**IEEE P802.15**

**Wireless Personal Area Networks**

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| Abstract |  | |
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# Overview

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# Physical layer

**<707r1>** Marco (NICT)

## Block Diagram



1. —Schematic diagram of common mode PHY

Note: Layer mapping and precoding includes configurations for 1,or 2 or 4 antennas.

**</707r1>**

Note: Diagram is so specific. Modify it more generally. Describe each block. Remove Buffer. MIMO will be discussed. Add schematic diagram for Sub 1GHz band and UWB band.

## Channelization

### Sub-GHz band

**<Park>** (ETRI)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Band* | *Central freq (MHz)* | *n* | *No of channels* | *Max Tx power (mW)* |
| Japan-A | *fc=917+n* | *0,1,…,10* | 11 channels of 1 MHz | 1 |
| Japan-B | *fc=922+n* | *0,1,…,5* | 6 channels of 1 MHz | 20 |
| Japan-C | *fc=921.5+n* | *0,1* | 2 channels of 1 MHz | 250 |
| Japan-D | *fc=928.7+n* | *0,1* | 2 channels of 500 kHz | 1 |
| Korea-A | *fc=917.1+n*ⅹ*0.2* | 1, 3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18 | 12 channels of 200 kHz | 3 mW |
| Korea-B | *fc=917.1+n*ⅹ*0.2* | 2, 5, 8, 11, 14, 17, 19, …, 32 | 20 channels of 200 kHz | 10 mW |

**<Park>**

### 2.4 GHz band

**<707r1>** Marco (NICT)

Such frequency band ranges from 2.4 GHz to 2.5 GHz, which is divided into 9 channels of 10 MHz. By regulation, the maximum transmit power at the input antenna is 1 W. The central frequencies are given by

*fc = 2410* MHz *+ 10n for n = 0, 1, ..., 8*

**</707r1>**

PAC uses unlicensed bands with multiple channels. E.g. PAC can use all or partial channels among 3 channels in 2.4GHz and 8 channels in 5GHz (UNII-1, UNII-3) when bandwidth is 20MHz per channel.

### 5.7 GHz band

**<707r1>** Marco (NICT)

Such frequency band ranges from 5.725 GHz to 5.875 GHz, which is divided into 14 channels of 10 MHz. By regulation, the maximum transmit power at the input antenna is 1 W. The central frequencies are given by

*fc = 5735* MHz *+ 10n for n = 0, 1, ..., 13*

**</707r1>**

PAC uses unlicensed bands with multiple channels. E.g. PAC can use all or partial channels among 3 channels in 2.4GHz and 8 channels in 5GHz (UNII-1, UNII-3) when bandwidth is 20MHz per channel.

### 6.2.4. UWB band

**<382r0>** Igor (NICT)

We are using higher UWB band of 6 – 10.25 GHz as specified in “Technical Guidance for 802.15.8 Proposals.” We are proposing a single channel in upper UWB band for the system to maximize allowed Tx power level. Channel location and bandwidth are determined by regulation at a given Geo.

**</382r0>**

**<Decawave>**

Refer to IEEE STD 802.15.4a-2007 Clause 6.

**</Decawave>**

Note: Decawave and NICT will provide channelization for UWB

### Channelization harmonized proposal

#### Sub-GHz channelization

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Band* | *Central freq (MHz)* | *n* | *No of channels* | *Max Tx power (mW)* |
| Japan-A | *fc=917+n* | *0,1,…,10* | 11 channels of 1 MHz | 1 |
| Japan-B | *fc=922+n* | *0,1,…,5* | 6 channels of 1 MHz | 20 |
| Japan-C | *fc=921.5+n* | *0,1* | 2 channels of 1 MHz | 250 |
| Japan-D | *fc=928.7+n* | *0,1* | 2 channels of 500 kHz | 1 |
| Korea-A | *fc=917.1+n*ⅹ*0.2* | 1, 3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18 | 12 channels of 200 kHz | 3 mW |
| Korea-B | *fc=917.1+n*ⅹ*0.2* | 2, 5, 8, 11, 14, 17, 19, …, 32 | 20 channels of 200 kHz | 10 mW |

#### 2.4 GHz channelization

Such frequency band is divided into 9 channels of 10 MHz. The central frequencies are given by

*fc = 2410* MHz *+ 10n for n = 0, 1, ..., 8*

#### 5.7 GHz channelization

Such frequency band is divided into 14 channels of 10 MHz. The central frequencies are given by

*fc = 5735* MHz *+ 10n for n = 0, 1, ..., 13*

#### UWB channelization

## Duplex schemes

### TDD

**<395r1 [7.2]>** Kim (LG)

~~PAC is TDD system.~~

**</395r1>**

**<392r1>** Cho (ETRI)

PAC should use TDD scheme.

**</392r1>**

**<707r1>** Marco (NICT)

Support for TDD scheme.

**</707r1>**

### FDD

**<707r1>** Marco (NICT)

Support for FDD scheme. See clause 6.6.1 for frame structure in FDD mode.

**</707r1>**

### Duplex scheme harmonized proposal

PAC PHYs should support TDD. See clause 6.6.2 for frame structure in TDD mode.

## Multiplex schemes

~~(e.g. CDMA, OFDMA)~~

~~PAC should support OFDM.~~

**<377r0>** Shannon (Samsung)

Apparently time-frequency multiplexing (OFDM modulation with TDMA)

**</377r0>**

**<392r1>** Cho (ETRI)

Apparently time-frequency multiplexing (OFDM modulation with TDMA)

**</392r1>**

**<707r1>** Marco (NICT)

Support for time-frequency multiplexing.

**</707r1>**

**<373r1>** BJ (ETRI)

Apparently frequency division multiplexing.

**</373r1>**

## Multiple access

**<377r0>** Shannon (Samsung)

Apparently TDMA.

**</377r0>**

**<392r1>** Cho (ETRI)

Apparently TDMA

**</392r1>**

**<707r1>** Marco (NICT)

Support for OFDMA-TDMA.

**</707r1>**

**<373r1>** BJ (ETRI)

Apparently CSMA

**</373r1>**

## Frame structure

Note: This clause will be discussed by email reflector. And members should provide harmonized text by January meeting.

**<707r1>** Marco (NICT)

### Frame structure in FDD mode



One slot contains 7 DTF-S OFDM or OFDM symbols.

### Frame structure in TDD mode



where L1=PD1 transmits and PD2 receives, L2=PD2 transmits and PD1 receives, S-L1=synchronization for L1, RS-L1=reference signals for L1, RA=random access or channel sounding for MIMO or beamforming, GP=guard period.

The GP is computed as GP=(73+1024)Ts=71.42 µsec and satisfies Tp+Tdec+Tsw+Tcomp+Tp=GP

where Tdec=time to detect the last symbol, Tsw=time to switch from Rx to Tx or vice-versa,

Tcomp=compensation time to align to GP, and Tp=1 Km/3x108m/s=3.3 µsec (worst case).

The TDD frame configuration is given in the following table:

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TDD  configuration | Slot number | | | | | | | | | | | | | | | | | | | |
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| 0 | L1 | S | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | S | L1 | L1 | L1 | L1 | L1 | L1 | L1 | L1 |
| 1 | L1 | S | L2 | L2 | L2 | L2 | S | L1 | L1 | L1 | L1 | S | L2 | L2 | L2 | L2 | S | L1 | L1 | L1 |
| 2 | L1 | S | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | S | L1 | L1 | L1 | L1 | L1 |
| 3 | L1 | S | L2 | L2 | L2 | L2 | L2 | L2 | S | L1 | L1 | L1 | L1 | L1 | L1 | L1 | L1 | L1 | L1 | L1 |
| 4 | L1 | S | L2 | L2 | L2 | L2 | S | L1 | L1 | L1 | L1 | L1 | L1 | L1 | L1 | L1 | L1 | L1 | L1 | L1 |
| 5 | L1 | S | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | L2 | S | L1 | L1 | L1 |

### Cyclic prefix

The cyclic prefix is based on the typical RMS delay spread of the considered unlicensed bands:

****The CP length is 73*Ts*=4.75 µsec. For sampling time *Ts* see clause **6.7.2.1**.

### Resource block

A resource block (RB) is a set of time-frequency slots that enables multiplexing in the time and frequency domains.



where **7 DFT-spread OFDM or OFDM symbols (see clause **6.5.2.1**),  6 subcarriers, and  170 (2 upper and lower subcarriers are empty).

Transmission bandwidth (BW) is obtained by concatenating RBs as



The proposed bandwidths for a maximum FFT size of *M*=1024 are given in the table

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| BW (MHz) | No of RBs | No subcarriers | FFT size | Sampling rate |
| 1 | 12 | 72 | 128 | 1.92 MHz |
| 3 | 33 | 198 | 256 | 3.84 MHz |
| 5 | 56 | 336 | 512 | 7.68 MHz |
| 10 | 111 | 666 | 1024 | 15.36 MHz |
| 15 | 166 | 996 | 1024 | 15.36 MHz |

### Data frame structure

The physical layer protocol data unit (PPDU) is formed by concatenating synchronization header (SHR), Discovery header (DIS), physical layer header (PHR) and physical layer service data unit (PSDU) as illustrated:



Reference signals for demodulation/equalization are embedded in the PSDU.

The MAC protocol data unit (MPDU) is passed to the PHY. Such data is encoded by QC-LDPC codes.

**</707r1>**

**<373r1>** BJ (ETRI)

The transmitted RF signal is generated by modulating the complex baseband signal, which is composed of multifarious fields. The fields are delimited by timing boundaries. The general PHY frame format is shown in Figure 1.



Figure 1 – General PHY frame format

The Preamble field is composed of STF and LTF, and is a part of PPDU that is used for packet detection, AGC, time and frequency synchronization, indication of transmission mode (OFDM or SC), collision detection, and channel estimation. A detailed description of the Preamble field is in 6.6.6

The PHY Header field is used to describe the content in the MPDU as well as the protocol used to transfer it.

The MPDU consists of MAC header, payload, and FCS.

SSF (Self Spatial Filtering) uses a technique called beam jittering. The Beam Jitter field is transmitted at the end of SSF request frame. The presence of Beam Jitter field is indicated in the MAC header in the MPDU, and payload of MPDU includes IE that contains the threshold for the correlation level used in SSF which is defined in 6.6.7.

### Preamble

[Option 1]

The preamble consists of two fields named STF (Short Training Field) and LTF (Long Training Field). Figure 2 is a time-domain illustration of the preamble structure.



Figure 2 – Proposed preamble structure (option 1)

[Option 2]

The preamble consists of two fields named STF (Short Training Field) and LTF (Long Training Field). Figure 3 is a time-domain illustration of the preamble structure.



Figure 3 – Proposed preamble structure (option 2)

#### STF

[Option 1]

The STF is used for AGC (automatic gain control), packet detection, initial timing and frequency synchronization, and implicit transmission mode indication (e.g., OFDM or SC). The length of STF is equivalent to two OFDM symbols, and contains 5 repetitions of a periodic signal. The sign of the 4th period in the STF can be used to indicate the transmission mode.

There are three candidate sequences that can be used to generate the periodic signal used in the STF. The standard shall choose the best sequence considering performance, implementation complexity, and capability. The three candidates are MZC1 (Modified Zadoff-Chu sequence 1), MZC2 (Modified Zadoff-Chu sequence 2), and GSW (Gold Sine Wave), which are described in 6.6.6.3

[Option 2]

The STF is used for AGC (automatic gain control), packet detection, initial timing and frequency synchronization, and implicit transmission mode indication (e.g., OFDM or SC), and also for the first collision detection. The length of STF is equivalent to two OFDM symbols, and contains 5 repetitions of a periodic signal. The sign of the 4th period in the STF can be used to indicate the transmission mode.

There are two candidate sequences that can be used to generate the periodic signal used in the STF. The standard shall choose the best sequence considering performance, implementation complexity, and capability. The two candidates are MZC1 (Modified Zadoff-Chu sequence 1) and MZC2 (Modified Zadoff-Chu sequence 2), which are described in 6.6.6.3.

The last period of the STF is used for 1st stage collision detection. The same collision detection principle described in 6.6.6.2 is used for the STF.

#### LTF

[Option 1]

The LTF consists of two OFDM symbols. The first symbol of LTF is used for refined timing/frequency synchronization and channel estimation.

There are four candidate sequences that can be used to generate the signal used in the first symbol of LTF. The standard shall choose the best sequence considering performance, implementation complexity, and capability. The four candidates are Base Zadoff-Chu sequence, MZC1 (Modified Zadoff-Chu sequence 1), MZC2 (Modified Zadoff-Chu sequence 2), and GSW (Gold Sine Wave) which are described in 6.6.6.3

The second symbol of LTF is used for collision detection. The sub-carriers of the second symbol of LTF are divided into two groups by DC sub-carrier. A PD selects a random sub-carrier in each group of sub-carriers and transmits a busy tone. Figure 4 illustrates an example of the frequency domain structure of the second symbol of LTF.



Figure 4 – The second symbol of LTF for collision detection.

When a PD receives a frame, the PD checks the second symbol of LTF to detect a collision. For example, if one of the groups of sub-carriers contains more than one busy tone, the PD decides a collision occurred and may decide not to process the remainder of the radio frame. When there are *P* sub-carriers in each group of sub-carriers, the probability of collision detection failure is 1/*P*2.

[Option 2]

The LTF is two OFDM symbols long, and consists of a long CP followed by two repetitions of a periodic signal, where the combination of the sign of each period of the signal can be used to indicate transmission mode. LTF is used for refined timing/frequency synchronization, collision detection, and channel estimation.

Either Base ZC sequence or MZCs in frequency domain is used for LTF.

The 2nd period of the periodic signal in the LTF is used for 2nd stage collision detection. The collision detection procedure is illustrated in Figure 5.



Figure 5 – Collision detection procedure using preamble sequence

The collision detection is performed in two stages, the 1st stage using the STF and 2nd stage using the LTF. PHY reports collision detection if collision is detected in any of the two stages.

#### Preamble sequences for PAC

In this sub-clause, candidate sequences that can be used to generate the STF and the LTF of the Preamble field of PAC PHY frame.

***Base Zadoff-Chu sequence****:*

A length-*P* ZC sequence in frequency domain is defined as follows

where *u* is the root index of base ZC sequence, odd *P* is the sequence length, and the sequence element index is *m* = 0, 1, …, *P*-1.

***MZC1 (Modified Zadoff-Chu sequence 1):***

Modified ZC sequence 1 in frequency domain is obtained by interleaving a base ZC sequence with it negative. Let be a length-*N* modified ZC sequence 1, then can be written as follows

* For odd *m*,
* For even *m*,

where .

***MZC2 (Modified Zadoff-Chu sequence 2):***

Modified ZC sequence 2 in frequency domain is obtained by concatenating a base ZC sequence with its complex conjugate. Let be a length-*N* modified ZC sequence 2, then can be written as follows

where .

***GSW (Gold Sine Wave sequence):***

Gold Sine Wave sequence in time domain is obtained by multiplying a Gold sequence with a half sine wave window function. Let be a length-*N* GSW sequence, then

where

and *N=2P+2*, *G1* and *G2* are *m*-sequences of same order, *u* is the index of GSW sequence, and [ ]*N* is a modulo-*N* operator. The term is applied to maintain the same average power as MZCs.

### Beam Jitter field

SSF request frame includes a Beam Jitter field. Beam Jitter field comprises of a single OFDM symbol. A sequence (TBD) is assigned to the sub-carriers of the OFDM symbol.

When a PD transmits an SSF request frame, the Beam Jitter field is transmitted using beam jittering described in 6.8.2.3.

When a PD is receiving an SSF request frame, the Beam Jitter field is received without channel equalization. On receiving an SSF request frame, a PD calculates the correlation coefficient defined as follows.

where is a vector of the known sequence that is assigned to the sub-carriers of the OFDM symbol of Beam Jitter field, and is a vector the OFDM sub-carriers of the received Beam Jitter field.

The cross-correlation coefficient is compared with the threshold found in the IE received in the SSF request frame. If is larger than the threshold, the PD transmits an SSF response frame to the transmitter of the SSF request frame with the calculated .

Beam jittering can be implemented for single carrier systems with minor modification. The detailed structure of beam jittering for single carrier system is TBD.

**</373r1>**

**<377r0>** Shannon (Samsung)

### Discovery frame structure

Discovery frame is comprised of multiple Discovery slots. A Discovery Slot delivers single Peer Discovery Message (PDM).

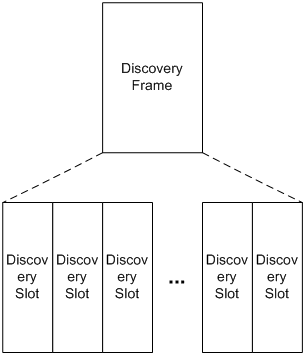
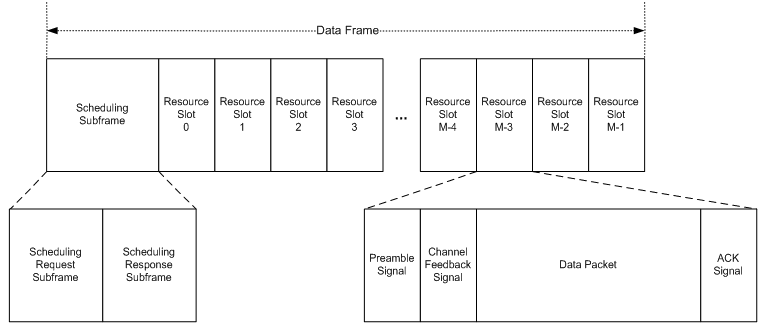


Figure 6. Discovery Frame Structure

### Data frame structure

A Data frame is comprised of one or multiple scheduling subframe and the multiple resource slots (RSs) which are associated to one scheduling subframe.

A RS consists of Preamble Signal duration, Channel Feedback Signal duration, Data Packet duration, and ACK Signal duration.



**</377r0>**

**<392r1>** Cho (ETRI)

The ultraframe has a fixed length and appears repeatedly. Ultraframe, superframe, frame has a hierarchical structure.



Figure 7. Hierarchical structure of ultraframe

Every frame consists of a synchronization region, a discovery region, a peering region and a data region. The type of a frame can be the frame type 0 of the frame type 1 according to the configuration. The frame type 0 consists of a synchronization region, a discovery region, a peering region and a data region. Frame type 1 consists of a synchronization region and a data region. The frame type 0 is used if the frame number is 0 and the frame type 1 is used otherwise.

### Synchronization region

The synchronization region is located at the head of a frame. The synchronization signal for the distributed synchronization is sent in the synchronization region. A PD transmits the synchronization signal without interference sensing but the synchronization signal is transmitted by low power for coexistence with heterogeneous devices. The synchronization signal is transmitted repeatedly for reliability. There are two kinds of synchronization signals. One is used at the synchronization region of the first frame in an ultraframe and another is used at other frame.



Figure 8. Synchronization region

### Discovery region

In the discovery region, a discovery signal is transmitted. The discovery region consists of multiple discovery RUs, ISs and GIs. The discovery RU consists of a preamble signal and a discovery signal. The Forward Blocking scheme is used for coexistence. The discovery region consists of 8 blocking unit and one blocking unit consists of 8 discovery RUs. The IS interval is present in front of every blocking unit.



Figure 9. Discovery region

### Peering region

The peering region consists of the Peering-REQ/RSP interval and the PID broadcast interval. The Peering-REQ/ RSP interval consists of multiple PID-REQ RUs, PID-RSP RUs, ISs and GIs. The Peering-REQ RU consists of a preamble signal and a Peering-REQ signal. The Peering-RSP RU consists of a preamble signal and a Peering-RSP signal. Forward & Backward Blocking scheme is applied at Peering-REQ blocking unit, and Forward Blocking scheme is applied at Peering-RSP blocking unit. Four Peering-REQ blocking units and four Peering-RSP blocking units exist in the Peering-REQ/RSP interval. A Peering-REQ blocking unit has four Peering-REQ RUs and a Peering-RSP blocking unit has four Peering-RSP RUs.

In the PID broadcast interval, multiple PID broadcast RUs mapped to PID exist. Forward Blocking scheme is used.



Figure 10. Peering region

### Data region

The data region is comprised of multiple data channels with a fixed size. In case of frame type 0, the data region has 13 data channels because 3 data channels (0~2) are used for the control such as Discovery and Peering. In case of frame type 1, data region has 16 data channels.

A data channel consists of a scheduling interval and a data interval. The scheduling interval consists of DS-REQ RUs, DS-RSP RUs, IS, GIs, and SRI. In case of the DS-REQ RU and the DS-RSP RU, a preamble signal is followed by a DS-REQ signal and a DS-RSP signal, respectively. Forward and Backward Blocking schemes are utilized in both DS-REQ and DS-RSP blocking units. The data interval consists of GIs and multiple pairs of data burst and ACK. The data burst consists of a preamble signal, a BCI (Burst Control Indicator) signal, and a data signal. The BCI signal is used to indicate the modulation order, the code rate, and the length of data signal. ACK consists of a preamble signal and a ACK signal. The number of data bursts and each burst size are determined by the distributed scheduling.



Figure 11. Data region

**</392r1>**

**<384r0>** Park (ETRI)

### Discovery frame structure

The LESD Mode PPDU shall be formatted as illustrated.

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | Octets | |
|  |  | 1 | Variable |
| Preamble | SFD | PHY Header | PHY Payload |
| SHR | | PHR | PSDU |

#### Preamble field

The Preamble field shall contain multiples of the 8-bit sequence “01010101”.



#### SFD

The SFD shall be the selected 16-bit sequence selected from the list of values shown in the following Table.

|  |  |  |
| --- | --- | --- |
| Message type | SFD value for uncoded (PHR+PSDU) | SFD value for coded (PHR+PSDU) |
| Request | 1011 0001 1001 1100 | 1011 0001 1011 0001 |
| Response | 0100 1110 1001 1100 | 0100 1110 0100 1110 |
| Notification | 0110 0011 1001 1100 | 0110 0011 0110 0011 |

Devices that support FEC shall support the SFD associated with coded (PHR + PSDU) and Devices that do not support FEC shall support the SFD associated with uncoded (PHR + PSDU).

#### PHR

The format of the PHR is shown in the following Table.

If the frame type is not “preamble”, the Frame Length field (L5–L0) specifies the total number of octets contained in the PSDU (prior to FEC encoding, if enabled). Otherwise, The field (L5–L0) represents the remaining time of repeated preamble set.

|  |  |  |
| --- | --- | --- |
| **Bit string index** | **0–1** | **2–7** |
| **Bit mapping** | T1–T0 | L5–L0 |
| **Field name** | Frame Type | Frame Length / Remaining time |

|  |  |
| --- | --- |
| **(T1 T0)** | **Frame Type** |
| **0 0** | Request |
| **0 1** | Response |
| **1 0** | Notification |
| **1 1** | Preamble(No PSDU field) |

#### PSDU field

The PSDU field carries the data of the PPDU.

**</384r0>**

**<686r0>** Igor NICT

### UWB Pulse shape and duration

We do not define a specific pulse shape in order to allow different low-complexity pulse generators.

Furthermore, operating bands are not defined will be different at different Geos.

Pulse shape is constrained

In spectrum by the local regulations.

In duration by the Duty Cycle (DC) of no more than DC=1/32=3.1%.

### Packet structure

SHR

PHR

PPDU

Fig. 1: **Packet structure.**

As Fig, 1. shows, packet consists of SHR – Synchronization Header, PHR – PHY Header and PPDU – Physical Layer Protocol Data Unit.

### SHR Structure



Preamble

SFD

Fig. 2. **SHR structure.**

Preamble consists of M=8 times repetition of the sequence *Si*. *Si* is one of the Gold sequences of length 31. Since set of Gold sequences of length 31 has 33 sequences, there are 33 virtual channels available per physical channel. Gold sequences of length 31 have relatively short length with good circular autocorrelation properties.

Synchronization Frame Delimiter (SFD) represents inversion of *Si* used in the preamble.

### Symbol structure

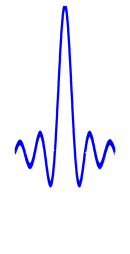
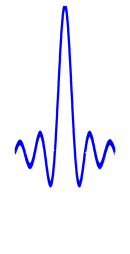
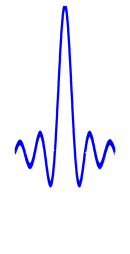


Fig. 3. **Symbol structure**

Symbol structure is shown in Fig. 3. The whole packet, is transmitted using the same symbol structure regardless of the data rate used with On-Off Keying (OOK) modulation. For , where  is the symbol index, the same symbol duration of  is used. Transmitted pulse waveform is denoted . Hence, transmitted signal for the -th transmitted symbol is

 (1)

where  is transmitted bit and  is pseudo-random sequence used in  to flatten the spectrum of the transmitted signal, while for   is set. Pseudo-random sequence used is the same Gold sequence used in PR and SFD for 

### Symmetrical double-sided two-way ranging

*Tround*1

*Tprop*

*Treply*1

*t*

*Tprop*

*Tprop*

*t*

*Tround*2

*Treply*2

Device 1

Device 2

*Tprop*

Fig. 4. **Principle of symmetrical double-sided two-way ranging.**

As Fig. 4. shows, symmetrical double-sided two-way ranging is achieved by measuring two round trip times: round trip time from device 1 to device 2 denoted  and round trip time from device 2 to device 1 denoted .

 denotes propagation time that is being estimated, while  and  represent reply times of device 1 and 2 respectively. Hence,  estimate is calculated as follows

. (2)

If relative errors of timing at device 1 and 2 are denoted  and  it follows that

 (3)

 (4)

 (5)

 (6)

Thus error of  estimation is:

 (7)

Hence, relative error of the range estimation is also in the same order of magnitude as  and , which for crystal oscillators is usually around 20 ppm.

**</686r0>**

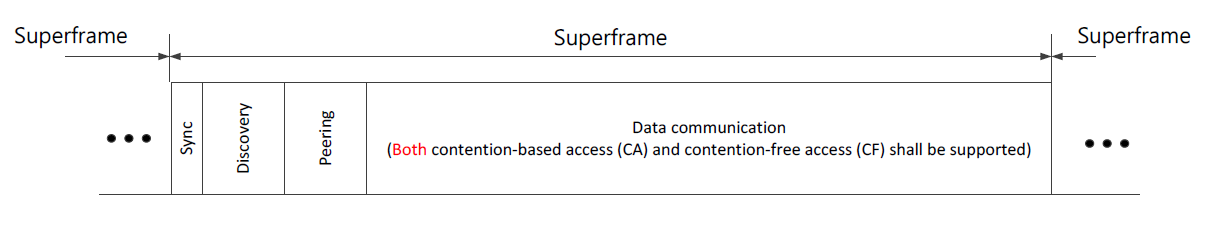
**<Decawave>**

Refer to IEEE Std 802.15.4a-2007 clause 6.

**</Decawave>**

### Frame structure harmonized proposal

**<737r0>** Cho (ETRI)



The radio resource is comprised of successive super frames with fixed time duration. A super frame includes synchronization, discovery, peering and data communication intervals. Each interval has fixed time duration.

In the data communication interval, both contention-based access (CA) and contention-free access (CF) should be supported.

PDs should maintain discovery transmission or reception in low duty cycling mode to save power.

PDs should be ready for peering in low duty cycling mode as well (because a PD does not know when another PD sends a peering request).

**</7370>**

## Modulation and coding scheme (MCS)

Note: NICT’s proposal is so detail for PFD. Members will discuss depth of text for PFD.

NICT responded a Call for “Technical” Proposals, no a Call for bogus text.

### Modulation summary

#### Sub-GHz band

**<707r1>** Marco (NICT)

GFSK, OFDM or DFT-spread OFDM

**</707r1>**

**<384r0>** Park (ETRI)

GFSK

**</384r0>**

#### 2.4 GHz and 5.7 GHz bands

**<707r1>** Marco (NICT)

BPSK, QPSK, 16QAM

**</707r1>**

64QAM

#### UWB band

**</686r0>** Igor (NICT)

OOK

**</686r0>**

**<Decawave>**

Refer to IEEE STD 802.15.4a-2007 clause 6.

**</Decawave>**

Note: Harmonized text will be provided by NICT and Decawave.

### 6.6.2 Modulation

**<707r1>** Marco (NICT)

In the modulation mapper, the scrambled coded bits *bi* for *i=0,1,…,n-1* are modulated with either BSPK, QPSK or 16QAM modulations, resulting in the a block of complex modulation symbols *di* for *i=0,1,…,Nsym-1,* where *di=I+jQ.*

The mapping between bits onto symbols are given by

BPSK mapping:

|  |  |  |
| --- | --- | --- |
| *bi* | *I* | *Q* |
| 0 |  |  |
| 1 |  |  |

QPSK mapping:

|  |  |  |
| --- | --- | --- |
| *bi  bi+1* | *I* | *Q* |
| 00 |  |  |
| 01 |  |  |
| 10 |  |  |
| 11 |  |  |

16QAM mapping:

|  |  |  |
| --- | --- | --- |
| *bi  bi+1 bi+2 bi+3* | *I* | *Q* |
| 0000 |  |  |
| 0001 |  |  |
| 0010 |  |  |
| 0011 |  |  |
| 0100 |  |  |
| 0101 |  |  |
| 0110 |  |  |
| 0111 |  |  |
| 1000 |  |  |
| 1001 |  |  |
| 1010 |  |  |
| 1011 |  |  |
| 1100 |  |  |
| 1101 |  |  |
| 1110 |  |  |
| 1111 |  |  |

#### Optional GFSK modulation

An optional and very low power PHY based on CP-2FSK modulation is contemplated for the sub-GHz band with no support for MIMO technologies, i.e., layer mapper and precoding are not necessary. The proposed channel encoder, bit interleaver and scrambler are used as well. The modulation mapper is CP-2FSK that is given by



where *V* is amplitude, *S(t)*=sin*(*2*πfc t)* is the modulating-carrier signal, *fc*is the central carrier frequency, *Tsym* is the symbol time, *β=*1 is the modulation index, *∆f=β/*2*Tsym* is the peak frequency deviation, and *φ0* is the initial phase of the modulating-carrier signal.

The information bearing signal is given by



where *gm* is information bits, *p(t)* is a Gaussian pulse shape of bandwidth-symbol duration product of 0.8.

**</707r1>**

**<384r0>** Park (ETRI)

The modulation for the LESD Mode is a 2-level filtered FSK.

The following Table shows the modulation and channel parameters for the LESD Mode PHY.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Frequency Band  (MHz) | Modulation | Modulation index | Channel spacing  (kHz) | Data rate  (kb/s) |
| Sub-GHz | Filtered 2FSK | 1 | 200 | 50 |

a Data rates shown are over-the-air data rates (the data rate transmitted over the air regardless of whether the FEC is enabled).

**</384r0>**

### Multi-carrier modulation

PAC should support OFDM.

**<707r1>** Marco (NICT)

PAC should support OFDM and optionally DFT-spread OFDM and GFSK

#### DFT-S OFDM or OFDM

The Parameters are given by

|  |  |
| --- | --- |
| Description | Notation |
| Total No. of subcarriers | *M* |
| Transmission bandwidth | *BW* |
| No. of used subcarriers | *N* |
| Subcarrier spacing | *∆f=BW/N* |
| Sampling time | *Ts* |
| Clock rate | *Rc* |
| Frame time | *Tframe* |
| Slot time | *Tslot* |

*∆f* is constant and equal to 15 KHz.

Maximum FFT size *M*=1024.



Sampling time

Timing based on a common clock at rate



**</707r1>**

**~~<395r1>~~** ~~Kim (LG)~~

~~PAC multiplexing scheme is OFDM.~~

**</395r1>**

**<377r0>** Shannon (Samsung)

IEEE802.15.8 PAC should use OFDM to support high efficient control and data transmission.

**</377r0>**

**<392r1>** Cho (ETRI)

PAC should use OFDM scheme.

**</392r1>**

### Modulation harmonized proposal

PAC should support OFDM modulation for sub-GHz, 2.4 GHz and 5.7 GHz bands with parameters:

|  |  |
| --- | --- |
| Description | Notation |
| Total No. of subcarriers | *M* |
| Transmission bandwidth | *BW* |
| No. of used subcarriers | *N* |
| Subcarrier spacing | *∆f=BW/N* |
| Sampling time | *Ts* |
| Clock rate | *Rc* |
| Frame time | *Tframe* |
| Slot time | *Tslot* |

*∆f* is constant and equal to 15 KHz.

Maximum FFT size *M*=1024.



Sampling time

Timing based on a common clock at rate



OFDM modulation should employ BPSK, QPSK, 16 QAM and 64 QAM symbols with the following mapping:

BPSK mapping:

|  |  |  |
| --- | --- | --- |
| *bi* | *I* | *Q* |
| 0 |  |  |
| 1 |  |  |

QPSK mapping:

|  |  |  |
| --- | --- | --- |
| *bi  bi+1* | *I* | *Q* |
| 00 |  |  |
| 01 |  |  |
| 10 |  |  |
| 11 |  |  |

16QAM mapping:

|  |  |  |
| --- | --- | --- |
| *bi  bi+1 bi+2 bi+3* | *I* | *Q* |
| 0000 |  |  |
| 0001 |  |  |
| 0010 |  |  |
| 0011 |  |  |
| 0100 |  |  |
| 0101 |  |  |
| 0110 |  |  |
| 0111 |  |  |
| 1000 |  |  |
| 1001 |  |  |
| 1010 |  |  |
| 1011 |  |  |
| 1100 |  |  |
| 1101 |  |  |
| 1110 |  |  |
| 1111 |  |  |

#### Optional GFSK modulation for sub-GHz band

#### UWB modulation

Two modulations should be supported: OOK and BPSK-2PPM.

OOK modulation. For , where  is the symbol index, the same symbol duration of  is used. Transmitted pulse waveform is denoted . Hence, transmitted signal for the -th transmitted symbol is

 (8)

where  is transmitted bit and  is pseudo-random sequence used in  to flatten the spectrum of the transmitted signal, while for   is set. Pseudo-random sequence used is the same Gold sequence used in PR and SFD for 

Refer to IEEE STD 802.15.4a-2007 clause 6.

For BPSK-2PPM modulation refer to IEEE STD 802.15.4a-2007 clause 6.

### Coding Scheme Channel coding or FEC

Note: Another coding scheme may be provided in response to call for contribution. This will be addressed in January meeting.

**<707r1>** Marco (NICT)

#### Channel coding

Channel coding is based on quasi-cyclic low density parity check codes (QC-LDPC).

Quasi-cyclic LDPC codes are systematic, linear codes satisfying **Hc**T=**0,** where **c** is the codeword and **H** is the parity check matrix.

**H** is constructed from the prototype matrix **H**p of size MpxNp by replacing each entry of such matrix [**H**p]i,j with either a cyclic shift matrix **P**c, or identity matrix or null matrices of size ZxZ. The final size of **H** is MpZxNpZ.

Details of the encoding process can be found in document with DCN 369r1.

QC-LDPC parameters for different coding rates to enable link adaptation are given by

|  |  |  |
| --- | --- | --- |
| Coding rate | *k* | *n* |
| 1/2 | 972 | 1944 |
| 1/2 | 324 | 648 |
| 2/3 | 1296 | 1944 |
| 2/3 | 432 | 648 |
| 3/4 | 1458 | 1944 |
| 3/4 | 486 | 648 |
| 5/6 | 1620 | 1944 |
| 5/6 | 540 | 648 |

The prototype matrices **H**p for different coding rates can be found in document with DCN 369r1.

Discovery frame is protected with CRC-6-ITU error detection code and shorten RS(126,63) code.

**</707r1>**

**<686r0>** Igor (NICT)

#### UWB Channel coding and data rates

RS coder

Bit interleaver

Conv. coder

Modulator

Fig. 4.: **Concatenated coding scheme used.**

Coding is concatenation of outer Reed-Solomon RS6(63,55) codes and inner convolutional codes. Different data rates have different convolutional coding as in Table 1.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Data rate (Kbps)** | 54.56 | 109.12 | 218.25 | 436.51 | 873.02 |
| **Conv. coding rate** | 1/4 | 1/4 | 1/4 | 1/2 | 1/1 |
| **Chips per symbol** | 4 | 2 | 1 | 1 | 1 |

Table 1.: **Data rates used with convolutional coding rates and number of chips per symbol.**

Table 2. provides detailed specification of the convolutional codes used. Bit interleaver used is algebraic bit interleaver specified in the UWB PHY of the IEEE 802.15.6-2012 standard for Body Area Networks.

|  |  |  |
| --- | --- | --- |
| **Conv. coding rate** | ½ | ¼ |
| **Constrained length** | 3 | 4 |
| **Generators in octal** | 5 7 | 13 15 15 17 |
| **Free distance** | 8 | 13 |

Table 2.: **Convolutional codes used.**

**</686r0>**

**<Decawave>**

Refer to IEEE STD 802.15.4a-2007 clause 6.

**</Decawave>**

### Channel coding harmonized proposal

PAC should support quasi-cyclic low density parity check codes (QC-LDPC) for sub-GHz, 2.4 GHz and 5.7 GHz bands.

Quasi-cyclic LDPC codes are systematic, linear codes satisfying **Hc**T=**0,** where **c** is the codeword and **H** is the parity check matrix.

**H** is constructed from the prototype matrix **H**p of size MpxNp by replacing each entry of such matrix [**H**p]i,j with either a cyclic shift matrix **P**c, or identity matrix or null matrices of size ZxZ. The final size of **H** is MpZxNpZ.

Details of the encoding process can be found in document with DCN 369r1.

QC-LDPC parameters for different coding rates to enable link adaptation are given by

|  |  |  |
| --- | --- | --- |
| Coding rate | *k* | *n* |
| 1/2 | 972 | 1944 |
| 1/2 | 324 | 648 |
| 2/3 | 1296 | 1944 |
| 2/3 | 432 | 648 |
| 3/4 | 1458 | 1944 |
| 3/4 | 486 | 648 |
| 5/6 | 1620 | 1944 |
| 5/6 | 540 | 648 |

The prototype matrices **H**p for different coding rates can be found in document with DCN 369r1.

Discovery frame is protected with CRC-6-ITU error detection code and shorten RS(126,63) code.

#### Optional channel coding for sub-GHz band

#### UWB channel coding

Two channel codes should be supported, both based on the concatenation of RS code with convolutional code.

Channel code is the concatenation of outer Reed-Solomon RS6(63,55) codes and inner convolutional code with parameters:

|  |  |  |
| --- | --- | --- |
| **Conv. coding rate** | ½ | ¼ |
| **Constrained length** | 3 | 4 |
| **Generators in octal** | 5 7 | 13 15 15 17 |
| **Free distance** | 8 | 13 |

For the second concatenation refer to IEEE STD 802.15.4a-2007 clause 6.

## Multiple antennas

Note: NICT&ETRI will simplify and provide the harmonized text. by January meeting

**<707r1>**Marco (NICT)

### Layer mapping

Two MIMO technologies are supported: open loop spatial multiplexing and transmit diversity space- frequency block codes (SFBC) for 2 and 4 antennas.

The [complex] modulation symbols per codeword *di* for *i=*0*,*1*,…,Nsym-*1are mapped onto several layers as (a layer represents an independent stream of symbols in a MIMO configuration, and rank is the number of layers transmitted):



where ν is the number of layers and *NLsym*is the number of symbols per layer for the *q*th codeword.

#### Open loop spatial multiplexing

Open loop spatial multiplexing enables the transmission of parallel data streams. The mapping of codeword symbols onto layer streams can be found in document with DCN 369r1.

#### Transmit diversity

Transmit diversity enables to transmit the same information from multiple antennas. The mapping of codeword symbols onto layer streams can be found in document with DCN 369r1.

### Precoding

Precoding allows increasing system performance and robustness by feeding back to the transmitter channel state information (CSI). The schematic diagram of MIMO support with precoding is illustrated as



#### Open loop spatial multiplexing

Precoding for open loop spatial multiplexing increases robustness by feeding back the rank of the wireless channel (RI=rank indicator). The transmitter chooses a pre-fixed codeword according to the RI.

Single antenna mapping is trivial and given by



where *pɛ*{0,1,2,3}, *i*=0,1,…,*NPsym*-1, and *NPsym=NLsym*.

Multiple antennas mapping is given by



The transmitter chooses a codeword according to reported RI=*ν*. The codebook for 2 and 4 antennas can be found in document with DCN 369r1.

#### Transmit diversity

Transmit diversity is aimed to increase robustness in scenarios with low SNR, low delay tolerance or no feedback to the transmitter is available or reliable.

In case of 2 antennas:

* + STBC (space-time block code) for DTF-Spread OFDM.
  + SFBC (space-frequency block code) for OFDM.

SFBC for 2 antennas is given by



In case of 4 antennas there is a combination of SFBC (2 antennas) with frequency switch transmission diversity and given by



**</707r1>**

**<373r1>** BJ (ETRI)

#### Beam Jittering.

Beam jittering is an open-loop transmit beamforming technique that uses an array antenna, where each sub-carrier of an OFDM symbol is transmitted with a beam pattern independently selected from a set of *K* predefined beam patterns.

The predefined beam patterns are designed so that all the beam patterns have an identical array gain in the boresight direction of the array, while the array gains in other directions are random.

The number of predefined beam patterns (*K*), design of beam patterns, and beam selection pattern are implementation specific, and is outside of the scope of this document.

Figure 12 and Table 1 show plots and array parameters of an example of a set of pre-defined beam patterns, respectively, where *K*=2. SSF with *K*=2 shows good performance when the beam patterns are well designed.

|  |  |
| --- | --- |
| M:\SkyDrive\802.15.8\20130714_Geneva\our_contributions\ssf\figures\beam_pattern_2_3_overlap.png  Amplitude of array response | M:\SkyDrive\802.15.8\20130714_Geneva\our_contributions\ssf\figures\phase_response_2_3_overlap.png  Phase of array response |

Figure 12 – An example of pre-defined beam patterns.

Table 1 – An example of array parameters for *K* pre-defined beam patterns.

|  |  |
| --- | --- |
| Antenna configuration | 4 antenna ULA |
| Antenna spacing | 0.5λ |
| *K* | 2 |
| Null locations | Beam L: |
| Beam R: |

**</373r1>**

## Bit interleaver

**<707r1>** Marco (NICT)

In order to minimize latency and integration on parallel architectures within the encoder/decoder implementation in a chip, an algebraic interleaver is proposed.

A maximum contention-free quadratic permutation interleaver is defined as

Short length interleaver: 

Long length interleaver: 

where *i=*0,1,…,*NI*-1. *NI* is the length of interleaver. Elements of codewords (*ci* for *i=*0,1,…,*n*-1*)* are interleaved in blocks of *NI* bits as *c*∏(*j*) for *j=*0,1,…,*NI*-1.

**</707r1>**

### Bit interleaver harmonized proposal

A maximum contention-free quadratic permutation interleaver is defined as

Short length interleaver: 

Long length interleaver: 

where *i=*0,1,…,*NI*-1. *NI* is the length of interleaver. Elements of codewords (*ci* for *i=*0,1,…,*n*-1*)* are interleaved in blocks of *NI* bits as *c*∏(*j*) for *j=*0,1,…,*NI*-1.

## Scrambling

**<707r1>** Marco (NICT)

A scrambler is used to shape the data spectrum and to randomize data across users in order to reduce interference. A Gold code generator of length 63 is proposed as scrambler.

Such PN sequence with period 263 appears truly random even for long packets. Moreover, different initialization seeds enable a different Gold code per user with low correlation respect to other user using a different seed.

The Gold code generator outputs *si* for *i=*0,1,…,263-1, which is used to scramble the interleaved codeword bits *ci* for *i=*0,1,…,*n*-1 prior to the modulation mapper as



The shift registers initialization at the start of a packet is given by

* + User ID (1st register) and group ID (2nd register).
  + Fast forward both shift registers 100 times to reduce PAPR.

**</707r1>**

### Scrambling harmonized proposal

The Gold code generator outputs *si* for *i=*0,1,…,263-1, which is used to scramble the interleaved codeword bits *ci* for *i=*0,1,…,*n*-1 prior to the modulation mapper as



The shift registers initialization at the start of a packet is given by

* + User ID (1st register) and group ID (2nd register).
  + Fast forward both shift registers 100 times to reduce PAPR.

## Discovery signalling

**<707r1>** Marco (NICT)

### Discovery frame structure

The *discovery preamble (*DP) is based on a ZC sequence and a *discovery* *resource block* (DRB) from a modified DTF-S OFDM or OFDM signal. The DP and DRB formed the Discovery Signal (DS).

Moreover, we propose to use one channel (from the proposed channelization for sub-GHz, 2.4 GHz and 5.7 GHz bands) for only discovery of devices.

PAC devices can either transmit or receive the DS in this unique channel asynchronously. Such unique channel for discovery is named Shared Discovery Channel (SDCH). The discovery signal (DS) sent over a discovery shared channel (DSCH) is illustrated as



The DS consists of a preamble sequence plus a DRB formed by *Nfs* frequency slots and *Nts* time slots. Once synchronized, a receiver knows the location of the discovery resource block (DRS) to scan for possible peers or to pick time-frequency slots to transmit its DS.

The proposed ZC sequence for initial synchronization during discovery (or communication mode) is a ZC sequence with the following parameters: Sequence length *N = 63*, relative prime *r = 62* and *q = 0*.

Such ZC sequence is mapped onto 62 sub-carriers. The first subcarrier and the DC subcarrier are empty. Of course, several repetitions of the DP may be transmitted to improve reliability.



The discovery process is energy intensive. In order to minimize power consumption only one subcarrier of the N-point IFFT is used per user. Consequently, the PAPR is set to the minimum value. Furthermore, across the frequency domain, users are orthogonal (OFDM).

For discovery, the *n*th symbol transmitted over the *k*th subcarrier is given by



where *l=L*+1,…,0,1,…,*N*-1 and *L* is the cyclic prefix length.

Contiguous subcarriers are orthogonal as illustrated in the figure:



The DS is transmitted with a predefined duty-cycle (see NICT MAC proposal). From upper layers, terminals pick time-frequency slots in the DRB to transmit the DS.

A set of 126 symbols are transmitted per time slot. Such frame contains information about a given peer (peer ID, group ID, service ID, application ID, etc.) and which channel is used for association or peering (different from the SDCH).

The number of frequency slots *Nfs =*1024 (IFFT size) and the number of time slots *Nts* is chosen as 20. Consequently, the DRB can support up to *Nfs*x*Nts*=20,480 users for discovery per group.

The discovery data is formatted as illustrated in the figure:



Append 57 bits for user ID, device ID, Group ID, etc.

Append 6 bits from CRC-6-ITU error detection code.

Append 63 bits from shorten BCH(126,63) code.

### Discovery procedure

Devices are in three possible states:

* + **RDM** – receiving discovery mode,
  + **TDM** – transmitting discovery mode,
  + **Sleep** – idle.

Also, devices are equipped with clear channel assessment (CCA).

**1)** At start up or after idle or after command, a device enters into receiving discovery mode (**RDM**) and listens for a DS.

The synchronization subsystem detects the preamble (and hence the position of the DRB) and the detection subsystem scans the DRB for DRB usage and detection of peer ID, service ID, etc. Go to **Sleep** mode.

**2)** After command, a device enters into transmitting discovery mode (**TDM)**.

Device chooses a free time-frequency slot to transmit its DS over the next DRB transmission. Go to **Sleep** mode.

Of course, there are intermediate steps like time-out for DRB scanning, miss detection, etc. Here, we present the core algorithm idea only.

### Peering

For association or peering, intended devices that want to establish a communication link, request peering through a random access preamble transmitted in the ACH.

The random access association preambles are named Random Access Preambles (RAPs).

Such RAPs are formed with ZC sequences as well. Hence, a pool of orthogonal RAPs is formed in order to reduce interference from competing terminals for random access.

A unique RAP is assigned to every device in a Group. Such unique RAP is used for fine synchronization and control messages that control how a communication link is granted.

The RAP signal is illustrated as



where GI is guard interval.

Thus, a set of orthogonal preamble sequences of length 1024 can be generated from ZC sequences for random access, which satisfy the maximum round-trip time and coverage performance for a maximum distance of 500m. Details of preamble design can be found in document with DCN 369r1.

The CP and GI lengths are given by



#### Peering procedure

Once initial synchronization and detection of discovery RB are achieved by Terminal 2 over Terminal 1, for instance, the peering procedure flow is as follows:

Terminal 2 requests association by a random access procedure based on an orthogonal RAP (the process is initiated and control by the MAC and possibly upper layers):



**1)** Terminal 2 sends a **RAP** over the ACH.

The RAP is randomly selected from a pool of orthogonal ZC sequences. It contains finer frequency granularity for Terminal 1 to acquire fine time and frequency synchronization of Terminal 2, plus information about the resources needed to transmit in step **3)**.

**2)** Terminal 1 replies with a **RA response** message.

It contains timing information (round-trip delay), RAP-ID, RB element grant to transmit in step **3)**, plus Group identifier, etc.

**3)** Scheduling request

It contains scheduling request information for transmission. If this message is successfully detected in Terminal 1, still contention remains unsolved for other terminals. A quick resolution is needed.

**4)** Contention resolution

Terminal 1 echoes Terminal 2 ID contained in **3)**, so that one of the following statements is true:

Terminal 2 detects its ID and sends ACK (RA terminated) a communication link is scheduled and established.

Terminal 2 detects another ID (RA terminated and restarts a new one).

Terminal 2 fails to detect ID (RA terminated and starts a new one).

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## Reference signals

**<707r1>** Marco (NICT)

Reference signals are required to perform channel estimation for doubly dispersive wireless channels (time and frequency) for reliable detection, equalization and synchronization.

### Channel’s time dispersion

Considering a maximum speed of *v*=100 Km/h (27.78 m/s).

The Doppler spread is given by *fd=fc v/c*, where *fc* is the carrier’s central frequency.

The minimum sampling time to reconstruct the channel is *Tc=1/2fd*.

|  |  |  |
| --- | --- | --- |
| Freq. band | fd (Hz) | Tc (msec) |
| 5.7 GHz | 527.82 | 0.947 |
| 2.4 GHz | 222.24 | 2.2 |
| 920 MHz | 85.2 | 6 |

The DFT-spread OFDM or OFDM frame structure has a slot time of *Tslot*=0.5 msec. Then, *one* reference symbol per slot is needed in the time domain to estimate the channel correctly.

### Channel’s frequency dispersion

Considering 90% and 50% coherence bandwidth as *BC*,90=1/50 *στ* and *BC*,50=1/5 *στ* ,

where *στ* is the channel’s RMS delay spread.

Such RMS delay spread is estimated as . For a distance *d=*500m, the 90% and 50% coherence bandwidth are given in the table:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Freq. band | Ca | γa | στ | Bc,90 (KHz) | BC,50 (KHz) |
| 5.7 GHz | 10 | 0.51 | 238 nsec | 84 | 840 |
| 2.4 GHz | 55 | 0.27 | 295 nsec | 67 | 678 |
| 920 MHz | 1254.3 | 0.06 | 1.82 usec | 11 | 110 |

If *BC*,50*<BW*, then the wireless channel is frequency selective fading and frequency domain equalization is required. We propose that the spacing between 2 reference symbols in the frequency domain in a RB is 30 KHz to resolve the channel’s frequency dispersion.

### Zadoff-Chu sequences

Preambles or beacons for synchronization and random access are formed with Zadoff-Chu (ZC) sequences of length *N.*

ZC sequences are constant-amplitude zero-correlation (CAZAC) sequences given by



where  is a primitive *n*th root of unity, *r* is a relative prime to *N*, k is the sequence index such that *k =* 0, 1*,* ...,*N*-1and *q* is any integer.

ZC sequences have constant amplitude and so its *N*-point DFT. Hence, this limits the PAPR and simplifies implementation as only phases have to be generated and stored. Furthermore, ZC sequences have ideal cyclic autocorrelation, i.e., the correlation with its shifted version is a delta function. Consequently, a [large] set of orthogonal preambles are possible to generate.

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**<Billy>**

# ~~UWB Physical (PHY) layer specification~~

## ~~General~~

## Appendix A

**<395r1>**

Table A. List of Service types

|  |  |
| --- | --- |
| **Value** | **Meaning** |
| 0 | All Service Types |
| 1 | real-time streaming |
| 2 | display |
| 3 | talking (VoIP) |
| 4 | two-way gaming |
| 5 – 254 | Reserved |
| 255 | Vendor Specific |

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**<390r1**> Cho (ETRI)

|  |  |  |  |
| --- | --- | --- | --- |
| **Contents** | **Size(bits)** | **Description** | **Notes** |
| Type | 3 | Type of discovery signal  0: device advertisement  1: service advertisement  2: service info request  3: service info response  4: peer search request  5: peer search response |  |
| ID | 48 | Identifier of PD  Type=0 : (own)device ID (e.g. mac address)  Type=1: (own) (app. Type ID + app. specific ID+ app. Specific user ID)  Type=2: (target) device ID  Type=3: (own) (app. Type ID + app. specific ID+ app. Specific user ID)  Type=4:(target) (app. Type ID + app. specific ID+((opt.)app. Specific user ID))  Type=5:(own) (app. Type ID + app. specific ID+ app. Specific user ID) | In case type=4, (target) app. Specific user ID can be included.  ID bits are provided from upper layer (or management block) based on information of application layer |
| SIV(Service Information Version) | 5 | Version of service information provided by each PD  .value:0~31(modulo 32)  .value can be changed due to addition/deletion of application(s) or change of user | In case Type=0, type=2,  Provided from upper layer based on information of application layer |
| Request range | 1 | Request Range of service information  - 1: Delta with (pervious) service info. Ver.  - 0: Full with (received) service info. Ver. | In case Type=2 |
| SN | 5 | Sequence number | In case Type=1or 3 |
| End indicator | 1 | end indication (0: continue, 1:end) | In case Type=1or 3 |
| GI | 1 | Service info. for group communication  (0: individual, 1:group) | In case Type=1,3, 4 or 5 |
| Reserved | 7 or 6 | Reserved bits |  |
| total | 61 |  |  |

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