**IEEE P802.15**

**Wireless Personal Area Networks**

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| Project | IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) |
| Title | NICT Final Impulse Radio Ultra-Wideband PHY Proposal in response to CFC (text) |
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| Re: | TG8 Call for Contributions (CFC) (15-14-0087-00-0008) |
| Abstract | This is the text of the NICT Impulse Radio Ultra-Wideband PHY proposal in response to Call for Contributions of IEEE 802.15.8 group for PAC. |
| Purpose | This document provides the details of the NICT IR-UWB PHY proposal to IEEE 802.15.8 |
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# Band plan

Proposed band plan is given in Table 1. with the specification of the mandatory frequencies provided in Table 2.

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| **Band plan** |
| **Channel index** | **Lower band edge (MHz)** | **Upper band edge (MHz)** | **Region** | **Comment** | **Available mandatory frequencies** |
| 1 | 4200 | 4800 | China | Low band in China | a |
| 2 | 3100 | 4800 | Europe, Korea | Low band in Europe and Korea | a,b,c |
| 3 | 3400 | 4800 | Japan | Low band in Japan | a,b,c |
| 4 | 3100 | 5700 | USA | Low band in USA | a,b,c |
| 5 | 6000 | 9000 | Europe, China | High band in Europe and China | d,e,f,g |
| 6 | 7250 | 10250 | Japan | High band in Japan | e,f,g,h |
| 7 | 7200 | 10200 | Korea | High band in Korea | e,f,g,h |
| 8 | 6000 | 10600 | USA | High band in USA | d,e,f,g,h |
| 9 | 5925 | 7200 | USA | Wideband in USA | d |

**Table 1.** Proposed band plan.

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| --- |
| **Mandatory frequency\* allocation** |
| **Index** | **Mandatory frequency (MHz)** |
| a | 3500 |
| b | 4000 |
| c | 4500 |
| d | 6500 |
| e | 7500 |
| f | 8000 |
| g | 8500 |
| h | 9000 |

\* Mandatory frequency is frequency at which PSD level is less than 6 dB below maximum.

**Table 2.** Mandatory frequency allocation.

# Pulse shape and duration

We do not define a specific pulse shape in order to allow different low-complexity pulse generators. Pulse shape is constrained in spectrum as per Sec. 1 and 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.

As Fig. 2 shows SHR consists of Preamble and Synchronization Frame Delimiter (SFD). Preamble consists of M=8 times repetition of the sequence *Si* which is one of the Gold sequences of length$ L=31$, with the property $S\_{i}\left(l\right)\in \left\{0,1\right\},$ where $l\in \{0,1,…,L-1\}$. Since set of Gold sequences of length $L=31$ 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. 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. More precisely, the same symbol duration of $T\_{sym}=1024ns$ is used for $k\in \left\{PR,SFD, PSDU\right\}$, where $k$ is the chip index. Transmitted pulse waveform is denoted $w(t)$. Transmitted signal for the $k$-th transmitted chip is

|  |  |  |
| --- | --- | --- |
|  | $$a\_{k}\left(t\right)=b\_{k}v\_{k}w\left(t-k T\_{sym}\right),$$ | **(1)** |

where$ b\_{k}\in \{0,1\}$ is the transmitted chip; $v\_{k}=2S\_{i }\left⌊k/L\right⌋-1$ holds for $k\in PSDU$, while for $k\in \left\{PR,SFD\right\},$ $v\_{k}=1$ is set. Hence, the same Gold sequence used in preamble and SFD is used to exchange the phase of the PSDU chips in order to flatten the spectrum of the transmitted signal.

# Channel coding and data rates

RS coder

Conv. coder

Modulator

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

As shown in Fig. 4, the coding scheme is concatenation of the outer Reed-Solomon RS6(63,55) code and the inner convolutional code. Convolutional coding rate for different data rates is specified in Table 3. Notice that the highest data rate specified uses only Reed-Solomon coding without any convolutional coding.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Data rate (Kbps)** | 54.56 | 109.12 | 218.25 | 436.51 | 873.02 |
| **Conv. coding rate** | 1/2 | 1/2 | 1/2 | 1/2 | 1/1 |
| **Chips per symbol** | 8 | 4 | 2 | 1 | 1 |

**Table 3.** Data rates used with convolutional coding rates and number of chips per symbol.

Table 4. provides detailed specification of the convolutional code used.

|  |  |
| --- | --- |
| **Conv. coding rate** | ½ |
| **Constrained length** | 3 |
| **Generators in octal** | 5 7 |
| **Free distance** | 8 |

**Table 4.** Convolutional code used.

# 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 $T\_{round1}$ and round trip time from device 2 to device 1 denoted $T\_{round2}$. $T\_{prop}$ denotes propagation time that is being estimated, while $T\_{reply1}$ and $T\_{reply2}$ represent reply times of device 1 and 2 respectively. Hence, $T\_{prop}$ estimate is calculated as follows

|  |  |  |
| --- | --- | --- |
|  | $$\hat{T}\_{prop}=\frac{1}{4}(T\_{round1}-T\_{reply1}+T\_{round2}-T\_{reply2})$$ | **(2)** |

If relative errors of timing at device 1 and 2 are denoted $e\_{1}$ and $e\_{2}$ it follows that

|  |  |  |
| --- | --- | --- |
|  | $$T\_{round1}=T\_{round}×\left(1+e\_{1}\right),$$ | **(3)** |
|  | $$T\_{round2}=T\_{round}×\left(1+e\_{2}\right),$$ | **(4)** |
|  | $$T\_{reply1}=T\_{reply}×\left(1+e\_{1}\right),$$ | **(5)** |
|  | $$T\_{reply2}=T\_{reply}×\left(1+e\_{2}\right).$$ | **(6)** |

Thus error of $T\_{prop}$ estimation is:

|  |  |  |
| --- | --- | --- |
|  | $$\hat{T}\_{prop}=T\_{prop} \left(1+\frac{e\_{1}+e\_{2}}{2}\right).$$ | **(7)** |

Hence, relative error of the range estimation is also in the same order of magnitude as $e\_{1}$ and $ e\_{2}$, which for crystal oscillators are usually around 20 ppm.