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INTERNATIONAL STANDARD

Information technology – Home electronic system (HES) architecture – Part 3-10: Amplitude modulated wireless short-packet (AMWSP) protocol optimized for energy harvesting – Architecture and lower layer protocols

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INFORMATION TECHNOLOGY – HOME ELECTRONIC SYSTEM (HES) ARCHITECTURE –

Part 3-10: Amplitude modulated wireless short-packet (AMWSP) protocol optimized for energy harvesting – Architecture and lower layer protocols

FOREWORD

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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 and ISO websites.

This second edition cancels and replaces the first edition published in 2012. This edition constitutes a technical revision.

The text of this standard is based on the following documents:

CDV	Report on voting
JTC1-SC25/2842/CDV	JTC1-SC25/2864/RVC

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

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

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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 harvesting devices can provide and at the same time spans distances to be bridged within a home environment.

Several such devices used within a home often come from different sources. They are required to interwork with each other using a common internal network (in this document 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).

Alternative transmission technologies are specified by ISO/IEC 14543 (all parts). ISO/IEC 14543-3-10 and ISO/IEC 14543-3-11 are optimized for energy harvesting based on similar techniques, but with different modulation schemes. ISO/IEC 14543-3-10 and ISO/IEC 14543-3-11 specify two lower layer wireless short-packet protocols: ISO/IEC 14543-3-10 uses an amplitude modulated (AM) signal and ISO/IEC 14543-3-11 a frequency modulated (FM) signal.

Amplitude modulated wireless communications are more energy efficient but less adapted to mobile devices. This is because the impedance of a mobile antenna is affected by the environment of the mobile device, for example, when the device is held in the hand or moved to metal surface. Changes in impedance affect the amplitude linearity of the radio frequency output amplifier, but have no impact on the frequency itself. Thus an AM wireless system is more sensitive to changes in environment than an FM wireless system. Also frequencies above 800 MHz are better suited for mobile devices, since they require smaller antennas. Thus the frequency 315 MHz is not used in the FM specification, which makes the FM wireless system more efficient for mobile devices.

Compared to the AM wireless system, the FM wireless system provides more flexibility in the size of various pieces of information that can be transmitted. This includes the possibility to have larger payloads, different lengths of the identifiers of originators and destinations, and greater variability of structures and lengths of the telegram types. The number of steps a telegram can be repeated is two for the AM wireless system and 15 for the FM wireless system.

They are both efficient enough to

- support energy harvesting products for sensors and switches that require neither cabling nor batteries, and
- extend the life of battery-operated devices.

Both an AM and an FM system can be active at the same time, since each system is so constructed that only permitted messages are accepted. Collisions can be avoided by listen-before-talk (LBT) technology or overcome by redundant transmissions.

INFORMATION TECHNOLOGY – HOME ELECTRONIC SYSTEM (HES) ARCHITECTURE –

Part 3-10: Amplitude modulated wireless short-packet (AMWSP) protocol optimized 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 harvesting 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 characterized 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 harvesting devices that can compete with similar battery-powered devices. The messages sent by energy harvesting 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 ISO/IEC 14543 (all parts), is defined as a home electronic system.

This document specifies OSI Layers 1 to 3 of the amplitude modulated wireless short-packet (AMWSP) protocols.

The AMWSP protocol system consists of two and optionally three types of components that are specified in this document. 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 document.

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.

ETSI EN 300 220-1 V3.1.1, *Short Range Devices (SRD) operating in the frequency range 25 MHz to 1 000 MHz; Part 1: Technical characteristics and methods of measurement*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

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

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

3.1.2
bit duration
time between transitions of the mesial amplitude 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
ordered set of eight binary digits, operated on as an entity

Note 1 to entry: The non-qualified term "byte" designates an 8-bit byte.

[SOURCE: IEC 60050-702:2016, 702-05-09]

3.1.5
collision
state which exists when two wireless transmitters use the same wireless channel and transmit 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 device
device able to capture and store (harvest) energy from the environment to power its operations

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 synchronization 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 four bits of the byte

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

3.1.12
high state amplitude
amplitude corresponding to the physical 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 an AMWSP telegram consisting of four bytes

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

3.1.16
inverse bits
INV
bits added by the encoding procedure into a subframe behind the third and the sixth 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 four bits of the byte

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

3.1.19
low state amplitude
amplitude corresponding to the physical 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
RX maturity time
maximum time, determined at the receiving device, between the end of the first subtelegram and the end of the last subtelegram belonging to the same telegram

3.1.28
repeated telegram
telegram transmitted by a repeater

3.1.29
repeater
device that receives telegrams and sends refreshed signals to any AMWSP receiver

3.1.30
subframe
subtelegram byte expanded by protocol control and synchronization 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 four bits long and that it does not contain a STATUS field.

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

Note 1 to entry Synchronization 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
field that identifies the type of a telegram in the AMWSP 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 telegram; however, with the exception of the switch telegram, they are not defined in this document.

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

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

3.1.38
transmitting device maturity time
TX 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 a signal is still emitted from the transmitter after the last '0' bit of end of frame (EOF) has been transmitted

3.2 Abbreviated terms

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	synchronization bits
TX	transmitter
TXID	transmitting device identity
AMWSP	amplitude modulated wireless short-packet

4 Conformance

The three components of the AMWSP protocol system that are specified in this document 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 document, 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

Subclause 5.1.1 provides a comprehensive overview of the amplitude modulated wireless short-packet (AMWSP) protocol stack (see Table 1). The AMWSP is a lightweight layered protocol designed to minimize both energy demand and the probability of a transmission collision. The AMWSP protocol stack accommodates the structure of the OSI reference model (see ISO/IEC 7498-1).

Table 1 – AMWSP protocol stack structure (OSI)

Amplitude modulated wireless short-packet protocol (AMWSP) stack			
Standard	**Layer**	**Services**	**Data units**
Not defined in this document	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 synchronization (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), synchronization 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 AMWSP 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: a conversion process, a repeating process and potentially a targeting process. The first of these 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 document.

5.1.6 Session layer

This layer is not described in this document.

5.1.7 Presentation layer

This layer is not described in this document.

5.1.8 Application layer

This layer is not described in this document.

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 synchronization 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 these control (PRE, SOF, INV and EOF) and synchronization (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 AMWSP 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 eight bits.

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 document;
- DATA – the payload of the transmitted subtelegram;
- TXID – identifies the transmitter, each transmitter has a unique four-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 AMWSP protocol are described in Clause 6. Subclause 6.2 defines and illustrates the physical parameters for which specifications for the AMWSP protocols are provided. Subclauses 6.3 and 6.4 specify the values that shall be supported by the two wireless frequencies specified in this document. 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

Subclause 6.2 describes the physical parameters for the two wireless frequencies 315 MHz and 868,3 MHz of the AMWSP protocol, which shall be supported by the AMWSP 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 1 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 AMWSP 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 AMWSP protocol uses amplitude shift keying (ASK) as modulation type. This means that the amplitude 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 amplitude is low. The amplitude is high when transmitting a logical '0'. ASK has been selected in order to reduce power consumption when transmitting a logical '1'.

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

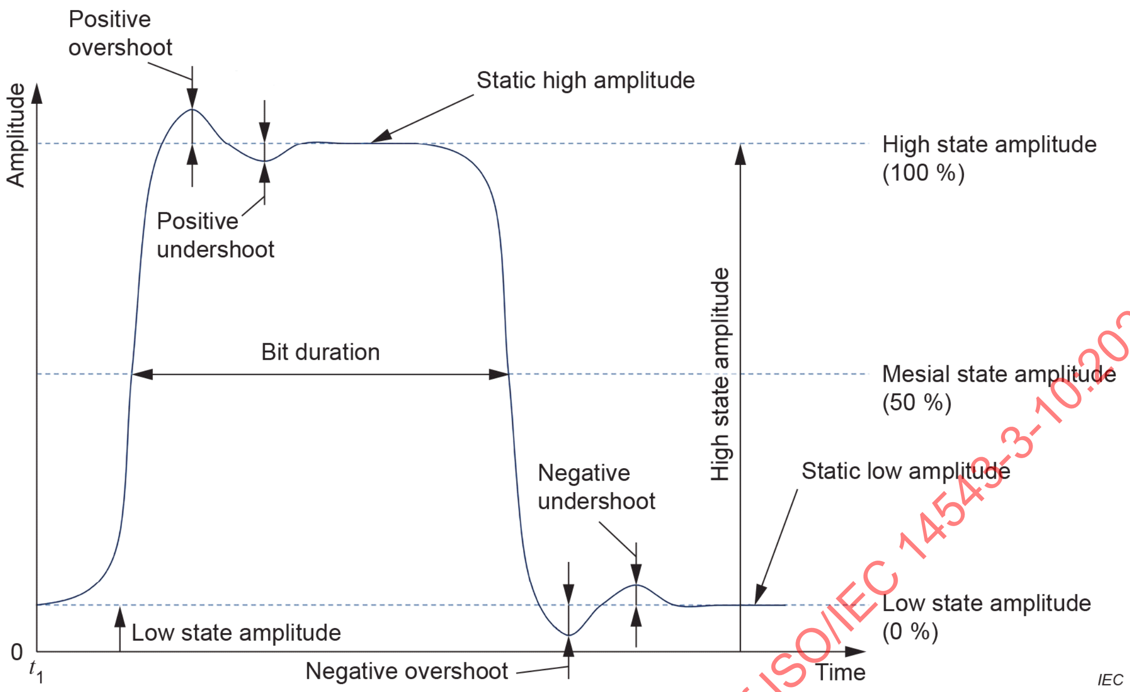


Figure 2 – Illustration of an ASK envelope and various physical parameters

- 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 waiting 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 waiting for all oscillations to cease.
- The maximum TX positive overshoot to high state amplitude ratio defines how much higher the amplitude of the wireless signal is permitted to be with respect to the static high amplitude (see Figure 2).
- The maximum TX negative overshoot to low state amplitude ratio defines how much lower the amplitude of the wireless signal is permitted to be with respect to the static low amplitude (see Figure 2).
- The maximum TX positive undershoot to high state amplitude ratio defines how much lower the amplitude of the wireless signal is permitted to be with respect to the static high amplitude (see Figure 2).
- The maximum TX negative undershoot to low state amplitude ratio defines how much higher the amplitude of the wireless signal is permitted to be with respect to the static low amplitude (see Figure 2).
- The TX bit rate is the rate at which bits are transmitted.

  NOTE 2 A relatively high data rate has been chosen in order to get short bursts. This helps to reduce energy consumption in the transmitter.
- The mesial amplitude is defined as the average of the high state and low state amplitudes (high state amplitude plus low state amplitude divided by two).
- The TX bit duration is defined as the time between two transitions of the mesial amplitude 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 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.
- The antenna gain describes how well an antenna converts input power into radio waves headed in a specified direction.
- The link margin is the difference between the receiver sensitivity and the received power for extra losses due to fade or other external factors.
- The link budget is the accounting of all the gains and losses from the transmitter, through the medium (free space, cable, waveguide, fibre, etc.) to the receiver in a telecommunication system. In this document, it excludes the link margin.
- 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 AMWSP 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. The receiver bandwidth shall be large enough to take account of the TX frequency deviation.

  NOTE 3 The typical receiver for such a system will have a bandwidth lower than 500 kHz.

  The deviation tolerance of any RX high state amplitudes from the first high state amplitude (second bit of preamble) is mentioned because energy harvesting transmitters do not have a permanent power supply. Variation in power supply may lead to changes in the output power of the transmitter. The receiver thus shall be able to tolerate such changes to a certain degree.
- 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 AMWSP protocol

Subclause 6.3 provides the requirements for the 315 MHz AMWSP 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 are described in 6.2. In addition, values for the link budget and the range of the system are also shown.

Table 2 – Transmitter requirements for the 315 MHz AMWSP protocol

Parameter	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 state amplitude [b]
logical ‘1’	Low state amplitude [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	−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 AMWSP protocol

Parameter	Value or applicable standard
RX blocking performance	ETSI EN 300 220-1 V3.1.1, 5.18.3 for class 2 receivers
RX centre frequency	f_c = 315 MHz
Maximum RX frequency tolerance	±17,336 kHz
The deviation tolerance of any RX high state amplitudes from the first high state amplitude	−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 −32 dBm

The link budget values for the 315 MHz AMWSP protocol are shown in Table 4. This is the minimum link budget a system supporting the 315 MHz AMWSP 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 AMWSP 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 AMWSP 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.

If a receiving device (receiver or a repeater) is saturated, the distance between the sending device (sender or repeater) and receiving device should be increased. In most cases, there should be no problem if the distance is more than a metre.

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

Description	Value
TX EIRP	−3 dBm
Maximum TX to RX antenna coupling	−31 dB
RX antenna gain	+2 dBi
RX power	−32 dBm

6.4 Requirements for the 868,3 MHz AMWSP protocol

Subclause 6.4 provides the requirements for the 868,3 MHz AMWSP 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 are all described in 6.2. 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 AMWSP protocol

Parameter	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 state amplitude [b]
logical '1'	Low state amplitude [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 AMWSP protocol

Parameter	Value or applicable standard
RX blocking performance	ETSI EN 300 220-1 V3.1.1, 5.18.3 for class 2 receivers
RX centre frequency	f_c = 868,3 MHz
RX frequency tolerance	±17,336 kHz
Deviation tolerance of any RX high state amplitudes from the first high state amplitude	−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 −25 dBm

The link budget values for the 868,3 MHz AMWSP protocol are shown in Table 8. This is the minimum link budget a system supporting the 868,3 MHz AMWSP 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 AMWSP 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 needs to be supported by the 868,3 MHz AMWSP 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.

If a receiving device (receiver or a repeater) is saturated, the distance between the sending device (sender or a repeater) and receiving device should be increased. In most cases, there should be no problem if the distance is more than a metre.

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

Description	Value
TX EIRP	+13 dBm
Maximum TX to RX antenna coupling	–40 dB
RX antenna gain	+2 dBi
RX power	–25 dBm

6.5 Frame structure

Subclause 6.5 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 AMWSP 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.

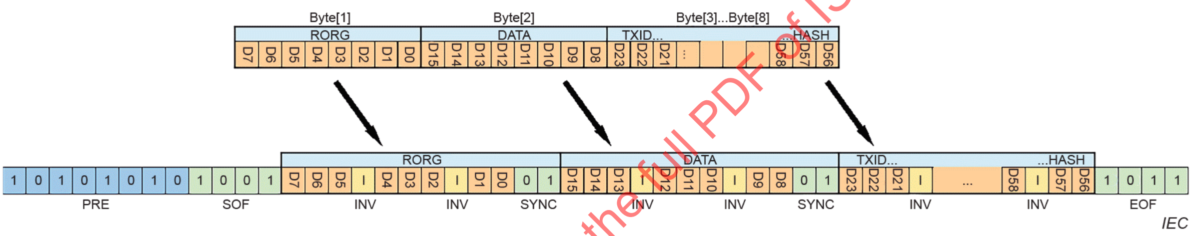


Figure 3 – Complete frame structure for the 868,3 MHz AMWSP protocol

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

The PRE is followed by the SOF. The SOF enables the receiver to synchronize 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 resynchronization in some receivers. To avoid these problems inverse bits are inserted into the transmitted data. These bits are inverse to the third bit and sixth bit of one byte and are inserted behind the corresponding bit. Figure 4 shows the position of the inserted inverse bits. Telegrams containing incorrect inverse bits shall be discarded.

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

In addition to the inverse bits, two synchronization 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 sequences for 315 MHz and 863,3 MHz are specified in Table 10 and Table 11, respectively. The SYNC is used for clock resynchronization. Telegrams containing incorrect SYNC shall be discarded.

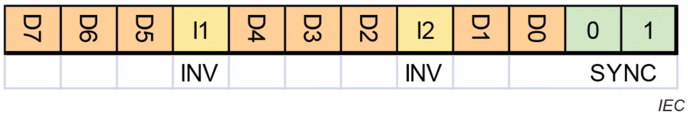


Figure 4 – Encoded subframe

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. Since the TX power is low for the bits ‘1’, a receiver cannot distinguish if a sender sends the frame with the full EOF ‘1011’ or if it has been turned off after sending only the bits ‘10’. The sender may thus suppress sending the last two bits of the frame.

For the 315 MHz AMWSP protocol, the structure and definition of the frame are shown in Table 10.

Table 10 – Frame definition for the 315 MHz AMWSP protocol

Fields	Value
Preamble (PRE)	bit sequence ‘1010101010101010’
Start of frame (SOF)	bit sequence ‘1001’
DATA	MSB is transmitted first
Inverse bits (INV)	bit with inverse value to every third and sixth bit is appended behind the corresponding bit
Synchronization bits (SYNC)	bit sequence ‘01’
End of frame (EOF)	bit sequence ‘1011’

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

Table 11 – Frame definition for the 868,3 MHz AMWSP 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 third and sixth bit is appended behind the corresponding bit
Synchronization 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. Clause 7 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 shall be completed and received. The values of the TX and RX maturity times are specified in Table 12.

A complete telegram consists of a maximum of three 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.

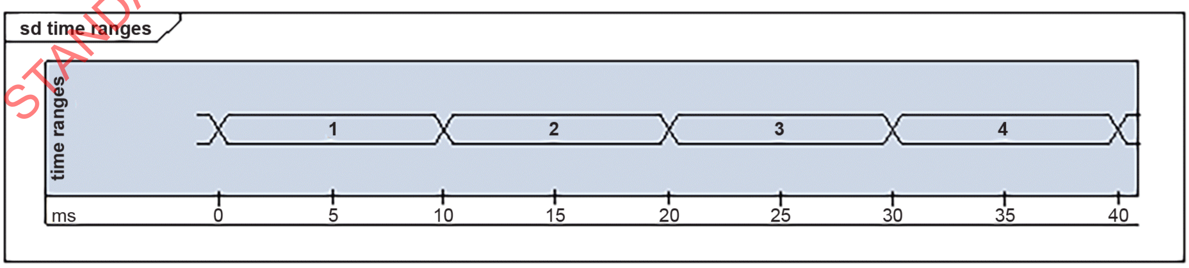
For the receiver, all subtelegrams received from the same transmitter between the end of the first subtelegram until the RX maturity time shall be considered part of the same telegram, including when repeaters are involved. Subtelegrams received after the RX maturity time shall be considered to be part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

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

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



sd = slot divided

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

These four time ranges (see Figure 5) shall be used to send a maximum of three subtelegrams. The scheduling determines which subtelegram number may 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	First subtelegram	Second subtelegram	Third subtelegram
Original	0	1 to 9	20 to 39
Level 1 repeated	10 to 19	20 to 29	
Level 2 repeated	0 to 9	20 to 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 AMWSP protocol. Two are summation based – one of which is four bits long and only used in switch telegrams, and the other is eight bits long – and the third uses an eight-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 summarized in Table 14.

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

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

7.3.2 4 bit summation hash function algorithm

Subclause 7.3.2 describes the 4-bit summation type hash algorithm. The result of the calculation has the length of four 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

Subclause 7.3.3 describes the 8-bit checksum algorithm. The result of the calculation has the length of eight 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 (eight 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 AMWSP protocol is based on the CRC 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 Rec. ITU-T 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.

LBT should be implemented and used 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 AMWSP protocol are described in Clause 8. 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 an AMWSP 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 AMWSP 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 energized by turning a switch. These devices generate a small amount of power only when used and cannot receive messages.

A normal telegram has four 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 four bits long and identified as such by having the value 5 or 6.
– DATA is always one byte long.
– TXID is four bytes long, same as in a normal telegram.
– STATUS byte is not present.
– HASH is four bits long instead of eight 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 four 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.

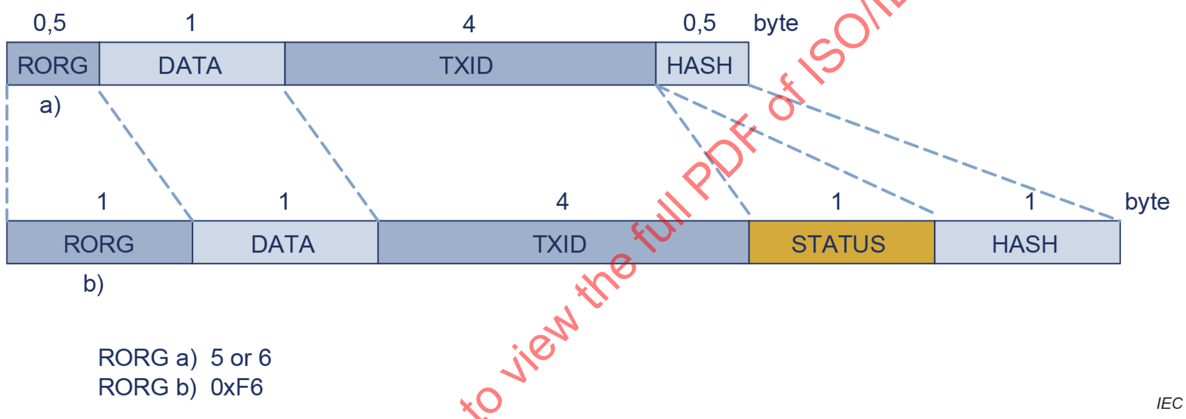


Figure 6 – Conversion of a switch telegram to a normal telegram

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 three 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.

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.

Table 16 – STATUS byte with repeater level bits

Repeater level bits				Description
2^3	2^2	2^1	2^0	
‘0’	‘0’	‘0’	‘0’	Original sender
‘0’	‘0’	‘0’	‘1’	Subtelegram was repeated once
‘0’	‘0’	‘1’	‘0’	Subtelegram was repeated twice
‘1’	‘1’	‘1’	‘1’	Telegram shall not be repeated

Table 17 shows how the repeater bits shall be modified in the repeated subtelegram and the expected action from the repeater.

Table 17 – Repeating bits in STATUS byte

Repeater	Received subtelegram status	Repeater action
Level 1	‘0000’ = original subtelegram received	Subtelegram status set to ‘0001’; subtelegram is repeated
	‘0001’ = once repeated subtelegram received	Subtelegram is not repeated
	‘0010’ = twice repeated subtelegram received	Subtelegram is not repeated
	‘1111’ = subtelegram shall not be repeated	Subtelegram is not repeated
Level 2	‘0000’ = original subtelegram received	Subtelegram status set to ‘0001’; subtelegram is repeated
	‘0001’ = once repeated subtelegram received	Subtelegram status set to ‘0010’; subtelegram is repeated
	‘0010’ = twice repeated subtelegram received	Subtelegram is not repeated
	‘1111’ = subtelegram shall not be repeated	Subtelegram is not repeated

To prevent telegrams from being repeated, a transmitter may output ‘1111’ in the lower nibble of STATUS.

If a repeater receives subtelegrams of a telegram from a transmitter or a repeater, the STATUS byte of the three repeated subtelegrams and the decision, whether the subtelegram is to be repeated, depends on the first received subtelegram according to Table 17.

8.4 Addressing

8.4.1 General

Addressing of telegrams is an essential feature for bidirectional communication by including a specific destination address to which the telegram is directed instead of broadcasting, as in a normal telegram. It is designed to enable future incorporation of additional features.