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# UWB Technology for WSN Applications

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## 1. Introduction

Ultrawide band (UWB) technology has been recognized as a feasible technology for wireless sensor networks (WSNs) applications due to its very good time-domain resolution allowing for precise location, tracking, coexistence with existing narrowband systems (due to the extremely low power spectral density) with low power and low cost on-chip implementation facility. Sensor Nodes (SN) that builds the backbone of such networks is normally micro controller based small devices. As batteries normally supply powers to these nodes that can only provide relatively small and limited processing capabilities. As a result, a number of UWB-based sensor network concepts have been developed both in the industrial and the government domain. For UWB devices, there are three independent bands i.e. the sub-gigahertz band (250–750 MHz), the low band (3.1–5 GHz), and the high band (6–10.6 GHz). Each UWB band has a single mandatory channel and devices that operate independently of the other band. Here, emphasis given on the low band of UWB (3.244-4.742 GHz) that is based on spread spectrum technique for WSN applications. The main feature of the system is the design simplicity having the advantage of using simple binary modulation technique and non-coherent detection scheme. Simulation result shows that, the pulse repetition coder has significant impact on performance as well as controlling data rates and reliable reception. Moreover, data is successfully recovered by an energy detection method (detect and avoid), which facilitates design simplicity at the receiver by avoiding pulse synchronization and coherent detection. We have also analyzed pulse repetition coder in conjunction with spread spectrum technique that facilitates robust and low power transmission system design. The remaining part of this chapter briefly discusses the feasibility of UWB for WSN as a physical layer communication system and then describes the UWB system design, transmission and reception process as well as performance analysis.

## 2. Applications and overview of WSNs

WSN can be used for many different applications and generally be deployed in an ad hoc manner without stringent advance planning. Therefore, they must be able to organize

themselves to form viable single-hop or multi-hop wireless communications networks. After deployment, sensor nodes detect environmental changes and report them to other nodes over their flexible network architecture. Sensor nodes are excellent for deployment in hostile environments, over small, or even large, geographical areas. A WSN is usually deployed on a global scale for information sharing; over a battle field for military surveillance and inspection, in emergent environments for search and rescue, in factories for condition based maintenance, in building for infrastructure health monitoring, in homes to realize smart homes, or even in bodies for patient monitoring. One can retrieve required information from the network by injecting queries and gathering results from the sink. A sink acts like an interface between users and the network. In addition, monitoring environmental conditions extend to irrigation, chemical or biological detection, precision agriculture, forest fire detection, flood detection, bio-complexity mapping of the environment, and pollution study etc. To ensure long-term sustainable economic growth, it is essential to efficiently monitor our environment as well as resources (Land, water etc.). By monitoring the environment we can also protect the environment and people from toxic contaminants that can be released into a variety of sources including air, soil and water from variety of sources.

A WSN is simply defined as a large collection of sensor nodes. Each node equipped with its own sensor, processor and radio transceiver reported by Azim et al (2008). Such networks have substantial data acquisition and processing capabilities that deployed densely throughout the area to monitor specific environmental phenomena. In a multi-hop sensor network, communicating nodes are linked by a wireless medium. To enable global operation of these networks, the chosen transmission medium must be available worldwide. The communication device is used to exchange data between individual nodes. Radio frequency (RF) based communication is commonly used for most WSN applications. The expected feature should be relatively long range, high data rate communications with acceptable error rates at a low energy expenditure that does not require line of sight between sender and receiver. For actual communication, both the transmitter and a receiver are required in a sensor node but can be further optimized to a full or reduced function device as proposed by ZigBee. Generally, each node of a WSN system comprises a transceiver unit, which is in charge of the wireless communication with other nodes. The essential task is to convert a bit stream coming from a micro-controller and convert them to and from radio waves. Recent advancement in wireless communications and electronics has enabled the development of low-cost sensor networks. The IEEE 802.15.4 standard and Zigbee wireless technology are designed to satisfy the market's need for a low-cost, standard-based and flexible wireless network technology, which offers low power consumption, reliability, interoperability and security for control and monitoring applications with low to moderate data rates. The key requirements for transceivers in sensor networks are given in ZigBee discussed by Zhang J, et al (2009).

- Low cost: Since a large number of nodes are to be used, the cost of each node must be kept small. For example, the cost of a node should be less than 1% of the cost of the product it is attached to.
- Small form factor: Transceivers' form factors (including power supply and antenna) must be small, so that they can be easily placed in locations where the sensing actually takes place.

- Low energy consumption: A sensor usually has to operate for several years with no battery maintenance, requiring the energy consumption to be extremely low. Some additional requirements are needed to make the wireless sensor network effective. To evaluate the energy consumption behavior of a radio transceiver, the following parameters need to be considered such as the modes of operation, duty cycle and models for the energy consumption per bit for both sending and receiving. In principle, the sources of energy consumption are RF signal generation, which depends on modulation scheme and target distance as well as on the transmission power (power radiated by the antenna) and the necessities of electronic component for RF front end, amplifier, filter etc.
- Robustness: Reliability of data communication despite interference, small-scale fading, and shadowing is required so that high quality of service (e.g., with respect to delay and outage) can be guaranteed.
- Variable data rate: UWB provides variable data rate although the required data rate for sensor networks is not as high as multimedia transmissions, low data rate is adequate for simple applications while some other applications require moderate data rates.
- Heterogeneous networking: Most sensor networks are heterogeneous, i.e., there are nodes with different capabilities and requirements. In a typical heterogeneous network, clusters are formed around some more capable nodes, usually selected as cluster head (CH), which are responsible for communicating with the sink and the low capability nodes which perform the data collection task, are only responsible for forwarding data to the CH.

## 3. WSN physical layer and feasibility of UWB

In 2004, the IEEE established the standardization group IEEE 802.15.4a, with the mandate to develop a new physical layer (PHY) for applications such as sensor networks. This UWB PHY provides variable data rates such as: 110 kb/s, 1.70 Mb/s, 6.81 Mb/s, 27.24 Mb/s. In 2005 Reed reported that UWB technology could deliver a large amount of data with low power spectral density (PSD) due to the modulation of extremely narrow pulses. The brief duration of UWB pulses spreads their energy across a wide range of frequencies from near DC level to several GHz. By spreading the energy, UWB signal shares the frequency spectrum with existing radio services. Figure 3.1 illustrates the overlay of UWB devices with some existing radio services, based on the FCC approved emission limits for UWB signals. The UWB signal can be seen as random noise to the IEEE 802.11 WLAN signal whose bandwidth is 22 MHz. The bandwidth of the WLAN interference signal is only a small fraction of the UWB signal bandwidth that means UWB system has robust noise performance. The transmitted average power of the UWB signal is extremely low. Therefore the WLAN and WPAN systems can coexist in the same 2.4 GHz ISM band. Recently, most wireless sensor networks relied upon narrowband transmission schemes such as direct sequence or frequency hopping along with multiple access techniques. Compared to narrowband systems, UWB has several advantages. UWB spreads the transmit signal over a very large bandwidth (typically 500 MHz or more). Due to the combination of wide bandwidth and low power, UWB signals have a low probability of detection facility. Additionally, the wide bandwidth gives UWB excellent immunity to interference from narrowband systems as well as from multi-path effects. FCC regulations limit UWB devices to low average power in order to minimize interference that enables UWB coexists with narrowband systems.
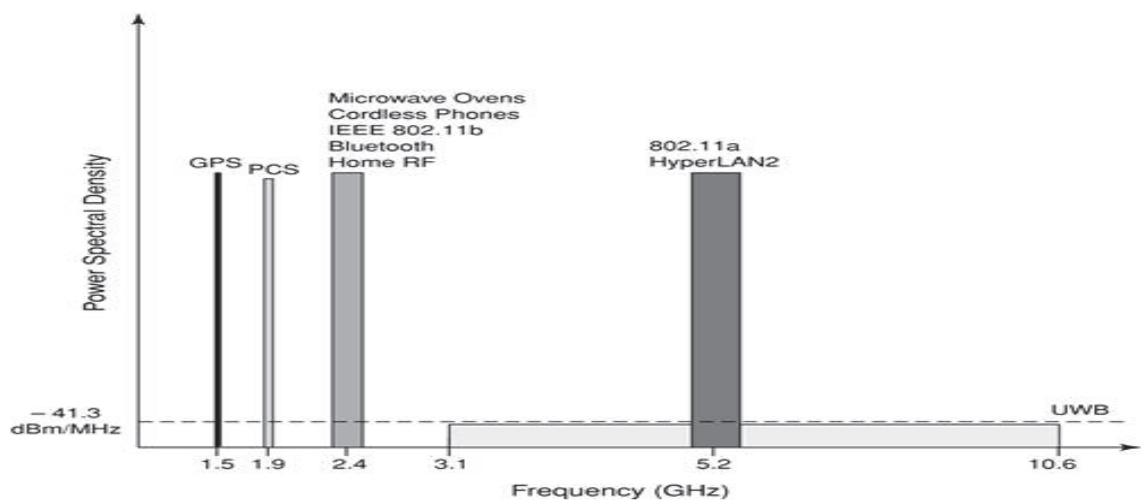
Fig. 3.1. UWB spectrums with some existing radio services (Source: IEEE 802.15).

The PHY is an essential component in any computer network. It is generally used for data transmission and reception, channel sensing, link quality determination, channel selection etc. The UWB PHY was specifically designed to provide enhanced robustness for LR-WPAN applications like WSN. The IEEE 802.15 LR-WPAN specification (2007) is designed to provide robust performance in data and communication system while leveraging the unique capability of UWB waveforms to support precision ranging between devices. The UWB PHY design is intended to make use of the wide bands of spectrum available for UWB operation around the world. The LR-WPANs can operate in multiple independent license-free bands and can be implemented in a single band or multiple bands. In August 2007, IEEE 802.15.4a was released expanding the four PHYs available in the earlier 2006 version, including one PHY using Direct Sequence UWB and another using Chirp Spread Spectrum (CSS). The UWB PHY is allocated frequencies in three bands e.g. below 1 GHz, between 3 to 5 GHz, and between 6 to 10 GHz. The CSS PHY is allocated spectrum in the 2450 MHz ISM band. This standard defines the protocol and compatible interconnection for data communication devices using low data rate, low power and low complexity as well as short-range radio frequency (RF) transmissions within the WPAN. DS-UWB is spectrally efficient that has precision ranging capability. The CSS PHY was added to the standard because it supports communications to devices moving at high speeds and at longer ranges than any of the other PHYs in the IEEE 802.15.4 standard. Basically both new PHYs added scalability to data rates, longer ranges, and lower power consumption into the standard and hence meet the intent of the IEEE 802.15 standard to emphasize very low cost communication system. Table 3.1 represents the standards and technology trend of WPAN technologies.

In 802.15.4a, the UWB PHY layer, which includes modulation, coding, and multiple access schemes, has been designed to achieve optimum performance for WSN applications. At present, Zigbee technology is used as a communication standard for wireless personal area networks like sensor network. UWB technology is more suitable for WSN because it is recommended by the IEEE 802.15.4 standard of Low-Rate Wireless Personal Area Networks (LR-WPANs) that provides low complexity, low cost and low power wireless connectivity among inexpensive devices. The IEEE 802.15.4 specifications according to its upper layers were developed under the ZigBee alliance (a consortium formed in 2002). This standard deals with two PHYs i.e. 868/915 MHz PHY and 2450 MHz PHY where both use the DSSS modulation scheme. This communication standard will be tailored for low power, low data

rate, secure wireless communication in the US and European ISM bands. The IEEE 802.15.4/Zigbee technology is specified with a wide range of low-power features at physical and higher levels. The operational power-saving features include low duty cycle operation together with strict power management and low transmission overhead. The implementation of standard-compliant radio-on-a-chip is mainly governed by the PHY specification. The main parameters of the IEEE 802.15.4 PHY are summarized in IEEE 802.15.4a standard (2007). The 2.4 GHz PHY of the IEEE 802.15.4 standard attracts a lot of focus from the wireless industry because the globally available 2.4 GHz ISM band with the largest bandwidth promotes world wide market and flexibility of application design. The IEEE 802.15.4a Task Group has developed an UWB based PHY standard for short-range networks with a precision ranging capability that is optimized for low data rate application. Therefore, comparing to narrow band signals, UWB signal has the advantage of high data throughput, fine range resolution that enables location-aware wireless networking. Moreover, UWB communication system is inherently secure. Since the power density of UWB signals is usually below the environmental noise due to FCC emission limit (i.e. -41 dBm) and with DSSS, signal energy becomes very low which facilitates low probability of detection as well as interference with other radio operating in the same frequency band is negligible. UWB impulse radio is carrier less, so it has only base band processing and no intermediate frequency (IF) processing. This makes impulse radio devices much cheaper than other communication devices.

| WPAN (IEEE) | Technology | Data rate | Distance |
|---|---|---|---|
| IEEE 802.15.1 | Bluetooth | 1 Mbps | 10m (Class 3) 100m (Class 1) |
| IEEE 802.15.2 | Coexistence Mechanisms between WLAN and WPAN | | |
| IEEE 802.15.3 | High Rate WPAN (UWB) | 22, 33, 44, 55 Mbps | 30-50m |
| IEEE 802.15.3a | Alternate 15.3 PHY | >100 Mbps | 10m |
| IEEE 802.15.4 | Low Rate WPAN(ZigBee) | 250 Kbps | 1-100 m |
| IEEE 802.15. 4a | Low Rate Alternative PHY of 802.15.4 (UWB) | 5 Mbps | <1000 m |
| IEEE 802.15.4b | Revisions and Enhancements IEEE 802.15.4 | | |

Table 3.1. Standards and technology trend of WPAN

## 4. UWB system design

In recent years, there are a number of implementations of UWB system, such as impulse radio approaches using pulse-position modulation (PPM), binary phase-shift keying (BPSK) modulation, pulse-amplitude modulation (PAM) as well as frequency based approaches using pulsed orthogonal frequency division multiplexing (OFDM) etc. The UWB system can be implemented in a carrier less fashion due to the absence of modulating carrier frequency while conventional narrowband and wideband systems use RF carriers to move the signal from base band to the actual carrier frequency where the system is allowed to operate. So the data transmission as digital pulses substantially simplifies the transceiver circuitry as

compared to a traditional RF radio system. The proposed DS-UWB transmitter is shown in Figure 4.2 and the receiver in Figure 4.3, which is simplified greatly as a simple energy detection method reported by Azim et al (2008).
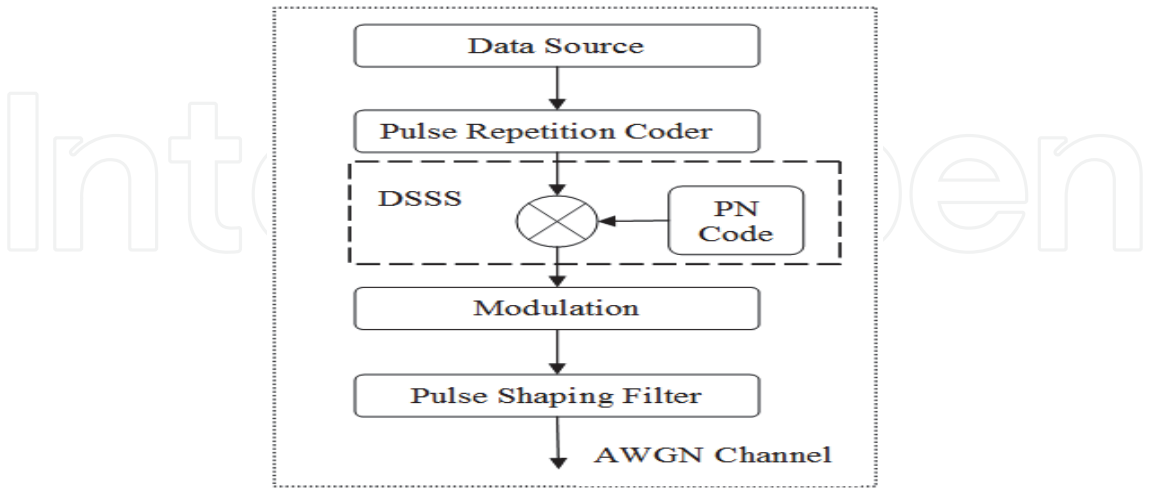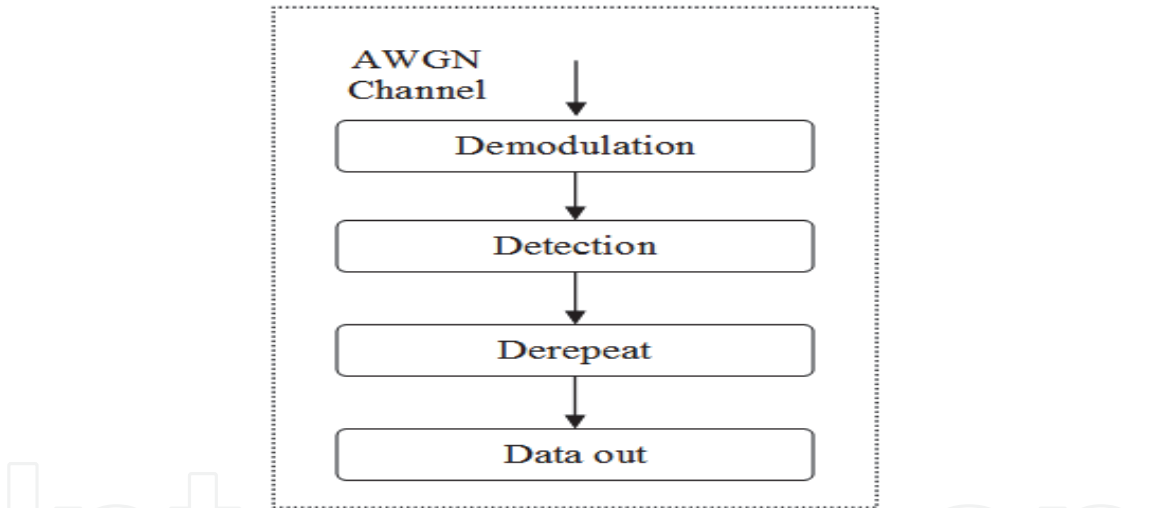


Fig. 4.2. DS-UWB transmitter.



Fig. 4.3. DS-UWB energy detection receiver.

### 4.1 UWB signal

The FCC rules provide the following definitions for UWB operation:

a.  *UWB bandwidth*: The UWB bandwidth (3.244-4.742 GHz or 5.944-10.234 GHz) is the frequency band bounded by the points that are 10 dB below the highest radiated emission.

b.  *Center frequency*: The center frequency, $f_C$, equals $(f_H + f_L)/2$.

c.  *Fractional bandwidth*: The fractional bandwidth equals $2(f_H - f_L) / (f_H + f_L)$ and fractional bandwidth equal to or greater than 0.20 and occupies more than 500 MHz of spectrum.

d.  *EIRP*: Equivalent isotropic radiated power not greater than -41 dBm or 560 micro-watts.

To generate the UWB signal based on the FCC rules, the following parameter shown in Table 4.1 is considered and simulation performs using matlab.

| SN | Parameter | Value | Unit |
|---|---|---|---|
| 1. | Pulse width (Pw) | 1.3358e-009 | Sec |
| 2. | Pulse repetition period (Tp) | 2.0035e-009 | Sec |
|  | Pulse repetition frequency, Tf = 1/Tp | 4.9913e+008 | Hz |
| 3. | Lower frequency(fl), Fl = fc-(1/pw) | 3.2444e+009 | Hz |
| 4. | Higher frequency(fh), Fh = fc+(1/pw) | 4.7416e+009 | Hz |
| 5. | Centre frequency(fc)=(fh+fl)/2 | 3.9930e+009 | Hz |
| 6. | Bandwidth(Bw) = fh-fl | 1.4972e+009 | Hz |
| 7. | Fractional bandwidth(fb)=2(fh-fl)/(fh+fl) | 0.3750 | ---- |
| 8. | Sampling frequency(fs)=fc*3 | 1.1979e+010 | Hz |
| 9. | Duty cycle (dc) =Pw/Tp*100 | 66.6733 | ---- |
| 10. | Number of pulse per bit (Ns) | 4 | ---- |
| 11. | Length of PN code or chip rate | 11 | ---- |
| 12. | Eb/No | 5 | dB |
| 13. | Coding rate (N = fs/f_chip) | 1.0890e+009 | Hz/Sec |
| 14. | Average transmitted power in dBm | -30 | dBm |
| 15. | Average transmitted power in watt | 1.0000e-006 | Watt |
| 16. | Energy per pulse (Ex) | 2.0035e-015 | Jule |
| 17. | Shaping factor | 4.0000e-010 | Unit less |
| 18. | Pulse Energy after shape (E) | 3.3259e-011 | Jule |
| 19. | Energy normalization factor (E^0.5) | 5.2922e-006 | Unit less |
| 20. | Distance (d) | 1000 | Meter |

Table 4.1. Parameters value of UWB system.

*Bandwidth, bit rate and symbol rate:* Bit rate, $R_b= (N_s/P_w)$, where $N_s$ = Number of pulse per bit and Symbol rate, $T_s = (1/N_sT_p)$ where $T_p$ = pulse repetition period. In the binary case $B = R_b = T_s$ and Bandwidth efficiency can be calculated as $R_b/B$ bits per cycle. Effective bandwidth $B_s = (R_b/N)$, where $N = Log_2M$ (where $M = 2$ in the binary case), in a pulse transmission, signal bandwidth for 90% signal power $B_s = Rb$ Hz and for 95% signal power, $B_s = 2/R_b$ Hz. So depending on the system requirement reliability and accuracy can be achieved while compensating the bit rate and bandwidth utilization.

*Capacity:* In UWB system, the signal is directly modulated as impulses with a very sharp rise and fall time, thus resulting in a waveform that occupies several GHz of bandwidth. Shannon's capacity formula shows capacity increasing as a function of bandwidth faster than the SNR (signal to noise ratio), $C = Bw \times \log_2(1+SNR)$. Where, $C$ is the channel capacity (bits/sec) and $B_w$ is the channel bandwidth in Hz.

*Duty cycle (dc):* According to FCC rules, UWB signals consist of very short pulses of energy separated in times but an amount much larger than the length of the pulse. This means that the duty cycle is very low and hence provides low power consumption. The pulse width (or, pulse duration) $P_w$ is much shorter than the pulse repetition time $T_p$. So duty cycle, $dc = Pw/Tp \times 100$. This means if the duration of pulse increases, the duty cycle decreases and vice versa.

**4.2 Transmitter**

The first step is to design an information source. Here, we consider the bits "*10110010*". Secondly, A repetition code represents the simplest type of linear block code where a single message bit is encoded into a block of identical *n* bits, producing *(n, 1)* block code. This is exercised by means of forward error correction method and acts as a channel coder. Generally the channel coder accepts message bits and adds redundancy according to prescribed rule and exploits the redundancy to decide which message bit was actually transmitted at the receiver end. In our simulation model, repeat bit is the channel encoder and de-repeat bit is the channel de-coder. The goal is to minimize the effect of channel noise. In UWB system we emphasize on reliable transmission than the bandwidth utilization, since we have more bandwidth as required and sensor network needs lower data rates. Therefore, we can adjust the pulse repetition frequency ($T_f$) to control data rates as required as well as to increase the number of pulse per bit ($N_s$) provides a lower bit rate, while the redundant pulses improve the processing gain.

*Spread spectrum and modulation:* The spread spectrum is a means of transmission in which the data of interest occupies a bandwidth in excess of the minimum bandwidth necessary to send the data. In DSSS technique two stage modulations are used reported by Haykin (2006). First the incoming data sequence is used to modulate a wideband code that transform the narrowband data sequence into a noise like wideband signal. The spectrum spreading is accomplished before transmission by using a code sequence that is independent to the data sequence. Usually the same code (PN code) is used in the receiver to de-spread the received signal. But in our system only the length of code is used to estimate the transmitted bits. PN code or chip code spreading the signal bandwidth and its time duration, $T_c$ is called chip interval. So, chip rate, $R_c = 1/T_c$ and corresponds to the bandwidth $B_w$ of the transmitter signal is used to make wideband signal. Where $B_w>>B_s$ and $B_s$ is the signal bandwidth. The PN code usually $\pm 1$'s sequence is generated at a rate $R_c = N_s/T_p$ bits/s. The ratio of the bit interval $P_w$ to the chip interval ($T_c$) is usually selected to be an integer in practical spread spectrum system. We consider single user point-to-point communication but in multi-user case DS-CDMA can be used. In our system PN sequence is [-1 -1 1 1 -1 1 1 -1 1 1 1] generated by randsrc (f_chip,1,[1,-1; .6,.4]) , where f_chip is the length of PN code. Figure 4.4 shows signal amplitude after spreading.
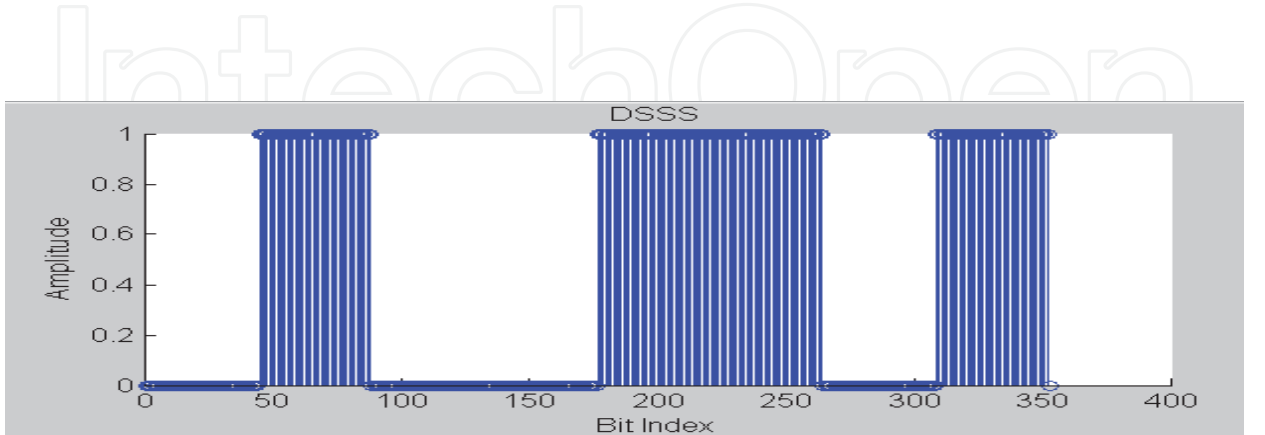


Fig. 4.4. Spreading signal amplitude.

Due to the PN code having a higher rate than the information signal, there will be several chips representing a single information symbol. This adds redundancy to the signal and employs a processing gain due to the increase in the signal bandwidth. It facilitates to resist interference effects and enable secure communication in a hostile environment such that the transmitted signal cannot be easily detected or recognized by unwanted listeners. We consider single user, point-to-point UWB operation. But for multiple users, spread spectrum can be used as a multiple-access communication system where a number of independent users are required to share a common channel without an external synchronizing mechanism. Here DSSS technique is used prior with modulation, which greatly reduced the noise sensitivity (i.e. noise immunity). Spreading creates a lower power spectral density than the original signal; however the total transmitted power remains the same. This allows the SNR of the signal to be below the noise floor level. It has several advantages for the system, as the signal will be less likely to interfere with other users on the same spectrum. Also other unauthorized users are unable to detect the signal, as the signal amplitude will appear as a slight increase in noise, so adds security to the system.

*Modulation format:* In this UWB system lower order modulation format is used for the transmission of sensor information. Table 4.2 shows the BPSK and PAM modulation format discussed by Haykin (2006).

| Polarity of data sequence b(t) at time t | | + | | - | |
|---|---|---|---|---|---|
| | | PSK | PAM | PSK | PAM |
| Polarity of PN sequence c(t) at time t | + | 0 | 1 | $\pi$ | -1 |
| | - | $\pi$ | -1 | 0 | 1 |

Table 4.2. BPSK and BPAM modulation format.

*Pulse shaping:* The choice of the pulse is critical as its impulse response affects the PSD of the transmitted signal. Zeng (2005) has proposed several UWB pulse shapes where Gaussian pulse is more suitable for UWB transmission. To increase the derivative of the pulse, the relative bandwidth decreases while the center frequency increases for a fixed value of pulse width. The N$^{th}$ order Gaussian pulse can be generated by

$$p(t) = A \frac{(2\pi f \sigma)^{10} e^{-(2\pi f \sigma)^2}}{n^n e^{-n}}$$ and Figure 4.5 shown different pulse shapes. We used

Gaussian doublet (2nd order Gaussian pulse) because it is the most currently adopted pulse that meet the appropriate UWB operation with regulation explained by Benedetto

and Giancola (2004), which is usually generated by the equation. $p(t) = (1 - 4\pi \frac{t^2}{pw^2})e^{-\frac{2\pi t^2}{pw^2}}$

Here *p(t)* is a Gaussian pulse (Gaussian doublet) where pulse duration or width is much smaller than pulse repetition period, i.e. $T_p >> P_w$, so it can produce low duty cycle operation.
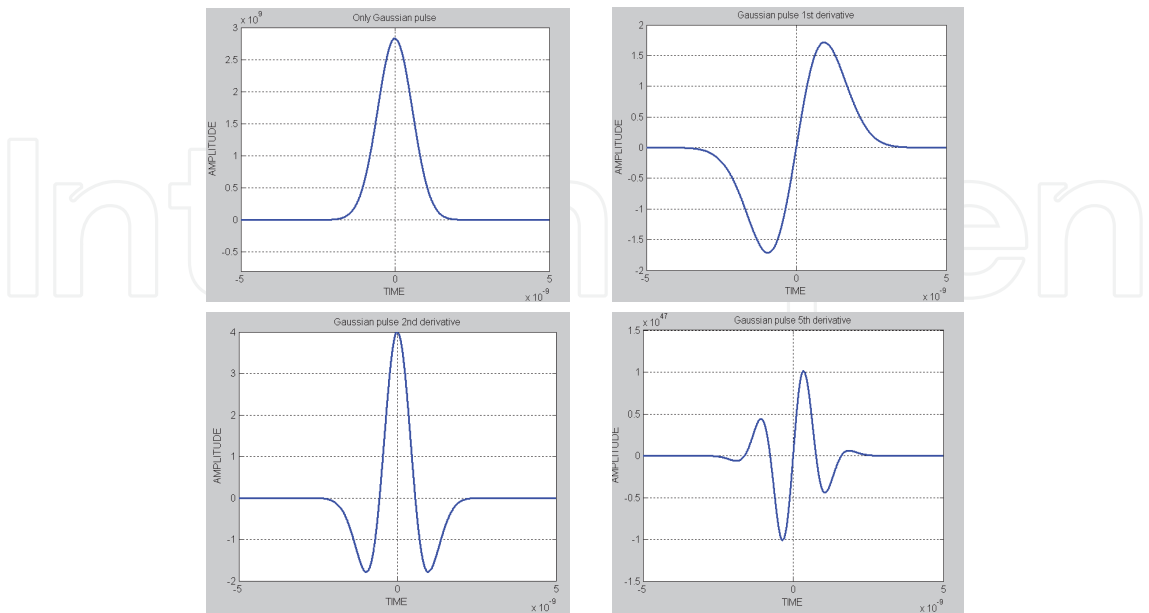
Fig. 4.5. Gaussian pulse shape.

The output of the modulator enters the pulse shaper filter, which acts as a low pass filter and after convolution operation between the modulated data and Gaussian pulse. Signal amplitude is shown for BPSK and BPAM in Figure 4.6 and transmitted pulse after shaping is shown in Figure 4.7.
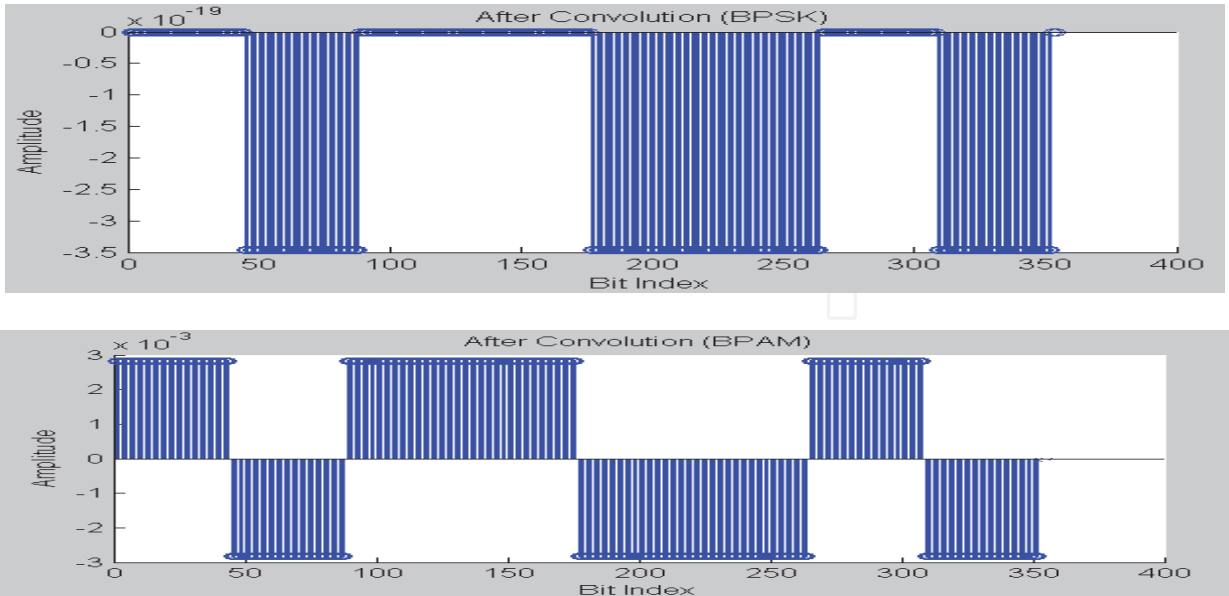


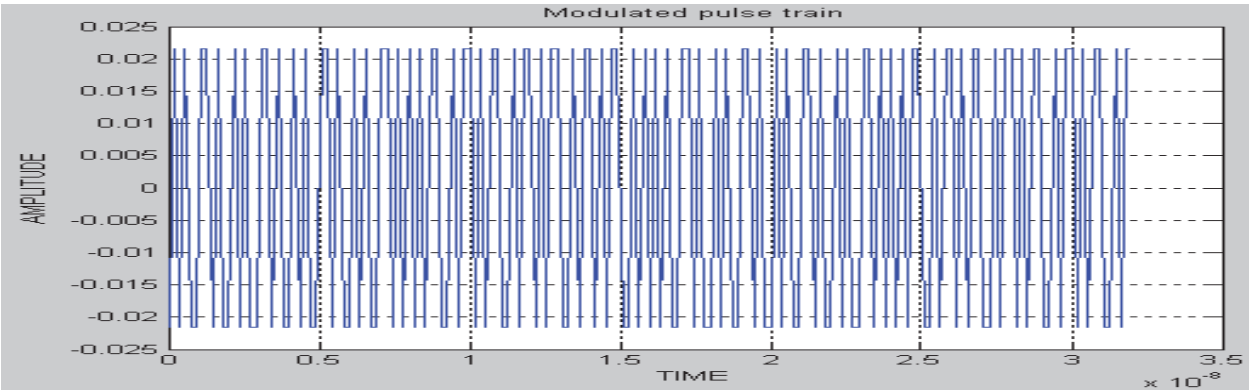Fig. 4.6. Transmitted signal amplitude (BPSK & BPAM).

Fig. 4.7. Transmitted pulse train after shaping.

## 4.3 Channel

The UWB radio signal is ideally composed of a sequence of pulses that do not overlap in time. Each pulse is confined within a specific time interval and the pulse itself has finite duration. The received signal can be expressed as $r(t) = s(t)+n(t)$, $0 \leq t \leq T$. where $n(t)$ denotes a sample function of the additive white Gaussian noise (AWGN) process with power spectral density of $N_0/2$ W/Hz. Here single user point-to-point communication system is considered with the absence of inter symbol interference (ISI) and multi-user interference (MUI) phenomenon. Figures 4.8 and 4.9 show the channel output of BPSK and BPAM respectively.
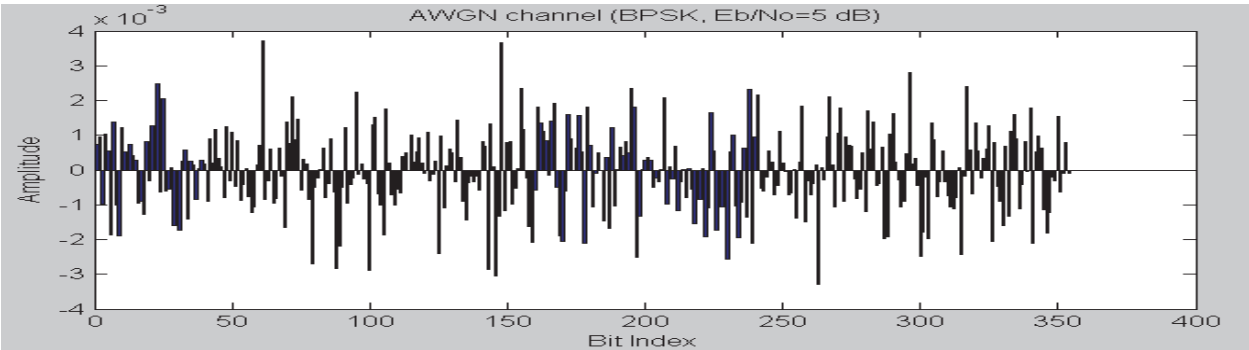


Fig. 4.8. AWGN channel output (BPSK), where Eb/No=5 dB.
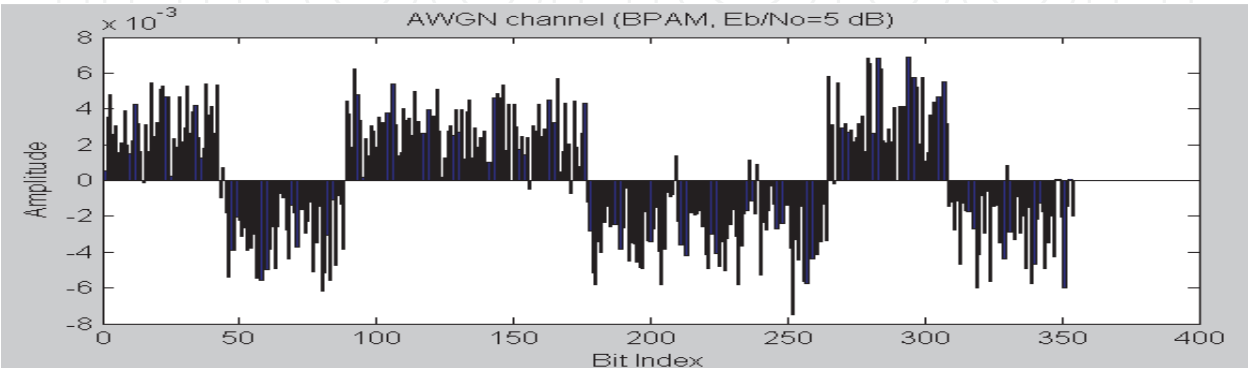


Fig. 4.9. AWGN channel output (BPAM), where Eb/No=5 dB.

The BPSK output shown in Figure 4.8 is more noise like and undetectable comparing to BPAM output shown in Figure 4.9. The probability of error depends on the modulation scheme and Signal to Noise Ratio (SNR). The performance of the impulse radio signal over the AWGN channel can be realized with the BER performances as shown in Figure 4.10 and 4.11, where number of pulse per bit is one and four, while different modulation technique is used. In the DS-UWB propagation through AWGN channel, transmitted pulses are delayed and attenuated due to thermal noise, but multi path effect, ISI and MUI were not considered. Here by increasing the number of pulses per bit ($N_s$), the received energy is increased by a factor $N_s$, without increasing the average transmitted power ($P_{av}$). To increasing the number of pulses per bit we can achieve better SNR performance.
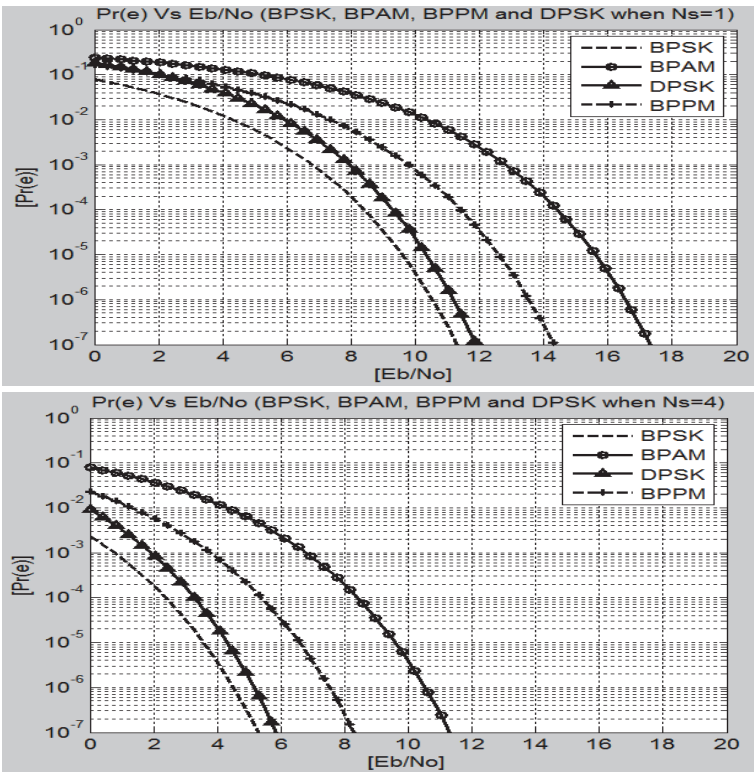


Fig. 4.10. BER performance BPSK, BPAM, DPSK, BPPM (*Ns=1, 4*).
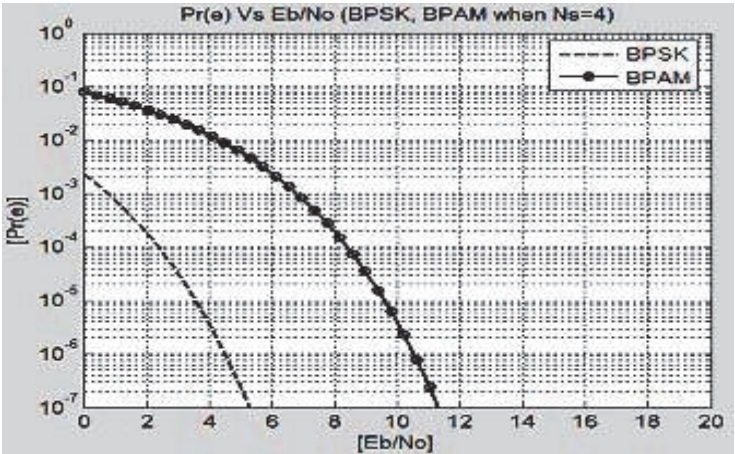
Fig. 4.11. BER performance BPSK, BPAM (*Ns*=4).

## 4.4 Receiver

At the receiver shown in Figure 4.3, de-modulation operation is performed with the noisy signal. The constellation diagram is shown in Figure 4.12 and the signal after demodulation is shown in Figure 4.13. The received signal is successfully recovered by using an energy detection method. A sample of matlab code for detection is shown in Figure 4.14.
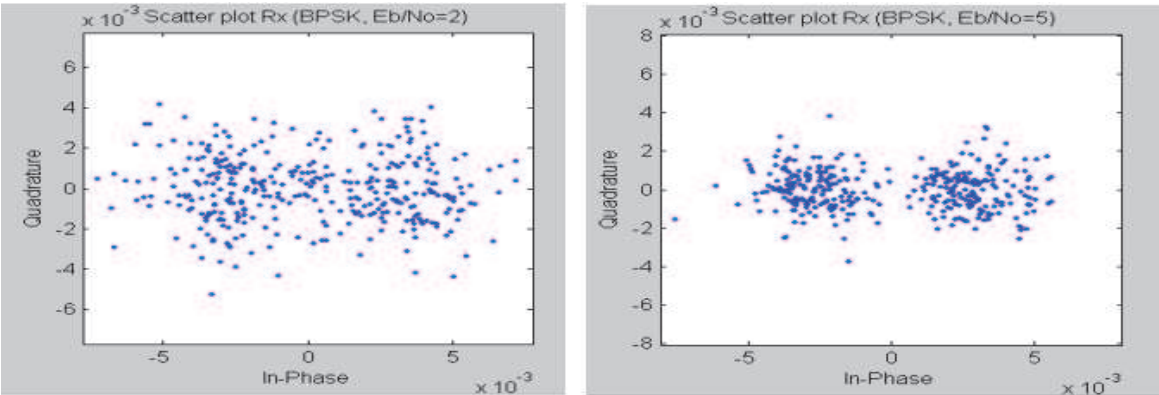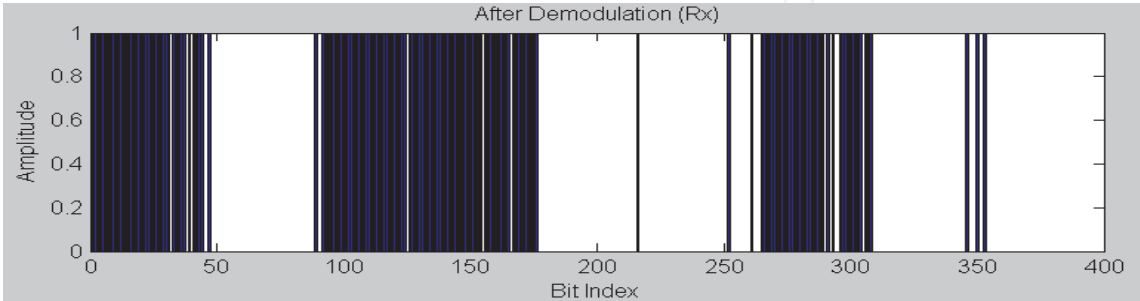


Fig. 4.12. Received signal constellation (BPSK, Eb/No=2, 5)



Fig. 4.13. Received signal amplitude after demodulation.

The decision is obtained by applying a simple majority criterion. Given the number of pulses falling over a threshold and comparing this number with the number of pulses falling below the same threshold, the estimated bit corresponds to the higher of these two numbers. An error occurs if more than half of the pulses are misinterpreted. So this decision factor achieves accurate reception and by increasing the number of pulses per bit provides more efficiency. The length of PN code ( f_chip ) is used to correlate with the received bits after demodulation while f_chip/2 decision metrics provides the estimated repeat bits at the receiver shown in Figure 4.15. Finally $N_s/2$ decision threshold facilitates to recover bits in the de-repetition process, which are compared to the transmitted bits for error estimation. For large number of transmitted data, no error is found as shown successfully by the simulation results.

```
%Detection
 j=1;
 for i = 1:length(tx_repbits)
    sum=0;
    for k = j:j+f_chip
       sum=sum+rx_demod(k);
    end;
    if (sum >=f_chip/2)
       msg_rep(i)=1;
    else
       msg_rep(i)=0;
    end;
 j = f_chip*i+1;
 end;
```
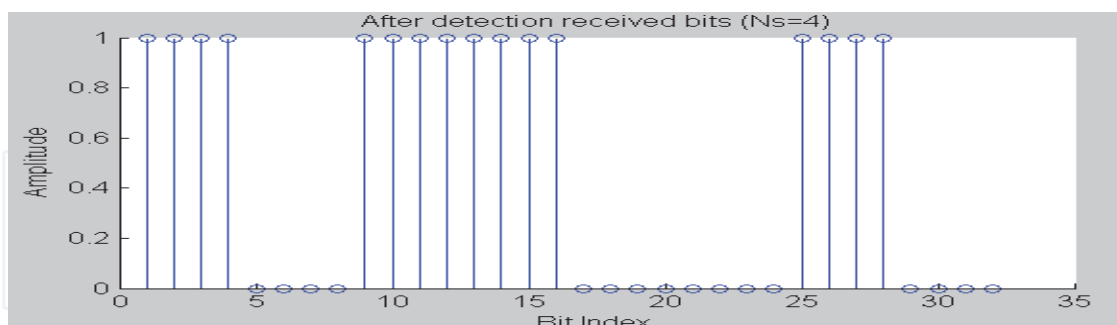
Fig. 4.14. Detection code.



Fig. 4.15. Output after detection (*10110010*), *Ns = 4.*

The proposed transceiver model is efficient and ensures reliable transmission, so it is suitable for sensor network communication system. Here, by increasing the number of pulses per bit (*Ns*), the received energy is increased by a factor Ns, without increasing the average transmitted power but at the same time compensating the bit rate of dividing by *Ns*. Data is successfully recovered by energy detection technique (detect and avoid), which facilitates the design simplicity at the receiver by avoiding pulse synchronization and coherent detection. Moreover having 50% of data corruption during the propagation, the system still recovers the bit stream accurately $(Ns/2, bit=8, Tx \ bit=8\times 4, Sum> Ns/2)$. Also

power emission and consumption are very low .(Power = 794 µW and Energy per pulse = 280 nW).So it's a noise like signal, which is difficult to detect by unwanted user and immune to interference with other existing radio operating in the same band.

## 5. Summary

UWB technology is feasible for the implementation of sensor networks as it offers high robustness to interference and provides low complexity receivers and transmitters with low energy consumption. The IEEE 802.15.4a standard enables UWB-based sensor networks, which offer a high degree of flexibility and includes modulation, coding, and multiple access schemes that permit non-coherent receiver design. The specification for UWB LR-WPAN devices incorporates a number of optional enhancements to potentially improve performance, reduce power consumption and enhance coexistence characteristics. In particular, DS-UWB is a suitable communication platform for wireless sensor networks where accuracy and reliability is more important factor than bandwidth utilization. Due to the ability of noise immunity and low probability of detection and interference rejection, DS-UWB is a good choice for wireless sensor networks. Pictorial signal behavior shown in the simulation process helps to realize the above-mentioned facts. The UWB information rates as a function of transmission distance over AWGN and other channels can be considered for further development. Moreover, in future, multiple access interference on transceiver design can be investigated in a multi user environment. It might be interesting to explore the coding-spreading tradeoffs, channel estimation and design of optimum transceiver architecture.

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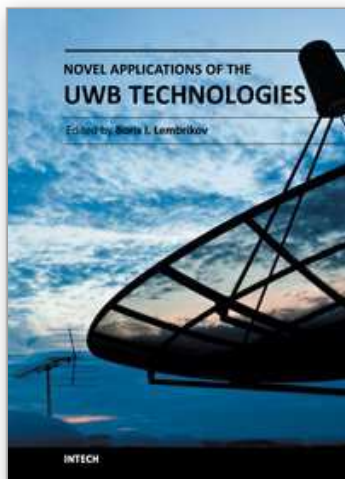
**Novel Applications of the UWB Technologies**

Edited by Dr. Boris Lembrikov

Ultra wideband (UWB) communication systems are characterized by high data rates, low cost, multipath immunity, and low power transmission. In 2002, the Federal Communication Commission (FCC) legalized low power UWB emission between 3.1 GHz and 10.6 GHz for indoor communication devices stimulating rapid development of UWB technologies and applications. The proposed book Novel Applications of the UWB Technologies consists of 5 parts and 20 chapters concerning the general problems of UWB communication systems, and novel UWB applications in personal area networks (PANs), medicine, radars and localization systems. The book will be interesting for engineers and researchers occupied in the field of UWB technology.

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