IEEE P802.15

Wireless Personal Area Networks

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)
Title	TG6 UWB-PHY Coexistence Assurance Document
Date Submitted	March 14th, 2011
Source	Marco Hernandez (NICT)
Re:	802.15 Interim Session in Los Angeles, January 2011.
Abstract	Coexistence analysis of 802.15.6 UWB-PHY with other 802 Stds.
Purpose	This UWB-PHY Coexistence Assurance Document is being provided by the IEEE 802.15.6 Task Group to satisfy the requirements of the IEEE 802.19 Task Group and IEEE 802 Executive Committee to determine if a proposed IEEE 802 standard has made a reasonable effort to be able to coexist with devices compliant to other IEEE 802 standards in their operating band.
Notice	This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.
Release	The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.

Contents

1. Acronyms and Abbreviations

BAN	Body Area Network.
BCH	Bose, Ray-Chaudhuri, Hocquenghem Code
FM-UWB	Frequency Modulation Ultra-Wide Band.
IR-UWB	Impulse Radio Ultra-Wide Band.
PLCP	Physical Layer Convergence Procedure.
DAA	Detect And Avoid.
PPDU	PHY Protocol Data Unit.
SHR	Synchronization Header
PHR	PHY Header
PSDU	PHY Service Data Unit.
CCA	Clear Channel Assessment
EIRP	Equivalent Isotropically Radiated Power
HARQ	Hybrid Automatic Repeat Request
MPDU	MAC Protocol Data Unit
LFSR	Linear Feedback Shift Register
LSB	Least Significant Bit
MSB	Most Significant Bit

2. Introduction

The IEEE 802.15.6 Task Group is developing a new UWB-PHY that operates in the designated UWB frequency bands between 3.1 and 10.6 GHz. In order to assure that such PHY will provide reasonable performance when operating near other wireless devices, the 802.15.6 Task Group has adopted the policies and conventions of the IEEE 802.19 Coexistence Technical Advisory Group (TAG).

The IEEE 802.19 TAG has mandated that new wireless standards developed under IEEE 802 be accompanied by a *Coexistence Assurance* document. In [1], guidelines are provided for how coexistence can be quantified based on predicted packet error rates among IEEE 802 wireless devices. A detailed discussion of coexistence and coexistence methods can be found in IEEE Std 802.15.2-2003.

Hence, this coexistence assurance document is provided by the IEEE 802.15.6 Task Group to satisfy the requirements of the IEEE 802.19 Task Group and IEEE 802 Executive Committee.

3. IEEE Standards and proposed IEEE Standards characterized for coexistence

This clause enumerates IEEE-compliant devices that are characterized in the document and devices that are not characterized for operation in proximity to IEEE 802.15.6 devices.

IEEE Standards characterized for coexistence are as follows:

- IEEE Std 802.11-2007 (5 GHz)
- IEEE Std 802.11y-2008 (3 GHz)
- IEEE Std 802.11n-2009 (5 GHz)
- IEEE Std 802.16-2009 (below 11 GHz: primarily 3 GHz, 5-6 GHz)
- IEEE Std 802.15.4a-2007 (UWB band)

Proposed IEEE standard characterized for coexistence is as follows:

- IEEE 802.15.4f (high band UWB)

4. Overview of UWB-PHY of IEEE 802.15.6

5. General coexistence mechanisms

The proposed standard IEEE 802.15.6 provides several mechanisms that enhance coexistence of its UWB PHYs with other wireless devices operating in the same spectrum. These mechanisms include:

- Very low transmit power
- Low duty cycle

- Modulation
- Time hopping
- Hybrid ARQ
- Clear channel assessment (CCA)
- Active and inactive frames periods
- Local regulations that may require detect-and-avoid (DAA) techniques

5.1 Low transmit power

The UWB PHYs operate under strict regulations for unlicensed UWB devices worldwide. The least restrictive regulations for UWB are available under the Federal Communications Commission (FCC) rules, US 47 CFR Part 15, subpart F. Under these rules, the highest allowable limit for UWB emissions are based on an effective isotropically radiated power (EIRP) of –41.3 dBm/MHz. Other future UWB regulations in other regions will be likely at this same level or even lower.

Under these limits, the allowable transmit power for a train of pulses with spectrum $G(f)$, whose power spectral density (PSD) is centered at frequency f_c and whose amplitude has been set to 1 for convenience is given by

$$P_{\mathrm{EIRP}} = 10\,\mathrm{Log}_{10}\left[\left(\int_0^{\infty} G^2(f)\,df\right)10^{-41.3/10}\right] \qquad (1)$$

If all available spectrum in a 10 dB point bandwidth of 500 MHz were perfectly filled with the maximum allowed signal PSD, the total $P_{\mathrm{EIRP}}^{\max}$ = -14.3 dBm. This value represents the maximum possible EIRP limit for a UWB signal under this particular regulation and setting.

The maximum allowable EIRP for a compliant pulse shape is found by computing Equation (1) and satisfies $P_{\mathrm{EIRP}} < P_{\mathrm{EIRP}}^{\max}$ assuming any channel in the frequency band plan.

This transmit power level is at or below the limits for unintentional emissions from other electrical or electronic devices. In addition, this power level value is less than the out-of-band emission limits for other unlicensed devices operating in designated bands such as the 2.4 GHz ISM or 5 GHz UNII bands.

Additionally, since this transmits power is spread over at least 500 MHz of bandwidth, the highest power in the operating bandwidth of a typical narrowband 20 MHz victim system is less than –28.29 dBm. These very low power levels emitted into the operating band of any potential victim system with this characteristic will reduce the likelihood that UWB devices might interfere with other narrowband systems.

5.2 Low duty cycle

The IR-UWB specifications of this standard are tailored for applications with low power and low data rates with a constant duty cycle of 3% for all data rates. This will make IEEE 802.15.6 devices less likely to cause or be subject to interference by other standards.

On the other hand, at the MAC level, the maximum interference level to victim systems can be limited by controlling the duty cycle of packets or frames through active and inactive periods. The traffic can occur only in the active period. Victim systems are free of interference in the inactive period. The control of active and inactive periods is handled by the hub and a given application.

The interference level is restricted by the ratio of active period to the active plus inactive period. The possible packet collision in the active period can be mitigated by

1) CSMA-CA mechanism. FM-UWB can implement carrier sense of a narrowband system.
2) Slotted Aloha with channel indicator. This channel-dependent Aloha sets transmission probability related with channel's quality, which can be obtained through listening to a beacon or preamble symbol from the hub by means of ED. The function to map channel quality to transmission probability is defined at application layer.
3) Limit the number of node devices through association.
4) Traffic shaping like a combination of short packet to large packet.
5)

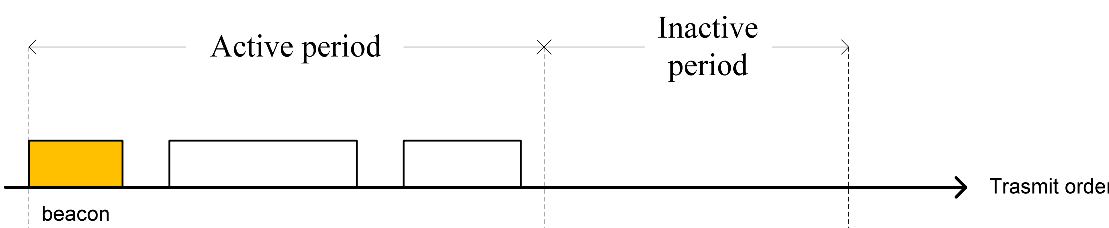

Figure 1—Concept of active and inactive periods

6. Modulation

The IR-UWB PHY has a high QoS mode in which differentially encoded BPSK or QPSK combined with differential detection are employed. This strategy is the best compromise between performance and complexity. Performance is better and more robust to interference than on-off modulation, but slightly more complex. Furthermore, the use of complaint chirp pulses opens the possibility of novel detection strategies that have been proof resilient against interference.

The FM-UWB PHY combines CP-2FSK modulation with wideband FM. The mandatory data rate is 250 kbps, the central frequency of CP-2FSK modulation is 1.5 MHz and bandwidth of 800 kHz, also known as subcarrier. Subsequently, the wideband FM signal has a transmission bandwidth given approximately by the Carlson's rule:

$$BW_{\mathrm{FM}} \approx (2\beta + 1) f_m \qquad (2)$$

where β is the modulation index and f_m is the largest frequency component of the CP-2FSK signal. Hence, if f_m =1.9 MHz, then $BW_{\mathrm{FM}} \approx$ 500 MHz for β =130.5.

The effect of spreading the data signal's bandwidth of 800 kHz to 500 MHz transmission bandwidth is similar to spread spectrum. This high processing gain of FM-UWB allows resilience against interference. On the other hand, a BAN hub with a FM-UWB radio must implement an IR-UWB radio as well. Thus, the hub has control of both UWB technologies and can enforce low interference between them.

7. Time hopping

A dynamic time hopping sequence (TM) is generated by a linear feedback shift register (LFSR). A hub initializes such TM generator according to the Kasami sequence number used to form the synchronization header (SHR). There are 8 possible sequences. Hence, a different TH sequence can be associated for a different BAN. Simulation results show the performance under multiple BANs improves significantly.

8. Clear channel assessment

The receiver energy detection (ED) measurement for clear channel assessment (CCA) is an estimate of a (mostly) narrowband signal's power around its central frequency. It is meaningless when the signal's power is below the noise floor (ultra wideband signal). No attempt is made to identify or decode signals on the channel.

The FM-UWB PHY can perform carrier sense of a narrowband system after FM demodulation by ED over a certain threshold. Carrier sense cannot be applied for IR-UWB as the signal power level is below the noise floor. However, a hub with FM-UWB radio must implement an IR-UWB radio as well. Consequently, carrier sense by FM-UWB can be use for the IR-UWB radio as well.

The IR-UWB PHY can perform CCA by preamble detection. CCA shall report a busy medium upon detection of a synchronization symbol $\mathbf{S}_i$. Otherwise, slotted Aloha is employed.

9. Hybrid type II ARQ

The high QoS mode employs a more powerful channel code based on the shortened BCH(126,63) in case of a packet is found in error by CRC-16 error detection mechanism. Thus, the BANs under high QoS mode is more robust to interference.

10. Coexistence assurance methodology

The coexistence assurance methodology [1] predicts the Packet Error Rate (PER) of an Affected Wireless Network (AWN) or victim in the presence of an Interfering Wireless Network (IWN) or assailant. Such methodology assumes an AWN and an IWN each composed of a single transmitter and a receiver. The methodology takes as input a path loss model, a bit error rate function for the AWN and predicted temporal models for packets generated by the AWN and the IWN. Based on these inputs, the methodology predicts the PER of the AWN as a function of the physical spacing between the IWN transmitter and the AWN receiver.

10.1 Minimum coupling loss

In addition, the minimum coupling loss method gives the minimum distance at which a victim system can accept 1 dB of degradation in receiver sensitivity. Thus, zones of protection can be recommended.

11. IEEE Std 802.11-2007 (5 GHz) coexistence performance

Bibliography

[1] S.J. Shellhammer, “Estimating Packet Error Rate Caused by Interference - A Coexistence Assurance Methodology”, IEEE 802.19-05/0029r0, September 2005.

[Online] Available: http://www.ieee802.org/19/pub/2005/

[2] S.J. Shellhammer, S. J., “Estimation of Packet Error Rate Caused by Interference using Analytic Techniques - A Coexistence Assurance Methodology,” IEEE 802.19-05/0028r2, October 2005.

[Online] Available: http://www.ieee802.org/19/pub/2005/

[3]