

UWB Coexistence and Cognitive Radio: How Multiband-OFDM Leads the Way

Jim Lansford, Ph.D.
Chief Technology Officer, Alereon, Inc.
7600 North Capital of Texas Highway, Suite C200
Austin, TX USA 78731
jim.lansford@alereon.com
+1 512 345 4200 x2166

Abstract

The recent history of Ultrawideband communications technology has seen great debate over whether these UWB cause unacceptable interference to existing users of the same and nearby bands. Building on the IEEE 802.15.2 Recommended Practice and the framework developed by IEEE 802.19, researchers are developing techniques to separate UWB signals for others using time, frequency, power, space, and coding, the five techniques available to minimize interference and maximize capacity. This paper explores general methods for using these parameters either to eliminate interference, or to achieve graceful, deterministic degradation. It concludes with next steps for bringing these techniques into the standards process.

1.0 BACKGROUND

According to the FCC ruling that permitted operation of Ultrawideband communication systems[1], an ultrawideband signal is defined as a signal that fits the following criteria:

Given:

f_H = upper 10dB cutoff frequency

f_L = lower 10 dB cutoff frequency

Define:

Center frequency

$$f_C = (f_H + f_L)/2$$

Fractional bandwidth

$$F_P = 2(f_H - f_L) / (f_H + f_L)$$

Then a signal is ultrawideband

if $F_P > 0.20$ or

$f_H + f_L > 500\text{MHz}$

In its earliest form, ultrawideband was generated by broadband spark discharges that could be detected by a

cat-whisker (galena) detector. A detailed history of UWB can be found in a comprehensive paper by Barrett [2].

While ultrawideband as a technology has generated a great deal of interest, it has also generated a great deal of controversy. Since UWB signals are spread over a broad swath of spectrum at power levels near the noise floor, there has been concern among many other users of the radio spectrum that UWB will artificially boost the noise floor and degrade performance of the incumbent users. After a great deal of public debate, argument and comment, the FCC approved the first Report and Order on February 14, 2002. In this R&O, the FCC not only defined UWB signals as noted previously, but also defined a spectrum mask that specifies the amount of power that can be radiated by UWB systems across the band. This spectrum mask is shown in Figure 1.

The concept of a spectral mask was an attempt to calm the fears of other users of the spectrum over UWB; in reality, this is a draconian approach because it requires UWB to avoid emissions in a given band, even if it is not in use by any other device within the limited range of the UWB signal. Since the UWB signal is generally at or near the thermal noise floor[3], it is essentially imperceptible by devices more than 10 meters away unless they have a high gain antenna.¹ This potential for interference has been studied extensively, such as in the paper by Foerster [4]

While this debate rages on, there are a variety of techniques being explored by companies in the UWB community that will measurably improve the coexistence of these signals. For example, the IEEE created the P802.15.2 Task Group in 1999 to address the potential interference between 802.11b systems (also known as Wi-Fi) and Bluetooth systems, which share the same 2.4GHz ISM band. In the Recommended Practice that was

¹ Systems in the 3.1-4.7 GHz band, where initial UWB systems are likely to be deployed, are generally either radar or satellite systems. Since UWB communication devices are destined for consumer use inside homes, the likelihood of one of them being in the boresight or even a significant sidelobe of these systems is virtually nil.

approved in July of 2003, the group describes techniques that these two systems can employ to avoid interfering with each other so that performance is degraded in a graceful, deterministic way[5]. These techniques will be described in more detail later in this paper.

The FCC has created a group called the Spectrum Policy Task Force[6], that is looking for new and innovative ways to manage spectrum, given the kind of debate that new technologies such as UWB have generated. Among the concepts generated by the SPTF are the concepts of:

1) Interference “temperature”[7], where the contribution of a low-level communication system such as UWB is assumed to be just another noise source that is included in a link budget. As shown in Figure 2, the noise level in a given environment can be thought of as the sum of thermal (kTB), natural sources of noise, unintentional man-made and intentional man-made noise. All of these terms taken together comprise the “true” noise floor. Since most existing wireless systems are already designed with a link margin in mind, devices such as UWB will be imperceptible when the desired signal is just a dB or two above the existing noise floor. As Figure 2 shows, this will cause a slight reduction in range of the narrowband system, but the overall capacity of the RF environment has increased since many low power systems can be overlaid within the coverage footprint of the higher powered system, and

2) Cognitive radio [8]. The idea behind cognitive radio is that performance can be improved and interference reduced if wireless systems were aware of other RF signals in their environment [9]. The improvements accrued from this technology could be dramatic; while communication engineers have historically thought of channel capacity and Shannon’s Law simply in terms of bandwidth, a cognitive radio takes an expanded view of the channel by managing time, frequency, space, power, and coding. Unfortunately, the benefits from device-centric spectrum management (as opposed to policy-based spectrum management) are only fully realized when all devices in a frequency band are cognitive, so that they can negotiate.

2.0 COEXISTENCE METHODS

As described by IEEE 802.15.2, techniques to improve coexistence can be put into two categories:

- 1) Collaborative – a mechanism exists for direct communication between the wireless systems, and

- 2) Non-collaborative coexistence – no direct mechanism exists for coordination, so one or both systems must infer the environment and take unilateral action.

Figure 3 shows this concept in terms of a traffic model; in non-collaborative coexistence, the traffic flows through both systems, and interference (collisions) can only be avoided through medium sensing techniques such as CSMA (“look before crossing”) or adaptive frequency hopping (we’re having lots of accidents at this intersection, so let’s try a different route that hopefully will have less traffic). If one of the signals is an OFDM signal, then some of the tones could be nulled (“let’s close down one lane of the highway so it can be used by other traffic”) In any of these cases, the channel (highway) is not being used to its maximum efficiency.

In the case of collaborative coexistence, collisions can be completely avoided if the wireless systems are capable of sharing detailed information in real-time about their desired occupancy of time, frequency, space, and power (neglecting code for the moment). The figure shows a traffic light (TDMA), which clearly only orthogonalizes the time dimension of this space. In a more complete implementation of a cognitive radio, the systems would optimize their performance (throughput, latency, error rate or whatever is desired) under the constraints of shared knowledge of these parameters, where complete orthogonalization of the parameter space would allow fully independent operation.²

More formally, we can state the problem in the following way:

A cognitive radio optimizes:

- Cost of connection
- Data rate
- Error rate
- Quality of service (QoS)

By controlling:

- Protocol (if multiple available)
- Power levels
- Antenna beamforming
- Frequency of transmission

² There are corner cases where the orthogonalization breaks down, such as when the protocols dictate that both systems must collide (one transmits while the other receives) because quality of service requires both to be active at the same time, in the same frequency band, within overlapping antenna beams, with conflicting power levels. Cognitive radio does not do away with retransmission required for an unreliable channel!

- Coding (if available)
- Timing

While the set of protocols is generally fixed to a small number, the other parameters can generally be chosen independently from a range of values. There is likely some fruitful research into methods for including protocol as part of the optimization; for example, wireless LAN systems can often choose to modify packet size and data rate. Optimal choices of these parameters in a cognitive radio environment are an active research area.

3.0 SPECIFIC EXAMPLE: Multiband-OFDM

As an example, consider the system shown in Figure 4. This shows a multiband OFDM UWB signal that has been shaped in frequency to avoid generating interference in certain parts of the spectrum. The spectral mask that is applied to the OFDM signal could be based on a priori decisions about restricting emissions in certain bands such as the radio astronomy bands in Japan; the tone weightings could also be derived from an environment survey done by the OFDM modem to measure the “interference temperature” of the environment. In either case, the multiband OFDM signal permits flexibility in this “spectral sculpting” that is not practical with pulsed or direct sequence UWB signals

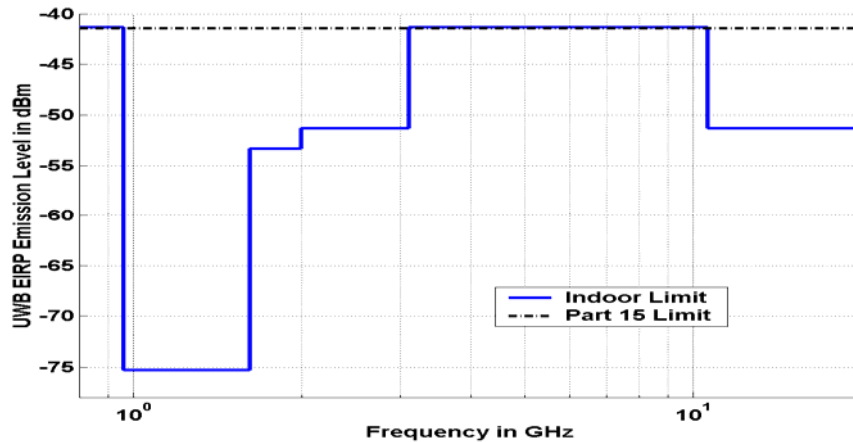


Figure 1: UWB emission spectral mask

4.0 STANDARDS PROCESS

In addition to the regulatory process that is driving development of cognitive radio, the IEEE has created a Coexistence Technical Advisory Group, called 802.19. The charter of this TAG is to work with the wireless working groups within IEEE 802 to develop better coexistence techniques for the WPAN, WLAN, and WWAN systems under development by this standards body. The TAG expects to assist in development of Recommended Practices that will complement the cognitive radio initiative. There are also 802.11 activities underway to explore cognitive radio.

5.0 CONCLUSION

UWB is an exciting new communications technology that approaches spectrum management in a different way than prior wireless systems. Through the use of collaborative coexistence and, eventually, cognitive radio techniques, these systems as well as those in close proximity to them can give users a better, more reliable radio connection.

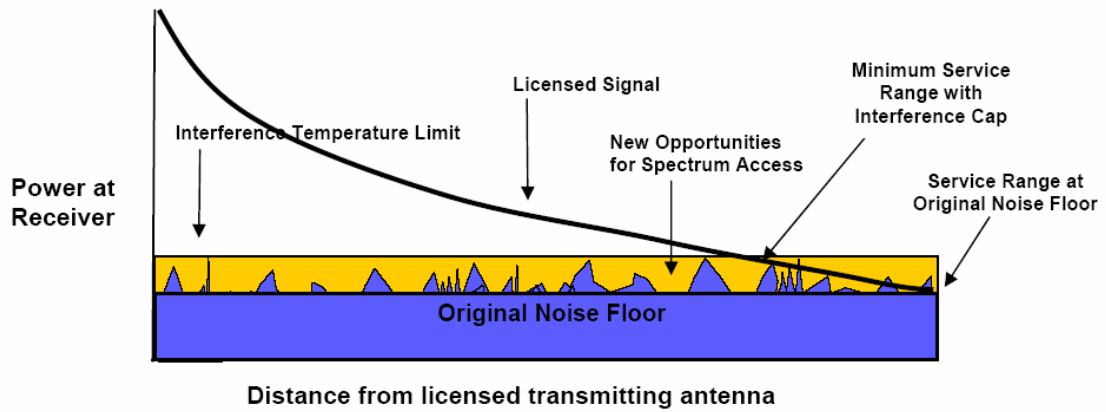


Figure 2: Interference "temperature" concept (from FCC 03-289A1)

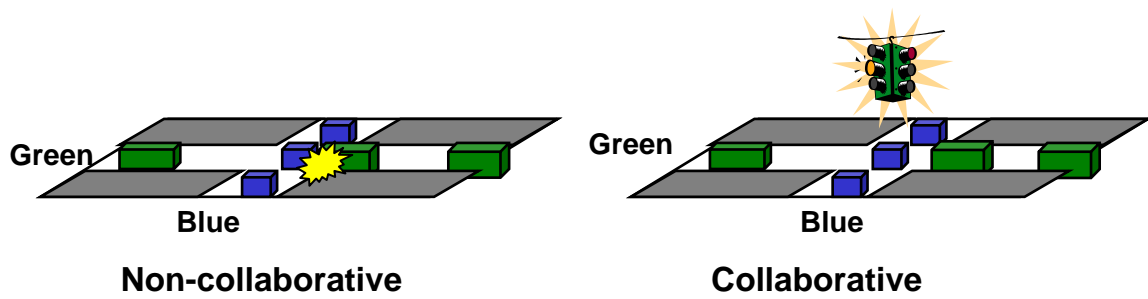


Figure 3: Non-collaborative vs. collaborative coexistence

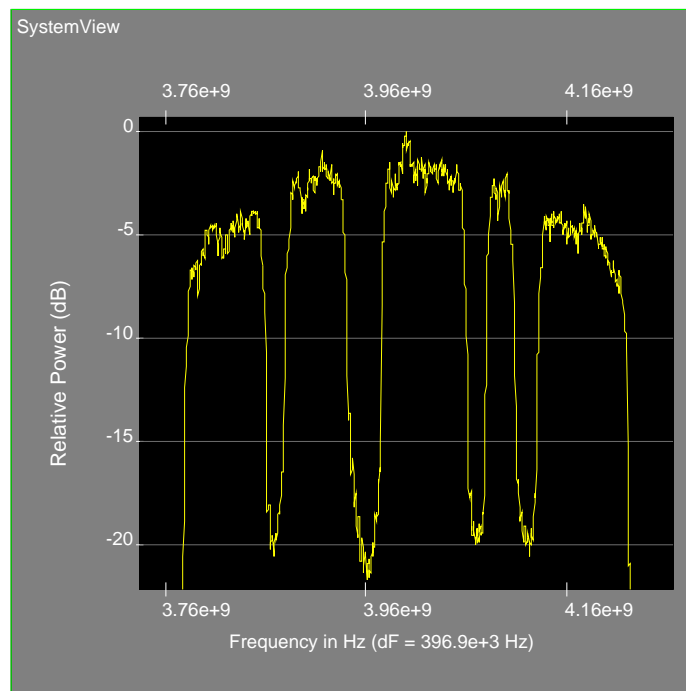


Figure 4: Spectral Sculpting of an OFDM signal (courtesy Dave Leeper, Intel)

6.0 REFERENCES

- [1] Ultrawideband Report and Order is available at http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-02-48A1.pdf
- [2] T.W. Barrett, "[History of UltraWideBand \(UWB\) Radar & Communications: Pioneers and Innovators](#)," Progress In Electromagnetics Symposim 2000 (PIERS2000), Cambridge, MA, July 2000.
- [3] Matthew Welborn, "UWB Coexistence Issues," IEEE document 802.15-02/467r0
- [4] Jeffrey R. Foerster, "[Interference Modeling of Pulse-based UWB Waveforms on Narrowband Systems](#)," October 2002.
- [5] <http://www.ieee802.org/15/pub/TG2.html>. The Recommended Practice must currently be purchased from IEEE via links on that web site.
- [6] <http://www.fcc.gov/sptf/>
- [7] See FCC document FCC 03-289a1, available from www.fcc.gov
- [8] <http://ftp.fcc.gov/oet/cognitiveradio/>
- [9] Jim Lansford, "Universal Radio: Making New Spectrum (sort of)," 2002 Fourth Annual International Symposium On Advanced Radio Technologies, Boulder, CO, March 4-6, 2002, http://www.its.bldrdoc.gov/meetings/art/art02/slides02/lan/lan_slides.pdf