IEEE P802.15
Wireless Personal Area Networks

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)
Title	**Proposal for Partial PHY and MAC Including Emergency Management in IEEE802.15.6**
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Re:	[Response to TG6 Call for Proposals (CFP), IEEE P802.15-08-0829-01-0006]
Abstract	[Proposal for partial Physical (PHY) and Media Access Control (MAC) layers and for the management of emergency scenarios in IEEE802.15.6 Body Area Networks (BANs). The proposed solutions apply to both medical BANs (MBAN) and non-medical BANs.]
Purpose	[This proposal consists of a set of ideas to be included in the PHY and MAC layers of the IEEE802.15.6 specification. The partial PHY proposal consists of ideas for narrowband radio, while the partial MAC proposal consists of ideas for the management of both medical and non-medical emergency situations in BANs. The proposed MAC Frame Control format, with new information bits and octets, should be considered in the design of the MAC layer for IEEE802.15.6.]

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Contents

1 Introduction

Medical applications are critical applications and may be life critical. The requirements for medical Body Area Networks (BANs) include: robust links for bounded data loss and bounded latency, capacity for high density of patients and sensors, coexistence with other radios, battery life for days to months of continuous operation, and small form factors for body devices.

These requirements can be satisfied through the utilisation of a number of techniques including error control techniques and adaptive repeat requests, low duty cycle and power management, and the development of more efficient, diverse antennas.

Existing standards such as IEEE802.15.4 have been designed for commercial applications with little or no consideration for life saving emergency scenarios. In particular, there is a need to ensure reliable communications by network devices such as sensors that are involved in emergency situations, while ensuring low power consumption.

One major requirement of IEEE802.15.6 is high reliability and improved QoS when devices involved in medical applications are actively transmitting data under emergency situations, specially in situations where the life of a patient depends on the reliability of wireless links. This can be addressed by the sending of acknowledgements in response to received data and commands. There is also the need to ensure timely acknowledgments between a coordinator and BAN devices involved in emergency situations.

Further, in order to ensure reliability of communication with network devices involved in emergencies, management of traffic congestion is needed. The prioritisation of the data and links, for example by using channel access switching, are the enablers for this traffic congestion management. Current IEEE standards such as IEEE802.15.3 and IEEE802.15.4 do not include adequate traffic congestion management mechanisms that are required for wireless medical BANs.

One of the key requirements of the existing IEEE802.15.3 and IEEE802.15.4 and the upcoming IEEE802.15.6 standard relating to wireless sensor networks, in which at least some of the devices are powered by batteries, is increasing battery life. Battery-powered devices have a sleep pattern, spending much of their operational lifetime in a sleeping state. These devices then wake up periodically to transmit or receive. The requirement to conserve battery life using sleep patterns (a process known as duty cycling), while making sure that the sensor data is sent to a coordinator in a timely and reliable manner, must be balanced with the need to provide sufficient network throughput under normal conditions and also in emergency situations. Some channel access schemes are designed for high throughput whereas others are more suitable for low throughput, low power situations. It is advantageous, therefore, for a network device to be able to switch between the two schemes as appropriate.

In this document, we propose a MAC layer frame structure that provides hooks to help ensure reliability, adaptive duty cycling for power management, prioritised streaming capability, and for increased QoS, as needed by medical BANs and introduced above.

In addition, a narrow band PHY proposal based on wake-up radio is provided. The PHY has two main circuits: a wake-up circuit and a main circuit for normal communication. Two different modulation schemes are proposed, namely, Amplitude Shift Keying (ASK) in particular the On Off Keying (OOK) for the wake-up circuit and Gaussian Frequency Shift Keying (GFSK) for the main circuit.

1.1 Definition of Emergency

We define a medical emergency as a situation under which the value or values of one or more of the physiological parameters being measured breech a critical threshold on a consistent basis. The situation may be life threatening.

In addition, a medical device that is behaving abnormally, has low battery power, or is faulty, results in an emergency.

2 TG6 Requirements Addressed

This section specifies the technical requirements of TG6 that we are addressing in our proposal. Section 8: Quality of Service (QoS) section of the TG6 Technical Requirements Document (TRD), 15-08-0644-09-0006-tg6, mandates emergency and power management capabilities for the IEEE802.15.6 specification.

The emergency management requirement mandates support for alarm state notification across a BAN in less than one second. Additionally, prioritisation mechanisms for emergency traffic and notifications must be provided.

The power management requirement must be met by mechanisms that allow power consumption to be lowered or cancelled in emergencies. This should be fulfilled by mechanisms (e.g. duty cycling) that do not impact latency requirements of applications.

3 Wake-up Based Radio for Narrow Band PHY

This section introduces a proposal for an energy efficient wake-up scheme employing dual-PHY for narrow band radio. In addition, a signal probing scheme for antenna-control capability to overcome shadowing issues and more stable communication is provided. The probing scheme is explained in Section 6.3.

3.1 Motivation

As extending battery life is an important aspect of design for many BAN devices, specially for implant devices, energy efficient "sleep" and "wake-up" are required. The energy efficient sleep/wake-up proposal here is based on that used in RFID technologies. In particular, RFID tags operating in a "semi-passive" mode have a very long battery life due to the very low-power, oscillator-free wait circuitry.

Moreover, shadowing may be caused by changes in body posture (e.g. sitting, standing or lying down), which may in turn cause severe degradation in signal. A simple "antenna-control" mechanism will help to alleviate this problem.

The proposed modulation schemes have important advantages. OOK for PHY with sleep/wake-up is easy to implement and may be possible to implement without oscillators, in a similar way to RFID tags; the modulated backscattering method is applicable. Also, GFSK for general PHY provides non-linear amplification that can achieve effective transmission and non-coherent detection.

3.2 Description

The PHY proposal herein consists of two main circuits, the wake-up circuit and the main circuit. Two main modulation schemes are proposed as mentioned previously. OOK is employed by the sleep/wake-up mechanism for the wake-up circuit, and GFSK is employed for normal communication for the main circuit.

Two states are defined: sleep and wake-up states. In the sleep state, all circuits are powered off except the wake-up circuit that remains on, under low power consumption, and waits for a wake-up packet (OOK based PHY). Optionally, the wake-up circuit can be battery-free, similar to that used in passive RFID tag technologies, and powered by energy generated from wake-up signals.

In the sleep state, an interrogation and response procedure is provided as an additional functionality for short messages such as identification, battery life state, or the state of the circuit. The responses of the wake-up circuit to interrogations are communicated at a very low data rate, 10 kbps. In addition, some *commands* are interpreted by wake-up circuits similar to those of RFID systems. Examples of such commands are the following:

- *Read <address>*: This command reads the internal memory at the indicated address and sends back information such as sensor log, battery level, history of sensing, etc.

- *Wake-up:* This command wakes up the main circuit in anticipation of incoming normal communication.

Figure 1 depicts wake-up based narrow band PHY in a sleeping state, including the interrogation and response procedure.

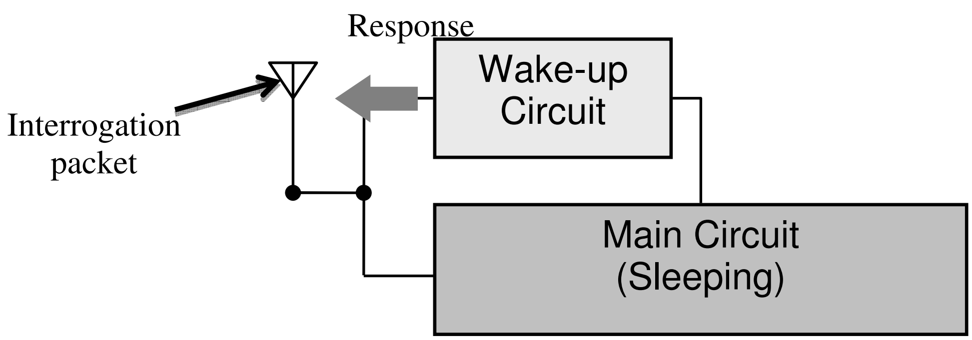


Figure 1 Wake-up based narrow band PHY in a sleeping state showing interrogation procedure.

The wake-up procedure is initiated by the reception of a wake-up packet by the wake-up circuit. The latter will trigger the main circuit according to the "wake-up command" in the wake-up packet.

Figure 2 depicts the wake-up based narrow band PHY including a wake-up trigger.

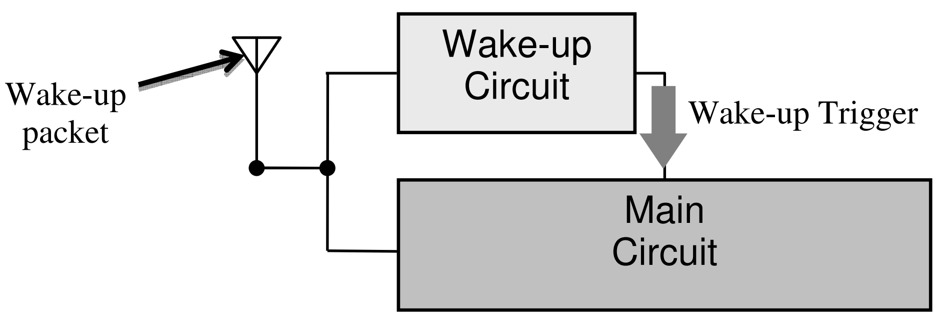


Figure 2 Wake up based narrow band PHY with wake-up trigger.

Figure 3 shows examples of block diagrams for a wake-up sequence and an interrogation and response procedure, respectively.

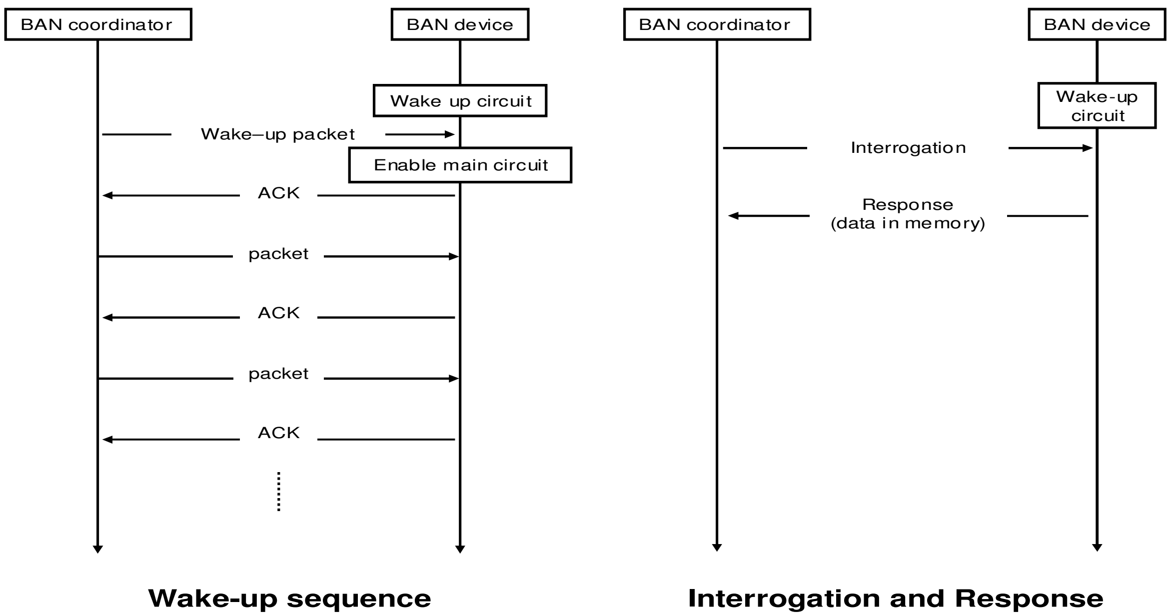


Figure 3 Wake up sequence and interrogation and response block diagrams

3.3 Data Rate, Modulation, and Applicable Frequency Bands

The following table provides a summary of the data rates, supported modulation schemes, applicable frequency bands and the occupied bandwidth for the above PHY proposal.

Modulation	FEC	Data Rate	Occupied Bandwidth	Applicable Bands
FSK	None	40 kbps 160 kbps 320 kbps 640 kbps (optional)	40 kHz 80 kHz 1.28 MHz 2.56 MHz	MICS, WMTS, ISM
OOK	None	10 kbps(mandatory) 20 kbps 40 kbps	20 kHz 40 kHz 80 kHz	MICS, WMTS, ISM

Note that the data rate of 10 kbps is mandatory for OOK where as the data rate of 640 kbps is optional for FSK.

3.4 Wake-up Based PHY Performance

Figure 4 shows the performance of the wake-up based PHY proposal in terms of Bit Error Rate (BER) / Packet error Rate (PER) with respect to signal-to-noise ratio. No Forward Error Correction (FEC) mechanism has been employed and the required signal-to-noise ratio for OOK and GFSK are 16 dB and 15 dB, respectively.

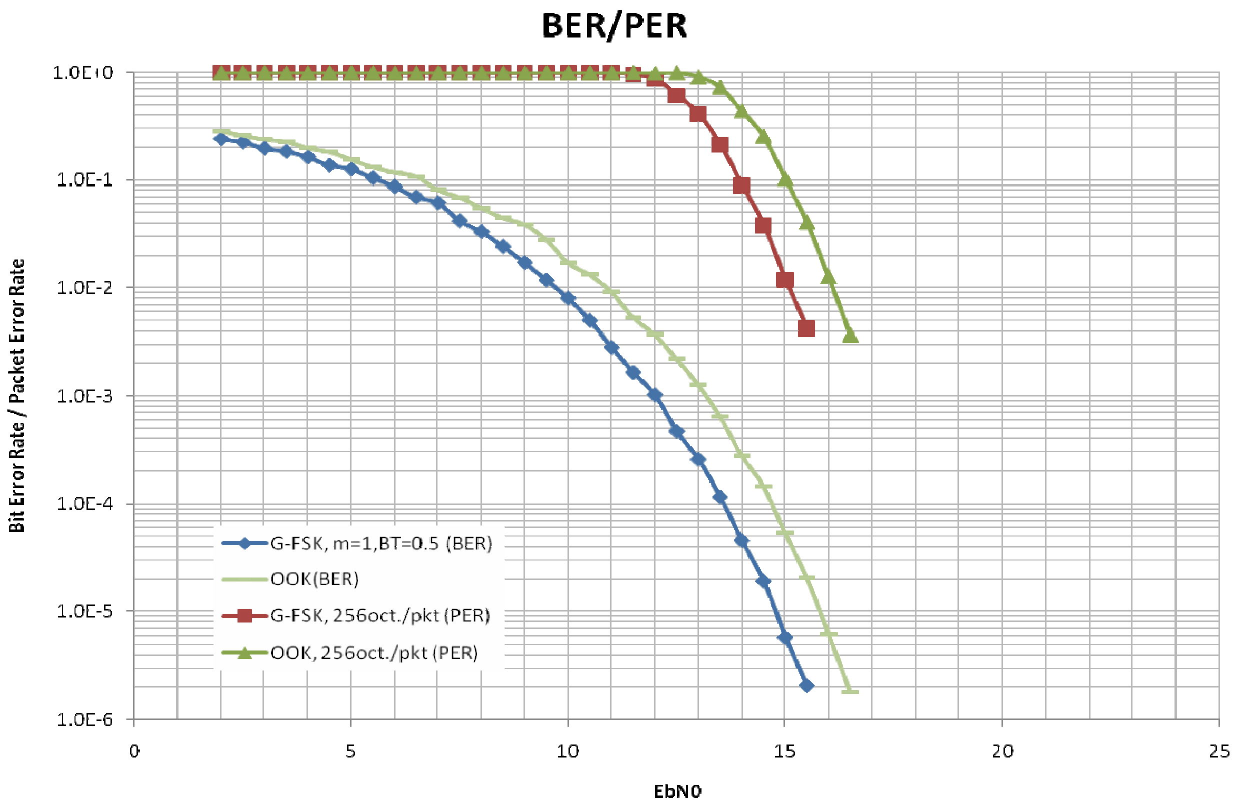


Figure 4 Bit Error Rate (BER) / Packet error Rate (PER) wake-up based PHY performance.

3.5 Link Budget

The path loss in the budget evaluation is based on the channel mode document [4].

4 MAC Frame Structure For IEEE802.15.4

The format of IEEE 802.15.4 MAC frame [1] is as follows:

Octets: 2	1	0/2	0/2/8	0/2	0/2/8	0/5/6/10/14	Variable	2
Frame Control	Sequence Number	Destination PAN Identifier	Destination Address	Source PAN Identifier	Source Address	Auxiliary Security Header	Frame Payload	FCS
		Addressing Fields						
MHR							MAC Payload	MFR

The format of the MAC Frame Control [1] is as follows:

Bits: b0-b2	b3	b4	b5	b6	b7-b9	b10-b11	b12-b13	b14-b15
Frame Type	Security Enabled	Frame Pending	ACK Request	PAN ID Compression	Reserved	Destination Addressing Mode	Frame Version	Source Addressing Mode

The MAC Frame Type values [1] are defined as follows:

Frame Type Value b_2 b_1 b_0	**Description**
000	Beacon
001	Data
010	ACK
011	MAC Command
100	Reserved
101	Reserved
110	Reserved
111	Reserved

The IEEE802.15.4 MAC Commands [1] for the management of BAN devices are listed in the following table:

Command Frame Identifier	Command Name	RFD		FFD	
		Tx	Rx	Tx	Rx
0x01	Association Request	X		X	X
0x02	Association Response		X	X	X
0x03	Disassociation Notification	X	X	X	X
0x04	Data Request	X		X	X
0x05	PAN ID Conflict Notification	X		X	X
0x06	Orphan Notification	X		X	X
0x07	Beacon Request			X	X
0x08	Coordinator Realignment		X	X	X
0x09	GTS Request			X	X
0x0a-0xff	Reserved				

5 Proposed MAC Frame Structure For IEEE802.15.6

We propose a frame structure for IEEE802.15.6 based on the IEEE802.15.4 standard. The proposed IEEE802.15.6 MAC frame format is as follows:

Octets: 2	1	0/2	0/2/8	0/2	0/2/8	0/5/6/10/14	1	1	Variable	2
Frame Control	Sequence Number	Destination PAN Identifier	Destination Address	Source PAN Identifier	Source Address	Auxiliary Security Header	Device State	Stream Index	Frame Payload	FCS
		Addressing Fields								
MHR									MAC Payload	MFR

The MAC Frame Control field is defined as follows:

Bits: b0-b2	b3	b4	b5-b6	b7	b8	b9	b10-b11	b12-b13	b14-b15
Frame Type	Security Enabled	Frame Pending	ACK Policy	PAN ID Compr-ession	Device State Flag	Reserved	Destination Addre-ssing Mode	Frame Version	Source Addre-ssing Mode

The highlighted fields are described in the following subsections. The remaining fields are as defined in IEEE802.15.4 [1].

5.1 IEEE802.15. 6 MAC Commands

As in IEEE802.15.4, a MAC command is indicated using the MAC command Frame Type field. The specific MAC command is identified in the MAC Payload, which is a combination of a MAC Command ID and a MAC Command Payload. A MAC Command ID identifies a MAC command and a MAC Command Payload contains a command's parameters.

The MAC command frame is defined as follows:

Octets: 2	1	0/2 + 0/2/8 + 0/2 + 0/2/8	0/5/6/10/14	1	1	1	Variable	2
Frame Control	Sequence Number	Addressing Fields	Auxiliary Security Header	Device State	Stream Index	MAC Command ID	MAC Command Payload	FCS
MHR						MAC Payload		MFR

The IEEE802.15.6 MAC commands are listed as follows:

Command Frame Identifier	Command Name	RFD	
		Tx	Rx
0x01	Association Request	X	
0x02	Association Response		X
0x03	Disassociation Notification	X	X
0x04	Data Request	X	
0x05	PAN ID Conflict Notification	X	
0x06	Orphan Notification	X	
0x07	Beacon Request		
0x08	Coordinator Realignment		X
0x09	GTS Request		X
0x0a	Device State Request		X
0x0b	Emergency Notification	X	X
0x0c	Handover		X
0x0d	Stability Notification	X	X
0x0e	Test Packet	X	X
0x0f	Antenna Change Request	X	X
0x10	Stream Request	X	X
0x11	Stream Response	X	X
0x12-0xff	Reserved		

A RFD is Reduced Function Device such as a sensor node, as opposed to a Full Function Device (FFD) such as a BAN coordinator, which can transmit and receive every MAC command.

5.1.1 Device State Request

This command is used by the coordinator to request the state of a device. It is defined as follows:

Octets: 2	1	0/2 + 0/2/8 + 0/2 + 0/2/8	0/5/6/10/14	1	1	1	2
Frame Control	Sequence Number	Addressing Fields	Auxiliary Security Header	Device State	Stream Index	Device State Request Command ID	FCS
MHR						MAC Payload	MFR

The Device State Request command does not have a MAC Command Payload. In response to this request, a device sends a data frame with the device state flag in the frame control set to 1 and the device state octet set to the appropriate status, both in the MAC header.

5.1.2 Emergency Notification

By definition a medical emergency is a situation under which the values of one or some of the physiological parameters being measured breech a critical threshold on a consistent basis. The situation can be considered as life threatening or critical.

In such circumstances, it is important to send a notification to the BAN coordinator. The coordinator can then broadcast this notification for group emergency management and give channel access priority to the BAN devices in emergency.

The Emergency Notification command is sent when a BAN device is in state of emergency. It can be triggered at the BAN device or at the BAN coordinator depending on which one has the necessary emergency detection capability.

This command can be used to raise an emergency (Emergency Bit = 1) or to lift a state of emergency (Emergency Bit = 0) depending on the MAC Command Payload.

The MAC frame format of the Emergency Notification command is as follows:

Octets: 2	1	0/2 + 0/2/8 + 0/2 + 0/2/8	0/5/6/10/14	1	1	1	1 bit	2
Frame Control	Sequence Number	Addressing Fields	Auxiliary Security Header	Device State	Stream Index	Emergency Notification Command ID	Emergency Bit	FCS
MHR						MAC Payload		MFR

5.1.3 Handover

The Handover command is used by a coordinator to tell a BAN device, which is either unstable, or in a state of emergency, to hand itself over to another coordinator.

This command can be issued if a BAN device is judged to be at risk of experiencing interference or performance degradation, in other words the BAN device is unstable. This instability can be "sensed" when expected ACKs are missed or miss a predefined time window (time-out) within which they are expected.

In addition, the handover command may be issued by a coordinator to a BAN device in a state of emergency, if another more suitable coordinator (e.g. one which is dedicated to emergency traffic) can handle the emergency traffic from that device.

The payload of the command is set to the ID of the alternate coordinator or coordinators that a BAN device can handover to.

The Handover command is defined as follows:

Octets: 2	1	0/2 + 0/2/8 + 0/2 + 0/2/8	0/5/6/10/14	1	1	1	Variable	2
Frame Control	Sequence Number	Addressing Fields	Auxiliary Security Header	Device State	Stream Index	Handover Command ID	List of Alternative Coordinator ID(s)	FCS
MHR						MAC Payload		MFR

5.1.4 Stability Notification

The definition of stability is based on a number of missed ACKs. A device is considered to be unstable, or a point of instability, if it breeches a threshold of ACK time-outs. The cause of an instability could be: 1) shadowing effect 2) poor radio channel and 3) very low battery.

This command is sent by a BAN device which could not transmit its data to the next hop in a multi-hop mesh topology. This may happen for a number of reasons, including instability of links between hops, instability of one or more devices in the path due to diminishing power or technical failure and so on.

The Stability Notification command is defined as follows:

Octets: 2	1	0/2 + 0/2/8 + 0/2 + 0/2/8	0/5/6/10/14	1	1	1	Variable	2
Frame Control	Sequence Number	Addressing Fields	Auxiliary Security Header	Device State	Stream Index	Stability Notification Command ID	Stability Notification Command Payload	FCS
MHR						MAC Payload		MFR

The Stability Notification command can be interpreted as follows:

- If the command is sent from a device to a coordinator without a payload, then the device is notifying the coordinator that it is simply unstable.

- The command can be sent from a device to a coordinator with a payload that specifies the reason for its instability; or
- The command can be sent from a device with a payload that contains the ID of other unstable devices which are routing traffic through it. Note that the device sending the Stability Notification may not itself be unstable, and may be using the command to inform of other unstable devices as well.
- If the command is sent from a coordinator to a device with a payload, then the coordinator is notifying the device that the device is unstable, with a payload message to the device as to what action to take. This may result in two or more outcomes. Either:
  - The coordinator is indicating that the device should go to sleep, i.e. “forced sleep” payload; or
  - The coordinator is indicating that the device should lower its duty cycle, i.e. “lower duty cycle” payload; or
  - The coordinator is indicating that the device should use other means to communicate, e.g. change its antenna configuration or radiation pattern, i.e. “change radio configuration” payload.

5.1.5 Test Packet

A Test Packet command is sent by a BAN device which has not received an expected packet within a predefined time window (time-out). The command is sent to the sending BAN device which should acknowledge the test packet. This command initiates a probing process consisting of a number of back-to-back Test Packet commands sent to test the quality of the channel between the two BAN devices. The measure of the quality of a channel is given by the success rate of the returned ACKs corresponding to a number of Test Packet commands sent.

The format of the Test Packet command is as follows:

Octets: 2	1	0/2 + 0/2/8 + 0/2 + 0/2/8	0/5/6/10/14	1	1	1	Variable	2
Frame Control	Sequence Number	Addressing Fields	Auxiliary Security Header	Device State	Stream Index	Test Packet Command ID	Antenna Configurat-ion	FCS
MHR						MAC Payload		MFR

The payload of this command may be used to indicate that the BAN device has multiple antenna or radiation pattern configurations that it can use.

5.1.6 Antenna Change Request

The Antenna Change Request command may be sent by a BAN device, or a coordinator, to another BAN device, to request that that device change its antenna, where multiple antennas are available. This command may also be interpreted as a request to a BAN device to change its radiation pattern configuration.

The format of the Antenna Change Request command is as follows:

Octets: 2	1	0/2 + 0/2/8 + 0/2 + 0/2/8	0/5/6/10/14	1	1	1	2
Frame Control	Sequence Number	Addressing Fields	Auxiliary Security Header	Device State	Stream Index	Antenna Change Request Command ID	FCS
MHR						MAC Payload	MFR

Note that this command does not have a payload.

5.1.7 Stream Request

This command is used by a device to request the allocation or modification of a stream. This is similar to the Channel Time Request command in IEEE802.15.3 [2], but, with minor modifications that are explained later in the section.

A device sending a Stream Request command to a coordinator with the Stream Index (SI) set to a value of 0xFE is requesting the creation of a new stream. Otherwise, it is a request to modify the existing stream. Note that a SI value of 0x00 is reserved for asynchronous data.

We assume that medical and non-medical devices will use different PHYs in IEEE802.15.6. Therefore, the coordinator can distinguish medical from non-medical devices in order to allocate the priority of the stream according to whether or not a device is medical or non-medical.

In addition, the coordinator can use the knowledge of whether or not a device is in a state of emergency to allocate the appropriate priority to that device’s stream. Knowledge of emergency state can be had from previous emergency state notifications from a device using the Emergency

Notification command, or from a device's state, if the device has indicated its state in the Device State octet of the MAC header as it requests a stream using the Stream Request command.

A coordinator who receives an emergency state notification from a device can, based on its resources, assign an appropriate priority level and resources to the stream that has been requested by that device.

The Stream Request command is defined as follows:

Octets: 2	1	0/2 + 0/2/8 + 0/2 + 0/2/8	0/5/6/10/14	1	1	1	As specified by IEEE802.15 .3 [2] with variations (see below)	2
Frame Control	Sequence Number	Addressing Fields	Auxiliary Security Header	Device State	Stream Index	Stream Request Command ID	Stream Request Payload	FCS
MHR						MAC Payload		MFR

The Stream Request command is equivalent to the Channel Time Request command of IEEE802.15.3 with the following exceptions:

- The *DSPS* octet in the Channel Time Request field [Section 7.5.6.1 of [2]] is eliminated; and
- *Ctrq control* in the Channel Time Request field [Section 7.5.6.1 of [2]] is eliminated.

5.1.8 Stream Response

A BAN coordinator uses the Stream Response command to inform a BAN device that it has allocated or unallocated a stream for that device. This command is similar to the Channel Time Response in the IEEE802.15.3 [2] specification and is defined according to that specification.

A coordinator that receives an emergency state notification from a device can, based on its resources, assign a stream and streaming index if the device has requested a stream using the Stream Request command. The allocated stream is then treated with an appropriate level of priority based on a number of factors, which are: resource availability, level of emergency as indicated by the device state, and the demand for high priority streams from other devices.

The stream response is defined as follows:

Octets: 2	1	0/2 + 0/2/8 + 0/2 + 0/2/8	0/5/6/10/14	1	1	1	As specified by IEEE802.15.3 [2] with variations (see below)	2
Frame Control	Sequence Number	Addressing Fields	Auxiliary Security Header	Device State	Stream Index	Stream Response Command ID	Stream Response Command Payload	FCS
MHR						MAC Payload		MFR

The Stream Response command is similar to the Channel Time Response command of IEEE802.15.3 with minor modifications. The *reason code* in the Channel Time Response command payload [Section 7.5.6.2 of IEEE802.15.3] is modified to eliminate the following reason code values:

- *Success, device in save mode*;
- *Priority unsupported*;
- *Destination in power save mode*; and
- *Unable to allocate as pseudo-static Channel Time Allocation*.

5.2 IEEE802.15.6 Frame Types

The frame type indicates different types of frames and is defined as follows:

Frame Type Value b2 b1 b0	Description
000	Beacon
001	Data
010	Acknowledgement
011	MAC Command
100	Immediate Acknowledgement
101	Delayed Acknowledgement
110-111	Reserved

The highlighted frame types are described in later subsections. The remaining frame types are according to IEEE802.15.4 [1].

5.3 Acknowledgement Policy

BAN devices may acknowledge receipt of data and commands. If an acknowledgement is specifically requested, a BAN device must send an ACK. Different types of acknowledgements can be used to suit different situations. The ACK types are indicated in the ACK Policy fields in the MAC Frame Control as follows:

ACK Policy b6 b5	Description
00	No ACK
01	ACK
10	Delayed ACK
11	Immediate ACK

- An **ACK** (b6 b5 = 01) is sent at the *earliest opportunity*, when one is requested. The ACK frame does not have a payload.

- An **Immediate ACK** (b6 b5 = 11) is sent *immediately* when one is requested in the MAC header of a MAC Command frame or a Data frame for increased reliability. The Immediate ACK frame does not have a payload.
- A **Delayed ACK** (b6 b5 = 10) is sent *after a number of transmitted frames*, acknowledging receipt of multiple frames in the Delayed ACK payload, following receipt of a '0' Frame Pending bit in the frame control. This may be used in non-critical, delay tolerant situations that require a certain level of reliability. This option has the advantage of reducing the power consumption by decreasing the number of ACKs, but increasing the resource requirement of devices for buffering. There is a trade-off between power consumption, delay, and buffer requirements.

The frame format of the ACK and Immediate ACK is as follows :

Octets: 2	1	0/2 + 0/2/8 + 0/2 + 0/2/8	0/5/6/10/14	1	1	2
Frame Control	Sequence Number	Addressing Fields	Auxiliary Security Header	Device State	Stream Index	FCS
MHR						MFR

The ACK and Immediate ACK frames do not have payloads. Note that for the Immediate ACK, the MAC Frame Type in the MAC Frame Control is set to Immediate ACK.

The frame format of the Delayed ACK is as follows :

Octets: 2	1	0/2 + 0/2/8 + 0/2 + 0/2/8	0/5/6/10/14	1	1	Variable	2
Frame Control	Sequence Number	Addressing Fields	Auxiliary Security Header	Device State	Stream Index	Delayed ACK Payload	FCS
MHR						MAC Payload	MFR

The payload of the delayed ACK is defined according to IEEE802.15.3 [2]. Note that the MAC Frame Type in the MAC Frame Control is set to delayed ACK.

5.4 Device State

The Device State is one octet in the MAC header, outside of the MAC Frame Control. It is subdivided into fields that indicate different urgency levels of an emergency state and different battery levels for a device.

The device state is only interpreted when the device state flag in the MAC Frame Control (b8 = 1) is set to one. In addition, the device state may be published upon request by a coordinator using a Device State Request command as described in Section 5.1.1. The device state may be used for BAN management by a coordinator and / or an application (e.g. for adaptive duty cycling, or for optimised channel access).

In order to enable the urgency and battery levels to be used independently, device state is defined as follows:

Bits: b0–b1	b2-b3	b4-b8
Urgency Levels (“u1 u2”)	Battery Levels (“b1 b2”)	Reserved

5.5 Stream Index

We propose a stream index that allows the identification of individual streams as defined in IEEE802.15.3 [2]. The reason for introducing the stream index is to be able to handle medical streams such as ECG, EEG, etc.

The stream index is used in conjunction with either the Emergency Notification command or the Device State octet as specified in the MAC Frame Header. It is used to provide different classes of QoS. These classes are mapped into different QoS parameters as follows:

- Data pipe data transfer rates (i.e. high versus low data rate pipes);
- Data pipe availability; and
- BAN device priority and delay, based on that device’s emergency level.

As a result, medical and non-medical emergency streams can be given the highest streaming priority, lowest delay in response to the required delay and the highest available data rate pipe in response to the required bit rate. In addition, medical streams can be given higher priority over non-medical streams.

We assume that medical and non-medical devices will use different PHYs in 15.6. Therefore, a BAN coordinator can distinguish medical from non-medical devices in order to allocate priority to streams appropriately. Knowledge of emergency state can be had from previous emergency state notifications from a device using the Emergency Notification command, or from a device's state, if the device has indicated its state in the device state octet of the MAC header in the Stream Request command frame.

6 Potential Protocols Exploiting the Proposed MAC Frame

Section 5 provides hooks in the MAC layer, which can be used by a variety of protocols to perform various BAN management activities such as:

- Congestion control;
- Stability management;
- Handover procedure;
- On demand stream scheduling according to QoS requirements;
- Emergency induced channel access mode switching; and
- Adaptive duty cycling for power management.

These protocols could be implemented at the MAC layer or at higher network and application layers depending on the need and device requirements, e.g. medical or non-medical, and device resource constraints.

6.1 Congestion Control

This section provides a description of potential congestion control mechanisms for devices in a state of emergency, which are either part of a star or a multi-hop, mesh network topology. For example, if a number of non-emergency devices are routing their traffic through a device A, and that device A goes into a state of emergency, then the congestion control mechanism can be activated to limit the traffic routed through device A.

Two cases may be considered:

1) Device A continues to route high-priority traffic, i.e. traffic for devices in emergencies, and may support low-priority traffic, i.e. traffic for devices not in emergency, if it has the resources; and
2) Device A stops routing high-priority traffic and, but, may still support low-priority traffic if it has the resources and the number of existing low-priority links does not exceed a predefined limit.

In the first case, device A, which is routing traffic from other devices in addition to its traffic, goes into a state of emergency. It then sends an emergency notification to the coordinator and its neighbouring devices which are routing their traffic through it. The coordinator then allocates a high-priority link to device A which is in a state of emergency. Device A continues to support existing high-priority traffic from devices in emergency. In addition, device A may continue to support existing low-priority traffic from other devices that are not in emergency, based on its available resources. If not enough resources are available at device A, device A drops or transfers some or all of the existing low-priority traffic to another coordinator.

An alternative test for alleviating the congestion at device A is to evaluate the level of congestion (i.e. buffer utilisation) and or the QoS of high-priority links in the presence of low-priority links.

Figure 5 illustrates the details of the congestion protocol for this first case.

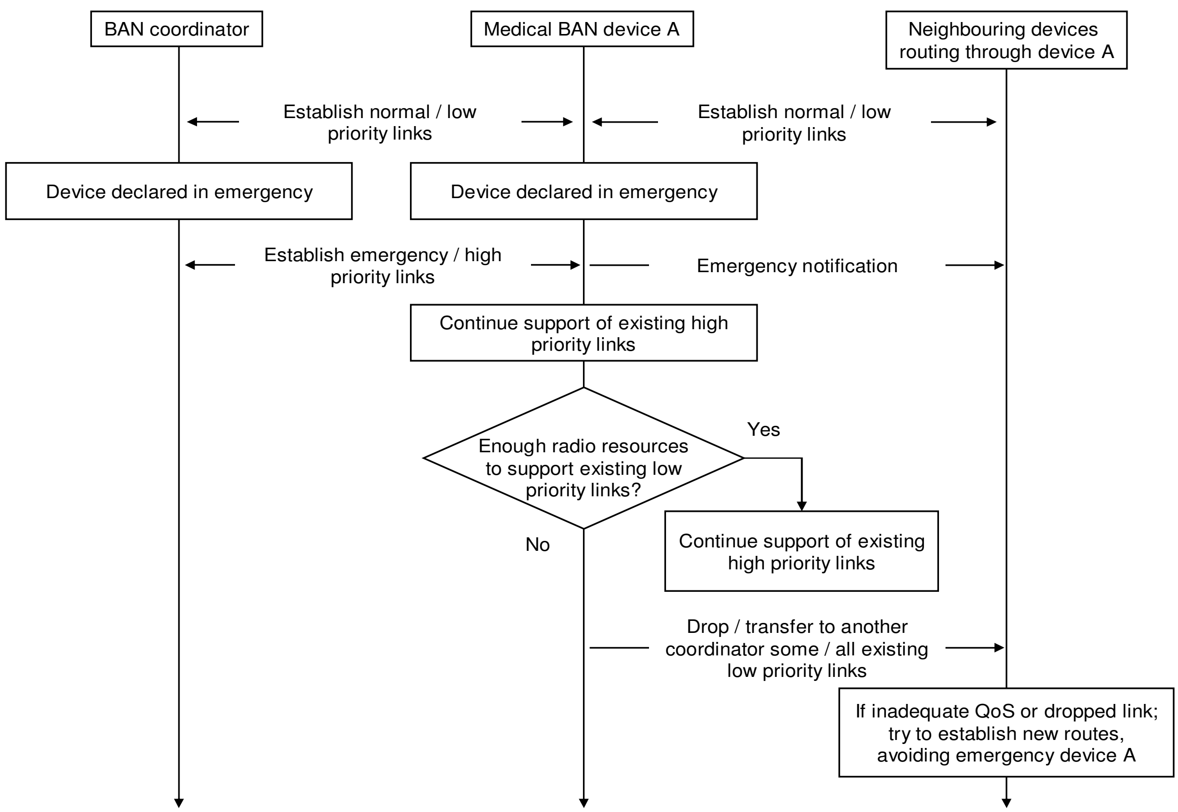


Figure 5: Case 1: Device A is in a state of emergency and continues to route high-priority traffic. It may also support low-priority traffic if resources available.

In the second case, a device A, which is routing traffic from other devices in addition to its own traffic, goes into a state of emergency. It sends an emergency notification to the coordinator and its neighbouring devices which are routing their traffic through it. The coordinator then allocates a high priority link to device A. Device A stops routing the high-priority traffic of other devices. However, device A may continue to support low-priority traffic from other devices which are not in emergency, based on its available resources and if the number of existing links does not exceed a defined limit. Figure 6 illustrates the details of the congestion protocol in this second case.

Note that this congestion procedure makes use of the Emergency Notification MAC command issued by a device in a state of emergency.

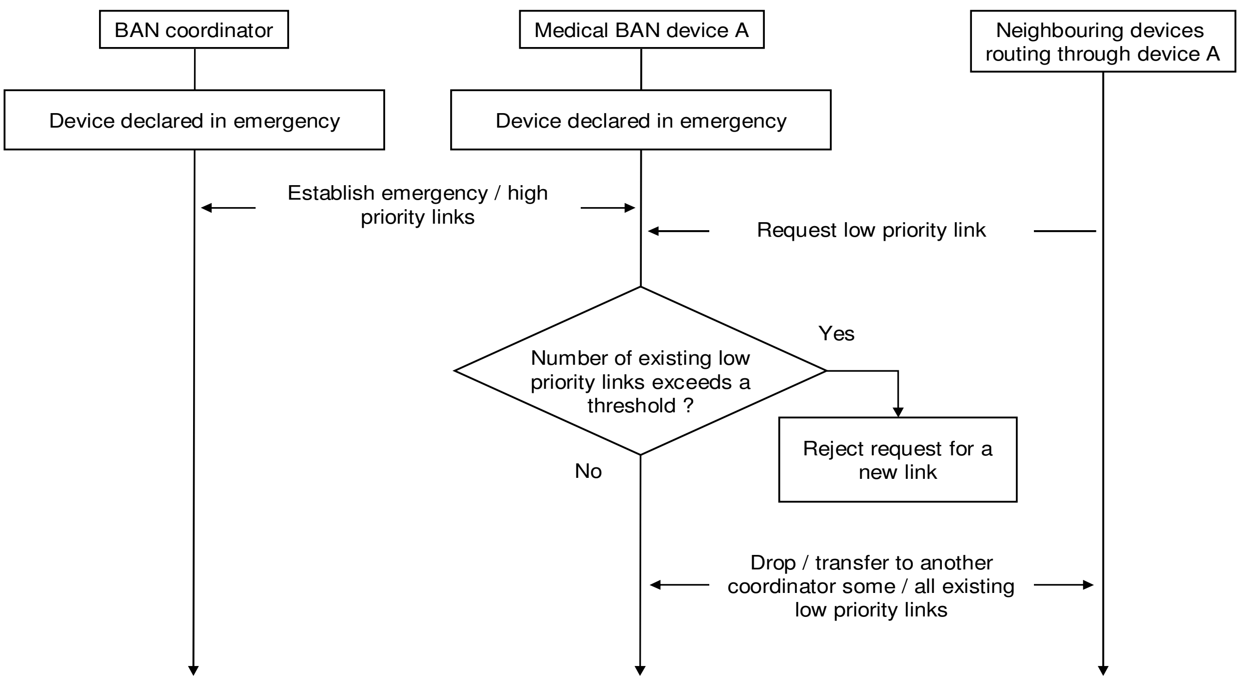


Figure 6: Case 2: Device A is in a state of emergency and stops routing high-priority traffic. It may support low-priority traffic if resources available.

6.2 Stability Management

Although error correction mechanisms are capable of dealing with poor radio transmission, there are situations under which a patient's body posture, position or motion can effect the radio channel and result in communications becoming severely unstable. This may lead to a situation where error correction algorithms are inadequate. Under such circumstances, other stability management mechanisms are required to avoid interruption to potentially vital medical procedures.

We define stability based on a number of missed ACKs. A device is considered to be unstable or a point of failure if a predefined number ACKs are missed. An ACK is considered to have been missed if the device has waited for a predefined timeout period after it has sent a message that requires acknowledgement. The causes of instability may be: 1) shadowing effects, 2) poor radio channels, or 3) low device battery.

The stability management procedure described herein is suitable for multi-hop, mesh topologies. Consider the scenario where the coordinator is sending a message to a device C through two intermediate devices A, then B, i.e. the coordinator transmits to A, which then transmits to B, which in turn transmits to C.

Device B is considered unstable or a point of failure if it has not received acknowledgements for a message that it forwarded to device C. Missed ACKs may be measured against the number of ACK timeouts and, in addition, if the buffer utilisation exceeds a predefined threshold. Under such circumstances, other devices e.g. device A, which precedes device B by one hop, may change antenna direction or increase transmission power in order to leapfrog the unstable device B in order to reach device C.

Once an unstable device, like device B, detects itself to be unstable, it sends a stability notification command to other devices, possibly stating the cause of the instability together with its identity in the payload of the Stability Notification command. This notification may be propagated to the coordinator. As a result, the coordinator may command the unstable device to go to sleep using the Stability Notification command, see Section 5.1.4.

Figure 7 depicts the details of the stability management protocol.

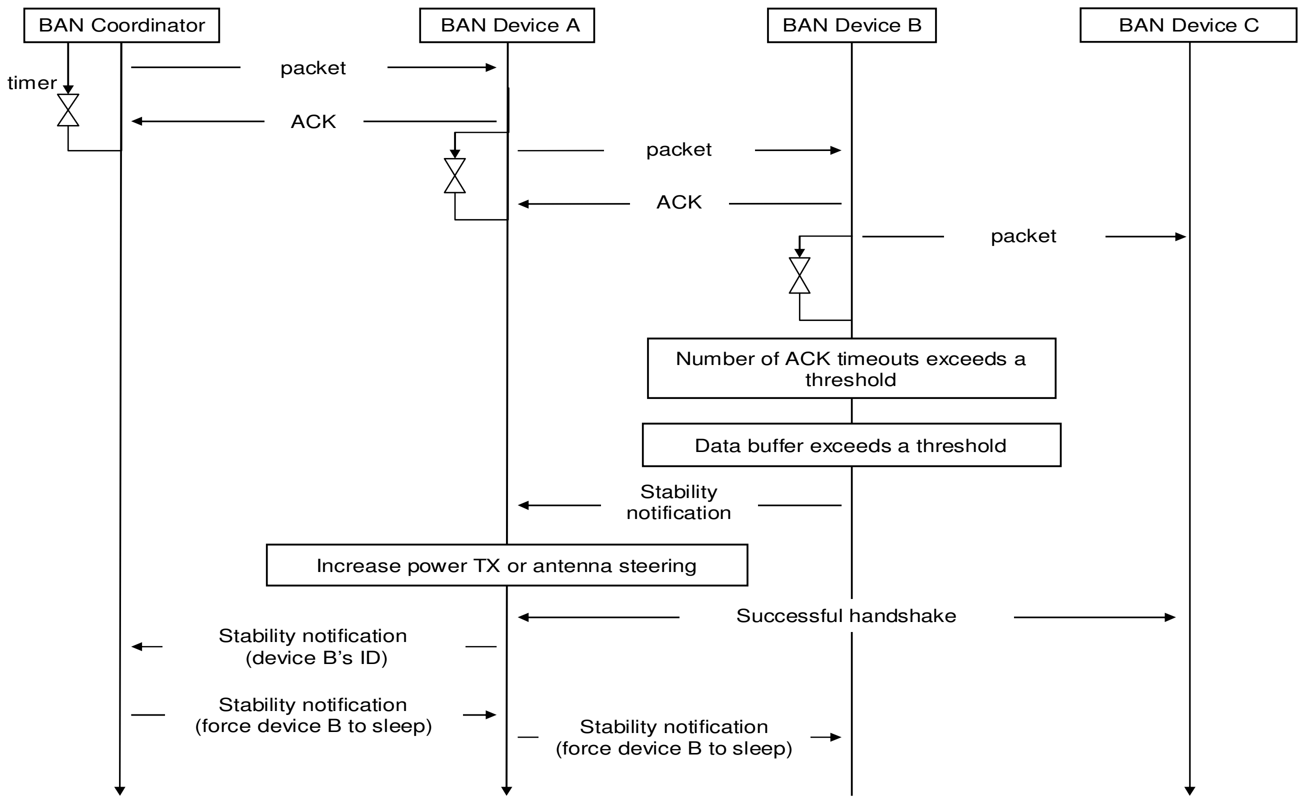


Figure 7: Stability management protocol.

6.3 Stability Management in Star Topology with Antenna Switching

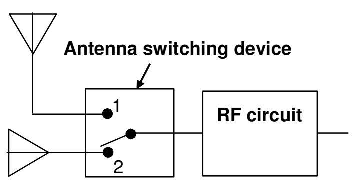
The stability management method in this section is for networks using a star topology. It is initiated by a node receiving data when it has not received the next data packet after a predefined timeout, when more data packets are expected.

It is assumed that devices have different antennas (Figure 8) or different radiation pattern configurations (Figure 9) to switch between in order to improve the quality of the channel. The stability management consists of two main phases: 1) a probing process and 2) changing antenna or radiation pattern configuration. Once the receiver waiting for data has timed out, it initiates the probing process by sending a number (N) of Test Packet commands (Section 5.1.5) requiring ACKs to the sending device, and assess the success rate (R) of the corresponding returned ACKs from the sender. If $R > R_{th}$, where R_{th} is a predefined threshold for the success rate of returned

ACKs to Test Packet commands, the channel is declared stable and communication between the sender and receiver resumes as before.

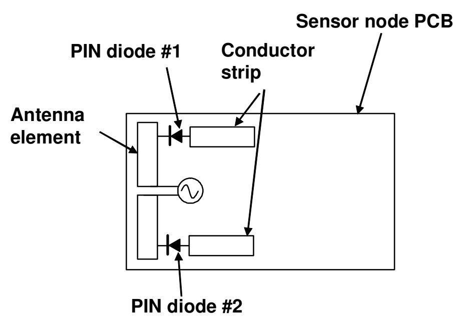
If $R \leq R_{th}$, the receiver changes the configuration of its radio antenna or radiation pattern and repeats the process of probing. If after exhausting all configurations (M) at the receiver, or after M configuration changes, if R is still below threshold, the receiver sends a request to the sender to change its configuration for a number of times (k) and assess the returned ACKs from the sender.

If R is still is still below threshold, the receiver checks for low battery and, if low, sends an alert, otherwise it sends an alert informing of the cause of the instability. This alert may be further propagated to a central medical care unit for post processing and action.



Config. No.	Switch port
1	1
2	2

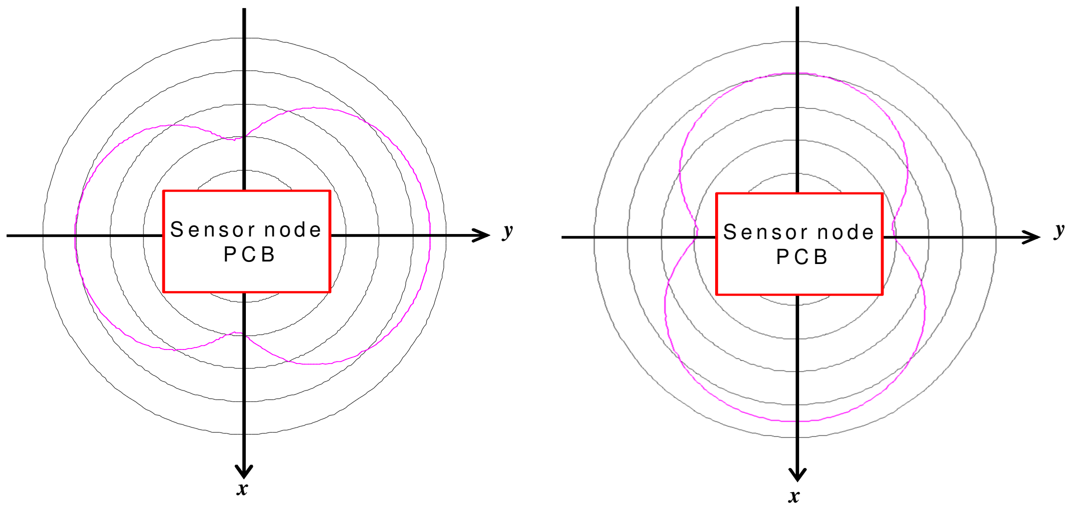
Configuration for switching antennas



Config. No.	PIN diode #1	PIN diode #2
1	OFF	OFF
2	OFF	ON
3	ON	OFF
4	ON	ON

Configuration for antenna with conductor strips

Figure 8 Device with multiple antennas.



Directivity of the configuration #1 Directivity of the configuration #2

Figure 9 Example of variation of directivity according to changes of signal radiation method.

Figure 10 illustrates the stability management procedure.

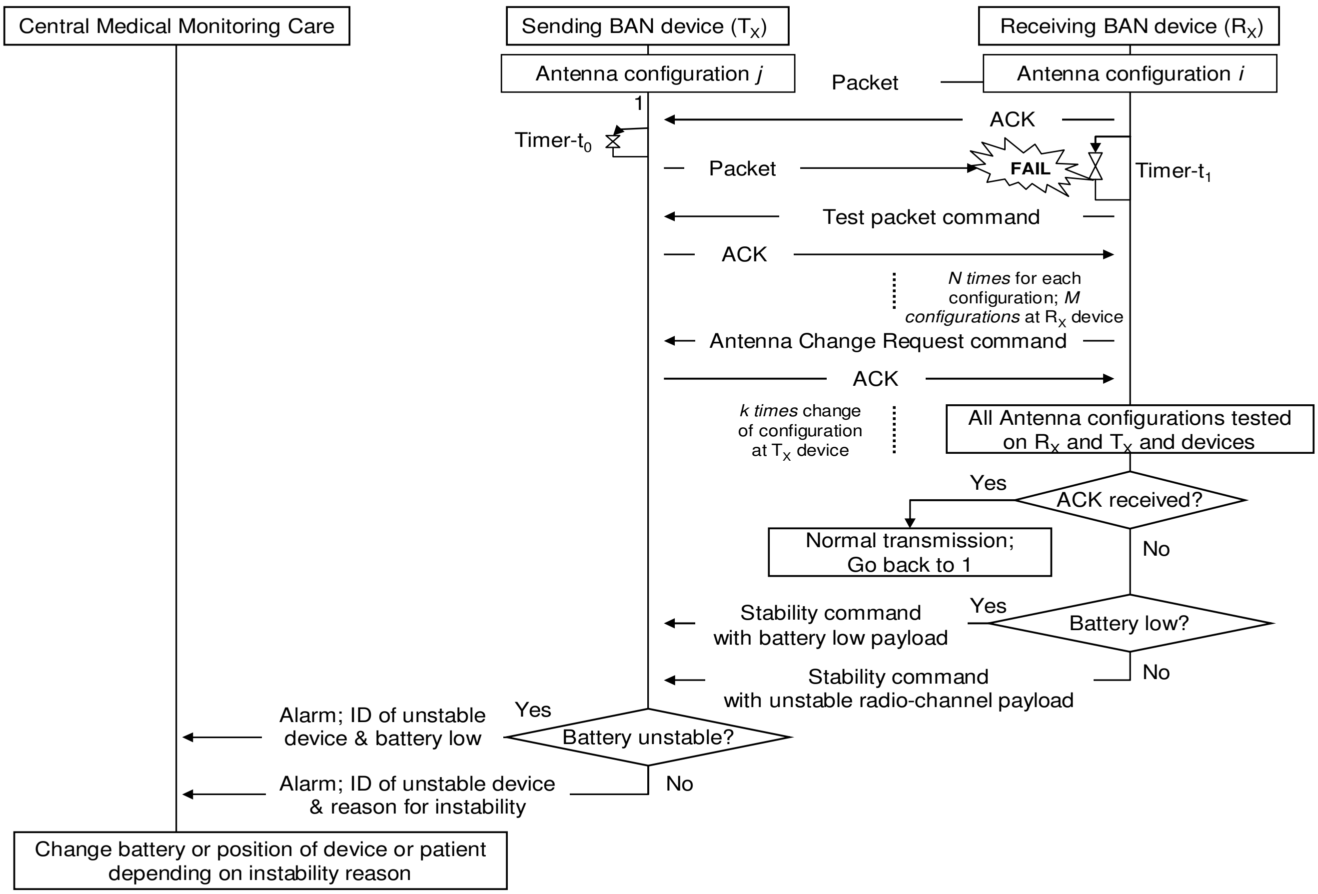


Figure 10 Stability management based on antenna switching.

6.4 Handover Procedure

When a patient using a BAN without a coordinator is on the move, the BAN will have to associate with fixed point coordinators. When the BAN moves beyond the transmission range of the coordinator to which it is currently associated, it is essential to handover the moving BAN to a new, more suitable coordinator.

This handover procedure is to help maintain the connectivity and seamless operation of mobile BANs. The fundamental assumption is that handover functionality on the device side should be minimum to avoid too much power consumption due to potentially frequent switching between T_X and R_X.

In what follows, a simple handover procedure for devices with limited resource is proposed.

The handover procedure may be triggered for various reasons, including low signal-to-interference ratio (SIR) and increasing distance between a device and the coordinator with which it is associated.

The Handover MAC command is used to trigger the process of disassociating from one coordinator and associating with another. The handover command, as described in Section 5.1.3, has a payload that lists potentially suitable target coordinators with which the device receiving the command can associate with.

As mentioned above, the handover procedure is used to assist medical BAN devices associated with a patient moving in a closed environment, such as hospital, in handing over from one coordinator to another for improved performance or sustaining the required performance.

BAN devices associated with a patient form a group that may be labelled with the identity of that patient. The network operates in two modes: beacon and non-beacon modes. The non-beacon mode is used when there is no device in a state of emergency in the BAN group. On the other hand the beacon mode is used when at least one device goes into a state of emergency in the BAN group.

The group associated with the patient having at least one device in a state of emergency can be transferred to the beacon mode coordinator. There are multiple coordinators operating in various network modes for different situations and they assist the BAN devices to perform the handover to the appropriate coordinator depending on several factors:

- *At least one device in a group goes into emergency;*
- *Location of the group with at least one device in a state of emergency relative to the current coordinator;*
- *Location of the group with at least one device in a state of emergency relative to the current coordinator and SIR.*

Figure 11 illustrates the initiation of the handover procedure.

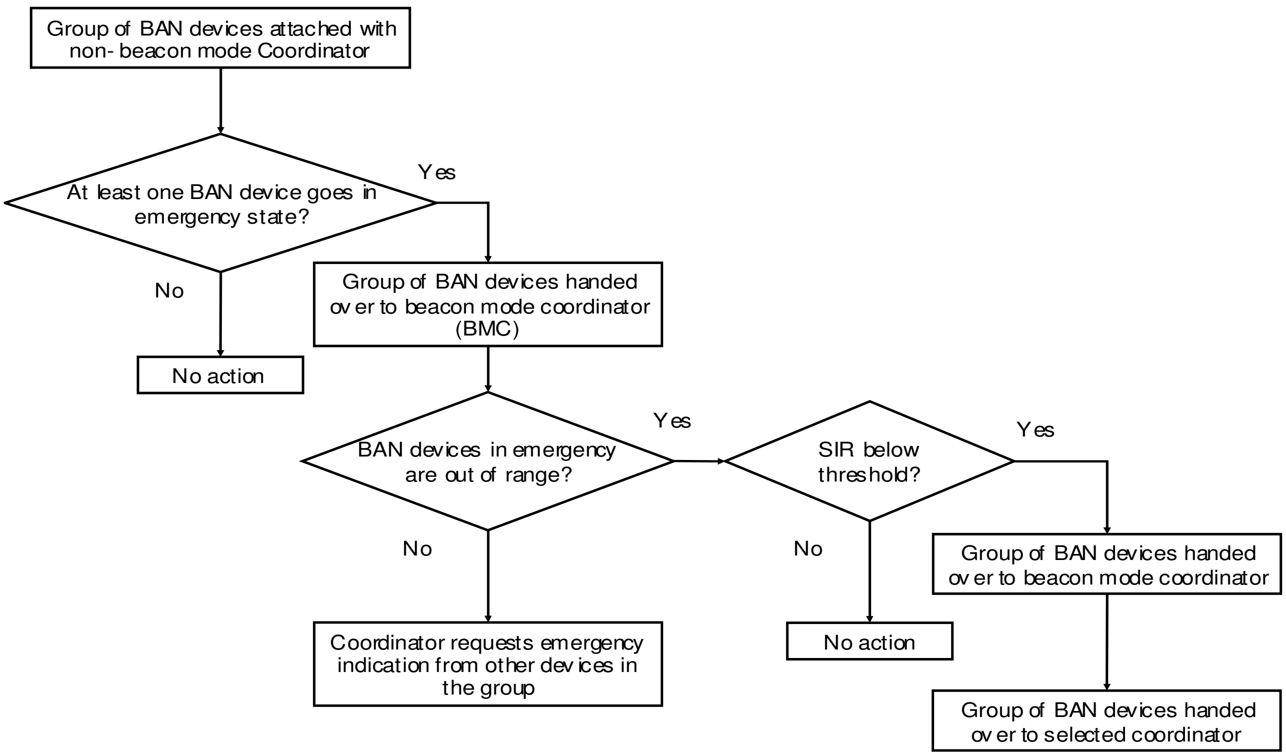


Figure 11: Emergency induced handover procedure.

Figure 12 depicts the handover procedure when at least one medical BAN device in a BAN group, which is in emergency state, is moving. The criteria for handover are based on the distance of the group of devices with respect to the coordinator to which the group is associated. If the distance of the group is beyond a predetermined radius for reliable communication, the handover is triggered. Note that the Handover MAC command is used by the coordinator to inform the devices to perform the handover. The handover procedure may be triggered based on other criteria as mentioned above.

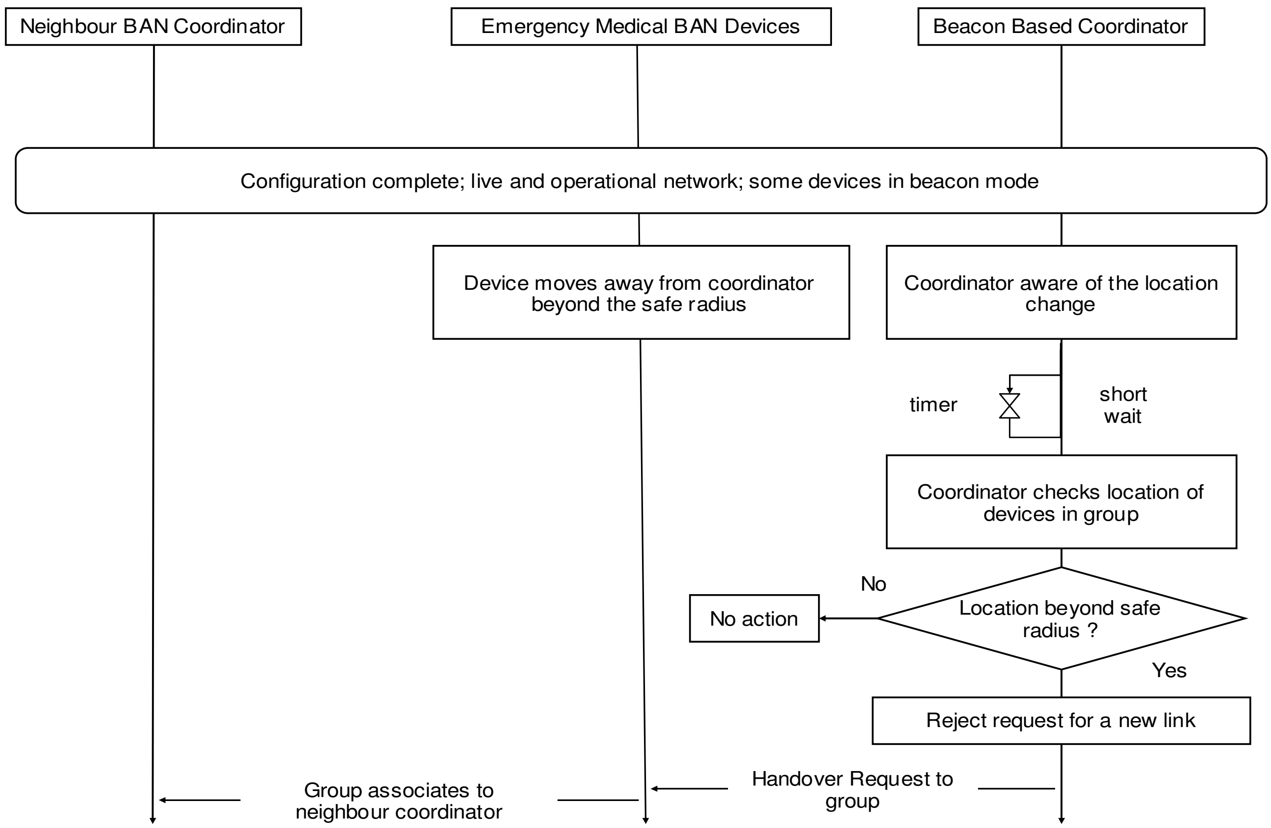


Figure 12: Handover protocol.

6.5 On Demand Data Stream Scheduling According To QoS

The Stream Index octet described in Section 5.5 is used to accommodate streaming capability. The Stream Index may be used in conjunction with either the Emergency Notification command or the Device State octet (Section 5.4) in a MAC Frame Header for the provision of different classes of stream QoS.

As a result, medical and non-medical *emergency streams* can be given the highest streaming priority, lowest delay in response to the required delay, and the highest available data rate pipe in response to the required bit rate. In addition, *medical streams* can be given higher priority over non-medical streams. For example, medical applications such as ECG, EEG and medical video may get higher streaming priority in emergencies.

The prioritisation mechanisms associated with stream scheduling are dynamic. This means that in response to the lifting of an emergency, the streaming of non-emergency and non-medical data may be resumed automatically by reallocation of streaming resources. Further, this mechanism allows for the slowing down, or temporarily stopping, of non-medical streaming when emergency data is present.

Figure 13 illustrates on demand scheduling of the channel access in response to streaming requests from BAN devices, giving higher priority to emergency streams over other traffic.

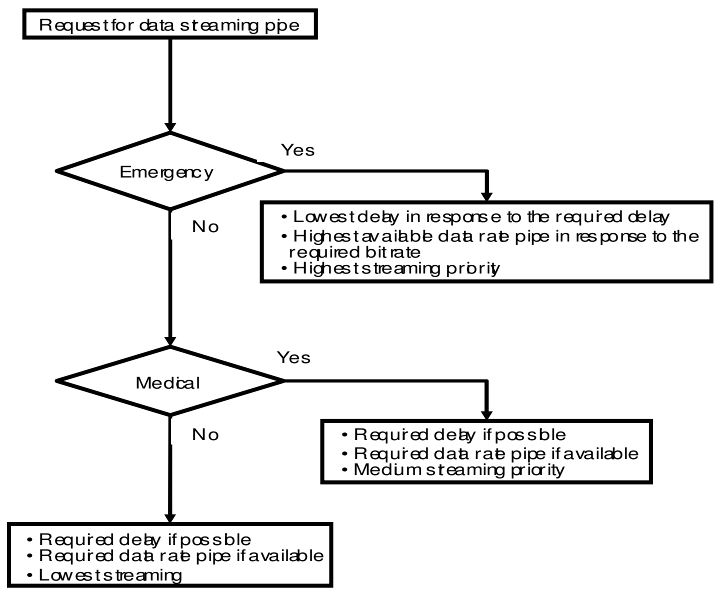


Figure 13: On demand channel access scheduling procedure.

Figure 14 illustrates the details of on the demand scheduling.

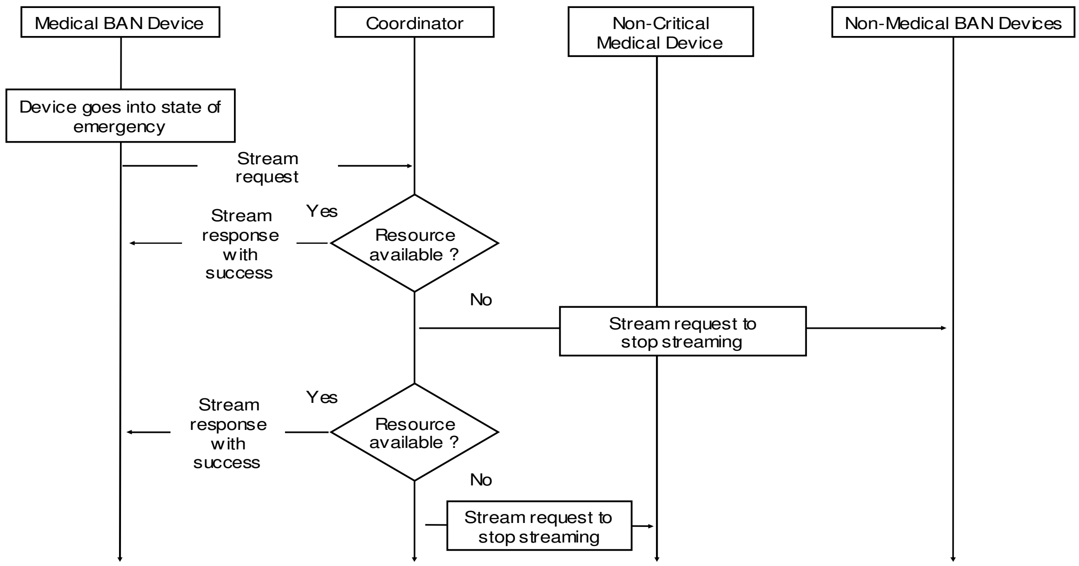


Figure 14: On demand channel access scheduling protocol.

Regarding requests issued from a coordinator to stop other devices from streaming to that coordinator; according to IEEE802.15.3 [2] there is no such command to request a device to stop streaming. Normally, the Channel Time Allocation (CTA) response is issued in response to a request form a device to the coordinator for channel allocation. Therefore, a new command may be needed in IEEE802.15.6 that allows the coordinator to request that other devices stop streaming.

Using the on demand scheduling protocol, a network device can make use of a stream request to create a new stream or to modify an exiting stream and the coordinator can use the stream response to grant or cancel a stream allocation to network devices according to network conditions and available resources (see also Sections 5.1.7 and 5.1.8).

6.6 Emergency Induced Switching Between Different Channel Access

Either the Emergency Notification command or the Device State, which includes urgency levels and battery levels, can be considered as potential criteria for switching between different network modes, such as non-beacon mode and beacon mode depending on the criticality of the BAN conditions.

We assume that BAN devices initially operate in non-beacon mode and with low duty cycles under normal conditions. As the urgency level of an emergency situation is raised as a result of an abnormality in the measurement or as a result of low battery level, this is indicated in the Device State in MAC Frame Header. This device state can be propagated throughout the BAN to trigger tighter synchronisation and increased level of monitoring and, therefore, switching into a more synchronised network modes of operation, such as the beacon mode. In the beacon mode, channel access follows a superframe structure which consists of three zones: 1) contention based zone, 2) contention free zone and 3) inactive zone. The superframe structure for the beacon mode is illustrated in Figure 15.

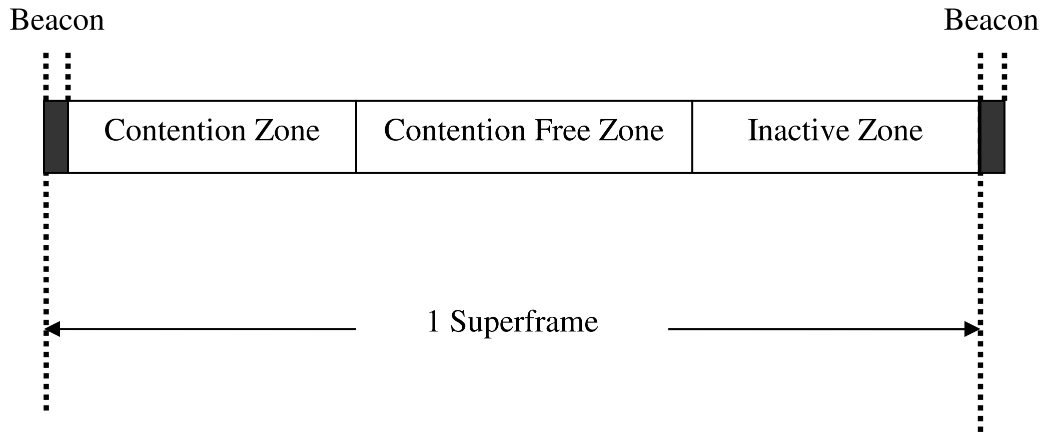


Figure 15: Superframe structure.

6.7 Adaptive Duty Cycling

By definition duty cycling is a power saving mechanism. It is defined as the ratio of the time that a radio is active to the time it is inactive.

The motivation for adaptive duty cycling is that, under medical emergencies, it may sometimes be necessary to increase the frequency of the acquisition of measurements by a BAN device (e.g. from once every 10 hours to once every 30 minutes). This is particularly suitable for remote applications, such as those that may be implemented in isolated care homes where there may also be a lack of qualified medical staff.

The device state (which includes urgent bits and battery bits) may be used by a protocol that allows a BAN device to coordinate its duty cycle in harmony with a BAN coordinator for adaptive channel access, for emergency management in the BAN. By harmonising a BAN device in a state of emergency with a coordinator, it should be possible to achieve the best duty cycle taking into account a BAN device's current battery level.

More specifically, the BAN device duty cycle may be adapted depending on the severity of the emergency as identified by the device or the coordinator. The two "urgent" bits in the device state octet, "u1 u2", differentiate levels of emergency may be mapped to the thresholds and duty cycles shown in Table 1. The meaning of the "urgent" bits will be known to both the BAN device and the BAN coordinator. The latter can use them use them for scheduling channel access and other resource management.

Table 1 Urgent bits of the device state octet, mapping emergency levels to thresholds and duty cycles.

Device State Urgent Bits: "u1 u2"	Example Emergency Level	Thresholds	Example Duty Cycling
00	Device in normal condition	measurement < Th1	**Low Wakeup:** Longest sleep time, very low duty cycle
01	Device in slightly abnormal condition	Th1 < measurement < Th2	**Medium Wakeup:** Slight increase of duty cycle
10	Device in abnormal condition	Th2 < measurement < Th3	**High Wakeup:** Increase of duty cycle
11	Device in emergency	Th3 < measurement	**Continuous Wakeup:** Dramatic increase of duty cycle or continuous wake mode

The adaptation of duty cycle may take into consideration battery levels in the device state. Table 2 provides an example of mapping battery levels into permissible duty cycles.

Table 2 Battery bits of the device state octet, mapping battery levels to permissible duty cycles.

Battery		Example Duty Cycle			
Device State Battery bits: "b1 b2"	**Battery Levels**	**Low Wakeup**	**Medium Wakeup**	**High Wakeup**	**Continuous Wakeup**
00	L1=0%-25%	✓	×	×	×
01	L2=25%-50%	✓	✓	×	×
10	L3=50%-75%	✓	✓	✓	×
11	L4= 75%-100%	✓	✓	✓	✓

7 References

1. IEEE 802.15.4-2006 standard.
2. IEEEE802.15.3 standard.
3. 15-08-0644-09-0006-tg6-technical-requirements-document.
4. P802.15-‘08/780r5; TG6 Channel Model.