INTERNATIONAL STANDARD

ISO/IEC 15149-2

First edition
2015-05-01

Information technology — Telecommunications and information exchange between systems — Magnetic field area network (MFAN) —

Part 2:
In-band Control Protocol for Wireless Power Transfer

Technologies de l'information — Téléinformatique — Réseau de zone de champ magnétique (MFAN) —

Partie 2: Protocole de contrôle dans la bande pour le transfert de puissance sans fil

Reference number
ISO/IEC 15149-2:2015(E)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: Foreword — Supplementary information.

The committee responsible for this document is ISO/IEC JTC 1, *Information technology*, Subcommittee SC 6, *Telecommunications and information exchange between systems*.

ISO/IEC 15149 consists of the following parts, under the general title *Information technology — Telecommunications and information exchange between systems — Magnetic field area network (MFAN)*:

— *Part 1: Air interface*

— *Part 2: In-band control protocol for wireless power transfer*

— *Part 3: Relay protocol for extended range*

— *Part 4: Security protocol for authorization*

Introduction

This International Standard provides protocols for magnetic field area network (MFAN). MFAN can support the service based on wireless communication and wireless power transfer in harsh environment. MFAN is composed of four protocols; air interface, in-band control protocol, relay protocol, and security protocol.

ISO/IEC 15149–1 specifies the physical layer and media access control layer protocols of wireless network over a magnetic field.

ISO/IEC 15149–2 specifies the control protocol for wireless power transfer based on magnetic field area network.

ISO/IEC 15149–3 specifies the relay protocol to extend effective network coverage of magnetic field area network.

ISO/IEC 15149–4 specifies the security protocol to authorize nodes to communicate in magnetic field area network.

Information technology — Telecommunications and information exchange between systems — Magnetic field area network (MFAN) —

Part 2: In-band Control Protocol for Wireless Power Transfer

1 Scope

This International Standard establishes a system for an in-band network, from which both wireless power transfer and data transmission are carried out simultaneously at the same frequency band. It provides technical solution for a remote and consistent power supply, along with a stable network.

For the purpose of this International Standard, the system is designed based on the principles described in ISO/IEC 15149 (Magnetic Field Area Network). In this way, it is expected to achieve superiority in control of devices, while managing wireless power transfer to multiple devices in request. The focus is on the physical and media access control layer protocol; it will not discuss matters on the upper layer protocols. As together, the PHY and MAC layers have to be able to carry out the following tasks: data transmission, signal control, wireless power transfer.

This International Standard is applicable in various situations and environments, but is expected to perform excellently in the following certain use cases:

— mobile phones: provide ubiquitous charging environments for portable devices;

— home appliances: allow unrestrained placement of appliances with the elimination of wire cables and plugs for power supply.

The media access control layer protocol is designed for the following scope:

— variable superframe structure for wireless power transfer to multiple devices;

— simple and effective network topology for efficient wireless power transfer;

— dynamic address assignment for efficient timesharing among multiple devices.

The physical layer protocol is designed for the following scope:

— one frequency band for both wireless power transfer and magnetic field communication;

— simple and robust modulation for low-cost implementation and minimized margin of error;

— variable coding and bandwidth for dynamic charging environment.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 15149-1:2014, *Information technology — Telecommunications and information exchange between systems — Magnetic field area network (MFAN) — Part 1: Air interface*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
wireless power transfer
WPT
method of consistent and simultaneous power supply to multiple devices within a range without physical contact

3.2
magnetic field area network
MFAN
wireless network that provides reliable communication in harsh environments using magnetic field

3.3
magnetic power network
MPAN
in-band wireless power transfer network that incorporates magnetic field area network (MFAN) in its communication and wireless power transfer within a single frequency band

3.4
magnetic power area network–coordinator
MPAN-C
device that carries out integral operations for magnetic power area network; wireless power transfer, connection and release of devices, and time scheduling of power transfer and data

3.5
magnetic power area network–node
MPAN-N
devices that comprises magnetic power area network and that is not a coordinator

4 Symbols and abbreviated terms

The following acronyms are used in this document:

ARq	Association Request
ARs	Association Response
ARA	Association Response Acknowledgement
ASC	Association Status Check
ASK	Amplitude Shift Keying
ASRq	Association Status Request
ASRs	Association Status Response
ASRA	Association Status Response Acknowledgement
BPSK	Binary Phase Shift Keying
CRC	Cyclic Redundancy Check
DA	Data Acknowledgement
DaRq	Disassociation Request

DaRs	Disassociation Response
DaRA	Disassociation Response Acknowledgement
DRq	Data Request
DRs	Data Response
DRA	Data Response Acknowledgement
FCS	Frame Check Sequence
GSRq	Group ID Set-up Request
GSRs	Group ID Set-up Response
GSRA	Group ID Set-up Response Acknowledgement
LSB	Least Significant Bit
MAC	Media Access Control
NRZ-L	Non-Return-to-Zero Level
PHY	Physical Layer Protocol
PLRC	Power Level Request Command
PLRCA	Power Level Request Command Acknowledgement
PS	Power Status
PSF	Power Status Feedback
PSFI	Power Status Feedback Interval
PT	Power Transfer
PTBRq	Power Transfer Beacon Request
PTEC	Power Transfer Execution Command
PTECA	Power Transfer Execution Command Acknowledgement
PTPC	Power Transfer Permission Command
PTRC	Power Transfer Request Command
PTRq	Power Transfer Request
PTRs	Power Transfer Response
RA	Response Acknowledgement
RR	Response Request
SIFS	Short Inter Frame Space
TDMA	Time Division Multiple Access
UID	Unique Identifier

5 Overview

MPAN is an in-band wireless network system that enables wireless communication and wireless power transfer within a single frequency band. Data and control commands are communicated according to the MFAN system; power is transferred wirelessly according to the consistent WPT system, both at the same frequency band. Due to the characteristics of magnetic field and legal regulations on the power level, the range of MFAN is wider than that of WPT. Within the MPAN, the maximum WPT efficiency is achieved with an MPAN-C taking in charge of every scheduling accordingly for devices in most effective orders.

The MFAN has a low carrier frequency bandwidth of 30 KHz to 300 KHz; the same frequency band is used for WPT. It uses a simple and robust modulation method like BPSK for low cost implementation and low error probability. Also dynamic coding methods like Manchester and NRZ-L are considered in specific against noises. It can provide data transmission speed of several kbps within a distance of several meters. For WPT, unmodulated sine sinusoidal signal is used to enhance WPT efficiency. The MPAN uses a simple and efficient network topology like the 'star topology' for low power consumption. It uses dynamic address assignment for small packet size, so to manage address efficiently as well. Also it incorporates an adaptive link quality control by using various transmission speeds, and coding methods suitable for various MPAN environments.

There are two kinds of devices participating in an MPAN according to their functions: MPAN-C and MPAN-N. Only one MPAN-C may exist within an MPAN, where a number of MPAN-Ns may be registered to. As a base station of MPAN, MPAN-C manages connection and release of MPAN-Ns when there is response to its request. For the data transmission, MPAN uses TDMA method; When an MPAN-N joins MPAN managed by MPAN-C, MPAN-C allocates time-slots for the MPAN-N. WPT and data transmission would begin as MPAN-C requests for the responses of MPAN-Ns.

As shown in Figure 1, MPAN-C and MPAN-Ns are to be located elsewhere within the network. If MPAN-C receives relevant data for WPT — ID, battery information, etc. — from MPAN-Ns, it examines factors like power transfer sequences or the number of time slots for an appropriate WPT. MPAN-C then sends control data back to MPAN-Ns to manage overall WPT operations.

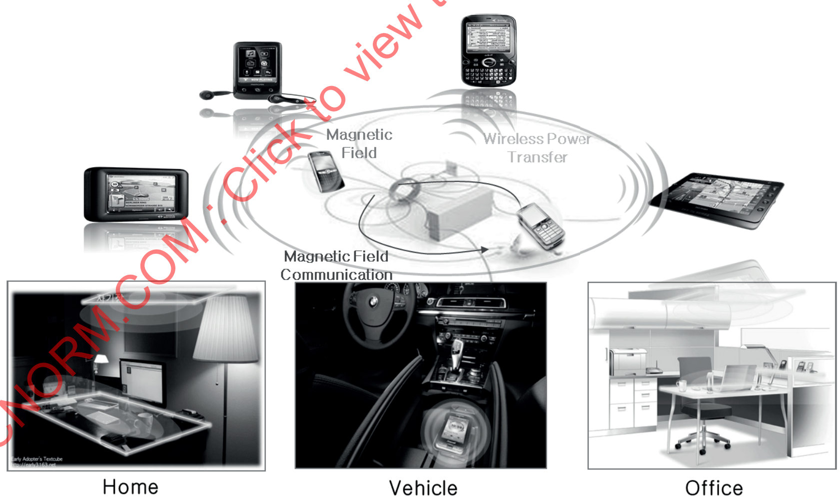

Figure 1 — Wireless Power Transfer System

MPAN can be applied to various industries. It may be applied to a situation where electric devices are in need of constant power supply to function properly. For some industries, significant improvement in efficiency is attainable simply by providing power wirelessly. In any cases, duration of battery life no longer becomes a problem; no need to spare broad space for spacious batteries and charging equipment.

As for an example, there has always been a battery issue when it comes to using mobile devices (Figure 2) due to its running time. MPAN is able to provide a ubiquitous charging environment while on a stable network service. Also for the home appliances (Figure 3), complex wire cables and plugs can be eliminated; a placement of home appliances at one's convenience becomes possible with MPAN.

Figure 2 — Mobile Devices

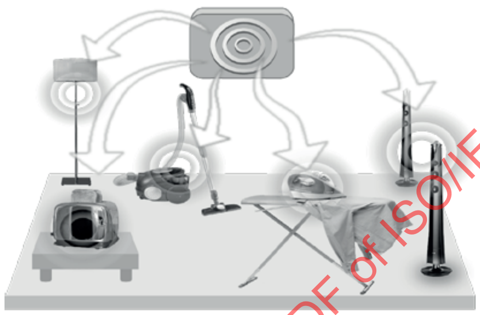

Figure 3 — Home Appliances

6 Network elements

6.1 General

The elements of MPAN, based on the elements of MFAN, are classified in two: time and physical element. The time element refers to the superframe structure consisting of request period, response period, and spontaneous period. The physical element refers to the MPAN devices: MPAN-C and MPAN-Ns. The most basic unit in the physical element is device. A device may be defined according to its role either as an MPAN-C that manages network, or an MPAN-N that communicates with MPAN-C.

When an MPAN is set up, a node is allocated to be an MPAN-C: the device in charge of the perfect control of association, disassociation, release, and time scheduling for MPAN-Ns. The superframe begins when a device is set as an MPAN-C, and starts to transmit request packets during the request period. Within MPAN, only a single channel is permitted by an MPAN-C; the rest devices within the MPAN become MPAN-Ns. Note that a device within an MPAN may participate as an MPAN-C or MPAN-N depending upon its role. For the connection between an MPAN-C and an MPAN-N, a peer-to-peer connection is used.

6.2 Time element

6.2.1 General

The MPAN inherits the same time elements used in MFAN, ISO/IEC 15149-1, which is much similar to the method used in TDMA time slot; MPAN-C arranges times slots for individual MPAN-Ns. MPAN-C manages data from the group of MPAN-Ns during response period. There are some new features newly introduced from ISO/IEC 15149-2 in relation to WPT.

6.2.2 Time element for MPAN

The time element of MPAN, as shown in Figure 4, consists of request period, response period, and spontaneous period. The lengths of request and response period are varied; the length of spontaneous period is subject to the length of request and response period.

The superframe begins when MPAN-C transmits a PTRq packet to MPAN-Ns during the request period. When MPAN-N receives the packet, it sends PTRs packet back as a response. According to the PTRs packets received, MPAN-C sends PTBRq packet with information on the WPT time schedule. In that case, relevant MPAN-Ns can receive WPT during the following response periods. During the power status feedback interval, MPAN-Ns will transmit the PSF packet as a response to the PS beacon from MPAN-C.

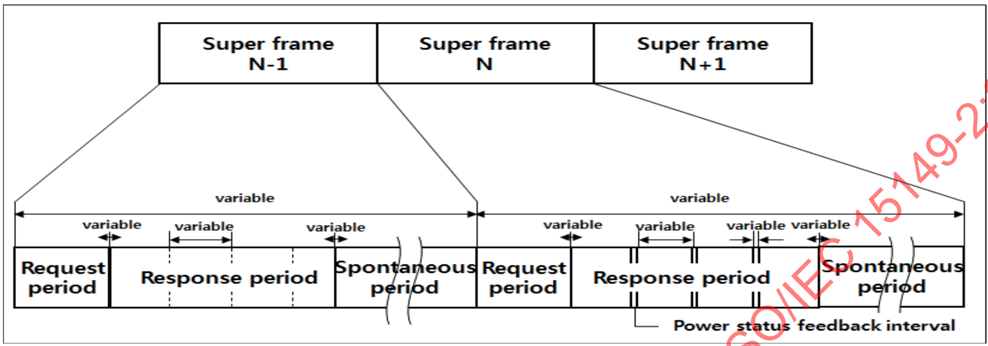

Figure 4 — MPAN superframe structure

6.2.2.1 Request period

During the request period, MPAN-C transmits PTRq packet to invite MPAN-Ns to WPT time schedule. Receiving PTRq packet, MPAN-Ns prepare to take WPT from MPAN-C.

6.2.2.2 Response period

The response period can be divided into several time slots by the number of MPAN-Ns for WPT. The length of each time slot varies according to the total length of WPT. When MPAN-C schedules for a response period, MPAN-C allocates slot numbers to each time slots in a numerical order; if there is not an MPAN-N, the slot number will be zero. MPAN-C may assign each time slot either to an individual MPAN-N or to a group of MPAN-Ns. According to a sequence of the schedule, an MPAN-N or all the MPAN-Ns in a group may receive wireless power simultaneously.

During the response period of MPAN, MPAN-Ns send PTRs to MPAN-C if the node is in need of WPT. The MPAN-Ns put in schedule by MPAN-C can receive WPT during the response period. MPAN-C, with the information received, calculates distance to MPAN-Ns. MPAN-C will then return PTBRq to MPAN-Ns to provide detailed time schedule and start WPT at a power level appropriate for the distance.

Distinguishable to the MFAN response period, the response period of MPAN has PSFI. After each time slot, there is a PSFI for quick power status update and abnormal situation. During WPT, when MPAN-N receives the PS beacon in the PSFI, it transmits the PSF packet to MPAN-C for notifying the updated power status as the response for the PS beacon in the PSFI. When abnormal situation is sensed by the MPAN-C, it is notified to all MPAN-Ns in the PSFI by the MPAN-C. When the MPAN-Ns recognize error by receiving the PS beacon, they wait until receiving a request from the MPAN-C.

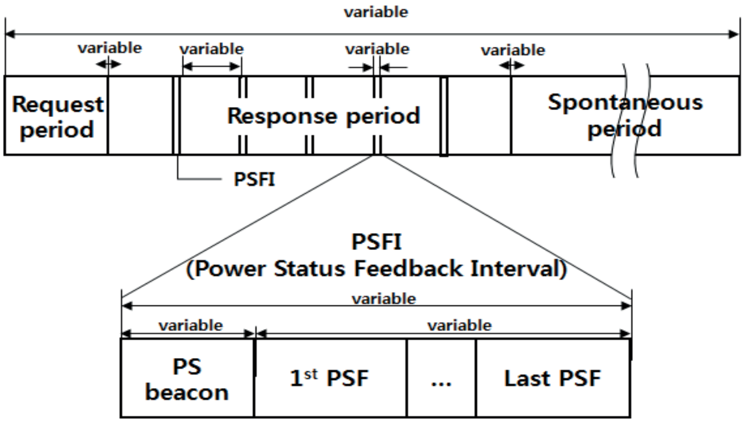

Figure 5 — PSFI in response period

6.2.2.3 Spontaneous period

The spontaneous period begins when MPAN-C confirms all PSF packets from MPAN-Ns in the last time slot of the response period and broadcasts PTPC. It will last until MPAN-C will transmit a RR packet again. During this period, low power devices can request power transfer without MPAN-C's request. When MPAN-C receives PTRC packet, it returns PTEC packet. As MPAN-C receives PTECA, the acknowledgement, it provides WPT to low power devices for a certain length of time. Afterward, MPAN-C and MPAN-N sends PLRC and PLRCA correspondently to check on the power level received. This period will last until MPAN-C transmits a request packet, or until it engages into a request period again.

6.3 Physical element

There are two kinds of physical elements within MPAN, which are MPAN-C and MPAN-N. The basic unit, device, can be categorized either as an MPAN-C or MPAN-N according to its role. An MPAN-C manages entire MPAN. An MPAN-C is able to control MPAN-Ns with RR packets. MPAN-Ns must return response packets back accordingly to MPAN-C in order to proceed with operations. A basic configuration of MPAN is shown in Figure 6.

6.3.1 Coordinator

MPAN-C is a node that manages MPAN; there is only a single MPAN-C per network. By transmitting an appropriate RR packet, it can manage and control MPAN-Ns within MPAN.

6.3.2 Node

MPAN-N is a device that is associated to an MPAN, and is not an MPAN-C. As much as 65 519 MPAN-Ns can link to a network at the same time. It returns response packets according to the RR packet sent by MPAN-C.

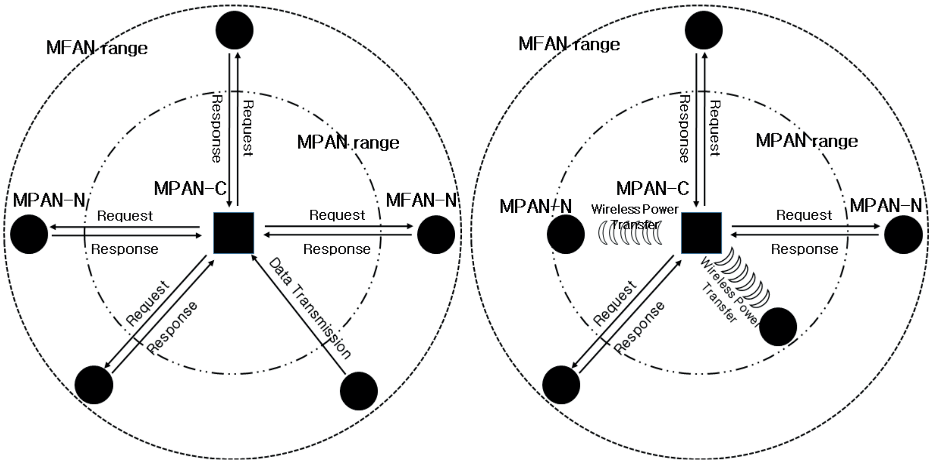

Figure 6 — MPAN physical element

6.4 Address element

In order to identify MPAN-Ns, MPAN uses an address system for MFAN ID, UID, group ID, node ID, and charging ID.

6.4.1 MFAN ID

Specified in ISO/IEC 15149-1:2014, 5.4.1

6.4.2 UID

Specified in ISO/IEC 15149-1:2014, 5.4.2

6.4.3 Group ID

Specified in ISO/IEC 15149-1:2014, 5.4.3

6.4.4 Node ID

Specified in ISO/IEC 15149-1:2014, 5.4.4

6.4.5 WPT ID

WPT ID is an identifier used during WPT. The ID has a 8-bit address assigned by MPAN-C for quick communication during WPT. The ID is allocated to MPAN-Ns during the request period right before WPT begins. Some WPT IDs are reserved in Table 3.

Table 1 — Reserved charging ID

Node ID	Content	Remarks
0xFF	All nodes	When broadcasting or transmitting all nodes
0xFE	Unjoined node	Default ID for node
0xF0 – 0xFD	Reserved	—

7 Network status

7.1 General

The MPAN inherits the same network status used in MFAN, ISO/IEC 15149-1. On top of it, there are some newly introduced status for MPAN in relation to wireless power transfer: stabilization, invigoration, revitalization status.

7.2 Network status for MPAN

7.2.1 Stabilization

MPAN in stabilization carries out wireless power transfer in every normal conditions. As MPAN-C sends PTRq packet during the request period, MPAN-Ns probe the packet and transmit PTRs packet accordingly during the response period. Based on the information in the PTRs packet, MPAN-C schedules time slots for WPT and transmits the schedule in PTBRq packet. WPT will commence as MPAN-C transmits PTS beacon. MPAN-Ns receive WPT from MPAN-C according to the scheduling sequence during the response period to MPAN-Ns in a time slot. After a time slot for WPT is finished, there is PSFI for quick power status update. When MPAN-Ns receive PS beacon from MPAN-C during the PSFI, MPAN-Ns will send PSF packet upon MPAN-C's requests. After confirming the PSF packets, the MPAN-C will inform MPAN-Ns the start of WPT with PTS beacon, engaging in WPT for the next time slot. During WPT, MPAN-C may stop WPT if it detects error. Otherwise, WPT is completed when MPAN-C receives every PSF packet from the last time slot.

7.2.2 Invigoration

MPAN in invigoration prioritizes devices low in power, and supplies power during spontaneous period to keep them on-line. When an MPAN-N becomes low in power, the MPAN-N will operate in power-saving mode, minimizing its operations. The MPAN-N may request power supply to MPAN-C in order to prevent shutting down. To do so, the MPAN-N will send PTRC to MPAN-C upon receiving PTPC; the MPAN-N will then receive returning PTEC from MPAN-C. MPAN-N will send PTECA and be engaged in WPT. The WPT to an MPAN-N low in battery is to be kept minimal, not to interrupt originally scheduled WPT. If MPAN-N receives power up to a threshold level (to be cut off from the WPT), the WPT will be terminated. After the power transfer in invigoration, MPAN-C sends PLRC to check on the power level received. MPAN-N will return PLRCA and if the power level is above threshold 2, the status will then become stabilization.

7.2.3 Revitalization

MPAN in revitalization provides power transfer to unassociated devices completely dried up of power. MPAN system includes distinctive WPT scenario to power down devices. When an MPAN-N is run out of power, the device is unable to process any signalling operations. Therefore, MPAN-C is unable to control the MPAN-N out of power; although it is not properly scheduled and may interrupt current WPT, the MPAN-N out of power will receive WPT during response period. However, in spontaneous period, MPAN-C transmits PTEC (no ack.) and transfer power regularly, to receive PLRCA for PLRC from revived power-down devices as soon as possible. MPAN-C will then be able to manage and control the revived MPAN-N and undergoes procedures explained from 7.2.2 invigoration.

7.3 MPAN state

MPAN device state includes MPAN-C state and MPAN-N state as justified in ISO/IEC 15149-1. Put in detail, MPAN-C states are divided into standby state, packet analysis state, packet generation state; power transfer state, power transfer standby state, power status packet analysis state, and power status packet generation state. MPAN-N states are composed of hibernation power level detection state, stable hibernation state, general activation state, standby state, packet analysis state, packet generation state; power reception state, power isolation state, power down hibernation state, low power hibernation state, low power packet analysis state, low power packet generation state, PSF activation state, power status packet analysis, power status packet generation.

7.3.1 Coordinator state

7.3.1.1 Communication procedure

The state of MPAN-C will be at standby when power is turned on. During standby state, the system commands transmission of RR packet and the superframe begins; MPAN-C enters packet generation state. Once the transmission of RR packet is carried out, MPAN-C returns to standby state, waiting for responses. When MPAN-C receives response (or whichever packet) from MPAN-Ns while performing carrier detection during standby state, MPAN-C enters packet analysis state. If the destination ID of the received packet and the node ID of MPAN-C correspond, MPAN-C enters packet generation state. During packet generation state, MPAN-C generates either RA or DA packet accordingly, and sends to MPAN-Ns. The state of MPAN-C will return to standby state, afterward.

In case of error detection within the data packet while on packet analysis, the MPAN-C returns directly to standby state. If errors are detected within the received response packet or destination ID of the received response packet do not corresponds to node ID of MPAN-C during packet analysis state, MPAN-C regenerates RR packet from generation state and re-transmits it to MPAN-Ns after a certain length of time; the MPAN-C returns to standby state. If the failure continues, the procedure will be repeated as many times as configured (maximum of N times). On the (N+1) th attempt, MPAN-C returns to standby state from packet analysis state.

7.3.1.2 Stabilization procedure

For WPT, MPAN-C enters packet generation state as the superframe begins (system commands), and sends PTRq packet. Once the transmission of PTRq packet is carried out, MPAN-C returns to standby state. When MPAN-C receives PTRs packet from MPAN-Ns, MPAN-C enters packet analysis state. After confirming the packet, MPAN-C enters packet generation state to create PTBRq packet with the schedule for WPT. With the transmission of PTBRq packet, MPAN-C enters power status packet generation state. MPAN-C, after sending PTBRq packet, again sends PTS to MPAN-Ns, informing the start of WPT according to the schedule provided; MPAN-C enters power transfer state.

MPAN-C enters power status packet generation state, when PSFI begins. As MPAN-C transmits PS beacon to all MPAN-Ns during the PSFI, MPAN-C will enter power transfer standby state and receive PSF packets from MPAN-Ns. Receiving PSF packets, MPAN-C enters power status packet analysis state. From power status packet analysis, MPAN-C counts the number of PSF packets and the number of time slots. If the number of PSF does not equal to the number of total PSF packets to be received, MPAN-C returns power transfer standby, waiting for the next PSF packet. If the number of PSF packets equal to the total number of PSF packets, MPAN-C counts on the slot number. If slot number does not equal to the number of total slots (last slot number), MPAN-C enters power status packet generation state to re-send PTS beacon packet for the WPT in the next time slot. If the slot number equals to the number of total time slots, it indicates the WPT time scheduling has finished for the response period; MPAN-C returns standby state. For error detection during power transfer, MPAN-C immediately enters power transfer standby. MPAN-C waits until current time slot times-out, and enter power status packet generation for PSFI.

7.3.1.3 Invigoration procedure

During invigoration, MPAN-C enters packet generation state as system commands to send PTPC to indicate the start of spontaneous period. MPAN returns to standby to wait for PTRC. When MPAN-C receives PTRC, MPAN-C enters packet analysis to check node ID. If it corresponds, MPAN-C enters packet generation to create PTEC (with ack.) and returns standby. Upon receiving PTECA, it goes packet analysis, then onto power transfer state to engage in power transfer to low power devices. When power transfer times out in spontaneous period, MPAN-C enters standby. After every power transfer in spontaneous period, MPAN-C check on the power level received from the MPAN-Ns that received power. MPAN-C enters from standby to packet generation to generate PLRC. MPAN-C waits from standby for PLRCA. As MPAN-C receives PLRCA, it goes to packet analysis state, then returns standby.

7.3.1.4 Revitalization procedure

During revitalization, MPAN-C enters packet generation at the beginning of spontaneous period as the system command, to generate PTEC (without ack.) broadcasting. MPAN-N enters power transfer as MPAN-C sends PTEC; MPAN-C returns standby afterward. After the power transfer, the system commands to broadcast PLRC. MPAN-C will enter packet generation and standby consecutively. On receipt of PLRCA, MPAN-C realizes MPAN-Ns in low-power, and engages in invigoration.

The states of MPAN-C are as described on Figure 7.

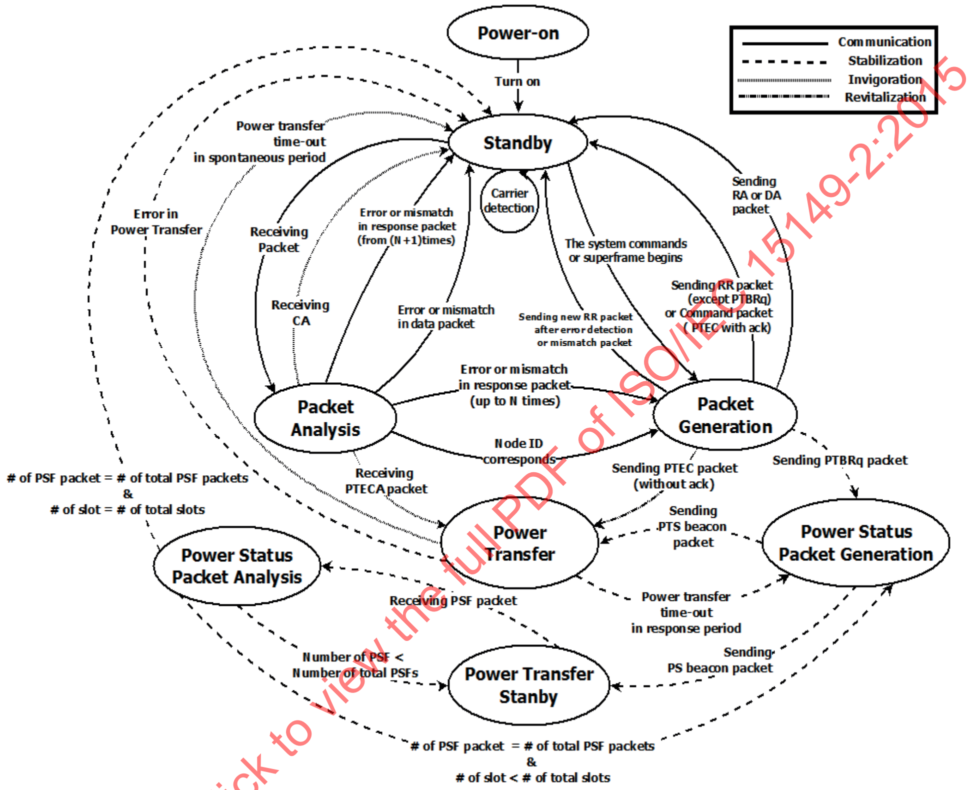

Figure 7 — MPAN-C state diagram

7.3.2 Node state

7.3.2.1 Communication procedure

As MPAN-N is turned on, it will enter hibernation power level detection state. According to power level condition, it diverges into power down hibernation, low battery hibernation, and stable hibernation states. While in stable hibernation state, MPAN-N enters general activation state when wake-up1 sequence (defined in 8.1) is detected. When MPAN-N receives RR packet, MPAN-N enters packet analysis state to probe on received RR packet. If the destination ID of the RR packet and MPAN-N ID (group ID or node ID) correspond, MPAN-N enters packet generation state. By sending an appropriate response packet to MPAN-C, MPAN-N enters standby state. From standby state, MPAN-N will enter stable hibernation state if it receives appropriate RA packet returned from MPAN-C; if it receives RA packet for other nodes, MPAN-N returns to packet generation state to send response packet again.

If MPAN-N detects error or mismatch during packet analysis (if the IDs will not correspond), MPAN-N enters hibernation power level detection state. MPAN-N may also enter hibernation power detection state from standby state when slot-number is not allocated before it is timed out; if MPAN-N is allocated of slot-number but has not received RA packet during time-out period, or if MPAN-N has received RA for other MPAN-Ns, MPAN-N enters packet generation state. MPAN-N will regenerate and retransmit response packet to MPAN-C, retuning to standby state. The retransmission of the response packet may be repeated for as much as N times. On the N+1th time-out, MPAN-N enters hibernation power detection state. If RR packet arrives to MPAN-N while on the carrier detection during standby state, it enters packet analysis state. If sensor system interruption occurs during stable hibernation state, MPAN-N enters general activation state. According to the command from the system, MPAN-N enters packet generation state. MPAN-N will generate and send appropriate data to MPAN-C, entering to standby state. If MPAN-N receives DA packet, it returns hibernation power level detection state; if not, MPAN-N enters packet generation state to retransmit previous data to enter standby state, until it will receive DA packet. If received DA is for other MPAN-Ns, the MPAN-N also returns to packet generation. On the (N+1) th time-out, MPAN-N enters hibernation power detection state.

7.3.2.2 Stabilization procedure

MPAN-N undergoes a little more complicated states for WPT. MPAN-N in stabilization will receive wake-up 1 (along with PTRq) during request period, which wakes-up MPAN-N in stable hibernation state. MPAN-N will enter general activation state as MPAN-N receives PTRq packet, and packet analysis state in consequence. If the ID in packet corresponds with node ID, MPAN-N goes to packet generation state to create PTRs. At transmission MPAN-N enters hibernation power detection state. When MPAN-N receives PTBRq from MPAN-C, MPAN-N wakes up to general activation state, analyses to receive WPT from packet analysis state. If the packet is PTBRq, then MPAN-N probes on the packet and returns to hibernation power level detection state. When MPAN-C sends PTS packet along with wake-up3, MPAN-N enters PSF activation state, then onto power status packet analysis state. According to the time schedule on the previous PTBRq, the path for MPAN-N diverges into two. One will lead MPAN-N to power reception right away, and the other will guide MPAN-N to power isolation state to maximize overall WPT efficiency.

If MPAN-N has received PTS beacon and is scheduled for the following time slot, it will enter power reception state to receive WPT. When power transfer finishes, MPAN-N enters hibernation power level detection state, before entering to stable hibernation state. From stable hibernation state, MPAN-N that has received PS beacon will go through PSF activation, power status packet analysis and power status packet generation to create PSF. Sending PSF, MPAN-N will enter hibernation power level detection state to appropriate hibernation state. MPAN-N will wait for next PTS or other relevant packets from hibernation states. If MPAN-N has received PTS beacon and is not scheduled for the following time slot, MPAN-N enters power isolation state. When PSFI begins, MPAN-N in power isolation state enters hibernation power level detection state. MPAN-N will wait for PS beacon to go through PSFI procedures. MPAN-N will wait for next PTS or other relevant packets from hibernation states.

7.3.2.3 Invigoration procedure

MPAN-N in low power hibernation state may request for power transfer during spontaneous period: invigoration. While in low power hibernation state, MPAN-N may detect wake-up 2 signal and enter low power packet analysis state. If the packet is PTPC, MPAN-N enters low power packet generation state to generate PTRC to request for power transfer; MPAN-N returns hibernation power level detection state. As MPAN-N receives PTEC, MPAN-N wakes to low power packet analysis state, then send PTECA from low power packet generation state to confirm power transfer. After sending PTECA, MPAN-N enters power reception state. When power transfer finishes, MPAN-N enters hibernation power level detection state, then onto an appropriate hibernation state. The following PLRC will wake MPAN-N to either low power packet analysis or to packet analysis state, depending on the power level of MPAN-N. MPAN-N will enter appropriate packet generation state to send PLRCA, and enter hibernation power level detection. The power supplied at this time is of small amount, little affecting WPT originally intended for other MPAN-Ns.

7.3.2.4 Revitalization procedure

When MPAN-N is in revitalization, MPAN-N is in power-down state. The power-down MPAN-N can receive power transfer automatically within MPAN range due to the nature of magnetic resonance. To make such procedure much effective, MPAN-C regularly broadcasts PTEC (no ack.) along with power transfer during spontaneous. If power down device is turned on and enter low-battery hibernation state, MPAN-N will reply PLRCA to PLRC after power transfer. From then on, MPAN-N engages in invigoration.

The states of MPAN-N are as described on Figure 8.

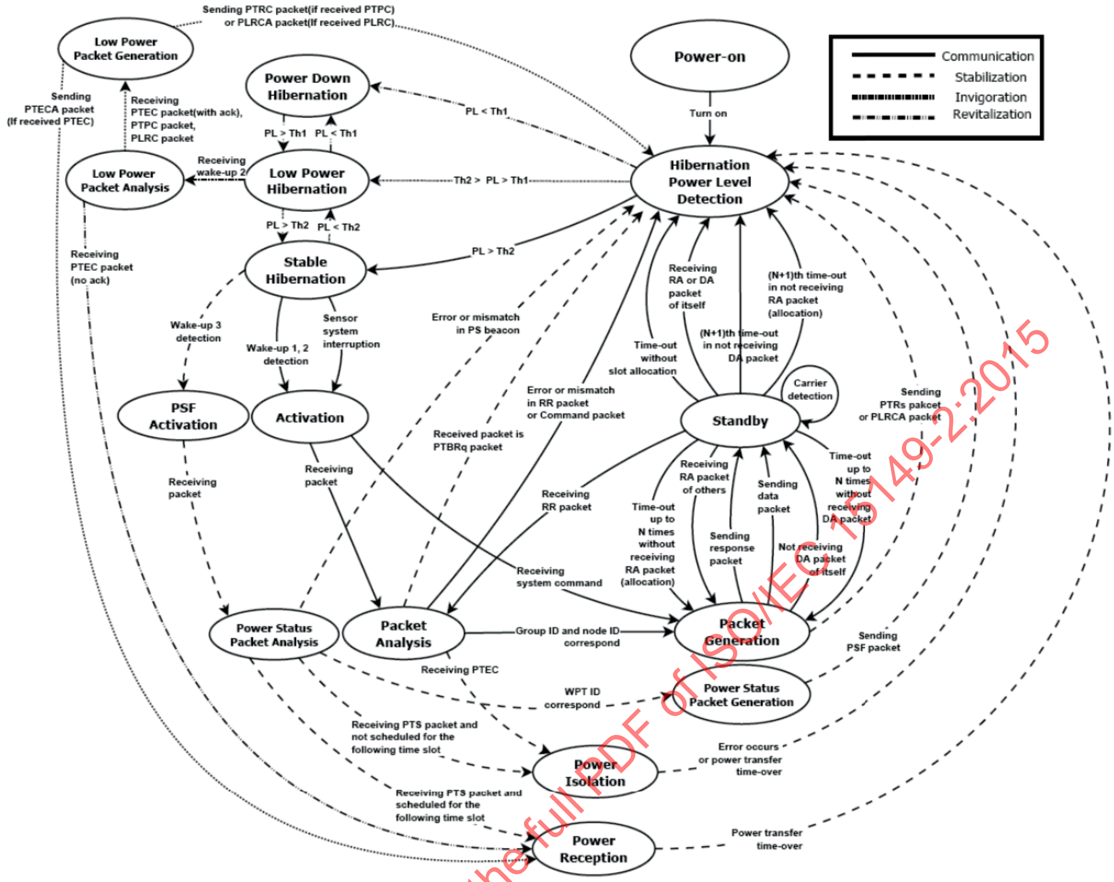

Figure 8 — MPAN-N state diagram

8 Physical layer frame format

8.1 General

This section describes the physical layer frame format of MPAN, adopting that of MFAN. As shown in Figure 9, the physical layer frame consists of three components: the preamble, the header, and the payload. When transmitting the packet, the preamble is sent first, the header follows, and finally the payload comes last. An LSB is the first bit transmitted.

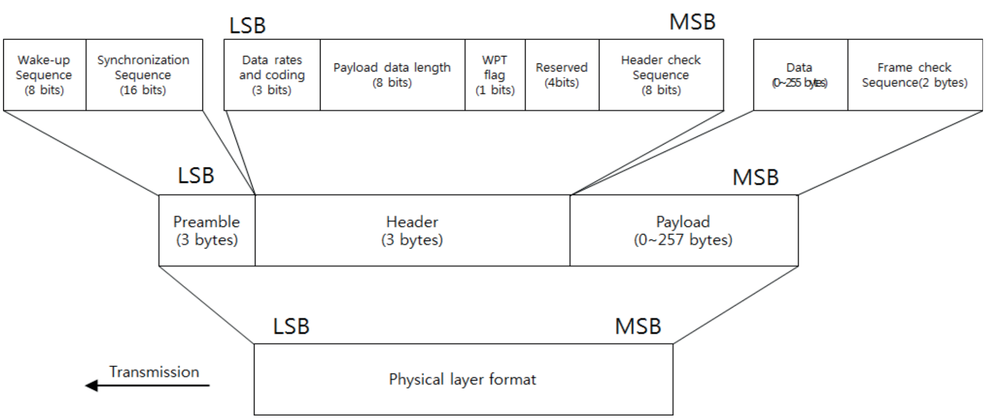

Figure 9 — physical layer frame format

8.2 Preamble

As shown in Figure 10, the preamble consists of two parts: a wake-up sequence and a synchronization sequence. An 8-bit wake-up sequence is categorized in two types: one is for general MFAN communication, and the other one is for WPT. The wake-up 1 sequence for MFAN communication consists of [0000 0000], and the wake-up 2 sequence for command consists of [1111 1111] and wake-up 3 sequence for WPT consists of [1111 0000].The following 16-bit synchronization sequence consists of a 12-bit sequence [0000 0000 0000]. A 4-bit sequence of [1010] comes after the synchronization sequence. The wake-up 1 sequence is only included in the preamble of RR packet during the request period; the wake-up 2 sequence is included in the preamble of PTEC packet during the spontaneous period; the wake-up 3 sequence is included in the preamble of PS beacon during the response period. The synchronization sequence is used for the packet acquisition, symbol timing, and the carrier frequency estimation.

The preamble is coded using the TYPE 0 defined in 8.1.3. The wake-up sequence is modulated by ASK, but the synchronization sequence is coded using BPSK.

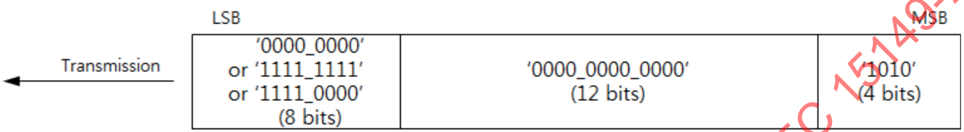

Figure 10 — Preamble format

8.3 Header

The WPT flag frame of the header verifies whether the entire frame is for WPT, or MFAN. If the frame has the value of 1, then it is for WPT; if it has the value of 0, then it is for MFAN.

Specified in ISO/IEC 15149-1:2014, 7.1.3

8.4 Payload

Specified in ISO/IEC 15149-1:2014, 7.1.4

8.5 Frame check sequence

Specified in ISO/IEC 15149-1:2014, 7.1.5

9 MAC layer frame format

9.1 General

The MAC frame of MPAN consists of frame header and frame body. It inherits the MAC layer frame format justified in ISO/IEC 15149-1. Frame header has information for data transmission to devices. Frame body has the actual data to be transmitted.

9.2 Frame format for MPAN

All the MAC layer frames consist of frame header and frame body as shown in Figure 11.

a) Frame header: Consists of the MFAN ID, frame control, source node ID, destination node ID, and sequence number. Frame header contains information for the transmission.

b) Frame body: Consists of the payload that contains actual data to be transmitted to MPAN devices and FCS used to check errors within the payload.

Unit: Byte

1	2	2	2	1	Variable	2
MFAN ID	Frame control	Source node ID	Destination node ID	Sequence number	Payload	Frame check sequence
Frame header					Frame body	

Figure 11 — MAC layer frame format of MPAN

9.2.1 Frame header

Specified in ISO/IEC 15149-1:2014, 8.2.1

9.2.2 Frame body

Specified in ISO/IEC 15149-1:2014, 8.2.2

9.2.3 Frame type

There are four types of frame: request frame, response frame, data frame, and acknowledgement frame.

Table 2 — Frame type

Frame type	Value (Binary)	Content	Period
Request frame	000	Request for the response of association (ARq), disassociation (DaRq), association status (ASRq), data transmission (DRq), power transfer (PTRq), power transfer beacon (PTBRq), and so on.	Request
Response frame	001	Response for the request of association (ARs), disassociation (DaRs), association status (ASRs), data transmission (DRs), power transfer (PTRs), and so on.	Response
Data frame	010	Data transmission without the request of coordinator	Spontaneous
Acknowledgement frame	011	Acknowledgement of the response (RA*) data transmission (DA), and command (CA) for nodes	Response, Spontaneous
Command frame	100	Command for power transfer permission (PTPC), power transfer execution (PTEC), power level request (PLRC) to devices	Spontaneous
* RA includes ARA, DaRA, ASRA, and so on.			

9.2.3.1 Request frame

Specified in ISO/IEC 15149-1:2014, 8.3.1

9.2.3.2 Response frame

Specified in ISO/IEC 15149-1:2014, 8.3.2

9.2.3.3 Data frame

Specified in ISO/IEC 15149-1:2014, 8.3.3

9.2.3.4 Acknowledgement frame

Specified in ISO/IEC 15149-1:2014, 8.3.4

9.2.3.5 Command frame

The command frame consists of UID, command code, command block, and FCS. If the value for control code is 0, then it is WPT request; if the value is 1, then it is WPT response.

Unit: Byte

8	8	1	L	2
Frame header	UID	Command code	Command block	Frame check sequence
	Frame body			

Figure 12 — Format of command frame

9.2.4 Payload format

Payload format is composed of request frame, response frame, data frame, and acknowledgement frame.

9.2.4.1 Request frame

As shown in Figure 13, payload for the request frame consists of group ID, request code, length, and more than one request block. When group ID is 0xFF, it indicates that MPAN-C requests a response from all MPAN-N groups.

Unit: Byte

1	**1**	**1**	**L1**	**L2**	.....	**Ln**
Group ID	Request code	Length $(=\sum L_n)$	Request block-1	Request block-2	....	Request block-n

Figure 13 — Payload format of request frame

a) Group ID

Group ID field consists of 1 byte and is used to send RR packets to certain groups. For the details of the group ID, refer to 6.4.3.

b) Request code

Request code in payload of a request frame is shown in Table 3.

Table 3 — Payload request code of request frame

Category	Request code	Content	Remarks
Network	0x01	Association request	Request for association response to unjoined nodes
	0x02	Disassociation request	Request for disassociation response to joined nodes
	0x03	Association status request	Request for association status response to joined nodes
	0x04 – 0x0F	Reserved	—
Data	0x11	Data request	Request for data transmission to joined nodes
	0x12 – 0x1F	Reserved	—
Configuration	0x21	Group ID set-up request	Request for group ID change to joined nodes
	0x22 – 0x2F	Reserved	—
Wireless Power Transfer	0x31	Power transfer request	Request for power transfer response to joined nodes
	0x32	Power transfer beacon request	Request for power transfer beacon to joined nodes
	0x33 – 0x3F	Reserved	—
Reserved	0x40 – 0xFF	Reserved	—

c) Length

Length field consists of 1 byte; it indicates the total length of request block. The length field value is variable to the length and the number of request blocks.

d) Request block

The data format of request block is composed differently according to request codes; more than one request blocks can be included in the payload of request frame.

The details for the data format of each request block are as follows:

1) Association request

Specified in ISO/IEC 15149-1:2014, 8.4.1.4

2) Disassociation request

Specified in ISO/IEC 15149-1:2014, 8.4.1.4

3) Association status request

Specified in ISO/IEC 15149-1:2014, 8.4.1.4

4) Data request

Specified in ISO/IEC 15149-1:2014, 8.4.1.4

5) Group ID set-up request

Specified in ISO/IEC 15149-1:2014, 8.4.1.4

6) Power transfer request

The block format of PTRq is shown in Figure 14. The first 2 bytes are for the node ID of MPAN-N for PTRq. If the node ID is 0xFFFF, PTRq is requested to all MPAN-Ns under the group ID. The next 1 byte is for the slot number. The last 1 byte is for the signal strength at transmission from MPAN-C, and is measured in dB.

Unit: Byte

2	1	1
Node ID	Slot number	Signal strength sent at coordinator

Figure 14 — Block format of power transfer request

7) Power transfer beacon request

The block format of PTBRq is shown in Figure 15. The first 1 byte is for the WPT ID of MPAN-N for PTBRq. If the WPT ID is 0xFF, PSBRq is requested to all MPAN-Ns. The next 1 byte is for the slot number; next 2 bytes for the length of power transfer frame; last 2 bytes for the power level at transmission. The last field, power transfer level, consists of significant figure and (n-2) power. Simply put to equation, the power transfer level is (Significant figure)*$10^{(n-2)}$ W.

Unit: Byte

1	1	2	2	
			1	1
WPT ID	Slot number	Time Length (ms)	Power Transfer Level (W)	
			Significant figure	n

Figure 15 — Block format of power transfer beacon request

9.2.4.2 Response frame

The payload format of response frame has responsive information to the request of MPAN-C. The response frame payload is shown in Figure 16. The first byte is for the group ID, the second byte is for the response code, the third byte is for the response date length (L), and the next L bytes are for the response data.

Unit: Byte

1	1	1	L1	L2	...	Ln
Group ID	Response code	Length (=L)	Response block-1	Response block-2	...	Response block-n

Figure 16 — Payload format of response frame

a) Group ID

The group address field consists of 1 byte and is used to send RR packets to a certain group. For the details of the group ID, refer to 6.4.3.

b) Response code

Response code types are shown in Table 4.

Table 4 — Response code of response frame payload

Category	Response code	Content	Remarks
Network	0x01	Association response	Transmission of node UID
	0x02	Disassociation response	Transmission of node UID
	0x03	Association status response	Transmission of node UID
	0x04 – 0x0F	Reserved	—
	0x11	Data response	Transmission of requested data
	0x12 – 0x1F	Reserved	—
Data	0x11	Group ID set-up response	Transmission of UID and group ID after changes in group ID
	0x12 – 0x1F	Reserved	—
Set-up	0x21	Group ID set-up response	Transmission of UID and group ID after changes in group ID
	0x22 – 0x2F	Reserved	—
Wireless Power Transfer	0x31	Power transfer response	Transmission of requested data to receive wireless power transfer
	0X31 – 0x3F	Reserved	—
Reserved	0x40 – 0xFF	Reserved	—

c) Length

Length field consists of 1 byte and indicates the length of response data; it is variable according to the response data.

d) Response data

Response data are divided into ARs, DaRs, ASRs, DRs, GSRs, and PTRs. The response data format is as follows:

1) Association response

Specified in ISO/IEC 15149-1:2014, 8.4.2.4

2) Disassociation response

Specified in ISO/IEC 15149-1:2014, 8.4.2.4

3) Association status response

Specified in ISO/IEC 15149-1:2014, 8.4.2.4

4) Data response

Specified in ISO/IEC 15149-1:2014, 8.4.2.4

5) Group ID set-up response

Specified in ISO/IEC 15149-1:2014, 8.4.2.4

6) Power transfer response

The block format of PTRs is shown in Figure 17. The PTRs data consist of 2 bytes for remaining amount of power in battery, 2 bytes for required power level by node. The next 4 bytes are for the signal level: 2 bytes for reception at node, and 2 bytes for transmission at coordinator. Probing on power levels and signal level, MPAN-C calculates distances to MPAN-N; efficient level of power may be transferred.

Unit: Byte

2	2	2	2
The remaining amount of power in battery	Required power level by node	Signal level received at node	Signal level sent at coordinator

Figure 17 — Block format of power transfer response

9.2.4.3 Data frame

Specified in ISO/IEC 15149-1:2014, 8.4.3

9.2.4.4 Acknowledgement frame

The RA frame payload has data referring to the received response packet. The RA payload format is shown in Figure 18. The first byte is for the group ID, the second byte is for the response confirmation code, the third byte is for the length (L), and the next L bytes are for the response confirmation blocks.

Unit: Byte

1	**1**	**1**	**L1**	**L2**	.....	**Ln**
Group ID	Response confirmation code	Length (=L)	Response confirmation block-1	Response confirmation block-2	....	Response confirmation block-n

Figure 18 — Payload format of acknowledgement frame

a) Group ID

The group ID field consists of 1 byte and is used to send RR packets to a certain group. For the details of the group ID, refer to 6.4.3.

b) Response confirmation code

Response confirmation code types are shown in Table 5.

c) Length

The length field consists of 1 byte; it indicates the length of response confirmation data and is variable according to the response confirmation data.

Table 5 — Response confirmation code

Category	Reception confirmation code	Content	Remarks
Network	0x01	Association response confirmation	UID and assigned node ID transmission of nodes
	0x02	Disassociation response confirmation	UID and node ID transmission of nodes
	0x03	Association status response confirmation	UID transmission of nodes
	0x04 – 0x0F	Reserved	—
Data	0x11	Data response confirmation	Confirmation of data transmission to a joined node
	0x12 – 0x1F	Reserved	—
	0x21	Group ID set-up response confirmation	UID and group ID transmission after group ID changes
Set-up	0x22 – 0x2F	Reserved	—
Wireless Power Transfer	0x31	Power transfer response confirmation	confirmation of power transfer response
	0x32	Power transfer execution command conformation	Confirmation of power transfer execution command
	0x33	Power level request command confirmation	Confirmation of power transfer request command
	0x34 – 0x3F	Reserved	—
Reserved	0x41 – 0xFF	Reserved	—

d) Response confirmation block

Response confirmation block is divided into ARs confirmation, DaRs confirmation, ASRs confirmation, DRs confirmation, and GSRs confirmation. The block formats of the response confirmation are as follows:

1) Association response confirmation

Specified in ISO/IEC 15149-1:2014, 8.4.4.4

2) Disassociation response confirmation

Specified in ISO/IEC 15149-1:2014, 8.4.4.4

3) Association status response confirmation

Specified in ISO/IEC 15149-1:2014, 8.4.4.4

4) Data response confirmation

Specified in ISO/IEC 15149-1:2014, 8.4.4.4

5) Group ID set-up response confirmation

Specified in ISO/IEC 15149-1:2014, 8.4.4.4

6) Power transfer response confirmation

The block format for power transfer response confirmation is shown in Figure 19. The first 2 bytes are for the destination node ID; the last 1 byte is for the WPT ID to be assigned to.

Unit: Byte

2	1
Node ID	Assigned WPT ID

Figure 19 — Block format of Power transfer response confirmation

7) Power transfer request command confirmation

The block format for power transfer request command confirmation is shown in Figure 20. The first 2 bytes are for the destination node ID. Next 1 byte is for the command policy (accept if 0, deny if 1); the last 1 byte is for the WPT ID to be assigned to.

Unit: Byte

2	1	1
Node ID	Policy	Assigned WPT ID

Figure 20 — Block format of Power transfer request command confirmation

8) Power transfer execution command confirmation

The block format for power transfer execution command confirmation is shown in Figure 21. The first 2 bytes are for the destination node ID; the last 1 byte is for the received power strength.

Unit: Byte

2	1
Node ID	Received power strength

Figure 21 — Block format of Power transfer execute command confirmation

9) Power transfer execution command confirmation

The block format for power level request command confirmation is shown in Figure 22. The first 2 bytes are for the destination WPT ID; the last 1 byte is for the received power strength.

Unit: Byte

1	1
WPT ID	Current Power Level

Figure 22 — Block format of power level request command confirmation

9.2.4.5 Command frame

The block format of command frame is shown in Figure 23. The first 8 bytes are for the UID, next 1 byte is for the command code. Following L bytes are for the command block.

Unit: Byte

8	1	L
UID	Command code	Command block

Figure 23 — Payload format of command frame

a) UID

UID field has 8 bytes in length.

b) Command code

Command code defines the usage of command blocks. Only the code values for WPT are defined at this point in time; other values are reserved for up to 30 functions to be included in the future.

Table 6 — Command code of command frame payload

Category	Command code	Content	Remarks
Power transfer	0x01	Power transfer request command	Request of wireless power transfer from node in invigoration
	0x02	Power transfer execution command	Execution of wireless power transfer from coordinator
	0x03	Power transfer permission command	Permission of transfer packet in spontaneous period
	0x04	Power level request command	Request for power level status of node
	0x05 – 0x0F	Reserved	—
reserved	0x10 – 0xFF	Reserved	—

c) Command block

The format of command block is varied according to the command code used. Only one command block may be appropriately used: either a request or confirmation block. The details of each command block is as follows:

1) Power transfer request command

Power transfer request command block is composed of 2 bytes. First 1 byte is for the power level, and the following 1 byte is for the time. The block format is shown in Figure 24.

Unit: Byte

1	**1**
Power Level	Time

Figure 24 — Block format of power transfer request command

2) Power transfer execution command

Power transfer execution command block is composed of 2 byte; it has information of the time length of WPT. The block format is shown in Figure 25.

Unit: Byte

1	**1**
Length of Power transfer time(ms)	Strength of WPT

Figure 25 — Block format of power transfer execution command

3) Power transfer permission command

The block for power transfer permission command is omitted; it is identifiable from the header by putting appropriate value for its type.

4) Power level request command

The block for power level request command is composed of 1 byte. It is identifiable from the header, but specifies its destination by putting WPT ID. The block format is shown in Figure 26.