PERFORMANCE IMPROVEMENT OF IMPULSE RADIOS IN MULTIPATH ENVIRONMENTS

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Abstract: In this paper, we propose two receiver structures of the impulse radio (IR) system to improve its performance in multipath environments. Recently, the impulse radio system has drawn much attention for future high-speed wireless communication services. The conventional IR receiver directly correlates received signals with the ideal reference waveform, which results in performance degradation in multipath environments. The key idea of the proposed receiver structures is to reflect the multipath characteristics into the IR receiver. One is to deconvolve the received waveform with estimates of the multipath gains to obtain the transmitted waveform while the other is to modify the reference waveform of the correlator according to the estimates of the multipath gains. We examine the performance of the proposed schemes for the statistical indoor wireless communication channel model using computer simulation.

1. INTRODUCTION

Recently, the use of digital wireless communication systems has been rapidly increasing, which results in a difficult problem in the control of frequency resources. In this aspect, the impulse radio (IR) considered in this paper, which is based on the ultra wideband time hopping transmission technique, is a new type of spread spectrum that does not require extra frequency band allocation unlike the conventional communication systems using information-bearing continuous RF carriers. Currently, this impulse radio is receiving careful study for applications to military communication systems and indoor wireless local area networks [1, 2].

The IR system uses trains of time-shifted subnanosecond impulses, which are generally modeled with Gaussian monocycle pulses, as communication signals. Data is modulated with pulse position modulation (PPM) scheme and the IR receiver utilizes correlators for demodulation. Multiple access (MA) capability is achieved with utilization of time hopping spread spectrum with a different hopping code for each user. Thus, the power spectrum of the time-hopped IR signal has an ultra-wide bandwidth from near D.C. to a few GHz and very low density well below the thermal noise floor. For this reason, the IR systems do not interfere with narrowband radio systems operating in dedicated bands. The use of subnanosecond pulses makes the IR systems to achieve high processing gains, which allows a large number of users to be accommodated in the system [1]. These attractive features make the IR system a candidate for short-range communication applications. In order to obtain more complete understanding of this potential, an accurate model of the propagation characteristics of the IR waveforms is required [1, 2, 3, 4].

In general, reflectors and scatterers surrounding transceivers generate multipath components arriving at the receiver with different time delays. Since the IR directly transmits impulse trains, the received waveforms are distorted by the multipath components. Furthermore, since the conventional IR receiver makes binary decisions depending on the sign of correlations of the received signals with respect to a reference signal, the multipath components affect correlation values to degrade the performance of the IR receiver. Related to this, there are several reports dealing with the multipath characteristics of the IR signal [5, 6, 7, 8], which are based on experimental measurements of indoor and outdoor transmission, and analyses on ideal Rake-type receivers for dense multipath environments.

In this paper, we present two schemes of the IR receiver to improve the performance of the IR system in multipath environments. The key idea of the proposed receiver structures is to reflect the multipath characteristics into the IR receiver; one is to deconvolve the received waveform with estimates of the multipath gains to obtain the transmitted waveform while the other is to modify the reference waveform of the correlator according to the estimates of the multipath gains. We examine the performance of the proposed schemes for the statistical indoor wireless communication channel model [9] using computer simulation.

The paper is organized as follows: Section 2 introduces the principle of the IR system based on the results reported in [1, 2, 3, 4]. In Section 3, the statistical indoor wireless communication channel model of Saleh and Valenzuela is introduced and its application to the IR system is discussed. In Section 4, the new receiver structures are explained to enhance the performance of the IR system in the multipath environments. The performance of the proposed receivers is

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evaluated for the Saleh and Valenzuela's model using computer simulation in Section 5. Finally, we make a conclusion in Section 6.

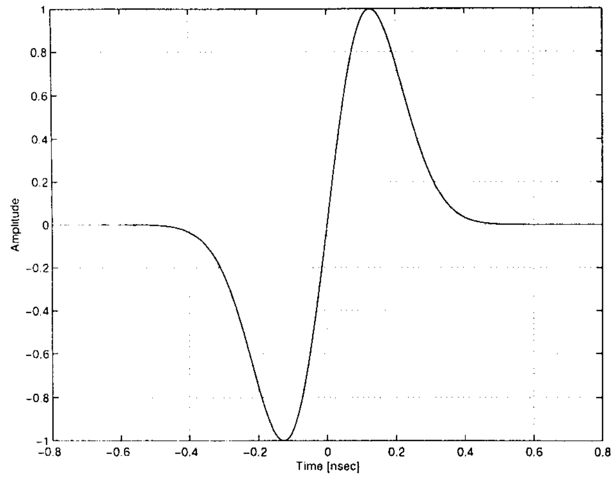

Figure 1: Gaussian monocycle pulse.

2. IMPULSE RADIO SYSTEM MODEL

In the IR system, the transmitted signal of each user consists of impulses which are randomly located in the time domain. Each user transmits one pulse per one transmit frame, and the width of each pulse is less than 1 nsec. The frame of T_f sec contains N hopping slots of duration T_c sec. Among the N hopping slots of each transmit frame, one slot is allocated to one user depending on the user's hopping code consisting of pseudo-random noise (PN) sequence. The user's information bit to be transmitted determines the location of pulse within the allocated hopping slot. Because of the very narrow pulse width and the randomness of the pulse position, the transmitted signal has ultra-wide bandwidth up to a few GHz and very low power spectrum density.

The transmitted signal $s^{(k)}(t)$ for the k-th user with time hopping can be equivalently modeled as follows:

$$s^{(k)}(t) = \sum_j w_{tx}(t - jT_f - c_j^{(k)}T_c - \delta d_j^{(k)}), \qquad (1)$$

where $w_{tx}(t)$ represents the transmitted monocycle pulse as shown in Figure 1, $c_j^{(k)}$ corresponds to the decimally represented j-th time hopping code for the k-th user, and T_c is the slot duration. In (1), $d_j^{(k)} \in \{0, 1\}$ is the j-th binary data bit of the k-th user, and δ represents the time interval between data bits '0' and '1' in the PPM. Therefore, the time delay with respect to the frame clock represents hopping code pattern for multiple access capability and transmitted information in the IR system. The optimal value δ for the ideal single user channel environment was discussed in [4, 10].

In the receiver of the IR system, the receiving antenna system alters the transmitted monocycle pulse waveform $w_{tx}(t)$

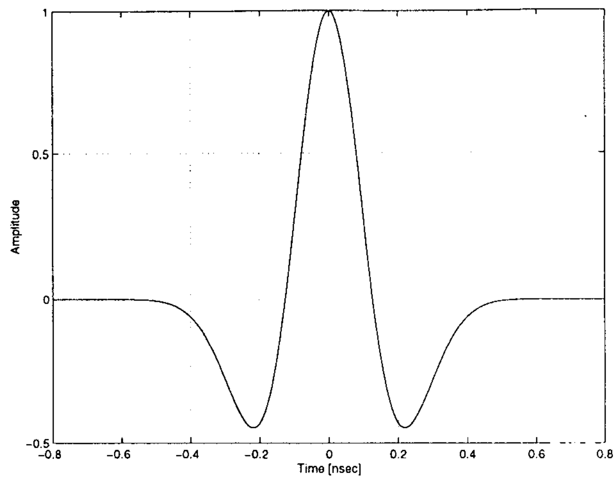

Figure 2: Ideal received monocycle pulse shape at the output of antenna subsystem.

to $w_{rx}(t)$ at the output of the antenna system that is modeled as a differentiator. An idealized received monocycle pulse shape $w_{rx}(t)$ can be modeled as [11]

$$w_{rx}(t) = [1 - 4\pi(t/\tau)^2]exp(-2\pi[t/\tau]^2). \qquad (2)$$

Figure 2 shows the waveform of $w_{rx}(t)$ of (2) with τ = 0.4472 nsec. The conventional IR receiver correlates the received signals with a reference signal and makes binary decisions depending on the sign of correlation values, where the reference signal is given by

$$w_{ref}(t) = w_{rx}(t) - w_{rx}(t - \delta). \qquad (3)$$

3. MULTIPATH CHANNEL MODEL

In this study, we consider the statistical model, which Saleh and Valenzuela proposed in [9]. This statistical model is based on clustering phenomenon of rays observed in their experimental data. The clustering phenomenon is that rays arrive in several groups within an observation window, and the clusters are attenuated in amplitude. In addition, the magnitudes of rays within a cluster decay with time. Their model proposes that both of these decaying patterns are exponential with time, and are controlled by the cluster arrival decay time constant Γ and the ray arrival decay time constant γ.

The cluster arrival times (the arrival time of the first ray within each cluster) are modeled as a Poisson arrival process with the cluster arrival rate Λ. Within each cluster, subsequent rays also arrive according to a Poisson process with the ray arrival rate λ. Let the arrival time of the ℓ-th cluster be denoted by T_ℓ ($\ell = 0, 1, 2, \cdots$). Moreover, let the arrival time of the k-th ray measured from the beginning of the ℓ-th cluster be denoted by $\tau_{k\ell}$ ($k = 0, 1, 2, \cdots$). Thus, according to this model, T_ℓ and $\tau_{k\ell}$ are described by the independent interarrival exponential probability density functions.

$$p(T_\ell | T_{\ell-1}) = \Lambda \exp[-\Lambda(T_\ell - T_{\ell-1})], \ell > 0 \qquad (4)$$

$$p(\tau_{k\ell} | \tau_{(k-1)\ell}) = \lambda \exp[-\lambda(\tau_{k\ell} - \tau_{(k-1)\ell})], k > 0 \qquad (5)$$

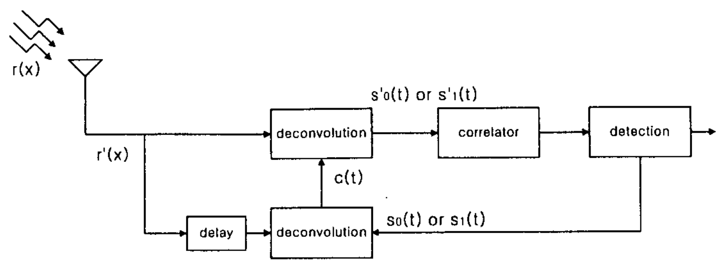

Figure 3: Block diagram of the receiver using deconvolution.

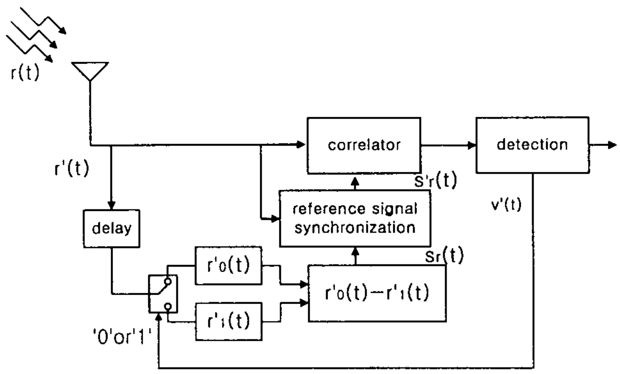

Figure 4: Block diagram of the receiver using modified reference signals.

The impulse response of the channel is given by

$$h(t) = \sum_{\ell=0}^{\infty}\sum_{k=0}^{\infty} \beta_{k\ell}\delta(t - T_\ell - \tau_{k\ell}), \quad (6)$$

where $\beta_{k\ell}$ represents the complex gain of each arrival. The amplitude of $\beta_{k\ell}$ is a Rayleigh distributed random variable, while the phase of $\beta_{k\ell}$ is a uniformly distributed random variable. The mean square value of $\beta_{k\ell}$ is described as follows:

$$\overline{\beta_{k\ell}^2} = \overline{\beta^2(T_\ell, \tau_{k\ell})} = \overline{\beta^2(0,0)}e^{-T_\ell/\Gamma}e^{-\tau_{k\ell}/\gamma} \quad (7)$$

where $\overline{\beta^2(0,0)}$ is the average power gain of the first ray of the first cluster.

The characteristics of channels are changed according to the values of the channel parameters mentioned previously. Therefore, it is important to select appropriate values of the channel parameters. In the simulation study, we adjusted the parameters taking into account that the pulse width of the IR system is less than 1 nsec.

4. PROPOSED RECEIVER STRUCTURES

Since the IR system directly transmits impulse trains, the reference signal waveform for the AWGN channel is not applicable to the multipath channel environments. That is, when the received signal is influenced by the multipath channels, demodulation is impossible. Thus, we propose new receiver structures in this section in order to enhance the performance of the IR system in the multipath environments.

4.1. Receiver Using Deconvolution

The proposed receiver structure is shown in Figure 3. In this receiver, the path gains are estimated by deconvolving the received signal with the transmitted waveform corresponding to the decision since the received signal is a convolution of the transmitted signal with the path gains. The estimates of the path gains are used for deconvolution of the current received signal. This deconvolved received signal is applied to the correlator, which utilizes the ideal reference waveform as in the conventional IR receiver. Since this receiver rests on deconvolution and decision, the performance is subject to the channel noise and the time-varying characteristics of the channel.

4.2. Receiver Using Modified Reference Signal

In the receiver structure shown in Figure 4, the correlator employs the reference signal generated from the received signal waveforms. Since the reference signal is updated with the received waveforms corresponding to the detection results, the channel characteristics are reflected into the reference signal. In this receiver, the synchronization between received signals and the reference signal of the correlator is critical.

5. SIMULATION RESULTS

In this section, we investigate the bit error rates (BER's) of the proposed receivers and the conventional one for the multipath channel model explained in Section 3. The parameters of the model are set to $1/\Lambda = 2$ nsec, $1/\lambda = 0.5$ nsec, $\gamma = 5$ nsec and $\Gamma = 33$ nsec, respectively.

Figure 5 shows the BER performance versus E_b/N_0 of the IR systems for the statistical channel model assuming that the indoor wireless channel is slowly time-varying. In the figure, the curve denoted by diamonds represents the BER's of the conventional IR receiver with the ideal reference signal based on the waveform in Figure 2, which indicates that

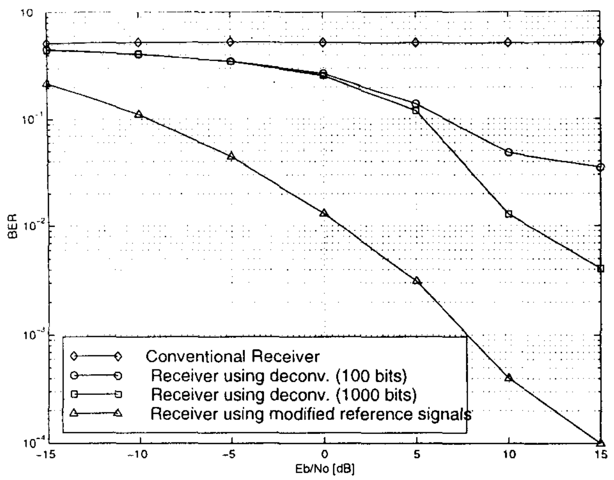

Figure 5: Bit error rates versus E_b/N_0 for the statistical indoor multipath model.

demodulation is impossible. The path gains are updated every 100 bits. The curve denoted by circles shows the performance of the receiver using deconvolution when the path gains are updated every 100 bits. The one by squares is that of the same receiver when the gains are updated every 1000 bits. The curve with triangles is the BER's of the receiver using the reference signals modified according to the channel characteristics. In this case the path gains are updated every 100 bits. As expected, the proposed receivers are superior to the conventional receiver for the multipath channel. It is observed that the performance of the receiver using deconvolution is limited by the channel update rates for higherE_b/N_0's. This is why bit errors occur whenever the path gains are changed. The receiver using modified reference signals achieves better performance than the others.

6. CONCLUSION

In this paper, we presented two receiver structures for the impulse radio system in order to improve its performance in multipath environments. The performance of the proposed receivers was evaluated using computer simulation with the statistical model of Saleh and Valenzuela. According to the simulation results, the proposed ones significantly improve the performance of the IR system for the multipath channels in terms of the bit error rate. However, the drawback of the proposed receivers is to require accurate synchronization between the received and reference signals and additional computational complexity for updating the reference signal according to the multipath channel characteristics.

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