Ultra Wideband (UWB): Characteristics and Applications

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Abstract - Since the release by the Federal Communications Commission (FCC) of a bandwidth of 7.5GHz (from 3.1GHz to 10.6GHz) for Ultra-wideband (UWB) wireless communications, UWB is rapidly advancing as a short range high-speed high data rate wireless communication technology. This technology is an unlicensed service that can be used anywhere, anytime, by anyone. UWB which is well known for its use in ground penetrating radar (GPR) has shown interest in communications and radar applications. Unlike traditional systems, this can only operate over a specific range of frequencies. UWB devices operate by employing a series of very short electrical pulses (billionths of a second long) that result in very wideband transmission bandwidths. In addition, UWB signals can run at high speed and low power levels. In this paper we discuss several applications where UWB supports, such as positioning, geo-location, localization (accurate positioning and high multipath environments), radar and sensor applications (vehicular, marine, GPR, sense-through-the-wall (STTW) and surveillance systems), communications (high multipath environments, short range communications and high data rates) and roles of UWB in medical applications, medical monitoring and medical imaging.

Keywords – Ultra Wideband, Wireless Technology

1. INTRODUCTION

Ultra Wide Band (UWB) is a wireless technology developed to transfer data at high rates over very short distances at very low power densities. UWB short-range radio technology complements other longer-range radio technologies such as Wi-Fi, WiMAX, and cellular wide area communications. UWB is used to relay data from a host device to other devices in the immediate area (up to 10 m or 30 feet). Has the ability to carry signals through doors and other obstacles that tend to reflect signals at more limited bandwidths and at higher power levels [1]. UWB is a radio technology that modulates impulse based waveforms instead of continuous carrier waves as shown in the Figure 1.

Figure 1 Time and frequency-domain behaviors for Narrowband (NB) versus Ultra Wide Band (UWB) communications
II. CHARACTERISTICS

A. Large Bandwidth

The FCC allocated an absolute bandwidth more than 500 MHz up to 7.5 GHz which is about 20% up to 110% fractional bandwidth of the center frequency. This large bandwidth spectrum is available for high data rate communications as well as radar and safety applications to operate in. Figure 1 shows the comparison between conventional narrowband (NB) versus UWB communications in both time- and frequency-domains. The conventional NB radio systems use NB signals which are sinusoidal waveforms with a very narrow frequency spectrum in both transmission and reception. Unlike a NB system, an Ultra-wideband radio system can transmit and receive very short duration pulses. These pulses are considered UWB signals because they have very narrow time duration with very large instantaneous bandwidth [2].

B. Very Short Duration Pulses

A typical received UWB pulse shape which is known as a Gaussian doublet (is considered a simple and efficient approach for UWB pulse generation [3]) is shown in Figure 2. This pulse is often used in UWB systems because its shape is easily generated. Ultra-wideband pulses are typically of nanoseconds or picoseconds order. This is the origin of the name Gaussian pulse, monocycle or doublet. Transmitting the pulses directly to the antennas results in the pulses being filtered due to the properties of the antennas. This filtering operation can be modeled as a derivative operation. The same effect occurs at the receive antenna. Due to using UWB systems those very short duration pulses, they are often characterized as multipath immune or multipath resistant.

![Image](image_url)

*Figure 2 Idealized received UWB pulse shape*

C. High Data Rates with Fast Speed

The huge bandwidths for UWB systems –compared to other conventional NB systems– can show a number of important advantages. There is an increasing demand for high speed and high data rate applications in communication system. One of those advantages of UWB transmission for communications is the ability of UWB system to achieve high data rates in future wireless communications which requires increasing the bandwidth of the communication system. While current chipsets are continually being improved, most UWB communication applications are targeting the range of 100 Mbps to 500 Mbps. Table 1 shows the spatial and spectral capacity for different communication systems such as UWB, wireless local area network (WLAN) and Bluetooth. Using UWB technology will enable us to achieve higher data rates with higher spatial capacity compared to other existing systems. In addition, UWB technology achieves very high speed for data transmission. Another advantage of UWB systems is the ability to effectively reduce fading and interference problems in different wireless propagation channel environments because of the limited transmitted power of UWB.
systems [4]. This is in addition to exploiting multipath or frequency diversity because of the huge bandwidth of UWB systems. The signal-to-noise ratio (SNR) of the UWB system can be increased using some techniques such as antenna diversity and beamforming which in turn will provide range extension and boost the capacity of worldwide interoperability for microwave access (WiMAX) for wireless metropolitan area networks (WMAN), and wireless fidelity (Wi-Fi) for wireless local area networks (WLAN).

<table>
<thead>
<tr>
<th>System</th>
<th>Max. data rate [Mbps]</th>
<th>Transmission distance [m]</th>
<th>Spatial capacity [kbps/m²]</th>
<th>Spectral capacity [bps/Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>UWB</td>
<td>100</td>
<td>10</td>
<td>318.3</td>
<td>0.013</td>
</tr>
<tr>
<td>WLAN 802.11a</td>
<td>54</td>
<td>50</td>
<td>6.9</td>
<td>2.7</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>1</td>
<td>10</td>
<td>3.2</td>
<td>0.012</td>
</tr>
<tr>
<td>WLAN 802.11b</td>
<td>11</td>
<td>100</td>
<td>0.35</td>
<td>0.1317</td>
</tr>
</tbody>
</table>

**Table 1 Spatial and spectral capacity for different communication systems**

**D. Low Power Consumption**

The UWB technology has another advantage from the power consumption point of view. Due to spreading the energy of the UWB signals over a large frequency band, the maximum power available to the antenna –as part of UWB system– will be as small as in order of 0.5mW according to the FCC spectral mask shown in Figure 3. This power is considered to be a small value and it is actually very close to the noise floor compared to what is currently used in different radio communication systems [4].

![Figure 3 UWB versus other radio communication systems](image)

**E. Small Size and Low Cost**

The small size of UWB transmitters is a requirement for inclusion in today’s consumer electronics. The main arguments for the small size of UWB transmitters and receivers are due to the reduction of passive components. However, antenna size and shape is another factor that needs to be considered. Ultra-wideband antennas are considered in the next article. Among the most important advantages of UWB technology are those of low system complexity and low cost. Ultra-wideband systems can be made nearly “all-digital”, with minimal radio frequency (RF) or microwave electronics. The low component count leads to reduced cost, and smaller chip sizes invariably lead to low-cost systems. The simplest UWB transmitter could be assumed to be a pulse generator, a timing circuit, and an antenna.
III. PRINCIPLES OF UWB

- US FCC defined a UWB signal as any signal with a bandwidth at the 10 dB attenuation points (90% spectral power bandwidth); Most narrowband Systems occupy less than 10% of the center frequency bandwidth, and are transmitted at far greater power levels greater than 20% of the modulation frequency.
- *In Time Domain:* Extremely short pulses and very low duty cycle. Figure 4.
- *In frequency domain:* Ultra wide spectrum and low power spectral density. Figure 4.

![Time-domain behavior](image1) ![Frequency-domain behavior](image2)

*Figure 4 Time and Frequency-domain*

IV. UWB TECHNOLOGIES

A. **DS UWB - Direct sequence ultra wideband technology**

DS UWB, direct sequence format for ultra wideband is often referred to as an impulse, baseband or zero carrier technology. It operates by sending low power Gaussian shaped pulses which are coherently received at the receiver. In view of the fact that the system operates using pulses, the transmissions spread out over a wide bandwidth, typically many hundreds of Megahertz or even several Gigahertz. This means that it will overlay the bands and transmissions used by more traditional channel based transmissions.

Each of the DS UWB pulses has an extremely short duration. This is typically between 10 and 1000 picoseconds, and as a result it is shorter than the duration of a single bit of the data to be transmitted. The short pulse duration means that multipath effects can usually be ignored, giving rise to a large degree of resilience in ultra wideband UWB transmissions when the signal path is within buildings.

B. **Multiband OFDM UWB**

Multi Band OFDM UWB is a form of ultra wideband technology that differs in approach to the impulse, or direct sequence form of ultra wideband.

MB-OFDM UWB transmits data simultaneously over multiple carriers spaced apart at precise frequencies. Fast Fourier Transform algorithms provide nearly 100 percent efficiency in capturing energy in a multi-path environment, while only slightly increasing transmitter complexity. Beneficial attributes of MB-OFDM include high spectral flexibility and resiliency to RF interference and multi-path effects.

Although a wide band of frequencies could be used from a theoretical viewpoint, certain practical considerations limit the frequencies that are normally used for MB-OFDM UWB. Based on existing CMOS technology geometries, use of the spectrum from 3.1GHz to 4.8GHz is considered optimal for initial deployments. Limiting the upper bound simplifies the design of the radio and analogue front end circuitry as well as reducing interference with other services. Additionally the frequency band from 3.1 GHz to 4.8 GHz is sufficient for three sub-bands of 500 MHz when using MB OFDM UWB.
V. APPLICATIONS

A. Wireless Personal Area Network

Due to the wide bandwidth and high time resolution UWB signals are much more robust to interferences and multipath fading. The large channel capacity and wide bandwidth offer wireless transmission of real-time high quality multimedia files.

The extremely small transmit power and the very short communication distances result in a large number of other advantages for WPAN applications. Since UWB signals are operating below the noise floor, they provide better security, lower RF health hazards, and lower interference to other systems.

B. Ground penetrating radar (GPR)

Because of Accurate timing information and ultra wide bandwidth it is widely applicable for the detection of unknown objects under the ground. The UWB GPR is used to draw a map of gas pipelines buried under ground by connecting GPS system to the GPR. UWB GPR have been intensively investigated for mine detection.

C. Military Communication

Attractive for manned and unmanned military vehicles: Issues associated with cable weight, space, and costs and Substantial cost associated with installing and modifying cabling embedded within the platform.

D. Home Networking and Home Electronics

One of the most promising commercial application areas for UWB technology is wireless connectivity of different home electronic systems. It is thought that many electronics manufacturers are investigating UWB as the wireless means to connect together devices such as televisions, DVD players, camcorders, and audio systems, which would remove some of the wiring clutter in the living room. This is particularly important when we consider the bit rate needed for high-definition television that is in excess of 30Mbps over a distance of at least a few meters [3].

E. Wireless Body Area Networks (WBAN)

WBANs are another example of how our life could be influenced by UWB. Probably the most promising application in this context is medical body area networks. Due to the proposed energy efficient operation of UWB, battery driven handheld equipment is feasible, making it perfectly suitable for medical supervision. Moreover, UWB signals are inherently robust against jamming, offering a high degree of reliability, which will be necessary to provide accurate patient health information and reliable transmission of data in a highly obstructed radio environment [3].

The possibility to process and transmit a large amount of data and transfer vital information using UWB wireless body area networks would enable tele-medicine to be the solution for future medical treatment of certain conditions. In addition, the ability to have controlled power levels would provide flawless connectivity between body-distributed networks. UWB also offers good penetrating properties that could be applied to imaging in medical applications; with the UWB body sensors this application could be easily reconfigured to adapt to the specific tasks and would enable high data rate connectivity to external processing networks (e.g. servers and large workstations).

F. Medical Application

It is known that the UWB pulse is generated in a very short time period (sub-nano second). So it has spectrum below the allowed noise level. This feature makes it possible to get Gbps speed by using
10GHz spectrum. So UWB is suitable to be used for high-speed over short distances. Such “noise-like” feature relies on ultra-short waveforms and does not require IF processing because they can be operated at baseband. This UWB feature has long been appreciated as key advantages for medical engineering [5].

G. Medical Monitoring: Patient motion monitoring

Because of the highly intense pulses used in UWB technology, it is possible to use UWB radar in medical field for remote monitoring and measuring the patients' motion in short distance [5]. This monitoring function could be applied in intensive care units, emergency rooms, home health care, pediatric clinics (to alert for the Sudden Infant Death Syndrome, SIDS), rescue operations (to look for some heart beating under ruins, or soil, or snow). For example in Figure 5, the using of UWB in monitoring the patient in intensive care unit could avoid usage of too many wires around the patient.

In Figure 5, signals emitting from UWB radars setting on ceiling can reflect when they meet human body. When the patient moves, the reflected signals will fluctuate. The fluctuation of signals denoting the movement of objects is transferred to the control center of the surveillant. The information could be fed back instantaneously to the doctors or nurses. It could also be recorded and analyzed in the future for the health condition of the patient.

H. Medical Imaging: Cardiology Imaging

Actually, the first applications using UWB radar technology was for heart monitoring since the heart related research has a high impact on general public. A scientist name Thomas McEwan in Lawrence Livermore National Laboratory (LLNL) developed the first patent on “radar stethoscope” as shown in Figure 6.
UWB transmitter emits discrete pulses to the human body and the reflected pulses from the heart arrived at UWB receiver and then the result is recorded. Signal processing is performed through obtaining the pulses response. For example, there exists a definite difference in reflection magnitude between the heart muscle and the blood when detecting the heart wall by UWB radar. Because of the impedance difference between the cardiac muscle and blood, a roughly 10% reflection magnitude of the radio frequency energy at the heart muscle-blood boundary can be expected. The UWB receiver can measure the difference, and show it on the screen, which reflects the status of heart.

I. Medical Imaging: Obstetrics Imaging

Another possible medical imaging application of UWB radar is in obstetrics imaging, shown as Figure 7 [5].

![Figure 7 Obstetrics Imaging using UWB radar](image)

However, unfortunately great concern regarding the RF safety in UWB for the newborn exists although everybody think the ultrasound generally is safe. The "emissions" from the device make this concern a "fear generating" situation. Obviously, more time is needed for everyone could accept the UWB radar. In the future, UWB radar device for obstetrics will be very useful and might be produced in large scale sales.

Actually UWB radar emission is safe and the system is well suited for chronically positioned equipments to monitor the last period of pregnancy or to assist in evaluating labor progress. UWB radar in this application area has many advantages over current ultrasound based fetal monitoring system. These new features include: no contact with patient, unimpaired mother and child care, remote operation, no cleaning and easier use.

VI. CONCLUSION

This paper has reported on how UWB wireless technology works, its characteristics and major application areas including from personal area network to medical applications. The simple transmit and a receiver structure of UWB makes it a potentially powerful technology for low complexity and low cost communications. The physical characteristics of the signal also support location and tracking capabilities of UWB much more readily than with existing narrower band technologies.

The severe restrictions on transmit power have substantially limited the range of applications of UWB to short distance, high data rate, or low data rate, longer distance applications. The great potential of UWB is to allow flexible transition between these two extremes without the need for substantial modifications to the transceiver.
REFERENCES


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