Theoretical Aspects of Ultra Wide Band

Vladimir Sanchez Padilla, *Member, IAENG*

Abstract—**Ultra Wide Band (UWB) technology can provide alternative communication solutions within the unlicensed band. Despite many years of development and deployment, UWB and its applications have been underutilized within the communications industry. Some reasons for this lack of acceptance are industry preference for more established technologies and a lack of vendor support in terms of equipment and facilities. This paper attempts to show the advantageous aspects of UWB in the hope of informing telecommunications professionals of UWB's potential applications, expecting that engineers and analysts take interest and find out more once they know its fundamentals.**

Index Terms—**indoor and outdoor communications, PPM, radar transmission, Ultra Wide Band.**

I. INTRODUCTION

THE most common definition of the term "Ultra Wide Band (UWB)" comes from the UWB radar world and refers to electromagnetic waveforms that are characterized by an instantaneous fractional energy bandwidth greater than about 0.20-0.25 [1] or occupies a bandwidth equal or greater to 500 MHz [2] or any transmission where the bandwidth at the -10 dB points of the spectrum exceeds 25% of the center frequency [3]. These systems were approved for the first time in 2002 for unlicensed use under the Federal Communications Commission (FCC) and focused on UWB wireless emissions within restricted frequency bands at very low power spectral-density emission levels [4]. UWB has a wide range of civilian and military applications, including radar and multimedia, which could represent an alternative to overcrowded unlicensed bands as 2.4 GHz and 5.7-5.8 GHz.

II. REGULATION

The instantaneous fractional energy bandwidth of UWB can be determined using the equation

$$B_f = \frac{(f_H - f_L)}{\left(\dfrac{f_H + f_L}{2}\right)} \qquad (1)$$

where f_L is the lower limit and f_H is the higher limit of the energy spectral density, then the center frequency of the spectrum is located at $(f_H + f_L)/2$ [1]. The origins and development of UWB were initially concentrated in radar and positioning system applications for the military i.e. low frequency ground penetrating radar. The United States was the first country to legalize UWB for commercial applications. Specifically, UWB was leveraged in collision avoidance, collision detection and tracking systems [5]. In Europe, for example, UWB rules and operation parameters are governed by the European Conference of Postal and Telecommunications Administrators, CEPT, under the classification for short-range devices. CEPT rules and regulations pertaining to UWB were influenced by the decisions of the FCC. The recommendations of the FCC are generally accepted by CEPT, but the rules generated do not necessarily mirror FCC standards [6].

UWB transmission is more considered for low-power indoor applications where there is high clutter, that is, the surrounding environment causes significant amounts of multipath [3].

As per FCC recommendations, UWB devices that operate in vehicular radar systems operate within the spectrum of 22 to 29 GHz, and use directional antennas (mounted on terrestrial vehicles) provided the center frequency of the emission and the frequency at which the highest radiated emission occurs are greater than 24.075 GHz. These specifications permit monitoring of an object's location or movement near a vehicle thereby enabling collision avoidance, proper airbag operation, and suspension systems that respond according to road conditions. Attenuation of the emissions under 24 GHz is required above the horizontal plane to protect space borne passive sensors that operates in the 23.6-24.0 GHz band; UWB devices for communications and measurement systems must operate in the 3.1 to 10.6 GHz spectrum in order to guarantee that operation can only occur indoors or is limited to hand held equipment that may be employed for peer-to-peer operation activities [2].

III. MODULATION WITH PPM

A time based Pulse Position Modulation (PPM) technique is employed by UWB systems. Each pulse is sent in advance or with some delay according to a regular time scale [5]. With PPM, as illustrated in Figure 1, there is a nominal time separation, *Tp*, between successive pulses. To transmit a binary signal "0", the pulse is transmitted slightly early (-*Tc*). To transmit a binary signal "1", the pulse is transmitted slightly late (+*Tc*). The receiver detects this early/late timing and demodulates the data accordingly. Typical separations between pulses (*Tp*) range from 25 nanoseconds to 100 nanoseconds, resulting in a range of data rates from 40 Mbps to 1 Mbps [3].

PPM's primary advantage over other techniques is its simplicity and the ease in which delay can be controlled. In UWB systems, appropriate time control is needed to

---

Manuscript received June 12, 2014; revised June 26, 2014.

V. Sanchez Padilla is a M.Sc. candidate in the Graduate Program of Telecommunications, Volgenau School of Engineering, George Mason University, VA, USA (e-mail: vsanche5@gmu.edu).

modulate pulses to obtain the lowest time precision [5]. A system model for UWB using PPM is described in Figure 2.

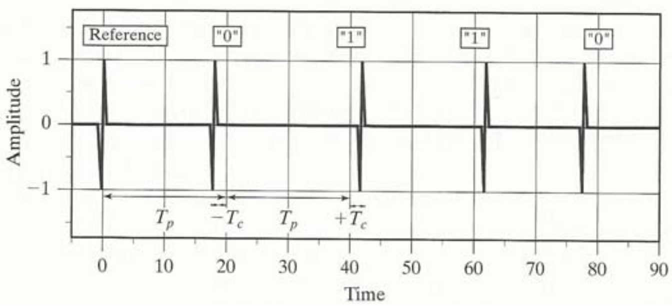


Fig. 1. Pulse Position Modulation of impulse radio [3]

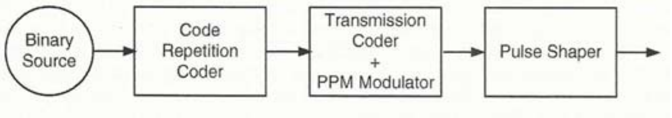


Fig. 2. System model for UWB using PPM [1]

In Figure 2, in the first block (Binary Source) the output is a stream of bits to be transmitted onto the physical channel. Each bit of the binary stream is repeated Ns times by the second block (Code Repetition Coder). The third block (Transmission Coder + PPM Modulator) simulates both the time hopping code and the binary PPM. Pseudorandom time hopping codes are considered. The impulse response of the last block (Pulse Shaper) represents the waveform of the basic pulse of the UWB signal to be transmitted [1].

IV. ANTENNAS

In UWB communication systems high-and-low frequency signal components arrive at the receiver simultaneously and the antenna must capture the electronic products for the receiver. This requires a small size antenna with a flat group delay. A comparison between UWB antennas and conventional antennas is difficult because traditional performance considerations are based on continuous wave or narrowband theory [5], the UWB antennas possess a larger bandwidth, which causes a greater impact in these systems than in narrow band systems [6].

Instead of transmitting and receiving modulated sinusoidal waveforms as in carrier-based systems, an UWB communication system transmits pulses which occupy several gigahertz of spectrum (from near DC). Therefore, UWB antennas need to be optimized for a wide range of frequencies, and pulse waveform distortion by the antennas is no longer negligible, as is reasonably assumed for carrier-based systems [7].

Base station antennas may be either directive or omnidirectional. Radio links can use directional antennas; mobile applications tend to be more achievable with omnidirectional antennas. In the case of portable applications the antenna should be small, which imply omnidirectional pattern. In the base station antennas the use of resistive loading makes it possible that radiation efficiency need not be a major consideration parameter. If possible, the transceiver should be embedded in the same circuit board as the antenna [6].

Real and theoretical antennas (e.g. high gain, waveguide, isotropic) for far-field and near-field radiations are available due to the research and development of impulse-radiating antennas, improving the capacity of wideband systems [5].

UWB antennas should have a fixed phase center and be linear in phase, unlike the impedance circuits, which typically are not phase linear, for this reason antennas should be inherently impedance matched because its radiation characteristics can significantly impact the antenna's performance. To avoid dispersion of the pulse transmission, the antenna gain should be precisely within its operating frequency. The antenna gain will typically appear different from different angles. This will lead to different pulse shapes depending on the angle to the receiver [6].

V. PERFORMANCE

UWB radio signals must coexist with other radio signals. Possible interference from and onto other communication systems must be contained within regulated values that indicate the maximum tolerable power to be present in the air interface at any given frequency, as set by emission masks [1]. UWB must mitigate or be able to operate in presence of these interferences and must not provide substantial interferences to users of these other services [5]. Figure 3 shows how the unlicensed band of 5 GHz could be interfered by the operation of UWB systems in the range of 3.1 to 10.6 GHz. Table 1 is shown as a complement of unlicensed bands characteristics of frequency and bandwidth.

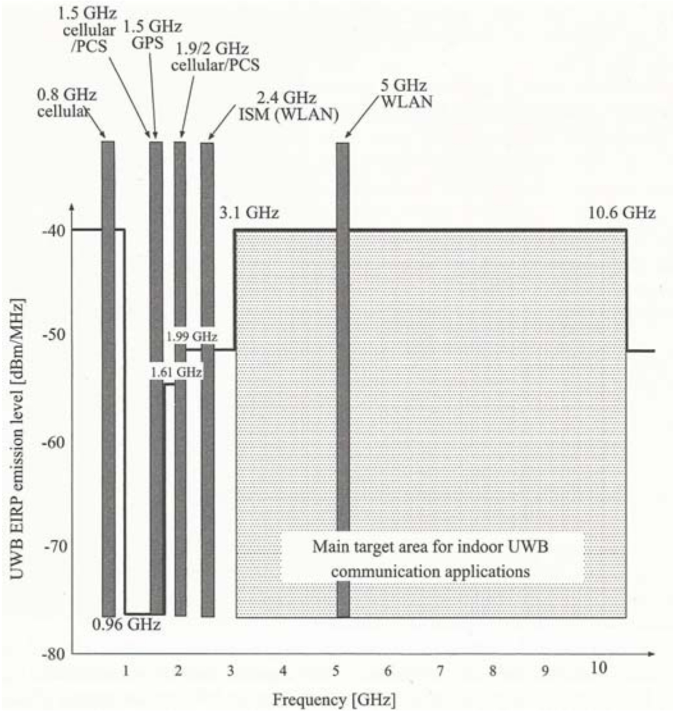


Fig. 3. Comparison of bandwidth between UWB systems and other frequency systems [5]

Any transmission signal that meets the FCC requirements for UWB spectrum can be considered UWB technology. This is not restricted to impulse radios or high speed spread spectrum radios pioneered by companies so far, but to any technology that utilizes more than 500MHz spectrum in the allowed spectral mask and with the current emission limit's restrictions [8]. Currently, the only available emission masks for UWB radio communications are those issued by the FCC in the United States [1]. Table 2 shows the average power limits set by the FCC in the United States for indoor and outdoor applications [6].

TABLE I. COMPARISON OF UNLICENSED BANDS [8]

Unlicensed bands	Frequency of operation	Bandwidth
ISM at 2.4 GHz	2.4000-2.4835	83.5 MHz
U-NII at 5 GHz	5.1-5.35 GHz 575-5.85 GHz	300 MHz
UWB	3.1-10.6 GHz	7,500 MHz

TABLE II. FCC RADIATION LIMITS: INDOOR AND OUTDOOR APPLICATIONS [6]

	Indoor	Outdoor
Frequency in MHz	EIRP in dBm	EIRP in dBm
960-1610	-75.3	-75.3
1610-1990	-53.3	-63.3
1990-3100	-51.3	-61.3
3100-10600	-41.3	-41.3
Above 10600	-51.3	-61.3

The ultra wide band nature of the modulated signal has both good aspects and bad. Since the signal power is spread over such a large bandwidth, the amount of power that falls in any particular narrowband channel is small. However, such power falls in all such narrowband channels. Consequently, there is a concern that UWB radios will cause harmful interference into existing narrowband radio services occupying the same radio spectrum. As a consequence, although UWB radio has been allowed in various jurisdictions, there are strict limits on the power spectra that may be transmitted. Due to this limitation on transmit power UWB radio is limited to short-range applications, typically less than a few hundred meters [3].

The transmission of a wireless signal employs finite energy and should be as low as it can, due to the specifications and parameters of today's electronics consumer devices. Transmitting a very small amount of energy density over a large bandwidth, or vice versa, could be achieved if the power is fixed to a constant level. The tag of "Ultra Wide Band" comes essentially because its energy is spread out over a large bandwidth, and usually employs low power spectral density. Only in the case of radar systems (restricting the coverage area) the transmission applies high power energy over a large bandwidth. It is estimated that the power consumption of a UWB is less than 100 mW, which could be lower comparing to other mobile communication devices [5].

VI. MULTIPATH

A fundamental mechanism in wireless propagation is multipath propagation, which could be defined as the fact that the signal can get from the transmitter to the receiver via different paths and interactions, as shown in Figure 4. In order to understand this phenomenon, it is helpful to represent the electromagnetic field emitted by the transmit antenna as a sum of components that are sent into different directions [9]. Objects between the transmitter and the receiver cause the physical effects of reflection, absorption, diffraction, and scattering, creating multiple paths, producing the pulses arrive at different times, with the delay proportional to the path length [5].

Because of the large bandwidth of the transmitted signal, very high multipath resolution is achieved. Great frequency diversity is required to achieve a large bandwidth. To minimize multipath effects or interference a discontinuous transmission of the signal time is modulated [10]. Slowing down the system duty cycle can help to avoid multipath as well. Unwanted reflections can be avoided at the receiver if the pulses are being transmitted with time delays greater than the maximum expected multipath delay, restricting the maximum speed of data transmission for a given modulation system [5]. The intersymbol interference between pulses can be eliminated if the time between pulses is greater than the channel delay spread [6].

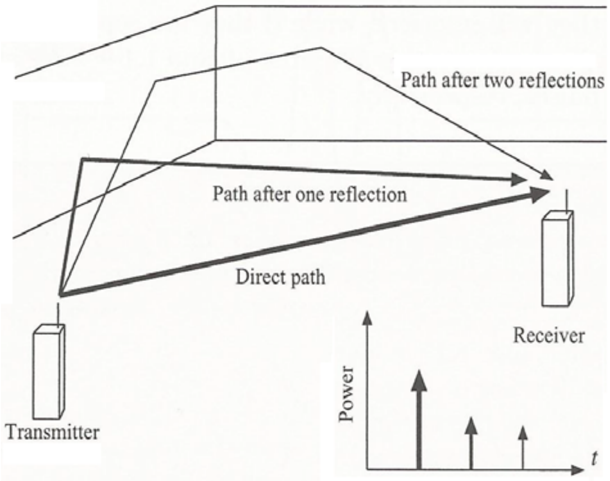
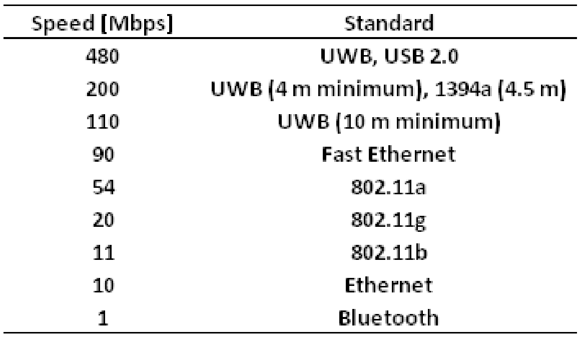


Fig. 4. Scenario with multipath propagation [5]

VII. DATA RATE

The IEEE established two study groups for physical layer: 802.15.3a for short range and high data range applications; and 802.15.4a for low data range applications using UWB technology at the air interface [6]. Most of its applications are between the range of 100 to 500 Mbps. Concerning to indoor wireless transmission, different speeds can be achieved according to the distance of propagation: 480 Mbps with no fixed minimum transmission distance; 200 Mbps with a minimum transmission distance of 4 meters; and 110 Mbps with a minimum transmission distance of 10 meters. Complex timing circuitry will be necessary if the data rate is to be increased. To cut costs in the manufacture of new products, more functionality is implemented on fewer chips, improving the capacity and design in integrated circuits [5]. Table 3 shows difference in speed of UWB with other standards.

TABLE III. COMPARISON OF DATA RATE [5]



Speed [Mbps]	Standard
480	UWB, USB 2.0
200	UWB (4 m minimum), 1394a (4.5 m)
110	UWB (10 m minimum)
90	Fast Ethernet
54	802.11a
20	802.11g
11	802.11b
10	Ethernet
1	Bluetooth

VIII. APPLICATIONS

There are several indoor and outdoor applications for UWB. Some of them according to 802.15.3a include video and audio distribution, and high-speed data transfer [10]. Military applications and others that need reliability in the transmission (e.g. camouflage communications or radar) are of particular interest, due to the lower power spectral density, allowing a low probability of detection [5]. The UWB radio equipments offer timing precision much better than other radio systems, as the global positioning ones. The time modulated UWB signals allow short range radar applications, very useful in case of anti-crime operations, mining industry or searches in disaster events. UWB provides either a function of timing precision targeting or extreme penetration; because of its waveforms is considered a better election than other conventional radio systems [6]. Due to its high data rate, applications could include internet access and multimedia services, wireless peripheral interfaces and location based services, as for patient location in case of critical condition, hikers injured in remote areas, tracking cars, and managing a variety of goods in a shopping store. A short-pulse UWB technique has several radar applications such as higher range measurement accuracy and range resolution, enhanced target recognition, increased immunity to co-located radar transmissions, increased detection probability for certain classes of targets and ability to detect very slowly moving or stationary targets. The nature of creating millions of UWB pulses per second has the capability of high penetration in a wide range of materials such as building materials, concrete block, plastic and wood [11].

IX. CONCLUSIONS

This paper is a guide to the potential of UWB technology as an alternative in the deployment of wireless systems requiring a minimal amount of interference. Its implementation would be attractive in unlicensed bands due to the saturation of the radio spectrum for other applications, especially those that are in the 5.7-5.8 GHz band, which have been very useful for data transmission in indoor and outdoor applications. It can also be considered an alternative when a technical implementation needs short range low power emission, replacing wired or wireless standards of low data rate, for example, in home or store environments, where the distances transmissions are no more than a few meters and there is a necessity of data transfer to verify or track locations.

ACKNOWLEDGMENT

To Dr. Seema Sud for her recommendations, and Lt. Leigh G. Cotterell in reviewing the literature of the paper.

REFERENCES

[1] M. Di Benedetto and G. Giancola, Understanding Ultra Wide Band Radio Fundamentals, Prentice Hall, 2004, ISBN 0-13-148003-0.

[2] FCC 02-48, Revision of Part 15 of the Commission’s Rules Regarding Ultra-Wideband Transmission Systems, First Report and Order, Released: April 22, 2002.

[3] S. Haykin and M. Moher, Modern Wireless Communications, Pearson Education Inc., 2005, ISBN 0-13-022472-3.

[4] F. Dowla, Handbook of RF and Wireless Technologies, Elsevier Inc., 2004, ISBN 0-7506-76957.

[5] M. Ghavami, L.B. Michael and R. Kohno, Ultra Wideband Signals And Systems In Communication Engineering, second edition, Wiley, 2007, ISBN 978-0-470-02763-9.

[6] I. Oppermann, M. Hämäläinen and J. Iiniati, UWB Theory And Applications, Wiley, 2004, ISBN 0-470-86917-8.

[7] G. Lu, P. Spasojevic and L. Greenstein, “Antenna and pulse designs for meeting UWB spectrum density requirements”, 2003 IEEE Conference on Ultra Wide Band Systems and Technologies, Nov. 2003.

[8] Y. Zehforoosh, C. Ghobadi and J. Nourinia, “Antenna design for ultra wide band application using a new multilayer structure”, PIERS Online, Vol. 2, No. 6, 2006.

[9] A.F. Molisch, “Ultra-wide-band propagation channels”, Procedings of the IEEE, Vol. 97, No. 2, Feb. 2009.

[10] K.R. Rao, Z.S. Bojkovic and D.A. Milovanovic, Wireless Multimedia Communications, CRC Press, 2009, ISBN-13:978-0-8493-8582-7.

[11] S. Ullah, M. Ali, M.A. Hussain and K. S. Kwak, “Applications of UWB technology”, The 5th Annual International New Exploratory Technologies Conference 2008 (NEXT 2008), pp. 225-232, Jul. 2000.