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Ultra-Wideband (UWB) Wireless System

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ABSTRACT

Ultra wide bandwidth (UWB) signals are commonly defined as signals that have a large relative bandwidth (bandwidth divided by the carrier frequency) or a large absolute bandwidth .On the other hand, generating, receiving, and processing UWB signals poses significant challenges that require new research in signal generation, transmission, propagation, processing, and system engineering. In the past 20 years, UWB was used for applications such as radar, sensing, military communication and localization. A substantial change occurred in February 2002, when the Federal Communication Commission (FCC) issued a report allowing the commercial and unlicensed deployment of UWB with a given spectral mask for both indoor and outdoor applications in the USA. This wide frequency allocation initiated a lot of research activities from both industry and academia. In recent years, UWB technology has mostly focused on consumer electronics and wireless communications.

Keywords: WPAN, MB-OFDM, IR-UWB, PNC, LDR, LLC

1. INTRODUCTION

The FCC Report and Order (R&O), issued in February2002 [6], allocated 7,500 MHz of spectrum for unlicensed use of UWB devices in the **3.1 to 10.6 GHz frequency band**. The UWB spectral allocation is the first step toward a new policy of open spectrum initiated by the FCC in the past few years. More spectral allocation for unlicensed use is likely to follow in the next few years [7]. The FCC defines UWB as any signal that occupies more than 500 MHz bandwidth in the 3.1 to 10.6 GHz band and that meets the spectrum mask shown in Figure 1. [6]. this is by far the largest spectrum allocation for unlicensed use the FCC has ever granted. It is even more relevant that the operating frequency is relatively low.

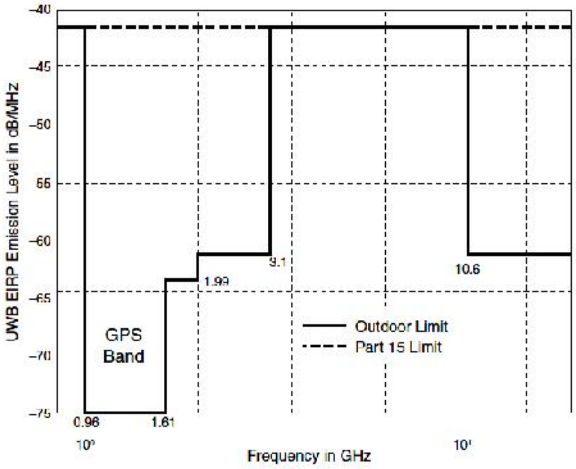

Figure 1 FCC spectrum mask for UWB [6]

Ultra-Wideband (UWB) technology is defined as any wireless transmission scheme that occupies a bandwidth of more than 25% of a centre frequency, or more than 1.5GHz. A UWB system can also be determined by a duty cycle less than 0.5 %. Equation 1 illustrates the duty cycle of a UWB pulse. Where, t_w stands for symbol duration and t_b stands for UWB pulse width.

$$\text{Duty Cycle} = \frac{\tau w}{\tau b} \qquad (1)$$

UWB characteristics can be analyzed according to the Shannon capacity (C) formula. For an AWGN channel of bandwidth, the maximum data that can be transmitted can be expressed as, [4]

$$C = B\,log_2\,(1 + SNR)\;bit/second \qquad (2)$$

SNR is representing the signal-to-noise ratio. From Equation 2 it is clear, if bandwidth of the system is increased, the capacity of the channel will increase. In the context of UWB, the bandwidth is very high and very low power is required for transmission. So we can gain a very high channel capacity using UWB with lower power that can make batter life longer and reduce the interference with existing systems.

Figure 2 shows the capacity comparison of UWB technology with IEEE WLAN and Bluetooth standard. [8]

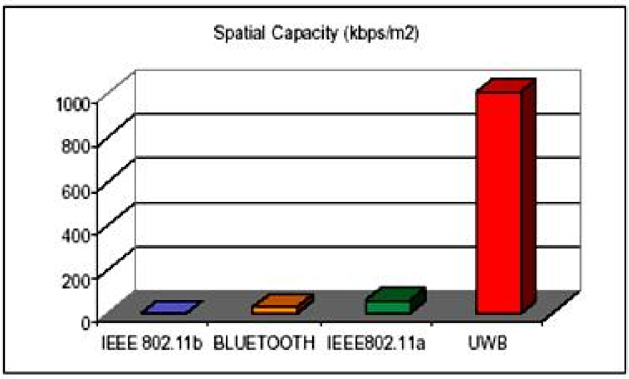

Figure 2 Spatial capacity comparison of UWB with other technology [8]

UWB is a Radio Frequency (RF) technology that transmits binary data, using low energy and extremely short duration impulses or bursts (of the order of picoseconds) over a wide spectrum of frequencies. It delivers data over 15 to 100 meters and does not require a dedicated radio frequency, so is also known as carrier-free, impulse or base-band radio. UWB systems use carrier-free, meaning that data is not modulated on a continuous waveform with a specific carrier frequency, as in narrowband and wideband technologies.

A comparison with the other unlicensed bands currently available and used in the United States is shown in Table 1. This allocation opens up new possibilities to develop UWB technologies different from older approaches based on impulse radios.

Table 1: US spectrum allocation for unlicensed use [6]

Unlicensed bands	Frequency of operation	Bandwidth
ISM at 2.4GHz	2.400-2.4835	83.5MHz
U-NII at 5GHz	5.15-5.35GHz	300MHz
UWB	**3.1-10.6GHz**	**7,500MHz**

2. HISTORY AND BACKGROUND

Ultra-wideband communications is fundamentally different from all other communication techniques because it employs extremely narrow RF pulses to communicate between transmitters and receivers. Utilizing short-duration pulses as the building blocks for communications directly generates a very wide bandwidth and offers several advantages, such as large throughput, covertness, robustness to jamming, and coexistence with current radio services. [4]

Ultra-wideband communications is not a new technology; in fact, it was first employed by *Guglielmo Marconi in 1901* to transmit Morse code sequences across the Atlantic Ocean using spark gap radio transmitters. However, the benefit of a large bandwidth and the capability of implementing multiuser systems provided by electromagnetic pulses were never considered at that time. [4]

Approximately fifty years after Marconi, modern pulse-based transmission gained momentum in military applications in the form of impulse radars. Some of the pioneers of modern UWB communications in the United States from the late 1960s are *Henning Harmuth of Catholic University of America and Gerald Ross and K. W. Robins of*

Sperry Rand Corporation. From the *1960s* to the *1990s*, this technology was restricted to military and Department of Defense (DoD) applications under classified programs such as highly secure communications. However, the recent advancement in micro processing and fast switching in semiconductor technology has made UWB ready for commercial applications. Therefore, it is more appropriate to consider UWB as a new name for a long-existing technology.

As interest in the commercialization of UWB has increased over the past several years, developers of UWB systems began pressuring the FCC to approve UWB for commercial use. In **February 2002**, the FCC approved the First Report and Order (R&O) for commercial use of UWB technology under strict power emission limits for various devices Figure 3 below summarizes the development timeline of UWB. [4]

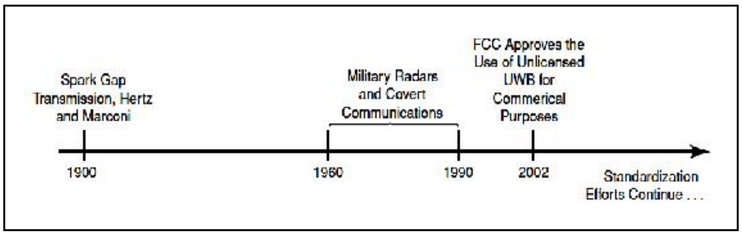

Figure 3 Brief history of UWB development [4]

2.1 The evolution of UWB and IEEE 802.15.3a for very high data rate WPAN

The IEEE 802.15 working group develops personal area network consensus standards for short distance wireless personal area networks (WPANs). Task group 3 has developed a standard (IEEE 802.15.3) to deliver data rates from 20 Mbps to 55 Mbps over short range (less than 10 meters) WPANs. Table 2 lists a variety of wireless applications in the WPAN space and their estimated requirements for data rates. [5]

Table2: Estimated data rate for various WPAN applications [5]

Applications	Minimum data rate	Maximum data rate
H.323 / T.120 Video Conferencing	188+ Mbps	1.4+ Gbps
Home Theater	43 Mbps	56.8 Mbps
Interactive Application (e.g. gaming)	76.8+ Mbps	Unknown
Content Downloading (e.g. photos, MP3, CD, movies)	90+ Mbps	Unknown

IEEE 802.15.3 would not be able to provide the data rates necessary to support many of these applications. In November 2001, an additional task group within IEEE 802.15, Task Group 3a, was formed to identify a higher speed physical layer alternative that could support data rates between 110 Mbps and 480 Mbps over short ranges of less than 10 meters. The February 2002 FCC approval of ultra wideband (UWB) devices prompted many companies to consider UWB radio when proposing physical layers to IEEE 802.15.3a.

The FCC ruling allows UWB communication devices to operate at low power (an EIRP of -41.3 dBm/MHz) in an unlicensed spectrum from 3.1 to 10.6 GHz (Fig.1). The low emission limits for UWB are to ensure that UWB devices do not cause harmful interference to (i.e. coexist with) ―licensed services and other important radio operations‖ (e.g. 802.11a devices).

Table 3: FCC requirement for indoor and handheld UWB systems [5]

Operating Frequency Range	**3.1GHz to 10.6GHz**
Frequency range in MHz	EIRP in dBm (indoor/handheld)
960-1610	-75.3 / -75.3
1610-1900	-53.3 / -63.3
1900-3100	-51.3 / -61.3
3100-10600	**-41.3 / -41.3**
Above 10600	-51.3 / -61.3
Peak emission level in band	60 dB above average emission level

2.2 UWB and IEEE 802.15.3a

The indoor wireless standards effort can be broadly categorized into three standards groups. The first of which is IEEE 802.11, responsible for Wireless Local Area Network (WLAN) standards. This deployment can provide connectivity in homes, factories, and ―hot spots‖ (public wireless internet access networks [5]). The IEEE 802.16 group is responsible for Wireless Metropolitan Area Networks (WMAN) standards. This body is concerned with fixed broadband wireless access systems, also known as ―last mile‖ access networks. IEEE 802.15, of which we are concerned with, is responsible for Wireless Personal Area Network (WPAN) standards [9].

The efforts of IEEE 802.15 are divided up into four main areas (as shown in Figure 4):

(1) Task Group 1 (TG1) is creating a WPAN standard based on Bluetooth to operate in the 2.4 GHz ISM band.
(2) TG2 is concerned with the coexistence of unlicensed spectrum devices.
(3) TG3 is responsible for high data rate (in excess of 20 Mbps) WPAN standards
(4) TG4 is creating a low data rate, low power WPAN standard.

An additional group, TG3a, was created to investigate physical layer alternatives for high data rate WPAN systems (i.e. alternatives for the IEEE 802.15.3 physical layer).IEEE 802.15.3-*2003* is a MAC and PHY standard for high-rate (11 to 55 Mbit/s) WPANs.

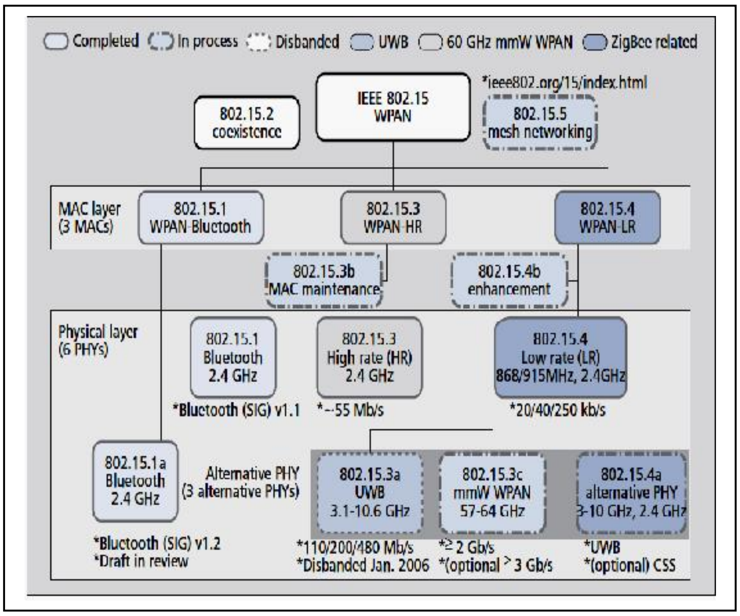

Figure **4: IEEE 802.15 working group for WPAN evolution [9]**

3. ULTRA-WIDEBAND CONCEPTS

Traditional narrowband communications systems modulate continuous waveform (CW) RF signals with a specific carrier frequency to transmit and receive information. A continuous waveform has well-defined signal energy in a narrow frequency band that makes it very vulnerable to detection and interception. Figure 5 represents a narrowband signal in the time and frequency domains [4].

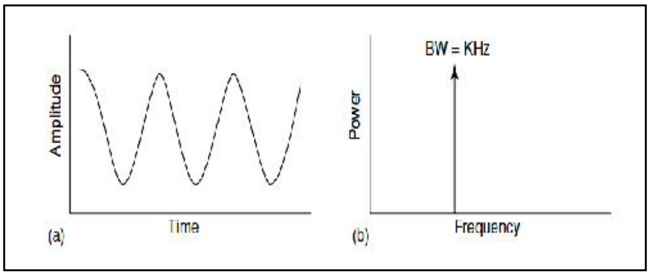

Figure 5: A narrowband signal in (a) the time domain and (b) the frequency domain [4]

As mentioned in earlier, UWB systems use carrier less, short-duration (pico-second to nano second) pulses with a very low duty cycle (less than 0.5 percent) for transmission and reception of the information. A simple definition for *duty cycle* is the ratio of the time that a pulse is present to the total transmission time. Figure 6 and Equation 3 represent the definition of duty cycle [4].

$$Duty\ cycle = \frac{T_{on}}{T_{off}} \qquad (3)$$

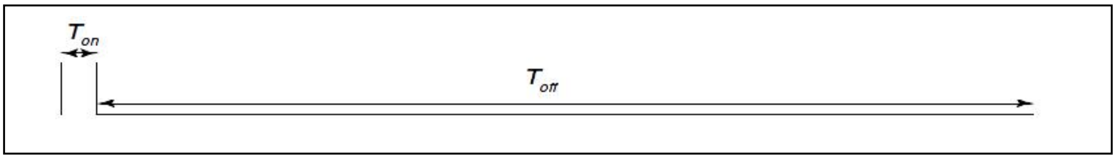

Figure 6: a low-duty-cycle pulse. Ton represents the time that the pulse exists and Toff represents the time that the pulse is absent [4]

Low duty cycle offers a very low average transmission power in UWB communications systems. The average transmission power of a UWB system is on the order of microwatts, which is a thousand times less than the transmission power of a cell phone. However, the peak or instantaneous power of individual UWB pulses can be relatively large, but because they are transmitted for only a very short time (< 1 nanosecond), the average power becomes considerably lower.

Consequently, UWB devices require low transmit power due to this control over the duty cycle, which directly translates to longer battery life for handheld equipment. Since frequency is inversely related to time, the short-duration UWB pulses spread their energy across a wide range of frequencies—from near DC to several giga hertz (GHz)—with very low power spectral density (PSD). Figure 7 illustrates UWB pulses in time and frequency domains.

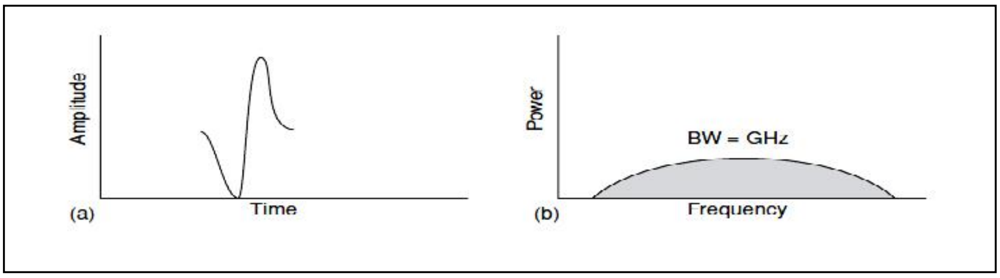

Figure 7 A UWB pulse in (a) the time domain and (b) the frequency domain [4]

3.1 UWB Signal

As defined by the FCC‘s First Report and Order, UWB signals must have bandwidths of greater than 500 MHz or a fractional bandwidth larger than 20 percent at all times of transmission [3]. Fractional bandwidth is a factor used to classify signals as narrowband, wideband, or ultra-wideband and is defined by the ratio of bandwidth at –10 dB points to centre frequency. Equation 4 shows this relationship [4].

$$B_f = \frac{BW}{f_c} \times 100\% = \frac{(f_h - f_l)}{(f_h + f_l)/2} \times 100\% = \frac{2(f_h - f_l)}{(f_h + f_l)} \times 100\% \qquad (4)$$

Where, *fh* and *f1* are the highest and lowest cut-off frequencies (at the –10 dB point) of a UWB pulse spectrum, respectively.

A UWB signal can be any one of a variety of wideband signals, such as Gaussian, chirp, wavelet, or Hermite-based short-duration pulses. Figure 8 represents a Gaussian monocycle as an example of a UWB pulse in the time and frequency domains.

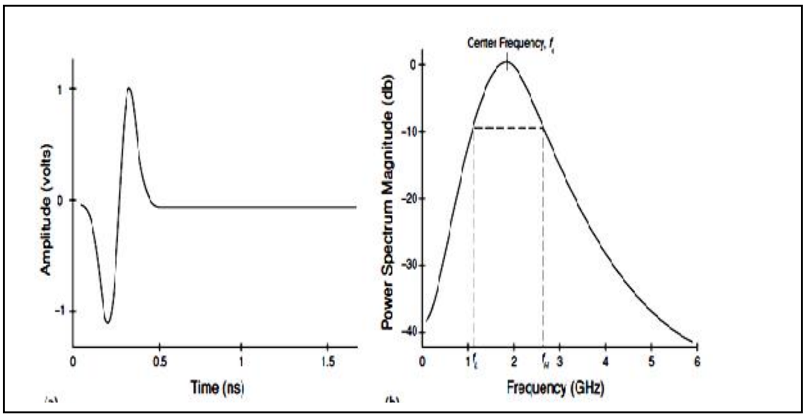

Figure 8 A 500-picosecond Gaussian monocycle in (a) the time domain and (b) the Frequency domain [4]

As shown in Figure 8, a 500-picosecond pulse generates a large bandwidth in the frequency domain with a centre frequency of 2 GHz. In Figure 8(b), the lowest and highest cut-off frequencies at –10 dB are approximately 1.2 GHz and 2.8 GHz, respectively, which lead to a fractional bandwidth of 80 percent; this is much larger than the minimum *Bf* required by the FCC [4].

$$B_f = 2 \times \frac{(2.8 - 1.2)}{2.8 + 1.2} \times 100\% = 80\% \qquad (5)$$

- Narrowband *Bf* < 1%
- Wideband 1% < *Bf* < 20%
- Ultra-Wideband *Bf* > 20%

4. UWB TYPES DS-UWB AND MB-OFDM

4.1 Impulse Radio(IR-UWB) technique

There are two general ways to use the bandwidth available for UWB. Impulse Radio was the original approach to UWB. It involves the use of very short- duration baseband pulses that use a bandwidth of several Gigahertz’s. Data could be modulated using either pulse amplitude modulation (PAM) or pulse-position modulation (PPM). Multiple users could be supported using a time-hopping scheme [5].

Direct-sequence UWB is a single-band approach that uses narrow UWB pulses and time-domain signal processing combined with well-understood DSSS techniques to transmit and receive information. Figure 9 illustrates this approach [4].

The DS-UWB adopts variable-length spreading codes for binary phase shift keying (BPSK) or (optional) quadrature biorthogonal keying (4BOK) modulations. A data symbol of BPSK (one bit) and 4BOK (two bits) modulation is mapped into a spreading sequence and bi-orthogonal code with length ranging between 1 and 24, respectively. It can provide (optionally) a maximum data rate of 1.32 Gb/s [9].

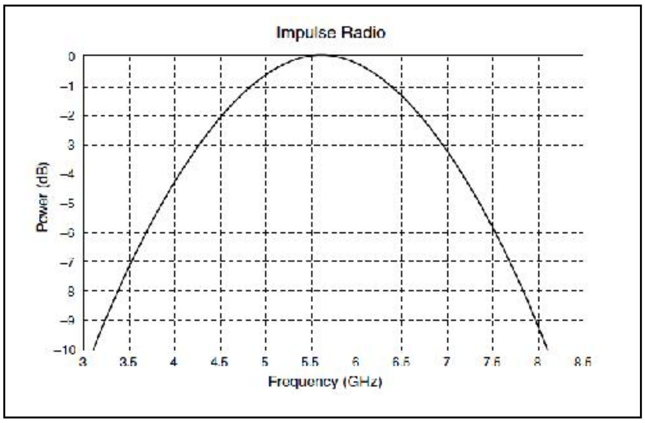

Figure 9 DS-UWB transmits a single pulse over a huge swath of spectrum to represent data [4]

Chip rate can be changed from 1313 to 2730 Mchips/s according to data rates and piconet channels. There is a difference between each chip rate of piconet channels of about 13 MHz, and carrier frequency is exactly a multiple of three times the chip rate. As a receiver structure, the Rake receiver is generally assumed to mitigate an adverse effect of multi-path. DS-UWB supports two spectrum bands of operation, the lower band (3.1–4.85 GHz) and the optional upper band (6.2–9.7 GHz).

Each operation band has six piconet channels, where distinguished spreading codes, chip rates, and centre frequencies are specified in Figure 10 below.

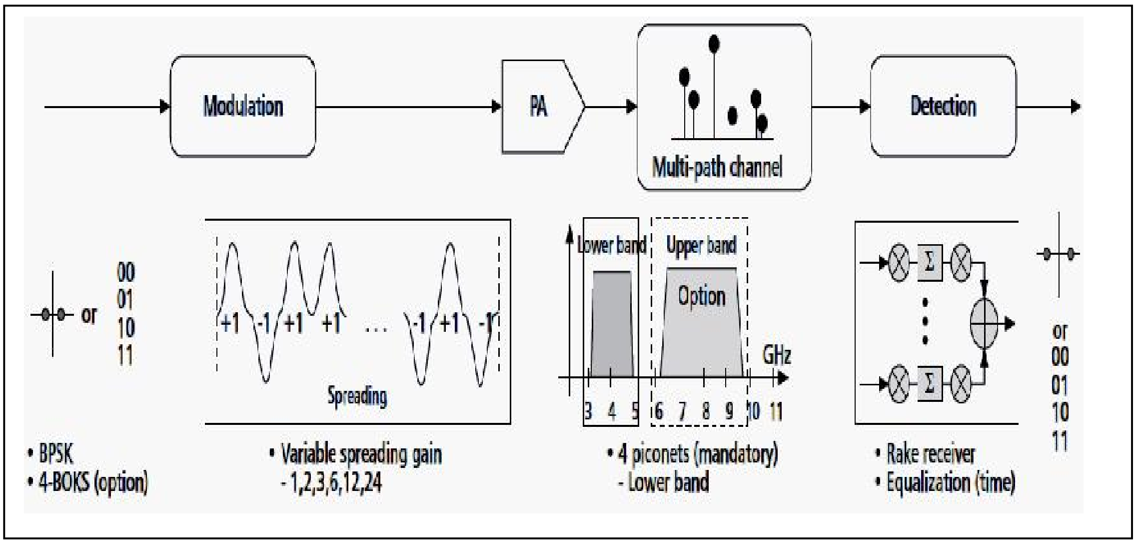

Figure 10 Direct sequence-UWB system (DS-UWB) [9]

For DS-UWB, efficient synchronization and detection are critical to realize the technology. Although Rake reception is generally assumed to capture the spread energy over multi-path propagation, the complexity of the ideal Rake receiver creates a realization problem. In addition, long acquisition times must be addressed. Regarding piconets, there is a question as to whether the given spreading gains and structures are sufficient for coexistence of piconets.

4.2 Multiband-Orthogonal Frequency Division Multiplexing Technique

MB-OFDM is a multi-band technology, using orthogonal frequency division multiplexing. The total bandwidth that could be occupied, as defined by FCC, is from 3.1 GHz to 10.6 GHz. This covers a total span of 7.5 GHz. MB-OFDM divides the available spectrum into 14 bands of 528 MHz The first 12 bands are grouped into 4 band groups consisting of 3 bands, and the last two bands are grouped into a fifth band group (Figure 11). [5]

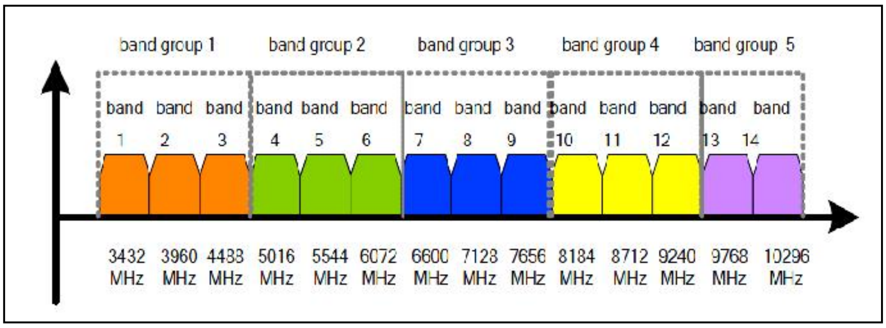

Figure 11 UWB standard Spectrum allocation for MB-OFDM [5]

Within each of the first four band groups, four time-frequency codes using TFI and three time-frequency codes using FFI are defined; thereby, providing support for up to seven channels per band. For the fifth band group, two time-frequency codes using FFI are defined. Therefore, 30 channels are available in total to define a piconet.

Finding a realistic solution to avoid pulse-related issues of impulse radio (IR) UWB drives the MB-OFDM scheme that combines OFDM modulation and multiband transmission. The MB-OFDM uses a 128-point inverse fast Fourier transforms IFFT) and FFT with a subcarrier spacing of 4.125 MHz (528 MHz /128). Each data subcarrier is modulated by a quadrature phase-shift keying (QPSK) symbol as shown in Figure 12 below. [9]

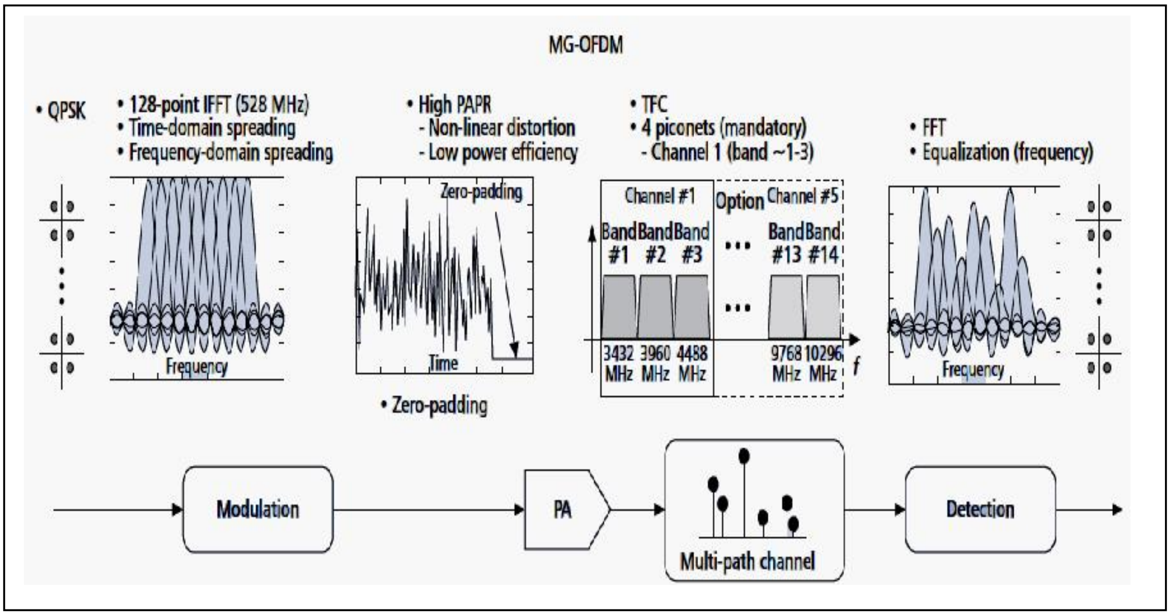

Figure 12 MB-OFDM system [9]

Zero padded suffix of length 32 samples (60.61 ns) and a guard interval of five samples (9.47 ns) are used to prevent multi-path or inter-block interference and guarantee band switching time, respectively. Modulation can use time- and frequency-domain spreading of an order of two by repeating identical data in time- or frequency domain, respectively. Maximum data rate of 480 Mb/s can be provided.

The multiband mechanism of MB-OFDM provides five band groups over 3.1–10.6 GHz and each band group consists of three different bands except the last group that is composed of two bands. In addition, a time-frequency code (TFC), that specifies a sequence of frequency bands for OFDM symbol transmission, is used to interleave information data over a band group.

Although this proposal avoids the disadvantages of IR schemes, the inherently high peak to- average power ratio (PAPR) of the OFDM and the sensitivity to frequency offset, timing error, and phase noise creates challenges for circuit design and a power-efficient implementation. For example, in an extreme case, the PAPR of the MB-OFDM can be approximately 20 dB, and this large PAPR may restrict the achievable power efficiency and power amplifier design.

5. UWB MEDIUM ACCESS CONTROL (MAC)

5.1 Introduction

UWB holds enormous potential for wireless ad-hoc and peer-to-peer networks. One of the major potential advantages in impulse radio based systems is the ability to trade data rate for link distance by simply using more or less concatenated pulses to define a bit. Without dramatically changing the air interface, the data rate can be changed by orders of magnitude depending on the system requirements. This means, however, that high data rate (HDR) and low data rate (LDR) devices will need to coexist. The narrow time domain pulse also means that UWB offers the possibility for very high positioning accuracy.

However, each device in the network must be ‘heard’ by a number of other devices in order to generate a position from a delay or signal angle-of- arrival estimate. These potential benefits, coupled with the fact that an individual low power UWB pulse is difficult to detect, offer some significant challenges for the multiple access MAC design.

UWB systems have been targeted at very HDR applications over short distances, such as USB replacement, as well as very LDR applications over longer distances, such as sensors and RF tags. Classes of LDR devices are expected to be very low complexity and very low cost, implying that the MAC will also need to be very low complexity. [1]

The potential proliferation of UWB devices means that a MAC must deal with a large number of issues related to coexistence and interoperation of different types of UWB devices with different capabilities. The complexity limitations of LDR devices may mean that very simple solutions are required. HDR devices, which are expected to be higher complexity, may have much more sophisticated solutions.

5.2 Medium Access Control for Ultra-wideband

The typical structure of cellular networks or access-point based networks is to have a central coordinating node which may be reached by each node in the network. In ad-hoc networks, the coordinator is dynamically selected among capable devices participating the network. In fully ad-hoc networks, or multi-hop networks, there is no coordinator at all and access is entirely distributed.

Regardless of the network topology, the role of the MAC is to control access of the shared medium, possibly achieving targeted goals such as high performance (quality of service provision), low energy consumption (energy efficiency), low cost (simplicity), and flexibility (for example with ad-hoc networking capabilities).

For all mobile applications, energy efficiency is an important consideration, and it is crucial in sensor networks. Energy efficiency affects the MAC design by requiring the protocol overhead due to signaling (connection set-up, changing configuration, etc.) to be minimized.

The physical layer provides a bit stream to the upper layers, utilizing techniques and signals to optimize the usage of the available channel. At the physical layer, no distinction is made with respect to the significance of the bits carried. The role of the MAC is to arbitrate access to the resources made available from the physical layer (Figure 13) [1].

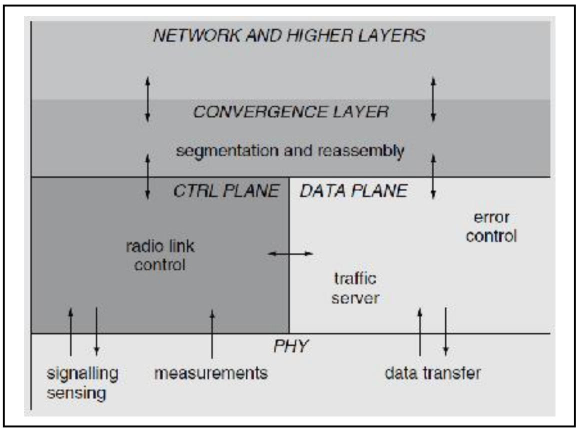

Figure 13 Reference model [1]

Figure 13 shows the packet traffic between two users in an UWB ad-hoc network. The approach assumes a very simple CSMA/CA protocol. Synchronization preambles must be sent at the beginning of each transmission burst. In order to exchange data with the CSMA/CA protocol, the receiver must first synchronize and decode the RTS (request to send) packet.The transmitter then needs to synchronize and decode the CTS (clear to send) packet, before starting transmission. In Figure 14, the UWB preambles are highlighted and denoted by ‘p’. Processing times are neglected.

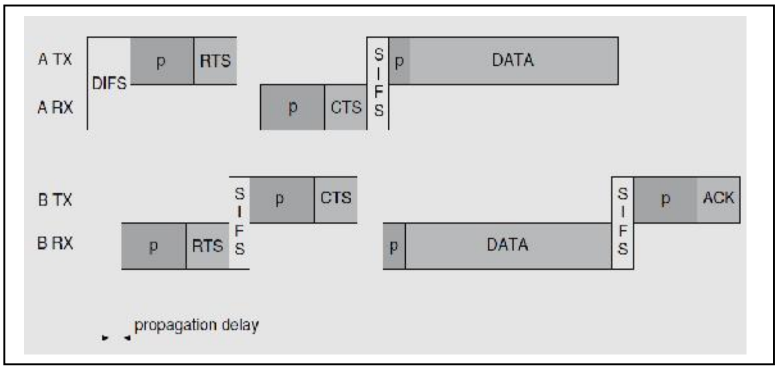

Figure 14 Messages between sender A and destination B using the CSMA/CA protocol [1]

A long preamble is needed in order to achieve synchronization for both the RTS and CTS packets. A shorter preamble is possible for data transmission since synchronization may be assumed to be maintained after reception of the RTS packet. Further packets may be received with only fine corrections or tracking. Depending on the allowed length of the data packet, a longer preamble may be needed for the following ACK packet.

The time to achieve bit synchronization in UWB systems is typically high, of the order of few milliseconds. Considering that the transmission time of a 10 000 bit packet on a 100 Mbit/s rate is only 0.1 milliseconds, it is easy to understand the impact of synchronization acquisition on CSMA/CA-based protocols. The efficiency loss due to acquisition time can be minimized by using very long packets. However this may impact performance in other ways.

6. Features, Challenges and Applications of UWB

6.1 Features

(a)High Data Rate: UWB can handle more bandwidth-intensive applications like streaming video, than either 802.11 or Bluetooth because it can send data at much faster rates. UWB technology has a data rate of roughly 100 Mbps, with speeds up to 500 Mbps.

(b)Low Power Consumption: UWB transmits short impulses constantly instead of transmitting modulated waves continuously like most narrowband systems do. UWB chipsets do not require Radio Frequency (RF) to intermediate Frequency (IF) conversion, local oscillators, mixers, and other filters. Due to low power consumption, battery-powered devices like cameras and cell phones can use in UWB [4].

(c)Interference Immunity: Due to low power and high frequency transmission, USB‘s aggregate interference is “undetected” by narrowband receivers. Its power spectral density is at or below narrowband thermal noise floor. This gives rise to the potential that UWB systems can coexist with narrowband radio systems operating in the same spectrum without causing undue interference [4].

(d)Low Probability of interception and detection: Because of their low average transmission power, UWB communications systems have an inherent immunity to detection and intercept.

(e)Reasonable Range: IEEE 802.15.3a Study Group defined 10 meters as the minimum range at speed 100Mbps However, UWB can go further.

(f) Low Complexity, Low cost: Traditional carrier based technologies modulate and demodulate complex analog carrier waveforms. In UWB, Due to the absence of Carrier, the transceiver structure may be very simple. Recent advances in silicon process and switching speeds make UWB system as low-cost. Also home UWB wireless devices do not need transmitting power amplifier.

(g)Large Channel Capacity: The capacity of a channel *(c)* can be express as the amount of data bits transmission/second. Since, UWB signals have several gigahertz of bandwidth available that can produce very high data rate even in gigabits/second.

(h)Ability to share the frequency spectrum: The FCC‘s power requirement of –41.3 dBm/MHz,5 equal to 75 nano watts/ MHz for UWB systems, puts them in the category of unintentional radiators, such as TVs and computer

monitors. Such power restriction allows UWB systems to reside below the noise floor of a typical narrowband receiver and enables UWB signals to coexist with current radio services with minimal or no interference.

(i) High Performance in Multipath Channels: The phenomenon known as multipath is unavoidable in wireless communications channels. It is caused by multiple reflections of the transmitted signal from various surfaces such as buildings, trees, and people. The straight line between a transmitter and a receiver is the line of sight (LOS); the reflected signals from surfaces are non-line of sight (NLOS).

(j) Superior Penetration Property: Unlike narrowband technology, UWB systems can penetrate effectively through different materials. The low frequencies included in the broad range of the UWB frequency spectrum have long wavelengths, which allows UWB signals to penetrate a variety of materials, including walls. This property makes UWB technology viable for through-the-wall communications and ground-penetrating radars.

6.2 Challenges

(a)Pulse-Shape Distortion: The transmission characteristics of UWB pulses are more complicated than those of continuous narrowband sinusoids. A narrowband signal remains sinusoidal throughout the transmission channel. However, the weak and low-powered UWB pulses can be distorted significantly by the transmission link.

(b)Channel Estimation: Channel estimation is a core issue for receiver design in wireless communications systems. Because it is not possible to measure every wireless channel in the field, it is important to use training sequences to estimate channel parameters, such as attenuations and delays of the propagation path. Given that most UWB receivers correlate the received signal with a predefined template signal, prior knowledge of the wireless channel parameters is necessary to predict the shape of the template signal that matches the received signal. However, as a result of the wide bandwidth and reduced signal energy, UWB pulses undergo severe pulse distortion; thus, channel estimation in UWB communication systems become very complicated [4].

(c)High Frequency Synchronization: Time synchronization is a major challenge and a rich area of study in UWB communication systems. As with any other wireless communications system, time synchronization between the receiver and the transmitter is a must for UWB transmitter/receiver pairs. However, sampling and synchronizing nanosecond pulses place a major limitation on the design of UWB systems.

(d)Multiple-Access Interference: In a multiuser or a multiple-access communications system, different users or devices send information independently and concurrently over a shared transmission medium (such as the air interface in wireless communications). At the receiving end, one or more receivers should be able to separate users and detect information from the user of interest. Interference from other users with the user of interest is called multiple-access interference (MAI), which is a limiting factor to channel capacity and the performance of such receivers. The addition of MAI to the unavoidable channel noise and narrowband interference discussed earlier can significantly degrade the low-powered UWB pulses and make the detection process very difficult.

6.3 Applications

(a) Communications: High Speed WLANs, Mobile Ad-Hoc wireless networks, Ground wave Communications, Handheld and Network Radios, Intra-home and Intra-office communication. Stealthy communications provide significant potential for military, law enforcement, and commercial applications [4],[13].

(b) Sensor Networks: Ground penetrating Radar that detects and identifies targets hidden in foliage, buildings or beneath the ground. Intrusion Detection Radars, Obstacle Avoidance Radars, and Short-range motion sensing [4],[13].

(c) Tracking and Positioning: Precision Geolocation Systems and high-resolution imaging. Indoor and outdoor tracking down to less than a centimeter. Good for emergency services, inventory tracking, and asset safety and security. Personnel identification, lost children, prisoner tracking, inventory tracking, tagging and identification, asset management.

(d) UWB Consumer Applications: Home Entertainment, Computing, Mobile Devices, Automotive, Content Transfer, Low power and high data rate use, content streaming.

7. Radio over Fiber (ROF)

7.1 Introduction

The NTC institute at UPV has been conducting pioneering research on radio-over-fibre since the mid-1990s.[24] Developing new concepts for both radio-over-fibre systems and their associated technologies has been the focus of more than 15 engineers and scientists working in the Fiber-Radio Group. This group joined the NTC in 2003. Currently, the NTC comprises more than 80 researchers.

7.1.1 Optical Beam Forming Network:

Optical beam forming networks can provide time delay, phase, and amplitude control for antenna arrays and benefit from the advantages of optical technology, such as the ability to implement RF independent time delays (also known as true-time delays), high-speed reconfigurability, and immunity to RF interference and noise.

Spatial light modulators are typically realized by means of pixelated liquid crystal structures in which the transmitted or reflected intensity and/ or phase of incoming light can be controlled for individual pixels. Beam steering, amplitude distribution weighting, and multibeam operation were demonstrated; far-field radiation patterns for an eight-antenna array at the X-band (8–12.4 GHz) were measured. The use of a single spatial light modulator to control many antenna elements allows the parallelization of the phase control between antenna elements. In addition, due to the availability of spatial light modulators with a large number of pixels, it was demonstrated that the architecture can be used to control several simultaneous beams.

7.2 Photonic Microwave Filters

In a photonic microwave filter based on the stimulated Brillouin scattering mechanism was proposed and demonstrated. This mechanism is caused by the photon-phonon nonlinearity induced by a high-power light wave pumping an optical fibre (typically made of silica). The pump signal produces a high-power counter propagating light wave slightly frequency-down-shifted when the incoming optical power is above a threshold determined by the effective area of the fibre and the line width of the optical source.

7.3 Photonic Analog-to-Digital Convertors for Management of Ultra-Wideband Signals.

To extend the UWB system’s range, a picocell clustering technique has been proposed in the European project UCELLs. Clustering a large number of UWB transceivers in simultaneous operation in spite of the low transmitted power allowed in UWB regulations, results in the presence of mutual interference between the different UWB transceivers. This interference could exceed the regulation if a large number of UWB transceivers operate in the same channel. To guarantee proper operation, it is necessary to manage the spectral allocation of the UWB transmitters and to control their transmitted power level. UWB spectrum management implies the monitoring of UWB transmissions and the proper configuration of UWB terminals to avoid interference and to optimize spectrum usage.

The UCELLS project is aimed at developing a real-time spectrum monitoring system based on a photonic analog-to digital converter and a radio-over-fibre infrastructure. This concept is illustrated in Figure 15, in which the operation of different UWB transmissions (downlink or uplink/downlink) with different ranges and different bit rate requirements is shown. The photonic analog-to-digital converter is typically based on a parallel architecture in which optical time stretching, i.e., time expansion of optically sampled wide-band RF signals, is performed.

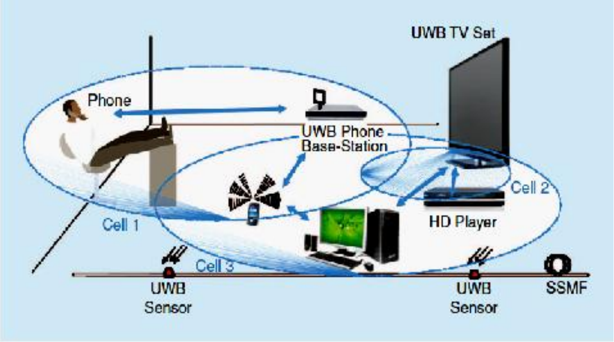

Figure 15 Multicell spectral management strategy addressed in UCELLS project [24]

7.4 OFDM UWB Radio-over-Fiber distribution for optical access

The UWB-on-fibre approach exhibits several advantages over other radio-over-fibre solutions. First, the huge bandwidth of the fibre infrastructure can support the distribution of a large number of UWB wireless channels in a frequency division arrangement. UWB transmission is also well suited to compensate for fibre transmission impairments such as chromatic dispersion, intrachannel nonlinear effects, and nonlinear phase noise if WiMedia-defined OFDM modulation is employed. In addition, UWB-on-fibre is a low-cost approach.

The UWB-on-fibre distribution approach is depicted in Figure 16. This figure shows an optical line terminal that distributes high-definition audio/video content from the core network to a number of users through a fibre-to-the home network.

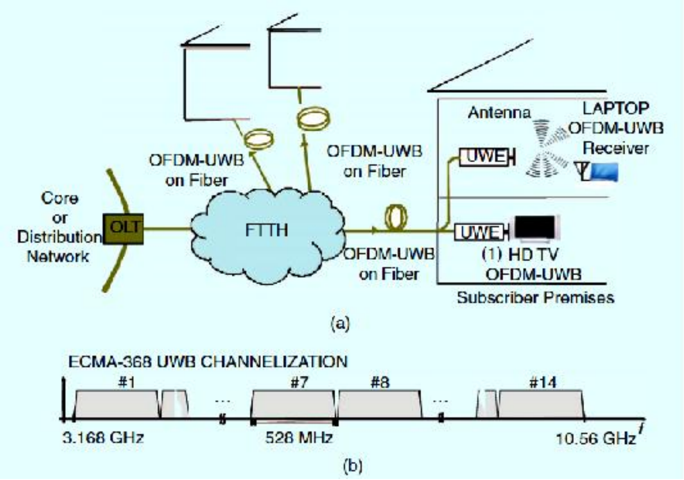

Figure 16 (a)Fiber-to-the-home distribution of OFDM-UWB signals. (b) Band group allocation [5]. UWE: wireless extractor. OLT: optical line terminal [24]

These signals are transmitted to the subscriber’s premises, where they are received by a wireless extractor system. The wireless extractor system extracts the UWB signal from the fibre-to the- home network and transmits the UWB wireless signal to the UWB-enabled television or computer. The wireless extractor system performs the photo detection of the transmitted signal, electrical filtering, and amplification and directly radiates the resulting signal to establish a standard UWB communication link.

Conclusion

The recent FCC frequency allocation for UWB has generated a lot of interest in UWB technologies. There are 7,500 MHz of spectrum for unlicensed use. Due to its unique features, UWB can potentially provide solutions for a wide array of applications, including low complexity, low power WPAN for both high data rate and low data rate networking, wireless connection and localization among low-power distributed sensors, BAN for medical as well as entertainment purposes. Currently, UWB RoF links can be used to replace cables in UWB wireless channel sounding. Such technology was used in. Channel measurements for frequencies around and above 10 GHz are extremely challenging as the loss introduced by RF cable increases with frequency. With RoF links, this challenge can be addressed since the advantage is that a wideband RoF link represents approximately a constant gain or attenuation over the entire frequency span for bandwidths of up to 20 GHz enabling measurements impossible with standard coaxial cables.

Future Scope

One of the main drawbacks of the UWB technology is its limited range that is typically below 10 m within a single room. As a result, it cannot compete with 802.11 standards in distributing wireless connectivity throughout a building. To overcome this issue, the radio-over-fiber (RoF) technology can be used. RoF is an important tool for future UWB systems as well for current research.

For the future, the use of RoF as part of UWB communication systems is considered, for example, by the EU project UWB radio over optical fiber. This project studies future systems and discusses architectures that might provide the platform for the requirements of such systems. UWB RoF are considered as distribution network for wireless connectivity throughout buildings.

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