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Information technology — Real time locating systems (RTLS) —

Part 61: Low rate pulse repetition frequency Ultra Wide Band (UWB) air interface

Technologies de l'information — Systèmes de localisation en temps réel (RTLS) —

Partie 61: Interface d'air ultra large à bas taux de bande de fréquence de répétition d'impulsion (UWB)

Reference number
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Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of the joint technical committee is to prepare International Standards. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

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ISO/IEC 24730-61 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 31, *Automatic identification and data capture techniques*.

ISO/IEC 24730 consists of the following parts, under the general title *Information technology — Real time locating systems (RTLS)*:

— *Part 1: Application program interface (API)*

— *Part 2: Direct Sequence Spread Spectrum (DSSS) 2,4 GHz air interface protocol*

— *Part 5: Chirp spread spectrum (CSS) at 2,4 GHz air interface*

— *Part 21: Direct Sequence Spread Spectrum (DSSS) 2,4 GHz air interface protocol: Transmitters operating with a single spread code and employing a DBPSK data encoding and BPSK spreading scheme*

— *Part 22: Direct Sequence Spread Spectrum (DSSS) 2,4 GHz air interface protocol: Transmitters operating with multiple spread codes and employing a QPSK data encoding and Walsh offset QPSK (WOQPSK) spreading scheme*

— *Part 61: Low rate pulse repetition frequency Ultra Wide Band (UWB) air interface*

— *Part 62: High rate pulse repetition frequency Ultra Wide Band (UWB) air interface*

Introduction

This series of standards defines an air interface protocol for Real Time Locating Systems (RTLS) for use in asset management and is intended to allow for compatibility and to encourage interoperability of products for the growing RTLS market.

This document establishes an air interface technical standard for Real Time Locating Systems that operates within the 6 – 10.6 GHz unlicensed band. RTLSs are wireless systems with the ability to locate the position of an item anywhere in a defined space (local/campus, wide area/regional, global) at a point in time that is, or is close to, real time. Position is derived by measurements of the physical properties of the radio link.

Conceptually there are four classifications of RTLS:

– Locating an asset via satellite - requires line-of-sight - accuracy to 10 meters
– Locating an asset in a controlled area, e.g., warehouse, campus, airport - area of interest is instrumented - accuracy to 3 meters
– Locating an asset in a more confined area - area of interest is instrumented - accuracy to tens of centimetres
– Locating an asset over a terrestrial area using a terrestrial mounted readers over a wide area, cell phone towers for example – accuracy 200 meters

With a further two methods of locating an object which are really Radio Frequency Identification (RFID) rather than RTLS:

– Locating an asset by virtue of the fact that the asset has passed point A at a certain time and has not passed point B
– Locating an asset by virtue of providing a homing signal whereby a person with a handheld can find an asset

Method of location is through identification and location, generally through multilateration types

– Time of Flight Ranging Systems
– Amplitude Triangulation
– Time Difference of Arrival (TDOA)
– Cellular Triangulation
– Satellite Multilateration
– Angle of Arrival

This standard defines the air interface protocol needed for the creation of an RTLS system. There are many types of location algorithms that could be used. Examples of location algorithms are given in Annex A.

Significant portions of this standard were excerpted from IEEE 802.15.4a-2007, *IEEE Standard for Information Technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific Requirements Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs) Amendment 1: Add Alternate PHYs* and from IEEE 802.15.4f-2012, *IEEE Standard for Local and metropolitan area networks — Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs) Amendment 2: Active Radio Frequency Identification (RFID) System Physical Layer*, copyright IEEE, and reproduced with permission by limited license from IEEE. Permission for further use of this material must be obtained from IEEE. Requests may be sent to stds-ipr@ieee.org

Information technology — Real time locating systems (RTLS) —

Part 61:
Low rate pulse repetition frequency Ultra Wide Band (UWB) air interface

1 Scope

This part of ISO/IEC 24730 defines the physical layer (PHY) and tag management layer (TML) of an ultra wide band (UWB) air interface protocol that supports one directional simplex communication readers and tags of a real time locating system (RTLS). This protocol is best utilized for low-data-rate wireless connectivity with fixed, portable, and moving devices with very limited battery consumption requirements.

2 Normative references

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

ISO/IEC/IEEE 8802-15-4, *Information technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements Part 15-4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs)*

ISO/IEC 15963, *Information technology — Radio frequency identification for item management – Unique identification for RF tags*

ISO/IEC 19762, *Information technology AIDC techniques — Harmonized vocabulary — (all parts)*

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC/IEEE 8802-15-4, ISO/IEC 19762 (all parts), and the following apply.

3.1.1
burst
group of ultra wide band (UWB) pulses occurring at consecutive chip periods

3.1.2
frame
format of aggregated bits from a tag management layer (TML) sublayer and/or physical layer (PHY) entity that are transmitted together in time

3.1.3
hybrid modulation
transmission methodology used in the ultra wide band (UWB) physical layer (PHY) that combines both binary phase-shift keying (BPSK) and pulse position modulation (PPM) so that both coherent and non-coherent readers can be used to demodulate the signal

3.1.4
location enhancing information postamble
LEIP
optional set of bits added after the completion of a frame that is used to enhance the ability to locate the transmitter

3.1.5
packet
formatted, aggregated bits that are transmitted together in time across the physical medium

3.1.6
real time locating system
set of radio frequency readers and associated computing equipment used to determine the position of a transmitting device relative to the placement of the reader.

3.1.7
reader
device that receives signals from radio frequency identification (RFID) or real time locating system (RTLS) transmitters.

3.1.8
tag management layer
TML
layer above the physical layer that is utilized for control and encoding of message

3.2 Symbols (and abbreviated terms)

AOA	angle-of-arrival
API	application program interface
BPM	burst position modulation
BPSK	binary phase-shift keying
CRC	cyclic redundancy check
DSN	data sequence number
ETSI	European telecommunications standards institute
FC	frame control for PHY
FCC	federal communications commission
FCS	frame check sequence
IC	Industry Canada
ITU-T	international telecommunication union – telecommunication standardization sector
LEIP	location enhancing information postamble
LRP	low rate PRF
LSbit	least significant bit
MSbit	most significant bit
OOK	on-off keying

PHR	PHY header
PHY	physical layer
PPDU	PHY protocol data unit
PPM	pulse position modulation
PRF	pulse repetition frequency
PSD	power spectral density
PSDU	PHY service data unit
RF	radio frequency
RFID	radio frequency identification
RSSI	received signal strength indicator
RTLS	real time locating system
SECDED	single error correct, double error detect
SFD	start-of-frame delimiter
SHR	synchronization header
TDOA	time difference of arrival
TFR	TML footer
THR	TML header
TML	tag management layer
TOA	time-of-arrival
TPDU	TML protocol data unit
TSD	temperature sensor data bit
UWB	ultra wide band

4 General description

4.1 Introduction

A low rate PRF (LRP) UWB RTLS network is a simple, low-cost locating network. The main objectives of an LRP UWB RTLS network are ease of installation, precision locating, medium range, and RFID auto-identification.

Some of the characteristics of an LRP UWB RTLS network are as follows:

- Over-the-air data rates of 1 Mbit/s, 250 kbit/s, 31.25 kbit/s
- ALOHA media access
- Low rate pulse repetition frequency UWB (1 or 2 MHz)
- Star wireless topology
- Low power consumption
- 3 LRP UWB frequency bands

There are many types of algorithms that could be used to determine the location of objects in the network. Examples of location algorithms are given in Annex A.

4.2 Components of the ISO/IEC 24730-61 RTLS network

The major components of an RTLS and the relationship of those components are shown in Figure 1 — RTLS components. As shown in this figure, the tags communicate with an infrastructure over an air interface. This standard defines this interface from the tag to the infrastructure. There is an optional interface from the infrastructure to the tag, whose definition is outside the scope of this standard. The infrastructure is manufacturer specific and is not within the scope of this document. The infrastructure provides an application program interface (API) through which an application can control the RTLS and retrieve information about location and state of tags. This API is defined by ISO/IEC 24730-1.

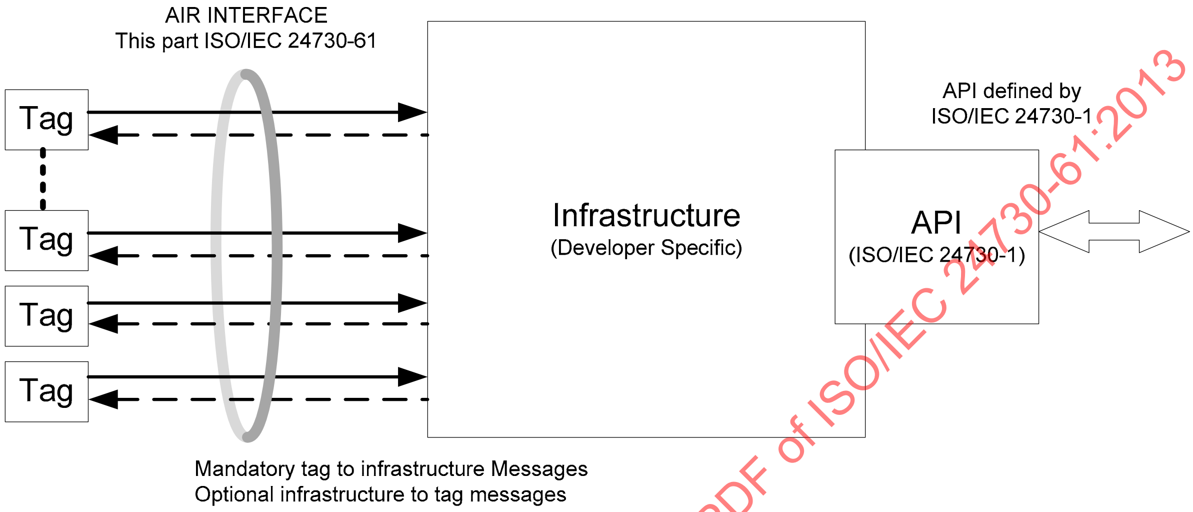


Figure 1 — RTLS components

The design of the infrastructure (e.g., the density of RTLS reader nodes, how the RTLS readers are controlled and communicate with each other, how the infrastructure is set up, etc.) is left completely to the developer. Due to variations in the design of the infrastructure, there may be large variations in vendor design as well as specific implementation scenarios.

4.3 Architecture

The ISO/IEC 24730-61 architecture is defined in terms of a number of blocks in order to simplify the standard. These blocks are called layers. Each layer is responsible for one part of the standard and offers services to the higher layers. An LRP UWB device comprises at least one PHY, which contains the radio frequency (RF) transceiver along with its low-level control mechanism, and a TML sublayer that provides access to the physical channel for all types of transfer. This layered approach is shown in Figure 2.

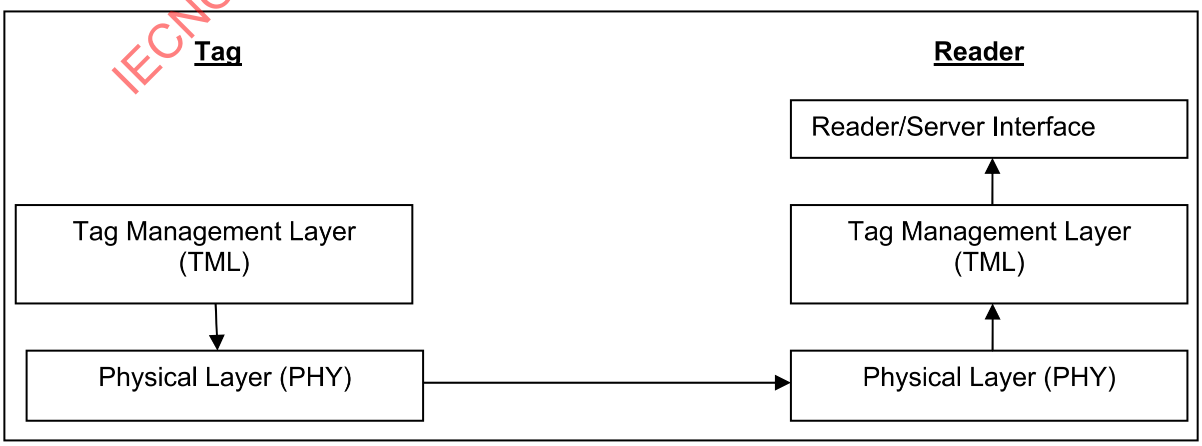


Figure 2 — LRP UWB device architecture

The upper layers, shown in Figure 2, consist of a network layer, which provides network configuration, manipulation, and message routing, and an application layer, which provides the intended function of the device. The definition of these upper layers is outside the scope of this standard.

4.4 Functional overview

A brief overview of the general functions of an LRP UWB system is given in this subclause.

4.4.1 Data transfer from tag to infrastructure reader

When a tag wishes to transfer data to an infrastructure reader, it uses an ALOHA protocol.

In the ALOHA protocol, a device transmits when it desires to transmit without sensing the medium or waiting for a specific time slot. The ALOHA mechanism is appropriate for LRP UWB networks since the probability of collision is reasonably small if the probability of clear channel is sufficiently large. In addition, the energy required for a UWB transmission is so small, it allows for rapid blink rates, thereby allowing an occasional transmission to be sacrificed for the benefits of simplifying the tag transmit protocol.

Due to the inherent broadcast nature of the ALOHA protocol, care should be taken to ensure that groups of tags that are blinking at the same rate do not overlap for long periods of time. Depending on the precision of the clock used to time the blink rate, design considerations should be considered to prevent sustained collisions between tags.

4.4.2 Frame structure

The frame structures have been designed to keep the complexity to a minimum while at the same time making them sufficiently robust for transmission on a noisy channel. Each successive protocol layer adds to the structure with the layer-specific headers and footers. The TML frames are passed to the PHY as the PHY service data unit (PSDU), which becomes the PHY payload. The PHY protocol data unit (PPDU) or PHY layer is shown in Figure 3.

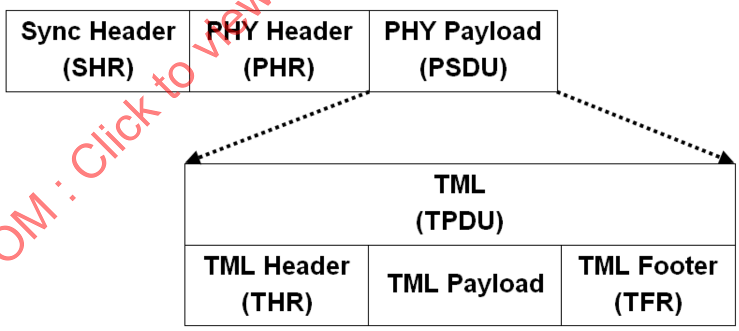


Figure 3 — PHY layer frame Structure (PPDU)

The format of the synchronization header (SHR) and PHY header (PHR) is defined in clause 5 in their respective clause.

The format of the TML header (THR) and TML footer (TFR) is defined in clause 6 in their respective clause.

4.4.3 Data verification

In order to detect bit errors, a frame check sequence (FCS) mechanism employing a 16-bit International Telecommunication Union—Telecommunication Standardization Sector (ITU-T) cyclic redundancy check (CRC) is used to detect errors in every PSDU, as defined in clause 6.10.

4.4.4 Overview of UWB options

The UWB PHY allows for operation using possibilities selected from lists of the following variables:

- Center frequencies
- Bandwidths occupied
- Pulse repetition frequencies (PRFs)
- Data rates
- Pulses per bit

5 PHY specification

5.1 General requirements and definitions

Unless otherwise specified in the PHY clause, all reserved fields shall be set to zero on transmission and may be ignored upon reception.

The LRP UWB PHY waveform is based upon an impulse radio signalling scheme using band-limited data pulses. It consists of three frequency channels and occupies the spectrum from 6.2896 to 9.1856 GHz.

A combination of on-off keying (OOK) modulation or pulse position modulation (PPM) is used to support both coherent and non-coherent readers using a common signaling scheme. The choice of OOK or PPM is used to modulate the symbols, with each symbol being composed of one or more active bursts of UWB pulses. The various data rates are supported through the use of variable-length bursts.

The LRP UWB PHY supports three transmission modes as shown in Table 1.

Table 1 — LRP UWB signalling modes and data rates

Mode	PRF (MHz)	Data Rate	Comment
Long Range Mode	2.0	31.25 kbit/s	Best Sensitivity
Extended Mode	1.0	250 kbit/s	Moderate data rate, but improved sensitivity
Base Mode	1.0	1 Mbit/s	Highest data rate

All transmit modes are optional, but all shall be implemented in the reader and operate concurrently. Active RFID systems are often simplex systems so mandatory modes are not defined for the PHY but separately for the transmitter and reader.

Where the PHY has different characteristics depending on the transmission mode, those characteristics are defined for each mode separately. Otherwise, the characteristics of the PHY are independent of transmission mode.

5.2 Modulation and data rates

A compliant device shall operate in one or more frequency bands using the modulation and spreading formats summarized in Table 2.

Table 2 — Modulations and data rates

PHY (MHz)	Chip Rate (kchip/s)	Modulation	Bit Rate (kbit/s)	Symbol Rate (ksymbol/s)	Symbols
LRP UWB (optional)	2000	Manchester PPM	31.25	31.25	Binary
LRP UWB (optional)	1000	OOK	250	250	Binary
LRP UWB (optional)	1000	OOK	1000	1000	Binary

This standard is intended to conform to established regulations in Europe, Japan, Republic of Korea, Canada, China, and the United States. The regulatory documents listed below are for information only and are subject to change and revisions at any time. Devices conforming to this standard shall also comply with specific regional legislation.

Europe:

- Approval standards: European Telecommunications Standards Institute (ETSI)
- Documents: ETSI EN 302 500-1, ETSI EN 302 500-2]
- Approval authority: National type approval authorities

United States:

- Approval standards: Federal Communications Commission (FCC), United States
- Documents: FCC CFR47, Clauses 15.247 and 15.519

Canada:

- Approval standards: Industry Canada (IC), Canada
- Document: GL36 Document: IC RSS210

5.3 LRP UWB PHY channel numbering

The LRP UWB PHY uses three possible frequencies, and the channel numbers are defined in Table 3. A total of 3 channels, numbered 0 to 2, are available in the 6289.6-9185.6 MHz frequency band.

Table 3 — LRP UWB PHY channel frequencies

Channel Number	Center Frequency (MHz)
0	6489.6
1	6988.8
2	7987.2

5.4 LRP UWB PHY symbol structure

In base mode, a LRP UWB PHY symbol consists of presence/absence of pulses in 1 MHz PRF train.

In extended mode, LRP UWB PHY symbol consists of presence/absence of pulses in 1 MHz PRF train generated by convolution code with octal generators (5, 7, 7, 7).

In long range mode, LRP UWB PHY symbol consists of Manchester-encoded groups of 64 pulses (32 on, 32 off) in 2 MHz PRF train.

5.4.1 Base mode OOK PHY symbol structure

5.4.1.1 General

In the base mode OOK modulation scheme, each symbol carries one bit of information. The base mode operates at 1 chip per symbol and with a PRF of 1 MHz, so the symbol time T_{DSYM} is 1 μs and the chip time T_{CHIP} is also 1 μs. Binary data values 0 and 1 are encoded as per Table 4. The data rate is thus 1 Mbit/s. The pulse duration T_{PULSE} is much shorter than the symbol time. The pulse is nominally sent in the centre of the chip and symbol period T_{DSYM} as shown in Figure 4.

Table 4 — Base mode OOK symbol encoding

Binary value being encoded	Transmitted signal
0	No energy is transmitted during the 1 μs symbol time
1	A single pulse is transmitted during the is 1 μs symbol time

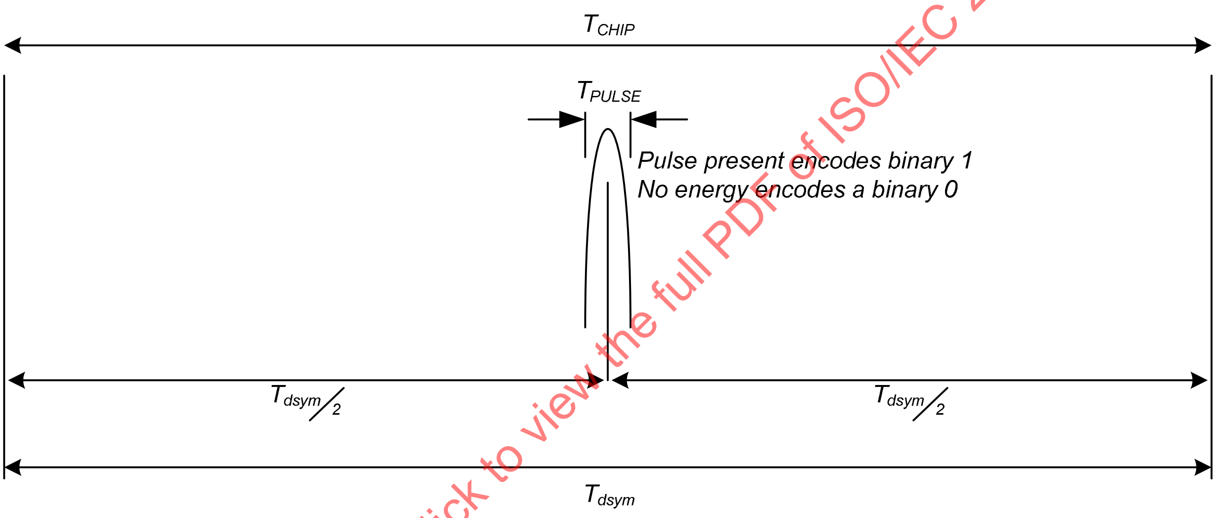


Figure 4 — Base mode OOK PHY symbol structure

5.4.1.2 Base mode OOK PHY PSDU synchronization signal

During the base mode PSDU transmission, after every 128 symbols of user data, the PHY inserts four chips of binary 1. This ensures that the reader has enough information to retain synchronization when the user data is all zeros. These four chips/symbols are removed in the PHY and not decoded as user data.

5.4.2 Extended mode OOK PHY symbol structure

5.4.2.1 General

In the extended mode OOK modulation scheme, each symbol consists of four chips generated by a rate ¼ convolutional code using octal generators 5,7,7,7 for k=3, as shown in Figure 5.

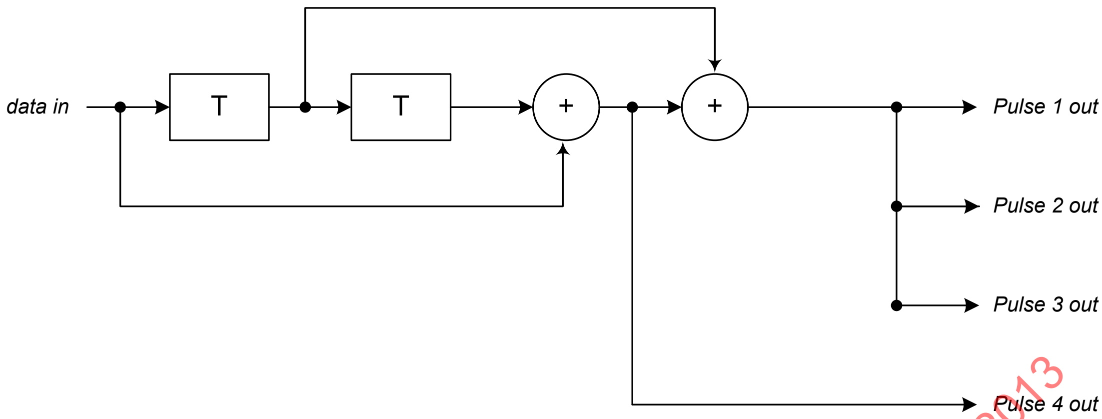


Figure 5 — Extended mode OOK PHY transmitter convolution code

The extended mode reader may employ a relatively simple Viterbi decoder with hard or soft decisions to make use of the coding gain afforded by the transmitter convolution code.

Extended mode employs a PRF of 1 MHz with a rate ¼ code giving a symbol time of 4 µs. The data rate is thus 250 kbit/s. The pulses are nominally centred within the chip periods as shown in Figure 6. The individual pulses shown here may or may not be present depending on whether the pulse out value is binary 1 or binary 0 as per Table 5. During each symbol period, the least significant pulse, Pulse 1, is transmitted first, and the most significant pulse, Pulse 4, is transmitted last.

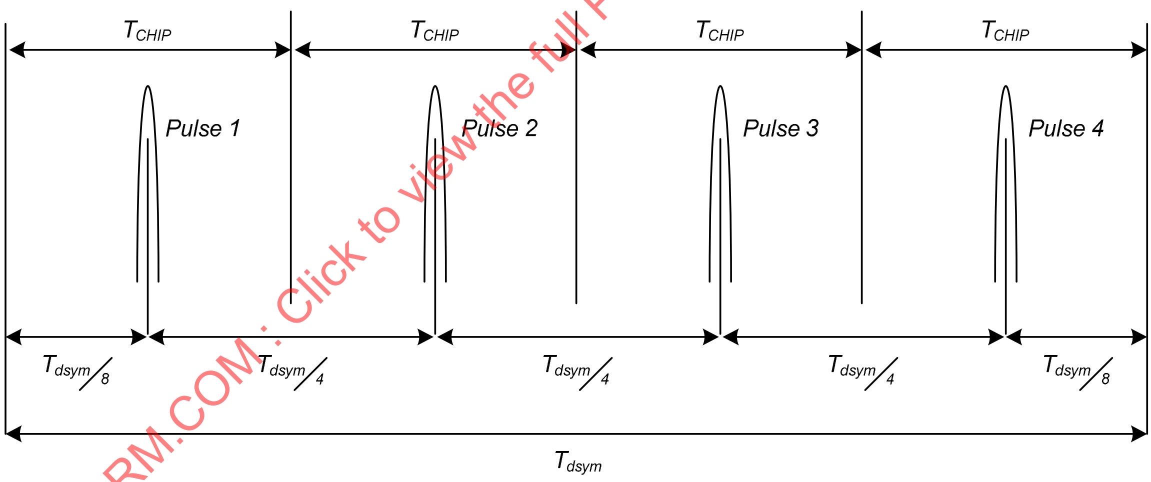


Figure 6 — Extended mode OOK PHY symbol structure

Table 5 — Extended mode OOK pulse to chip encoding

Pulse Out value	Transmitted Chip
0	No energy is transmitted during this chip time
1	A pulse is transmitted during this chip time

5.4.2.2 Extended mode OOK PHY PSDU synchronization signal

During the extended mode PSDU transmission, after every 32 symbols of user data (equivalent to 128 chips) the PHY inserts four chips of ‘1’ pulse. This ensures that the reader has enough information to retain synchronization when the encoded output pulses are ‘0’ pulses (i.e. no transmitted energy). These four chips (1 symbol of pulses) are removed in the PHY before the received pulse (Viterbi) decoding and therefore are not included in the convolutional decoding and not decoded as user data.

5.4.3 Long range mode PPM PHY symbol structure

5.4.3.1 General

In the long range mode PPM modulation scheme, each symbol encodes one bit using 64-chips at a chipping rate of 2 MHz PRF, with Manchester encoding as given in per Table 6. The data rate is thus 31.25 kbit/s. Figure 7 shows this diagrammatically. When a pulse is present it is nominally centred within the chip period.

Table 6 — Long Range mode PPM symbol encoding

Binary value being encoded	Transmitted signal
0	The symbol period is 32 μs (64 chip times). No energy is transmitted during first 16μs (32 chip times), and then in the second 16 μs (32 chip times) 32 pulses are transmitted.
1	The symbol period is 32 μs (64 chip times). In the first 16μs (32 chip times) 32 pulses are transmitted, and then no energy is transmitted during second 16 μs (32 chip times).

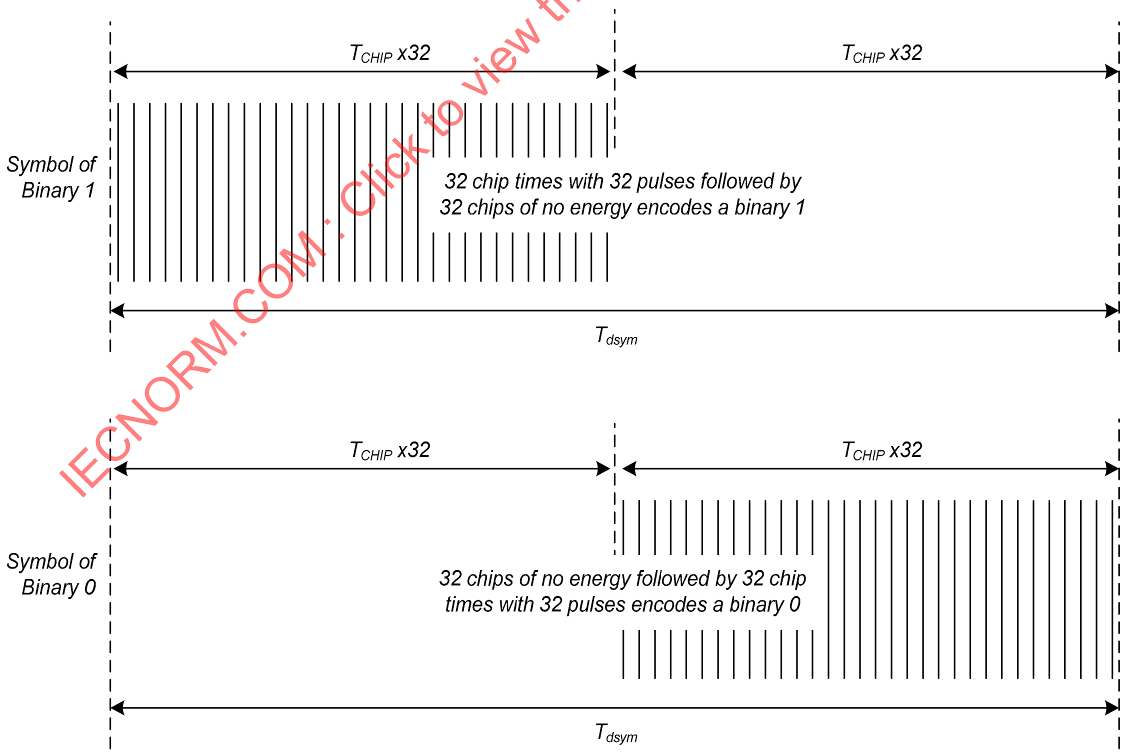


Figure 7 — Long range mode OOK PHY symbol structure

5.4.3.2 Long range mode PPM PHY PSDU synchronization signal

No additional synchronization measures are needed in long range mode since its Manchester encoding scheme ensures that sufficient pulses are transmitted.

5.4.4 LRP UWB SHR

The SHR consists of two components – the preamble and start-of-frame delimiter (SFD). The following clauses describe the formats of the preamble and SFD for the different LRP UWB PHY transmission modes.

5.4.4.1 UWB SHR preamble

5.4.4.1.1 LRP UWB base mode SHR preamble

The LRP UWB base mode SHR preamble consists of a continuous stream of pulses at the base mode PRF of 1 MHz, with a length between 16 and 128.

5.4.4.1.2 LRP UWB extended mode SHR preamble

The LRP UWB extended mode SHR preamble consists of a continuous stream of pulses at the extended mode PRF of 1 MHz, with a length between 16 and 256.

5.4.4.1.3 LRP UWB long range mode SHR preamble

The LRP UWB long range mode SHR preamble consists of three segments, which are transmitted in turn:

A continuous stream of pulses at the long range mode PRF of 2 MHz, with a length between 1024 and 8192 pulses.

The following pulse/no-pulse sequence, transmitted at a PRF of 2 MHz:

'-' represents 'no pulse', 'P' represents a pulse:

- - - P - P - - P - - P P P - P

A series of between 16 and 64 '1' symbols, transmitted as per the long range mode PHY symbol structure defined in clause 5.4.3.1

5.4.4.2 LRP UWB SHR SFD

The LRP UWB SHR start-of-frame delimiter (SFD) consists of the 16-bit pattern, shown in Figure 8. This is defined in symbols for long range mode and as pulses for basic and extended mode. The SFD is transmitted starting from the leftmost bit (b0).

LRP UWB SHR SFD (b0-b15)
0001 0100 1001 1101

Figure 8 — LRP UWB SHR start-of-frame delimiter

5.4.5 LRP UWB PHY header (PHR)

5.4.5.1 General

This is defined in symbols and is therefore common to base, extended, and long range modes with the exception of the encoding type (bits 0-2). The encoding type is defined in symbols for long range mode and as pulses for basic and extended mode.

The PHY header, as shown in Figure 9, is inserted between the SFD and the PSDU. The PHR contains information about the modulation mode used to transmit the PSDU, the length of the frame payload, and the specification for the optional location enhancing information postamble (LEIP) sequence. Additionally, six parity check bits are used to further protect the PHR against channel errors. The sub-fields of the PHR header are defined in individual sub-clauses below.

Bit 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
E2	E1	E0	EXT	C5	C4	C3	C2	C1	C0	L6	L5	L4	L3	L2	L1	L0	R	LL2	LL1	LL0	LP
Encoding Type			Header Extension	SECDED Check Bits						Frame Length							Reserved	LEIP Length			LEIP Position

Figure 9 — PHR bit assignment in LRP UWB PHY

5.4.5.2 PHR encoding type field

Long range mode is specified (and detected) by its own unique symbol mapping, defined in Clause 5.4.3.1 and the use of a 2 MHz PRF. In long range mode the encoding type field of the PHR is given by Table 7.

Table 7 — PHR encoding type field in long range mode

Encoding Type Value E2 – E0	Meaning
000	Each symbol encodes 1 bit. Each symbol consists of 64-chips and uses Manchester encoding.
001 to 111	Reserved

In base mode and extended mode where the PHR is sent with a chip rate of 1 MHz the Encoding Type field of the PHR is given by Table 8. These three bits are encoded as pulses per clause 5.4.1.1. Only two values are legal, 000 and 111. This allows a reader to use all three bits in a voting scheme to determine whether it should switch to using extended mode decoding for the remainder of the PHR and the PSDU or should continue decoding the PHR and PSDU in base mode.

Table 8 — PHR encoding type field in base mode and extended mode

Encoding Type Value E2 – E0	Meaning
000	This value indicates the operating mode is base mode. All remaining bits in the frame continue to be encoded as per clause 5.4.1.1
111	This value indicates the operating mode is extended mode. All bits in the remaining fields of the PHR and PSDU are encoded as per clause 5.4.2.1
001 to 110	ILLEGAL – These values can never be legally used. The reader may use all three bits of the two legal values 000 and 111 in a voting scheme to decide which is actually present.

5.4.5.3 PHR header extension bit

The PHR header extension bit shall be set to zero upon transmission. If a PPDU is received with the PHR Header Extension bit set, the device shall discard the PPDU.

5.4.5.4 PHR SECDED check bits

The SECDED (single error correct, double error detect) field, C5–C0, is a set of six parity check bits that are used to protect the PHR from errors caused by noise and channel impairments. The SECDED bits are a simple Hamming block code that enables the correction of a single error and the detection of two errors at the reader. The SECDED bit values depend on PHR bits 0–21 and are computed as follows:

C0 = XOR (LP, LL2, LL1, LL0, R)

C1 = XOR (L6, L5, L4, L3, L2, L1, L0)

C2 = XOR (E1, E0, EXT, L3, L2, L1, L0, LL0, R)

C3 = XOR (E2, E0, EXT, L5, L4, L1, L0, LL2, LL1)

C4 = XOR (E2, E1, EXT, L6, L4, L2, L0, LP, LL1, R)

C5 = XOR (all bits including C0 to C4, but excluding C5)

5.4.5.5 PHR frame length field

The Frame Length field shall be set to the length of the PSDU in octets where L6 represents the most significant bit and L0 represents the least significant. For example, b0000000 {L6-L0} ≡ Frame Length 0, b0000001 {L6-L0} ≡ Frame Length 1, etc.

5.4.5.6 Reserved bit

This bit is reserved for possible extension of the LEIP length field or for some other future use. It shall be set to zero upon transmission and may be ignored upon receipt.

5.4.5.7 PHR LEIP length field

This gives the length of the LEIP in pulses. The meaning of this field is defined in Table 9.

Table 9 — PHR LEIP length field meaning

LEIP Length Field value LL2 to LL0	Meaning
000	The LEIP sequence is not present.
001	The LEIP sequence is 16 pulses in length
010	The LEIP sequence is 64 pulses in length
011	The LEIP sequence is 128 pulses in length
100	The LEIP sequence is 192 pulses in length.
101	The LEIP sequence is 256 pulses in length.
110	The LEIP sequence is 512 pulses in length.
111	The LEIP sequence is 1024 pulses in length.

5.4.5.8 PHR LEIP position bit

This bit specifies the position of the optional LEIP sequence. This bit only applies if the LEIP length field has a non-zero value, in which case the meaning of this bit is then as defined in Table 10. When the LEIP length field is 000, then the LEIP position bit is reserved and thus shall be set to zero upon transmission and may be ignored upon receipt.

Table 10 — PHR LEIP position bit meaning

LEIP Position Bit Value LP	Meaning
0	The LEIP is delayed
1	The LEIP is not delayed

When the LEIP sequence is delayed, it is delayed by 0.815 ms from the start of the SFD. The LEIP then starts on the first chipping interval after the delay. Where the PSDU is of sufficient length that it has not ended by this time, then the LEIP is deferred to start in the chipping interval immediately following the final chipping interval being used for the PSDU.

When the LEIP is not delayed, the LEIP starts in the chipping interval immediately following the final chipping interval being used for the PSDU.

5.4.6 LRP UWB data field

The data field shall use the same encoding as the other portions of the symbol structure for the given modulation method.

5.4.7 LRP UWB location enhancing information postamble

The LEIP consists of a train of UWB pulses. The PRF of the LEIP pulse train is:

- 1 MHz in the LRP UWB base and extended modes
- 2 MHz in the long range mode.

Information in the PHY header (see clause 5.4.5) indicates whether or not the LEIP is appended to a transmitted packet.

If the information in the PHY header indicates that the LEIP is appended to the transmitted packet, further information in the PHY header indicates when the first LEIP pulse occurs immediately. It occurs either immediately after the end of the PSDU, or 0.815 ms after the start of the SHR SFD

The length of the LEIP (in pulses, at the appropriate rate) is defined in Table 9 by the PHR LEIP length field in clause 5.4.5.7.may be 16, 64, 128, 192, 256, 512 or 1024, as indicated by information in the PHY header.

5.4.8 LRP UWB transmitter specification

5.4.8.1 Pulse shape

The OOK UWB PHY shall employ an impulse transmitter that instantaneously produces an ultra wide band frequency response. There are no constraints on the specific pulse shape providing that the pulse shall comply with the transmit power spectral density (PSD) mask defined in clause 5.4.8.3.

5.4.8.2 Pulse timing

The transmission time of any individual pulse shall not drift more than 11 ns from its nominal transmission time during a 128 symbol period over the specified operating temperature range of the device.

In order to avoid long sequences of zeros driving the need for high quality clocks, the symbol structure in the base and extended modes includes a periodic sync marker as described in clause 5.4.1.2 and 5.4.2.2, respectively. No additional sync marker is required in the long range Mode.

5.4.8.3 Transmit power spectral density mask

The transmitter shall operate with a power spectral density (PSD) contained by one of three PSD masks defined in Table 11 and Figure 10. The permitted spectral density is defined relative to maximum spectral density, dBr, and shall be made using a 1 MHz resolution bandwidth and a 1 MHz video bandwidth. Additionally, the upper -10 dBr point of the transmitter PSD shall be at least 200 MHz above a nominal frequency, f_n, and the lower -10 dBr point shall be at most 200 MHz below the same nominal frequency.

Table 11 — LRP UWB PHY PSD mask

Channel Number	f_n	Frequency	PSD Limit
0	6489.6 MHz	< 5624.32 MHz	-18 dBr
		5624.32 MHz to 5786.56 MHz	-10 dBr
		5786.56 MHz to 7192.64 MHz	0 dBr
		7192.64 MHz to 7354.88 MHz	-10 dBr
		> 7354.88 MHz	-18 dBr
1	6988.8 MHz	< 6090.24 MHz	-18 dBr
		6090.24 MHz to 6165.12 MHz	-10 dBr
		6165.12 MHz to 8311.68 MHz	0 dBr
		8311.68 MHz to 8386.56 MHz	-10 dBr
		> 8386.56 MHz	-18 dBr
2	7987.2 MHz	< 6922.24 MHz	-18 dBr
		6922.24 MHz to 7121.92 MHz	-10 dBr
		7121.92 MHz to 8852.48 MHz	0 dBr
		8852.48 MHz to 9052.16 MHz	-10 dBr
		> 9052.16 MHz	-18 dBr

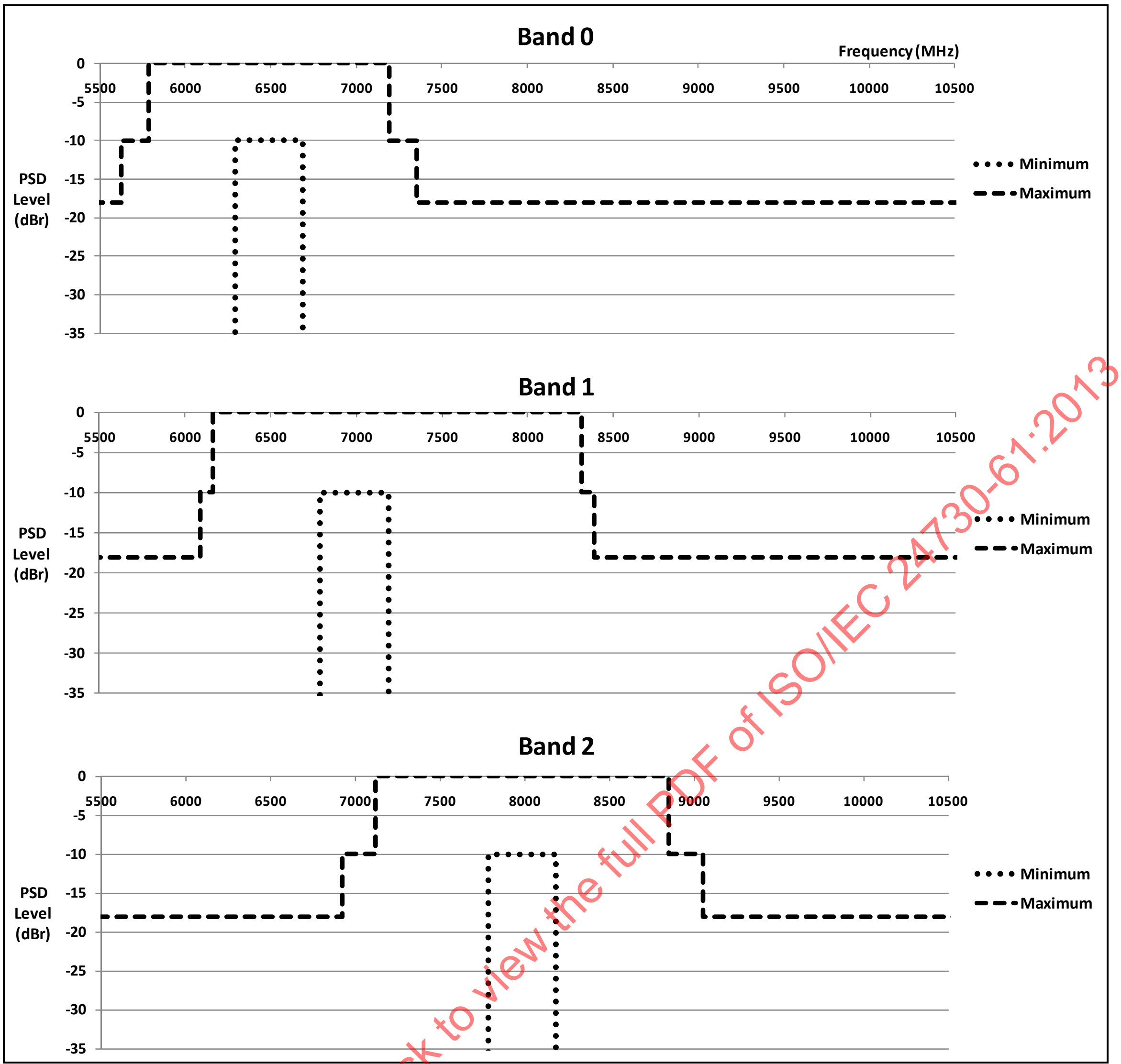


Figure 10 — Low rate PRF PHY PSD Mask

5.4.9 LRP UWB reader specification

The reader shall support each mode of operation: base mode, extended mode and long range mode.

Receiving devices shall be capable of receiving at least one channel allowed by regulations for the region(s) in which the device operates.

6 Tag management layer

This clause specifies the format of the tag management layer protocol data unit (TPDU). All values shall use the same encoding as the other portions of the symbol structure for the given modulation method. The frame length as defined in the PHY header clause 5.4.5 may be required to fully decode a TPDU frame.

The frames in the TPDU sublayer are described as a sequence of fields in a specific order. All frame formats in this subclause are depicted in the order in which they are transmitted by the PHY, from left to right, where the leftmost bit is transmitted first in time. Bits within each field are numbered from 0 (leftmost and least significant) to k-1 (rightmost and most significant), where the length of the field is k bits. Fields that are longer than a single octet are sent to the PHY in the order from the octet containing the lowest numbered bits to the octet containing the highest numbered bits.

Unless otherwise specified in this clause, all reserved bits shall be set to zero upon transmission and may be ignored upon receipt.

6.1 Overview

Two ID encoding options are allowed, one employing an ISO/IEC 15963 type of ID, and the other employing an IEEE EUI-64 ID. The tag may use either option. The infrastructure should be capable of decoding both options.

Three message types are defined for the two ID encoding options:

- A Minimum blink with no encoding header, temp info, optional extended ID, or optional extended data
- A Basic blink with optional extended data
- An Extended ID blink with optional extended data

The minimum blink is defined in detail in clause 6.5. The basic and extended ID blink are controlled by the frame control octet as defined in detail in clause 6.2.4. Figure 11 shows the general frame format of the Tag Management Layer.

		ID Option 1		ID Option 2								
		IEEE ID		ISO/IEC 15963 ID, 6 octets				Optional Extended ID, 0/3-34 octets			Optional Extended Data	
1 octet	1 octet	8 octets	1 octet	1 octet	1 octet	4 octets	0/1 octets	1 octet	1 octet	1-32 octets	Variable # octets	2 octets
Frame Control (FC)	Sequence Number	Tag ID – EUI-64 (Source Address)	Encoding Header	Allocation Class	Mfg ID	Tag ID	Temp Sensor	Ex-ID Source	Ex-ID Length	Ex-ID	EXT Data	FCS
THR			TML Payload									TFR

Figure 11 — General TML frame format

6.2 Frame control

The frame control (FC) is a single octet with bits defined in Figure 12.

Frame Control (FC)			
Bit 0-2	3	4-5	6-7
Frame Type	Long Frame Control	Destination Address Mode	Source Address Mode
101	0	00	00 (ISO ID Option) 11 (IEEE ID Option)

Figure 12 — TML frame control frame format

This octet allows for configuring the ID Option as defined in clause 6.2.4. The options are:

- ID Option 1: IEEE ID (FC = 0xC5)
- ID Option 2: ISO/IEC 15963 ID (FC = 0x05)

6.2.1 Frame type

The frame type field is 3 bits in length and shall contain the value that indicates a multipurpose frame. The binary value is 101 (b_0=1, b_1=0, b_2=1).

6.2.2 Long frame control

The long frame control field is 1 bit in length and shall be set to zero to indicate a 1-octet frame control field.

6.2.3 Destination address mode

The destination address mode field is 2 bits in length and shall be set to 00 (b_4=0, b_5=0) to indicate that no destination address is required since a blink message is inherently a broadcast frame.

6.2.4 Source address mode

The source address mode field is 2 bits in length and shall be set to one of the values listed in Table 12.

Table 12 — Source address mode field

Source Address Mode b6 b7	Description
00	No source address in THR. This mode selects ID option 2, ISO/IEC 15963 as defined in clause 6.6
11	8-octet source address. This mode selects ID option 1, IEEE ID as defined in clause 6.4

6.3 Sequence number

The frame shall have a sequence number. The sequence number octet contains the current value of the data sequence number (DSN). The DSN is inserted into the outgoing blink frame, after which the DSN is incremented by 1 (modulo 256).

6.4 Tag ID (EUI-64)

The tag ID within this blink frame is the 64-bit source address (EUI-64). Every tag employing this blink format shall have a unique EUI-64 identifier. This address shall be defined by the IEEE Registration Authority[1]. The company_ID (OUI) within the EUI-64 Tag ID defines the interpretation of the optional extended data from clause 6.9.

6.5 Encoding header

The encoding header is a single octet value as defined in Table 13. This value is typical to a TPDU message, but may only be omitted in order to send the minimal length blink as shown in Figure 13 and Figure 14. If this octet is omitted, it may be assumed that the bi-level telemetry values and the battery level are either unknown or unchanged from any previous report. In this case, there must not be any additional data present in the frame. A tag may send a mixture of minimal blinks and longer blinks.

[1] Interested applicants should contact the IEEE Registration Authority, http://standards.ieee.org/develop/regauth/grpmac/.

Table 13 — Encoding header sub-fields

Field	Bit number(s)	Meaning
Encoding Mode	7,6	This two-bit field defines the encoding mode of the frame with the following meanings: 0, 0 – Reserved. 0, 1 – The blink frame has no optional extended ID 1, 0 – The blink frame carries an additional optional extended ID 1, 1 – Reserved.
TSD	5	This bit defines whether the frame contains temperature sensor data, with the following meanings: 0 – means no temperature sensor data 1 – means temperature sensor data is present in the frame
Bi-Level telemetry	4, 3, 2	These bits are available for signalling the value of three separate bits of bi-level sensor telemetry data. The meaning and use is tag manufacturer ID dependant. Example uses are for conveying button state, motion sensor trigger, or anti-tamper alarms.
Battery Level	1,0	These bits are used to signal the battery health, with the following meanings: 0, 0 – battery good 1, 0 – battery 10% to 30% 0, 1 – battery 0% to 10% 1, 1 – tag does not provide battery status

1 octet	1 octet	1 octet	1 octet	4 octets	2 octets
Frame Control (FC) 0x05	Sequence Number	Allocation Class	Mfg ID	Tag ID	FCS

Figure 13 — Minimal blink frame encoding with an ISO ID

1 octet	1 octet	8 octets	2 octets
Frame Control (FC) 0xC5	Sequence Number	Tag ID – EUI-64 (Source Address)	FCS

Figure 14 — Minimal blink frame encoding with an IEEE ID

6.6 ISO/IEC 15963 ID

The ISO/IEC 15963 ID is a 6-octet field, consisting of an allocation class octet, a manufacturer ID octet, and a four octet tag ID defined as follows:

6.6.1 Allocation class

The current class is 0, so this is eight bits of “0”.

6.6.2 Manufacturer ID

The manufacturer ID is a single octet that is a unique identification of the manufacturer of the tag. A single manufacturer may have multiple IDs assigned to them. The manufacturer ID defines the interpretation of the optional extended data from clause 6.9. The 8-bit manufacturer's identification number shall be assigned in accordance with ISO/IEC 15963, under Allocation Class 0x00.

6.6.3 Tag ID

Unique identification of the tag (4 octets) assigned by the manufacturer.

6.7 Temperature sensor data

This is an optional octet that shall be present if the temperature sensor data (TSD) bit of the encoding header is set to 1.

This octet gives the temperature as a signed 8-bit integer with the range -128 °C to +127 °C.

6.8 Optional extended ID

This is an optional field that shall be present if the encoding mode (bit 6) of the encoding header is set. When the extended ID is present it consists of an *Ex-ID Source* octet, an *Ex-ID Length* octet, and a variable length *ExID* field. This feature is reserved for a future version of this standard and is not currently defined.

6.8.1 Ex-ID source

This octet defines the source of the ExID (originating organization and/or ID encoding type).

Values 0-255, allocated according to Table 14.

Table 14 — Ex-ID Source codes and their meaning

Ex-ID Source	Description
0x00 to 0xBF	Reserved. ISO/IEC may define these Ex-ID Source codes in future versions of this standard.
0xC0 to 0xFF	Manufacturer Specific. Manufacturers may define their own meaning for these Ex-ID Source codes. Interpretation of these codes then is dependent on the manufacturer ID that is defined in clause 6.4 or clause 6.6.2

6.8.2 Ex-ID length

This octet defines the length of the ExID in octets as shown in Table 15. Bits 0-4 represent the number of octets and bits 5-7 are reserved and shall be set to zero upon transmission and may be ignored upon receipt.

Table 15 — Ex-ID length

Ex-ID length b0 (LSbit) – b4 (MSbit)		Reserved b5-b7
00000	1 octet	000
10000	2 octets	
---	---	
01111	31 octets	
11111	32 octets	

6.8.3 ExID

The *ExID* occupies the next n octets of the extended ID field, where n is *Ex-ID Length* plus 1. The least significant bit of the least significant octet of the *ExID* is sent first.

6.9 Optional extended data

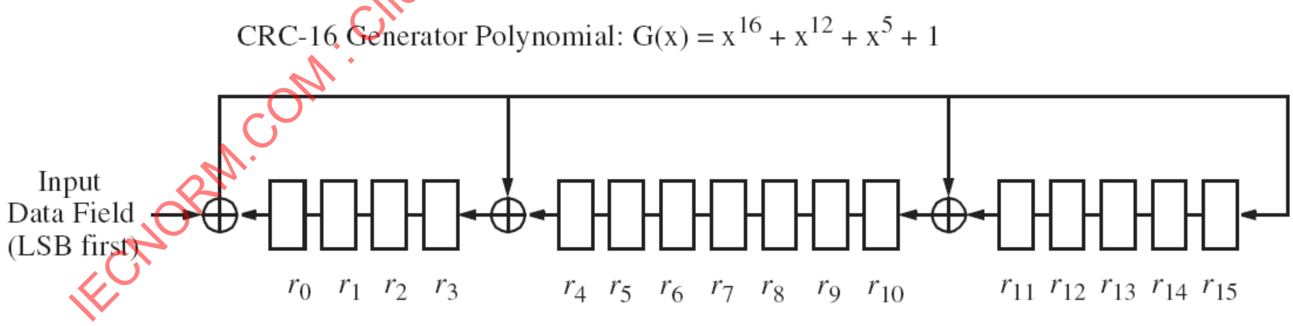
This field is an extension to allow the blink message to carry manufacturer specific information and is thus outside the scope of this document. The interpretation of data within this field depends on the manufacturer ID that is defined in clause 6.6 or the IEEE ID range that is defined in clause 6.4.

6.10 Frame check sequence

The frame check sequence (FCS) field, or TML footer (TFR) consists of a 16-bit ITU-T CRC. The FCS is calculated over the THR and TML payload parts of the frame. The FCS shall be calculated using the following standard generator polynomial of degree 16 (0x1021):

$$G_{16}(x) \quad x^{16} | x^{12} | x^5 | 1 \quad G_{16}(x) \quad x^{16} \ (x^{12} | x^5 | 1$$

A typical implementation is depicted in Figure 15.



1. Initialize the remainder register (r0 through r15) to all ones (0xFFFF).
2. Shift the THR and TML Payload into the divider in the order of transmission (LSBit first).
3. After the last bit of the data field is shifted into the divider, the remainder register contains the FCS.
4. The FCS is appended to the data field so that r0 is transmitted first.

Figure 15 — Typical FCS implementation

Annex A
(informative)

Using ISO/IEC 24730-61 and ISO/IEC 24730-62 for RTLS Applications

A.1 Introduction

RTLS devices are used to identify and locate people or objects in industrial or commercial environments. Typical applications include asset management, inventory management, process control and automation, safety and accountability, and many others.

In its simplest form an RTLS system comprises a number of transmit-only tags which periodically transmit a packet containing a unique ID and a small amount of data. The packet is received by one or more readers which may simply register the tag as present, or may employ further processing to determine the location of the tag. More complex RTLS systems might employ two-way communications with the tag for control, communication and coordination.

Active RTLS systems are generally characterized by the following attributes:

- Very low cost, low power consumption tags
- Large populations of tags
- Low duty-cycle transmissions
- A variety of readers from very short range (a few meters) to very long (hundreds of meters)
- Very short packet lengths, often with no data beyond the device ID and small number of status bits

ISO 24730-6 contains two PHYs particularly suitable for RTLS:

- The LRP UWB PHY in ISO/IEC 24730-61
- The HRP UWB PHY in ISO/IEC 24730-62

This Annex describes how these PHYs features can be configured for RTLS applications.

A.2 Overview of UWB RTLS PHYs

A.2.1 LRP UWB PHY

A.2.1.1 Description

The Low Rate PRF Ultra wide band (LRP UWB) PHY is a low complexity PHY optimized for RTLS devices. In RTLS systems the hardware components are highly asymmetric, with large populations of very low complexity tags being identified by much smaller populations of potentially complex readers. Typically a tag transmits messages to a reader, although the reverse architecture is also possible (though less common).

The LRP UWB PHY has therefore been predominantly driven by the need for very low complexity transmitters (tags). Low complexity considerations include:

- Simple to implement modulation
- No data encoding or whitening in Base Mode
- Simple to implement PSD mask
- No dithering of pulses for spectral smoothing
- Relaxed timing requirements

Additionally, the low PRF is a key feature which reduces location ambiguity and improves the performance of non-coherent readers in high multipath environments.

The low complexity approach drives low power consumption and low cost in discrete device implementations which are common in lower volume applications. Where very high volumes of devices re sold, silicon solutions are viable and the HRP UWB PHY becomes a feasible RTLS solution (see clause A.2.2).

The following clauses highlight the key features of each mode of operation.

A.2.1.1.1 Base mode

The Base Mode is the lowest complexity mode. It is used where there is a requirement for very large tag populations, but no requirement for very long range operation. Typically long range is not an issue in environments with a large number of line-of-sight obstructions.

The key Base Mode attributes are:

- Very simple modulation (OOK)
- No further encoding or whitening
- Shortest packet length
- Packet length designed to achieve maximum pulse amplitude under global UWB regulations (192 pulses at 1 MHz PRF).

This last point makes the Base Mode particularly useful for non-coherent (energy detect) readers which benefit from instantaneous pulse amplitude.

A reader encountering an incoming stream of UWB pulses will go through a process similar to the following in ascertaining whether it is receiving a Base Mode packet:

- A tone check on the incoming preamble to identify a 1 MHz pulse train (i.e. not a Long Range Mode packet)
- An SFD search, with a match confirming one of either Base Mode or Enhanced Mode
- A check of the first three bits of the PHR (the three bits immediately following the SFD) to confirm Base Mode
  - Three 0's = Base Mode
  - Three 1's = Extended Mode
  - The reader may choose to vote on the first three bits of the PHY header in a “best of three” manner in order to introduce simple error-proofing on the Encoding Type bits.

It should be noted that the preamble length is variable between 16 pulses and 128 pulses at the discretion of the implementer. 16 pulses have been shown to be sufficient for a wide variety of use cases, but the implementer may desire to improve acquisition performance by increasing the preamble length. However, doing so has three important negative effects on overall system performance, so the choice must be carefully considered. A longer preamble will:

- Risk increasing the packet length beyond 192 pulses, which may require the pulse amplitude to be reduced in order to comply with local UWB average emission limits
- Increase power consumption in the tag (more pulses transmitted and more processor on-time)
- Increase tag packet collisions (due to longer packets)

A.2.1.1.2 Extended mode

The Extended Mode adds simple forward error correction to the Base Mode for improved performance in certain circumstances. Additionally, the Extended Mode allows for a longer preamble (up to 256 pulses) if the implementer needs to increase acquisition robustness based on the more robust symbol structure. The encoding scheme is simple to implement in the transmitter, and allows for two different decoding schemes in the reader.

Since the Extended Mode packet length is longer than a Base Mode packet, the signal is likely to become constrained by the regulatory average emission limits for UWB. This requires individual pulse amplitudes to be reduced, which causes a loss in terms of link budget when using a non-coherent reader. This loss is to be weighed against an expected coding gain of up to 4dB to determine whether Extended Mode has net benefit in any given circumstance.

In general the use of Extended Mode is a trade-off, balancing coding gain with packet length (i.e. pulse energy loss). The packet length will be determined by a number of factors including preamble length, addressing mode used and payload size.

The reader process for identifying an Extended Mode packet is the same as for the Base Mode.

A.2.1.1.3 Long range mode

The Long Range Mode is targeted at coherent readers which can leverage coherent pulse integration in order to increase symbol energy. Since multiple pulses are integrated together to form a single symbol, packet length can be long meaning the pulse amplitude is certainly defined by regulatory average emission limits for UWB. However, coherent pulse integration more than compensates for the loss in pulse energy for a net gain in link budget.

The performance of a coherent reader depends primarily on two factors: the accuracy of the template pulse used in the reader, and the accuracy of the timing synchronization at the pulse level between the reader and the transmitter. The LRP UWB PHY does not make stringent demands on either of these parameters, and this is intentional in order to allow for low cost implementations (without sophisticated timing or pulse shaping). For this reason there is a limit to the extent that coherent gain can be achieved by simply adding more pulses per symbol. There is also a pulse amplitude penalty when adding more pulses due to regulatory limits. The parameters selected for the Long Range Mode therefore represent the peak performance for a coherent reader with relatively relaxed timing and pulse shaping; longer symbols would add little to coherent gain, and only serve to reduce pulse energy.

The Long Range Mode uses Manchester encoded binary PPM as a modulation scheme, rather than simple OOK as in the Base and Extended Modes, and operates at a 2 MHz PRF. It also uses a more complex preamble necessary to support this encoding scheme. The preamble consists of:

- A sequence of between 1024 and 8192 pulses, then
- The SFD encoded as per the Base and Extended Modes, then
- A sequence of between 16 and 64 binary 1 symbols encoded as per the Long Range Mode

The preamble is then followed by the SFD encoded as per the Long Range Mode. The purpose of this more complex preamble is to allow a coherent reader to detect a Long Range Mode packet and achieve symbol synchronization before the SFD, and also to allow a non-coherent reader to achieve synchronization.

A reader encountering an incoming stream of UWB pulses will go through a process similar to the following in ascertaining whether it is receiving a Long Range Mode packet:

- A tone check on the incoming preamble to identify a 2 MHz pulse train (i.e. not a Base or Extended Mode packet)
- A wait for the start of pulse transitions in the form of 32 present pulses followed by 32 absent pulses, repeating. At this point the reader will use these transitions to achieve symbol synchronization
- An SFD search, with a match confirming Long Range Mode
- A check of the first three bits of the PHR (the three bits immediately following the SFD) with 000 re-confirming Long Range Mode (other values are reserved for future use).

A.2.1.2 Mixed mode networks

A.2.1.2.1 Performance considerations

The Long Range Mode is primarily targeted at coherent readers, whereas the Base and Extended Modes are primarily targeted at non-coherent readers. Since RTLS systems are generally part of a fixed infrastructure, it is unlikely that a mix of coherent and non-coherent readers will be deployed in any given location. Instead, the characteristics of the location will demand one or the other type of reader for best overall system performance.

For example, an indoor environment with many obstructions, such as a warehouse or manufacturing facility, may not afford long line of sight distances and so extended range is not useful. Instead, a higher density of non-coherent readers is likely to be deployed with tags operating either in Base Mode or Extended Mode.

By contrast, large open space such as outdoors will afford very much longer line of sight distances, so a lower density of longer range readers might be more cost effective. In this case a coherent reader infrastructure may be deployed with tags operating in Long Range Mode.

There are many cases, however, where tags may roam from coherent to non-coherent infrastructure, and so this standard requires that all readers, coherent or non-coherent, can receive and demodulate all Modes. The “cross” cases do suffer from performance limitations as follows:

A non-coherent reader will have a short range of operation with a Long Range Mode tag when compared to either a Base or Extended Mode tag. A Long Range Mode tag has relatively long packets which cause the emissions to be regulated by average limits. This means that Long Range Mode pulses are smaller in amplitude than Base or Extended Mode pulses. Since a non-coherent reader relies on single pulse amplitude for reception, it cannot receive the smaller Long Range Mode pulses over a comparable range. Because of the shorter range of operation a Long Range tag may be only intermittently detected within a network of non-coherent readers and location of the tag may not be possible.

A coherent reader will have a short range of operation with a Base or Extended Mode tag when compared to a Long Range Mode tag. The Base and Extended Mode tags do not provide sequences of pulses sufficient for coherent pulse integration which negates the coherent reader advantage. However, a coherent reader may operate with similar range to a non-coherent reader when operating with Base and Extended Mode tags. Since coherent readers will generally be deployed more sparsely than non-coherent readers, a Base or Extended Mode tag may be only intermittently detected within a network of coherent readers and location of the tag may not be possible

The cross case characteristics are summarized in Table A.1.

Table A.1 — Cross case characteristics

Reader Type	Tag Mode	Reception Range	Notes
Non-Coherent	Base	Good	Typical configuration for large populations of very simple tags
	Extended	Better	Extended range operation in some circumstances
	Long Range	Shortened	Short range reception means tag detection coverage will be intermittent in typical non-coherent networks
Coherent	Base	Good	Wider spacing of coherent readers means tag detection coverage will be intermittent in typical networks
	Extended	Better	
	Long Range	Best	Typical configuration for smaller tag populations in open areas

A.2.1.2.2 Reader processing considerations

Any of the three modes can be easily decoded by any reader type once the RF signal has been converted to baseband. The key to operation in the cross cases is to be able to synchronize and demodulate the incoming RF.

When a coherent reader detects a pulse train at 1 MHz PRF, indicating a Base or Extended Mode packet, it must start to search for the preamble encoded as per the Base and Extended Modes. Once the preamble is detected, and synchronization achieved, the remainder of the packet can be demodulated as per a non-coherent reader.

When a non-coherent reader detects a 2 MHz pulse train then a Long Range Mode packet is indicated. The reader may run its normal acquisition/SFD sync process, but at a 2 MHz rate. The insertion of the Base/Extended Mode SFD in the Long Range Mode preamble facilitates this functionality.

After the inserted SFD, the non-coherent reader will start to demodulate bits with allowance for the pulse repetition and Manchester encoding. This might be accomplished by running the normal OOK engine at 2 MHz, and appending a compression step that translates the 32 pulse repetition Manchester PPM into actual bits. This is depicted in Figure A.1.

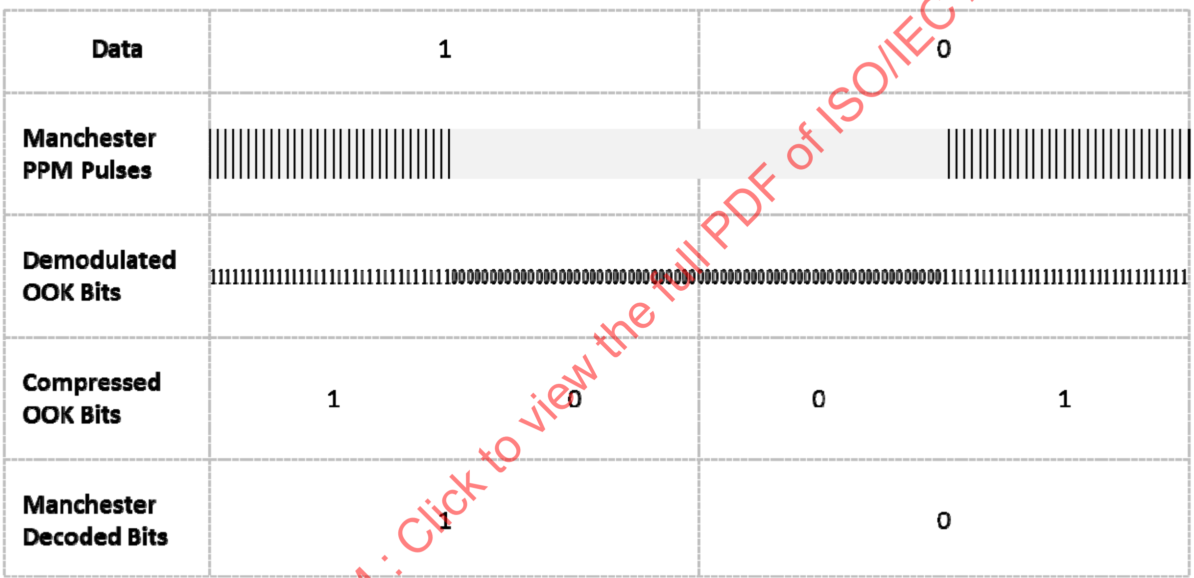


Figure A.1 — Converting Manchester PPM to OOK using digital bit compression

Alternatively the non-coherent reader may take an analog approach, averaging pulses over a 32 pulse window, and then applying OOK demodulation and Manchester decoding as depicted in Figure A.2.