEVs to the PNC to reject or disconnect
- 2 the stream
- 3 — A value of “5” indicates that the frame is sent by the PNC to one of the DEVs to reject or disconnect
- 4 the stream

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6 The ACK policy is a 2 bit field as defined in 7.2.1.2.

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8 The security field is a 3-bit field that <TBD>

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10 The direction field value of ‘1’ means that the stream is being transmitted from the DEV that sent the com-
11 mand. The value of ‘0’ means that the stream is being received.

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13 The reason code is a 4 bit field that is valid when a stream connection is being completed, rejected or discon-
14 nected. It is also valid in the response from the target to the PNC. Otherwise this field shall be ignored. Valid
15 reason codes are:

- 16 — 0 -> success
- 17 — 1 -> invalid stream parameters
- 18 — 2 -> non-negotiable stream parameters
- 19 — 3 -> system resources unavailable
- 20 — 4 -> insufficient channel time available
- 21 — 5 -> currently disassociating from the piconet
- 22 — 6 -> too many streams
- 23 — 7 -> lack of required security
- 24 — 8 -> unauthorized stream
- 25 — 9-> stream rejected or disconnected by other DEV
- 26 — 10 -> target unreachable
- 27 — ~~11 -> not a member of requested EPS set~~
- 28 — 11-16-> reserved

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31 The GTS type bit is set by the requesting DEV and shall be set to 0 for dynamic GTSs and shall be set to 1
32 for pseudo-static GTSs.

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The stream QoS parameters for the stream that is being established shall be formatted as illustrated in Figure 81.

octets	Parameter
2	Stream control field
2	Inter-time slot duration
2	Minimum requested channel time in a time slot
2	Requested channel time per time slot
1	Max TX delay variation
1	Reserved
2	Minimum rate
2	Peak rate
2	Average rate
2	Max burst size
2	Average frame size
1	Max ReTX duration
2	Receive window size

Figure 81—Stream QoS parameters in stream management command

The stream control field is defined in 7.2.4. The stream index is set to zero in all of the stream management commands meant for a stream whose index is not yet issued by the PNC. The priority field in stream control field is set by the original requestor and shall remain the same in all the stream management commands related to the same stream.

The inter-time slot duration indicates the requested frequency of time slots that needs to be allocated for the DEV. The resolution of this field is 8 μ s and so the range of this field is [0-524280] μ s.

The minimum requested channel time is the minimum duration of the time that is acceptable at the requesting DEV in any time slot. The resolution of this field is 8 μ s and so the range of this field is [0-524280] μ s.

The requested channel time is the time required at the DEV in every time slot for transmission of the indicated stream. Hence this field represents the time required for the given stream and not necessarily for the entire superframe. The resolution of the channel time field is 8 μ s and so the range of requested time is [0-524280] μ s.

The max TX delay variation indicates the maximum transmit delay that is tolerated, in K μ s.

The minimum rate indicates the minimum data rate, in Koctets/s.

The peak rate indicates the maximum data rate, in Koctets/s.

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The average rate indicates the average data rate, in Koctets/s.

The max burst size indicates the maximum burst size, in octets.

The average frame size indicates the average size of the frame, in octets.

The max ReTX duration indicates the time, in $K\mu s$, over which the retransmission of the frame is not needed. The value '0' in this field means no retransmission is required and a 0xFF value indicates that retransmission shall continue indefinitely to attempt to provide completely reliable transmission of the stream.

The receive window size indicates the size of the receive buffer, in kilo-octets. The receive-window in the command from a source DEV is always a request to the destination DEV. The destination DEV makes the final decision on the receive window.

8. MAC Functional Description

8.1 Introduction

This clause provides a description of the MAC functionality. The process of starting or associating with a piconet is described in sub-clause 8.2. As a part of starting the piconet, sub-clause 8.2.3 describes the PNC selection process. If there is more than one DEV that is capable of performing PNC activities in a piconet, those DEVs compare capabilities to determine which one will be the PNC during the start of a piconet. When the current PNC is going away, it will attempt to choose a DEV in the piconet that is capable to be the new PNC. This coordination handover mechanism is described in sub-clause 8.2.7. If there are no alternate PNCs are available, then the piconet ceases operation.

The channel access mechanisms are described in sub-clause 8.4. There are two different mechanisms used for channel access, contention based and contention free. In the contention access period (CAP), DEVs access the channel in a distributed style as described in sub-clause 8.4.2. On the other hand, the PNC controls all the accesses to the channel during the contention free period (CFP), as described in sub-clause 8.4.3. The PNC allocates channel time within the CFP for each DEV in the piconet, based on the currently pending requests by all the DEVs in the piconet and the available channel time within the CFP. The channel time request and allocation procedures are described in sub-clause 8.6. The required synchronization for the operation of the piconet and the channel access is described in sub-clause 8.5.

The process of stream connection, disconnection and the rest of the stream management are described in sub-clause 8.6. The fragmentation and defragmentation of the MSDUs at a DEV is described in sub-clause 8.7. The acknowledgement and retransmission mechanisms are described in sub-clause 8.8.

If the link between two DEVs is not satisfactory, then either of the DEVs are able to request that the PNC provides the repeater service for that entire link. The repeater service is described in sub-clause 8.11. To overcome the problems due to overlapping piconets and interference in a given channel, the PNC may choose to move the operations of the piconet to a new channel. The process of dynamic channel selection (DCS) is described in sub-clause 8.12. The DEVs in the piconet may employ power saving techniques to reduce their power consumption. The operation and the negotiations required for power management are described in sub-clause 8.13. Each DEV in the piconet may choose transmission power based on the current channel conditions. The operation and the negotiations required for such transmit power control (TPC) are described in sub-clause 8.14.

The frame exchange sequences at the MAC layer are described in sub-clause 8.15.

In this clause, unless otherwise indicated, receiving a frame means that the PHY has successfully received a data stream over the medium and both the FCS and HCS calculations match their respective data as defined in 7.2.6 and 11.2.8.

8.2 Starting piconets and maintaining piconets

A DEV that is instructed to start a piconet through MLME-START.request, 6.3.12.1, shall try only to start its own piconet and shall not attempt to associate with an existing piconet.

8.2.1 Scanning through channels

All DEVs shall use passive scanning to detect an active piconet. That is, DEVs shall be in the listen mode for a period of time in a channel, as specified in the MLME-SCAN.request, 6.3.2.1, or MLME-START.request command, 6.3.12.1, and look for beacon frames from a PNC. If open scan is specified in the MLME-SCAN.request, the DEV shall perform open scan. In open scan, the DEV searches for any PNID. If open

1 scan is not specified, the DEV shall ignore all the received frames with a different PNID than the one for
2 which the DEV is searching.
3

4 DEVs search for the piconet by traversing through all the indexed channels available in the PHY. For the 2.4
5 GHz PHY the available channels are specified in 11.2.3. A DEV may search the channels in any order as
6 long as all valid channels are contained in the search pattern. While searching, if any frame is received with
7 the desired PNID, the searching DEV shall stay in the channel for a minimum of a `aMinChannelScan` from
8 the time of reception of last frame and look for a beacon from the PNC. If the beacon frame from the PNC is
9 received, the scan is considered complete and the DEV shall return the piconet information via the `MLME-`
10 `SCAN.confirm`, 6.3.2.2. If the scan is an open scan, then DEV shall scan all indicated channels to find pico-
11 nets before returning the scan information via the `MLME-SCAN.confirm`.
12

13 While searching, if the DEV receives a PNC selection frame from another DEV, the searching DEV shall
14 stay in the same channel until the PNC selection is complete. If the searching DEV is allowed to start its own
15 piconet, then the DEV shall participate in the PNC selection process.
16

17 If all the channels are traversed and no frames with the desired PNID is received in any channel, then the
18 DEV takes one of two actions depending on the `MLME-SAP` command that initiated the scan. If the instruc-
19 tion through `MLME-SAP` allowed the start of its own piconet, then the DEV shall choose a channel and start
20 the PNC selection process in that channel. If, however, the `MLME-SAP` command was only to associate
21 with a piconet, then the MAC shall return a fail indication through `MLME-ASSOCIATE.indicate` primitive.
22

23 Channel change after the piconet is started is described in sub-clause 8.12.
24

25 **8.2.2 Randomization of PNID**

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27 The seed for generating a randomized PNID shall be the 48 bit PNC device ID. The randomization process
28 required to choose a unique PNID is beyond the scope of this standard.
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30 **8.2.3 PNC selection process**

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32 The PNC selection process begins with one AC sending an alternate PNC selection command, defined in
33 7.5.1.1, in a channel where there is currently no other active 802.15.3 piconet. The AC initiating this process
34 shall send the alternate PNC selection command for at least `aCSFrameRepeat` inviting other capable ACs to
35 participate. At the end of the indicated time-out in its PNC-selection frame, the AC shall start sending a bea-
36 con to start its own piconet if there are no other participants. During the indicated time-out the AC shall
37 broadcast the PNC-selection frame at least once in every `aCSFrameBroadcast` time period. The process of
38 PNC selection is illustrated in Figure 78.
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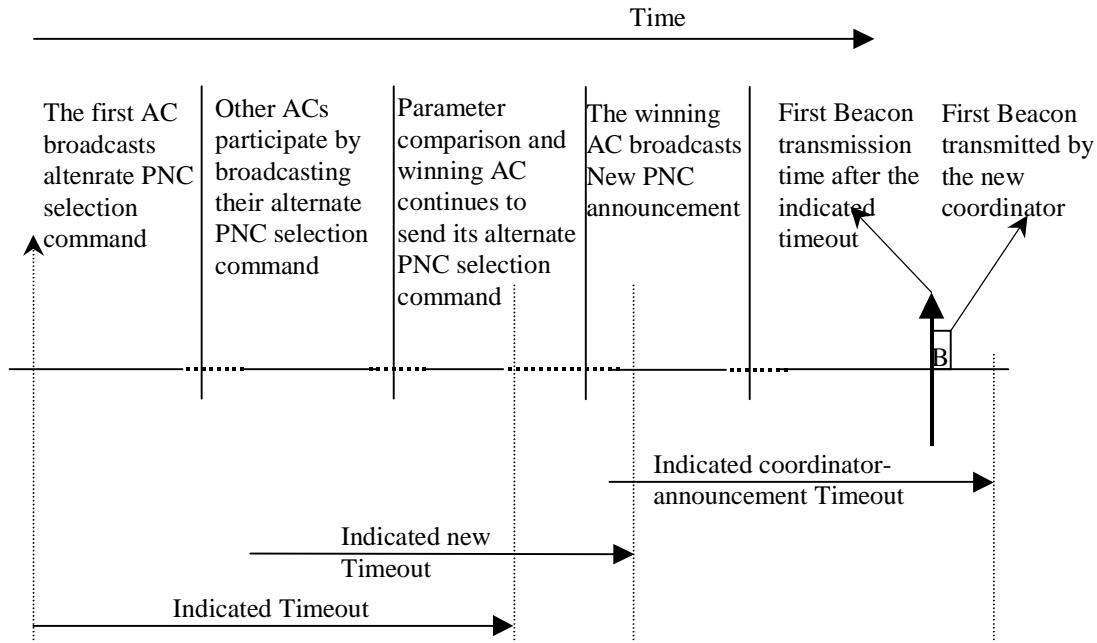


Figure 78—Illustration of coordination selection process

If more than one AC participates in the PNC selection process, then the AC receiving an alternate PNC selection command from another AC shall compare the received PNC selection parameters with its own using the evaluation criteria defined in Table 68. If the AC finds that its parameters score higher than the received ones, the AC shall continue to broadcast the PNC-selection frame. If the AC finds that its parameters score lower than the ones received, the AC shall no longer send the alternate PNC selection command and wait for the piconet to start within the last received indicated time-out. Thus the DEV with the highest capabilities will be chosen as the PNC. The Device ID acts as a tie breaker for DEVs with identical capabilities since it is unique for each DEV. In this case the highest Device ID will be chosen as the PNC.

Table 68—Comparison order of fields in AC-announcement command

Order	Information	Note
1	Designated mode bit in capability field	PNC designation is preferred
2	SEC bit in capability field	SEC=1 is preferred
3	PSRC bit in capability field	PSRC=1 is preferred
4	PSAVE bit in capability field	PSAVE=1 is preferred
5	Max number GTS	Higher value is preferred
6	Repeater memory	Higher value is preferred
7	Transmitter power level (PHY dependent)	Higher value is preferred
8	MAX PHY rate (PHY dependent)	Higher value is preferred
9	Device ID	Higher value is preferred

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As Table 68 shows, PNC Des-Mode is the top priority field in the PNC selection criteria. Since the PNC Des-Mode is the highest priority, a DEV with this bit set is more likely to become the PNC of the piconet. Thus, this bit should be set if it is desirable for the DEV to be the PNC of the piconet. If only one DEV has the PNC Des-Mode set, then that DEV would become the PNC. If two or more DEVs that are competing to become the PNC and all have the PNC Des-Mode bit set, then rest of the capabilities are used to determine which of the DEVs will be the PNC.

When no other AC is announcing its intention to compete, the winning AC shall broadcast a new PNC announcement command, 7.5.1.3, with a time-out indicated. The winning AC may announce this more than once via the new PNC announcement command before the indicated time-out. The winning AC shall take the responsibility of the PNC and start beacons before the indicated time-out.

8.2.4 Coordination handover

If during the life of a piconet the PNC decides to leave the piconet, the PNC shall attempt to choose a DEV that is capable of being a PNC as its successor. The AC bit in the capability field, 7.4.3, is used to decide whether a DEV is capable of being a PNC. The PNC shall use the capabilities information in the DEV-info table, 7.5.8, with the evaluation criteria defined in Table 68 to select the most qualified AC that is currently associated in the piconet to be the new PNC. The PNC shall send a PNC handover command, 7.5.1.4, to its chosen DEV with an indication of the handover time-out. The minimum handover time-out is aMinHandOvrTO and the maximum handover time-out is aMaxHandOvrTO. The DEV shall always accept the nomination and obtain the DEV information from the current PNC within the indicated time-out period. The new PNC shall announce its new responsibility as PNC in at least aCHFrameRepeat of the superframes before the indicated time-out period. The new PNC shall send its first beacon at the first expected beacon transmission time after the time-out period indicated in the PNC handover command. The new PNC shall begin using address of 0x00 for all PNC related traffic, but it shall continue to use its previously assigned AD-AD for all non-PNC traffic. When the PNC handover is successful, the association of the remaining DEVs with the piconet is unaffected and hence they are not required to re-associate with the new PNC. The process of PNC handover is illustrated in Figure 79.

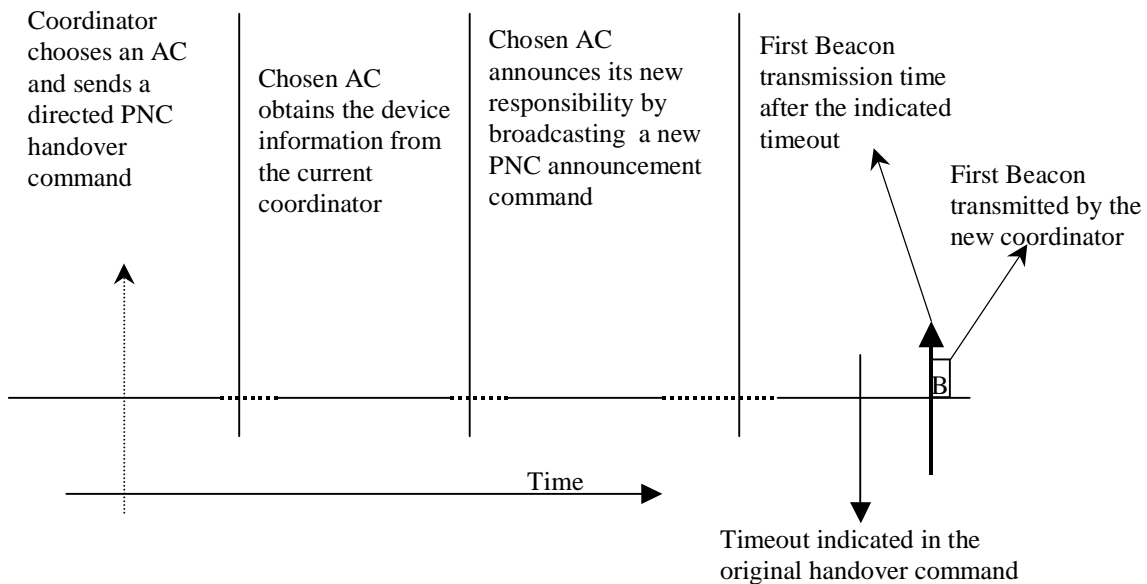


Figure 79—Illustration of PNC handover

Note that the PNC handover need not always stop all of the stream transmissions. Figure 79 illustrates only the handover process and hence does not show other traffic. The current PNC may choose a long enough time-out period which would allow enough time for the new PNC to obtain the DEV information in small quantities per superframe. When the current PNC chooses a small time-out it shall allocate enough time for the new PNC so that the new PNC is able to obtain all the DEV information for the piconet in that short time. Other data traffic may or may not be affected by this depending on the traffic conditions within the piconet. To facilitate fast handovers the PNC shall broadcast the DEV information table, described in 7.5.1.4, at least once every aBroadcastDEVInfoDuration.

When a station joins a piconet, the coordinator shall compare the capabilities field of the new station to its own. If the PNC-Des-Mode bit is set in the new station and not in the current PNC, the old PNC shall perform PNC handover. If the new station is more qualified to be the coordinator, based on the PNC selection criteria in Table 79, the coordinator may perform PNC handover. If security controlled by the old PNC is in use during PNC handover, the established security parameters shall be invalidated and all devices shall authenticate with the new PNC in order to re-establish security in the piconet. Therefore, if re-authentication is not desirable, a PNC running security in the piconet should not perform PNC handover unless it is leaving the piconet.

8.2.5 Child piconet

When an alternate coordinator of an existing piconet wants to form a child piconet, the alternate coordinator shall use the channel time request command, defined in 7.5.10.1 to request a private GTS. The AC shall set the source and destination addresses in the channel time request command to be the AD-AD of the AC. The parent PNC will recognize this as a request for a child piconet. The PNC may allocate a private GTS for the child piconet depending on the availability of network resources, its capabilities and security policy.

If the AC (now the child PNC) receives a private GTS, the child PNC shall start sending its beacon in its allocated private GTS. The child PNC shall use a PNID that is distinct from the parent PNID. The child piconet beacon contains the parent device ID, as shown in Table 60.

Included in the child piconet beacon is a private GTS for the parent piconet, using the PNC address (0x00) for both the source and destination DEV address. This is provided to reserve the slot, not to convey any information to the parent PNC.

Figure 80 illustrates the relationship between the parent piconet superframe and the child piconet superframe. Note that the superframe duration is the same for both the child and the parent piconets.

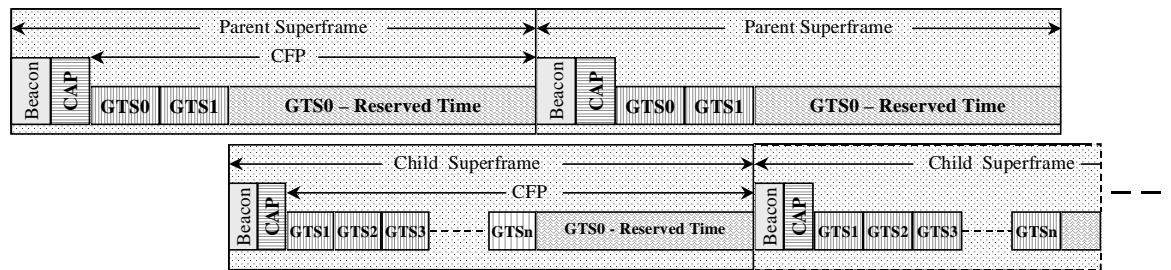


Figure 80—Parent piconet and child piconet superframe relationship

Note that the slot positions GTS0, GTS1, et al., are not to scale in Figure 80 and so are illustrative only.

The message sequence chart for the initiation of the child piconet is shown in Figure 81.

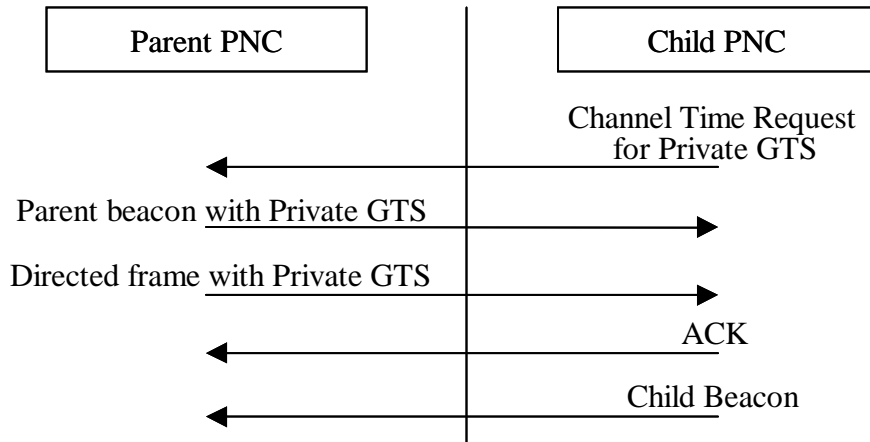


Figure 81—Message sequence chart for the initiation of a child piconet.

The child piconet is an autonomous piconet except that it is dependent on a private GTS from the parent piconet. Association, authentication, security and acknowledgments shall be handled within the child piconet and do not involve the parent PNC.

The child PNC device is a member of the parent piconet and thus may exchange data with any device in the parent piconet. The child PNC device is also a member of the child piconet and thus may exchange data with any device in the child piconet.

8.2.6 Neighbor piconet

If after following the scan procedure in 8.2.1, no channels are available, then a neighbor alternate coordinator (i.e. an AC from a different system), may attempt to start a neighbor piconet within an existing piconet. To start a neighbor piconet, the neighbor AC shall send an association request, defined in 7.5.2.1, using the association address, 7.2.3, as the source address of the frame. The neighbor PNC bit in the capability field shall be set as indicated in 7.4.3 when the association request command is sent.

If the parent PNC receives the association request correctly, it shall respond to the request with an association response command, 7.5.2.2. If the neighbor association request is accepted, then the PNC shall set the AD-AD in the command to be one of the unused neighbor piconet addresses, 7.2.3. If the request is not accepted, then the PNC shall set the AD-AD in the command to the association address, 7.2.3.

The neighbor PNC then sends a channel time request, 7.5.10.1, to obtain a private GTS for the neighbor piconet. The channel time request shall have both the source and destination addresses set to the neighbor piconet address that was assigned to the neighbor PNC by the parent PNC.

If the parent PNC permits the formation of a neighbor piconet, it shall allocate a private GTS using the neighbor piconet address as both the source and destination addresses. After receiving this channel time allocation in the parent PNC's beacon, the neighbor PNC shall start sending its beacon in the neighbor piconet's private GTS. The neighbor PNC shall use a PNID that is distinct from the parent PNID. The neighbor beacon contains the parent device ID, as shown in Table 60.

Included in the neighbor superframe is a private GTS for the parent piconet, using the PNC address for both the source and destination device addresses. This is provided to reserve the slot, not to convey any information to the parent PNC.

Figure 80 illustrates the relationship between the parent piconet superframe and the neighbor piconet superframe. Note that the superframe duration is the same for both the neighbor and the parent piconets.

The message sequence chart for the initiation of the neighbor piconet is shown in figure Figure 82.

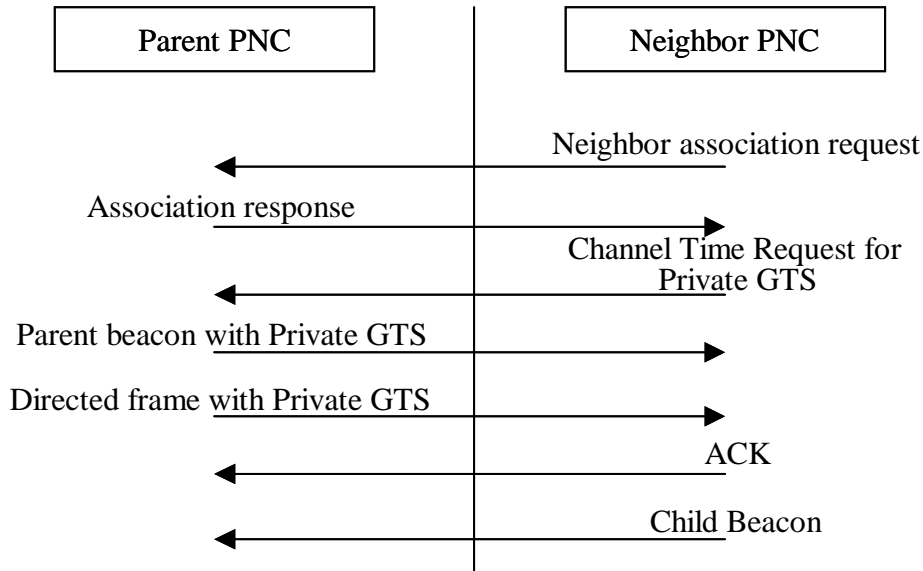


Figure 82—Message sequence chart for the initiation of a neighbor piconet.

The neighbor piconet is an autonomous piconet except that it is dependent on a private GTS from the parent piconet. Association, authentication, security and acknowledgments shall be handled within the neighbor piconet and do not involve the parent PNC.

The neighbor PNC is not a member of the parent piconet (i.e. it is neither authenticated nor associated) and thus is restricted to only sending channel time requests and reading the parent piconet beacon. The parent PNC is not a member of the neighbor piconet.

8.2.7 Broadcasting DEV information

The PNC shall broadcast the device information table using the device information command after a DEV associates or disassociates in order to inform the other DEVs in the piconet. In addition, the PNC shall send the device information table for each of the associated DEVs at least once every aBroadcastDEVInfoDuration via a device information command, 7.5.8. This broadcasting of the device information table is intended to help in reducing the delay in a PNC handover by enabling other PNC-capable DEVs to keep their local tables current.

8.3 Association and authentication with a piconet

8.3.1 Authentication

Authentication is described in clause 10.

8.3.2 Association

Before a DEV has completed the association process, all frames between the PNC and the DEV shall be exchanged either in the CAP of the superframe or in an association MTS.

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1 A DEV that is instructed to associate with a piconet through MLME-ASSOCIATE.request, 6.3.4.1, shall try
2 only to associate with an existing piconet and shall not attempt to start its own piconet.

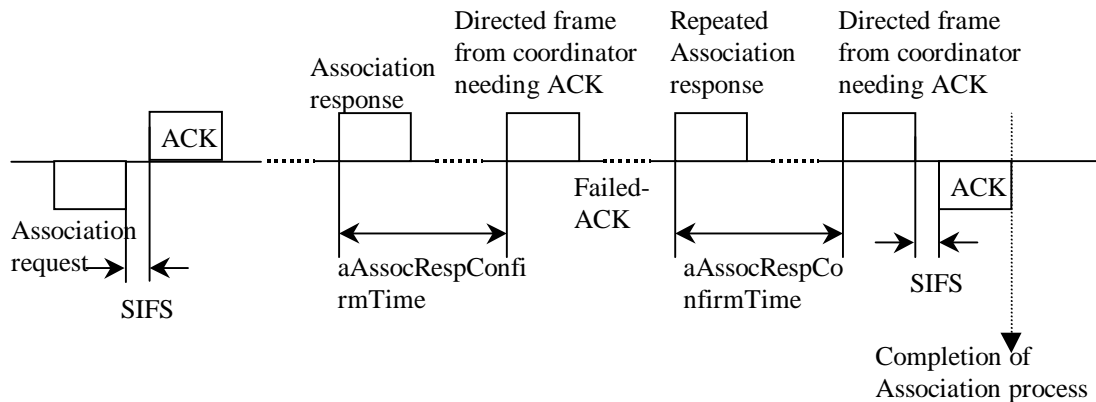
3
4 An unassociated DEV initiates the association process by sending an association request command, defined
5 in 7.5.2.1, during the CAP of an existing piconet. When the PNC receives a association request command, it
6 shall send an association response command, indicating that the DEV has been associated and its AD-AD or
7 that the request has been rejected with the reason for the rejection, as defined 7.5.2.2.

8
9 The PNC shall acknowledge all correctly received association request commands by sending an Imm-ACK
10 frame. The ACK to an association request command does not mean that the DEV is associated. The PNC
11 needs some time to make sure that there are enough resources available to support another DEV on the pico-
12 net and to allocate an AD-AD. After a decision is made regarding the association and AD-AD, the PNC
13 sends an association response command to indicate the acceptance or rejection of the association. The time
14 difference between sending ACK to an association request and sending an association response command
15 meant for the same DEV shall not exceed aAssocRespConfirmTime.

16
17 The association response command is not a directed frame. If an ACK was required for this command, when
18 there were multiple DEVs trying to associate during the same time interval, all of them will try to ACK and
19 collide. Therefore, an ACK is not allowed for the association response command. Instead each DEV trying
20 to associate shall compare its device-ID with the device-ID field in the association response command and if
21 there is a match, accept the AD-AD as its address for all future communications and consider itself associ-
22 ated.

23
24 Since the association response command is a broadcast command, all DEVs may use this command from the
25 PNC to update their association tables and hence keep track of other DEVs in piconet, if needed.

26
27 In the absence of a valid pending frame, the PNC shall send a directed command frame with null payload to
28 the currently associating DEV with the ACK policy set to Imm-ACK and the DA equal to the new AD-AD
29 allocated to the currently associating DEV. This sequence of association response followed by a directed
30 frame to the associating DEV confirms the reception of the association response by the newly associated
31 DEV. If the ACK from the newly associated DEV is not received by the PNC, the PNC shall repeat the
32 sequence of association response and the directed frame as illustrated in Figure 83. The message sequence
33 chart for the same is shown in Figure 84.



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47 **Figure 83—Illustration of association process**

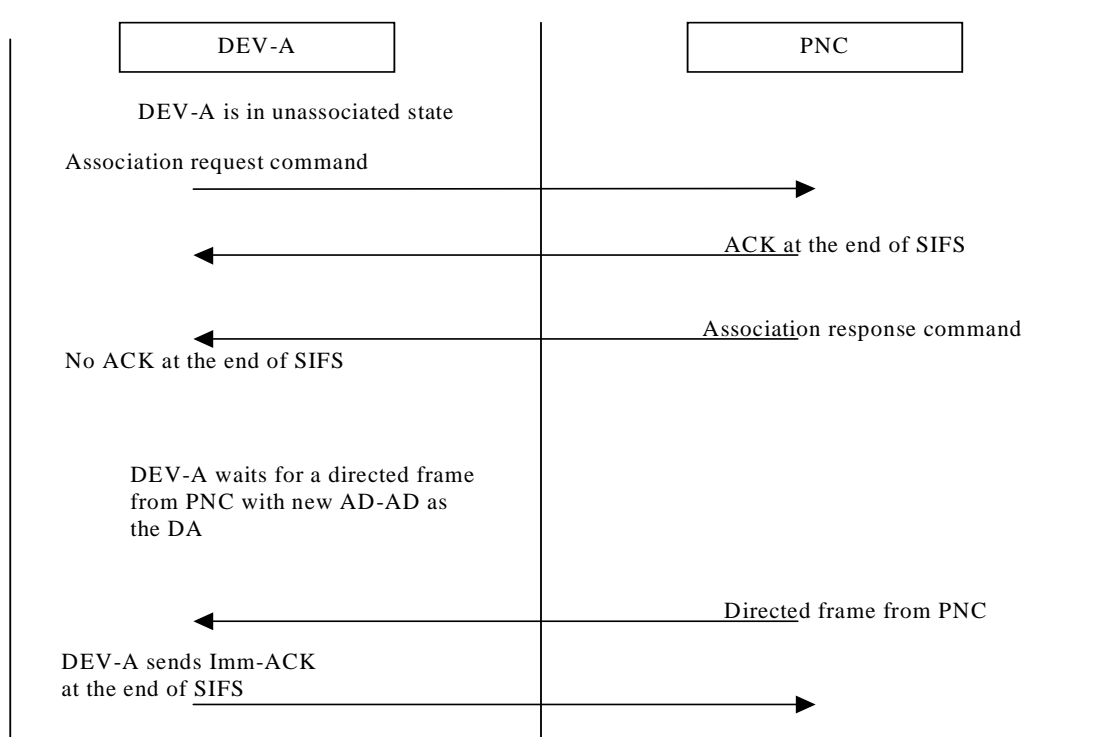


Figure 84—Message sequence chart for frame exchange during association

The addresses (AD-ADs) shall be assigned in sequence (increasing order) by the PNC except when PNC wishes to use an AD-AD that was freed up when a DEV leaves the piconet. However, the reallocation of the same AD-AD by PNC shall be at least an aADAddressReuseTime after the disassociation of the DEV that was allocated the same AD-AD. The coordinator shall ensure that there is only one associated DEV that has been allocated a given AD-AD at any given time within the piconet. Similarly any associated DEV shall be allocated only one AD-AD. Only exception to this is the PNC itself. The DEV serving as PNC shall have two values of AD-AD associated with it. The AD-AD value of '0x00' shall be assigned to the coordinator function within the DEV and the other non-zero value of AD-AD shall be for use for all of the non-coordinator traffic. When there is a coordination handover, 8.2.4, the new PNC shall assume the 0x00 address. The former PNC shall continue to use its non-zero AD-AD for its non-coordinator traffic. Hence the PNC shall be viewed as two logical operational entities within the same DEV.

8.3.3 Disassociation

When a PNC wants to disconnect a DEV, the PNC shall send a directed disassociation request command, 7.5.2.3, to that DEV with a reason code. Similarly when a DEV wants to disconnect from the piconet, the DEV shall send a directed disassociation request command to the PNC with a reason code.

All the disassociation request commands, when received correctly, shall be acknowledged by the intended recipient through an ACK frame.

8.4 Channel Access

The channel time is divided into superframes, with each superframe beginning with a beacon. The superframe is composed of three major parts: the beacon, the CAP and the CFP, as shown in Figure 85. The CFP

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1 is used for asynchronous and synchronous data streams with QoS provisions while the CAP is used for non-
2 QoS frames. During the CAP, the DEVs may access the channel in a distributed style using CSMA and a
3 backoff procedure. During the CFP, the PNC controls the channel access by assigning time slots to individ-
4 ual DEVs with each time slot having a fixed start time.



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13 **Figure 85—Superframe structure**

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16 **8.4.1 Inter-frame spacing (IFS)**

17 There are two IFSs that are defined; the short inter-frame space (SIFS) and the retransmission inter-frame
18 space (RIFS). The relation between the IFS is that $SIFS < RIFS$. The actual values of IFSs are PHY depen-
19 dent. For the 2.4 GHz PHY they are listed in 11.2.6.1.

20
21 Both in the CAP and the CFP, a response frame (ACK) transmission over the medium shall start within a
22 SIFS duration after the end of the transmission of the previous frame for which the response is intended.
23 Similarly a SIFS duration shall be allowed between a frame that does not expect an immediate response and
24 the next successive frame transmitted over the medium.

25
26 During the CFP, all DEVs shall use an RIFS for retransmissions. During the CAP, however, the retransmis-
27 sions shall not use an RIFS and shall instead follow the CAP rules described in sub-clause 8.4.2. The rules
28 for acknowledgement and retransmissions are described in sub-clause 8.8. The beacon frame, which is nei-
29 ther in the CAP nor the CFP, does not use inter-frame spacing.

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32 **8.4.2 Contention based channel access**

33 The basic medium access mechanism during the CAP is carrier sense multiple access with collision avoid-
34 ance (CSMA/CA). To minimize collisions, a transmitting DEV is required to first sense that the medium is
35 idle for a random length of time, as defined in 8.4.2.1. Only if the medium is idle after that time shall the
36 DEV start its transmission. This process of waiting before transmission is termed “backoff” and is described
37 in 8.4.2.1. The backoff procedure shall not be applicable for the transmission of the beacon that is transmit-
38 ted by the coordinator at the beginning of superframe.

39
40 During the CAP a DEV is allowed to transmit one frame at a time with backoff being applied to every frame,
41 except the Imm-ACK frame, attempted during CAP. In no case shall a DEV extend its transmissions that
42 started during the CAP in to CFP. Hence, once a DEV decrements its backoff counter to zero, it shall check
43 whether there is enough time in the CAP for the transmission of current frame and SIFS. If an Imm-ACK is
44 expected for that frame, the remaining time in CAP needs to be large enough to accommodate the current
45 frame, 2 SIFS periods and the Imm-ACK frame at the same PHY rate as the transmitted frame. If there is not
46 enough room for this entire frame exchange sequence, then the DEV shall abort the transmission.

47
48 The MAC shall use the PHY-CCA.indication, 6.9.4.12, from the PHY to detect whether the channel is busy
49 or idle.

50
51 The PNC controls what type of data or commands may be sent in the CAP via the CAP mode field of the
52 piconet synchronization parameter element, 7.4.2, in the beacon. A DEV shall only send frames of the type
53
54

indicated by the CAP mode field in beacon for the current superframe. The CAP mode field may be changed by the PNC from superframe to superframe.

8.4.2.1 Backoff Procedure

Except when transmitting an Imm-ACK, the following backoff procedure is performed when sending frames during the CAP.

The backoff algorithm uses the following information:

- `retry_count`: An integer that takes on values in the range [0,3].
- `backoff_window(retry_count)`: A table which has values [7, 15, 31, 63]
- `aBackoffSlot`: A PHY dependent parameter that is based on the amount of time it takes to sense the channel. For the 2.4 GHz PHY, this is defined in 11.2.6.1
- `bw_random(retry_count)`: A random integer drawn from a uniform distribution over the interval [0,`backoff_window(retry_count)`]. The method for choosing the random integer should be unique for each DEV and use the random number generator resident on the DEV. If the DEV does not possess a random number source, the random integer should be generated using its unique 48-bit device ID (and any other information that the implementer wishes to use) and a pseudo-random number generator (PRNG) such as MGF1 as defined in IEEE Std 1363-2000. Note that the current state of the PRNG should be maintained and subsequent backoffs should use subsequent bits in the pseudo-random sequence.
- `bw_random(retry_count)`: A pseudorandom integer drawn from a uniform distribution over the interval [0,`backoff_window(retry_count)`]. It is important that designers recognize the need for statistical independence among the random number streams among DEVs.

The backoff time in the CAP is measured at the air interface and indicates when a DEV may begin transmitting data. The DEV first waits `aRIFSTime` from when the medium is determined to be idle before beginning the backoff algorithm.

The DEV shall then choose `backoff_count = bw_random(retry_count)` and shall maintain a counter for `backoff_count` which is decremented only when the medium is idle for the entire duration of `aBackoffSlot`. The `retry_count` shall be set to 0 for the first transmission attempt of a frame. Whenever the channel is busy, the backoff counter shall be suspended. This avoids the problem of unfair channel access when a backoff counter of a DEV ending in the middle of a reception and hence resulting in larger backoff for that DEV while another DEV starting after the current reception choosing smaller value for backoff. When the backoff counter reaches zero, the DEV shall transmit its frame.

The backoff counter shall also be suspended outside of the CAP duration. Note that the backoff counter is maintained across superframes and is not reset with each beacon.

When a directed frame is transmitted and the expected ACK is not correctly received by the DEV, the `retry_count` shall be incremented but shall not be set to more than 3. The `backoff_count` shall then be set to `bw_random(retry_count)`. If the maximum number of retries for that frame has not been exceeded, the backoff procedure is again resumed. The DEV shall attempt transmission of a frame for a maximum of `aMaxRetransmissionLimit` times before the failure in frame transmission is reported through MLME interface via the MA-UNITDATA-STATUS.indication primitive, A.2.3.

8.4.3 Contention free channel access

Channel access in the CFP is based on a TDMA method in which all slots have a guaranteed start time. The guaranteed start times enable both power saving and good QoS characteristics. All the slot allocations within the current superframe are broadcast in the beacon. The process of channel time request and allocation is described in 8.4.3.2.

8.4.3.1 Guaranteed time slots (GTS)

The PNC divides the CFP into guaranteed time slots (GTSs). Each GTS is a single time slot with guaranteed start time and a guaranteed time duration reserved within the CFP. Hence a DEV that is allocated a GTS is guaranteed that no other DEVs will compete for the channel during the indicated time duration of the GTS. A DEV with a GTS may or may not make use of all the allocated time duration within the GTS. The selection of a stream for transmission during a GTS is determined locally by the DEV depending on the number of pending frames and the priority of the corresponding streams, see A.3 for more information on priority management.

There are two types of GTSs: dynamic GTS and pseudo-static GTS. The type of a GTS is indicated in the stream management command as specified in 7.5.10.3.

The PNC may move dynamic GTSs within the superframe on a superframe by superframe basis. This allows the PNC the flexibility to rearrange GTS assignments to optimize the utilization of the slot assignments. The PNC moves a dynamic GTS by simply changing the CTA parameters in the beacon.

Pseudo static GTSs shall be allocated only for stream connections. Non-stream GTSs shall not be pseudo-static. Pseudo-static GTSs may be moved within the CFP by the PNC, but the PNC needs to notify the affected DEVs by sending channel time grant frames, 7.5.10.2, with the new CTA. As with dynamic GTSs, the PNC may rearrange pseudo static GTSs so that the GTS assignments will be optimized. However, the PNC uses the channel time grant command and coordinate the channel time grants with the CTAs in the beacon.

Before a pseudo static GTS is moved, the PNC shall ensure that the new position is unoccupied by another GTS. Then, the PNC shall send a directed channel time grant to the receiving DEV so that the receiving DEV is listening to both the old GTS position as well as the new position. The channel time grant shall be acknowledged with an Imm-ACK by the DEV if it is received correctly. If the PNC does not receive an Imm-ACK, it may re-send the channel time grant command, but it shall not continue with the process until the acknowledgement is received. The channel time grant sent by the PNC to the receiving DEV contains both the old and the new CTA. If the old and the new position overlap, the CTA may be one larger CTA.

The PNC shall then send a channel time grant to the transmitting DEV that contains only the new CTA. The transmitting DEV shall acknowledge with an Imm-ACK if it is received correctly. If the PNC does not receive the Imm-ACK, it may re-send the channel time grant command, but it shall not move the pseudo-static GTS until the acknowledgement is received. By moving the receiver first, the PNC ensures that no frames are lost if channel time requests are corrupted.

Finally, the PNC shall send a channel time grant to the receiving DEV which only contains the new CTA. The receiving DEV shall acknowledge this command with an Imm-ACK if it is received correctly. If the PNC does not correctly receive the acknowledgement, it may re-send the channel time grant command. However, the PNC may re-allocate the original pseudo-static GTS even if it does not receive the acknowledgement to the command.

Throughout the process, the PNC will ensure that the beacon contains the current CTAs for the pseudo-static GTS that it is moving.

DEVs may request a change in a pseudo-static GTS channel time using the channel time request command.

A graphical illustration of the procedure for moving a pseudo-static GTS is illustrated in Figure 86

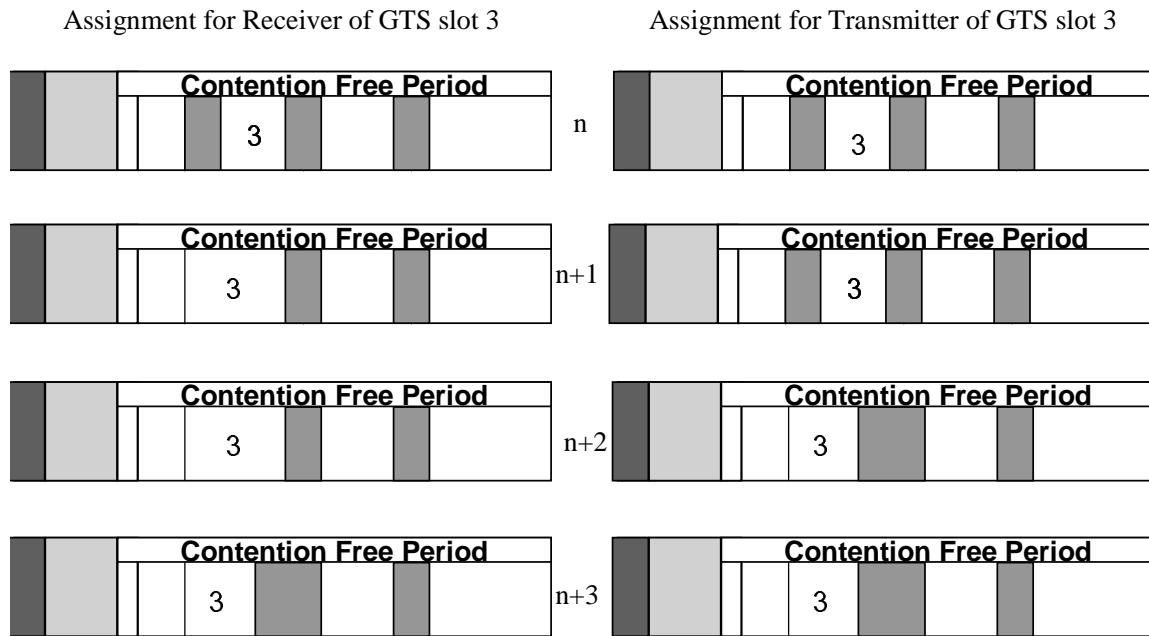


Figure 86—CTA assignment sequence for pseudo-static GTSs

8.4.3.2 Channel time allocation (CTA) and channel time usage

The DEVs associated with a PNC shall send their changes in channel time requirement whenever they wish to make a change. Once a request for channel time is received from a station, the PNC shall remember that as the outstanding request for every superframe until, a change in request is received from the DEV. In addition to this the PNC shall make use of the properties of the stream provided during the stream connection process. The slot assignments within the CFP are based on the current pending requests from all the DEVs and the currently available channel time within the CFP. The slot assignments for dynamic GTSs may change from superframe to superframe as required by the PNC. Changing the slot assignments for pseudo-static GTSs requires directed channel time grant commands, as described in 8.4.3.1. All of the slot assignments are broadcast in the beacon. In addition, the PNC may announce the slot assignments in either a directed or a broadcast channel time grant command, 7.5.10.2. However, additional announcements by the PNC shall not change from what was broadcast in the beacon. The start time of all the GTSs are with reference to the start of beacon frame, whether they were announced in beacon or channel time grant command. The algorithm used to allocate the channel time and assign slots is beyond the scope of this standard. Channel time requests that are ACKed are valid until the next channel time request is made.

The coordinator shall not assign more than MaxAssignedCTAs to a DEV and they shall fall within the first MaxProcessedCTAs. The coordinator may have more than MaxProcessedCTAs in a beacon, but the CTAs assigned to a DEV shall not exceed the first MaxProcessedCTAs for that particular DEV. If the coordinator is unable to meet the limitations of the DEV, the coordinator may reject additional channel time requests from the DEV.

When Del-ACK is employed, the recipient of the data frame is responsible for obtaining the time required for transmission of the return Del-ACK. In the case of Imm-ACK, it is the sender of the data frame, rather than the recipient, that guarantees the time required for Imm-ACK right after the end of current data frame plus SIFS duration. Each DEV is expected to estimate the channel time required depending on the number (and type) of streams that they are sending and receiving, and request for that channel-time with PNC. When PNC grants one or more time-slots, the DEVs are responsible for using those time-slots efficiently without

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1 abusing the priority order of the streams that are pending locally for transmission. If there is a DEV that has
2 not requested any time-slot (or obtained one) then the DEV shall use only the CAP for sending its Del-ACK
3 frames.

4
5 When a DEV has a frame of type other than data for the destination DEV, the DEV is free to send it during
6 an allocated time slot for that source DEV, destination DEV pair or use the CAP to communicate that frame.

7
8 In any superframe there may be one or more DEVs in the piconet that receives the beacon in error. This may
9 not happen to the same DEV all the time but may happen to different DEVs at different times depending
10 upon their location and type of interference to which they are subjected. If a DEV did not receive the beacon,
11 it shall not access any dynamic GTSs during the CFP. Stations with pseudo-static GTSs are allowed to trans-
12 mit during these GTSs as long as the number of consecutive lost beacons is less than or equal to aMaxLost-
13 Beacons. A DEV shall stop transmitting in its pseudo-static GTS when the number of consecutive lost
14 beacons exceeds aMaxLostBeacons.

15
16 The channel time grant command gives the flexibility to the PNC to broadcast the CTA information during
17 the superframe in addition to the beacon. This increases the chances of all DEVs obtaining the allocation
18 information. In addition, this also provides the flexibility to the PNC to help preserve the QoS by sending
19 directed channel time grant command to a DEV that may be experiencing more than usual channel errors
20 during certain time segments. The PNC may use the channel statistics to decide whether to send such a
21 directed channel time grant command. Note that when channel becomes too severe for the DEV to receive
22 the beacon, the directed channel time grant command or the data frame itself there is little help that is able to
23 be provided to that DEV through these channel time grant commands.

24
25 In no case shall a DEV extend its transmissions that started during an allocated time slot beyond the end of
26 that time slot. Hence, the source DEV shall check whether there is enough time in the time slot for the trans-
27 mission of current frame and SIFS. If an Imm-ACK is expected for that frame, the remaining time in the
28 time slot needs to be large enough to accommodate the current frame, 2 SIFS periods and the Imm-ACK
29 frame at the same PHY rate as the transmitted frame. If there is not enough room for this entire frame
30 exchange sequence, then the DEV shall abort the transmission and not use the remaining duration of the
31 time slot.

32
33 The PNC may compute more than one superframe slot allocation at a time and keep them repeating over
34 time until the situation changes. The allocation by the PNC may not exactly match the duration of time
35 requested by a DEV. However, the allocation shall be at least the minimum requested by the DEV in the
36 channel time request command except when the request is rejected. If the PNC allocates less time than
37 requested but more than minimum, it shall allocate more time if it becomes available in the CFP. If the time
38 slot is not allocated via the beacon, the DEV is free to request the time slot again. If the PNC wishes to reject
39 the channel time grant, it shall send a directed channel time grant command, 7.5.10.2, with the appropriate
40 grant status code to the requesting DEV.

41
42 A private GTS is a GTS where the same DEV is both the source and the destination. A private GTS is not
43 used for communication in the piconet. Instead, it is used to reserve channel time for some other use. The
44 other use may be for another 802.15.3 piconet, or a different type of network sharing the same channel.

45
46 Private GTSs will usually be pseudo-static GTSs, so that the slot is periodic for the other use. A DEV
47 requests a private GTS by using it's own AD-AD as the originator and target address for the stream manage-
48 ment command, 7.5.10.3, or channel time request command, 7.5.10.1.

50 **8.4.3.3 Management Time Slots**

51
52 Management Time Slots (MTSs) are identical to GTSs except that the PNC address is the source or the des-
53 tination address in the CTA. A PNC may choose to use MTSs instead of the CAP for command frames.
54 When MTSs are used, the PNC shall ensure that sufficient MTSs are allocated to allow for the transmission

of commands to and from the PNC. There may be as few as a single MTS in a superframe where the ownership of the MTS changes from superframe to superframe. At the other extreme, there may be one or more uplink and downlink MTSs per associated DEV per superframe plus MTSs for association. The PNC is responsible for determining the appropriate number of MTSs in a superframe in the same way that the PNC is responsible for choosing the CAP size if a CAP is used. The PNC determines which DEVs will be allocated MTSs and how often. The PNC shall allocate at least one association MTS every aMTSAssocPeriod.

An open MTS is one where the source address in the CTA for the MTS is the broadcast address. Any DEV that is associated to the piconet may attempt to send a command frame to the PNC in an open MTS. An MTS with the association address as the SA in the CTA for the MTS is called an association MTS. Any station not currently associated to the piconet may attempt to send an association command to the PNC in an association MTS. Association commands shall not be sent in open MTSs. Likewise, only association commands shall be sent in association MTSs. Open MTSs enable the PNC to service a large number of DEVs with low MTS requirements by using a minimum number of MTSs. When there are few DEVs in a piconet it would be more efficient to use MTSs assigned to a DEV instead of using an open MTS. It is the PNC's responsibility to determine how many and what type of MTSs to use for each superframe.

The PNC shall assign an uplink MTS within aMTSAssocPeriod of a successful association command in order to support a 1 second connection target.

The access mechanism for regular MTSs, i.e. neither open nor association MTSs, is TDMA, as described in 8.4.3.1

8.4.3.4 Slotted Aloha access for open and association MTSs

Slotted Aloha is the access mechanism in an open MTS or an association MTS. The access to an open or association MTS shall be controlled by a contention window CW_a maintained by each DEV. The contention window shall be derived from the number a , where a is the number of retransmission attempts made by the DEV. For the first access attempt, a shall be set to 0. The size of the contention window, CW_a , is defined as follows:

$$CW_a = \begin{cases} 256 & 2^{a+1} \geq 256 \\ 2^{a+1} & 2^{a+1} \leq 256 \end{cases} \quad (1)$$

The open or association MTS used for the a^{th} retransmission attempt shall be chosen by a uniformly distributed random integer value, r_a , within the interval $[1, CW_a]$. While the random number generator is not specified, it is important that designers recognize the need for statistical independence among the random number streams among DEVs. The DEV shall start counting r_a from the open or association MTS slot in the current superframe and continue across superframes. The lack of an ACK indicates the failure of the previous access attempt, but the presence of an ACK does not necessarily equal success for an association frame since all stations attempting to associate use the same unassigned SA. The association process is described in more detail in 8.3.2.

This first broadcast or unassigned MTS after the DEV begins the access process is specified by number ' $r_{a=1}$ '. The open or association MTS with number equal to r_a is the slot that the DEV shall access. The DEV shall not access the MTS before its counter has reached the open or association MTS with the number equal to r_a . After receiving an ACK, a shall be reset to 0.

8.5 Synchronization

All DEVs within a single piconet shall be synchronized to the PNCs clock. The beacon sent at the beginning of every superframe contains the information necessary to time-synchronize the DEV. See 7.4.2 for the definition of the timing parameters sent in the beacon.

Each DEV in the piconet, including the PNC, shall reset its clock to zero at the beginning of the beacon preamble as shown in Figure 87. All times in the superframe shall be measured relative to the beginning of the beacon preamble. If a DEV does not hear a beacon, it should reset its clock to zero at the instant where it expects the beginning of the beacon preamble.

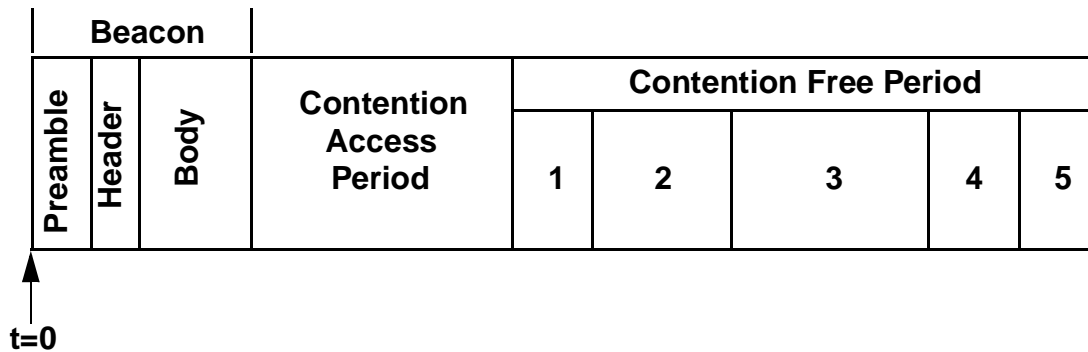


Figure 87—Piconet timing relative to the beacon

8.5.1 Time accuracy

A compliant implementation shall maintain the accuracy of the timer to be ± 25 ppm.

8.5.2 Beacon generation

The PNC shall send a beacon at the beginning of each superframe using the beacon frame described in 7.3.1.

8.5.3 Beacon reception

All of the DEVs that are associated shall use the beacon start time and the time slot allocations contained in beacon to start their transmissions. The superframe duration and the CFP duration in the beacon, 7.4.2, are used to accurately mark the beginning and the end of the CFP and the CAP.

8.5.4 Acquiring synchronization

All DEVs acquire synchronization through beacons from the PNC. Unassociated DEVs that wish to associate with the piconet shall use passive scanning to collect beacons and use the information within the beacons for synchronization. A DEV shall hear at least one beacon before sending its request for association. If an associated DEV did not receive a beacon from its PNC, it shall use the same superframe duration indicated in the last correctly received beacon from its PNC. If a DEV did not receive a beacon for more than the ATP given when the DEV associated with the piconet, then the DEV shall stop all of its transmissions and wait for a beacon before starting the association process again.

8.6 Stream management

Stream management involving stream connection, stream disconnection and priority management is described in this sub-clause. Each DEV shall support at least one stream connection. A DEV may support

more than one stream depending on the application for which it is designed to support. A PNC needs to support as many streams as it desires to source and sink including those additional streams needed to support the repeater service.

8.6.1 Stream connection

A stream shall be connected only after tripartite communication/negotiation among the DEV that is originating the stream, the DEV that is the intended receiver of the stream and the PNC. For a broadcast or multicast stream, the involvement of intended receiver is precluded. Once connected, the stream is sent in a peer-to-peer style.

Either the sending DEV or the intended recipient DEV for the new stream may send a stream management command with the request for stream connection. The process of stream connection is illustrated in Figure 88. In all stream management communications from the PNC to the other involved DEV, the PNC appropriately changes the value of the direction field to imply the same direction of the stream as originally requested.

The values for direction, security, stream type and priority shall be non-negotiable and are decided by the DEV that is sending the stream connection request. These values shall not be changed anytime after the first transmission of the command frame containing the request for that stream.

All the bandwidth and latency related requirements of the stream shall be negotiated between the sender of the stream and the PNC. The PNC decision on the values of the stream QoS parameters that are supported in the piconet shall be final. If the originating DEV does not accept the PNCs decision on the stream parameters, it shall send a stream management command to the PNC with action type set to disconnection/rejection as specified in 7.5.10.3. The PNC shall then send a stream management command to the target DEV with action type set to disconnection/rejection.

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The retransmission window shall be decided between the DEV that is originating the stream and the DEV that is the intended receiver of the stream for a directed stream. If the two DEVs request different sizes for the retransmission window, smaller of the two shall be adopted.

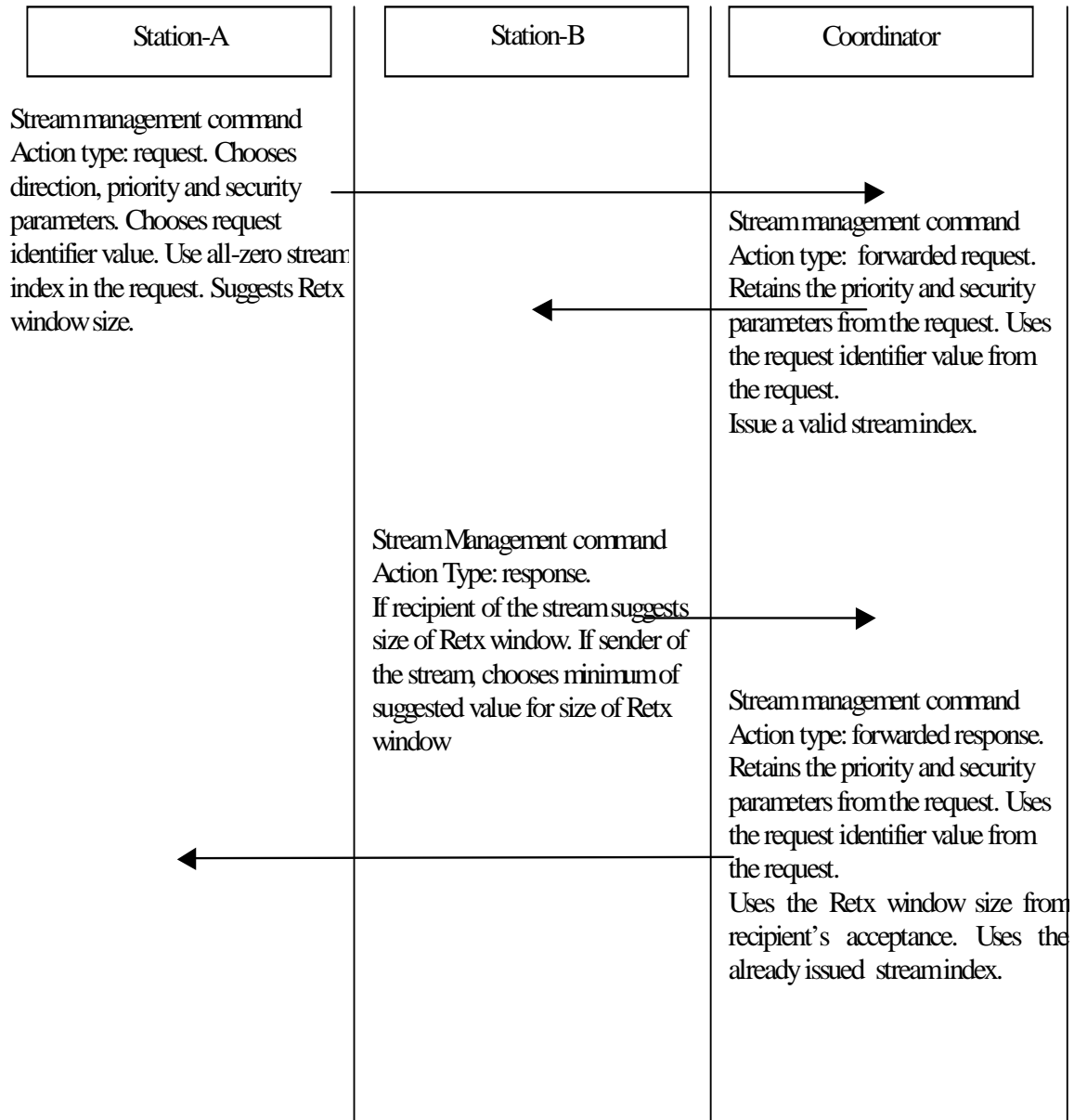


Figure 88—Stream connection process with sender of the stream initiating the stream connection process

In some cases it may be necessary for the PNC to initiate the stream connection process, even though the stream is supposed to be exchanged between two other DEVs in the same piconet. In this case, the PNC sends the request for stream connection to the expected originator of the stream. The originator of the stream

may change the QoS parameters in the command. The originator of the stream follows the same sequence of transactions described before for the connection of stream. This is illustrated in Figure 89

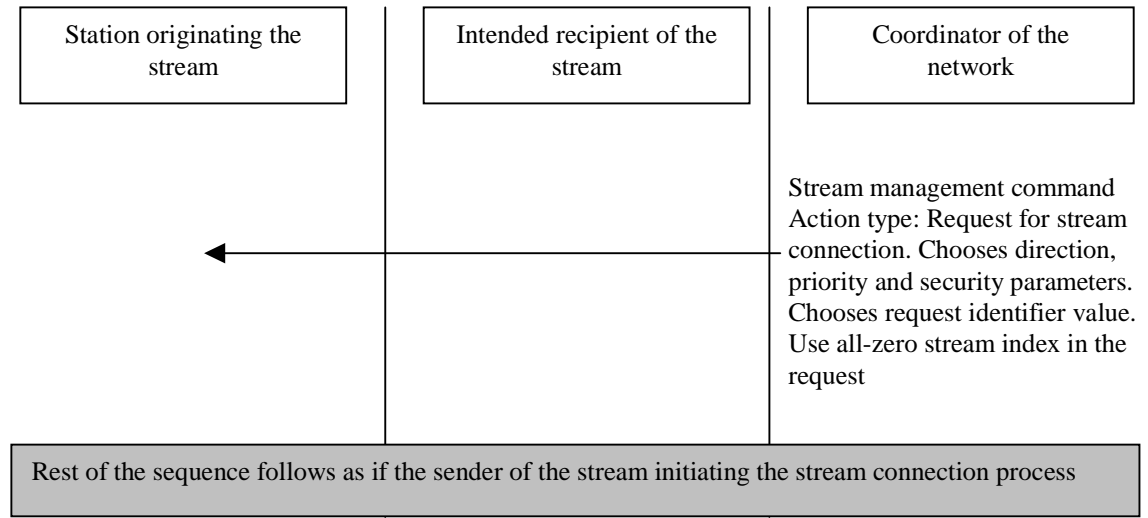


Figure 89—Stream connection process with the PNC initiating the stream connection process

If the stream is the broadcast address, the command transactions during the stream connection are only between the sender of the stream and the PNC.

For data frames that do not need a stream connection, the DEV may use a data frame with the stream control field set for non-stream data as described in 7.2.4.

8.6.2 Stream disconnection

During any of the transactions described in any of the scenarios for stream connection in 8.6.1, a DEV (or the PNC) may reject the stream connection. The frame used for either rejecting or disconnecting a stream shall be the stream management command with the action type set to rejection/disconnection as specified in 7.5.10.3. If the DEV wishes to reject the stream before it is connected, it shall send the stream management command with the action type set to rejection/disconnection to the PNC. In that case, the PNC shall communicate the disconnection information to the other DEV via same command. If the PNC wishes to reject the connection, it shall send the stream management command with the action type set to rejection/disconnection to the DEVs involved in the stream connection process.

If a stream is connected and if any of the three DEVs involved, sender, recipient or PNC, wishes to disconnect the stream, it shall send the stream management command with the action type set to rejection/disconnection. If the DEV initiating such a transaction is not the PNC, it shall send this command to the PNC. The PNC shall then communicate the disconnection to the other involved DEV via the stream management command. If the PNC wishes to disconnect the stream, it shall send the stream management command to the other DEVs involved in the connection.

The DEV sending the command to disconnect a stream shall consider the Imm-ACK received for that command frame as the acceptance by the other DEV.

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8.7 Fragmentation and defragmentation

Fragmentation is performed at the transmitting DEV on each MSDU or MCDU whose size is greater than fragmentation threshold, `aFragThreshold` octets. The transmitting DEV is free to choose different values for `aFragThreshold` parameter for different streams and change them as desired. However, all the fragments in an MSDU/MCDU shall be of the same size except for the last fragment that may be smaller than the rest of the fragments in the same MSDU/MCDU. Once the MSDU/MCDU is fragmented and a transmission attempted, it shall not be re-fragmented for any reason and all the retransmissions shall obey the original fragmentation threshold used on the MSDU/MCDU.

The first fragment of all MSDU/MCDUs shall have the frag-start bit in the frame control field set to '1'. Fragments other than the first shall have the frag-start bit set to '0'. The last fragment of all MSDU/MCDUs shall have the frag-end bit in the frame control field set to '1'. Fragments other than the last fragment shall have frag-end bit in the frame control field set to '0'. This implies that a frame consisting of an MSDU/MCDU that has only one fragment will have both the frag-start and the frag-end bit in the frame control field set to '1'.

Defragmentation of an MSDU/MCDU is the reassembly of the received fragments into the complete MSDU/MCDU before delivering the data unit to next higher processing layer. The defragmentation for MSDUs and MCDUs are handled differently. The receiving DEV may process, and if needed respond to, all of the commands in a received MCDU fragment for which the command payload was completely received. For the last command in a MCDU fragment, the payload may continue to the next fragment unless the fragment has the frag-end bit set to '1'. Hence the receiving DEV shall wait for the next MCDU fragment from the same sender to complete processing of that command.

Defragmentation of MSDUs are performed completely before delivering it to the next higher layer. The MAC is responsible for obtaining all the fragments of an MSDU before defragmentation. If for some reason, the receiving DEV could not obtain all the fragments of an MSDU and the transmitting DEV has indicated that it has discarded the frame, the receiving DEV shall discard all the fragments of the MSDU and indicate a receive failure to the next higher layer. The transmitting DEV shall indicate that it has discarded the frame through one of three different methods. If the stream does not need retransmissions at all, the ACK-policy indicated in the FC field is no-ACK. In this case, the receiving DEV shall throw away an MSDU if one of its fragments is missing and the stream has no-ACK as the ACK-policy. If the stream has Imm-ACK or implied-ACK as the policy, reception of new frame with a different sequence number is an indication to the receiving DEV that the transmitting DEV will not attempt retransmission on any of the fragments in the same stream with older sequence numbers. If the stream has employed Del-ACK as the policy, the transmitting DEV shall inform the receiving DEV to flush all its delayed-ACKs up to a sequence number using the transmission sequence sync command described in 7.5.9.2.

There is no theoretical limit for the size of an MSDU/MCDU with this fragmentation mechanism. However for practical reasons of limited resources at the receiving DEV, the largest size of MSDU/MCDU that is accepted for fragmentation is limited to `aMaxTransferUnitSize`.

8.8 Acknowledgement and retransmission

There are four types of acknowledgement policies defined for this standard; no acknowledgement (no-ACK), immediate acknowledgment (Imm-ACK), delayed acknowledgment (Del-ACK) and implied acknowledgement (implied-ACK).

8.8.1 No acknowledgment

A transmitted frame with an ACK policy set to indicate no-ACK shall not be acknowledged by the intended recipient(s). The transmitting DEV assumes that the frame is successful for all its local management and

proceeds to the next frame scheduled for transmission. The ACK policy in group addressed frames shall be set to “No acknowledgement” upon transmission.

8.8.2 Immediate acknowledgement frame

A directed frame that expects an immediate acknowledgement frame (Imm-ACK) shall have the ACK-policy in that directed frame set to indicate the same, as defined in 7.2.1.2. If the intended recipient of a directed frame correctly receives the frame, it shall start the transmission of the response frame within a SIFS duration after the end of the transmission of the directed frame.

8.8.3 Delayed acknowledgement

Delayed acknowledgement shall be applicable only for directed data frames. The intended recipient of the directed data frames is allowed to group the acknowledgement indications into a delayed-ACK command described in 7.5.9.1. The negotiated retransmission window for the stream and the available transmission opportunities for the intended recipient of the stream govern the frequency of the delayed-ACK command. The intended recipient of the stream is free to send the delayed-ACK command anytime before the expiration of the retransmission window. However the recipient of the stream shall also send the delayed-ACK command at the expiration of the retransmission window. In addition to this, the source DEV for the stream may solicit the delayed-ACK command by setting the Del-ACK request bit in the FC of any frame of a stream that is employing the Del-ACK policy.

8.8.4 Implied acknowledgement

Implied acknowledgement shall be applicable only for directed data frames sent during a time slot in the CFP, with the source-address (SA) in that frame being the address of DEV that has been allocated that time slot. The intended recipient of the directed data frames is allowed to send another data frame in response to a directed frame received with the ACK policy set to implied-ACK. The start of transmission of the response data frame shall start at the end of a SIFS, like an Imm-ACK frame transmission. The ACK-policy field in the response data frame shall take any value except for the implied-ACK value itself. Hence the responding DEV may expect an Imm-ACK to the data frame that is being sent as implied-ACK response to the original received data frame. Since the ACK-policy in the response data frame cannot be set to expect an implied-ACK, the chaining of implied-ACKs is not permitted. The frame exchange sequence involving implied-ACK is shown in Figure 90. If the responding DEV could not fit its SIFS + response frame + SIFS (+ Imm-ACK + SIFS, if Imm-ACK is expected) within the GTS slot, then the responding DEV shall simply send an Imm-ACK frame starting at the end of SIFS at the same PHY rate as the original received data frame. This is illustrated in Figure 91.

The responding DEV shall send only one frame in response to a received frame soliciting an implied-ACK. The responding DEV shall start its transmission at the end of SIFS, but may transmit its response-data-frame for any length of time without exceeding the current GTS. The responding DEV may send an Imm-ACK as a response to an implied-ACK solicitation. If the responding DEV does not know the end of current GTS, it shall send an Imm-ACK in response to an implied-ACK solicitation. The responding DEV shall make sure

that there is enough time remaining in the current GTS for the Imm-ACK, if required, for the frame sent as response to an implied-ACK solicitation

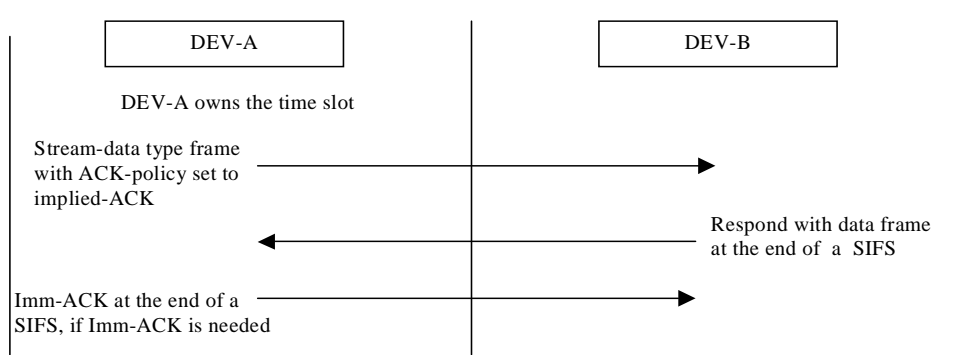


Figure 90—DEV-B responding with a data frame for a frame received from DEV-A that has ACK-policy set to implied-ACK

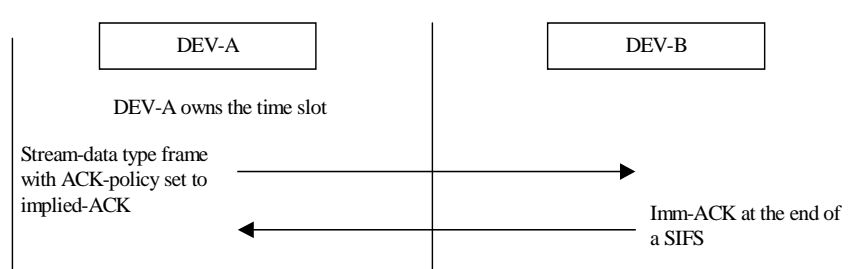


Figure 91—DEV-B sending an Imm-ACK as response to frame received from DEV-A that has ACK-policy set to implied-ACK

8.8.5 Retransmissions

During the CAP, retransmissions shall follow the backoff rules as specified in sub-clause 8.4.2.

During the time slots within a CFP when either Imm-ACK or the implied-ACK is expected, the source DEV shall use the PHY-CCA.indicate, 6.9.4.12, between the end of SIFS and the end of RIFS, to detect the start of the response frame. If PHY-CCA.indicate result is that the medium is idle, the source DEV shall start the retransmission of the frame (or new transmission) at the end of RIFS as long as there is enough channel time remaining in the time slot for the entire frame exchange. When an Imm-ACK is expected and the source DEV receives a medium idle indication, as described above, it shall wait for the duration of Imm-ACK frame plus SIFS before attempting another transmission. The retransmission of the frame or the transmission of a new frame shall start only after SIFS duration of the above events indicating the channel is available for transmission for the source DEV of the time slot.

When Del-ACK is used for a stream, the DEV transmitting the data frame may reject delayed-ACKs for the frames beyond the negotiated retransmission window for the stream. When retransmissions are rejected, the DEV transmitting the stream shall send transmission sequence sync command, as defined in 7.5.9.2, to the recipient of the stream in order to synchronize the delayed-ACKs.

A collision during the transmission of a directed frame in the CAP is detected by the absence of the acknowledgement for that frame.

Any frame may be attempted at most aMaxRetransmissionLimit number of times before the transmitting DEV gives up on that frame and discards it. However a DEV might choose to transmit a data frame for less number of times as some data streams have a short life time.

8.8.6 Duplicate detection

Since the DEV sending the data frame may not correctly receive an ACK, duplicate frames may be sent even though the intended recipient has already received and acknowledged the frame. Hence all the DEVs shall detect such multiple receptions and indicate the data frames to the higher layers only once. The stream index and the sequence number field are used to detect multiple receptions of the same frame. Duplicate detection is also required by the PNC when it is providing repeater service. The PNC shall detect multiple receptions of a frame and not send the repeated frame over the medium to the final recipient.

8.9 Peer discovery

Each DEV associated with a PNC may use the device information request command, 7.5.8.1, to obtain information about other DEVs in the piconet. In addition the DEV may use probe request command, 7.5.4.1, to obtain other information required for peer-to-peer communication (e.g. TPC/DCS).

To accommodate the peer discovery and peer-to-peer communication the response time for a probe request command needs to be limited. A DEV that receives a probe request command with any information request bit set shall respond with a probe response command, 7.5.4.2, with its response within aProbeResponseDelay. If an appropriate response to a request in the probe request command is not received by the requesting DEV within aProbeResponseDelay, the requesting DEV may send another probe request command with the same request. The time between these probe request frames with the same request shall increase by a factor of 2 (i.e. exponential increasing). If the probe request command is sent during the CAP, the required channel backoff time will be in addition to the delay described above.

~~EPS DEVs present a special case for use of the probe request command. It is the responsibility of the DEV sending a probe request command to understand when the EPS DEV will be able to receive it. Use of aProbeResponseDelay is not appropriate as a time-out. It is acceptable for the sending DEV to switch an EPS DEV into ACTIVE mode to improve the responsiveness. The sending DEV shall return the receiving DEV to EPS mode after completion of probing.~~

In addition to the above, any DEV may send the probe request command with the information request field set to zero and ACK set to immediate ACK to any other DEV in the piconet to determine if the destination DEV is still present in the piconet.

8.10 Multi-rate support

A compliant PHY may support more than one data rate. In each PHY there will be one mandatory base rate specified for the purposes described in this sub-clause. In addition to the base rate, the PHY may support rates that are both faster and slower than the base rate. A DEV shall send a frame with one of the supported data rates to a destination DEV only when the destination DEV is known to support that rate. The supported rates and the mandatory base rate are PHY dependent. For the 2.4 GHz PHY, the supported rates are defined in 11.3. Each DEV in a piconet shall use probe request command, 7.5.8.1, to obtain the supported rates from other DEV(s) that it is interested in communicating. Similarly, each DEV shall periodically use channel status request command, 7.5.4.3, to obtain the channel status information from other DEVs that it is interested and decide the PHY rate to be used in transmissions to that other DEVs.

All group addressed frames regardless of their type shall be sent at the base rate as all DEVs are able to receive these frames. The allowed PHY rates for each of the different types of frames are listed in Table 69.

Table 69—Frame data rate limits

Frame type	PHY Data rate limitation
All group addressed frames (including Beacon)	Base rate
Immediate Acknowledgement (ACK)	Same rate as the frame that is being ACKed
PNC selection	Base rate
Association request	Base rate
Association response	Base rate
Disassociation request	Base rate
Directed command frame	In a GTS or MTS, any rate supported by both the source and destination. In the CAP, any rate supported by the source and destination that is at least the base rate.
Broadcast command frame	Base rate
Directed data frame	In a GTS, any rate supported by both the source and destination. In the CAP, any rate supported by the source and destination that is at least the base rate.
Broadcast data frame	Base rate

8.11 Repeater service

If the link between the two DEVs in a piconet is not satisfactory, either of those DEVs may request that the PNC provide repeater service for that link using the repeater service request command, 7.5.6.1. The PNC may grant the service if there is enough channel time available for the PNC to repeat the entire link while preserving the quality of service that is currently expected by the streams in that link. The PNC shall communicate the repeater service grant command, 7.5.6.2, to both the DEVs. The sequence of events for the establishment of the repeater service is illustrated in Figure 8.12. During this process, if either of the DEVs does not wish to continue, that DEV shall send the repeater service reject command, 7.5.6.3, to the PNC. The PNC shall also send the repeater service reject command to the other DEV, if it is already involved.

Once the repeater service is granted between two DEVs, the sending DEV shall continue to send its frames as before. The PNC shall collect all the frames exchanged between the two DEVs and repeat them in the time slot of the PNC (or CAP) with the PNC repeater field set in the MAC header of the repeated frames as specified in 7.2.1.10. The only ACK policies that shall be used for repeater service are Del-ACK and no-ACK.

Once the repeater service has been established, the PNC may not be able to provide the best service on this link all of the time. If the service is not satisfactory, it is up to the DEVs to reject the service by sending the repeater service reject command to the PNC. If the PNC receives the repeater service reject command, it shall send the repeater service reject command to the other involved DEV. Also, if the PNC feels it is no

longer able to provide the repeater service for this link, the PNC may also send the repeater service reject command to both the DEVs to reject the service.

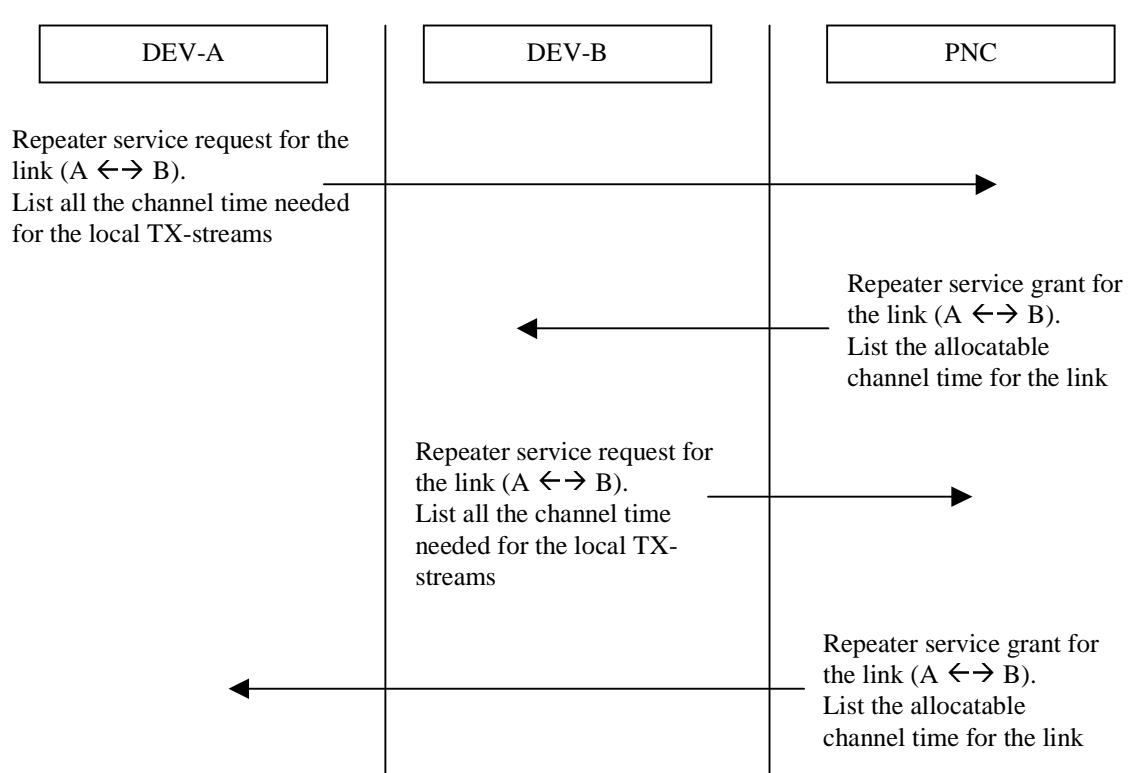


Figure 92—Illustration of the establishment of repeater service

8.12 Dynamic channel selection

The PNC initiates dynamic channel selection if the current QoS requirements cannot be satisfied due to adverse conditions of the channel. The PNC collects the channel status from the DEVs to arrive at this decision. The PNC shall send the channel status request command, defined in 7.5.4.3, to request that the DEVs provide their channel status in return via the channel status response command, 7.5.4.4. The algorithm required to use the channel status information and decide change of channel is beyond the scope of this standard.

If the decision is made by the PNC to change the channel, the PNC shall keep the piconet quiet by not transmitting any beacon for one or more beacon interval. Within that quiet time the PNC may change to one or more other channels to check if one of the other channels is better than the current channel and then return back to the current channel. If no beacons are received for the ATP duration specified in the association response command, the DEVs shall assume they are disconnected and restart the association process.

If the PNC returns to the current channel within the indicated time-out, the PNC shall send a beacon to cancel the quiet state of the piconet. In that beacon the PNC may send the channel change element indicating the new channel and the time-out for changing the channel. The DEVs that received the beacon with channel change element shall change the channel to the new channel within the time-out duration and wait for beacons in the new channel. Whenever another channel is not available, the PNC may decide to stay in the same channel and hence may not send channel change element in its beacon following the cancellation of quiet state of the piconet.

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The dynamic channel selection process is illustrated in Figure 93.

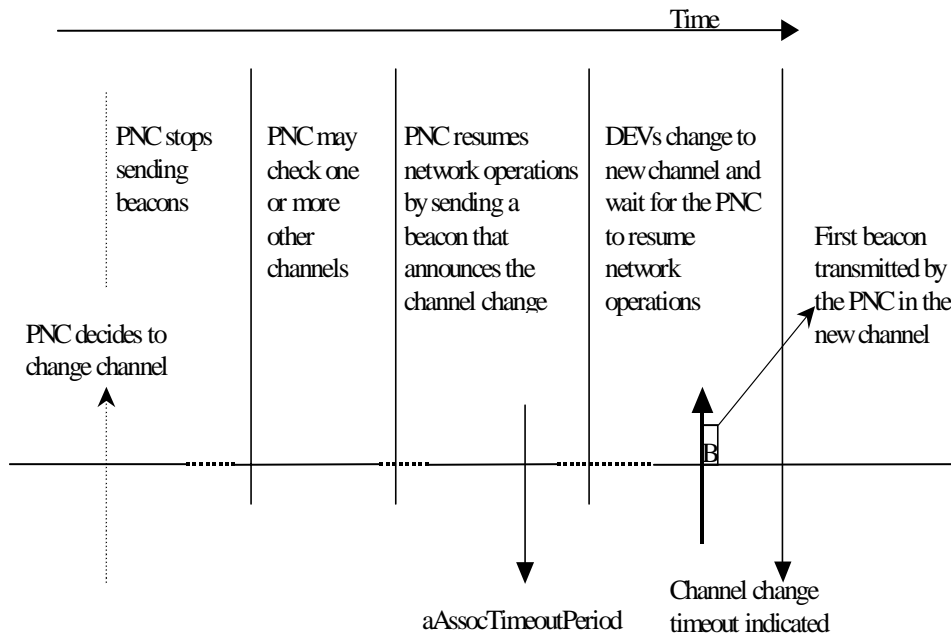


Figure 93—Illustration of dynamic channel selection process

8.13 Power management

Power management mechanisms defined in this clause allow lowered power consumption of attached DEVs while retaining the required performance of a piconet.

EPS mode is the principle power saving mode of devices in this standard and may be applied when data transfer requirements are very low for long periods of time. When EPS devices have higher volumes of data to transfer during portions of their association in a piconet, they will operate in an ACTIVE mode of operation. ACTIVE mode devices may use the capabilities defined in RPS mode to provide a modest power reduction.

It is outside of the scope of this standard what portions of a DEV, and any equipment a DEV is incorporated into, are powered down as a result of power save modes.

A summary of activity for elements is provided in Table 70 and it describes the elements of superframes that power managed DEVs participate in. The table information will be described in sub-clauses of the power management clause.

8.13.1 RPS/EPS priority CTA location

The PNC shall consider the operation of RPS and EPS DEVs provided in PowerManagementMode when allocating GTSS. When informed of the modes and the sensitivity to battery operation, the PNC shall provide a favorable location of slots. Favorable locations are immediately after the CAP and immediately before the beacon. For EPS DEVs, the requirement is immediately after the CAP. For RPS DEVs, either location is appropriate but priority shall be given to EPS DEVs. The PNC shall also consider the PowerManagementPriority parameter giving the best location to those with high priority for power saving. This param-

Table 70—Superframe elements PM DEVs participate in

Operation	Beacon	CAP	MTS (when used)	CFP
PM ACTIVE	All	All	All	All assigned as SRC or DST (as defined by RPS mode)
PM EPS SLEEP	No	No	No	No
PM EPS WAKE w/o data	Yes	No	No	No
PM EPS WAKE w/ data	Yes	No	Only if command to PNC	All assigned as SRC or DST with non null CTA

eter is conveyed to the MAC via the MLME PWRMGT.request command, 6.3.1.1. If the PNC is going to make the change in GTS location due to PowerManagementPriority, it shall do so when an EPS DEV transitions to ACTIVE or EPS.

8.13.1.1 Quality of Service and Preferred Location of assigned slots

Quality of service and power saving has the potential for conflicting requirements on location of assigned slots in the superframe. Any inefficiency for a DEV operating in reduced power returning to powered state is best mitigated with only a single power off cycle for each superframe.

Quality of service with requirements for multiple slots per superframe are not desirable and higher layer protocols have the responsibility to choose the best trade off of multiple slots vs. power saving. In some cases, the PNC will break up bandwidth requests into multiple slots to satisfy other piconet users. The PNC shall take this action only as necessary and not use it as a default approach to portioning out bandwidth for RPS and EPS DEVs.

For DEVs in the same EPS set, an additional location characteristic is that the PNC shall attempt to place their time slots close to each other in the EPS superframe.

For a piconet with many RPS and EPS DEVs, and multi frame Quality of service requirements, the PNC may be limited in its ability to provide beneficial location for all DEVs. It is up to each individual RPS or EPS DEV to select the optimal power reduction method available in those circumstances.

Higher order protocols should only request resources when needed and then release them promptly when not needed to reduce the piconet load and perhaps reduce the multiple slot problem mentioned above.

Algorithms to favorably locate slots are beyond the scope of this standard.

8.13.2 Reduced Power Save (RPS) Mode

Reduction of power within a superframe takes advantage of the scheduling methods defined in this standard. All DEVs using RPS shall receive the beacon and the CAP portions of every superframe. During the CFP, the DEV shall remain powered during slots, MTSSs or GTSSs, assigned to it for reception. If no information is being received within 25 percent of the slot time with CCA indicating channel being idle, the DEV is not required to be available for the remainder of the slot time. The DEV is not required to be powered during transmission slots, MTSSs or GTSSs, that will be unused for a given superframe. For any remaining periods in

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1 the CFP, the DEV may suspend transmit and receive activity and remove power or reduce power to sections
2 of the DEV. Use of RPS is a local decision to a DEV with no control exchange required.

3 4 **8.13.2.1 PNC operating in RPS**

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6 For piconets where use of RPS in the PNC is desired, the PNC may use the methods of RPS.

7
8 Piconet configurations of only a pair of battery sensitive DEVs require that one DEV assume the PNC role
9 and consume a greater amount of power than the non PNC DEV. If traffic permits, a network configured
10 with a long superframe length may help the PNC. Setting the CAP to a very small value and setting very
11 small slot times may also help. It is also possible that a DEV pair may swap PNC roles occasionally to aver-
12 age the power dissipation across both DEVs.

13
14 For piconets using MTSs instead of the CAP, the PNC may reduce the size of the MTSs and make them less
15 frequent as a power saving tool.

16
17 Latency to change is problematic for this configuration as is another DEV searching for this net or attempt-
18 ing to locate an empty channel.

19 20 **8.13.2.2 Control of RPS**

21
22 Use of RPS is a local decision to a DEV with no control exchange required. DEVs may use RPS based on
23 the operational requirements in 8.13.2. Slot positioning preference is described in 8.13.1.

24
25 Slot positioning preference is indicated by the PowerManagementMode value in the DEV to PNC PS infor-
26 mation command, 7.5.7.3. This is provided for PNC use in positioning slots used by RPS and EPS DEVs.

27 28 **8.13.3 Extended power save (EPS) mode**

29
30 EPS mode allows a DEV that is very sensitive to power utilization to remain associated with a piconet but
31 have power savings significantly greater than an RPS DEV. RPS DEVs are required to receive portions of
32 each superframe. EPS DEVs are permitted to be in a very low power sleep state for an extended period of
33 time spanning with the resulting in missed reception during many superframes.

34
35 EPS DEV hosts could have data characteristics where the DEV is typically quiescent for long periods of
36 time. During such quiescent periods, the greatest power savings is achieved through EPS obtained. When
37 DEVs exit EPS mode for RPS or AWAKE periods, it is considered acceptable to use power resources as dic-
38 tated by the DEV host.

39 40 **8.13.3.1 Overview of EPS**

41
42 The EPS mode is defined in this standard to maximize the use of the existing Quality of Service (QoS) archi-
43 tecture. EPS mode of operation between peer DEVs calls for the coordination of wake beacons between cor-
44 responding DEVs and the PNC for traffic indication in the beacons. The wake beacon periods range from
45 every superframe to periods ranging to tens of seconds. Coordinated activity is obtained using a series of
46 commands to initialize EPS mode or change EPS mode. This is described in 8.13.3.3.

47
48 For DEVs configured for EPS mode of operation, specific operation of channel time allocation is necessary
49 for both EPS mode and when EPS DEVs operate in ACTIVE mode. The EPS channel time allocation is
50 described in 8.13.3.4.

51
52 When both initialization and channel time allocation is complete, then clause 8.13.3.5 describes the opera-
53 tions that allow data transfer for EPS DEVs.

8.13.3.2 Quality of Service in EPS mode

EPS mode is based on quality of service requirements of associated DEVs. The standard defines two quality of service operations using the channel time allocation command. One is for ACTIVE mode of operation where the EPS DEV is receiving each superframe and the second for EPS mode of operation where the EPS DEV receives information at a very much reduced rate. There are three typical uses for EPS mode.

The first is a scenario where little or no data is flowing followed by a rapid transition to a high data flow with much higher QoS requirements. An example of this is a multimedia stream from a camcorder that transitions from standby to record. Both the transmitting and receiving DEVs need to be able to tolerate the delay between the availability of the high rate data and the occurrence of the next wake superframe on which the transition to ACTIVE mode will occur.

A second requirement is an application where only small amounts of information will ever flow. This doesn't suggest QoS operation but this momentary operation shall use the channel time request for EPS mode to obtain the appropriate slot time.

A third application is for a persistent but low duty cycle application. This uses the EPS channel time request information.

8.13.3.3 Control of EPS

The MLME POWERMGT.request, response, and confirm primitives as defined in 6.3.1 govern the fundamental operation of EPS for a DEV. The information in this primitive is reflected in the commands in clause 7 used to establish operation. Relationships are between sending DEVs and receiving DEVs and the PNC.

DEV hosts determine the basic operating EPS parameters at a peer to peer level. Their DEVs then provide the necessary operations to configure the PNC so that it provides the necessary basic timekeeping operations and relation to the same EPS set. Annex B provides informative text on how EPS hosts may behave to provide the setup information through the MLME interface.

The role of the EPS Set is to establish a sharable time base for the occurrence of periodic EPS time slots. This time base shall be kept by the PNC with the same precision of an actual slot occurring at the rate specified by EPSTime, and starting on the beacon number specified by EPSNext.

Once an EPS set is established by a DEV (who becomes its first member) the PNC shall repeatedly update EPSNext with the beacon number associated with the end of the next EPSTime interval. When a DEV retrieves information about the EPS Set using the EPS Action Command, 7.5.7.1, that device obtains the beacon count of the next WAKE beacon for every member of the EPS set. Any DEV using the same EPS Set have a WAKE superframe that is identical to all other members of the EPS set who have switched to EPS mode.

Figure 94 is an illustration of the EPS control process. The EPS action command, clause, and EPS action response, 7.5.7.2, make up the first portion of configuration. The EPS action command operates with EPS set, EPSTime, and EPSNext parameters. The first DEV intending to be in a common EPS set shall issue the EPS action command requesting a new EPS set and provide the parameters of EPSTime and EPSNext. The EPS action response command from the PNC will provide an EPS set value that is not in use. Following this exchange, additional members of that EPS set request and receive acknowledgement that they have joined the EPS set. This is followed by use of the DEV to PNC PS information command, 7.5.7.3, to complete the process. The DEV to PNC PS information command provides the parameters PowerManagementMode and PowerManagementPriority to the PNC.

Once configuration as defined in this clause, and presented in Figure 94, Illustration of EPS control process is complete, DEVs shall remain in the ACTIVE mode awaiting further commands. A single DEV that asso-

ciates but does not yet have another DEV that it desires to communicate with may save battery power until another DEV enters the piconet. After configuring using the EPS action command and DEV to PNC PS information command, it may select EPS mode as described in 8.13.3.6

Configuration between DEVs occurs following association and as required by changing requirements at any time thereafter. DEVs requiring a change in EPS operation that will change EPSTime and EPSNext shall return to ACTIVE mode during the renegotiation operation.

An EPS action command requesting release shall be used by the last DEV in an EPS set to remove the EPS set time keeping of EPSTime and EPSNext from PNC activities.

A DEV requiring EPSTime and EPSNext information for a specific EPS set may use the EPS action command requesting information.

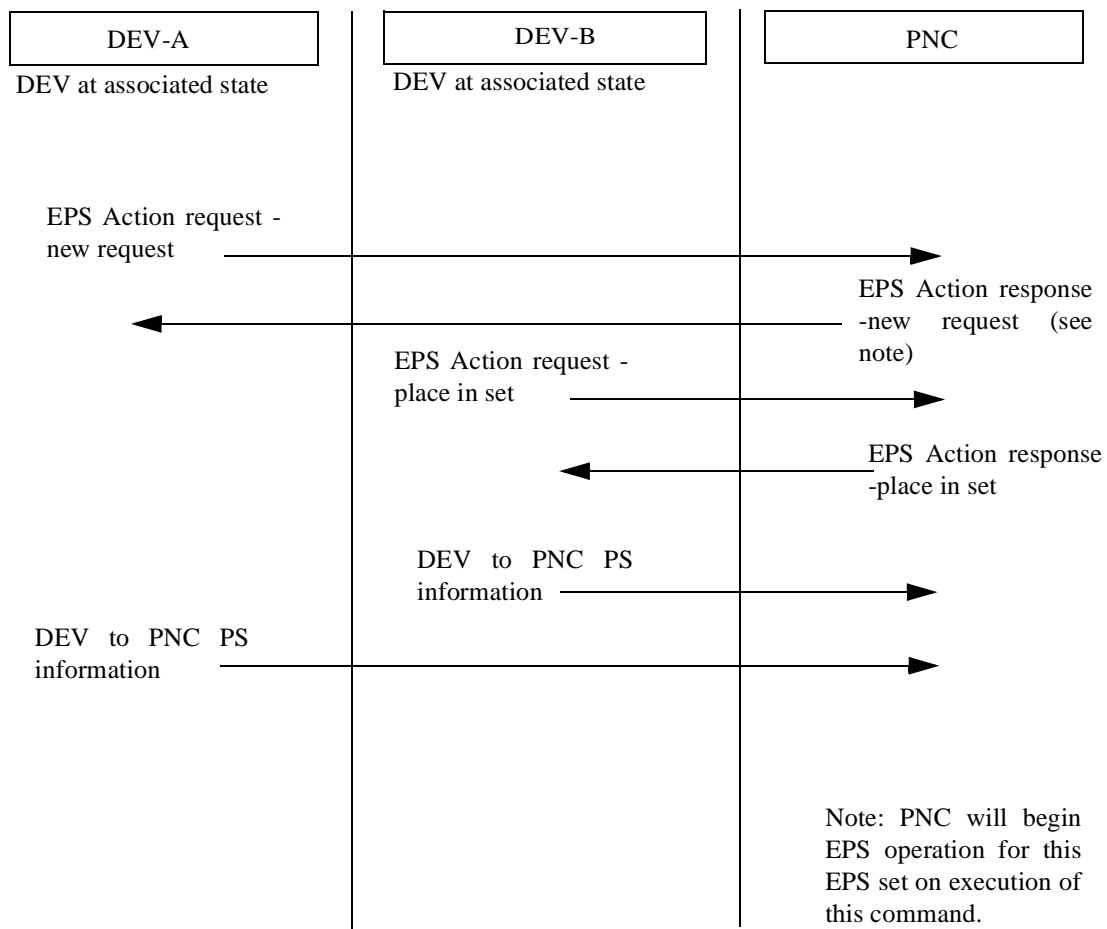


Figure 94—Illustration of the EPS control process

8.13.3.4 ACTIVE and EPS channel time requests and allocations

The operation of channel time requests for EPS mode is shown in Figure 95. Channel time requests (CTRs), 7.5.10.1 and 7.5.10.3, that correspond to the operation of ACTIVE CTA and EPS CTA are required for DEVs operating in EPS mode.

The ACTIVE CTA in a beacon by the PNC is the result of an ACTIVE CTR. The creation of an EPS CTA in a beacon by the PNC is the result of an EPS CTR. However, there is one additional requirement placed on a DEV for the creation of the EPS CTA. The DEV shall also be a member of at least one EPS set. The DEV shall first become a member of an EPS set, and then may issue an EPS CTR using the number of an EPS set to which it belongs as a parameter.

The role of the EPS CTR, as defined in 7.5.10.1, is to specify two parameters:

- 1) The size of the EPS time slots used for data
- 2) The value of N such that a proportion 1:N of EPS time slots that will be of that length.

For an EPS CTR, the allocation period field, 7.5.10.1, is used to specify the value of N. If the value of N is 1, then every EPS CTA has the slot duration specified by the CTR block. If instead, the value of N is 4, then 1 EPS CTA out of each 4 occurrences of the CTA has this specified size. In either case, each data slot is followed by N-1 null EPS slots (i.e. zero time duration slots).

For EPS channel time requests, N = 0 is a special case in which the PNC shall create all EPS CTA slots with zero length. The zero length, or null CTA identifies that the EPS DEV shall listen to this beacon, and that the EPS DEV does not have GTS time allocated for data transmission.

After 2 or more EPS mode CTA devices have submitted EPS type CTR blocks with the same EPS set value, the PNC follows the rules defined in 8.13.1.

The PNC shall decline the EPS channel time request if the DEV is not a member of the EPS set specified, which could be due to the condition that the EPS set does not exist. This rejection shall be sent with a channel time grant command containing the reject code, not a member of requested EPS set, 7.5.10.3.

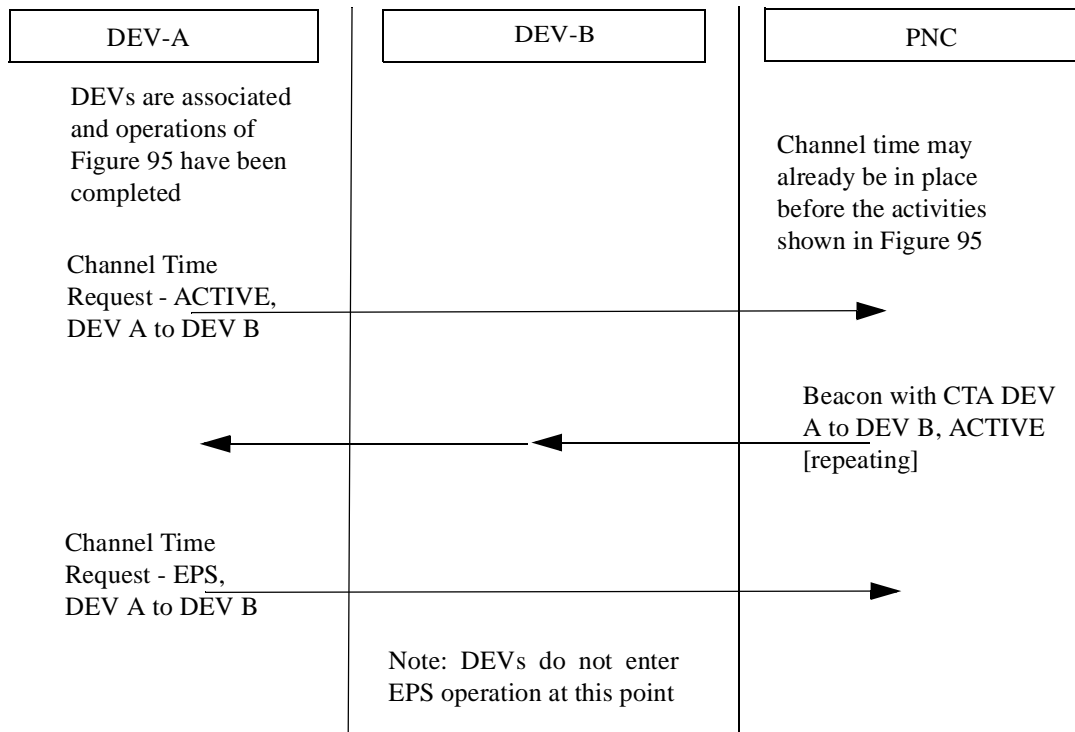


Figure 95—Operation of EPS mode channel time requests

8.13.3.5 Overview of CTA Management

The PNC shall create CTA elements in every beacon, after the PNC has allocated their slot time. An EPS CTA is the CTA of a DEV in EPS mode. An ACTIVE CTA is the CTA of a DEV in ACTIVE mode. If a DEV does not have an ACTIVE or EPS slot in a particular superframe, the PNC shall include a CTA with the beacon number of the next ACTIVE or EPS time slot according to the CTA block definitions of 7.4.10.

The constant presence of CTA element allows any member of the network that has missed hearing some number of beacons, to re-synchronize with other members of the piconet after hearing just one beacon. Any DEV may read the CTA mode of a device as well as its slot start time or beacon number value.

In order for a device to determine the duration of the time slot identified in a particular CTA, that same device shall use the Slot Location field of the next contiguous CTA whose Time Beacon bit is set to 0. This slot location field shall be interpreted as "slot stop time + aSlotGuardTime". The device shall ignore all intermediate CTA blocks that have time beacon bit set to 1.

When a DEV is in EPS mode the EPS set and the EPS channel time request are used together by the PNC to create the EPS CTAs, and time slots with the correct characteristics and at the correct times.

Figure 96 describes the three sequences of switching CTAs for an EPS DEV that is depicted as DEV B. DEV A may be operating as EPS or ACTIVE for this description. Without loss of generality, the direction of information flow is shown here from DEV A to DEV B.

The first sequence describes the transition of DEV B from ACTIVE mode to EPS mode and the operation of the DEV when it is in EPS mode. DEV A first sends a switch to EPS CTA mode command, 7.5.7.5, to the PNC either in the CAP or an MTS. The PNC then switches both the mode of DEV B and the specification it uses to create CTAs. The CTA specification switches from the DEV Bs ACTIVE CTRB to the combination of the DEV Bs EPS CTRB and the EPS Set specified therein. The first sequence shows that DEV B previously specified the EPS CTRB using an allocation period field set to 2. The resulting CTAs have a time slot allocated in every other superframe, with a null CTA allocated in the superframes in between.

The second sequence set describes the operation for the momentary EPS CTA, 7.5.7.6. This command forces an EPS CTA into the next WAKE beacon. It may be issued by a source DEV by sending it in superframe prior to the desired WAKE superframe. The PNC shall create an EPS CTA in the next WAKE superframe with a slot size specified by the original EPS CTR block. It is possible for an EPS DEV to specify that all WAKE times have null slots except when the momentary EPS CTA command is issued. Doing so gives simple direct control over the creation of EPS slots that are still synchronized to the EPS set time base.

The third sequence describes the transition of DEV B from EPS mode back to ACTIVE mode. The switch to ACTIVE mode command, 7.5.7.4, is send by DEV A in the CAP or MTS slot allocated in the superframe before the WAKE superframe. Since this command is sent prior to the WAKE superframe, the PNC is able to switch DEV B to ACTIVE mode and begin using the corresponding CTA elements starting with the next (WAKE) superframe. Since this is the normal WAKE superframe, all devices hearing the beacon will see from the mode bit of the CTA element for DEV B that it is now in ACTIVE mode. The transition is both synchronized and seamless.

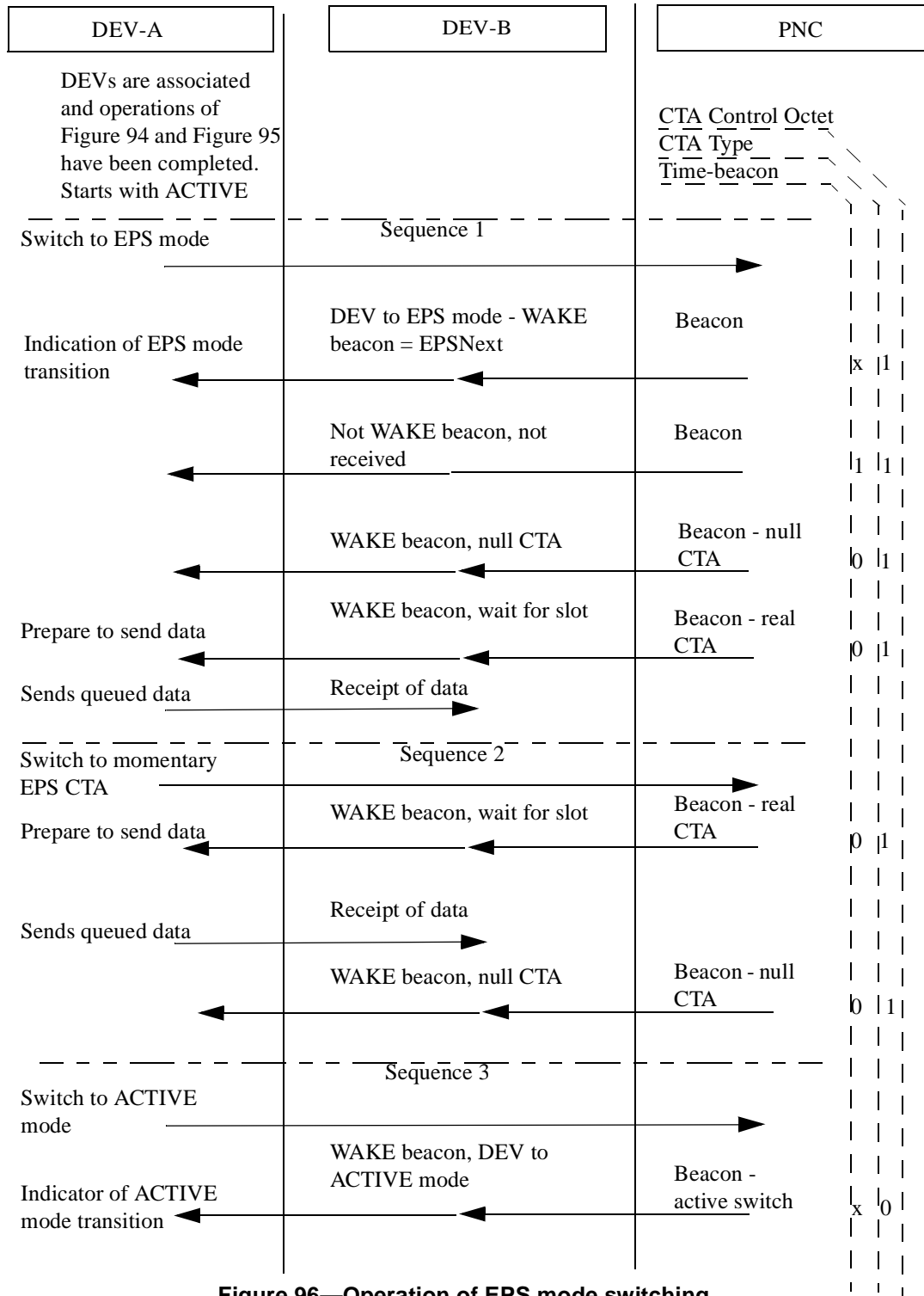


Figure 96—Operation of EPS mode switching

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~~8.13.3.6 Solo EPS~~

A device may allocate both zero slot time and zero allocation period in an EPS channel time request. Under these conditions the PNC shall consider the device to be conserving power without regard to any communication process. A valid EPS set shall still be required, but the PNC shall not associate this request with any stream or any other AD-AD other than the initiator of the command.

When a DEV switches to EPS mode with zero slot time and zero allocation period, that device shall be given WAKE frames with null CTAs and MTSs that are identical to any other EPS mode DEV. This will allow the EPS mode DEV to switch back to ACTIVE mode, as well as send any other valid command to the PNC.

~~8.13.3.7 Control of remote equipment power~~

Operations of EPS and AWAKE modes are extended into the equipment a DEV is incorporated into, i.e. the DEV host. The MLME POWERMGT.request and indicate primitives provide parameters to facilitate power saving in the equipment.

The MLME POWERMGT.request wakeup parameter causes a switch to AWAKE CTA mode or switch to EPS CTA mode to be sent to an EPS DEV. The EPS DEV receiving this command shall provide the MLME POWERMGT.indicate primitive parameter PeerWakeup to its DEV host.

The PeerWakeup parameter shall also provide indication that a packet has been received as a result of operation in EPS mode either with low duty cycle periodic information or momentary information. For each received packet while in EPS mode, the MLME POWERMGT.indicate primitive shall be generated.

Annex B.1 provides information to achieve the appropriate power management benefits both in the EPS DEV and the DEV host.

~~8.13.3.8 Combinations of EPS DEVs~~

A piconet may have several autonomous EPS DEV sets.

Directional operation of EPS DEVs is such that the same AWAKE superframe is used for both directions of a DEV pair.

A combination of EPS and RPS DEV is possible. Likely combinations are where a master is an RPS DEV and the slave is mobile and is an EPS DEV.

The PNC shall support up to sixteen EPS sets in the piconet.

~~8.13.3.9 Additional traffic to EPS DEVs~~

The PNC has the EPSTime information to send piconet wide multicast and broadcast to EPS DEVs. The PNC shall save these for the next wake superframe for each set of EPS DEVs in the piconet. The PNC shall generate a CTA block for this exchange as necessary and place it in the CTA element of the wake beacon for the EPS DEV. The EPS DEV shall interpret the full CTA information element and receive all frames directed to it. The EPS DEV shall switch to ACTIVE mode if network wide activity such as channel change is indicated in commands from the PNC.

If management time slots are used, the PNC shall only assign management time slots for a DEV in EPS mode during superframes when the EPS device is scheduled to be listening to the beacon. The preceding superframe shall have an MTS allocated with the EPS DEV as the source to allow for a Switch to ACTIVE CTA mode command, 7.5.7.4, or a Momentary EPS CTA command, 7.5.7.6, to be sent to the PNC.

8.13.3.10 Association time-out for EPS DEVs

~~It is the responsibility of EPS DEVs that they observe the AssociationTimeOutPeriod operation while in EPS mode. Values of AssociationTimeOutPeriod should be sufficiently large such that an EPS DEV is only required to inform the PNC of its continued presence on an infrequent basis. This should be much greater than the EPSTime value.~~

8.13.3.11 Exception conditions in EPS

~~EPS DEVs recognizing that an error condition has occurred may operate in a special case. Exception conditions processing shall not cause a change of EPSTime or EPSNext. The PowerManagementRecoveryMode parameter, 6.3.1, defines recovery operation. The EPS DEV shall make at least two additional attempts to recover a from an error if set to recover immediately. If set to wait for the next wake cycle, the EPS DEV will not attempt an immediate remedy to the error, except for the following.~~

~~An EPS DEV waking for its wake superframe and receiving a message other than the expected beacon with its CTA zero length or CTA non-zero length shall remain awake and recover synchronization with the network.~~

8.13 Power management

There are three states in power management (PM) at MAC, (a) ACTIVE state (b) RPS state (or snooze state) and (c) EPS state (or sleep state). The DEV shall remain awake as long it is in ACTIVE state. The DEV can be in low power mode in RPS state within a superframe when it has no frames to tx/rx. The DEV could sleep for multiple superframes' duration when in EPS state.

8.13.4 Reduced Power Save (RPS) Mode

Reduction of power within a superframe in RPS state takes advantage of the channel time allocation methods defined in this standard. All DEVs using RPS shall shall be ACTIVE for the beacon and the CAP portions of every superframe. During the CFP, the DEV shall be ACTIVE during slots, MTSs or GTSSs, assigned to it or group address for reception. If no information is being received within 25 percent of the slot time with CCA indicating channel being idle, the DEV is not required to be available for the remainder of the GTS/MTS time. The DEV is not required to be powered during transmission slots, MTSs or GTSSs, that will be unused for a given superframe. For any remaining periods in the CFP, the DEV may suspend transmit and receive activity and remove power or reduce power to sections of the DEV.

If a beacon is not received in any supreframe at a DEV that is not in EPS state, that DEV is expected to be awake for the entire superframe.

Use of RPS is a local decision to a DEV with no control exchange required.

8.13.4.1 PNC operating in RPS

For piconets where use of RPS in the PNC is desired, the PNC may use the methods of RPS.

Piconet configurations of only a pair of battery sensitive DEVs require that one DEV assume the PNC role and consume a greater amount of power than the non-PNC DEV. If traffic permits, a network configured with a long superframe length may help the PNC. Setting the CAP to a very small value and setting very small slot times may also help. It is also possible that a DEV pair may swap PNC roles occasionally to average the power dissipation across both DEVs.

8.13.5 Extended power save (EPS) mode

EPS is the principle power saving mode of devices in this standard. EPS allows a DEV that is very sensitive to power utilization to remain associated with a piconet but have power savings significantly greater than an RPS DEV. RPS DEVs are required to receive portions of each superframe. EPS DEVs are permitted to be in a very low power state in sleep for an extended period of time spanning many superframes. The EPS state is defined in this standard to maximize the use of the existing Quality of Service (QoS) architecture. EPS state of operation between peer DEVs call for the coordination between source DEV, destination DEV and the PNC, which is responsible for traffic indication in the beacons.

When EPS devices have higher volumes of data to transfer during portions of their association in a piconet, they can revert to ACTIVE/RPS mode of operation.

If a DEV is planning to use EPS for power save, then DEV shall set the EPS bit in the capability field to 1 at the association time to let the PNC know its intention. If PNC can not support EPS state then the association may be rejected.

The PNC shall not allocate GTS with any DEV that is currently in EPS state as the destination DEV, unless PNC is providing repeater service for that link. If the PNC is providing repeater service for the frames to a DEV that is currently in EPS state, then the PNC shall repeat the frames in a superframe when the destination DEV is out of EPS state.

The PNC shall not allocate GTSs for multicast dest-address if the PNC knows that any of the destination member for that multicast-stream is currently in EPS state.

PNC is responsible for indicating the “traffic pending” information in the beacon using TIM-information element described in <TBD>. The PNC shall check its local buffers meant for the repeat service and pending GTS-request list to decide if the traffic-indication for a DEV needs to be set to 1 in the outgoing Beacon. Before going to EPS state, the DEV shall inform the PNC of its intention using “Sleep time request” command and wait for PNC to respond. Only at the end of the supreframe in which the DEV receives a “Sleep time permit” command from PNC, shall the DEV is allowed to enter EPS state for a maximum sleep time duration as indicated by the PNC in the received “Sleep time permit” command. The DEV shall wakeup sufficient time before the expiration of that maximum sleep time in order to inform the PNC that it is awake. If the DEV did not successfully indicate that it is out of EPS state to PNC within the expiration of that maximum sleep time, the PNC may disassociate the DEV from its piconet after the expiry of aAssociationTimeout of that DEV. If the DEV receives “Sleep time reject” command from the PNC instead of “EPS state permit” command, the DEV shall not go to EPS state and wait for atleast one more beacon interal before attempting to send another “Sleep time request” command to PNC. But the device is free to use snooze state following the rules to enter snooze state described above. In addition to simply using the Sleep time request and permit commands for the power save operation, the DEVs can adopt a sleep cycle that is described in Figure 98 below. The DEVs can wakeup at periodic intervals, receive a beacon and check the power-save-information element in the received beacon to decide one of the following

- (a) Go back to sleep immediately if there is no traffic pending indication for the DEV and if the maximum sleep time has not expired. However the DEV must wakeup before the maximum sleep time permitted by the PNC expire.
- (b) Send another Sleep time request, if there is no traffic pending indication for the DEV but the maximum sleep time is close to being expired.
- (c) Send “active-state-indication” to PNC and expect the frames from PNC if there is traffic pending indication for the DEV

When the DEV wakes up from sleep, it shall remain awake until atleast one beacon is correctly received so as to detect the CAP correctly.

It is outside of the scope of this standard what portions of a DEV, and any equipment a DEV is incorporated into, are powered down as a result of power save modes.

The PNC shall set the repeater bit to 1 in all the frames it is relaying to a DEV that is awake from EPS state. Since the PNC is buffering broadcast frames and transmitting them when the DEV is awake, it is possible for any DEV in the piconet to receive the same broadcast frames multiple times with or without repeater bit set. Hence each DEV shall use duplication detection mechanism described in 8.8.6 to reject all the multiply received broadcast frames.

The sequence chart in Figure 97 show the sequence of frames/commands exchanged between DEV and PNC for sleep-state management.

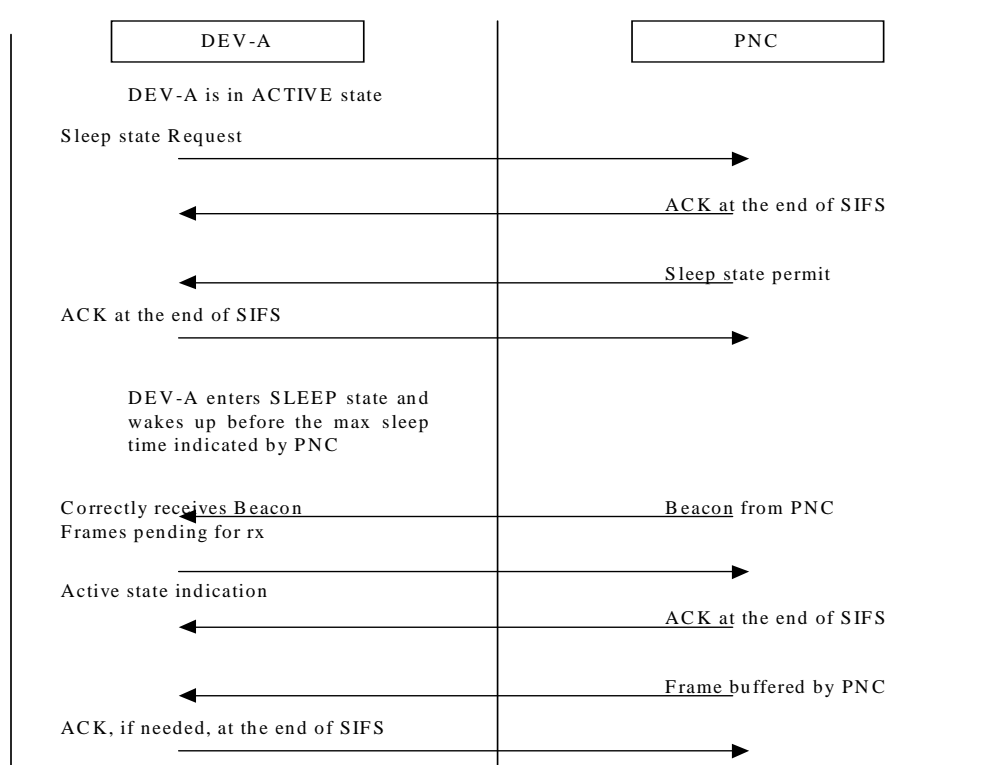


Figure 97—Message sequence chart for entering EPS state and buffered data reception at a DEV

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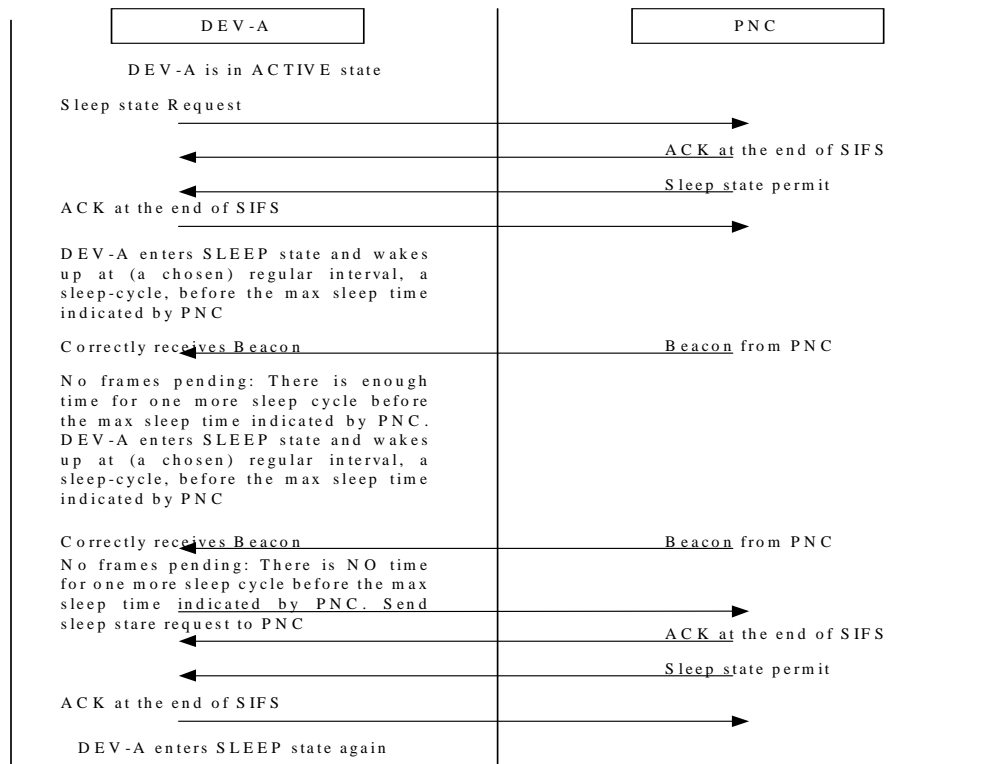


Figure 98—Message sequence chart for entering EPS state and buffered data reception at a DEV

8.13.5.1 Repeater service extensions for EPS mode

EPS DEVs may request repeater service to improve communication within a piconet. A PNC capable of repeater service shall also support repeating for EPS DEVs. The PNC shall receive and repeat during the same wake superframe.

It is the responsibility of the sending DEV to provide information destined for the EPS receiver to the PNC to place it in the appropriate slot when the EPS receiver is to wake.

8.14 Transmit power control

Two forms of transmit power control (TPC) are required for 802.15.3 systems, a fixed maximum power in the CAP and adjustable power in the GTS. The goal of TPC in the CAP is to prevent one DEV from having better access to the medium in the CAP due to a higher transmit power level. Adjustable transmitter power in the GTS is intended to support reduced power usage as well as reducing the overall interference levels of the piconet.

8.14.1 Fixed maximum transmitter power for CAP and beacon

The PNC may choose a maximum transmit power level for the CAP and beacon. The PNC shall convey this information to the DEVs via the beacon frames using the piconet maximum transmit power, 7.4.9. The PNC shall not set the maximum CAP power level below the aMinTPCLevel, which is defined for the 2.4 GHz PHY in 11.5.9. All DEVs within the piconet shall set their nominal maximum transmit power level for frames in the CAP to be no more than the value indicated in the piconet maximum transmit power in the beacon.

8.14.2 Adjustable transmitter power in the GTS

Each DEV participating in an allocated GTS may request that the other DEV it is communicating with the GTS either increase or decrease its transmitter power level. A DEV shall use the transmit power change command, 7.5.5.1, to request the change in the power level setting of the other DEV for all GTSs assigned between the two DEVs. The other DEV shall increase or decrease its transmit power level as indicated in the transmit power change command if the power level setting is supported by that DEV. If the power level change is not supported by the other DEV, it shall use the closest implemented TX power level. The other DEV shall apply the change in the power level for all GTSs assigned between the two DEVs.

An example of this is:

- 1) DEV-1 estimates that its receive power from the DEV-2 is 6 dB higher than necessary.
- 2) DEV-1 sends the transmit power change command, 7.5.5.1, to DEV-2 with the requested TX power level change.
- 3) DEV-2 sets the TX power level to the requested power level. If the chosen power level is not implemented by DEV-2, it chooses the closest implemented TX power level and sets that as the TX power level for subsequent transmissions to DEV-1 in the GTS allocated.

A DEV may also change its transmit power based on its own estimation of the channel.

8.15 Frame exchange rules

This clause defines the general frame exchange rules while the specific order of frames in a given frame exchange sequence is defined in an earlier clause describing the mechanism for which those frames are used. A list of the rules are specified in the tables below.

8.16 MAC layer parameters

The parameters that define some of the MAC characteristics are given in Table 73

Table 71—Frame exchange limitations during the CAP

Frame sequence	Number of frames in the sequence	Usage description
Association request - ACK	2	A DEV requesting association with a PNC
Association response - ACK	2	The PNC allows the DEV to associate
PNC selection	1	PNC selection: During this time there is no CFP running as there is no PNC for the piconet that is being established
Group addressed frame	1	Used only if the source DEV does not have any time slot allocated for non-isochronous stream
Directed Command frame -ACK	2	Used only if the source DEV does not have any time slot allocated for non-isochronous stream

Table 72—Frame exchange limitations during the CFP

Frame sequence	Number of frames in the sequence	Usage description
Group addressed frame	1	Only in the time slot allocated for source-DEV with DA of the time slot being the broadcast address
Directed frame (requiring no-ACK or Del-ACK)	1	Only in the time slot allocated for the source DEV with destination DA of the time slot being the same as that of the transmitted frame
Directed frame (requiring Imm-ACK) ACK	2	Only in the time slot allocated for the source DEV with destination DA of the time slot being the same as that of the transmitted frame
Directed frame (requiring implied-ACK) - Directed frame (requiring no-ACK or Del-ACK)	2	Only in the time slot allocated for the source DEV with destination DA of the time slot being the same as that of the first transmitted frame
Directed frame (requiring implied-ACK) - Directed frame (requiring Imm-ACK) - ACK	3	Only in the time slot allocated for the source DEV with destination DA of the time slot being the same as that of the first transmitted frame

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Table 73—MAC layer parameters

Parameter	Value
aMinChannelScan	aMaxSuperframeDuration
aCSFrameBroadcast	20 ms
aCSFrameRepeat	3
aCHFrameRepeat	3
aADAdressReuseTime	1024 ms
aBroadcastDEVInfoDuration	64*aMaxSuperframeDuration
SIFS	PHY dependent, defined in 11.2.6.2 for the 2.4 GHz PHY
aBackoffSlot	PHY dependent, defined in 11.2.6.1 for the 2.4 GHz PHY
aMinTPCLevel	PHY dependent, defined in for the 2.4 GHz PHY
aAssocRespConfirmTime	5 ms
aProbeResponseDelay	8 ms
aFragThreshold	DEV chooses this value
aMaxTransferUnitSize	8196 octets
aMaxRetransmissionLimit	16
aBroadcastDEVInfoDuration	1024 ms
aMinSuperframeDuration	512 μ s
aMaxSuperframeDuration	100 ms
aMinHandOvrTO	250 ms
aMaxHandOvrTO	1000 ms
aMaxFrameSize	PHY dependent, defined in 11.2.7 for the 2.4 GHz PHY
aMaxLostBeacons	4
aMTSAssocPeriod	0.6 s

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