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UNIQUE FEATURES AND APPLICATION OF ULTRA-WIDEBAND TECHNOLOGY

Nwabueze C. A. and Jaja V. I.*

Department of Electrical and Electronics Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria.

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***Corresponding Author**
Jaja V. I.
Department of Electrical and Electronics Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria.

ABSTRACT

Ultra-Wideband (UWB) communication has been considered a revolutionary technology for transmitting large amounts of digital data over a broad frequency spectrum using short-pulse, low powered radio signals. UWB is an emerging technology with unique attractive features incorporating major advances in wireless communication, networking, radar, imaging, and positioning systems. UWB devices operate by employing a series of millions of narrow pulses that result in very wideband transmission bandwidths and is very promising for low cost sensor networks. This large bandwidth spectrum is available for high data rate communication. In addition, UWB signals can run at high speed and low power levels. These unique features of UWB technology make it suitable for many different applications such as positioning, geo-location, localization, radar/sensor applications, communications (high multipath environments, short range communications, and high data rates). This paper presents the unique features of UWB technology which can be effectively harnessed to create entirely new products and services in the telecommunication industry.

KEYWORD: UWB, Wireless LAN, Carrierless, Beamforming, Bandwidth, Frequency Spectrum.

INTRODUCTION

The term UWB was introduced by the US Department of Defense (DoD) around 1989 and commonly refers to a signal or system that either has a bandwidth that exceeds twenty percent of the centre frequency or a large absolute bandwidth of more than 500 MHz (Osama, 2012). In 2002, the UWB technology received a major boost when the US Federal Communication Commission (FCC) permitted the authorization of using the unlicensed frequency band starting from 3.1 to 10.6 GHz for commercial communication applications. This development in Ultra-wideband (UWB) technology offers a promising solution to the RF spectrum drought by allowing new services to coexist with current radio systems with minimal or no interference. The unique feature of UWB systems are defined by their large instantaneous bandwidth and the potential for very simple implementation. Additionally, the wide bandwidth and potential for low-cost digital design enable a single system to operate in different modes as a communication device, radar, or locator. Taken together, these properties give UWB systems a clear technical advantage over other more conventional approaches in high multipath environments at low to medium data rates (Luna, 2004).

In order to understand where UWB fits in with current trends in wireless communications, we need to consider the general problems that communications systems try to solve. UWB systems have several features that differentiate it from conventional narrowband systems. These include: Large data, over long distance, at very high speed, with NLOS, high precision range, fading robust, security coexistence. Unfortunately, it is impossible to achieve all these attributes simultaneously for systems supporting unique, private, two-way communication streams; one or more of these attributes have to give way if the others are to do well (Foerster et al, 2001).

Attributes of Ultra Wideband Communication System

The various attributes of UWB technology includes.

Large data

Ultra wideband (UWB) communication systems can be broadly classified as any communication system whose instantaneous bandwidth is many times greater than the minimum required to deliver particular information.

Figure 1 shows the comparison between conventional narrowband (NB) versus UWB communications in both time and frequency-domains. As the name implies, ultra wideband technology is a form of transmission that occupies a very wide bandwidth. Typically this will be many Gigahertz, and it is this aspect that enables it to carry data rates of Gigabits per second.

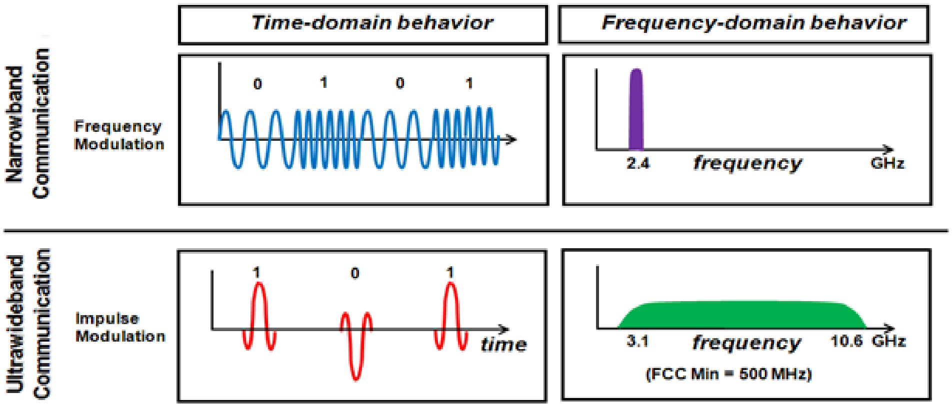

Figure 1: Time- and frequency-domain behaviors for narrowband versus UWB communications (Osama, 2012).

Over long distance

Originally, UWB systems were built to bridge large distances and achieve effective communications between parties for wider user coverage through the principle of spectrum reuse. The short duration pulse attribute of UWB can be leveraged on to provide robust performance in dense multi-path environments by exploiting more resolvable paths.

High data rate wireless transmission

Due to ultra-wide bandwidth of several GHz, UWB systems can support more than 500 Mb/s data transmission rate within the range of 10m, which support new services and applications. One of the main attractions for deployment of UWB in WAN/LAN applications is very high data rates that can be supported.

UWB is NON-line-of-sight (NLOS).

The fundamental physics of Ultra Wideband lends its technology to better propagation characteristics through walls and other obstacles. That is why UWB technology is also used for things such as "through-the-wall" imaging devices and ground penetration radar (Osama, 2005). UWB systems can penetrate obstacles and thus operate under both line-of-sight (LOS) and non-line-of-sight (NLOS) environments.

High precision ranging

Due to the nanosecond duration of typical UWB pulses, UWB systems have good time-domain resolution and can provide centimeter accuracy for location and tracking applications.

Fading robustness

UWB systems are immune to multipath fading and capable of resolving multipath components even in dense multipath environments. The transceiver complexity can be reduced by taking the advantages of the fading robustness. The resolvable paths can be combined to enhance system performance.

Security

For UWB signal, the power spectral density is very low. Since UWB systems operate below the noise floor, it is extremely difficult for unintended users to detect UWB signals. Probability of intercept is low in UWB. The UWB system is also difficult to be interfered with because of its large bandwidth.

Coexistence

The unique character of low power spectral density allows UWB system to coexist with other services such as cellular systems, wireless local area networks (WLAN), global positioning systems (GPS), etc.

Drawbacks of UWB Technology

The major drawbacks in UWB systems include:

Restrictions on Transmit Power

The severe restrictions on transmit power have substantially limited the operating range of UWB to about 10m distance. Radiated power and frequency bands determine to a large extent the communication links. In UWB there are regulatory constraints imposed in these two parameters. One is the power spectral limit measured in dBm/MHz, and the other is the frequency–band limit. Together they determine the maximum possible effective radiated power for an UWB signal at particular range of frequencies (Marenco and Rice, 2009).

Long synchronization time

Acquisition and synchronization of UWB systems are still an open issue, due to difficulties in tracking very short pulses with sufficient precision. An exact synchronization between transmitter and receiver is necessary unless a time-difference-of-arrival approach is applied. This would restrict the sophisticated demands on synchronization to the receivers only.

Potential Interference to/from existing system

Despite placing stringent power limitations on ultra-wideband signals, the regulation remains a concerned on potential interference with commercial wireless systems, global positioning system receivers and public-safety communications (Luna, 2004). Potential interference concerns have also lead to regulation and consequently shift in the permitted operating frequencies of UWB systems away from the congested 0–3 GHz band. However, higher frequencies propagate through construction materials less easily than lower frequencies, and so the effect of this aspect of the regulation is to further decrease the ability of UWB location systems to operate over long ranges indoors.

Large number of multipaths

Multipath is an enemy of narrow-band radio - It causes fading where wave interference is destructive. The UWB systems use "rake" receiver techniques to recover multipath generated copies of the original pulse to improve performance on receiver. A factor which results in sophistication in system design and rise in cost.

Inapplicability of super resolution beamforming

Beamforming is a type of RF (radio frequency) management in which an access point uses multiple antennas to send out the same signal. Ultra-wideband (UWB) technology is primarily aimed at short-range communications. It is expected that in many UWB networks transmitters and receivers are concentrated in close proximity thereby giving rise to mutual interference. UWB (Ultra Wide-Band) systems are used in a variety of applications, although the resolution of UWB system is basically restricted by its bandwidth, super-resolution techniques can be used to overcome the conventional resolution limit.

Application of UWB Technology

There are varieties of applications the UWB technology can be used for. They range from data and voice communications through to radar and tagging. With the growing number of way in which wireless technology can be used, the list is likely to grow. Although much of the hype about ultra wideband UWB has been associated with commercial applications, the technology is equally suited to military applications. One of the advantages is that with the pulses being spread over a wide spectrum they can be difficult to detect. This makes them ideal for covert communication.

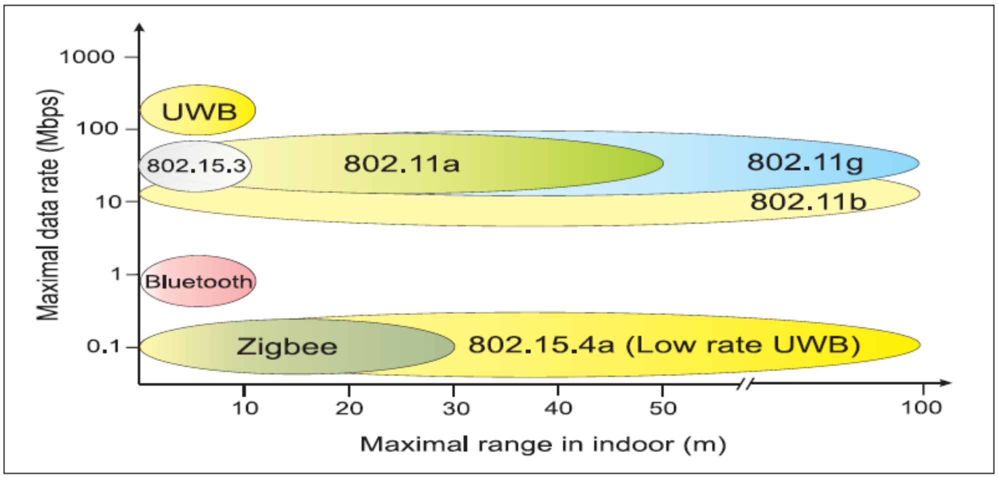

Figure 2: Positioning of the UWB compared to WLAN/WPAN (Xuemin et al, 2006).

Applications of UWB systems

1. UWB application in WSN:

(i) Monitoring Factory Systems and Devices.

(ii) WPAN Security

(iii)UWB link functions as a cable replacement

2. UWB application in tracking and positioning:

(i) High Accuracy Position and Attitude Integrating UWB and MEMS for Indoor Positioning.

(ii) High Accuracy Positioning in Hazardous Environments.

3. UWB application in active RFID:

(i) Indoor Real Time Location with Active RFID – System Precision and Possible applications.

(ii) Understanding the Benefits of Active RFID for Asset Tracking.

(iii)Implementation Example of Active UWB.

4. Other applications:

(i) Real-Time Locating Systems in Agriculture: Technical Possibilities and Limitations.

(ii) Ultra wide band (UWB) of optical fiber Raman amplifiers in advanced optical communication networks.

Comparison of UWB Technology with Traditional Carrier Wave System

UWB short-range wireless communication is different from a traditional carrier wave system. UWB waveforms are short time duration and have some rather unique properties. In spreading signals over very wide bandwidths, the UWB concept is especially attractive since it facilitates optimal sharing of a given bandwidth between different systems and applications. In recent years, rapid developments have been experimented on the communication technologies using UWB signals. UWB technology offer major enhancements in three wireless application areas: communications, radar and positioning or ranging. UWB technology can be delivered also over wire lines and cables such as CATV (cable television) application. Each of these applications illustrate the unique value of UWB (Foong and Lew, 2003).

Communication Systems

Using UWB techniques and the available large RF bandwidths, UWB communication links has become feasible. The exceptionally large available bandwidth is used as the basis for a short-range wireless local area network with data rates approaching gigabits per second. This bandwidth is available at relatively low frequencies thus the attenuation due to building materials is significantly lower for UWB transmissions than for millimeter wave high bandwidth solutions. By operating at lower frequencies, path losses are minimized and the required emitted power is also reduced to achieve better performance. Computer peripherals offers another applications of UWB especially when mobility is important and numerous wireless devices are utilized in a shared space. A mouse, keyboard, printer, monitor, audio speakers, microphone, joystick, and PDA are in wireless, all sending messages to the same computer from anywhere in the given range (Siwiak and McKeown, 2004).

UWB also is used as the communication link in a sensor network. A UWB sensor network frees the patient from the tangle of wired sensors. Sensors are being used in medical situation to determine pulse rate, temperature, and other critical life signs. UWB is used to transport the sensor information without wires, but also function as a sensor of respiration, heartbeat, and in some instance for medical imaging. UWB pulses are used to provide extremely high data rate performance in multi-user network applications. These short duration waveforms are relatively immune to multipath cancellation effects as observed in mobile and in-building environments. In addition, because of the extremely short duration waveforms, packet burst and time division multiple access (TDMA) protocols for multi-user communications are readily implemented (Fontana, 2000).

Radar Systems

For radar applications, these short pulses provide very fine range resolution and precision distance and positioning measurement capabilities. The very large bandwidth translates into superb radar resolution, which has the ability to differentiate between closely spaced targets. This high resolution is obtained even through lossy media such as foliage, soil and wall and floor of the buildings. Other advantages of UWB short pulses are immunity to passive interference (rain, fog, clutter, aerosols, etc.) and ability to detect very slowly moving or stationary targets (Luna, 2004). UWB antennas arrays are especially important to have both fine range and angular resolution in radars.

In radar cross-section (RCS) range, a single UWB antenna replaces a large set of narrow band antennas that are normally used to cover the whole frequency band of interest. UWB signals enable inexpensive high definition radar. Radar will be used in areas currently unthinkable such as; automotive sensors, smart airbags, intelligent highway initiatives, personal security sensors, precision surveying, and through the wall public safety application (Siwiak and McKeown, 2004).

Operation of vehicular radar in the 22 to 29 GHz band is permitted under the UWB rules using directional antennas on automobiles. These devices are able to detect the location and movement of the objects near a vehicle, enabling features such as near collision avoidance, improved air bag activation and suspension systems that better respond to road conditions (Siwiak and McKeown, 2004).

Positioning Systems

For Global Positioning Satellite System (GPS), location and positioning requires the use of time to resolve signals that allow position determination to within tenths of meters. Greater accuracy is enhanced with special techniques used. Since there is a direct relationship between bandwidth and precision, increasing bandwidth will also increase positional measurement precision. With UWB techniques extremely fine positioning becomes feasible, e.g., sub - centimeter and even sub-millimeter (Fontana, 2000). In satellite communications where wide band feeds save space and weight by supporting many communication channels with just one antenna. Therefore, the emission of UWB will greatly boost the performance of intrusion detection radar precision geo-location systems, proximity fuses and secure ground communications for troops which far outweigh the impact of UWB may have on other systems.

UWB over Wires

UWB technology is also delivered over wire lines and cables. This could effectively double the bandwidth available to cable television (CATV) systems without modification to the existing infrastructure. Over wire technology for coaxial cable provide up to 1.2 Gbps down-stream and up to 480 Mbps upstream of additional bandwidth, at low cost, on differing CATV architectures. The wire-line UWB technology does not interfere with or degrade television, high speed internet, voice or other services already provided by the CATV infrastructure (Siwiak and McKeown, 2004).

UWB Architecture

UWB transmission architecture is carrierless, which implies that data is not modulated on a continuous waveform with a specific carrier frequency, as is the case in narrowband and wideband technologies. Carrierless transmission requires fewer RF components than carrier-based transmission. Thus, UWB transceiver architecture is significantly simpler and thus cheaper to build. Despite the single named used for the ultra-wideband (UWB) transmissions, there are two architectural concepts in the design of UWB technology: The Carrier free direct sequence (DS-UWB) ultra wideband technology and the multi-band orthogonal frequency division multiplex (MB-OFDM) ultra wideband technology.

DS-UWB: Direct sequence format for ultra wideband is often referred to as an impulse, base band or zero carrier technology. This form of ultra-wideband technology entails the transmission of a series of impulses. Due to the very short duration of the pulses, the spectrum of the signal occupies a very wide bandwidth.

MBOFDM – UWB: This design which is based on multiband architecture uses a wide band or multiband orthogonal frequency division multiplex (MB-OFDM) signal at 500 MHz bandwidth. The 500 MHz signal is thereafter hopped in frequency to enable it occupy a sufficiently high bandwidth. The unique attributes of this architecture include high spectral flexibility and resiliency to RF interference and multipath effects.

Benefits of UWB Technology

Benefits of UWB technology are derived from its unique characteristics that are the reasons why it presents more eloquent solution to wireless broadband than other technologies (Oppermann et al, 2004). Table 1 shows the main advantages and benefits of UWB systems over narrowband wireless technologies.

Table 1: Advantages and Benefits of UWB Communication.

Advantage	Benefit
Coexistence with current narrowband and wideband radio services.	Avoids expensive licensing fees.
Large channel capacity.	High bandwidth can support real-time high-definition video streaming.
Ability to work with low SNRs.	Offers high performance in noisy environments.
Low transmit power.	Provides high degree of security with low probability of detection and intercept.
Resistance to jamming.	Reliable in hostile environments.
High performance in multipath channels.	Delivers higher signal strengths in adverse conditions.
Simple transceiver architecture.	Enables ultra-low power, smaller form factor, and better mean time between failures, all at a reduced cost.

CONCLUSION

This paper presented the unique features of ultra-wide band (UWB) technology which include wide bandwidth, high data rate, fading robustness, coexistence, high precision ranging and the ultra-short nature of electrical impulses used for signal generation. Benefits of UWB technology as derived from its unique characteristics includes: license free, high bandwidth, high degree of security, high resistance to jamming, simple transceiver architecture and accurate position location and elimination of multipath interference due to ultra-short pulse width of the UWB signals.

UWB technology is currently being deployed in short range wireless communication systems (e.g. WSN, WPAN, etc.), tracking, positioning and active RFID applications. While UWB is still the subject of significant debate on the drawbacks associated with the technology amongst which are low transmit power due to regulatory constraint and long synchronization resulting on the complexity in system design. These notwithstanding, there is no doubt that the UWB technology is capable of achieving very high data rates and is a viable alternative to existing technology for WPAN; short range, high data rate communications; multi-media applications, cable replacement and wireless sensor networks.

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