**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 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.

Preamble consists of M=8 times repetition of the sequence *Si* which 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. More precisely, the same symbol duration of $T\_{sym}=1024ns$ is used for $k\in \left\{PR,SFD, PSDU\right\}$, where $k$ is the symbol index. Transmitted pulse waveform is denoted $w(t)$. Hence, transmitted signal for the $k$-th transmitted symbol is

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

where $b\_{k}\in \{0,1\}$ is transmitted bit and $φ\_{k}\in \{0, π\}$ is pseudo-random sequence used in $k\in PSDU$ to flatten the spectrum of the transmitted signal, while for $k\in \left\{PR,SFD\right\}$ $φ\_{k}=0$ is set. Pseudo-random sequence used is the same Gold sequence used in PR and SFD for $b\_{k}\in \{0,1\}$.

# Channel coding and data rates

RS coder

Conv. coder

Modulator

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

As shown in Fig. 4, coding is concatenation of outer Reed-Solomon RS6(63,55) codes and 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.