Survey of Ultra-Wideband Communication and its Modulation Scheme

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Abstract

Ultra-Wideband (a.k.a. IEEE 802.15.3a or UWB) communication are gaining attention in the area of peer-to-peer communication between electronic devices in a home network. Due to it's nature of very low power spectral densities and span over a wide bandwidth, UWB is able to achieve high data rate communication, while not interfere with other existing wireless communication channel. Under this configuration, it worth to study various modulation scheme to exploit the best efficiency in communication.

In paper, we survey and give an overview on various communication techniques used in UWB, like spread spectrum, time hopping, impulse radio, and multiple access scheme, etc. Besides, we also presented various major proposed modulation scheme including the PPM (Pulse-position modulation), PAM (Pulse-amplitude modulation), and the BPSK (Binary phase-shift keying) to compare their relative merits in achieving a higher throughput of data rate. In the end, we compare UWB with other existing short-range wireless communication systems and introduce potential scenario of application.

Contents

1 Introduction

In the development of wireless communication, or just communication, we are always targeting on 1) sending a lot of data and very fast, 2) sending it far away, 3) and share with many users. Traditionally, the second criteria is more important and many researches had been done, resulting in technologies like cellular phone, satellite communications, radio/television broadcasting, GPS, etc. Nowadays, the research focus on achieving higher data rate and sharing with large number of users. According to the classical channel capacity formula developed by Shannon [8]:

$$C = Blog_2(1 + \frac{P}{BN_0}) \tag{1}$$

where C is Channel capacity measured in (bits/sec), B is the channel bandwidth measured in (Hz), P is the received signal power measured in (watts), and N_0 is the noise power spectral density measured in (watts/Hz). We see that channel capacity C is an increasing function of both bandwidth B and the received signal power P. However, the rate of increase for bandwidth is much faster than that of received signal power. This motivate us to transmit signal in lower power across a large bandwidth rather than increasing signal power to improve the channel capacity.

Besides targeting for higher data rate, when designing future short-range wireless systems one needs to take into account the increasingly pervasive nature of communications and computing based on the vision that wireless systems beyond the third generation (3G) will enable connectivity for "everybody and everything at any place and any time." This ambitious view assumes that the new wireless world will be the result of a comprehensive integration of existing and future wireless systems, including wider area networks (WANs), wireless local area networks (WLANs), wireless personal area and body area networks (WPANs and WBANs), as well as ad hoc and home area networks that link devices as diverse as portable and fixed appliances, personal computers, and entertainment equipment as stated in [6].

Unlike continuous wave (CW) radio transmissions that usually employ a sinusoidal wave to encode information, UWB technologies encode large amounts of information over a series of short pulses, using brief, extremely low-power radio energy spread across a wide range of frequencies. The UWB radio system possesses some specific advantages for indoor broadband wireless communications[7], such as:

- High capacity: UWB increases capacity by inherently spreading bandwidth over a very large range while maintaining low power transmission.
- Low probability of multi-path fading: Due to transmission of data in short pulses rather than continuous wave, multi-path is resolvable down to path differential delays on the order of 1 ns or less, and the fading effects are significantly reduced.
- Immunity to interference and jamming: Like capacity, immunity to interference is proportional to bandwidth, as power is spread over numerous frequencies and it is also not vulnerable to signal jamming.
- Time and frequency diversity: UWB pulses are very short in time and sent at intervals that create discrete pauses between transmissions.

When pulses are sent out from a UWB transmitter, they arrive at the receiver at different times depending on the traveling paths and results in signal that is combination of different time-delayed and attenuated version of the original signal. The receiver can be designed to take advantage of this effect by Rake combining the arriving signals of different paths, thereby increasing the received signals. Because of these features, UWB radio technology is a promising solution for broadband wireless communications in indoor environments.

In Section 2, we will address a more formal definition of UWB, like the bandwidth requirement, the spectrum allocation and the corresponding power spectral density requirement of it. We then describe the widely used signal waveform in UWB communication, essentially pulse radio, and it's multiple access scheme in section 3. In section 4, we will go through three different kinds of modulation schemes proposed in UWB, namely PPM, PAM, and BPSK, and their relative merits. We will compare UWB with existing short-ranged communications in section 5 and its potential application in a wireless personal area network (WPAN) in section 6. Lastly, we give concluding remarks in section 7.

2 Definitions and Characteristics of UWB

A UWB transmission consists of a train of very short pulses, where the information are encoded in the amplitude of a pulse via the pulse-amplitude modulation (PAM), or in the shift of a pulse via pulse-position modulation (PPM), which will be covered in detail in Section. 4. The pseudo-random time-hopping (TH) codes allow multiple users to access the same UWB channel[1] will be covered in Section 3. These ultrashort pulses, together with the data modulation, result in a transmitted signal with extremely low-power spectral density that spread across a very wide bandwidth, which gives itself the name Ultra-Wideband (UWB).

A fractional bandwidth of 0.25 or more is the commonly used definition for a UWB transmission, where fractional bandwidth stands for the ratio of the bandwidth of a signal to the center frequency of transmission. However, some groups are no now proposing a more broader definition by including all signals that have a bandwidth wider than 1.5GHz.

Based on this definition, two distinct categories of UWB systems are identified. First are the systems with bandwidth larger than 1.5GHz, but with fractional bandwidth less than 0.25. The low fractional bandwidth implied the usage of a high carrier frequency - typically above 10GHz (as $\frac{1.5}{10} < 0.25$). A low fractional bandwidth allows such systems to be designed with traditional RF principles. The antennas, frequency sysnthesisers, amplifiers, filters and other components are reasonably easy to manufacture. Unfortunately, these advantages are offseted by the high attenuation associated with the use of a high-frequency carrier.

The second category of UWB device has fractional bandwidth more than 0.25, thus implies the use of a low carrier frequencies - typically less than 2-3 GHz (as $\frac{1.5}{3} > 0.25$). In the past, the development of this class of UWB system has been constrained by the design difficulties associated with the use of traditional transceiver architectures. However, this problem has now been overcome by a new technology: time-modulated UWB (TM-UWB), a.k.a. impulse radio, which plays an important role in recent development of UWB.

In February 2002, the FCC Report and Order (R&O) allocated a 7500MHz (7.5GHz) of spectrum for unlicensed use of UWB devices in the 3.1GHz to 10.6GHz frequency range. The FCC defines UWB as **ANY**[2] signal that occupies more than 500 MHz bandwidth in the 3.1GHz to 10.6GHz band and that meets the spectrum mask shown in Figure. 2. This is by far the largest spectrum allocation of unlicensed use the FCC has ever granted according to what was reported in [1].

Given this recent spectrum allocation and the new definition of UWB adopted by the FCC, UWB is no longer considered as some specific technology anymore, but

[1] It is similar to the concept used in CDMA.

[2] By any we means, you are not restricted to use the impulse radio techniques to be qualified as UWB communication, any other transmission signals that fulfill the bandwidth and PSD requirement will do.

instead, is the available spectrum for unlicensed usage. This means that **ANY** transmission signal that meets the FCC requirements for UWB spectrum can be used. This is not just restricted to impulse radios or high-speed spread-spectrum radios; it also applies to any technology that uses more than 500MHz spectrum in the allowed spectral mask and with the current emission restrictions.

Different signals that occupy different bandwidths are illustrated in Figure 2[3], where all signals are of the same base frequency but have been shaped with different Gaussian envelops. Their bandwidths at the -10dB point[4] vary from 5GHz down to 5MHz. Thus, all signals shown in the graph, with the exception of the bottom one, are UWB signals because they all occupy at least 500MHz bandwidth. Their power spectral density (PSD), measured in 1 MHz bandwidth, must not exceed the specified FCC limit. The PSD is proportional to the UWB signal amplitude, bandwidth, and duty cycle, the latter defined as the ratio of the signal repetition rate and bandwidth, which we will cover more in Section 3 and 4. This means that, for a fixed PSD, the narrower the bandwidth, the smaller the allowed repetition rate for fixed amplitude. One thing that need to be clear is that, periodic non-modulated repetition of these pulse signals would generate a spectrum with spectral lines separated at the repetition rate, rather than the uniform spectrum envelop shown on the right hand side of Figure 2.

3 Multiple Access Scheme in UWB

In this section, we demonstrate the mathematical modeling of UWB signals and it's multiple access scheme. Before jumping into the mathematical formulation, the following is some general background on the relation of signal in its time domain and frequency domain. Typically when a baseband pulse of duration T_m seconds is transformed to the frequency domain, its energy is viewed as spanning a frequency band from DC up to roughly $2/T_m$ Hz. When this pulse is applied to an appropriately designed antenna, the pulse propagates with distortion. The antennas behave as filters, and even in free space a differentiation of the pulse occurs as the wave radiates. Impulse radio communicates with pulses of very short duration, typically on the order of a nanosecond, thereby spreading the energy of the radio signal very thinly from near DC to a few GHz. After familiarize yourself with the transform between time and frequency domain, the following in a commonly used model in UWB, which is adopted

[3]The figure is adopted from [1].

[4]The -10dB point is the point which is 10dB below the peak energy, and the bandwidth is the portion of spectrum which have energy about this point.

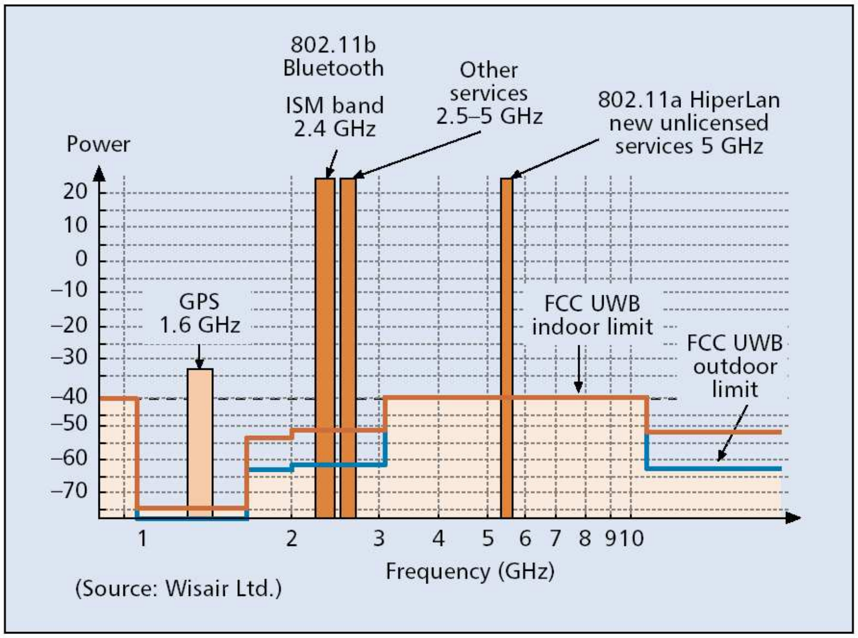

Figure 1: Spectrum mask requirement for UWB together with other unlicensed wireless communication systems.

from [7].

3.1 Time-Hopping Using Impulses

A typical time-hopping format employed by an impulse radio in which the k^{th} transmitter's output signal $s_{tr}^{(k)}(t^{(k)})$ is given by

$$s_{tr}^{(k)}(t^{(k)}) = \sum_{j=-\infty}^{\infty} w_{tr}(t^{(k)} - jT_f - c_j^{(k)}T_c - \delta d_{\lfloor j/N_s \rfloor}^{(k)}) \tag{2}$$

where $t^{(k)}$ is the k^{th} transmitter's clock time, and $w_{tr}(t)$ represents the transmitted pulse waveform, referred to as a monocycle, that nominally begins at time zero on the transmitter's clock. The frame time or pulse repetition time T_f typically may be a hundred to a thousand times the monocycle width, resulting in a signal with a very low duty cycle, thus low power spectral density. To eliminate catastrophic collisions due to multiple accessing, each user (indexed by k) is assigned a distinctive time-shift pattern $\{c_j^{(k)}\}$ called pseudo-random time-hopping sequence, which provides an additional time shift to each monocycle in the pulse train. The j^{th} monocycle undergoes an additional shift of $c_j^{(k)}T_c$ seconds, where T_c is the duration of addressable time delay bin. The elements $c_j^{(k)}$ of the sequence are chosen from a finite set $\{0, 1, \ldots, N_h - 1\}$, and hence hop-time shifts from 0 to N_hT_c are possible. The addressable time-hopping duration

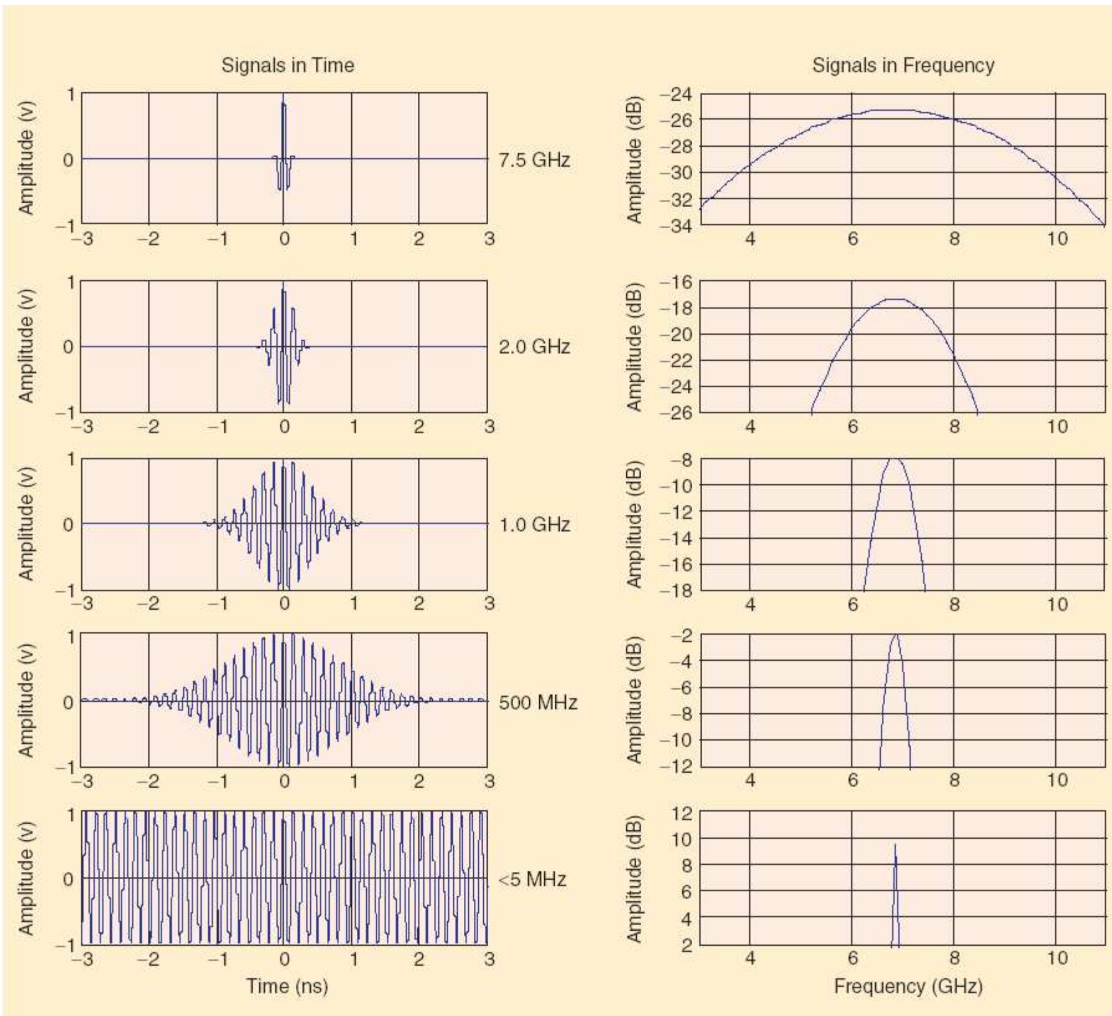

Figure 2: UWB signal of different bandwidth. (Left) Pulse in time domain, (Right) frequency spectrum.

is strictly less than the frame time since a short time interval is required to read the output of a monocycle correlator and to reset the correlator.

For performance prediction purposes, the data sequence $\{d_j^{(k)}\}_{j=-\infty}^{\infty}$ is modeled as a wide-sense stationary random process composed of equally likely binary symbols. A pulse position data modulation is considered here in which it is assumed that the data stream is balanced so that the clock tracking loop S-curve can maintain a stable tracking point. With more complicated schemes, pulse shift balance can be achieved in each symbol time. The parameter δ is a modulation factor, which can be chosen to optimize performance. If $\delta > T_m$, then the transmitted signals representing 0 and 1 are orthogonal.

3.2 The Multiple Access Channel

When N_u users are active in the multiple-access system, the composite received signal $r(t)$ at the output of the receiver's antenna is modeled as

$$r(t) = \sum_{k=1}^{N_u} A_k s_{rec}^{(k)}(t - \tau_k) + n(t), \tag{3}$$

in which A_k represents the attenuation over the propagation path of the signal, $s_{sec}^{(k)}(t - \tau_k)$, received from the k^{th} transmitter. The random variable τ_k represents the time asynchronism between the clock of transmitter k and the receiver, and $n(t)$ represents other non-monocycle interference (e.g., receiver noise, signals other than UWB) present at the correlator[5] input.

The number of transmitters N_u on the air and the signal amplitudes A_k are assumed to be constant during the data symbol interval. The propagation of the signals from each transmitter to the receiver is assumed to be ideal, each signal undergoing only a constant attenuation and delay. The antenna/propagation system modifies the shape of the transmitted monocycle $w_{tr}(t)$ to $w_{rec}(t)$ at its output.

3.3 Receiver Signal Processing

The optimal receiver for a single bit of a binary modulated impulse radio signal in additive white Gaussian noise is a correlation receiver, which can be reduced to Eq. 4, where the correlation template signal is $v(t) = w_{rec}(t) - w_{rec}(t - \delta)$.

[5]see Fig. 3 for detail.

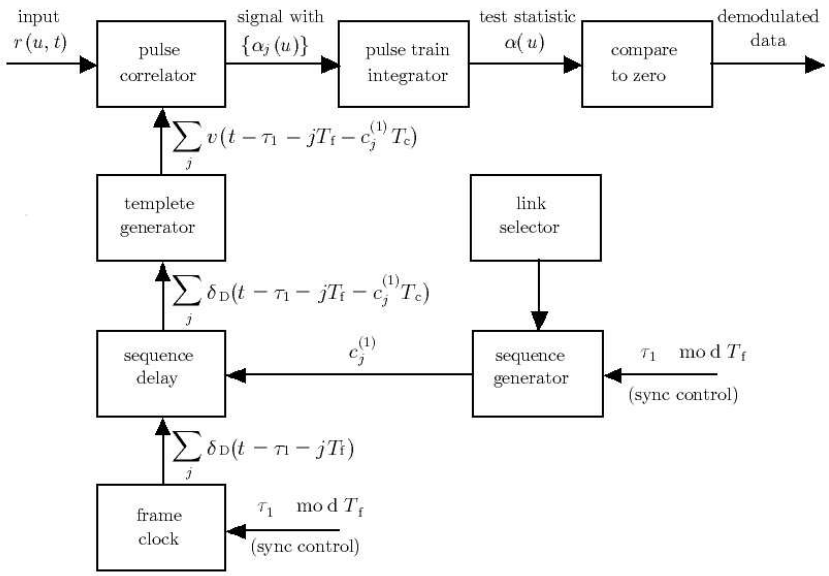

Figure 3: Receiver design in block diagram for the reception of the first user's signal. Clock pulses are denoted by Dirac delta functions $\delta_D(.)$.

$$\textbf{decide } d_0^{(1)} = 0 \Leftrightarrow \underbrace{\sum_{j=0}^{N_s-1} \overbrace{\int_{\tau_1+jT_f}^{\tau_1+(j+1)T_f} r(t)v(t-\tau_1-jT_f-c_j^{(1)}T_c)dt}^{\textbf{pulse correlator output } =\alpha_j}}_{\textbf{test statistic } =\alpha} > 0 \tag{4}$$

The optimal detection in a multi-user environment, with knowledge of all other time-hopping sequences, leads to very complex receiver designs. However, if the number of users is large and no such multi-user detector is feasible, then it is reasonable, or may be the only feasible method, to approximate the combined effect of the other users' de-hopped interfering signals as a Gaussian random process. Hence the single-link reception algorithm (4) is used here as a theoretically tractable receiver model, amenable as well to practical implementations.

The test statistic α in 4 consists of summing the N_s correlations α_j of the correlator's template signal $v(t)$ at various time shifts with the received signal $r(t)$. The signal processing corresponding to this decision rule in 4 is shown in Fig. 3.

3.4 Multiple Access Performance

The average output signal-to-noise ratio of the impulse radio is calculated for randomly selected time-hopping sequences as a function of the number of active users N_u as

$$SNR_{out}(N_u) = \frac{(N_s A_1 m_p)^2}{\sigma_{rec}^2 + N_s \sigma_a^2 \sum_{k=2}^{N_u} A_k^2} \tag{5}$$

Here σ_{rec}^2 is the variance of the receiver noise component at the pulse train integrator output. The monocycle waveform-dependent parameters m_p and σ_a^2 in Eq.5 are given by

$$m_p = \int_{-\infty}^{\infty} w_{rec}(x - \delta) v(x) dx, \tag{6}$$

and

$$\sigma_a^2 = T_f^{-1} \int_{-\infty}^{\infty} [\int_{-\infty}^{\infty} w_{rec}(x - s) v(x) dx]^2 ds, \tag{7}$$

respectively.

The $SNR_{out}(N_u)$ of the impulse radio can be rewritten as

$$SNR_{out}(N_u) = \{SNR_{out}^{-1}(1) + M \sum_{k=2}^{N_u} (\frac{A_k}{A_1})^2\}^{-1}, \tag{8}$$

where the parameter M is given by

$$M^{-1} = \frac{N_s m_p^2}{\sigma_a^2}. \tag{9}$$

Let's suppose that a specified signal-to-noise ratio SNR_{spec} must be maintained for the link to satisfy a performance specification. If this specification is to be met when $N_u - 1$ other users are active, then it follows that $SNR_{out}(1)$ in (8) represents the required equivalent single link signal-to-noise ratio (ignoring multiple access noise) such that $SNR_{out}(N_u) = SNR_{spec}$. Therefore the ratio of $SNR_{out}(1)$ to $SNR_{out}(N_u) = SNR_{spec}$ represents the fractional increase in every transmitter's power that is required to maintain its signal-to-noise ratio at a level SNR_{spec} in its receiver in the presence of multiple-access interference caused by $N_u - 1$ other users. We defined the fractional increase in required power (in units of dB) as $\Delta P = 10 log_{10}\{\frac{SNR_{out}(1)}{SNR_{spec}}\}$.

Under the assumption of perfect power control, the number of users that the multiple access impulse radio system can support on an aggregate additive white Gaussian noise channel for a given data rate is given by

$$N_u(\Delta P) = \lfloor M^{-1} SNR_{spec}^{-1}\{1 - 10^{-(\Delta P/10)}\}\rfloor + 1, \tag{10}$$

which is a monotonically increasing function of ΔP. Therefore

$$\begin{aligned} N_u(\Delta P) &\leq \lim_{\Delta P \to \infty} N_u(\Delta P) \\ &= \lfloor M^{-1} SNR_{spec}^{-1} \rfloor + 1 = N_{max} \end{aligned} \tag{11}$$

Hence the number of users at a specified bit-error rate (BER) based on SNR_{spec} cannot be larger than N_max, no matter how large the power of each user's signal is. In other words, when the number of active users is more than N_{max}, then the receiver cannot maintain the specified level of performance regardless of the additional available power. Similar results for direct sequence code division multiple-access systems is also observed in [9].

4 Modulation Scheme in UWB

Having introduced the multiple access scheme in UWB, we are going to describe how exactly the information are encoded in the signal and transmitted. According to some survey of UWB [1, 3], there are three major modulation schemes proposed and they are PPM, PAM, and BPSK respectively, we will go through each of them in the following.

4.1 PPM

PPM is based on the principle of encoding information with two or more positions in time, referred to the nominal pulse position, as shown in Figure 4. A pulse transmitted at the nominal position represents a 0, and a pulse transmitted after the nominal position represents a 1. The picture shows a two-position modulation, where one bit is encoded in one impulse. Additional positions can be used to provide more bits per symbol. The time delay between positions is typically a fraction of a nanosecond, while the time between nominal positions is typically much longer to avoid interference between impulses.

In general, the spectrum of a PPM signal tends to have a continuous component based on the shape of the pulse pulse a line spectrum with the frequency spacing of the lines determined by the baud rate ($\frac{1}{T_f}$ in the notation above). The proportion of total power in the continuous and line spectrums depends on the randomness of the pulse-position modulation; with the dithering to make the regularly-spaced pulse positions appear more random, the proportion of power in the link spectrum can be minimized but not entirely eliminated, as illustrated in Fig. 5. However, if the polarity of the pulses is pseudo-randomly switched and/or used to convey data, the lines can be eliminated.

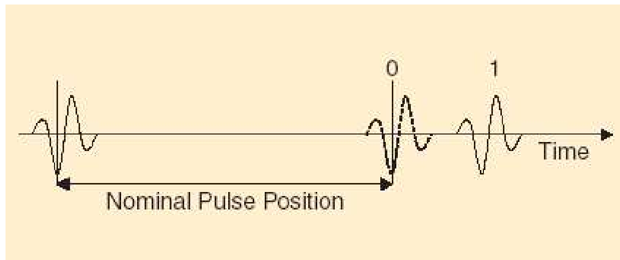

Figure 4: PPM of modulating 0 and 1.

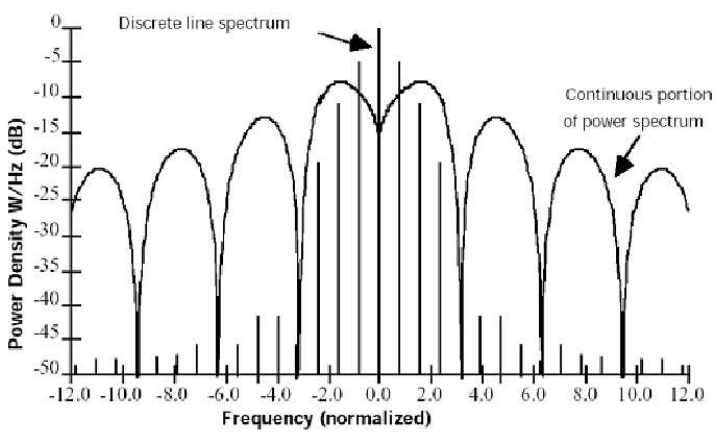

Figure 5: Example of PPM spectrum.

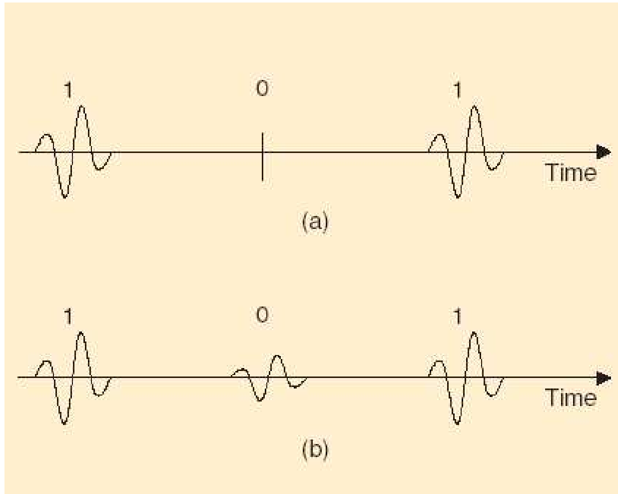

Figure 6: PAM of modulating 0 and 1.

4.2 PAM

PAM is based on the principle of encoding information with the amplitude of the impulses, as shown in Figure 6. The picture shows a two-level modulation, respectively, for zero and lower amplitude, where one bit is encoded in one impulse. As with pulse position, more amplitude levels can be used to encode more than one bit per symbol.

Even though PAM signals are comparatively easier to generate than PPM, this modulation scheme is not widely proposed. The reason is that for the receiver side to demodulate received signals, the signal energy level need to be know advance, in a wireless environment where attenuation of signals varies drastically, PAM is not practical and might introduce high error rate. However, we include this modulation scheme here for the sake of completeness.

4.3 BPSK

In biphase modulation, information is encoded with the polarity of the impulses, as shown in Figure 7. The polarity of them impulses is switched to encode a 0 or a 1. In this case, only one bit per impulse can be encoded because there are only two polarities available to choose from.

The biphase pulse modulated data signals, $V_{Bi-phase}(t)$, with Gaussian pulse waveform, $p(t)$, can be given as

$$V_{Bi-phase}(t) = \sum_{n=-\infty}^{\infty} b_n p(t - nT_f) \tag{12}$$

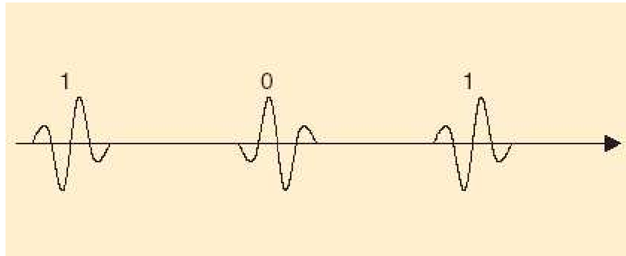

Figure 7: BPSK of modulating 0 and 1.

where b_n is the nth data bit (i.e., = +1 or -1), and T_f is the pulse repetition time. Generally, we have $T_f > T_m$ where T_m is the time delay spread of the UWB multi-path fading channel.

Following the above definitions, we can further extend the basic biphase pulse modulation scheme to include temporal diversity by repeating the monocycle waveforms K times. In this scheme, the repeated monocycle pulses are uniformly placed over the symbol interval, T_f. This diversity technique gives rise to different spectral features that provide an opportunity for the data rate increase needed for video content transfer. The biphase pulse modulated data signals with diversity K can then be given as

$$v_D(t) = \sum_{n=-\infty}^{\infty} b_n \sum_{k=0}^{K-1} p(t - nT_f - k\frac{T_f}{K}). \tag{13}$$

Among these three modulation schemes, in terms of signal generation, PAM should be the easiest, while PPM require a good circuit design and timing control to precisely generate pulse with different time elapse. However, PAM is not good for the receiver side as signal strength need to be know advance, and meanwhile, the dimension of basis signal used by BPSK is one more than PPM and PAM, thus occupying extra bandwidth(though it might not really matters in UWB). If the synthesis of PPM signal can be controlled easily, it would be the best modulation scheme among these three.

5 Comparison with Existing Short-range Communication

In this section, we choose four of the most popular wireless communication systems to compare with UWB, namely Bluetooth, IEEE 802.11a, 802.11b, and 802.11g. Among these four, the most similar one to UWB is Bluetooh as they are both targeting for wireless peer-to-peer communication of electronic devices. In general IEEE 802.11

family are used of medium range communication, for example, the wireless access point in a conference room to serve several users. while Bluetooth and UWB are used for short range (¡10m) communication, for example, replacing the wire of a hands-free cell-phone, the connecting wire between monitor and a PC.

For the interference point of view, UWB does an excellent job because the energy is spread across a wide spectrum. while the rest are all operating on the 2.4GHz frequency range, and some of the users might have experienced signal jamming when used together with a 2.4GHz cord-less phone. In terms of connection topology, both Bluetooth and UWB do not deploy a master/slave paradigm and require no centralized control to exist in order to form a communication network. Compared to the IEEE 802.11 family, this mobility set free the mobile device and allow them to form an ad-hoc network no-the-fly.

Table 1 shows the comparison of these 5 systems in different aspects[6].

6 Applications

While the commercialization of UWB is just beginning, the technology offers significant potential for the deployment of short-range communication systems supporting high-rate applications and lower-rate intelligent devices embedded within a pervasive and personal wireless world. A number of practical usage scenarios well suited to UWB have been identified by [6] (see Fig. 8). In these scenarios, system implementations based on UWB could be beneficial and potentially welcome by industry and service providers alike:

- High data rate wireless personal area network (HDR-WPAN)
- Wireless Ethernet interface link (WEIL)
- Intelligent wireless area network (IWAN)
- Outdoor peer-to-peer network (OPPN)
- Sensor, positioning, and identification network (SPIN)[7]

The first three scenarios assume a network of UWB devices deployed in a residential or office environment, mainly to enable wireless video/audio distribution for entertainment, control signals, or high-rate data transfers. The fourth scenario presents a deployment in outdoor peer-to-peer situations, while the fifth takes industry and

[6]The table composed of data from [5] and [6].

[7]The above short form are named in a ad-hoc manner, and it might not be consistent with the naming scheme used in other paper.

Table 1: Brief comparison with existing short-ranged communication systems

Characteristic	Bluetooth	IEEE 802.11a	IEEE 802.11b	IEEE 802.11g	UWB
Version/ status	V1.1	IEEE approved	IEEE approved	draft	draft
Max. data rate	1Mb/s	24Mb/s - 54Mb/s	11Mb/s	54Mb/s	110Mbs
Operation range	< 10m	50m	100m	100m	< 10m
Applications	Mobile phone, portable terminals	IP data transmission			Home devices (audio, video IP data)
Modulation	GFSK	COFDM BPSK	QPSK	OFDM	PPM, PAM BPSK
Spreading	DS-FH	OFDM	CCK	OFDM	(Multi-band)
Channel bandwidth	1MHz	20MHz	25MHz	25 MHz	Min. 500MHz Max. 7.5GHz
Frequency allocation	2.4GHz	around 5GHz	2.4GHz	2.4GHz	3.1-10.6GHz
Connection topology	Peer-to-peer, master-slave	MS-to-BS			Peer-to-peer, multi-hop
Number of RF channels	1, 10, 16	12, 8, 4	3	3	(1-15)
Maximum allowed RF power	1W +6dB antenna gain	50mW, 250mW, 1W, depends	30dBm	30 dBm	-41.3dBm/MHz (max. EIRP 0.562mW)

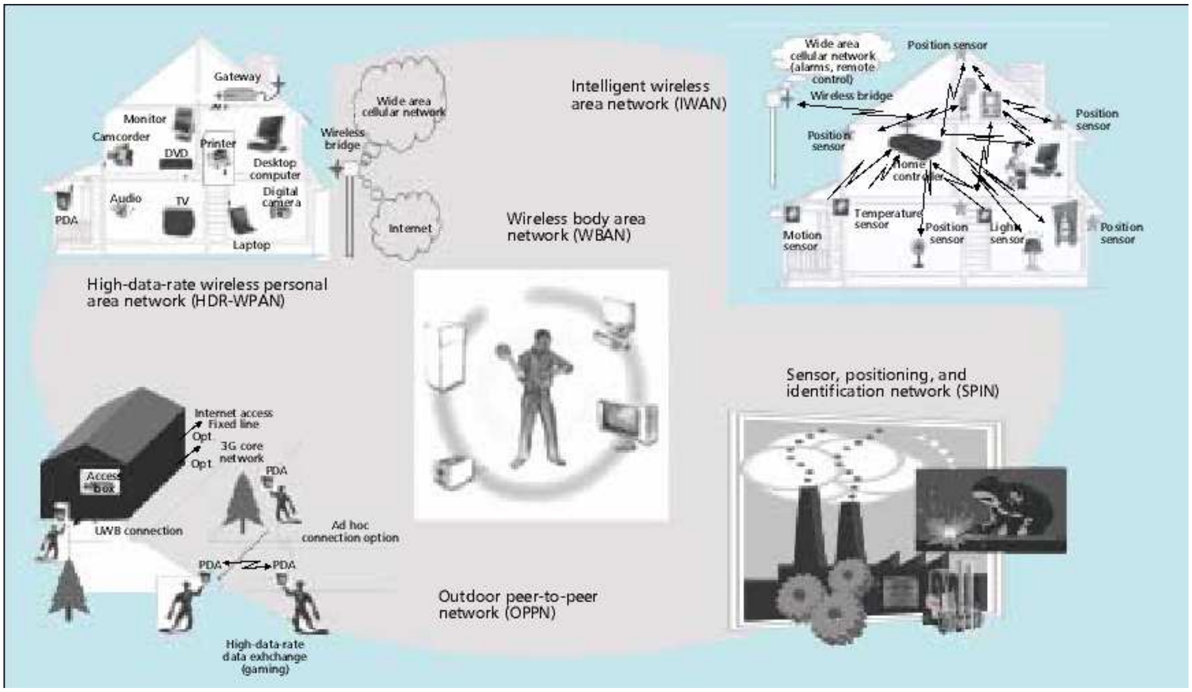

Figure 8: Scenarios for future UWB radio applications

commercial environments into account. The identification of common elements among the scenarios listed and the optimization of system cost, coverage range, data rate, localization precision, battery burden, and level of adaptability to channel conditions are still tasks ahead. But assuming adherence to FCC regulations in principle, some preliminary considerations can be given to the individual scenarios. In the following, we will give a brief introduction to the five area of applications stated above.

High Data Rate Wireless Personal Area Network

HDR-WPANs are networks with a medium density of active devices per room (5-10) transmitting at up to 100-500 Mbs data rate at a distance between 1 and 10 m, mainly based on a peer-to-peer topology and using a relay/bridge to the outside world based on existing (either wireless or cable) standards. There is a need to carefully define the interface and adaptation between local and remote modes, as the outside world may be limited to accept only lower data rates (e.g., WAN).

Wireless Ethernet Interface Link

This is an extension of the HDR transmission to extremely high data rate (e.g. 1Gb/s or 2.5Gb/s), probably only over rather short distance up to a few meters. The WEIL concept could probably satisfy the following two demands.

- The need for a direct wireless replacement for Ethernet cables.
- A high-quality wireless video transfer capability between a PC and an LCD screen, like wireless digital video interface (DVI).

Intelligent Wireless Area Network

IWANs are characterized by a high density of devices in a domestic or office environment, covering distances over 30m. The main requirements for the devices are: very low cost and very low power consumption to provide users with access to intelligences(e.g. automated smart appliances) distributed around the home/office. Device capability will include accurate location tracking in support of context-aware services that is not readily realizable with the current generations of narrow-band short-range networks. In this scenario an eventual wireless last mile and/or other interconnections (probably broadband Internet access nowadays) to the outer world could be used to send alarms and control signals, and/or remotely check the status of sensors around the home.

Outdoor Peer-to-Peer Network

It refers to a network of UWB-enabled devices deployed in outdoor areas, mainly to respond to new demands for PDA linkup and information exchange, digital kiosks for fast download of newspaper text to electronic paper, photographs, automatic video rental (downloading video data to mobile storage device from an access point), or sale distribution systems. However, situation might change, because it is anticipated that future UWB usage regulations will likely follow and evolutionary path to an even greater extent than that experienced for other wireless services in the past.

Sensor, Positioning, and Identification Network

A SPIN is a system characterized by a high density of devices in industrial factories or warehouses transmitting low-rate data combined with position information (e.g. data rate greater than several tens of kilobits per second and position accuracy well within 1 m). SPIN devices operate over medium to long distances between individual devices and a master station with a typical master-slave topology. In industrial applications, SPINs require a high level of link reliability and adaptive system features to react to the dynamically changing and very challenging interference and propagation environment.

Besides these civilian usage of UWB technology, there are a lot other application of UWB in other aspects as suggested by [4]. When operating at a frequency of 2GHz, radar, rather than communications, is likely to be the primary user of UWB technology.

UWB radar systems will benefit the radar community by providing excellent distance resolution and low propagation losses compared to conventional radars (where a comparable resolution can only be achieved by operating in a higher frequency band). The number of UWB radar applications is extensive, and can be grouped into the following 4 categories.

Medical

Hear monitors that use UWB technology could measure the actual contractions of the heart instead of its electrical impulses. This application would have the advantage of being non-intrusive, thereby reducing the stress often attributed to invasive medical monitoring equipment.

Automotive

A wide bandwidth means that the positional accuracy of vehicular UWB radars could be within a few centimeters - in contrast to more conventional vehicular radars where the accuracy is only of the order of a meter. This high positional accuracy makes possible a multitude of vehicular applications, including vehicle parking and reversing aids, air bag proximity measurements for safe deployment, and short-range, automatic cruise control for use in stop-start traffic jams.

Ground penetrating radar

UWB ground penetrating radars operating at low frequencies, over a low range of carrier frequencies, have the great advantage of relatively low penetration losses. This opens up many applications for ground penetrating radar, including determining the structural soundness of bridges, runways and roads, locating buried containers that may contain hazardous waste, and determining the location of underground pipes, irrespective of the composition of the piping. Other applications include the detection and imaging of land mines, especially plastic mines that are hard to detect using conventional radars.

Imaging systems

Imaging systems are technically similar to ground penetrating radars, without the restriction of pointing directly towards the ground. These systems are also likely to operate over low frequency ranges for enhanced imaging performance. The emergency services would benefit from UWB imaging systems that are able to locate people hidden behind walls or trapped under debris. Also, imaging systems could be used in home repairs to locate steel-reinforced bars in concrete, or electrical wiring or hidden pipes.

7 Conclusion

In this report, we have introduced the basic concepts and terminologies used in UWB. Besides we also outline the bandwidth/spectrum requirement as defined by the FCC for UWB. We described in detail one of the proposed multiple access scheme in UWB, the time hopping using pseudo-random sequence. We also focus on three major proposed modulation schemes, PPM, PAM, and BPSK used and compare their relative merits and disadvantages. We then compare the UWB with existing short-range high data rate wireless communication systems. Finally, we list out several possible applications of UWB that are going to impact our daily lives.

As we can see, UWB is not a new concept at all. For example impulse radio, the origin of UWB, was used by Heinrich Hertz in 1893. He used a spark discharge to generate electromagnetic waves for his experiments, and, for 20 years thereafter, spark gaps and arc discharges between carbon electrodes were the principal mechanisms for producing these signals. Marconi used the same techniques to send letters encoded in Morse code across the Atlantic Ocean. Eventually, rotating generators and, later, vacuum-tube and solid-state oscillators were used to produce sinusoidal radio waves and receivers that could then discriminate among transmitters. UWB come up recently just because the technology enable us to produce signal impulse precisely in nanoseconds scale so that we can make use of the wide bandwidth and low power spectral density properties.

We foresee the future of UWB to be promising and a lot of research can be done. In fact there is a lot of research effort involved in different aspects of UWB, like multi-antenna techniques [10], or multiple access scheme performance analysis [2], etc. As the low cost of sending large amount of data shed light on the possibility of building a "wire-less" home, while all electronic components communicate without the use of cables. More and more wearable computing equipment will be based on UWB and it also contribute to the advancement of sensor network.

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