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Smart Body Area Network (SmartBAN);
Low Complexity Medium Access Control (MAC) for SmartBAN

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Contents

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Smart Body Area Network (SmartBAN).

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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1 Scope

The present document specifies low complexity medium access control (MAC) for SmartBAN.

The present document applies to short range, wireless communication between wearable sensors devices and the hub coordinator. The present document specifies MAC protocol designed to facilitate spectrum sharing with other devices.

The specification describes:

- Channel Structure.
- MAC Frame Formats.
- MAC functions.

The devices are capable of operating in all or any part of the frequency band shown in Table 1.

Table 1: Industrial, Scientific and Medical (ISM) frequency band

Direction of Transmission	Industrial, Scientific and Medical (ISM) frequency band
Transmit / Receive	2,4 GHz to 2,4835 GHz

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

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The following referenced documents are necessary for the application of the present document.

[1] ETSI TS 103 326 (V1.1.1) (2015-03): "Smart Body Area Network (SmartBan); Enhanced Ultra-Low Power Physical Layer".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

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The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI EN 300 328-1 (V1.3.1) (2001-12): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Wideband Transmission systems; Data transmission equipment operating in the 2,4 GHz ISM band and using spread spectrum modulation techniques; Part 1: Technical characteristics and test conditions".

[i.2] IEEE™ Std. 802.15.6-2012: "IEEE Standard for Local and metropolitan area networks - Part 15.6: Wireless Body Area Networks".

[i.3] IEEE™ Std. 802.15.4-2011: "IEEE Standard for Local and metropolitan area networks - Part 15:4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specification for Low-Rate Wireless Personal Area Networks".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

active period: period within the superframe period that is ready for frame reception and transmission

active state: internal power management state that is ready for the frame reception and transmission

allocation: one or more time intervals that a node or a hub obtains using an access method for initiating one or more frame transactions

beacon: frame transmitted by a hub to facilitate network management, such as the coordination of medium access and power management of the nodes in the SmartBAN, and to facilitate clock synchronization therein

beacon period: duration when a beacon is transmitted

connection: relation between a node and a hub in a body area network (BAN), substantiated by an identification assigned to the node by the hub and by access arrangement between them

device: entity conforming to the SmartBAN medium access control and physical interface to the wireless medium

downlink: communication link for transfer of management and data traffic from a hub to a node

frame: uninterrupted sequence of octets delivered by the medium access control (MAC) sublayer to the physical (PHY) layer, or vice versa, within a node or a hub

hub: entity that possesses a node's functionality and coordinated the medium access and power management of the nodes in the SmartBAN

inactive period: period in time following an active transmission sequence during which the equipment does not transmit or receive

medical device: any instrument, apparatus, appliance, software, material or other article, whether used alone or in combination, together with any accessories, including the software intended by its manufacturer to be used specifically for diagnostic and/or therapeutic purposes and necessary for its proper application, intended by the manufacturer to be used for human beings for the purpose of:

- diagnosis, prevention, monitoring, treatment or alleviation of disease,
- diagnosis, monitoring, treatment, alleviation of or compensation for an injury or handicap,
- investigation, replacement or modification of the anatomy or of a physiological process,
- control of conception,

and which does not achieve its principal intended action in or on the human body by pharmacological, immunological or metabolic means, but which may be assisted in its function by such means

multi-use channel access mode: mode of operation where the slot structure during the scheduled and control and management periods is accessible by multiple different priorities based on a temporal order

node: entity conforming to the SmartBAN medium access control and physical interface to the wireless medium

operating frequency: frequency at which the equipment can be operated

priority channel access: highest priority access during multi-use channel access

re-use channel access: lowest priority access during multi-use channel access enables re-use of scheduled but not utilized slots

scheduled access: one or more scheduled reoccurring time intervals that a node and a hub obtains using scheduled access for initiating frame transactions

NOTE: A scheduled allocation is an uplink or downlink allocation suitable for servicing high or low duty cycle periodic or quasi-periodic traffic on a committed schedule.

star network: logical network partition comprising a hub and zero or more nodes whose medium access and power management are coordinated by the hub

uplink: communication link for transfer of management and data traffic from a node to a hub

3.2 Symbols

For the purposes of the present document, the following symbols apply:

×	Mathematical multiplication of the term immediately preceding the symbol and the term immediately following the symbol
CP_{max}	Maximum Contention Probability
CP_{min}	Minimum Contention Probability
GHz	Gigahertz
L_D	Number of time slots in Inter-Beacon Interval
L_F	Length of MAC Frame Body (bits)
MHz	Megahertz
N_{CM}	Number of time slots in Control and Management Period
N_S	Number of time slots in Schedule Period
T_C	Interval between control channel beacons
T_D	Inter-Beacon Interval
T_{MUA}	Total duration of sensing period in Multi-use Channel Access
T_S	Duration of a time slot

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ACK	Acknowledgement
BAN	Body Area Network
C-Ass	Connection Assignment
C-Beacon	Control Channel Beacon
CCH	Control Channel
C-Frame	Control Frame
CRC	Cyclic Redundancy Check
C-Req	Connection Request
D/SR	Downlink/Slot Reassignment
D-Beacon	Data Channel Beacon
DCH	Data Channel
D-Frame	Data Frame
DL	Downlink
D-Req	Disconnection Request
D-Res	Disconnection Response
EUI-48™	Extended Unique Identifier-48 bits
FCS	Frame Check Sequence
FEC	Forward Error Correction
IFS	Inter-Frame Spacing
IM	Information Module
ISM	Industrial, Scientific and Medical
IU	Information Units
MAC	Medium Access Control
NACK	Negative Acknowledgement
NID	Node ID
PHY	Physical Layer
REP	Repetition Coding
Rx	Receive

S-Ras	Slot Reassignment
Tx	Transmit
UL	Uplink

4 Introduction and Background

Modern medical and health monitoring equipment are moving towards the trend of wireless connectivity between the data collection or control centre and the medical devices or sensors. Therefore, the need for a standardized communication interface and protocol between the actors are required. This network of actors performing some medical monitoring or functions is called a Smart Body Area Network (SmartBAN).

A SmartBAN is a simple, low complexity, low energy communication network that allows wireless connectivity between the devices and a hub. The distinct features of the SmartBAN are ease of access, minimal listening, reliable data transfer, provision of additional control messages (in the form of C-Beacons) for the low duty cycling nodes while maintaining simple and flexible protocol. SmartBAN also has provision for multi-use channel access mechanism for emergency and other high priority access and for improved channel utilization.

The distinct characteristics of the SmartBAN are:

i) asymmetrical relation between hub and the device, where the hub performs most scheduling and computations;

ii) minimized listening period for the node;

iii) additional provisioning of beaconing messages and thus reliable and enhanced connectivity.

5 General MAC Framework

5.0 Different device types

This clause provides the basic MAC framework for the nodes and hubs.

Two different device types can participate in SmartBAN: medical sensor device (node) and coordinator device (hub). A hub is a device that acts as a SmartBAN coordinator. A node is any device that acts as an information source or an information sink. One hub and at least one node constitute a SmartBAN.

A SmartBAN shall be organized into a star topology consisting of at least one node communicating directly with the hub.

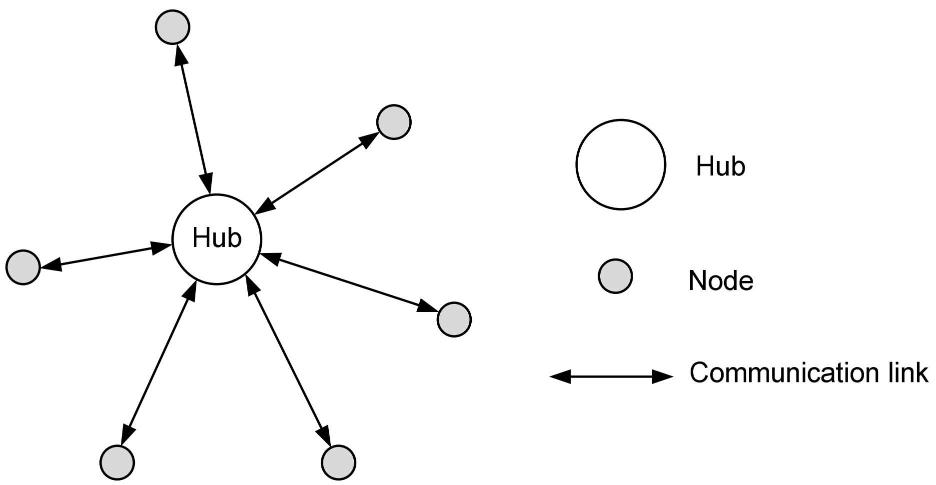

Figure 1: SmartBAN Topology

The hub and nodes shall communicate using communication media known as channels. A SmartBAN shall use two different channel entities to enable communication between the hub and nodes. The channel entities are assigned the following names:

- Data channel (DCH)

- Control channel (CCH)

Each SmartBAN shall utilize one control channel (CCH) and one data channel (DCH) at any one time.

5.1 Frequency Spectrum

The frequency of operation shall fall within 2 401 - 2 481 MHz. The channels shall be arranged in blocks of 2 MHz with centre frequencies:

$$f_c = 2\,402 + 2\times n \text{ MHz, where } n = 0 \text{ to } 39.$$

The channels are categorized into data and control channels with:

- 3 Control channels, where control frames (in the form of Control Channel Beacon) from the hub is transmitted;
- 37 Data channels, where data, control, and management frames are transmitted.

The list of channels can be found in ETSI TS 103 326 [1].

5.2 Channel Format

5.2.1 Control Channel (CCH) Format

Only hub devices shall transmit on control channels. A hub shall select one control channel from the list of control channels in ETSI TS 103 326 [1], Table 1 and transmit one control beacon frame (C-Beacon) on the chosen control channel (CCH) every T_C seconds. The format of the C-Beacon is set out in clause 6.1.

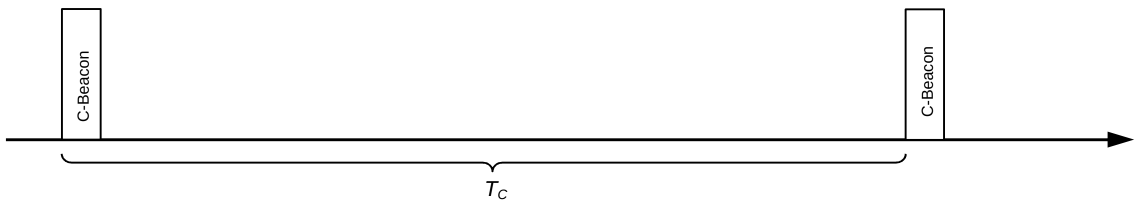

Figure 2: Control Channel

5.2.2 Data Channel (DCH) Format

5.2.2.0 Data channel description

Both hub and node devices may transmit on the data channels. A hub shall select one data channel from the list of data channels in ETSI TS 103 326 [1], Table 1 on which both hub and node devices in the associated SmartBAN may transmit. For any SmartBAN, the data channel is partitioned into time intervals of T_D seconds, known as the Inter-Beacon Interval. The boundaries of each Inter-Beacon Interval shall be marked by the transmission of a data channel beacon (D-Beacon). A hub shall transmit a D-Beacon at the beginning of each Inter-Beacon Interval.

Each Inter-Beacon Interval shall be partitioned into L_D distinct time epochs known as slots. The duration of each time slot is T_S. The duration of each Inter-Beacon Interval shall be $L_D \times T_S$ seconds. Any device transmitting in a time slot shall ensure that the transmission takes place within the duration of that time slot.

Each Inter-Beacon Interval shall consist of four distinct periods:

- Beacon Period, consisting of one single time slot, where the D-Beacon frame shall be transmitted by the hub. No nodes shall transmit in this period;
- Scheduled Period, consisting of N_S time slots, where scheduled transmissions and acknowledgements occur;
- Control and Management Period, consisting of N_{CM} time slots, where unscheduled access, and management and control signalling occur;

- Inactive Period, where no transmission occurs.

The time slots shall be identified by a 10 bit sequence denoting the position of the time slot in an Inter-Beacon Interval. The Beacon Period, consisting of 1 time slot shall have the sequence number 0000000000. Subsequent time slots shall have sequence numbers incremented by the number of time slots following the Beacon Period.

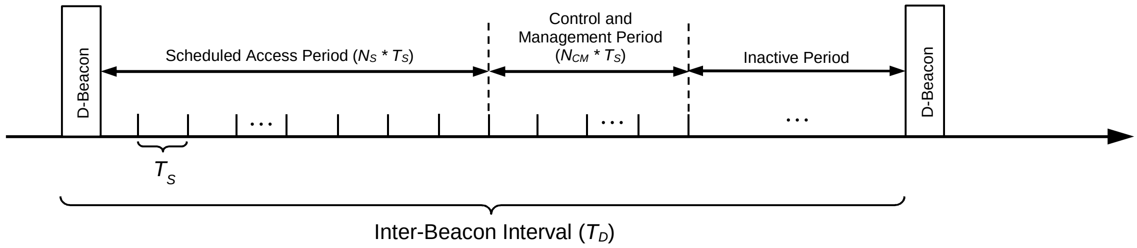

Figure 3: Access Periods in Data Channel

The Scheduled Access Period shall begin on the slot boundary immediately following the Beacon. The Scheduled Access Period may be of zero length, in which case, the Control and Management Period shall begin immediately following the Beacon Period. The Control and Management Period shall begin on the slot boundary immediately following the Scheduled Access Period. The Inactive Period shall begin on the slot boundary immediately following the Control and Management Period.

Three types of channel access mechanisms can be used in the access periods:

- Scheduled Channel Access, in the Scheduled Access Period.
- Slotted Aloha Channel Access, in the Control and Management Period.
- Multi-use Channel Access, in both Scheduled Access and Control and Management Period.

The hub shall support all three types of channel access mechanisms. Nodes shall always support Scheduled Channel Access and Slotted Aloha Channel Access, and may support Multi-use Channel Access. Multi-use Channel Access may only be used when every node in the SmartBAN supports it. Each channel access mechanism shall adhere to their respective slot structure as described in the following clause.

5.2.2.1 Scheduled Access Slot Structure

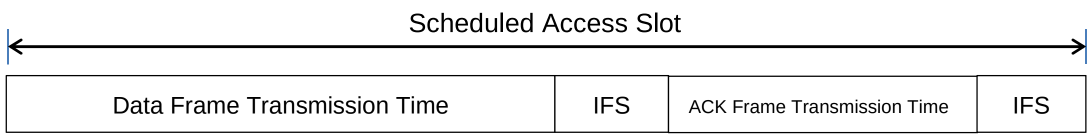

Figure 4: Scheduled Access Slot Structure

The Scheduled Access time slots shall follow the structure as illustrated in Figure 4. Any Scheduled Access time slots allocated by the hub shall be in the Scheduled Access Period.

The Scheduled Access slot shall consist of at most 2 transmission periods:

- Data Frame Transmission: the device allocated the time slot shall transmit;
- ACK Frame Transmission: If ACK policy of the received frame defined in clause 6.1.1.1.2 is '0' and the transmission is successful, the receiving device shall transmit an Acknowledgement Frame. If ACK policy is '1' and the transmission is not successful, the receiving device shall transmit a Negative Acknowledgement (NACK) Frame. The ACK Frame Transmission period shall commence 1 IFS after the end of the Data Transmission period and end at least 1 IFS before the end of the time slot.

5.2.2.2 Control and Management Slot Structure

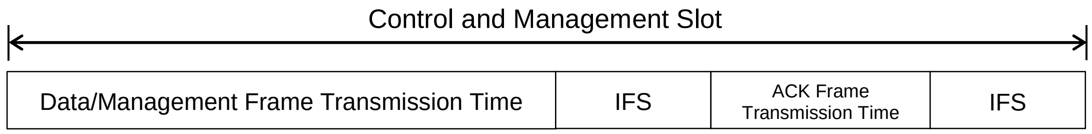

Figure 5: Control and Management Slot Structure

The Control and Management time slots shall follow the structure as illustrated in Figure 5.

The Control and Management slot shall consist of 2 transmission periods:

- Data/Management Frame Transmission: any device wishing to transmit either data or management frames may transmit;
- ACK Frame Transmission: If ACK policy of the received frame defined in clause 6.1.1.1.2 is '0' and the transmission is successful, the receiving device shall transmit an Acknowledgement Frame. If ACK policy is '1' and the transmission is not successful, the receiving device shall transmit a Negative Acknowledgement (NACK) Frame. The ACK Frame Transmission period shall commence 1 IFS after the end of the Data Transmission period and end at least 1 IFS before the end of the time slot.

5.2.2.3 Multi-use Access Slot Structure

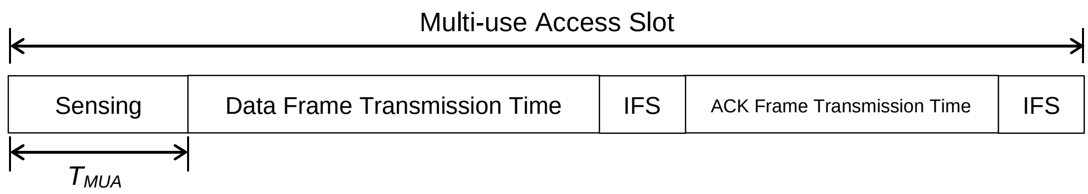

Figure 6: Multi-use Access Slot Structure

The Multi-use Access time slots shall follow the structure as illustrated in Figure 6. The Multi-use Access time slots shall be used when Multi-use Access is in operation.

The Multi-use Access slot shall consist of 1 sensing period, and at most 2 transmission periods:

- Sensing; the sensing period, T_{MUA}, shall depend on the traffic type. The values of T_{MUA} are defined in Table 2, where T_{sch} is the minimum sensing period as defined in clause 8. Any device wishing to transmit shall sense the channel for a period of T_{MUA}. If the channel is busy, they shall wait for the next available Multi-use Access time before another attempt is made. If the channel is found to be idle, the device may commence data transmission.
- Data Frame Transmission: any device that has sensed the channel for the sensing period above may transmit if the channel is found to be idle.
- Acknowledgement period; the receiving device may transmit an Acknowledgement frame if the transmission is successful, depending on the acknowledgement policy.

Table 2: Values of T_{MUA}

Type of User	Type of traffic	Access Period	T_{MUA}
Any User	Emergency traffic (User priority 3)	Scheduled Access	0
Slot Owner	Any traffic	Scheduled Access	T_{sch}
Non-Slot Owner	Any traffic	Scheduled Access	$2 \times T_{sch}$
Any User	Emergency traffic (User priority 3)	Control & Management Access	0
Any User	Any traffic	Control & Management Access	T_{sch}

5.3 User Priorities

Four user priority levels shall be defined in the operation of a SmartBAN. The user priorities are defined in Table 3. The user priority shall determine the contention probability of the node in Slotted Aloha Channel Access. The range of contention probabilities for different user priority levels is listed in Table 4.

Table 3: List of User Priorities

User Priority	Data Type
0	Low priority
1	Mid priority
2	High priority
3	Very High (Emergency)

Table 4: Contention Probabilities for Different User Priorities

User Priority	Contention Probability	
	CP_{max}	CP_{min}
0	1/8	1/16
1	1/4	1/16
2	1/2	1/8
3	1	1/2

5.4 Node IDs

The Node ID of devices in a SmartBAN shall be assigned according to Table 5.

Table 5: Node ID Table

NID Value	NID Subtotal	NID Notation	NID Usage
00000000	1	Unconnected NID	For unicast from/to unconnected nodes in a BAN
00000001-00010000	16	Connected NID	For unicast from/to connected nodes in a BAN
00010101	1	Hub NID	For hubs
11111111	1	Broadcast NID	For broadcast to all nodes

5.5 Information Units

Information Units (IUs) encapsulate the required information for specific operations. Operations requiring IUs shall use the appropriate Element ID listed in Table 6. An IU shall be formatted as in Figure 7.

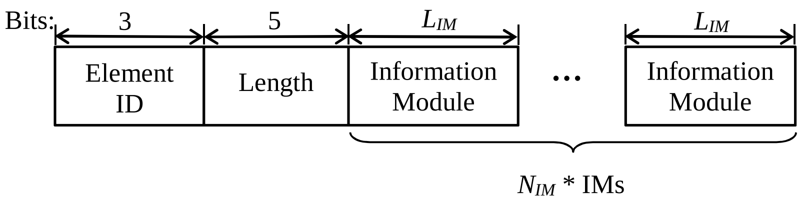

Figure 7: Structure of an Information Unit

An IU comprise of an Element ID field, a Length field, and multiple Information Module (IM) fields.

The Element ID field denote the type of operation the IU is used for. The field shall be set according to Table 6.

The Length field denote the number of IM fields the IU has. Each IU can have up to 32 IM fields.

The Information Module field is operation specific and have a length of L_{IM}.

Table 6: Element ID for different operations

Element ID	Operation	Description
000	Uplink Request	Specifies uplink requirements for scheduled uplink transmissions
001	Downlink Request	Specifies downlink requirements for scheduled downlink transmissions
010	Uplink Assignment	Specifies uplink assignment parameters for scheduled transmissions
011	Downlink Request Assignment	Specifies downlink assignment parameters for scheduled transmissions
100	Uplink Slot Reassignment	Specifies new slot allocations in the Scheduled Access Period for different nodes in the uplink
101	Downlink slot Reassignment	Specifies new slot allocations in the Scheduled Access Period for different nodes in the downlink

6 Frame Formats

6.1 MAC General Frame Format

6.1.0 General description

All MAC frames shall be formed by concatenation of a MAC Header of 48 bits, a MAC Frame body of L_F bits, and a Frame Parity of 16 bits. The MAC Frame Body has a length of L_F bits and is present only if it has a nonzero length. The MAC frame shall also be called the MAC Protocol Data Unit (MPDU).

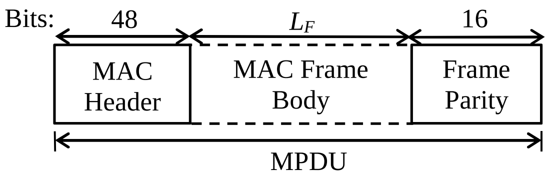

Figure 8: MAC General Frame Format

6.1.1 MAC Header

6.1.1.0 MAC Header Format

The MAC Header shall consist of:

- a Frame Control field,
- a Recipient ID field,
- a Sender ID field,
- a BAN ID field, and
- a FCS.

Bits:	24	8	8	8	8
	Frame Control	Recipient ID	Sender ID	BAN ID	FCS

Figure 9: MAC Header Format

6.1.1.1 Frame Control

6.1.1.1.0 Frame Control Format

The 24 bit Frame Control field shall be formatted as shown in Figure 10.

Bits:	3	1	2	3	8	3	1	1	2
	Protocol Version	ACK Policy	Frame Type	Frame Subtype	Sequence Number	Fragment Number	Non-final Fragment	Command Ack	Reserved

Figure 10: Frame Control Format

6.1.1.1.1 Protocol Version

The Protocol Version field is set to '000'. All other values are reserved.

6.1.1.1.2 Acknowledgement (ACK) Policy

The Ack Policy field indicates the acknowledgement type used by the current frame. The field is set to '0' to indicate that an Acknowledgement frame (ACK) will be sent when a transmission is successful. The field is set to '1' to indicate that no Acknowledgement (ACK) frames shall be sent when a transmission is successful, but a Negative Acknowledgement (NACK) shall be sent when a transmission is unsuccessful. When NID is set to '11111111' (Broadcast), ACK policy is not applied.

6.1.1.1.3 Frame Type

The Frame Type field is set to indicate the type of the current frame. The three defined Frame Types are: Management, Control, and Data. The Frame Subtype and Frame Type are given in Table 7.

Table 7: Frame Type and Frame Subtype Fields

Field Value	Frame Type	Field Value	Frame Subtype
00	Management	000	Beacon
00	Management	001	Connection Request
00	Management	010	Connection Assignment
00	Management	011	Slot Reassignment
00	Management	100	Disconnection Request
00	Management	101	Disconnection Response
00	Management	110	Inter HUB
00	Management	111	Reserved
01	Control	000	ACK
01	Control	001	NACK
10	Data	000	User Priority 0
10	Data	001	User Priority 1
10	Data	010	User Priority 2
10	Data	011	User Priority 3
10	Data	100	Inter HUB
11	Reserved	101-111	Reserved

6.1.1.1.4 Frame Subtype

The Frame Subtype field shall be set as defined in Table 7.

6.1.1.1.5 Sequence Number

The Sequence Number field specifies the sequence identifier of the frame.

The Sequence Number is applicable for both beacon and data frames. The values of Sequence Number field is set as follows:

- The field is set to zero if the frame is the first data type frame of this frame subtype to a recipient.
- The field is incremented by one, modulo 256, from its value in the frame that was the same frame type of this frame subtype and addressed to a recipient.
- For data type frames, the field is kept with the same value if frames containing fragments of the same MAC Frame Body; or being retransmitted to the same recipient.

6.1.1.1.6 Fragment Number

The 3 bit Fragment Number field is applicable for the data type frames. The values of Fragment Number is set as follows:

- The Fragment Number field is set to zero if the current frame contains no MAC Frame Body, a MAC Frame Body not fragmented, or the first fragment of a fragmented MAC Frame Body.
- The value of the field is incremented by one from its value in the frame containing the previous fragment of the MAC Frame Body if the current frame contains a non-first fragment of a fragmented MAC Frame Body; or, kept with the same value if the frame is being retransmitted to the same recipient.

In all other frames, it is reserved.

6.1.1.1.7 Non-final Fragment

The 1 bit Non-final Fragment field is only applicable to data type frames.

The Non-final Fragment field is set as follows:

- set to zero if the current frame contains no MAC Frame Body, a MAC Frame Body not fragmented, or the final fragment of a fragmented MAC Frame Body; or
- set to one if the frame contains a non-final fragment of a fragmented MAC Frame Body.

In all other frames, it is reserved.

6.1.1.1.8 Command Acknowledgement

The 1 bit Command Acknowledgement field shall be set as follows:

- set to one if the node acknowledges that he has received the slot reassignment or downlink data request command from the hub;
- set to zero otherwise.

6.1.1.2 Recipient ID

The Recipient ID is an 8 bit ID identifying the recipient of the frame, assigned previously by the hub according to Table 5. The specific recipient ID of each frame is defined in Table 8.

6.1.1.3 Sender ID

The Sender ID is an 8 bit sequence identifying the sender of the frame. The specific sender ID of each frame is defined in Table 8.

6.1.1.4 BAN ID

The BAN ID is an 8 bit abbreviated address identifying the SmartBAN of the sender and recipient. The specific BAN ID of each frame is defined in Table 8.

Table 8: Table of IDs

Type	Subtype	Sender ID	Recipient ID	BAN ID
Management	Beacon	Hub ID	Broadcast	Hub ID
Management	Connection Request	unconnected ID	Hub ID	Hub ID
Management	Connection Assignment	Hub ID	unconnected ID	Hub ID
Management	Slot Reassignment	Hub ID	Broadcast	Hub ID
Management	Disconnection Request	Node ID	Hub ID	Hub ID
Management	Disconnection Response	Hub ID	Node ID	Hub ID
Management	Interhub	Hub ID	Recipient BAN Hub ID	Hub ID
Data	User Priority (0 -3)	Hub ID/Node ID	Node ID/Hub ID	Hub ID
Data	Interhub	Hub ID	Recipient BAN Hub ID	Hub ID

6.1.1.5 FCS

The 8 bit Frame Check Sequence (FCS) of the MAC Header generated using the generator polynomial $x^8 + x^7 + x^3 + x^2 + 1$.

6.1.2 MAC Frame Body

The MAC Frame Body has L_F bits. The minimum permissible length of the MAC Frame Body is 0. The maximum permissible length of the MAC Frame Body is $L_{F,max}$, and this is defined in ETSI TS 103 326 [1].

The MAC Frame Body shall consist of one of the following types of data structures:

- Management Frames: These frames are concerned with the control of the medium access and the communication system information. The format of these fields are defined in clause 6.2.
- Control Frames: These are frames essential for the proper transfer of packets between the nodes. The format of these fields are defined in clause 6.3.
- Data Frames: These frames are the actual information carrying modules (the field is set to a sequence of octets passed as an MAC Frame Body, without altering the order of the sequence). The format of these are defined in clause 6.4.

6.1.3 Frame Parity

The Frame Parity field shall contain a 16 bit CRC sequence of the MAC Frame Body generated using the generator polynomial $x^{16} + x^{12} + x^5 + 1$.

6.2 Management Frames

6.2.1 Control Channel Beacon (C-Beacon)

6.2.1.0 Control Channel Beacon Frame Format

The MAC Frame Body of a Control Channel Beacon (C-Beacon) shall be formatted as illustrated in Figure 11.

Bits:	48	3	10	1	1	2	6	1	32
	Hub Address	Slot Length	Time Slots	Reserved	Interference Mitigation	Duty Cycling	DCH Channel Number	Initial State	Time Stamp

Figure 11: Control Channel Beacon Frame Format

The C-Beacon frame is formatted as shown in Figure 11. The hub transmits control channel beacon on the prior selected control channel. The hub shall transmit a beacon every T_C seconds.

The control channel beacon frame consists of 9 fields. They are:

- Hub Address
- Slot Length
- Time Slots
- Reserved
- Interference Mitigation
- Duty Cycling
- DCH Channel Number
- Initial State
- Time Stamp

6.2.1.1 Hub Address

The 48-bit field contains address of the hub of transmitting the data channel beacon frame.

6.2.1.2 Slot Length

The Slot Length field shall be set according to Table 9 to indicate the duration of each time slot, which is equal to $T_S = L_{SLOT} \times T_{min}$.

Table 9: Slot Length field encoding

Field Value	L_{SLOT}
000	1
001	2
010	4
011	8
100	16
101	32
110	Reserved
111	Reserved

6.2.1.3 Time Slots

The field indicates the total number of time slots in the Scheduled Access, Control and Management Period, and Inactive Period of each Inter-beacon Interval. The length of the each slot is indicated in clause 6.2.1.2.

6.2.1.4 Interference Mitigation

The interference mitigation bit indicates if the SmartBAN is currently executing interference mitigation procedures.

6.2.1.5 Duty Cycling

The duty cycling field indicates the current duty cycling of the SmartBAN. The values of the field shall be set according to Table 10.

Table 10: Bit values for the duty cycling field

Bit Value	Duty Cycling (%)
00	0 to <25
01	25 to < 50
10	50 to < 75
11	75 to 100

6.2.1.6 DCH Channel Number

The DCH Channel Number field indicates the DCH channel number which is currently active. DCH Channel Numbers are listed in ETSI TS 103 326 [1].

6.2.1.7 Initial State

The Initial State field indicates the state of the hub. The field shall be set to '1' when it is allowing nodes to join the BAN and set to '0' when the SmartBAN is closed to new nodes.

6.2.1.8 Time Stamp

The 32 bit Time Stamp field contains the value of the local clock of the device at the time of the beginning of the time slot. The timestamp is intended to be a relative time measurement that may or may not be made absolute, at the discretion of the implementer.

6.2.2 Data Channel Beacon (D-Beacon)

6.2.2.0 Data Channel Beacon Frame Format

The MAC Frame Body of the Data Channel Beacon (D-Beacon) shall be formatted as illustrated in Figure 12. The fields with dashed boxes indicate that they are not sent with all D-Beacon packets, but only those with a non-null Function Indicator field.

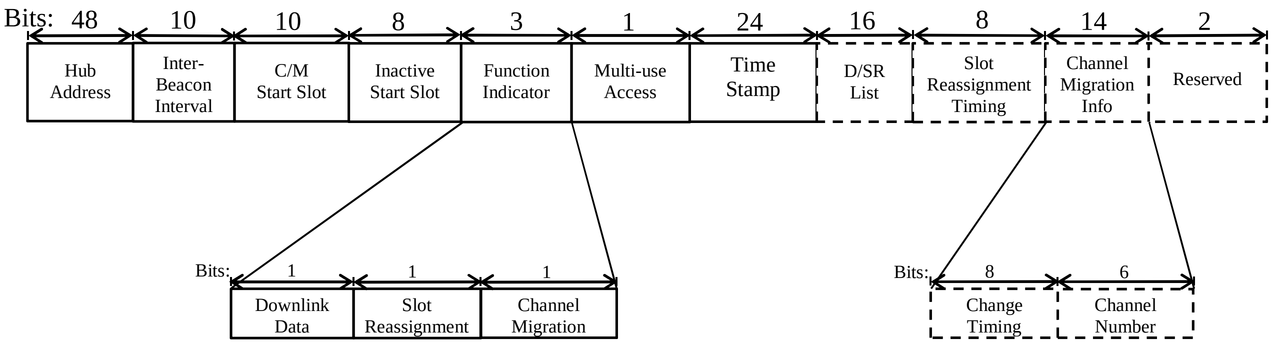

Figure 12: Data Channel Beacon Frame Format

The data channel beacon frame is formatted as shown in Figure 12. The hub transmits data channel beacon on the prior selected data channel. The hub shall transmit a beacon every T_D seconds.

The control channel beacon frame consists of 11 fields. They are:

- Hub Address
- Inter-Beacon Interval
- Control and Management Period Start Slot
- Inactive Period Start Slot
- Function Indicator
- Multi-use Access Indicator
- Time Stamp
- D/SR List
- Slot Reassignment Timing
- Channel Migration Information
- Reserved

6.2.2.1 Hub Address

The 48-bit field contains address of the hub.

6.2.2.2 Inter-Beacon Interval

The field indicates the number of slots in each Inter-beacon Interval. The length of the each slot is indicated in clause 6.1.2.

6.2.2.3 Control and Management Period Start Slot

The Control and Management Period Start Slot field contains the slot number at which the C/M period is set to begin.

6.2.2.4 Inactive Period Start Slot

The Inactive Period Start Slot field contains the slot number at which the Inactive period is set to begin.

6.2.2.5 Function Indicator

6.2.2.5.0 Function Indicator field

The Function Indicator field consists of three 1 bit subfields. When all the subfields are '0', the fields marked by dashed lines in Figure 12 will not be sent. When any of the subfields indicate a '1', the fields marked by dashed lines in Figure 12 will be sent to provide further information.

6.2.2.5.1 Downlink Data Indicator

The Downlink Data Indicator shall indicate whether any downlink data is available for any of the nodes. If the value of the indicator is '1', an accompanying D/SR List, which marks the nodes to listen for downlink, will be sent in the same D-Beacon frame. The marked nodes shall follow the procedure in clause 7.4 to acquire their downlink data.

6.2.2.5.2 Slot Reassignment Indicator

The Slot Reassignment Indicator shall indicate if any nodes will have their slots reassigned. If the value of the indicator is '1', an accompanying D/SR List, which marks the nodes which will have their slots reassigned, will be sent in the same D-Beacon frame. A "Slot Reassignment Timing" field will also be sent in the same D-Beacon frame to indicate the timing at which the new slot assignments will take effect. The marked nodes shall follow the procedure in clause 7.5 to obtain their new slot assignment.

6.2.2.5.3 Channel Migration Indicator

The Channel Migration Indicator shall indicate if the DCH will switch to a new channel. Bit value of '0' indicates no change of DCH, while bit value of 1 indicates that DCH will switch to another channel. An accompanying "Channel Migration Information" field will be sent in the same D-Beacon frame if the value of the indicator is '1'.

6.2.2.6 Multi-use Access

The Multi-use Access field indicates if the SmartBAN operates in Multi-use Access mode. Bit value of '0' indicates that SmartBAN is not operating in Multi-use Access mode, while bit value of 1 indicates that SmartBAN is operating in Multi-use Access mode.

6.2.2.7 Time Stamp

The Time Stamp field shall contain the value of the local clock of the device at the time of each Inter-beacon Interval. The timestamp is intended to be a relative time measurement that may or may not be made absolute, at the discretion of the implementer.

6.2.2.8 Downlink/Slot Reassignment (D/SR) List

The field shall indicate the nodes which will be either receiving downlink data or reassigned new slots. The number of bits indicates total number of supported nodes. Each bit represents a node, starting with the node with the smallest ID number (00000001) on the left. The right neighbouring bit shall represent the node with an ID number incremented by 1 from the current represented node. The node with the largest ID number (00010000) shall be represented by the rightmost bit. Bit value of 0 indicates no downlink data/reassignment, while bit value of 1 indicate downlink or reassignment of slot depending on the value of Downlink/Slot Reassignment Indicator.

In the event where no downlink or slot reassignment is scheduled, the D/SR List field shall have a value of '0000000000000000'.

6.2.2.9 Slot Reassignment Timing

The Slot Reassignment Timing field shall indicate the sequence number of the data channel beacon (D-Beacon) at which the new slot reassignment will take place.

6.2.2.10 Channel Migration Information

6.2.2.10.1 Migration Timing

The Migration Timing field shall indicate the sequence number of the data channel beacon (D-Beacon) at which the DCH change will take place.

6.2.2.10.2 Channel Number

The Channel Number field shall indicate the channel number which the DCH will switch to.

6.2.3 Connection Request (C-Req)

6.2.3.0 Connection Request Frame Format

Bits:	48	48	1	4	8	16	≥32	≥32
	Recipient Address	Sender Address	Multi-use Access	PHY Capability	Requested Wakeup Phase	Requested Wakeup Period	Uplink Request	Downlink Request

Figure 13: Connection Request Frame Format

The connection request command allows a device to request connection with a hub. This command shall only be sent by an unconnected device that wishes to connect with a hub. All nodes shall be capable of transmitting this command (though not required to be capable of receiving it).

A Connection Request frame shall be formatted as illustrated in Figure 13.

The connection request frame consists of 8 fields. They are:

- Recipient Address
- Sender Address
- Multi-use Access Capability
- PHY Capability
- Requested Wakeup Phase
- Requested Wakeup Period
- Uplink Request
- Downlink Request

6.2.3.1 Recipient Address

The Recipient Address Field is set to the EUI-48 of the recipient of the current frame.

6.2.3.2 Sender Address

The Sender Address Field is set to the EUI-48 of the sender of the current frame.

6.2.3.3 Multi-use Access Capability

A Multi-use Access Capability field shall indicate if the node sending the Connection Request has Multi-use Access enabled.

6.2.3.4 PHY Capability

The PHY capability field indicates the physical layer capability of the node. The mapping of the field is as follows:

Table 11: Mapping of PHY Capability field

Field Value b0 b1	FEC Type
00	None
01	BCH(127,113,2)
10	Reserved
11	Reserved

Field Value b2 b3	REP Type
00	None
01	2
10	4
11	Reserved

The field is split into two parts:

- FEC Type indicates the type of forward error correction the node is capable of.
- REP Type indicates the repetition coding that the node is using (number of repeated PPDUs).

6.2.3.5 Requested Wakeup Phase

The Requested Wakeup Phase field is set to the sequence number of the next Inter-beacon Interval in which the sender node plans to wake up for frame reception and transmission, with the sequence number of a beacon treated as incremented by one modulo 2^8, from that of the previous beacon period.

6.2.3.6 Requested Wakeup Period

The Requested Wakeup Period field is set to the length, in units of beacon periods, between the start of successive wakeup beacon periods in which the sender node plans to wake up for reception and transmission, starting from the one indicated in the preceding Requested Wakeup Phase field.

6.2.3.7 Uplink Allocation Request

The Uplink Allocation Request field shall be structured as an Information Unit as described in clause 5.5. The Information Unit shall consist of 1 or more Information Modules which shall be formatted as in Table 12.

Table 12: Information Module Field for Allocation Request Information Unit

Type	Number of bits	Subfields	Number of bits
Allocation Request	24	User Priority	2
		Reserved	4
		Allocation Length	10
		Allocation Period	8

The User Priority subfield shall denote the user priority level the node request for the current allocation request.

The Allocation Length subfield shall denote the total number of time slots requested in each Inter-Beacon Interval.

The Allocation Period subfield shall denote the sequence number of the Data Channel Beacon frame from which the allocation starts.

6.2.3.8 Downlink Allocation Request

The Downlink Allocation Request field shall be structured in the same way as the Uplink Allocation Request field as described above.

6.2.4 Connection Assignment (C-Ass)

6.2.4.0 Connection Assignment Frame Format

The connection assignment command allows the hub coordinator or coordinator to communicate the results of a connection attempt back to the device requesting connection.

This command shall only be sent by the hub coordinator or coordinator to a device that is currently trying to connect.

All devices shall be capable of receiving this command.

A Connection Assignment frame contains a Frame Payload that has the following format:

Bits:	48	8	16	16	≥40	≥40
	Recipient Address	Node ID	Assigned Wakeup Phase	Assigned Wakeup Period	Uplink Assignment	Downlink Assignment

Figure 14: Connection Assignment Frame Format

The connection assignment frame consists of 6 fields. They are:

- Recipient Address
- Node ID
- Assigned Wakeup Phase
- Assigned Wakeup Period
- Uplink Assignment
- Downlink Assignment

6.2.4.1 Recipient Address

The Recipient Address field is as defined in clause 6.2.3.1

6.2.4.2 Node ID

The Node ID is chosen according to Table 5.

6.2.4.3 Assigned Wakeup Phase

The Assigned Wakeup Phase field is set to the sequence number of the next beacon period in which the recipient node needs to wake up for frame reception and transmission. The field in the Connection Assignment frame supersedes the Requested Wakeup Phase field in the Connection Request frame previously exchanged between the sender and the recipient.

6.2.4.4 Assigned Wakeup Period

The Assigned Wakeup Period field is set to the length, in units of beacon periods, between the start of successive wakeup beacon periods in which the recipient needs to wake up for reception and transmission, starting from the one indicated in the preceding Assigned Wakeup Phase field.

6.2.4.5 Uplink Assignment

The Uplink Assignment field shall be structured as an Information Unit as described in clause 5.5. The Information Unit shall consist of at least 1 Information Module with elements listed in Table 13.

Table 13: Information Module Field for Allocation Assignment Information Unit

Type	Number of bits	Subfields	Number of bits
Allocation Assignment	32	User Priority	2
		Reserved	2
		Allocation Start	10
		Allocation End	10
		Allocation Period	8

The User Priority subfield shall denote the user priority level assigned to the current assignment.

The Allocation Start subfield shall denote the time slot number from which the allocation shall start.

The Allocation End subfield shall denote the time slot number at which the allocation shall end.

The Allocation Period subfield shall denote the sequence number of the Data Channel Beacon from which the allocation shall start.

6.2.4.6 Downlink Assignment

The Downlink Assignment field shall be structured in the same way as the Uplink Allocation Assignment field described above.

6.2.5 Slot Reassignment (S-Ras)

The Slot Reassignment frame shall be formatted as an Information Unit as described in clause 5.5. The Information Unit shall consist of at least 1 Information Module with elements listed in Table 14.

Table 14: Information Module Field for Slot Reassignment Information Unit

Type	Number of bits	Subfields	Number of bits
Slot Reassignment	32	Node ID	8
		Start Slot	10
		End Slot	10
		Reserved	4

The Node ID subfield shall denote the Node ID of the node for which the slot reassignment parameters in the IU is for.

The Start Slot subfield shall denote the reassigned starting time slot for the node.

The End Slot subfield shall denote the reassigned ending time slot for the node.

6.2.6 Disconnection Request (D-Req)

6.2.6.0 Disconnection request command

The disconnection request command either allows a device to request disconnection from a hub or a hub to terminate the connections of specific nodes.

1) This command is sent by a connected node that wishes to disconnect from a hub. The frame is a null frame. Nodes may be capable of transmitting this command, but not required to be capable of receiving it.

2) This command is sent by a hub. The frame format is shown in Figure 15. The length of the command frame is variable and dependent on the number of disconnections to invoke.

6.2.6.1 Length

The Length field indicates the number of nodes whose links will be terminated. If Length field is '00000,' it indicates that all nodes will be disconnected, and no Recipient ID fields will follow the Length field.

6.2.6.2 Recipient ID

The Recipient ID field denotes the previously assigned Node ID of the nodes whose links will be terminated.

6.2.7 Disconnection Response (D-Res)

The disconnection response is either sent by a hub to a node requesting disconnection or a node to a hub requesting disconnection.

The D-Res frame shall have a 1 bit MAC Frame Body consisting of a single 'Disconnection Information' field. The field shall be set to '0' if the receiving Hub/node allows disconnection. If this field is set to '1,' the receiving Hub/node denies the disconnection request.

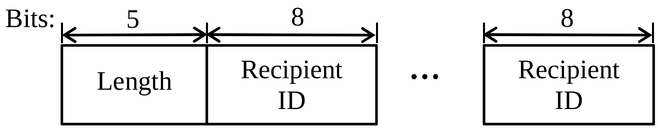

Figure 15: Disconnection Request Frame Structure (Hub to Node)

6.3 Control Frames (C-Frame)

6.3.1 Acknowledgement/Negative Acknowledge Frame (ACK/NACK)

The Acknowledgement and Negative Acknowledgement frames shall have zero length MAC Frame Bodies. The Acknowledgement and Negative Acknowledgement MPDU shall consist only of the MAC Header and the Frame Parity.

6.4 Data Frames (D-Frame)

The data frame shall be of maximum of $T_{F,max}$ bits. For data blocks that are greater than $T_{F,max}$ bits, the block shall be fragmented into multiple data frames. The calculation of $T_{F,max}$ can be found in ETSI TS 103 326 [1].

7 MAC Functions

7.1 General

This clause shall describe the essential operations that are required for the functioning of a SmartBAN.

7.2 SmartBAN Creation and Connection Initialization

7.2.1 SmartBAN Creation

A hub shall initiate the creation of a SmartBAN through the following steps:

- The hub chooses an 8 bit BAN ID which is not currently in use by neighbouring SmartBANs.
- The hub chooses a Control Channel (CCH) to transmit C-Beacon.
- The hub chooses a Data Channel (DCH).
- The hub commences periodic C-Beacon transmission with the Initial State field set to '1'.
- The C-Beacon provides the DCH number, slot length, and the number of time slots in each Inter-beacon Interval.
- A hub commences periodic D-Beacon transmission to mark the beginning and end of each Inter-beacon Interval, as well as provide the reference for the timing of the time slots.
- The hub shall set the Initial State field to '0' at a time when it decides not to allow any more nodes to join.
- A SmartBAN operates in the Scheduled and Slotted Aloha Channel Access modes, until a time deemed appropriate by the hub to switch to another Channel Access mode.

7.2.2 Connection Initialization

An unconnected node wishing to make a connection to the hub may follow the following procedure to join the SmartBAN:

- The node may monitor the CCHs to acquire a C-Beacon with the Initial State field set to '1'.
- The node may acquire the BAN ID, DCH Number, Slot Length, and the number of time slots in each Inter-beacon Interval from the C-Beacon.

Using the acquired parameters from C-Beacon, the node may monitor the DCH and initiate connection according to the following procedure which is also shown in Figure 16:

1) Acquire DCH parameters (e.g. Scheduled Access Period start, C/M Period start) from the D-Beacon.

2) Transmit a Connection Request (C-Req) frame during the C/M period using the Slotted Aloha Channel Access procedure described in clause 7.3.2.

On successful reception of the C-Req frame, the hub shall transmit an Acknowledgement frame, followed by a Connection Assignment (C-Ass) frame in the next available time slot, according to clause 7.3.2. The C-Ass frame shall contain details of allocated resources to the node, including the node's allocated Node ID.

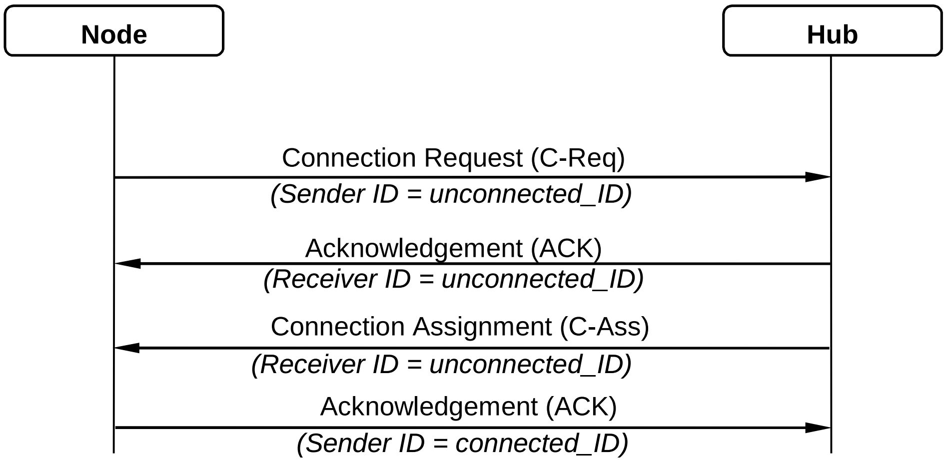

Figure 16: Connection procedure

7.3 Channel Access

7.3.1 Scheduled Channel Access

7.3.1.0 Scheduled Channel Access

A node and a hub by default shall employ Scheduled Channel Access in the Scheduled Access Period.

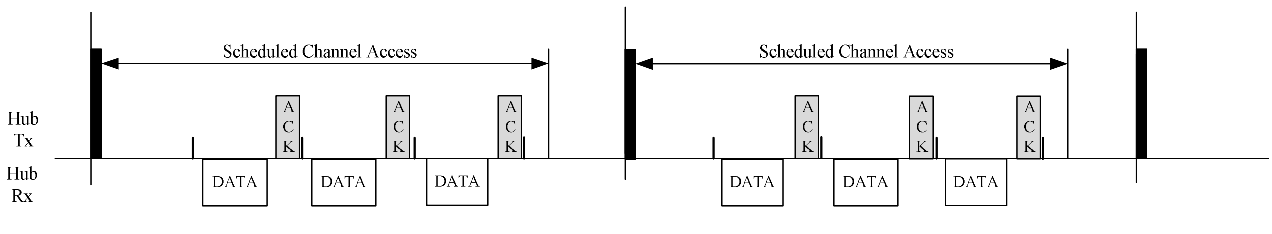

Figure 17: Scheduled Channel Access

7.3.1.1 Starting Scheduled Access

To obtain one or more new scheduled allocation, a node shall send a Connection Request (C-Req) frame in the C/M Period using Slotted Aloha Channel Access to the hub, setting the Requested Wakeup Period field in the frame to 1.

To grant scheduled access, requested by the node, a hub shall send a Connection Assignment (C-Ass) frame in the C/M Period using Slotted Aloha Channel Access to the node.

7.3.1.2 Using Scheduled Access

Upon receiving the C-Ass frame granting it scheduled access intervals, the node may transmit to or receive from the hub depending on the allocation assignment.

Scheduled Channel Access shall use the slot structure described in clause 5.2.2.1 and illustrated in Figure 4.

The transmitting device shall ensure that the MAC Frame Body has a length of less than or equal to $L_{F,max}$, such that there will be sufficient time left in the time slot to accommodate the transmission of an ACK or NACK frame (depending on ACK policy) and at least 2 IFS.

The receiving device shall transmit an ACK frame upon the successful reception of the frame, or an NACK frame upon failure to receive the frame, depending on ACK policy. An example of scheduled channel access is illustrated in Figure 17.

7.3.1.3 Modifying Scheduled Access

A node may modify existing allocation assignment by sending another C-Req frame specifying the new requirements for the allocations.

A hub may modify allocation assignments of a node by sending the node a Slot Reassignment (S-Ras) frame as described in clause 7.5.

7.3.1.4 Ending Scheduled Access

A node may at any time end Scheduled Channel Access by sending a C-Req frame that contains Allocation Request fields with the corresponding Allocation Length field set to 0.

A hub may at any time end any scheduled access of a node by signalling downlink data in the D-Beacon, and sending a C-Ass frame that contains Allocation Assignments fields with Interval End field set to 0.

7.3.2 Slotted Aloha Channel Access

7.3.2.0 Description

A hub or a node may employ Slotted Aloha Channel Access to transmit management frames or data frames when it has not been allocated sufficient time slots in the Scheduled Access Period for its purpose. A node shall maintain a CP to facilitate channel access as described in clause 7.3.2.1.

7.3.2.1 Starting Slotted Aloha Channel Access

A node shall start a Slotted Aloha Channel Access (SACA) session by transmitting in a time slot in the C/M Period with a probability of CP. At the beginning of each time slot in the C/M Period, a device shall choose its CP according to the following rules:

- Determine the User Priority of its traffic according to Table 3.
- Obtain the range of its CP based on the User Priority of its traffic according to Table 4.
- If the node had not begun a SACA session previously, its CP shall be set to CP_{max}.
- If the node had successfully completed a SACA session previously, its CP shall be set to CP_{max}.
- If the node did not successfully complete a SACA in the last attempt:
    - If it had failed m times consecutively, where m is an odd number, it shall keep its CP unchanged.
    - If it had failed n times consecutively, where n is an even number, it shall halve its CP if the CP is greater or equal to $2 \times CP_{min}$, or keep its CP unchanged otherwise.

7.3.2.2 Using Slotted Aloha Channel Access

Slotted Aloha Channel Access shall use the slot structure described in clause 5.2.2.2 and illustrated in Figure 5.

The transmitting device shall ensure that the MAC Frame Body has a length of less than or equal to $L_{F,max}$, such that there will be sufficient time left in the time slot to accommodate the transmission of an ACK or NACK frame (depending on ACK policy) and at least 2 IFS.

The receiving device shall transmit an ACK frame upon the successful reception of the frame, or an NACK frame upon failure to receive the frame, depending on ACK policy.

7.3.2.3 Ending Slotted Aloha Channel Access

Each session of Slotted Aloha Channel Access shall end with the end of each time slot in the C/M Period. A node may start a new session using the procedure in clause 7.3.2.1.

7.3.3 Multi-use Channel Access

7.3.3.0 Description

The node and hub may employ Multi-use Channel Access to access the channel if the Multi-use Channel Access bit is set to '1' in the D-Beacon. A flowchart describing the Multi-use Channel Access algorithm is presented in annex A.

7.3.3.1 Starting Multi-use Channel Access

7.3.3.1.0 Description

A device shall start a Multi-use Channel Access (MCA) session by sensing for channel use in a time slot in either the Scheduled Access Period or C/M Period. The sensing period, T_{MUA}, is dependent on the type of traffic and the Access Phase the time slot belongs to, and is listed in Table 2. At the beginning of each transmission, other than a beacon transmission by the hub, transmission of an acknowledgement frame, or a transmission of a data frame during Scheduled access period by the user allocated to the slot, a device shall use the backoff algorithm described in the following clause.

7.3.3.1.1 Backoff Algorithm

The device may use the following procedure to obtain channel access in MCA mode. At the beginning of each transmission attempt of a new packet a device shall set its backoff exponent (*BE*) to BE_{min}. If BE_{min} is set to 0, backoff will be disabled during the first transmission attempt. The device shall also maintain a Backoff Counter (*BC*), indicating the number of slots to the next transmission attempt, which is initialized to a random integer value between 0 and 2^{BE} - 1 before the start of each transmission attempt. A re-transmission (*RT*) counter is also maintained to keep track of the number of retransmission attempts. The device may transmit if the channel is sensed to be idle. However, if the channel is sensed to be busy, the device shall:

- Increment the *BE* by 1 if $BE < BE_{max}$.
- Wait for the number of time slots equalling the value of the *BC* counter before attempting to start an MCA session again.

If the channel is sensed to be idle, but the transmission is unsuccessful:

- Increment the *BE* by 1 if $BE < BE_{max}$, otherwise, keep *BE* as it is.
- Increment the *RT* counter by 1 if $RT < RT_{max}$, otherwise, discard the packet and abandon the MCA attempt for the packet.
- Wait for the number of time slots equalling the value of the *BC* counter before attempting to retransmit the packet.

7.3.3.1.2 Re-use Channel Access (RCA)

Re-use Channel Access (RCA) allows the use of an allocated slot in the Scheduled Access Period by other users when the allocated user is not using the slot. For Re-use Channel Access, the device maintains a Re-use Backoff (*RBC*) counter, which indicates the number of slots to the next transmission attempt. The *RBC* counter is initialized to a random value between 0 and 2^{BE} - 1 before the start of each RCA transmission attempt.

If RCA is supported by a device, the device may apply the backoff algorithm described in clause 7.3.3.1.1 to obtain access to the channel. The sensing time, T_{MUA}, to apply in this case is $2 \times T_{sch}$ as stated in Table 2. In addition to the procedure in clause 7.3.3.1, the device shall compare the *RBC* counter to the number of slots till its next allocated slot. If the *RBC* counter's value is larger than the number of slots till its next allocated slot, it stops the use of Re-use Channel Access.

If Re-use Channel Access is not supported, the device shall wait for its allocated slot and follow the procedure in clause 7.3.3.1 to transmit.

7.3.3.1.3 Priority Channel Access (PCA)

A device may use Priority Channel Access (PCA) to send User Priority 3 packets in both Scheduled Access, and Control and Management Periods. In order to transmit using PCA, a device supporting PCA initializes its *BE* to 0 for the first transmission attempt of a new User Priority 3 packet. In addition, the device maintains a separate Priority Backoff *BE* counter (*PBC*), which indicates the number of slots to the next transmission attempt, and a separate Re-Transmission counter, *RTP*, when using PCA. The *PBC* counter is initialized to a random value between 0 and 2^{BE} - 1 before the start of each PCA transmission attempt. The maximum number of re-transmissions allowed for User Priority 3 packets is denoted by $RT_{max,PCA}$.

The device may transmit a UP 3 packet at the start of a time slot. If the transmission is not successful:

- Set the *BE* to $BE_{\min}$, if it was the first transmission attempt.
- Keep the *BE* unchanged, if this was *n*th consecutive transmission failure, where *n* is an even number.
- Increment the *BE* by 1, if this was *m*th consecutive transmission failure, where *m* is an odd number, and if $BE < BE_{max}$.
- Increment the *RTP* counter by 1 if $RTP < RT_{max,PCA}$, otherwise, discard the packet and restart PCA if there is another UP 3 packet to send.
- Wait for the number of time slots equalling the value of the *PBC* counter before attempting to retransmit the packet.

7.3.3.2 Using Multi-use Channel Access

7.3.3.2.0 Description

Multi-use Channel Access shall use the Multi-use Access slot structure described in clause 5.2.2.3 and illustrated in Figure 6.

The transmitting device shall ensure that the MAC Frame Body has a length of less than or equal to $L_{F,max}$, such that there will be sufficient time left in the time slot to accommodate the transmission of an ACK or NACK frame (depending on ACK policy) and at least 2 IFS.

7.3.3.2.1 Scheduled Access Period

In the Scheduled Access Period, three types of transmission may take place.

For devices with packets of User Priority 3 to send, the device may use PCA to access the channel if it supports it.

For other transmissions, the device senses the channel for activity for a duration of T_{MUA}, which depends on the user type and the traffic type, according to Table 2. In slots which are allocated to the device, the device shall sense the channel for a period of T_{sch} for any PCA. If no PCA is detected, it may transmit in the slot.

For slots which are not allocated to the device, the device may employ RCA in clause 7.3.3.1.2 to obtain access to the channel.

7.3.3.2.2 Control and Management Period

In the Control and Management Period, two types of transmissions may take place.

For devices with packets of User Priority 3 to send, the device may use PCA to access the channel if it supports it.

For other devices, it may use the Backoff Algorithm in clause 7.3.3.1.1 to access the channel.

7.3.3.3 Ending Multi-use Channel Access

Each session of MCA shall end with the end of each time slot. A node may start a new session using the procedure in clause 7.3.3.1.

7.4 Supplementary Downlink Data Transmission

A hub may employ supplementary downlink data transmission to transmit data, control or management traffic to a node.

Supplementary Downlink Data Transmission is initiated by the following steps:

- The hub shall indicate downlink data transmission in the Downlink Data Indicator field of the D-Beacon.
- The hub shall also indicate the list of nodes marked for downlink data transfer in the accompanying D/SR List field.

The hub shall begin Supplementary Downlink Data Transmission in the C/M Period once it has received acknowledgement from the marked nodes. The nodes shall acknowledge the receipt of the command by setting the Command Acknowledgement field in the MAC header to '1' when transmitting a frame to the hub.

The hub shall employ the Slotted Aloha Channel Access mechanism described in clause 7.3.2.1 with the appropriate User Priority levels for the frames to be transmitted. The hub shall also determine the range of contention probabilities corresponding to the User Priority levels as defined in clause 5.3.

All the listed nodes shall listen for downlink data transmission in the C/M Period. The nodes may acknowledge the successful receipt of the transmission depending on the ACK policy. An illustration of supplementary downlink data transmission is shown in Figure 18.

If the hub is unable to gain access or transmit successfully in the current inter-beacon interval, the hub shall attempt again in the next inter-beacon interval using the procedure described above.

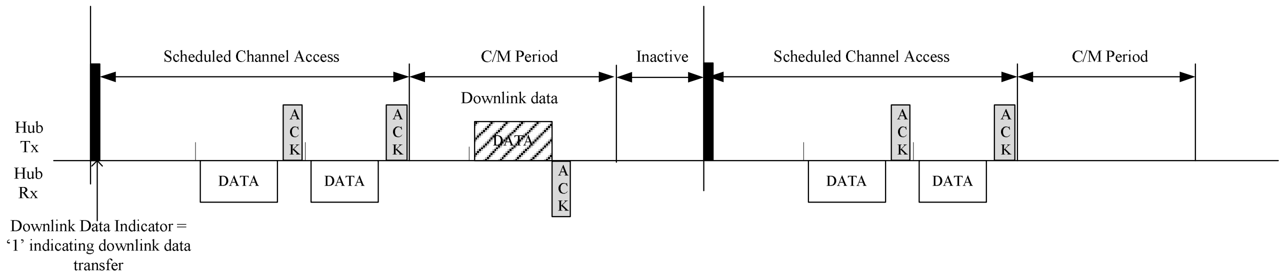

Figure 18: Downlink Data Transmission Illustration

7.5 Slot Re-assignment

A hub shall inform a node of the new scheduled slot re-assignment through following steps.

- A value of '1' in Slot Reassignment field indicates some of the nodes in the BAN will be allocated new slots, and that an accompanying D/SR List will be sent in the same D-Beacon frame.
- The hub shall indicate the list of nodes and timing due for re-assignment in the D-Beacon using D/SR List field and Slot Re-assignment Timing field respectively.
- The hub shall send Slot Re-assignment (S-Ras) frame in the C/M Period.
- The hub shall employ Slotted Aloha Channel Access mechanism with a User Priority level of 3. The hub shall also determine the range of contention probabilities corresponding to the User Priority levels as defined in clause 5.3.
- If the hub is unable to gain access or transmit in the current inter-beacon interval, the hub shall attempt again in the next Inter-beacon Interval using the procedure above.

The Start Slot and End Slot subfields of S-Ras frame denotes the slot reassignment timing information specifying starting and ending time slot for the node.

The nodes that received slot re-assignment frame successfully during C/M Period shall set the Command Acknowledgement field in the MAC header of the Data frame to '1' in the following Inter-beacon Interval.

The nodes shall transmit data in the newly re-assigned slots from the timing information provided in the S-Ras frame.

The hub shall clear the D/SR field if the node(s) acknowledged the receipt of the slot reassignments through the Command Acknowledgement field in the MAC header. An example of slot reassignment is shown in Figure 19.

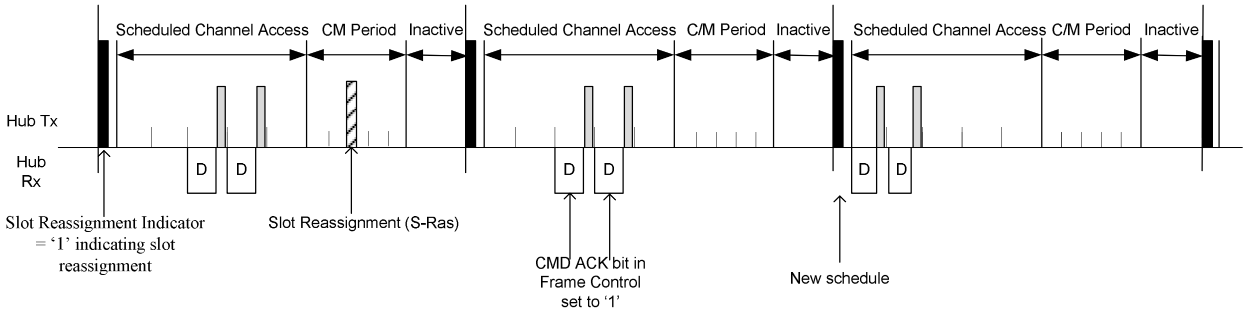

Figure 19: Slot Re-assignment Illustration

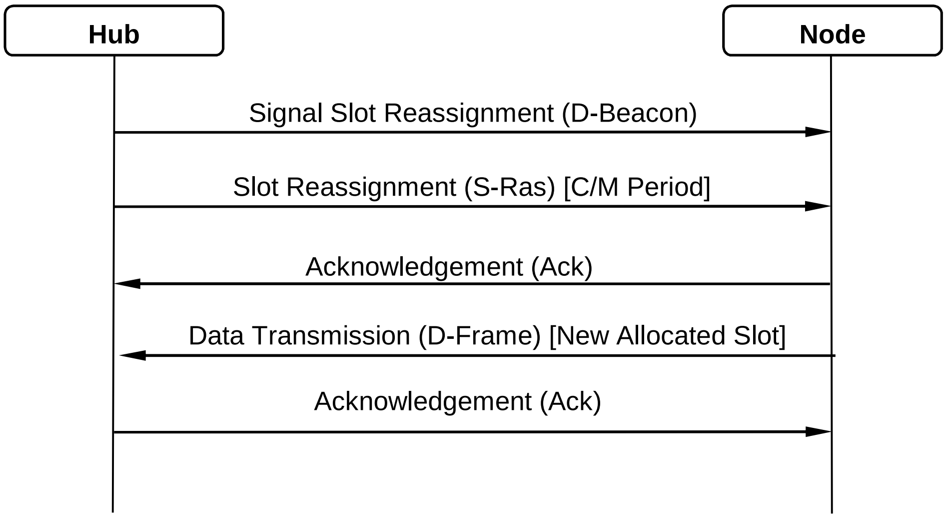

Figure 20: Scheduled Period Slot Reassignment Procedure

7.6 Data Channel Migration

A hub may switch the Data Channel (DCH) to a new channel. The hub shall commence the following procedure to switch DCH to a new channel:

- Indicate data channel migration through channel migration field in the D-Beacon, with the new channel number and sequence number of the D-Beacon at which the change will occur.
- C-Beacon will advertise the new DCH number after change has occurred.

An example of Data Channel Migration is illustrated in Figure 21.

For long sleeping nodes, upon wake up, they will:

1) Monitor the CCH last known to them.
2) Acquire C-Beacon of their hub, and if they fail to do so.
3) Cycle between the three CCH until they acquire the appropriate C-Beacon.
4) Read the current DCH number from the C-Beacon.

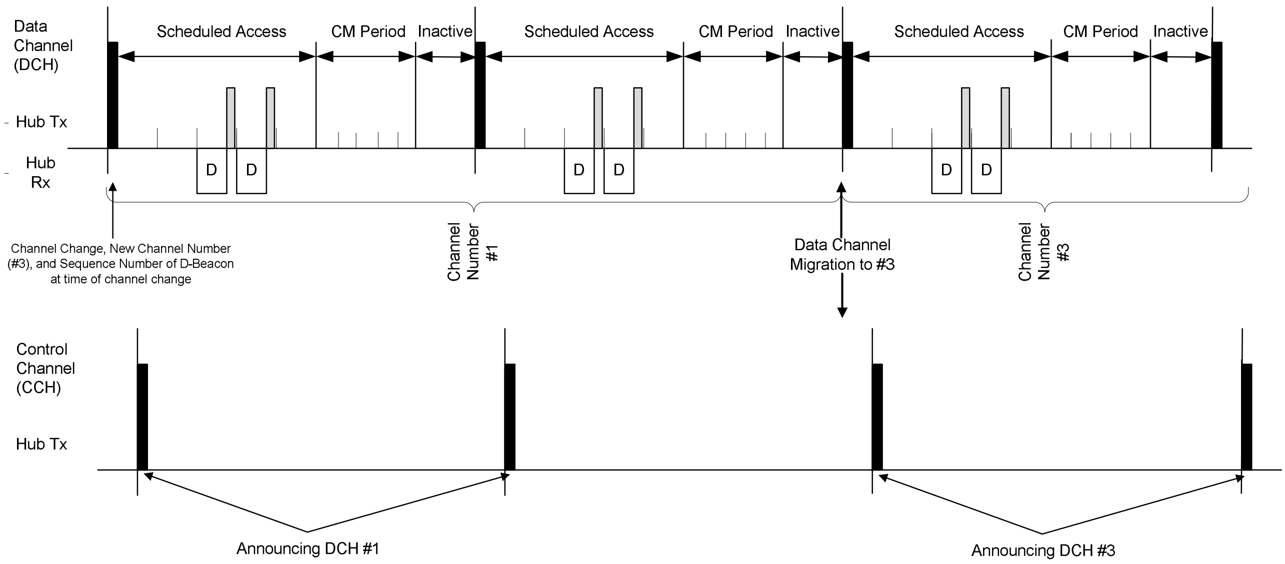

Figure 21: Example of Data Channel Migration (from #1 to #3)

8 MAC Parameters

Parameter	Value
T_c	variable
T_{min}	625 µs
T_{sch}	16 / symbol rate
T_{IFS}	150 µs

Annex A (normative): Multi-use Channel Access

Figure A.1 describes the operation of Multi-use Channel Access algorithm.

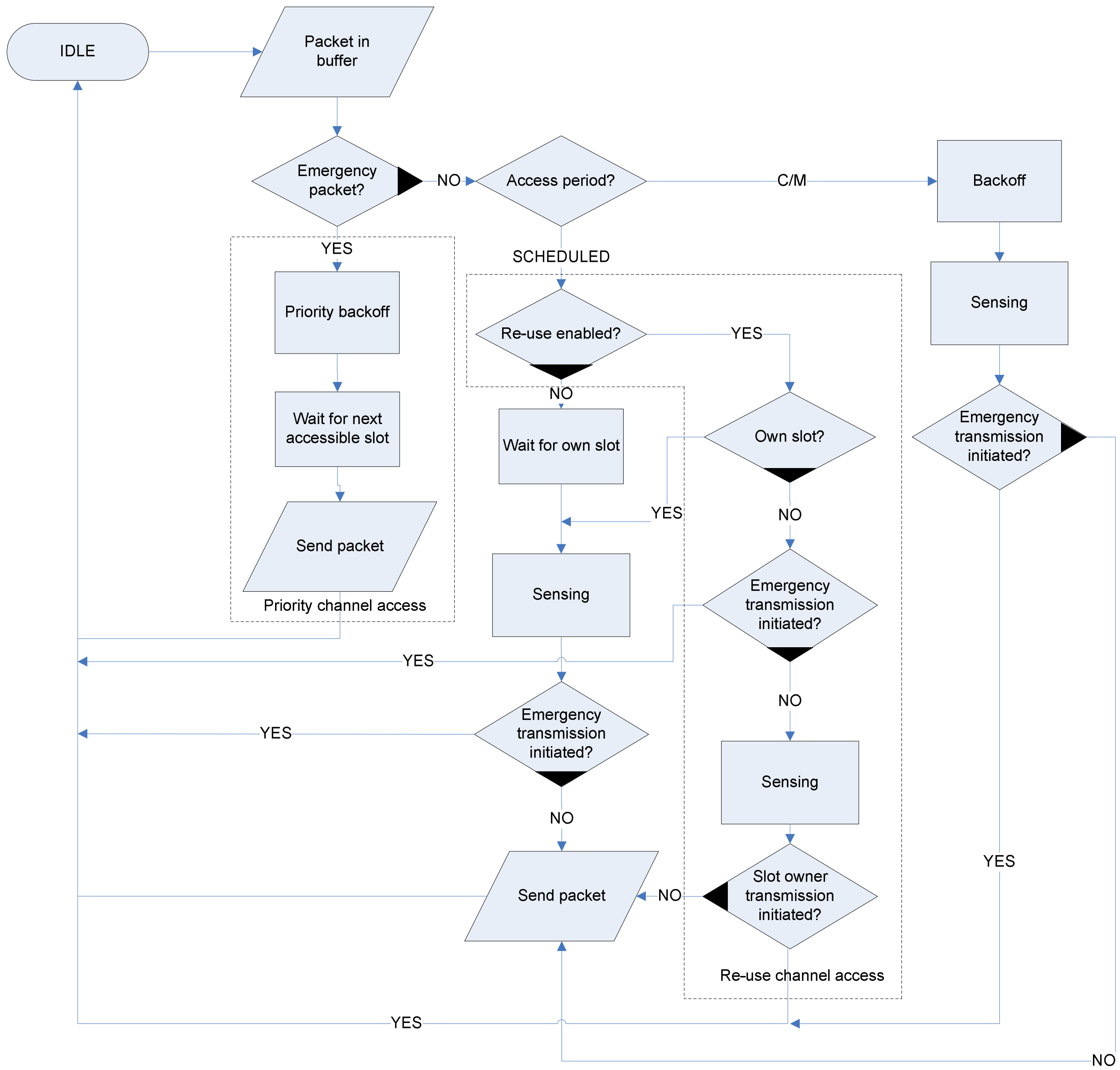

Figure A.1: Flowchart of Multi-use Channel Access

History

Document history		
V1.1.1	April 2015	Publication