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Information technology – Home electronic system (HES) architecture – Part 3-10: Wireless short-packet (WSP) protocol optimised for energy harvesting – Architecture and lower layer protocols

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colour inside

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INFORMATION TECHNOLOGY – HOME ELECTRONIC SYSTEM (HES) ARCHITECTURE –

Part 3-10: Wireless short-packet (WSP) protocol optimised for energy harvesting – Architecture and lower layer protocols

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The International Standard ISO/IEC 14543-3-10 was prepared by subcommittee 25: Interconnection of information technology equipment, of ISO/IEC joint technical committee 1: Information technology.

The list of all currently available parts of the ISO/IEC 14543 series, under the general title *Information technology – Home electronic system (HES) architecture*, can be found on the IEC web site.

This International Standard has been approved by vote of the member bodies, and the voting results may be obtained from the address given on the title page.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Various electrically controlled sensors and switches are used in homes and similar environments for many different applications. Examples of such applications are lighting, heating, energy management, blinds control, different forms of security control and entertainment (audio and video).

In most cases the device, e.g. a switch initiating an action, and the device, e.g., a lamp, are installed at different places. The distance can be bridged by wires, infrared or radio transmission. Presently equipment at both ends of a wireless transmission link needs to be powered by line or battery.

While wireless transmissions are especially attractive to retrofit homes, power maintenance of battery-driven devices is a burden. In addition, these batteries require scarce materials. Since the command and control messages sent by control and sensor devices in homes are very short, they can be powered using new techniques for energy harvesting, provided they use a wireless protocol that operates on relatively low power. Energy available in the environment of a device is captured and stored (harvested) to power operation of the device. Examples of energy sources are mechanical actuation, solar radiation, temperature differences, etc. If this is executed at least one device in the link neither needs a battery nor a wire. Energy harvesting devices need very limited power and use an energy efficient radio protocol to send data to other conventionally powered devices in the home. In order to ensure interoperability of such devices from different sources within a home, an international standard for a protocol is required that uses the little power that energy harvested devices can provide and at the same time spans distances to be bridged within a home environment.

Several such devices used within a home may come from different sources. They are required to interwork with each other using a common internal network (in this standard called a home network) and supporting a home automation system. When a home automation system meets ISO/IEC HES Standards, it is called a Home Electronic System (HES).

ISO/IEC 14543-3-10 specifies the Wireless Short-Packet protocol. The protocol is efficient enough to

- support energy harvested products for sensors and switches that do not require wires and batteries, and
- extend the life of battery-operated devices.

INFORMATION TECHNOLOGY – HOME ELECTRONIC SYSTEM (HES) ARCHITECTURE –

Part 3-10: Wireless short-packet (WSP) protocol optimised for energy harvesting – Architecture and lower layer protocols

1 Scope

This part of ISO/IEC 14543 specifies a wireless protocol for low-powered devices such as energy harvested devices in a home environment. This wireless protocol is specifically designed to keep the energy consumption of such sensors and switches extremely low.

The design is characterised by

- keeping the communications very short, infrequent and mostly unidirectional, and
- using communication frequencies that provide a good range even at low transmit power and avoid collisions from disturbers.

This allows the use of small and low cost energy harvesters that can compete with similar batteries-powered devices. The messages sent by energy harvested devices are received and processed mainly by line-powered devices such as relay switch actuators, repeaters or gateways. Together these form part of a home automation system, which, when conforming to the ISO/IEC 14543 series of standards, is defined as a home electronic system.

This part of ISO/IEC 14543 specifies OSI Layers 1 to 3 of the Wireless Short-Packet (WSP) protocol.

The WSP protocol system consists of two and optionally three types of components that are specified in this standard. These are the transmitter, the receiver and optionally the repeater. Repeaters are needed when the transmitter and the receiver are located in such a way that no good direct communication between them can be established.

Protection against malicious attacks is handled in the upper layers and thus not treated in this standard.

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 7498-1, *Information technology – Open systems interconnection – Basic reference model – Part 1: The basic model*

EN 300 220-1, *Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW – Part 1: Technical characteristics and test methods*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

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

3.1.1
amplitude shift keying envelope
ASK envelope
envelope of the modulated signal

3.1.2
bit duration
time between transitions of the mesial power level of an ASK envelope in an alternating sequence

Note 1 to entry: Figure 2 shows this in detail.

3.1.3
bit duration error
deviation of bit duration from specified bit duration

3.1.4
byte
represented by 8 bits

3.1.5
collision
two wireless transmitters using the same wireless channel and transmitting data at the same time

3.1.6
cyclic redundancy check
CRC
integrity hash algorithm based on a polynomial division

3.1.7
DATA
application payload data transmitted in the telegram

3.1.8
energy harvesting
energy available in the environment of a device that is captured and stored (harvested) to power operation of the device

Note 1 to entry: Examples of energy sources are mechanical actuation, solar radiation, temperature differences, etc.

3.1.9
frame
set of data to be transmitted as a complete unit on the physical layer

Note 1 to entry: A frame contains the necessary protocol control and synchronisation data for transmission between network nodes.

3.1.10
HASH
field in which the hash value for the data integrity control of each transmitted telegram and subtelegram is specified

3.1.11
high nibble
upper 4 bits of the byte

Note 1 to entry: The *N* value from the byte 0xNM.

3.1.12
high state amplitude
power level of the high state level

3.1.13
high state level
level of the ASK envelope that represents the high state amplitude

Note 1 to entry: The definition aligns with IEEE 194-1977, 5.2.2.5, static levels. Figure 2 gives an illustration.

3.1.14
identity of the destination device
DESTID
unique identity of the destination device of a WSP telegram consisting of four bytes

3.1.15
identity of the transmitting device
TXID
unique identity of the WSP protocol transmitting device consisting of four bytes

3.1.16
inverse bits
INV
added by the encoding procedure into a subframe behind the 3rd and the 6th bit to reduce the DC content of the data

3.1.17
listen before talk
LBT
technique of checking the occupancy of the wireless channel before transmitting any frames

3.1.18
low nibble
lower 4 bits of the byte

Note 1 to entry: The *M* value from the byte 0xNM.

3.1.19
low state amplitude
power level of the low state level.

3.1.20
low state level
level of the ASK envelope that represents the low state amplitude

Note 1 to entry: The definition aligns with IEEE 194-1977, 5.2.2.5, static levels. Figure 2 gives an illustration.

3.1.21
mesial power level
median between high state level and low state level of an ASK envelope

Note 1 to entry: Figure 2 gives an illustration.

3.1.22
negative overshoot
difference between minimum peak level and low state level of an ASK envelope after a transition from a high state to a low state has occurred

Note 1 to entry: Figure 2 gives an illustration.

3.1.23
negative undershoot
difference between maximum peak level and low state level of an ASK envelope after a transition from a high state to a low state has occurred

Note 1 to entry: Figure 2 gives an illustration.

3.1.24
nibble
four-bit aggregation or half a byte

3.1.25
positive overshoot
difference between maximum peak level and high state level of ASK envelope after a transition from a low state to a high state has occurred

Note 1 to entry: Figure 2 gives an illustration.

3.1.26
positive undershoot
difference between minimum peak level and high state level of ASK envelope after a transition from a low state to a high state has occurred

Note 1 to entry: Figure 2 gives an illustration.

3.1.27
receiving device maturity time
determines at the receiving device the maximum time between the end of the first subtelegram and the end of the last subtelegram belonging to the same telegram

3.1.28
repeated telegrams
telegrams transmitted by a repeater

3.1.29
repeater
receives telegrams and sends refreshed signals to any WSP receiver

3.1.30
subframe
subtelegram byte expanded by protocol control and synchronisation information

3.1.31
subtelegram
smallest interpreted data unit containing the fields telegram type (RORG), payload (DATA), transmitter identity (TXID), STATUS and HASH

3.1.32
switch telegram
telegram with fields telegram type (RORG), payload (DATA), transmitter identity (TXID) and HASH

Note 1 to entry: The switch telegram structure differs from the telegram in that the fields of RORG and HASH are only 4 bits long and that it does not contain a STATUS field.

3.1.33
synchronisation bits
SYNC
bits inserted by an encoding procedure at the end of each subframe (except for the last subframe) to provide clock resynchronisation

Note 1 to entry: Synchronisation bits also reduce the DC content of transmitted data and can be used to ensure data reliability and integrity.

3.1.34
telegram
data unit composed of one or more identical subtelegrams

Note 1 to entry: A telegram has the same structure and contains the same information as a subtelegram.

3.1.35
telegram type
RORG
identifies the type of a telegram in the WSP protocol

Note 1 to entry: This type of telegram is denoted CHOICE in ISO/IEC 8825-2.

Note 2 to entry: There are several types of telegrams, but with the exception of the switch telegram, they are not defined in this standard.

3.1.36
time slot
unit of 1 ms of RX or TX maturity time

3.1.37
transmitting device lead time
time between activation of transmitting device and the transmission of first preamble bit

3.1.38
transmitting device maturity time
maximum time for the transmission of one complete telegram as determined at the sending device

3.1.39
transmitting device overtravel time
time between deactivation of TX blocks and end of last EOF bit

3.2 Abbreviations

ASK	Amplitude Shift Keying
CRC	Cyclic Redundancy Check
DC	Direct Current
DESTID	Destination device Identity
EIRP	Effective Isotropic Radiated Power
ERP	Effective Radiated Power
EOF	End of Frame
INV	Inverse bits
LBT	Listen Before Talk
MSB	Most Significant Bit
PRE	Preamble
RX	Receiver
RORG	Telegram type
SOF	Start Of Frame
SYNC	Synchronisation bits
TX	Transmitter
TXID	Transmitting device Identity
WSP	Wireless Short-Packet

4 Conformance

The three components of the WSP protocol system that are specified in this standard are the transmitter, the receiver and the repeaters. The repeaters shall be able both to transmit and to receive telegrams and thus shall support both the requirements for the transmitters and the receivers.

To conform to this International Standard the components shall support one of the two wireless frequencies specified unless another frequency is mandated by local regulations. For the frequency chosen, the transmitter shall support all the transmitter requirements that are not explicitly listed as optional, and the receiver shall support all the receiver requirements that are not explicitly listed as optional. These requirements are specified in 5.2 and Clauses 6, 7 and 8.

5 Architecture

5.1 Generic protocol description

5.1.1 Overview

This subclause provides a comprehensive overview of the wireless short-packet (WSP) protocol stack (see Table 1). The WSP is a lightweight layered protocol designed to minimise both energy demand and the probability of a transmission collision. The WSP protocol stack accommodates the structure of the OSI reference model (see ISO/IEC 7498-1).

Table 1 – WSP protocol stack structure (OSI)

Wireless short-packet protocol (WSP) stack			
Standard	**Layer**	**Services**	**Data units**
Not defined in this standard	Application		
	Presentation		
	Session		
	Transport		
ISO/IEC 14543-3-10	Network	Destination addressed telegrams (Encapsulation/Decapsulation) Switch telegram conversion (RORG and STATUS processing) Repeating (STATUS processing)	TELEGRAM
	Data Link Layer	Subtelegram structure Hash algorithms Subtelegram timing Listen before talk	SUBTELEGRAM
	Physical	Encoding/Decoding (INV and SYNC) Wireless receiving/transmitting	BITS / FRAME

5.1.2 Physical layer

At the physical layer the data are transmitted on either the 315 MHz or the 868,3 MHz frequency band with 125 kbit/s data rate using amplitude shift keying (ASK). The functional distance of the system is up to 300 m line-of-sight including the Fresnel zone and up to 30 m in buildings. This may be subject to national regulations. One bit duration is 8 µs. The data are transmitted in frames. A frame consists of the preamble (PRE), the start-of-frame sequence (SOF), the subframes (with inverse (INV) and synchronisation (SYNC) bits) as well as the end-of-frame sequence (EOF). For further details see Clause 6.

5.1.3 Data link layer

A subtelegram is the part of a frame from which the preamble (PRE), start-of-frame (SOF), inverse bits (INV), synchronisation bits (SYNC) and end-of-frame (EOF) have been removed. The subtelegram is transferred to the data link layer where the data integrity of the subtelegram is checked. If the data integrity check fails, the subtelegram is discarded. An additional task of the data link layer is to manage the subtelegram timing of the received/transmitted subtelegram. The subtelegram timing is based on an algorithm that ensures that the probability of subtelegram collisions in transit is as low as possible. To reduce the collision risk the WSP protocol uses, if possible, a listen before talk (LBT) technique. This algorithm (see 7.4) ensures that no transmission is initiated while the wireless channel is occupied.

5.1.4 Network layer

Three tasks are performed at the network layer, namely a conversion process, a repeating process and potentially a targeting process. The former performs a conversion between switch and normal telegrams (see 8.2). The repeating process is used when the wireless signals are too weak to reach the receiver directly and involves intermediate devices, i.e., repeaters that have been installed between the sender and the final recipient of the wireless signal (see 8.3). Another process at this layer involves a telegram that contains target addresses. Most telegrams are broadcast, and thus contain no destination identity (DESTID). However, if a telegram is addressed, it is in an encapsulated format (see 8.4).

5.1.5 Transport layer

This layer is not described in this standard.

5.1.6 Session layer

This layer is not described in this standard.

5.1.7 Presentation layer

This layer is not described in this standard.

5.1.8 Application layer

This layer is not described in this standard.

5.2 Data unit description

The communication protocol is packet based and the data units can be of three different types:

- Frame
- Subtelegram
- Telegram

A frame is the representation of the encoded data on the physical layer. It includes control and synchronisation information for the receiver. A frame is transmitted as a bit by bit serial sequence. A subtelegram is the result of a decoding process, in which this control (PRE, SOF, INV and EOF) and synchronisation (SYNC) data are removed from the frame. The reverse mechanism to extract a frame from a subtelegram is the encoding process.

Subtelegrams are processed at the data link layer. The WSP protocol is designed to work mostly as a unidirectional protocol without handshaking. To ensure transmission reliability up to three identical subtelegrams are transmitted within a specified time range. Each transmitted subtelegram is an atomic unit and contains all the data that the composed telegram contains. The data structure of a subtelegram is shown in Figure 1, where each byte is represented by 8 bits.

1	1 ... X	4	1	1	byte
RORG	DATA	TXID	STATUS	HASH	

Figure 1 – Structure of a subtelegram

The universal fields are:

- RORG – identifies the subtelegram type. With the exception of switch subtelegrams (8.2) and encapsulated subtelegrams (8.4), these types are not defined in this standard;
- DATA – the payload of the transmitted subtelegram;
- TXID – identifies the transmitter, each transmitter has a unique 4 byte identity;
- STATUS – identifies if the subtelegram is transmitted from a repeater and the type of integrity control mechanism used. This field is not present in a switch telegram;
- HASH – data integrity check value of all the bytes, see 7.3.

The length of the subtelegram is not transmitted in the subtelegram structure. The length is determined by counting the number of bytes starting with RORG and ending with HASH.

6 Layer 1 – Physical layer

6.1 Overview

The physical parameters that shall be supported by the WSP protocol are described in this clause. The next subclause defines and illustrates the physical parameters for which specifications for the WSP protocols are provided. Subclauses 6.3 and 6.4 specify the values that shall be supported by the two wireless frequencies specified in this standard. They also provide the link budget for these protocols.

The structure and encoding of the wireless protocol frames are found in 6.5.

6.2 General description

This subclause describes the physical parameters for the two wireless frequencies 315 MHz and at 868,3 MHz of the WSP protocol, which shall be supported by the WSP signalling system. This includes all electrical parameters and associated tolerances for the transmitter and the receiver.

The TX centre frequency is the frequency the transmitter should emit. The centre of the actual TX frequency may deviate from this value only by the maximum TX frequency tolerance.

NOTE TX centre frequencies have been chosen below 1 GHz so as to achieve good penetration in buildings together with low power consumption.

The maximum TX duty cycle defines the maximum time a transmitter may transmit related to the total time. The reason for this parameter is that there are duty cycle regulations applicable for the selected frequencies. For example, the WSP protocol at 315 MHz can choose to either send 10 ms in a single transmission or transmit 10 times 1 ms during a 100 ms time frame, both within the maximum of 10 ms per 100 ms time range.

TX modulation type, logical '0' and logical '1'. The WSP protocol uses amplitude shift keying (ASK) as modulations' type. This means that the power level of the TX signal is modified to transmit the information. The information is inverted on the physical layer. So when a logical '1' is transmitted, the TX power level is low. The power level is high when transmitting a logical '0'. ASK has been selected in order to reduce power consumption when transmitting a logical '1'.

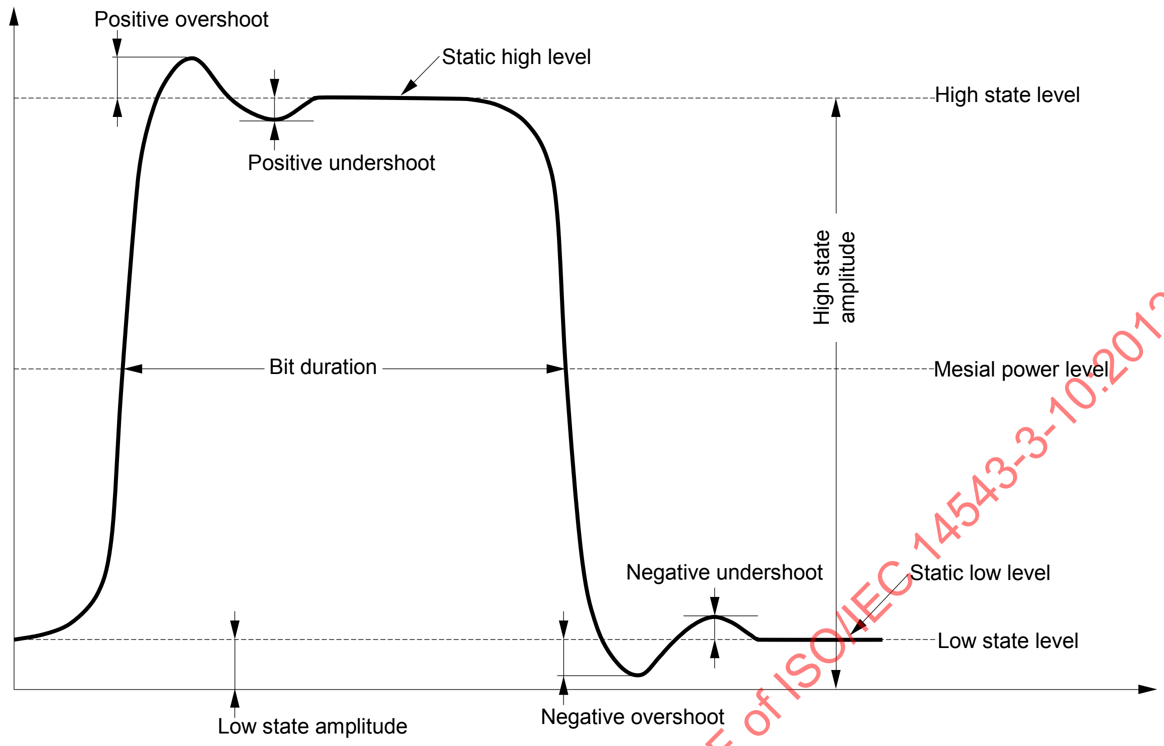


Figure 2 – Illustration of an ASK envelope and various physical parameters

Figure 2 shows an ASK envelope with one transition from a logical ‘1’ to ‘0’ and back to ‘1’. The ASK envelope is the power level of the wireless signal over a given time. Figure 2 also illustrates various physical parameters. These are needed for the understanding of how the WSP protocol is defined.

The TX high state to low state amplitude ratio defines how much the TX signal is reduced when transmitting a logical ‘1’. This ratio shall not be too low as most receivers need a minimum TX high state to low state amplitude ratio. But it shall also not be too high as this imposes problems for some automatic gain control mechanisms. The high-state level is defined by the static high level. The static high level can be determined by switching the transmitter to high state level and wait for all oscillations to cease. The low-state level is defined by the static low level. The static low level can be determined by switching the transmitter to low state level and wait for all oscillations to cease.

The maximum TX positive overshoot to high state amplitude ratio defines how much higher the power level of the wireless signal is permitted to be with respect to the static high level (see Figure 2).

The maximum TX negative overshoot to low state amplitude ratio defines how much lower the power level of the wireless signal is permitted to be with respect to the static low level (see Figure 2).

The maximum TX positive undershoot to high state amplitude ratio defines how much lower the power level of the wireless signal is permitted to be with respect to the static high level (see Figure 2).

The maximum TX negative undershoot to low state amplitude ratio defines how much higher the power level of the wireless signal is permitted to be with respect to the static low level (see Figure 2).

The TX bit rate is the rate at which bits are transmitted.

NOTE A relatively high data rate has been chosen in order to get short bursts. This helps to reduce energy consumption in the transmitter.

The TX bit duration is defined as the time between two transitions of the mesial power level from a logical ‘1’ to a logical ‘0’ and back to a logical ‘1’ (see Figure 2).

The maximum TX bit rate tolerance is the maximum tolerable deviation from the TX bit rate under which the transmitter is permitted to operate.

The maximum TX bit duration error is the maximum tolerable deviation from the TX bit duration that the transmitter is permitted to use.

The TX lead time is defined as the time a signal starts to be emitted from the transmitter until the first bit of the preamble starts.

The TX overtravel time is defined as the time a signal is still being emitted from the transmitter after the last bit of the end of frame (EOF) has been transmitted.

The TX EIRP (Effective Isotropic Radiated Power) is the radiated power of an antenna related to an ideal isotropic antenna. An ideal isotropic antenna has a gain of 0 dBi. The TX EIRP can be calculated from the TX power and the antenna gain. For details see 6.3 and 6.4 below.

The RX blocking performance defines how resistant the receiver is to other signals. It depends on the power level ratio between the other signal and that of the WSP protocol and its deviation from the TX centre frequency.

The RX centre frequency is the frequency the receiver is intended to receive at.

Maximum RX frequency tolerance. The RX frequency may only deviate from the centre frequency by the maximum RX frequency tolerance. It should be noted that the receiver bandwidth shall be large enough to take account of the TX frequency deviation.

The RX high power state deviation between two consecutive high states tolerance is mentioned because energy harvesting transmitters do not have a permanent power supply. Fade in supply power may lead to changes in the output power level of the transmitter. The receiver thus has to be able to tolerate such changes.

The tolerance of

Minimum TX positive overshoot to high state amplitude ratio,

Minimum TX negative overshoot to low state amplitude ratio,

Minimum TX positive undershoot overshoot to high state amplitude ratio,

Minimum TX negative undershoot to low state amplitude ratio,

Minimal RX bit rate,

Minimal RX bit duration error and

RX high state amplitude to low state amplitude ratio.

The receiver (RX) shall tolerate at least these minimum ratio values. Values outside this range mean better performance. Figure 2 gives an illustration of these ratios.

The RX sensitivity is defined as the high state amplitude at the receiver input at which the bit error rate exceeds 10^{-3} due to noise. Lower values mean better performance, meaning the transmitter and receiver can be further separated from each other.

The maximum RX power level is defined as the high state amplitude at the receiver input at which the bit error rate exceeds 10^{-3} due to signal distortion coming from too strong signals. Higher values mean better performance, meaning that the transmitter and receiver can be closer to each other.

6.3 Requirements for the 315 MHz WSP protocol

This subclause provides the requirements for the 315 MHz WSP protocol. Table 2 lists all required parameter values that shall be supported for both a transmitter and a repeater. Table 3 lists all required parameter values that shall be supported for both a receiver and a repeater. These parameters have all been described in 6.2 above. In addition, values for the link budget and the range of the system are also shown.

Table 2 – Transmitter requirements for the 315 MHz WSP protocol

Parameters	Value or applicable standard
TX centre frequency	f_c = 315 MHz
Maximum TX frequency tolerance	± 82,634 kHz
Maximum TX duty cycle	10 ms per 100 ms (10%) [a]
TX modulation type	ASK
logical ‘0’	High power state [b]
logical ‘1’	Low power state [b]
TX high state to low state amplitude ratio	20 dB to 36 dB
Maximum TX positive overshoot to high state amplitude ratio	1 dB
Maximum TX negative overshoot to low state amplitude ratio	4 dB
Maximum TX positive undershoot to high state amplitude ratio	0,5 dB
Maximum TX negative undershoot to low state amplitude ratio	2 dB
TX bit rate	125 kbit/s
TX bit duration	8 µs
Maximum TX bit rate tolerance	± 5 %
Maximum TX bit duration error	± 0,5 µs
TX lead time	0 µs to 56 µs [c]
TX overtravel time	0 µs to 40µs [d]
TX EIRP	–9 dBm to –3 dBm [e]
[a] Due to national regulations.	
[b] Note that bits are inverted on the wireless interface.	
[c] Defined excluding leading ‘1’ of preamble.	
[d] Defined excluding trailing ‘11’ of EOF.	
[e] Due to national regulations.	

Table 3 – Receiver requirements for the 315 MHz WSP protocol

Parameters	Value or applicable standard
RX blocking performance	EN 300 220-1, 9.3.3 for class 2 receivers
RX centre frequency	f_c = 315 MHz
Maximum RX frequency tolerance	± 17,336 kHz
RX high power state deviation between two consecutive high states tolerance	–1,5 dB to 3 dB
Minimum RX positive overshoot to high state amplitude ratio tolerance	3 dB
Minimum RX negative overshoot to low state amplitude ratio tolerance	16 dB
Minimum RX positive undershoot to high state amplitude ratio tolerance	1,5 dB
Minimum RX negative undershoot to low state amplitude ratio tolerance	6 dB
Minimal RX bit rate tolerance	6,25%
Minimal RX bit duration error tolerance	± 3 µs
RX high state amplitude to low state amplitude ratio tolerance	better than 16 dB to 50 dB
RX sensitivity	better than –95 dBm
Maximum RX power level	better than –10 dBm

The link budget values for the 315 MHz WSP protocol are shown in Table 4. This is the minimum link budget a system supporting the 315 MHz WSP protocol shall support. The link budget is used to estimate the range of the system. As the penetration of buildings tends to be good at 315 MHz, a relatively small link margin has been used.

Table 4 – Minimum required link budget for the 315 MHz WSP protocol

Description	Value
TX EIRP	–9 dBm
RX antenna gain	–10 dBi
RX sensitivity	–95 dBm
Link margin	4 dB
Link budget	72 dB

Table 5 gives the values of the maximum RX power that under perfect conditions need to be supported by the 315 MHz WSP protocol. The maximum TX to RX antenna coupling is a value that can be reached by placing a transmitter close to a receiver (antennas have a distance of a few centimetres). Receivers shall be able to receive such strong signals.

Table 5 – Maximum RX power for the 315 MHz WSP protocol

Description	Value
TX EIRP	–3 dBm
Maximum TX to RX Antenna coupling	–9 dB
RX antenna gain	+2 dBi
RX power	–10 dBm

6.4 Requirements for the 868,3 MHz WSP protocol

This subclause provides the requirements for the 868,3 MHz WSP protocol. Table 6 lists all required parameter values that shall be supported for both a transmitter and a repeater. Table 7 lists all required parameter values that shall be supported for both a receiver and a repeater. These parameters have all been described in 6.2 above. In addition, values concerning the link budget and the range of the system are also shown.

Table 6 – Transmitter requirements for the 868,3 MHz WSP protocol

Characteristics	Value or applicable standard
TX centre frequency	f_c = 868,3 MHz
Maximum TX frequency tolerance	± 82,634 kHz
Maximum TX duty cycle	1 % (36 s per hour) [a]
TX modulation type	ASK
logical '0'	High power state [b]
logical '1'	Low power state [b]
TX high state to low state amplitude ratio	20 dB to 36 dB
Maximum TX positive overshoot to high state amplitude ratio	1 dB
Maximum TX negative overshoot to low state amplitude ratio	4 dB
Maximum TX positive undershoot to high state amplitude ratio	0,5 dB
Maximum TX negative undershoot to low state amplitude ratio	2 dB
TX bit rate	125 kbit/s
TX bit duration	8 µs
Maximum TX bit rate tolerance	± 5 %
Maximum TX bit duration error	± 0,5 µs
TX lead time	0 µs to 56 µs [c]
TX overtravel time	0 µs to 40 µs [d]
TX EIRP	–8 dBm to +13 dBm[e]

a Due to national regulations.

b Note that bits are inverted on the wireless interface.

c Defined excluding leading '1' of preamble.

d Defined excluding trailing '11' of EOF.

e Due to national regulations.

Table 7 – Receiver requirements for the 868,3 MHz WSP protocol

Characteristics	Value or applicable standard
RX blocking performance	According to EN 300 220-1, 9.3.3 for class 2 receivers
RX centre frequency	f_c = 868,3 MHz
RX frequency tolerance	± 17,336 kHz
RX high power state deviation between two consecutive high states tolerances	–1,5 dB to 3 dB
Minimum RX positive overshoot to high state amplitude ratio tolerance	3 dB
Minimum RX negative overshoot to low state amplitude ratio tolerance	16 dB
Minimum RX positive undershoot to high state amplitude ratio tolerance	1,5 dB
Minimum RX negative undershoot to low state amplitude ratio tolerance	6 dB
Minimal RX bit rate tolerance	6,25 %
Minimal RX bit duration error tolerance	± 3 µs
RX high state amplitude to low state amplitude ratio tolerance	better than 16 dB to 50 dB
RX sensitivity	better than –95 dBm
Maximum RX power level	better than –7 dBm

The link budget values for the 868,3 MHz WSP protocol are shown in Table 8. This is the minimum link budget a system supporting the 868,3 MHz WSP protocol shall support. The link budget is used to estimate the range of the system. As the penetration of buildings tends to be good at 868,3 MHz, a relatively small link margin has been used.

Table 8 – Minimum required link budget for the 868,3 MHz WSP protocol

Description	Value
TX EIRP	–4 dBm
RX antenna gain	–6 dBi
RX sensitivity	–95 dBm
Link margin	4 dB
Link budget	81 dB

Table 9 gives the values of the maximum RX power that under perfect conditions need to be supported by the 868,3 MHz WSP protocol. The maximum TX to RX antenna coupling is a value that can be reached by placing a transmitter close to a receiver (antennas have a distance of a few centimetres). Receivers shall be able to receive such strong signals.

Table 9 – Maximum RX power for the 868,3 MHz WSP protocol

Description	Value
TX EIRP	+13 dBm
Maximum TX to RX Antenna coupling	–22 dB
RX antenna gain	+2 dBi
RX power	–7 dBm

6.5 Frame Structure

This subclause specifies the structure of a frame, i.e. the telegram as transmitted in the physical layer. Details for various aspects of the data encoding in the frame are described.

The complete frame consists of the preamble (PRE), the start of frame (SOF), the subframes with the inverse bits (INV) and the synchronization bits (SYNC) inserted, and finally the end of frame (EOF). For the WSP protocol at 868,3 MHz Figure 3 shows the subtelegram both before the encoding and after it has been encoded with the INV and SYNC bits inserted into a frame.

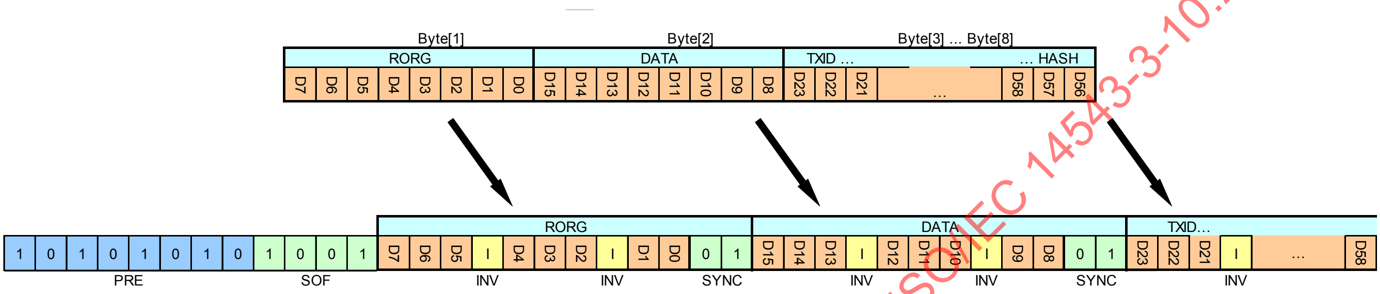


Figure 3 – Complete frame structure for the 868,3 MHz WSP protocol

Every frame starts with the preamble (PRE). For the wireless frequency of 315 MHz the length is 16 (Table 10) and for 868,3 MHz it is 8 bits (Table 11).

The PRE is followed by the start of frame (SOF). The SOF enables the receiver to synchronise the sampling clock with the bit stream of the received frame. The SOF sequence is specified in Table 10 and Table 11, respectively.

The SOF is followed by one or more subframes. The subframes are transmitted with the most significant bit (MSB) first.

NOTE The average value of the bytes depends on the content as the data is transmitted directly without a scrambler or Manchester encoding. This is done to reduce protocol overhead. Reduced protocol overhead leads to shorter frames and thus less energy consumption.

As it is possible to transmit all bits ‘0’ or all bits ‘1’, there would be problems with threshold generation or sampling clock resynchronisation in some receivers. To avoid these problems inverse bits are inserted into the transmitted data. These bits are inverse to the 3rd and 6th bit of one byte and inserted behind the corresponding bit. Figure 4 shows the position of the inserted inverse bits. The INV can also be used for data integrity checks.

Apply the following rule to the inverse bits: I1=NOT(D5) and I2=NOT(D2), where I1 stands for the value of the first INV bit and D5 of the third bit of a byte.

In addition to the inverse bits, two synchronisation bits (SYNC) are inserted at the end of each subframe, except the last one. The complete structure of a subframe with inserted SYNC is shown in detail in Figure 4. The SYNC sequence is specified in Table 10 and Table 11, respectively. The SYNC is used for clock resynchronisation, but can also be used for data integrity checks.

D7	D6	D5	I1	D4	D3	D2	I2	D1	D0	0	1
			INV				INV			SYNC	

Figure 4 – Encoded subframe

The EOF determines the end of the frame. The EOF sequences for 315 MHz and 868,3 MHz are specified in Table 10 and Table 11, respectively.

For the 315 MHz WSP protocol the structure and definition of the frame is shown in Table 10.

Table 10 – Frame definition for the 315 MHz WSP protocol

Fields	Value
Preamble (PRE)	bit sequence “101010101010101010”
Start-of-frame (SOF)	bit sequence “1001”
DATA	MSB is transmitted first
Inverse bits (INV)	bit with inverse value to every 3rd and 6th bit is appended behind the corresponding bit
Synchronisation bits (SYNC)	bit sequence “01”
End-of-frame (EOF)	bit sequence “1011”

For the 868,3 MHz WSP protocol the structure and definition of the frame is shown in Table 11.

Table 11 – Frame definition for the 868,3 MHz WSP protocol

Fields	Value
Preamble (PRE)	bit sequence “10101010”
Start-of-frame (SOF)	bit sequence “1001”
DATA	MSB is transmitted first
Inverse bits (INV)	bit with inverse value to every 3rd and 6th bit is appended behind the corresponding bit
Synchronisation bits (SYNC)	bit sequence “01”
End-of-frame (EOF)	bit sequence “1011”

7 Layer 2 – Data link layer

7.1 Overview

At the data link layer the transmitted data are one or more subtelegrams. The structure of these is described in 5.2 above. This clause describes three aspects of the subtelegrams. Subclause 7.2 specifies the timing of the subtelegram transmission. The data integrity mechanisms used are specified in 7.3 and finally, in 7.4, the optional listen before talk (LBT) mechanism is described.

7.2 Subtelegram timing

The subtelegram timing aims to avoid telegram collisions from different transmitters. Each subtelegram is transmitted in a different time range. The limits of the subtelegram timing are determined by the TX and RX maturity times. The maturity time specifies the length of the time range within which the transmission of all subtelegrams has to be completed and received. The values of the TX and RX maturity times are specified in Table 12 below.

A complete telegram consists of a maximum of 3 subtelegrams. The transmission of the start of the first subtelegram and the end of the last subtelegram by the transmitter shall not exceed the TX maturity time.

Repeaters have a different subtelegram timing range from the original transmitter.

For the receiver, all subtelegrams received from the same transmitter between the end of the first subtelegram until the RX maturity time shall be considered part of the same telegram, including when repeaters are involved. Subtelegrams received after the RX maturity time shall be considered to be part of another telegram.

The LBT technique (see 7.4) enables to avoid collision by controlling the subtelegram transmission timing, but it cannot completely guarantee the avoidance of a collision.

Table 12 – Maturity time parameters

Description	Parameter
Maximum TX maturity time	40 ms
RX maturity time	100 ms

To schedule the subtelegram transmission the TX maturity time is divided into 4 groups; each with 10 time slots of 1 ms. The enumeration of the time slots starts with 0 and ends with 39.

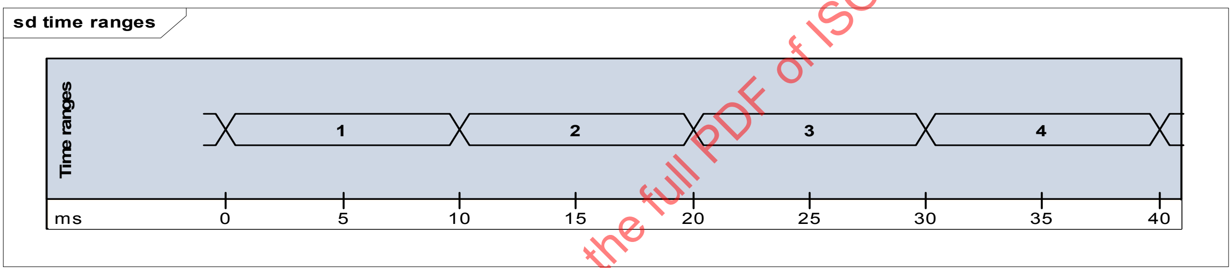


Figure 5 – TX maturity time divided into four 10 ms time ranges

These 4 ranges (see Figure 5) shall be used to send a maximum of 3 subtelegrams. The scheduling determines which subtelegram number is allowed to be sent in which range. To avoid collisions when using repeaters, the subtelegram timing of original and repeated telegrams differs depending only on the status of the repeated subtelegram and not on the configured level of the repeater. Table 13 defines the time range in which each subtelegram may be transmitted. The specific time range is determined by the numbered time slots.

Table 13 – Allocation of time slots to the different subtelegrams

Status of telegram	1st subtelegram	2nd subtelegram	3rd subtelegram
Original	0	1…9	20…39
Level 1 repeated	10…19	20…29	
Level 2 repeated	0…9	20…29	

All subtelegrams shall be transmitted within these time ranges. A second or third subtelegram transmission may only start if the previous subtelegram transmission has been completed. There is no specified minimum pause between subtelegrams. The transmitter and repeater may use any time slot within each time range.

The transmission start of the first subtelegram of an original transmitter starts the time counting for the transmitter. The completion of the first received subtelegram (which, due to disturbances, is not always the first one from the transmitter) starts the counting in the receiver or the repeater.

If the wireless channel is occupied by the transmission of other transmitters, the LBT functionality (see 7.4) can delay the transmission until the end of the TX maturity time is reached.

7.3 Data integrity

7.3.1 General

In order to check that a subtelegram has arrived intact, a hash of the telegram is calculated by the transmitting device, i.e. a transmitter or a repeater, before transmission and attached to the subtelegram (field HASH). The attached hash value is not protected and thus only serves to detect transmission failures and not protection against malicious intent. The verification is done by the device receiving the telegram, i.e. a receiver or a repeater. Three algorithms are supported by the WSP protocol. Two are summation based, one of which is 4 bits long and only used in switch telegrams, the other is 8 bits long, and the third uses an 8-bit long cyclic redundancy check (CRC) algorithm. All receivers and repeaters are required to support all three hash functions.

If the verification of the intactness of the received subtelegram fails, the subtelegram is ignored.

A switch telegram is identified by the telegram type field RORG (see 8.2). For other telegrams, the STATUS byte indicates which hash function is used. This is summarised in Table 14 below.

Table 14 – Identification of the hash function used in the telegram

Characteristics	Width	Used by telegram types
4bit Checksum	4 bit	used only by switch telegrams which is identified by RORG, no STATUS byte present
8bit Checksum	8 bit	any type of telegram when STATUS bit 2^7 = 0
8bit CRC	8 bit	any type of telegram when STATUS bit 2^7 = 1

7.3.2 4 bit summation hash function algorithm

This subclause describes the 4-bit summation type hash algorithm. The result of the calculation has the length of 4 bits.

The algorithm is as follows.

- The nibble at the end of the telegram is set to 0x00.
- The sum of the value of each byte starting with RORG in the subtelegram is calculated ignoring overflow, i.e. all bits in the sum beyond the byte are ignored. The last byte in the summation is formed by adding the placeholder nibble to the end of the subtelegram.
- The sum of the high and the low nibbles of the sum in the step above is formed, i.e. the first and last four bits of the sum above are added together. The resulting 4-bit value is the hash value.

Annex A provides an example of a C code implementation of this hash function algorithm.

7.3.3 8 bit summation hash function algorithm

This subclause describes the 8-bit checksum algorithm. The result of the calculation has the length of 8 bits.

The algorithm is as follows.

– The sum of the value of each byte in the subtelegram except the hash value field is evaluated ignoring overflow, i.e. all bits beyond the byte are ignored. This one byte (8 bits) sum value is the hash of the 8-bit algorithm.

Annex A provides an example of a C code implementation of this hash function algorithm.

7.3.4 8 bit Cyclic Redundancy Check (CRC) hash function algorithm

The third hash function supported by the WSP protocol is based on the Cyclic Redundancy Check algorithm providing a hash value of length one byte.

The algorithm starts with the first byte of the subtelegram (RORG) and calculates the remainder of the division (modulo 2) by the generator polynomial $x^8 + x^2 + x + 1$ of the product x^8 multiplied by the first byte of the subtelegram.

NOTE The CRC algorithm uses the same generator polynomial ($x^8 + x^2 + x + 1$) as the ATM Header Error Control (HEC) described in ITU-T recommendation I.432.1.

The result of this calculation is XORed with the next byte in the subtelegram and again the remainder of the division is calculated as above.

This procedure is repeated until the last byte of the subtelegram excluding HASH is reached. The remainder of the final division is used as hash value.

Annex A provides an example of an efficient C code implementation of this hash function algorithm.

7.4 Listen before talk

Listen before talk (LBT) is a technique used in wireless communications whereby a wireless transmitter or repeater first senses its wireless environment before starting a transmission. The aim is to avoid collisions with other senders. It is an optional feature of the transmitting device.

Prior to transmitting a subtelegram, the transmitting device checks whether there is an ongoing transmission. If this is the case, the transmission is suspended for the delay of a random time range. After this delay, the transmitter check is repeated. If no ongoing telegram transmission is detected, the subtelegram is transmitted. In case the calculated random delay would lead to a violation of the TX maturity time, the subtelegram is sent irrespective of any other transmissions.

It is recommended to implement and use LBT before each subtelegram transmission, but it is not required. Some transmitting devices cannot support this feature such as some energy harvesting devices.

8 Layer 3 – Network layer

8.1 Overview

Three aspects of the WSP protocol are described in this clause. Subclause 8.2 describes switch telegrams, which are used by a special type of energy harvesting device. Subclause 8.3 describes the functionality of repeaters, which are inserted in a WSP protocol system when a direct transmission between a transmitter and receivers cannot be made with sufficient quality. Subclause 8.4 deals with the cases when the WSP protocols transmit telegrams targeted to specific receivers.

8.2 Switch telegram

The switch telegram is a particularly small telegram. It is named a “switch telegram” because it was first used in energy harvesting devices that were energised by turning a switch. These devices generate a small amount of power only when used and cannot receive messages.

A normal telegram has 4 fields besides the payload DATA, namely an 8-bit long telegram type field (RORG), a 32-bit long transmitter identity TXID, an 8-bit long status field (STATUS) and an 8-bit long summation hash value, whereas a switch telegram has a 4-bit long telegram type field (RORG), a 32-bit long transmitter identity field (TXID), no status field and a 4-bit summation hash value. A switch telegram is thus shorter than a normal telegram and consumes less energy when sent.

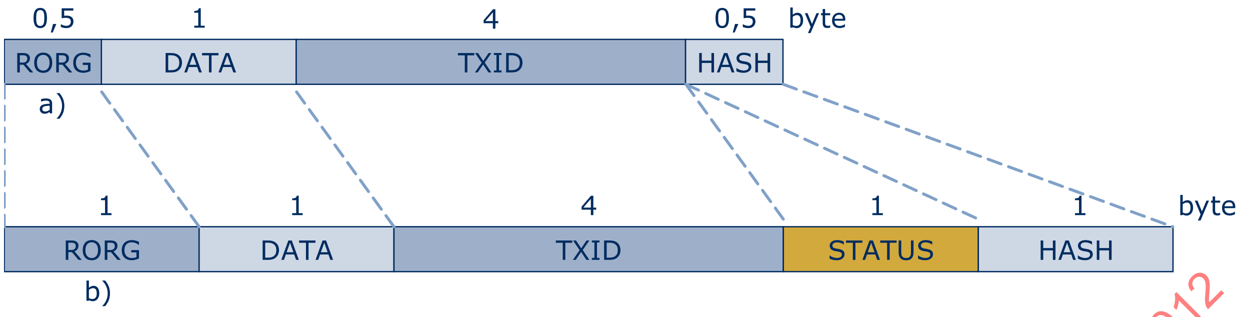
The characteristics of a switch telegram are the following.

- RORG is 4 bits long and identified as such by having the value 5 or 6.
- DATA is always 1 byte long.
- TXID is 4 bytes long, same as in a normal telegram.
- STATUS byte is not present.
- HASH is 4 bits long instead of 8 bits.
- As soon as a switch telegram is received by either the receiver or a repeater, it is detected to be a switch telegram and converted to a normal telegram structure as specified in Table 15 and illustrated in Figure 6. The conversion is as follows: The 4-bit telegram type field (RORG) 0x05/0x06 is converted to an 8-bit telegram type field (RORG) with the value 0xF6.
- The DATA and TX fields remain unchanged (they are shifted by 4 bits).
- A STATUS field of length one byte is added directly after the transmitter identity field TXID with a value encoded as shown below.
- An 8-bit summation type hash value replaces the 4-bit hash value of the switch telegram and is evaluated for the converted telegram using the 8-bit summation type hash value algorithm.

Table 15 – Conversion of the telegram type and STATUS fields from a switch telegram to a telegram

Switch telegram 4-bit RORG	Converted 8-bit RORG	Status field STATUS
5	0xF6	0x20
6	0xF6	0x30

Figure 6 illustrates the conversion.



RORG a) 5 or 6
RORG b) 0xf6

Figure 6 – Conversion of a switch telegram to a normal telegram

8.3 Repeater

8.3.1 General

Repeaters are necessary when the distance between sender and receiver is too large to establish an adequate wireless connection. For longer distances it is possible to place a maximum of two repeaters in a row. The function of the repeater is to receive the telegram from the sender or another repeater and send it again, so that the receiver of the message can get it. But before it is resent the repeater modifies the STATUS byte of the telegram. To limit the amount of repeated telegrams in an environment with more repeaters, two repeater levels are specified, as indicated below.

– Level 1 Repeaters repeat only received original subtelegrams.
– Level 2 Repeaters repeat only received original or once repeated subtelegrams.

If a level 2 repeater receives an original and also a once repeated subtelegram originating from the same transmitter, it shall repeat only once with 3 subtelegrams.

8.3.2 Time response for collision avoidance

When there are repeaters in a system, it is particularly important to avoid collisions. When a subtelegram is sent from a transmitter, it is thus necessary that the repeater does not repeat a subtelegram received at the same time as another subtelegram from the original sender or a second repeater is transmitted.

Therefore a special subtelegram timing for repeaters is defined, which depends on the received subtelegram repeater level. This is described in detail in 7.2 above.

8.3.3 Bits of a repeater level in the STATUS byte

The STATUS field is used for a repeater to differentiate between subtelegrams from a transmitting device and those from a repeater. Bits 2^0 to 2^3 in the STATUS field byte of each subtelegram show the number of repeater hops of the telegram. Table 16 shows the possible combinations.