

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Parasitic communication protocol for radio-frequency wireless power
transmission**

**Protocole de communication parasite pour le transfert d'énergie sans fil par
rayonnement radiofréquence**



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Parasitic communication protocol for radio-frequency wireless power transmission

Protocole de communication parasite pour le transfert d'énergie sans fil par rayonnement radiofréquence

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Draft	Report on voting
100/3797/FDIS	100/3818/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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INTRODUCTION

This document provides a parasitic backscatter communication protocol for battery-free internet-of-things (IoT) devices and sensors for radio-frequency (RF) wireless power transmission (WPT) without additional infrastructure.

PARASITIC COMMUNICATION PROTOCOL FOR RADIO-FREQUENCY WIRELESS POWER TRANSMISSION

1 Scope

This document defines procedures for transferring power to non-powered IoT devices using the existing ISM band communication infrastructure and RF WPT and a protocol for a two-way, long-distance wireless network in which IoT devices and APs communicate using backscatter modulation of ISM-band signals. Three components are required for two-way, long-distance wireless communication using backscatter modulation of ISM-band signals:

- an STA that transmits wireless power and data packets to SSNs by forming ISM-band signal channels between HIE-APs,
- a battery-free SSN that changes the sensitivity of the channel signals received from the STA using backscatter modulation, and
- an HIE-AP that practically decodes the channel signals whose sensitivity was changed by the SSN.

In this document, the procedures for CW-type RF WPT using communication among these three components are specified based on application of the CSI or RSSI detection method of ISM-band communication.

This document proposes a convergence communication protocol than can deploy sensors, which can operate at low power (dozens of microwatts or less) without batteries, collect energy, and perform communication, to transmit power to SSNs using RF WPT based on parasitic communication. This method can be applied to application service areas such as domestic IoT, the micro-sensor industry, and industries related to environmental monitoring in the future.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 63006:2019, *Wireless Power Transfer (WPT) – Glossary of terms*

IEC TR 63239:2020, *Radio frequency beam wireless power transfer (WPT) for mobile devices*

3 Terms, definitions and abbreviated terms

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1 Terms and definitions

3.1.1

BCU

backscatter communication unit

device that responds to a command from an STA with backscatter through load modulation, and that enables communication without power

3.1.2

BU

battery unit

battery and circuit capable of receiving wireless power to support the operations of devices and sensors

3.1.3

HIE-AP

hybrid information and energy access point

device that decodes the channel signals whose sensitivity was changed by the SSN into digital signals (0 or 1)

Note 1 to entry: An HIE-AP forms an STA and ISM-band channels for communication, detects the CSI or RSSI level of the response using backscatter from the SSN, and transmits the response data from the SSN to the STA. It also transmits CW-type power to the SSN for RF WPT.

3.1.4

impedance modulation

method of changing the sensitivity of the received signal from the channel between the STA and HIE-AP by using backscatter modulation in the SSN according to the data

3.1.5

SSN

smart sensor node

device that changes the sensitivity of the received channel signals using backscatter modulation

Note 1 to entry: SSNs include IoT devices, wearable devices, and micro-sensors.

Note 2 to entry: An SSN consists of a backscatter communication unit (BCU) that supports communication without power, a smart sensor unit (SSU) that identifies various sensors, and a battery unit (BU) that receives WPT.

3.1.6

SSU

smart sensor unit

sensor that can be attached to an SSN.

Note 1 to entry: Each sensor requires a different amount of power.

3.1.7

STA

station

device that can perform communication by occupying an ISM-band channel

Note 1 to entry: It transmits wireless power and data packets to SSNs by forming a channel and using the pulse interval encoding (PIE) method.

3.2 Abbreviated terms

ASK	amplitude shift keying
BCU	backscatter communication unit
BU	battery unit
CRC	cyclic redundancy check
CSI	channel state information

CW	continuous wave
FCS	frame check sequence
HIE-AP	hybrid information and energy access point
ISM	industrial scientific and medical equipment
NDP	null data packet
PIE	pulse interval encoding
RFID	radio-frequency identification
RFU	reserved for future use
RSSI	received signal strength indicator
RWP	response waiting packet
SSN	smart sensor node
SSU	smart sensor unit
STA	station

4 Overview

RF WPT includes WPT using energy harvesting, magnetic induction, or magnetic resonant methods, and involves the wireless transmission of power to sensors and facilities for practical use by employing RF waves. This document proposes a method of performing RF WPT to battery-free sensors or facilities. When developing the technology of this document, the developer shall refer to IEC 63006:2019 and IEC TR 63239:2020. The overall structure of parasitic communication for RF WPT proposed in this document is depicted in Figure 1. Parasitic communication (or ambient backscatter) uses existing radio frequency signals, such as radio, television and mobile telephony, to transmit data without a battery or power grid connection. Each such device uses an antenna to pick up an existing signal and convert it into tens to hundreds of microwatts of electricity. This document defines procedures for a bi-directional, long-distance wireless communication protocol for communication using backscatter modulation of industrial, scientific, and medical (ISM)-band frequency signals between stations (STA) and smart sensor nodes (SSNs), such as IoT devices, sensors, tags, and wearable devices, and for RF WPT from a hybrid information and energy access point (HIE-AP) to nearby SSNs.

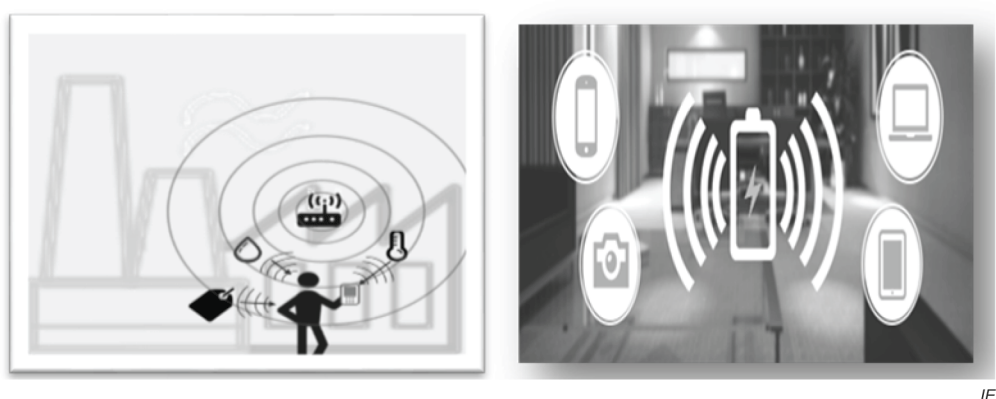


Figure 1 – Usage of RF-WPT

Three components are required for the bi-directional, long-distance wireless communication protocol using backscatter modulation of ISM-band signals, as shown in Figure 2:

- STA: performs communication by occupying a communication channel and transmits wireless power and data packets for communication to the SSN in the PIE method.

- HIE-AP: decodes the channel signals whose sensitivity was changed by the SSN into digital signals of 0 or 1. It forms a channel with the STA for communication, detects the CSI level of the response from the SSN that used backscatter, and transmits the response data from the SSN to the STA. It also transmits CW-type power to the SSN for RF WPT.
- SSN: changes the sensitivity of the channel signals received from the STA using backscatter modulation and consists of a BCU, an SSU, and a BU.
 - BCU: responding to a command from an STA with backscatter through load modulation and can respond with backscatter using the wireless power transmitted by the STA.
 - SSU: various sensors that can be attached to the SSN, each of which requires a different amount of power.
 - BU: battery and circuit capable of receiving wireless power to support the operation of nodes and sensors.

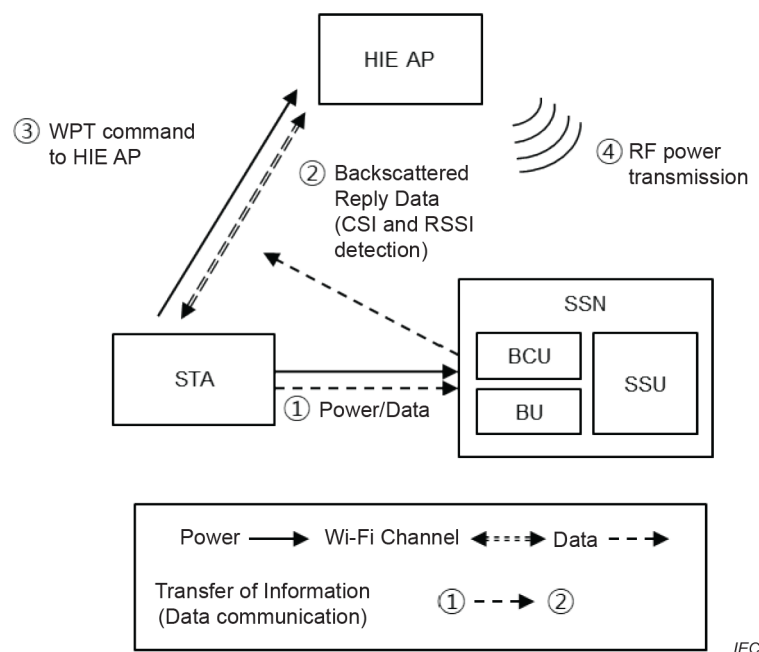


Figure 2 – RF-WPT structure of using parasitic Wi-Fi communication technology

To summarize the operation process, RF power is first transmitted from the STA to the SSN to drive the BCU of the SSN. Then, the SSN sends its data for the STA to the channel formed between the STA and HIE-AP by changing its load, and the HIE-AP can receive data from the SSN by decoding the CSI level of the information sent from the SSN. The information sent from the SSN includes ID information, battery information, and sensor data. The STA sends wireless power to the HIE-AP. The HIE-AP performs and controls RF WPT in real time based on the information received from the SSN on battery, voltage of the SSN itself, and remaining battery level.

Multi-device wireless charging systems that use the in-band field communication to exchange data and control signals utilize the same frequency within the field area to increase the efficiency of frequency. Information relating to regulation and certification is presented in Annex A.

5 Communication procedures for RF WPT

5.1 General

The parasitic communication technology involved in downlink and uplink RF WPT can be described separately. In downlink transmission, information is sent from the STA to the SSN, while in uplink transmission, information is sent from the SSN to the STA as shown in Figure 3.

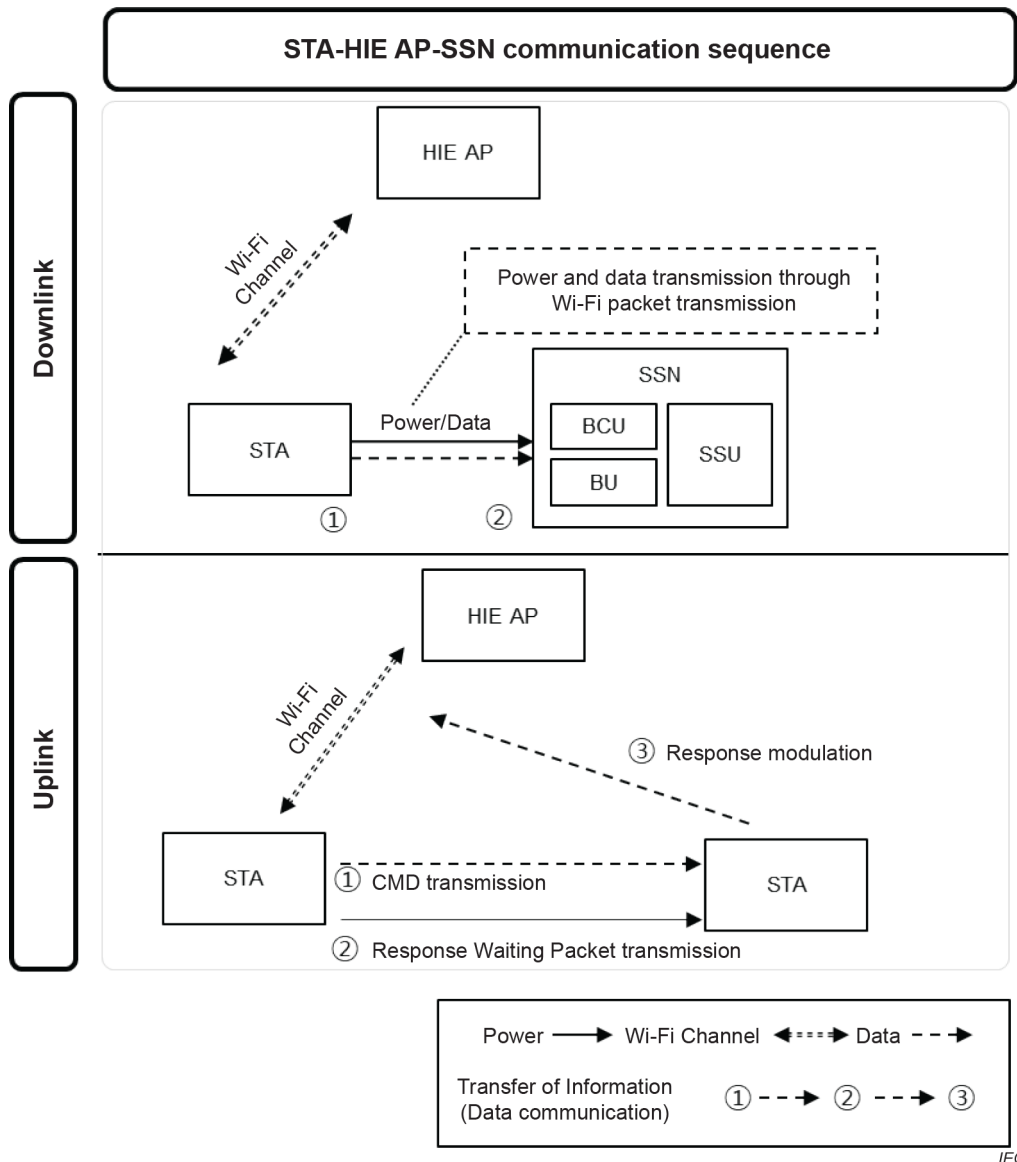
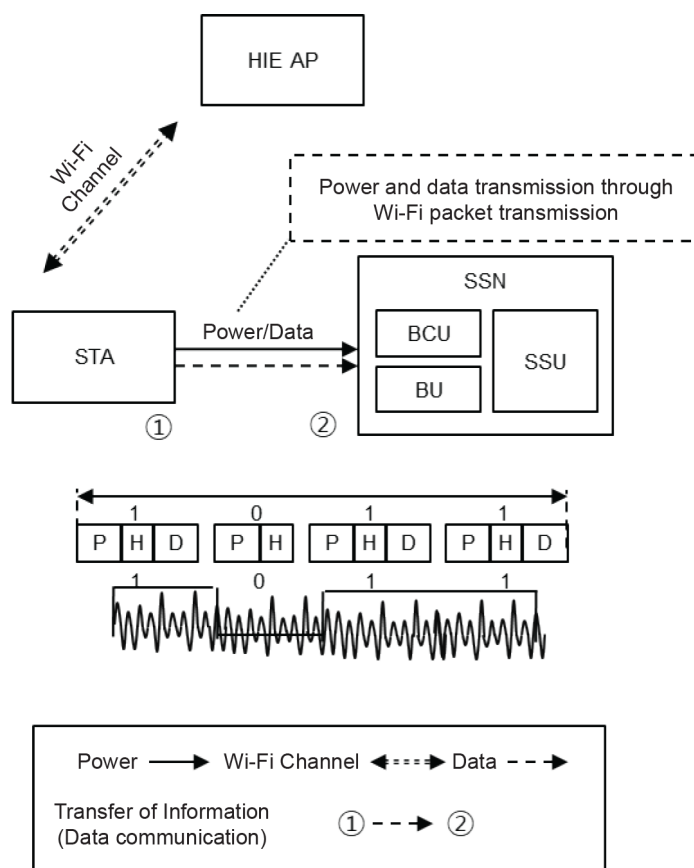


Figure 3 – Parasitic downlink/uplink communication procedures

5.2 Communication procedures for parasitic downlink communication

The downlink communication procedures are illustrated in Figure 4. First, the STA and HIE-AP form a communication channel. The STA transmits a data packet to the AP and SSN simultaneously (① -> ②). The SSN decodes the received packet, then interprets the information sent from the STA. And the STA performs its operation following command using the energy contained in the packet.



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Figure 4 – Specific parasitic downlink communication procedures

5.3 Communication procedures for parasitic uplink communication

The uplink communication procedures are depicted in Figure 5. In uplink communication, a separate HIE-AP is required to read the information from the SSN (① -> ② -> ③). First, the STA creates a channel with the HIE-AP and measures the sensitivity of the received signals through the RSSI or the CSI. This procedure is employed because the SSN does not directly perform active communication, but rather changes the sensitivity of the signals received from the channel between the STA and HIE-AP through backscatter modulation when the STA continuously sends power and packets. This signal change eventually affects the RSSI or the CSI of the received signal strength of the HIE-AP. In this way, when the SSN changes the sensitivity of the received signal through a kind of amplitude shift keying (ASK) method using backscatter modulation, the HIE-AP measures the sensitivity of the received Wi-Fi signal and decodes the information from the SSN according to the sensitivity (specifically, 1 is assigned when the received sensitivity is better than the reference sensitivity, and 0 otherwise).

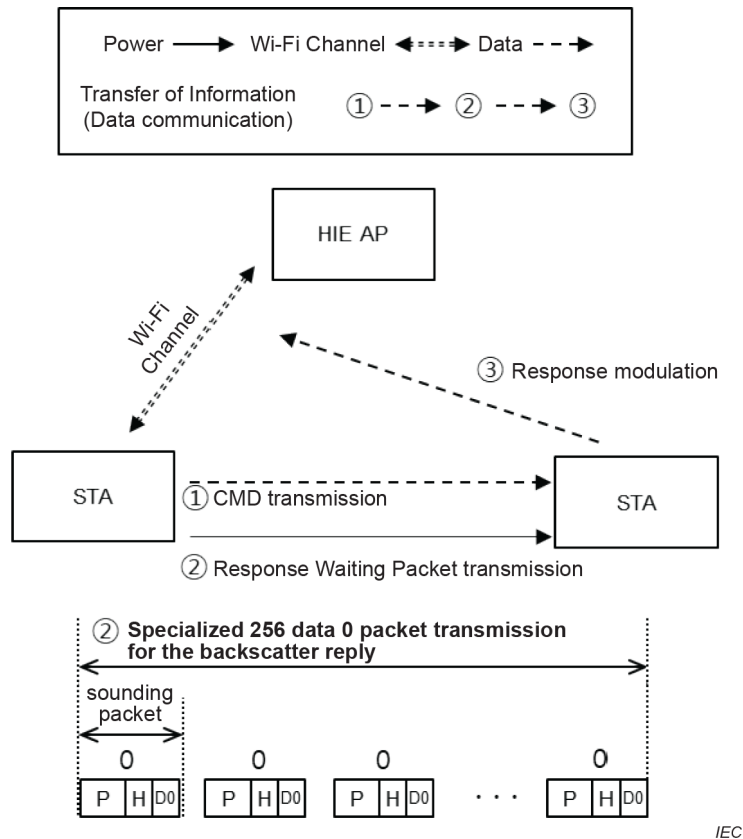


Figure 5 – Specific parasitic uplink communication procedures

5.4 Backscatter downlink/uplink data flow

Figure 6 shows the data flow during downlink/uplink communication in detail. During downlink transmission, the STA sends a preamble(P) + header(H) + data 1(D1) payload (P+H+D1) when transmitting 1, and a preamble(P) + header(H) + data 0(D0) payload (P+H+D0) when transmitting 0. Encoding is performed through a kind of PIE method. Figure 6 depicts the process of sending 1000111b as an example. The SSN decodes the command from the STA by detecting the energy level and measuring the length of the received packet. The SSN receives the bit information in the Wi-Fi packet without interpretation. During uplink communication, the tag sends a P+H+D0 payload. In this case, the SSN is decoded as 000...000b, and uplink transmission is recognized. The SSN performs backscatter modulation on the information to be sent. In the example, the SSN sends 1000...11b to the HIE-AP.

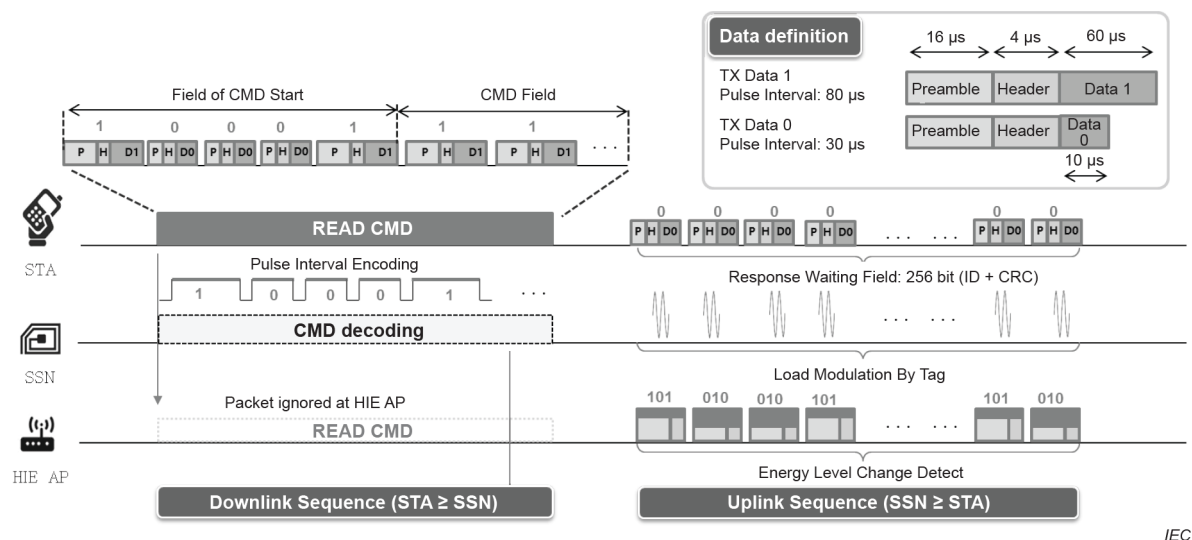


Figure 6 – Data flow during parasitic downlink/uplink communication

5.5 WPT process

Figure 7 depicts the RF WPT communication procedures in detail. The parasitic communication status consists of three states: select, inventory, and access. In the select state, the STA recognizes multiple SSNs. In the inventory state, an authentication procedure is performed to select one of the recognized SSNs. In the access state, the SSN information is identified and WPT is actively controlled. All of these communication methods involve downlink/uplink transmission. In the access state, the battery and status information of the SSN is continuously monitored, and the HIE-AP performs and controls the CW-type RF WPT. Figure 8 shows the RF WPT control protocol.

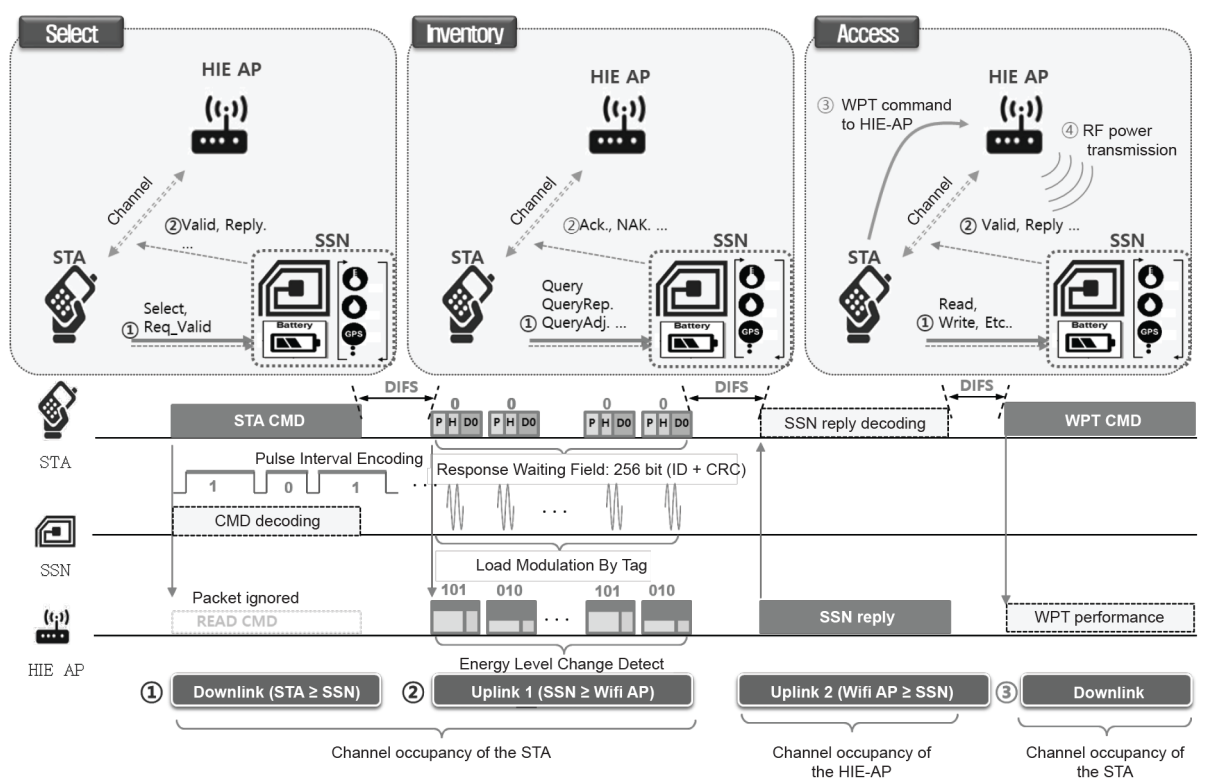


Figure 7 – RF WPT access procedures

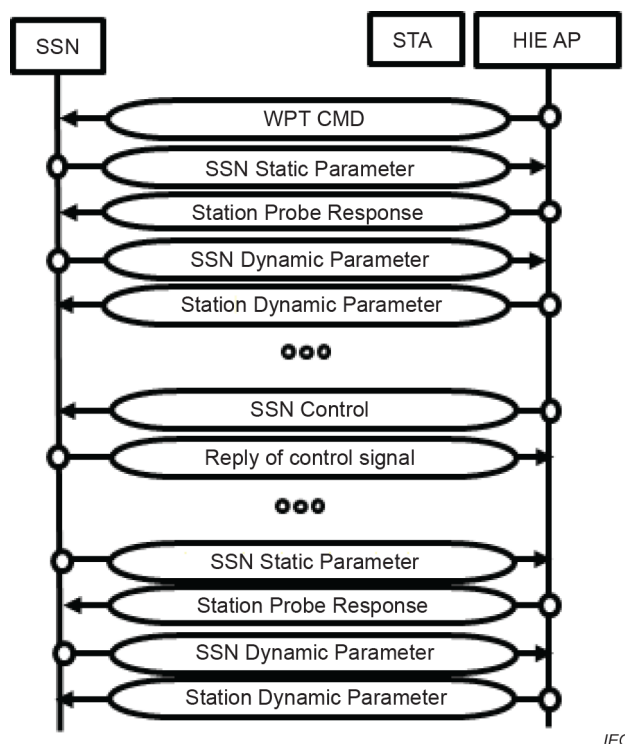


Figure 8 – RF WPT control protocol

6 Physical layer

6.1 Modulation/coding method

6.1.1 General

Clause 6 describes the construction of frames for each preamble, header, and payload, and defines a set of processes for modulation and coding.

6.1.2 Downlink modulation method

Downlink sequence of RF WPT communication uses the PIE method in which the length of a packet is modulated according to the data. As shown in Figure 9, Data "0" in this downlink method consists of a modulated preamble (P) + header (H) + data 0 (D0) that is a short null data packet (NDP) without a payload. Data "1" in this downlink method consists of a modulated preamble (P) + header (H) + data 1 (D1) that is a long null data packet (NDP) without a payload. The OFDM training structure in Figure 9 is mainly used in time division multiple access. The training sequence is used in order to maintain timings and to equalize them with the channel.

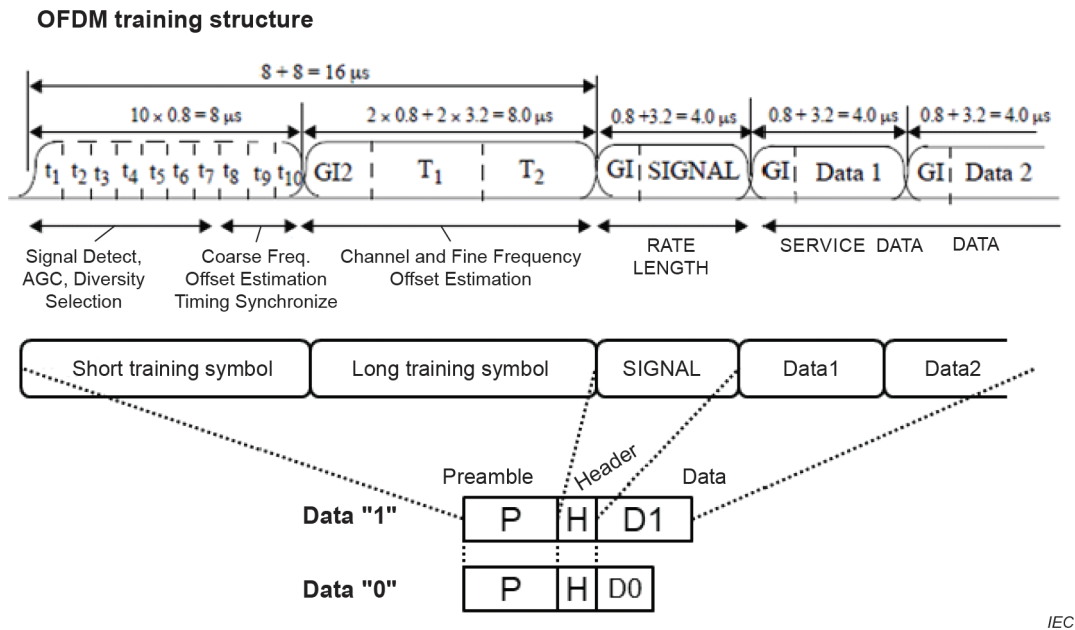


Figure 9 – PIE method packet configuration

6.1.3 Uplink modulation method

In uplink sequence of RF WPT, the SSN changes the sensitivity of the received signal of the channel between the STA and HIE-AP according to the data through backscatter modulation. The uplink transmission involves utilizing the NDP, which represents a signal of 0 in Figure 9, and the two-level method in which the sensitivities of the received signals of 0 and 1 are different.

6.1.4 Downlink coding method

6.1.4.1 Preamble

The preamble transmits the preamble sequence 1111_0000_2 (see 6.2.2.2) as shown in Figure 10, using the PIE method.

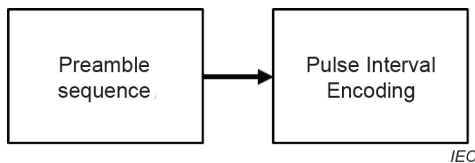


Figure 10 – Modulation and coding of the downlink preamble

When SSNs are woken up using the downlink preamble, variations of the preamble can be continuously transmitted so that the channel is not lost according to the power required by each SSN. The preamble transmission for wakeup continues while the STA attempts to communicate with the SSN. The variable wakeup process can require the transmission of additional preambles depending on the distance to the SSN, as well as the power required by the SSN.

6.1.4.2 Payload

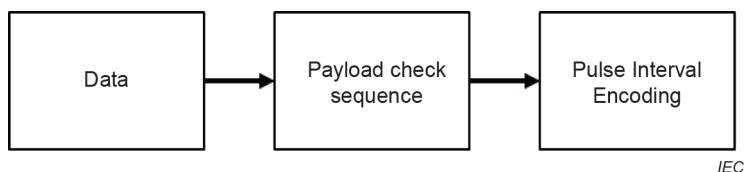


Figure 11 – Modulation and coding of the downlink preamble

The payload in Figure 11 adds 5 bits of the payload check sequence to the data to be transmitted, as described in 6.2.2.3, and it transmits the data using the PIE method.

6.1.5 Uplink coding method

6.1.5.1 Preamble

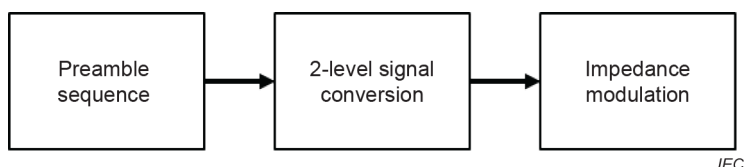


Figure 12 – Modulation and coding of the uplink preamble

The preamble in Figure 12 converts the preamble sequence defined in 6.2.3.2 using the two-level method, and then transmits it using impedance modulation.

6.1.5.2 Payload

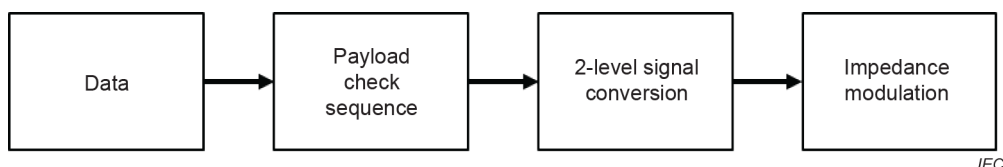


Figure 13 – Modulation and coding of the uplink payload

The payload data in Figure 13 can be a maximum of 256 bits. The payload adds 5 bits of the payload check sequence to the data to be transmitted, as discussed in 6.2.3.3, converts the data using the two-level method, and transmits the data using impedance modulation.

6.2 Frame structure

6.2.1 General

In 6.2, the frame structure of the physical layer is defined. The downlink frame is transmitted from the STA to the SSN, and the uplink frame is transmitted from the SSN to the HIE-AP. The transmission frame structure is defined accordingly. The packets to be transmitted in the frame are coded using the method defined in 6.1 according to the transmission direction.

6.2.2 Downlink frame structure

6.2.2.1 General

The downlink frame structure consists of a preamble and payload, as shown in Figure 14. The payload consists of data and frame check sequence fields. The frame is transmitted from the most significant bit (MSB). The data unit of the frame is bit, and it is coded using the method defined in 6.1.3.

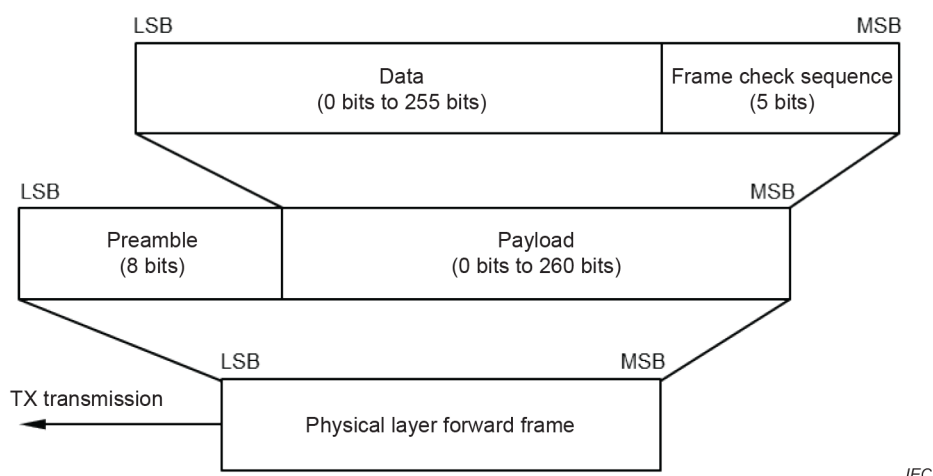


Figure 14 – Physical layer structure of the downlink frame

6.2.2.2 Preamble

The preamble has a total of 8 bits: 4 bits of 1111_2 and 4 bits of 0000_2 , as shown in Table 1. The first 4 bits of the preamble operate the SSN, which is the receiving end, and the next 4 bits are used to find the data start position

Table 1 – Downlink preamble structure

Downlink preamble	Wakeup	Sync finder
Number of bits	4	4
Description	1111_2	0000_2

6.2.2.3 Payload

The payload consists of a data field to be transmitted and a frame check sequence (FCS) field to check for errors in the data field as shown in Table 2. When the length of the data is zero, the frame check sequence is not included.

Table 2 – Downlink payload structure

Downlink preamble	Data	FCS
Number of bits	256	5

a) Payload data field

The recommended value of the quasi-static guarantee ratio (=payload/data rate), which is used to maintain channel stability during communication based on backscatter, is 0,012 8. In other words, 256 payloads are available because 320 payloads are available at a data rate of 30 kb/s, in accordance with this document.

b) FCS

The FCS field is created using a 5-bit cyclic redundancy code (CRC). It is calculated for the payload data and is not created if the length of the payload data is zero. The FCS is calculated according to the definition in Table 3 and is then replaced with a complement to be sent after the data.

Table 3 – Downlink frame check CRC

CRC type	Length	Polynomial	Initial value	Residual value
-	5 bits (packets)	$x^5 + x^3 + 1$	01001 ₂	00000 ₂

6.2.3 Uplink frame structure

6.2.3.1 General

The uplink frame structure consists of a preamble and payload, as shown in Figure 15. The preamble consists of the frame detection, starting point finder, and data preamble. The payload consists of data and the FCS. The data unit of the frame is the bit, and the frame is coded using the method defined in 6.1.4. When the same data (0 or 1) occurs consecutively due to the backscatter frequency during uplink transmission from the SSN to the STA, the data might not be distinguished because of the DC offset. Therefore, the FM0 and Miller encoding methods are introduced for the uplink process and summarized in 7.2.2 and 7.2.3.

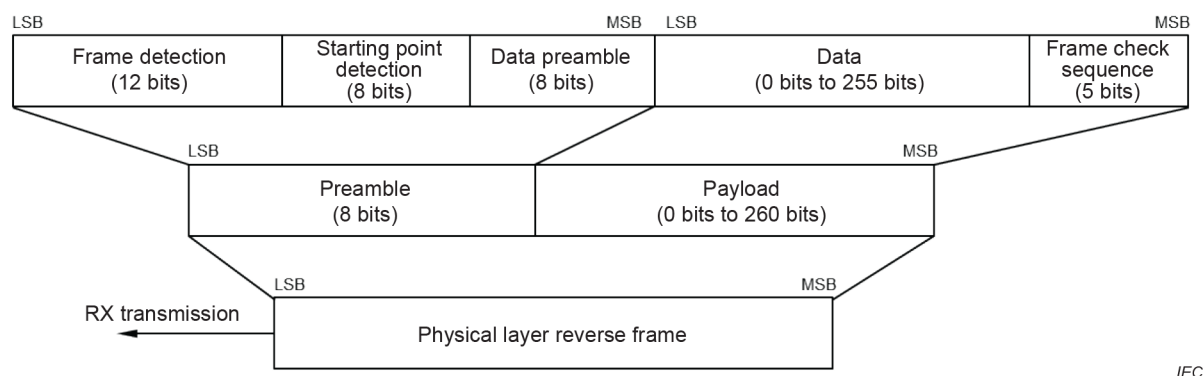


Figure 15 – Physical layer structure of the uplink frame

6.2.3.2 Preamble

The preamble consists of a 12-bit frame detection field, an 8-bit starting point finder field, and an 8-bit data preamble, as shown in Table 4. As the preamble is transmitted from the MSB, the MSB of the frame detection field is transmitted first, and the least significant bit (LSB) of the data preamble is transmitted at the end. The preamble is coded using the two-level method described in 6.1.2.

Table 4 – Uplink preamble structure

Uplink preamble	Frame detection	Starting point detection	Data preamble
Number of bits	12	8	8
Description	0010_1010_1010 ₂	1011_0000 ₂	

a) Frame detection

The frame detection method involves 2 bits of 00_2 , 8 bits of AA_h , and 2 bits of 10_2 , as shown in Table 5. The first 2 bits are employed to identify the characteristics of the reference channel. The next 8 bits are used to detect the frame using the channel reception sensitivity change of the SSN (the difference between data bit 0 and 1 in the two-level method of 6.1.2). The remaining 2 bits are used as a criterion for data determination through the RSSI or the CSI.

Table 5 – Uplink frame detection field structure

Uplink frame detection field	Reference channel	Packet detection	Criterion
Number of bits	2	8	2
Description	00_2	1010_1010_2	10_2

b) Starting point finder

The starting point finder consists of 8 bits of $B0_h$, and it identifies data using the criterion defined in the frame detection. The identified starting point detection period is employed to detect the starting position of the frame using a correlator.

c) Data preamble

The data preamble is represented by 8 bits (AA_h in the two-level case), according to the SSN modulation method, and is used as reference data during data restoration. During data restoration, data for each level are stored using the reference data, and the received data are restored by comparing the payload data with each stored level.

6.2.3.3 Payload

The payload consists of a data field to be transmitted and an FCS field to check for errors in the data field, as shown in Table 6. When the length of the data is zero, the FCS is not included.

Table 6 – Downlink payload structure

Uplink payload	Data	FCS
Number of bits	256	5

a) Data field

The data field contains data to be transmitted, and it can transmit from 0 bits to 255 bits.

b) Data check sequence field

The FCS field is created using a 5-bit CRC. It is calculated for the payload data and is not created if the length of the payload data is zero. The FCS is calculated in accordance with the definition in Table 3, and then it is replaced with a complement to be sent after the data.

7 Datalink layer**7.1 Message definition****7.1.1 General**

Subclause 7.1 proposes a message that enables the recognition of multiple SSNs for device charging and describes the configuration of a basic communication link for charging control and data transmission. Energy/data transmission is performed only for the selected SSNs.

Unlike radio-frequency identification (RFID), which continuously transmits fixed carrier frequencies, SSNs cannot maintain sustained power-on states. To address this problem, data in the volatile memory shall be maintained using minimum energy storage until the next transfer of power.

The message transmission from the STA to single or multiple SSNs uses the command transmission model, as shown in Figure 16. This model is used for the selection, initialization, and operation requests of the STA. First, for the STA to transmit a command (CMD) to the SSN, the CMD is transmitted to the SSN using the channel formed between the STA and HIE-AP. After the CMD is transmitted, the 128-bit response waiting packet (RWP) is transmitted so that the SSN can respond. The SSN responds to the STA by adjusting the signal level of the received RWP using the load modulation method. Figure 17 depicts the sequential message exchange method.

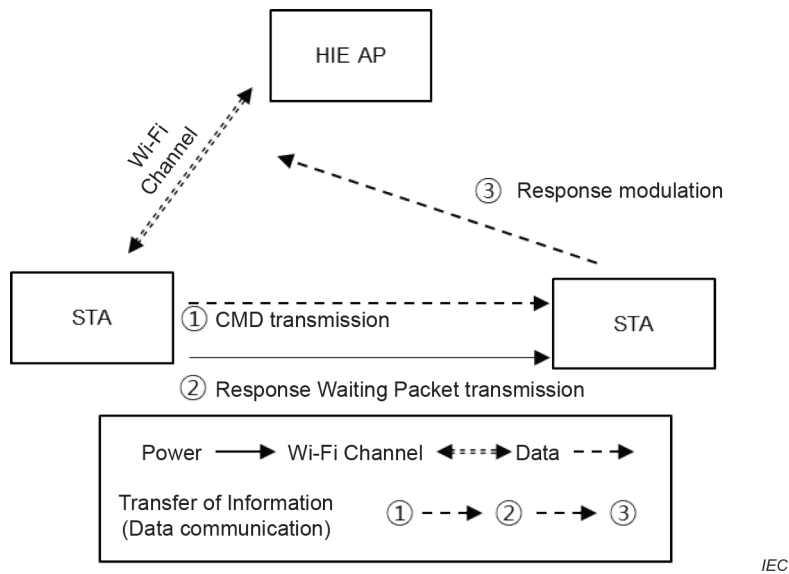


Figure 16 – Model of command transmission between the STA and SSN

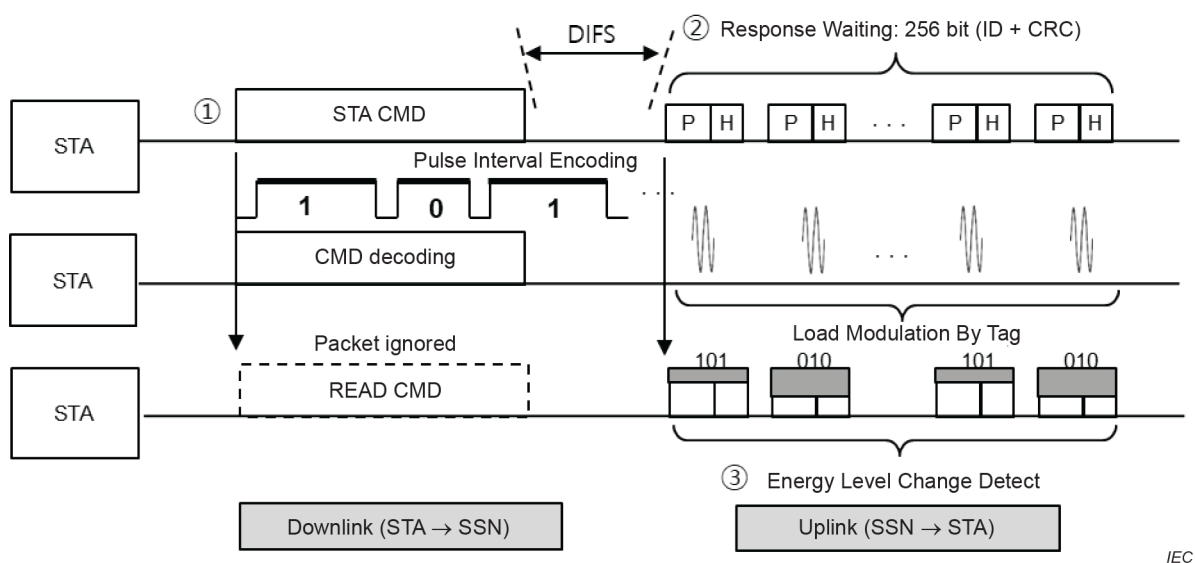


Figure 17 – Diagram of sequential command transmission between the STA and SSN

Table 7 and Table 8 list the kinds of commands transmitted from the STA to the SSN and their responses, respectively.

Table 7 – CMD list

CMD	Code	Length (bit)	Reply
Select	0000	25	Valid
Query	0001	17	Valid_Query
QueryRep	0010	6	Valid_Query
QueryAdj	0011	9	Valid_Query
Ack	0100	20	Valid_Ack
Read	0101	38	Read Reply
Write	0110	54	Write Reply
WPT	0111	24	-

Table 8 – Responses for each CMD

Response	Response code	Received CMD
Valid	8'b10101100	Select
Valid_Query	8'b01010011	Query/QueryRep/QueryAdj
Valid_Ack	16'h0ACC	Ack
Read reply	16'h0ACC	Read
Write reply	16'h0ACC	Write

In addition, the SSN (see Figure 18) proposed in this document has a memory to store battery information for WPT and consists of four banks. The value of each bank consists of 96 bits (because the response packet consists of 128 bits, 16 bits of which are used as the response preamble, while another 16 bits are used as CRC-16). The main information related to the battery and circuit is stored in bank 11 of the SSN memory space. The unique ID information of the SSN is available in bank 10. If additional sensors are connected, their measurements are stored in bank 01. In other words, sensors capable of measuring temperature, humidity, or illumination shall be added, and the memory located in bank 01, among the tag memories of the SSN, is used to access and control these sensors.

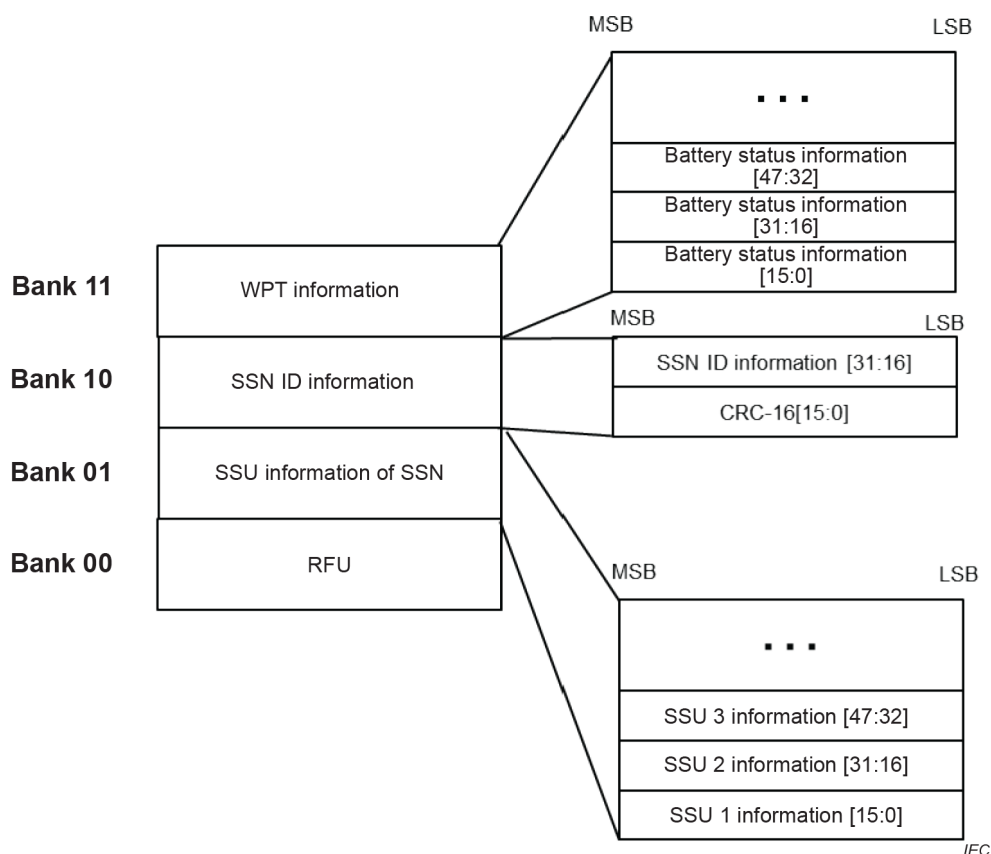


Figure 18 – SSN memory structure

The STA performs the following three steps to manage many SSNs. Each of these steps consists of multiple commands.

- Select step:** in this step, the STA selects SSNs within the power/data transmission range for use in the next process, the inventory step.
- Inventory step:** in this step, the STA recognizes SSNs. The STA starts the inventory round in one of the four sessions. When one or more SSNs respond, the STA recognizes a single tag response and requests the ID value and CRC-16 for the tag. The inventory round operates in single sessions, conducted one at a time.
- Access step:** in this step, various operations are performed on the selected individual SSNs. Prior to this step, a channel is selected so that only a single SSN can operate.

Although the entire basic operation has been described above, the communication procedure for a single SSN rather than multiple SSNs will be described in this document because authentication and security problems are not considered herein.

7.1.2 Select step

7.1.2.1 General

When there are multiple SSNs, the STA selects multiple SSNs under its control to choose a single SSN. In this case, the STA issues a select command to recognize that multiple SSNs are ready for communication. Figure 19 illustrates the method of message exchange with multiple SSNs in the select step.

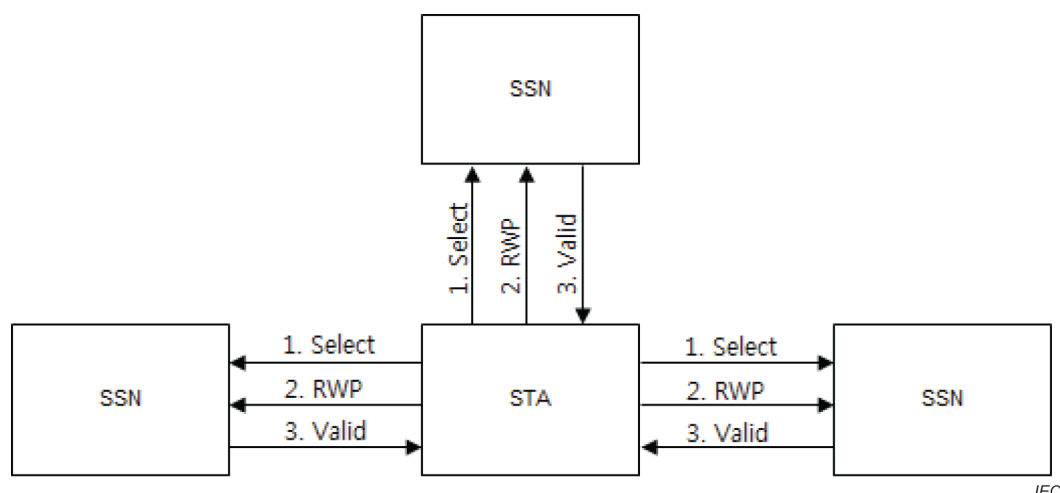


Figure 19 – Message exchange in the select step

7.1.2.2 Select step

The select CMD transmits a value to the SSN target registers, which are designated as S0-S3 and SL, so that the SSN of the corresponding register can respond. The definition of the command field used in the select CMD is as follows. The field configuration is shown in Table 9.

- Target: a field required for SSN grouping to issue a command to the SSN registers, which are designated as S0-S3 and SL.
- Action: a field determining whether the STA will continue to issue commands to the selected SSN or choose a new SSN.
- CRC-16: the polynomial $x^{16} + x^{12} + x^5 + 1$ for computing CRC-16 is illustrated in Figure 20 using the method proposed by the International Telecommunication Union (ITU) standard. The STA applies a 16-bit polynomial to the data block to be transmitted and appends the resulting code to the block. The SSN applies the same polynomial to the data and compares the result with that sent from the STA. If the results match, the data is successfully received.

Table 9 – Select CMD

Select CMD	Command	Target	Action	CRC
Number of bits	4	3	2	16
Description	0000	000: Inventoried (S0) 001: Inventoried (S1) 010: Inventoried (S2) 011: Inventoried (S3) 100: SL 101: RFU 110: RFU 111: RFU	00: Assert SL 01: De-assert SL 10: Do nothing 11: Negate SL	CRC-16

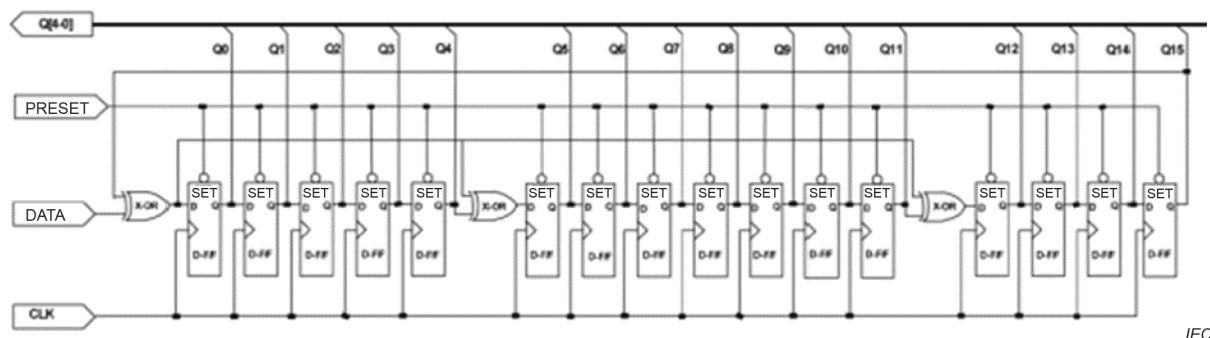


Figure 20 – CRC-16 circuit example

7.1.2.3 Valid response

The SSN selection is transmitted to the STA using the received RWP and load modulation. Valid responses are shown in Table 10. The STA recognizes the existence of the SSN by receiving 10101100, a peculiar type of response that cannot be detected by a general channel. In the case in which 248 bits of the response packet remain, they are left as an unresponsive packet.

Table 10 – Valid response

Valid response	Reply	Null
Number of bits	8	248
Description	10101100: Selected	248'h0

7.1.3 Inventory step

7.1.3.1 General

In this step, the STA performs an inventory round with the selected SSNs to recognize only one SSN. Figure 21 summarizes the procedure. The STA uses the collision avoidance algorithm to select only one SSN among the selected multiple SSNs. Since this process is beyond the scope of this document, the field is defined, but the specific action is not defined. SSNs that received a query-series command issue valid responses, and the STA transmits an Ack command to the SSNs for authentication and selects one SSN.