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Performance Analysis of Ultra Wideband Communication System

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Abstract - Ultra-Wideband (UWB) is a radio transmission scheme that uses extremely low power pulses of radio energy spread across a wide spectrum of frequencies. UWB has several advantages over conventional continuous wave radio communications including potential support for high data rates, robustness to multipath interference and fading. The paper covers Ultra Wide-Band technology. General description, Challenges, various modulation schemes such as OOK, PAM, PPM, and BPSK under specified Ultra Wide Band regimes: low Power spectral density, large spreading ratio and a highly dispersive channel. The capacity and BER performance of a single user ultra wideband communication is investigated for various modulation schemes and coded, uncoded methods also simulated. Fading channel like Ricean and Rayleigh are compared. Channelized digital receiver concept is discussed.

Keywords- UWB, fading, PAM, PPM, PSK, Data rate, SER, Capacity, PSD

I. INTRODUCTION

The communications industry is growing at a rapid pace. The communications corporations are searching for a way to increase the system capacity, while ensuring the bit error rate (BER) remains low. The answer that they have been looking for might now be in a new system called ultra wideband (UWB). Ultra wideband (UWB) transmission has recently received significant attention in both academia and industry for applications in wireless communications. In the near future, there will appear a demand for low-cost, high-speed, wireless links for short range (10 m) communications. Such links must support digital video transmission to be able to replace impractical cables. The ultra wideband (UWB) system with a data rate of several hundred megabits per second is a promising technique to achieve this objective. The FCC of United States in 2002 reserves the unlicensed frequency band between 3.1 GHz and 10.6 GHz for indoor UWB wireless communication systems. Industrial standards such as IEEE 802.15.3a (high data rate) and IEEE 802.15.4a (very low data rate with ranging) have been introduced. The centimeter accuracy in ranging and communications provides unique solution to applications, including logistics, security applications, medical applications, control of home appliances, search-and-rescue, and military application.[1] The FCC defines UWB signals as having a fractional bandwidth (the ratio of baseband bandwidth to RF carrier frequency) of greater than 0.2, or having a bandwidth greater than 500MHz. Here, the bandwidth is defined as 'the frequency band bounded by the points that are 10dB below the highest radiated emissions'. According to the Shannon theorem the channel capacity grows linearly with bandwidth and decreases logarithmically as the signal-to-noise ratio (SNR) decreases .This relationship suggests that the radio capacity can be increased more rapidly by increasing the occupied bandwidth than the SNR. In fact, for applications like wireless personal area networks (WPANs) that only transmit over small distances, where the signal propagation loss is small and less variable, a higher capacity can be achieved by using the large bandwidth of UWB signals.[8].UWB has four widely recognized application areas which exploit the unique properties of short pulse transmissions:(1) Multimedia communications,(2)Wireless sensor networks.(3)Bio-medical imaging and radar,(4)Positioning.

The range of applications covered indicates that UWB is much more than a wire replacement technology. UWB technology is still in the research stage and the following challenges in research and development of UWB must be resolved before it can be commercialized:
(1) Hardware: Development of circuits and elements for generating pulses having very short time intervals, UWB antennas and high-frequency circuits.
(2) Synchronization and detection: Accuracy and precision of pulse detection in spite of time displacement and channel distortion.
(3)Inter-symbol interference: Interference between pulse codes caused by the multi-path environment.
(4) Medium access control and multiple-access interference: The medium access control layer needs to operate with a dynamic interference profile from other spectrum users as well as UWB network users.
(5) Co-channel interference: The UWB spectrum under-lays a number of existing users, therefore detailed studies on the interaction between the users must be undertaken for a range of UWB operating scenarios.
(6) Pulse shaping for radio regulatory purposes: The design of the pulse will impact on the interference UWB causes to other users.
(7) Antenna arrays and beam forming: Using an antenna array for beam forming gives range extension to a communications system.
UWB is a promising technology for high-rate and short-range communications. There appears to be compelling applications that can take advantage of this for high-speed cable replacement and multimedia distribution. It has potential capacity advantages over comparable narrowband technologies at short ranges with lower integration cost and lower power consumption. Moreover, UWB has the potential to add accurate position location capability to a device. It opens up 7.5GHz of spectrum to allow for more unlicensed devices to share the same space as current licensed (cellular, GPS) and unlicensed systems (WLANs, WPANs).

II. MODULATION SCHEMES

In order to understand where UWB fits in wireless communication, we need to consider the general problems that communication systems currently face, such as high data rates, high transmit distances, high volume of data, large number of users and power consumption. It has been illustrated there is no way to achieve optimal solution at once. However, there are a number of challenges in an UWB system, such as receiver design techniques, inter-symbol interference (ISI)[11], pulse shape or Efficient Pulse Generation. There are some tradeoffs between maximum transmit distance, data rates, transmit power and complexity in different modulation schemes. Data modulation schemes used in the study are PAM, PPM, PSK and OOK[5]. OOK is the simplest modulation scheme, and its only benefit it has the lowest complexity of the considered modulation schemes. However, the tradeoff is that OOK is much more sensitive to noise. System specification is usually defined in terms of probability of symbol error (SER) rather than SNR. The relation between SNR and SER depends on the modulation schemes and levels. In this paper the performance of various UWB modulation schemes are evaluated in term of maximum power transmitter [6], data rate, maximum mutual information between source and receiver. Transmitter power is measured by integrating the fifth derivative of the power spectrum density (PSD) of the Gaussian pulse over whole bandwidth [4]. The UWB channel capacity and data rate depend on modulation schemes and channel model (propagation scenario) .But again evaluation performances of the modulation schemes depend on the specific application. E.g. if minimum complexity is important, the OOK modulation would be the choice [2]. If the Smooth PSD and power efficiency is important, then BPSK and M-PPM is the solution [3]. We will illustrate M-PPM will be the best option for the UWB communication, but still has some disadvantages [9].

III. UWB TRANSMITTER SIGNAL

A number of modulation schemes and such as PPM, PAM, PSK, OOK, may be used with UWB systems [1]. UWB communications come in one of two types – single-band and multiband. Impulse radio is a single-band system, in which the signal represents a symbol consist of serial pulses with a very low duty cycle. The pulse width is very narrow, typically in nanoseconds. This small pulse width gives rise to a large bandwidth and a better resolution of multipath in UWB channels. The multiband type of UWB modulation is multiband-based and is accomplished by using multicarrier of OFDM-based modulation with Hadamard or other spreading codes [2]. With OFDM-based modulation, system can effectively deal with delay spread or frequency selectivity of UWB channels. Prior to constructing an ultra wide band pulse, we need to determine the desired pulse shape. The most popular pulse shape for UWB communication system is the Gaussian pulse. For transmission, we usually employ the Gaussian monocycle. It is the first derivative of a Gaussian pulse. In principle, a baseband UWB pulse is carrier free; the carrier frequency is employed in here to meet the FFC's spectrum mask. The Gaussian pulse with a sinusoidal carrier with 6.85 GHz carrier frequency, we can easily obtain an UWB pulse for transmission. The Gaussian pulse can be described by:

$S_{g(t)} = e^{-2\pi(2t/.1T)2}$ Where, $T = 6.25\text{ns}$ is cycle duration.

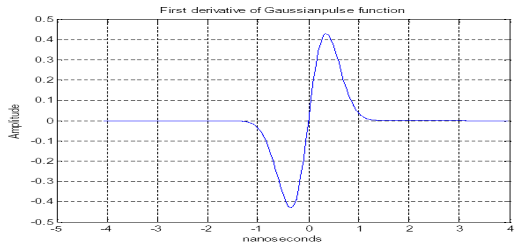

Fig 1. Gaussian monopulse.

The next step is to generate the transmitted UWB pulse. Above equation is then multiplied by sinusoidal carrier to get a bandpass UWB pulse. It is described by:

$$Suwb\ (t) = A*e^{-2\pi\ (2t/.1T)\ 2} *\sin(\omega t) \qquad E(1)$$

Where, ω=2πf, F=8.85 GHz (carrier frequency), A=0.006 V Amplitude.By adjusting the value of A, the power spectral density of the UWB pulse stream can be made to meet the FCC regulations.

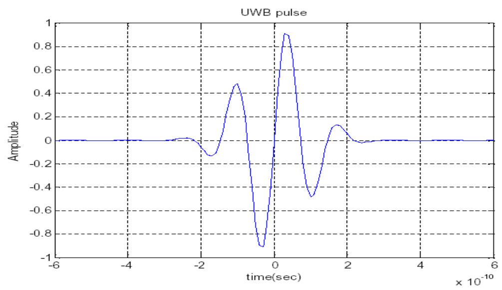

Fig 2. UWB transmitted Pulse

The regulatory limits placed on the power spectral density (PSD) of the transmitted signal affect the choice of the modulation scheme in two ways. First, the modulation technique has to be power-efficient; that is, the modulation needs to provide the best error performance for a given energy per bit. Second, the choice of a modulation scheme affects the structure of the PSD and thus has the potential to impose additional constraints on the total transmit power allowed [11]. A general UWB pulse train signal can be represented as a sum of pulses shifted in time, as shown in equation 2

$$S(t) = \sum_{K=-\alpha}^{+\alpha} a_k p(t - t_k) \qquad E(2)$$

Where, $S(t)$ is the pulse train signal; p(t) the basic pulse shape; a_k and t_k are the amplitude and time offset, respectively, of each individual pulse. By varying the values of a_k and t_k, the information can be encoded in many ways.

(1) Amplitude modulation

Pulse amplitude modulation (PAM) is based on the principle of encoding information with the amplitude of the impulses [11]. If we assume that pulses are uniformly spaced in time, we can rewrite *E(2)* as:

$$S_{AM}(t) = \sum_{K=-\alpha}^{+\alpha} a_k p(t - kT) \qquad E(3)$$

Where T is the period of pulse-spacing interval. If a_k is always different from zero, the modulation scheme is called pulse amplitude modulation. Figure 3 shows this type of modulation. The two bits, “0" and “1", are specified by a certain level of amplitude: all pulses above this level are interpreted as “1", and all below by “0".

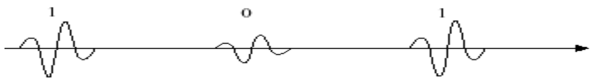

Fig. 3 Pulse Amplitude Modulated Wave (PAM)

The advantage of bipolar PAM modulation is its improvement of BER performance. The increased performance occurs because the pulse amplitude for bipolar PAM is twice as large as the pulse amplitude for OOK. Unfortunately, there are some drawbacks in using a binary PAM modulation such as complex implantation and non-periodicity. The complexity of physical implementation is increased due to polarity pulse. While using OOK modulation, only one pulse generator is needed as compared to two or more pulse generators for Binary PAM modulation. The power spectral density of this signal is the Fourier transform of the signal autocorrelation. If we assume that the pulse weights correspond to the data bits to be transmitted and the data is random, we find that the PSD is as given by

$$DSP_{AM} = \sigma^2_a/T \,|P(f)|^2 + \mu^2_a/T^2 \sum_{k=-\alpha}^{+\alpha} |P(k/T)|^2 \delta(f-k/T) \qquad E(4)$$

Where: σ_a^2 and μ_a^2 are respectively the variance and the mean of sequences; P(f) is the Fourier transform of the basic pulse P(t) and δ(f) is a unit impulse.
This PSD has both a continuous portion and discrete spectral lines. The presence of spectral lines can lead to reductions in total transmit power in order to meet regulatory PSD limits.

(2)On-off Keying modulation (OOK)

OOK is a particular case of amplitude modulation, and it obtained when a*k* can take the value 0, as shown in Figure 4. The benefit of using an OOK modulation is the simplicity of its implementation.

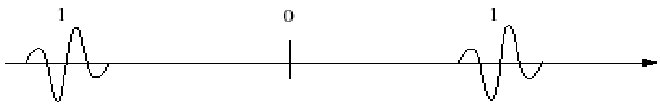

Figure 4. On-Off Keying Modulation (OOK)

OOK is special case of BPAM in which two alphabets are determined by the amplitude set d(0,1).Therefore, because of the equal probability of either symbol, $\sigma_d{}^2 = 0.25$ and $\mu_d = 0.5$ and PSD becomes

$$S_{ook}(f) = 1/4T_s|P(f)|^2 + 1/4T_s^2 \sum_{j=-\alpha}^{+\alpha} |p(j/T)|^2 \delta(f - j/T_s) \qquad E(5)$$

There is no need for the use of sophisticated physical components. Although OOK can reduce the complexity for the UWB system, it has several drawbacks. First of all, we are to likely lose synchronization at the receiver if the transmitted data includes a steady stream of zeros. Second, the difference in pulse amplitude may be small; its immunity against noise is reduced. Third, when compared with binary PAM, OOK modulation has lower BER performance. The decision process is more accurate when the gap between maximum and minimum amplitude is larger. For OOK modulation, the gap is twice as small as binary PAM modulation. This is clearly shown in figure 5, where bit errors occur much more often when OOK modulation is applied

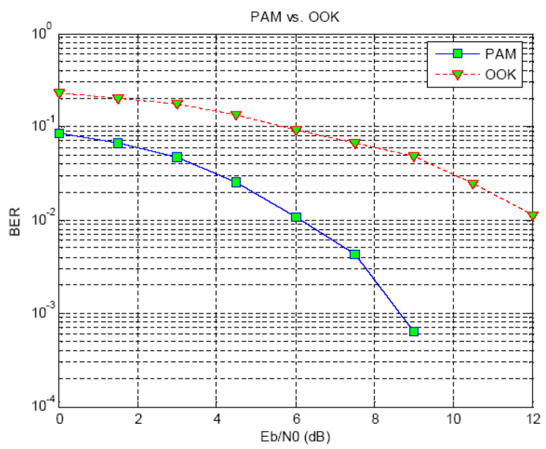

Fig.5 BER comparison of PAM and OOK

(3)Pulse position modulation

Pulse position modulation (PPM) consists of encoding the data bits in the pulse stream by advancing or delaying individual pulses in time, relatively to some reference, as shown in Figure 6 [10].

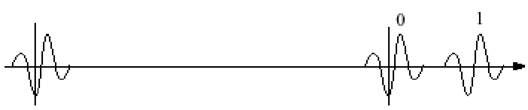

Figure 6 : Pulse Position Modulation

In this case, the signal can be written as

$$SPPM(t) = \sum_{k=-\alpha}^{+\alpha} p(t-kT = a_k\beta T) \qquad E(6)$$

where a_k ε {-1,+1} is the data; T is the reference interval between pulses; βT is the amount of pulse advance or delay in time, relative to the reference position. The interval between any two positions is made larger in order to avoid interference between symbols. The PSD of this PPM signal is given by equation 7

$$DSP_{PPM} = \sigma^2_a/T\,|B(f)|^2 + \mu^2_a/T^2 \sum_{k=-\alpha}^{+\alpha} |M(k/T)|^2\,\delta(f-k/T) \qquad E(7)$$

Where B(f) is the Fourier transform of b(t)=0.5[p(t-T)-p(t+βT)]; M(f) the Fourier transform of m(t) = 0.5[p(t-T)+p(t+βT)]. The modulation here tends to smooth the spectrum but this last still contains some spectral lines since the pulses are only delayed or advanced by a fractional part of the pulse width. To reduce the level of the lines further, an additional dithering sequence can be added. Dithering is a Pseudo-random process that jitters the reference position of the individual pulses according to a known random sequence. But dithering increases the level of complexity of a UWB system and adds to the Synchronization schedule.

The primary advantage of PPM is that it can be implemented non-coherently, as the phase lock loop is unnecessary for tracking the carrier phase. The PPM modulation is particularly beneficial to optical communication systems where coherent modulation and detection costs are prohibitively high. One of the disadvantages of PPM is its sensitivity to multipath interference that arises in channels with selective frequency fading. In multipath environments, the received signals are always composed of one or more transmitted pulses. It is difficult to extract the information from these received signals since the information is encoded at the time of arrival. Aside from its susceptibility to multipath interference, another drawback of PPM modulation is that it may suffer from synchronization loss. As the pulse stream is transmitted the receiver measures the timing of each arriving pulse, if the detection scheme is not able to synchronize with local time, the meaning of the symbol will be unrecognizable.

(4)Bi-phase (BPSK) modulation

In bi-phase modulation (BPSK), information is encoded with the polarity of the impulses, as shown in Figure 7 [10]. The polarity of the 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.

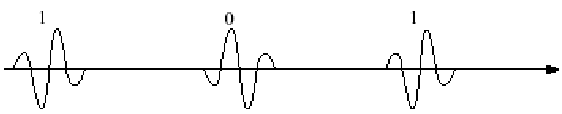

Figure 7. Bi-Phase (BPSK) Modulation

For this modulation scheme, values of the variance σ_a^2 and the mean μ_a^2 are respectively “1" and “0". Then the discrete portion of the PSD disappears as shown in equation 7.

$$DSP_{BPSK} = 1/T\,|P(f)|^2 \qquad E(7)$$

This ability to eliminate spectral lines is a key feature of BPSK. It is crucial for UWB to minimize the presence of those spectral lines since they might interfere with conventional radio systems. Fig. 8 Shows comparison of theoretical and empirical error rates for PAM & BPSK.

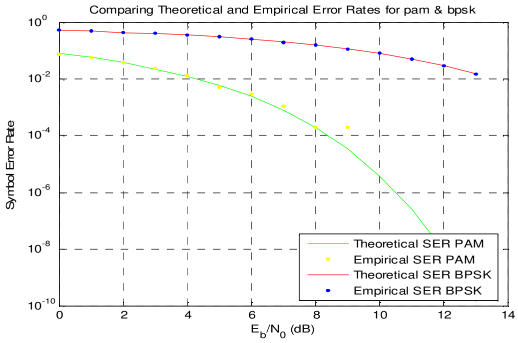

Fig.8 SER comparison of PAM and BPSK (Theoretical & Empirical Value)

IV. PROPOSED SYSTEM DESIGN

Following figure (9) shows proposed system design for UWB communication

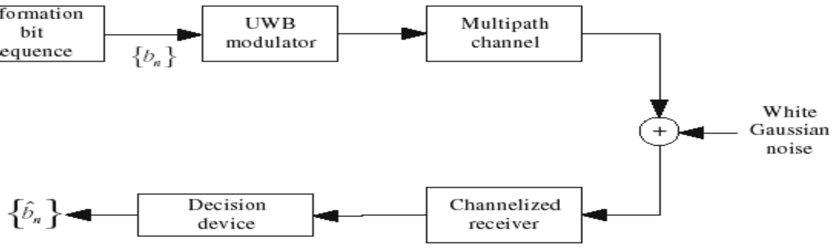

Fig.9 Proposed system design Transmitter Architecture

Due to its simplicity and better BER performance, Binary PAM modulation is used in this paper. Binary PAM modulation can be implemented by generating a stream of random binary bits and passing through the pulse shape filter. Prior to pulse shaping, a simple convolutional encoder is used to achieve a better BER performance. Our transmitter architecture is illustrated in following fig.10

Fig.10 Transmitter Architecture

In order to increase reliability and improved BER performance, a simple convolutional encoder is used. Specifically, we use a constraint length v= 5 and code rate R = ½ convolutional encoder [3]. Simulation results that show the proposed system performance will be presented. To achieve this, a Matlab based simulation was implemented. Performance will be presented in the form of BER curves for different propagation environments such as single path, multipath with/without channel coding. The details of system simulation are specified: sampling rate fs =50 GHz, carrier frequency

6.85 GHz. Figure 11 shows system performance with and without channel coding. The dashed line in figure 11 shows the performance when convolutional coding with constraint length five and rate ½. Under this condition, each input bit is coded into two output bits for transmission. Clearly, the convolutionally coded system yields better BER performance, as expected.

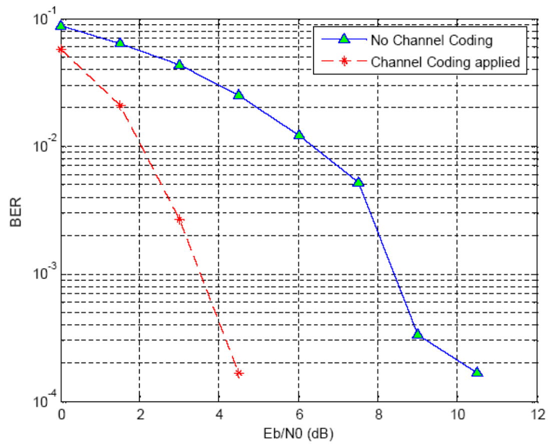

Fig.11 BER performance for with and without channel coding

Figure 12 illustrates the BER performance without channel encoding in single and multipath environments. Because the transmitted signal arrives at the receiver via different propagation paths with different delays, the distortion is caused by a combination of scaled and delayed reflection of the original transmitted signal. As seen in the figure, the BER performance in multipath environment is worse than in single path environment. The simulation is tested using 3 paths, including the main path and two secondary paths. The main path is the strongest and magnified by gain component. The second and third path is delayed for one and two pulse duration, respectively.

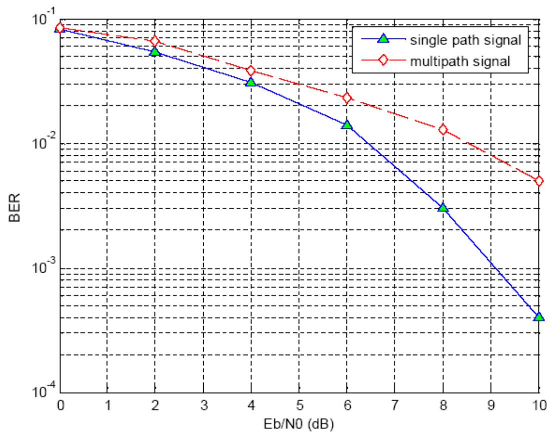

Fig.12 BER performance for single and multipath channel both without coding.

Following Figure 13 shows the simulation result in a multipath propagation environment with and without coding. The convolutional encoder has constraint length 5 and rate ½. Again, BER performance in multipath environment is improved by the channel coding technique.

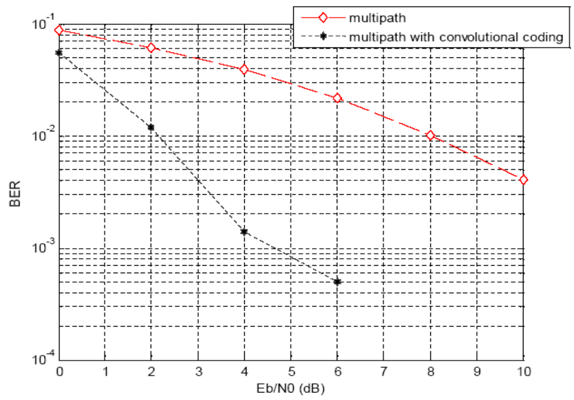

Fig.13 BER performance of multipath with and without coding

Channel Model

The transmitted signal propagates through the channel and white Gaussian noise (WGN) is added at the detector. Hence, the resulting signal is corrupted by noise and channel distortion. In this section, the characteristics of channel are discussed in the context of a multipath environment. Multipath occurs when the transmitted signal arrives at the receiver via multiple propagation paths. Consequently, the received signal suffers from undesired effects such as fading problem, Inter-Symbol Interference (ISI) and other types of distortion. Those are caused by the phase, attenuation, delay and Doppler shift of each path.

Fading: Rayleigh and Ricean fading channels are useful models of real-world phenomena in wireless communications. These phenomena include multipath scattering effects, time dispersion, and Doppler shifts that arise from relative motion between the transmitter and receiver. As the impulse response of channel is modeled as a zero-mean complex-valued Gaussian process, the envelope of impulse response at any time *t* is Rayleigh distributed. We call such channel Rayleigh fading channel. Because of fixed scatterers or signal reflectors in the transmission medium, in addition to randomly moving scatterers, the impulse response of channel can no longer be modeled as having zero-mean. In this case, the envelope of channel impulse response has a Ricean distribution. Thus, such channel is called Ricean fading channel.

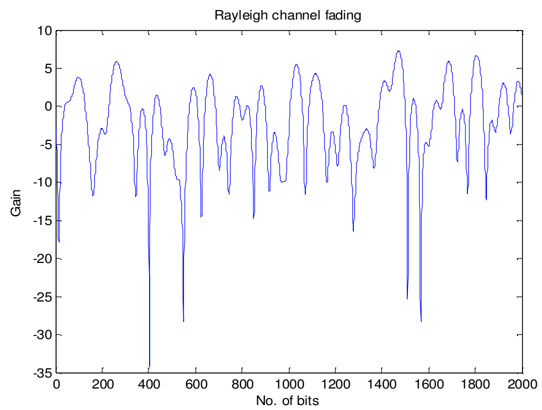

Fig.14 Rayleigh Channel Fading

V. CHANNELIZED DIGITAL RECEIVER

The basic theory of filter banks is presented. Due to the very wide bandwidth of UWB system, it is hard if not impossible to design high speed ADCs with today's technology. This problem can be solved if the received UWB signal is split into a number of subbands by power splitters, analog low-pass filters, mixers and digital filters [5]. Each of subbands is sampled at a fraction of effective sampling frequency. The complexity is relaxed and efficiency is enhanced. At the synthesis part of receiver, it is preferable to estimate optimally the transmitted signal rather than reconstruct it perfectly. Adaptive filters performing minimum mean square error criterion are employed as synthesis filter. At the output of receiver, the estimated signal is input to a decision device. A comparator is used to make decisions to regenerate the transmitted sequence before channel decoding [6].

VI. CONCLUSION

Various UWB pulse modulation schemes in the modified UWB channel model are evaluated in terms of SER, complexities, channel capacity and data rate. It seems that BPAM (BPSK) has the highest data rate in terms of maximum distance and transmitted power. However, M-PPM has better power efficiency and channel capacity. On the other hand, higher modulation level (M) requires more complexity and bandwidth. If bandwidth is not an issue, the MPPM is the best option, due to lower spectral lines(smoother PSD) and higher dimensionality(orthogonally of noises).If the complexity and bandwidth are limiting factors, OOK is the best, but has more spectral lines and higher probability of error. If a smoother PSD is desired, BPSK should be chosen. Finally, pulse amplitude position modulation (PPAM), which combines PPM and PAM, may be the best solution to provide good system performance and low computational complexity.

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