Available online at www.elixirpublishers.com (Elixir International Journal)

Network Engineering

Elixir Network Engg. 44 (2012) 7531-7535

ISSN: 2229-712X

Realization and performance evaluation of parallel interference cancellation (PIC) based code division multiple access (CDMA) transmission over Rayleigh fading channel

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ARTICLE INFO

Article history:

Received: 11 January 2012;

Received in revised form:

16 March 2012;

Accepted: 26 March 2012;

Keywords

Multimedia Signal Processing, Multiple Access interference (MAI), Rayleigh Fading channel, Doppler Shift.

ABSTRACT

Broadband and Wireless are the most common adoption in the communication market during the past ten years. Users want to be able to access to multimedia applications, data and voice while still using wireless mobility. To do so a high data rate is required. Moreover, multicasting is a tool used in networking which allows a selected group of users to receive the same information, and it is particularly useful for multimedia traffic. Obviously the research on the possible techniques to obtain such connection is a challenging topic in the field of mobile communication.The technological advances in wireless communications have enabled the realization of various systems which enable us to optimally use various multimedia applications. It is envisioned that many of the future wireless systems will incorporate considerable signal processing intelligence in order to provide advanced services such as multimedia transmission and detection. In general, wireless channels are hostile media to communicate, due to substantial physical impediments, primary radio frequency interference and time varying nature of the channel. The need of providing universal wireless access at high data- rate (which is the aim of many emerging wireless applications) presents a major technological challenge, and meeting this challenge necessities the development of advanced signal processing techniques for multiple- access communications in non- stationary interference rich environments. In this paper we present advanced signal processing methodologies for Multiple Access Interference (MAI) suppression in multiuser communication environment, while considering the transmission over Rayleigh fading channel. We also considered the effect of Doppler shift. A new model for realization of Rayleigh fading channel has been proposed. The statistical tests performed on the proposed channel were found satisfactory.

Introduction

Multiuser communications systems that employ Code Division Multiple Access (CDMA) exhibit a user capacity limit in the sense that there exists maximum number of users that can simultaneously communicate over the channel for a specified level of performance per user. This limitation in user capacity is brought about by the ultimate domination of the other user interference. Over the years researchers have sought ways to extend the user capacity of CDMA systems either by employing optimum (maximum likelihood) detection [3] or interference cancellation methods. A new Parallel Interference Cancellation (PIC) has been proposed in this paper for better interference cancellation. When compared with classical CDMA having no interference cancellationor with the successive (serial) interference cancellation technique previously proposed by Viterbi [5], the Parallel Interference Cancellation scheme discussed in this paper achieves a significant improvement in performance. Aside from increasing the user capacity, the Parallel Interference Cancellation scheme proposed here in has a further advantage over the serial cancellation scheme with regard to the required delay necessary to fully accomplish the interference cancellation for all the users in the system. Since in the latter, the interference cancellation precedes serially, a delay of the order of M bit times (M denotes the number of simultaneous users in the CDMA system) is required. Where as in the proposed PIC based scheme, since the interference cancellation is performed for all users, the delay required is only one bit for single stage cancellation.

Due to the problems of multiple-access interference (MAI), multi-user detection for CDMA based systems has received considerable attentionover the past few years. The utilization of multi-user detection has the potential to provide significant capacity improvement for CDMA systems. CDMA based multi-user detection is one of the fastest growing areas in wireless communications. With the adoption of CDMA techniques in 3G systems and 4G systems, CDMA with multi-user detection has become an important area of interest for researchers all over the world. Modern wireless communication systems based on CDMA techniques, such as the wideband CDMA (WCDMA) system, operate in environments that are interference, bandwidth, and multipath-fading limited. In order to combat these effects, complex receiver structures, such as those using complicated synchronization structures, demodulators and multi-user detectors, and RAKE processors, are often used. Many of these systems are not analytically tractable. The high complexity

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and the complicated performance analysis of the modern communication systems have become the major challenges in research. Researchers are often unable to see or experience the phenomena being practiced, and this problem often leads to an inability to learn basic principles and their practical relevance to implementation in real life. Many such constraints prohibit the study of more complex and more real-world systems.

The big challenge before the researchers is the problem of multiuser detection when the signal has been transmitted over multipath channel like Rayleigh fading channel and the receiver is supposed to receive the signal from multiple paths. In this paperaParallel InterferenceCancellation method has been used in the multipath environment when the sender and receiver have been assumed in motion (Doppler shift).

Signal Model

The reverse link in a cellular radio system described by an asynchronous Direct Sequence Code Division Multiple Access (DS/CDMA) model is considered. There are K users in the system employing different signature waveforms $s_1, s_2 s_3, \ldots\ s_k$. These K users transmit their information (a Binary Phase Shift Keying sequence) over the same frequency channel using their own signature waveforms. The transmitted base band signal due to k_{th}user is given by

$$X_k(t)=Ak\sum_{i=0}^{M-1} bk(i)sk(t-iT), k=1,2\ldots\ldots K \quad \ldots 1$$

Where M is the number of data symbols per frame, T is the symbol interval, $bk(i)\epsilon\ \{+1, -1\}$ is the i^{th} transmitted symbol by the k^{th}user, and A_k and S_k are the amplitude and normalized signature waveform of the k^{th}user respectively. The signature waveform of the K^{th} user has the following form

$$S_k(t)=\sum_{J=0}^{N-1} Ck(j)\psi(t-jTc),\ 0 \leq t \leq T \quad \ldots 2$$

where N is the processing gain equal to $T/\ Tc$, $CK(j)$ is the signature code assigned to a user with waveform of duration T, it is assumed that $Sk(t)$ is zero outside the interval [0,T] and has unit energy.It is also assumed that each user transmits independent equiprobable symbols and also users transmitted symbols are independent of each other. The transmissions are received by an array of P antennas. Assuming that each transmitter is equipped with a single antenna, then the baseband multipath channel between the k^{th} user's transmitter and the p^{th}antenna element at the receiver can be modelled as a tapped delay line with the following impulse response

$$h_k, p= \sum_{l=1}^{L} \propto k\ l,p \propto kl\ \delta(t-\tau kl)$$

$$\propto kl,p = \exp\left[j\frac{2\pi}{\lambda}(p-1)d\ sin\theta kl\right] \quad \ldots 3$$

Where L is the number of resolvable paths in each user channel $\propto k\ l$ is the complex amplitude, and τkl is the delay of the l^{th} path of the k^{th}user's signal. The array response vector corresponding to the l^{th}path of the k^{th}users signal as

$$[\ akl,\ 1,\ldots\ldots\ldots akl,p]^T \quad \ldots 4$$

Then the channel between the k^{th} user and the base station can be modelled by the following vector response

$$h_k(t) = \sum_{l=1}^{L} akl\ \alpha kl\ \delta(t-\ \tau kl) \quad \ldots 5$$

Assuming that the channel parameters remain constant during the whole frame period, the received multiuser signal at the receiver is then the superposition of the signals from all K users plus the additive complex white noise given by

$$r(t)=\sum_{k=1}^{K} xk(t) * hk\ (t) +\ \sigma\ n(t)$$

$$\sum_{i=0}^{M-1}\sum_{k=1}^{K}\sum_{l=1}^{L} a\ kl\ \alpha kl\ Akbk(i)\ \ Sk(t-iT-\ \tau kl)\ +\ \sigma n(t) \quad \ldots 6$$

where * denotes the convolution, and $n(t) = [\ n1(t)\ldots\ldots\ldots\ldots np(t)]^T$is a vector of independent zero mean complex white noise with variance equal toσ^2

Parallel Interference Cancellation Method

Multi-user detection (MUD) schemes can be mainly divided into two groups, linear and nonlinear techniques [16]. Linear MUD schemes invert the correlation matrix R of the used spreading sequences according to the zero-forcing or the MMSE solution. The latter one supplies a compromise between sufficiently decorrelating the interfering signals and the noise suppression. Due to the inversion of R, the above mentioned methods presuppose a repetition code for Spreading. Otherwise, the correlation matrix would be influenced by the coded data bits and calculating the inverse of R would require an estimation of the coded bits itself. Thus, to our knowledge, a joint implementation of linear MUD and decoding without a repetition code has not yet been realized and linear MUD cannot be applied for the SCCS.

Therefore, nonlinear multi-user detection operating behind the FEC decoder. Generally, successive and parallel interference cancellation schemes are distinguished has been considered. The former technique is suitable for systems without power control where the power of the received signals vary in a wide range. This scenario is redestinated for the successive detection of all signals starting with the highest power signal and proceeding till the weakest signal has been detected. After each detection, the re-constructed version is subtracted from the channel output reducing the interference and allowing a more reliable detection of the remaining signals.

In this paper, aParallel Interference Cancellation (PIC) where all incoming signals are detected simultaneously has been considered. In contrast to the conventional methods, the PIC scheme requires a strong power control ensuring the same receive power for all incoming signals.

The performance of the multiuser detector does not depend only on the MAI suppression techniques only but also on the performance of the characteristics of thetime varying channel, Doppler shift in vehicular communication environment etc.In this paper a Rayleigh fading channel has been proposed and simulated which takes into consideration the Doppler shift. The CDMA signal has been transmitted over the proposed Rayleigh fading channel.

Rayleigh Fading Channel

In wireless transmission scenarios, where a receiver is in motion relative to a transmitter with no line-of-sight path between their antennas, ithas been found that Rayleigh fading is a good approximation of realistic channel conditions. The term Rayleigh Fading channel refers to a multiplicative distortion h(t) of the transmitted signal $s(t)$,asin$y(t)= h(t)\cdot s(t)+n(t)$, where $y(t)$ is the received waveform and $n(t)$ is the noise. This section discusses how to design a simulator that mimics a sampled version of the channel waveform $h(t)$ in a statistically accurate and computationally efficient fashion. The channel waveform $h(t)$ is modelled as a wide-sensestationary complex Gaussian process with zero-mean, which makes the phase and amplitude of the transmitted signal uniformly and Rayleigh distributed respectively, hence the term Rayleigh fading. The autocorrelation properties of the random process h(t) are governed by the Doppler frequency f_D

$$R(Z)=E\{h(t)h*(t-\tau)\sim j0\ (2\pi fD\tau) \quad \ldots 7$$

Where j_0 (.) is the zero order Bessel function of the first kind. This gives rise to the well known non rational power spectral density (PSD) of the channel process

$$S_{hh}(f) = \left\{ \frac{1}{\pi f D} \frac{1}{\sqrt{1-\left(\frac{f}{fD}\right)^2}} \right\langle \quad |f| < fD \rangle \ldots 8$$

When both or any one of the transmitter and receiver are in motion, the Doppler shift will occur, which changes the characteristics as well as performance of the multiuser receiving system. The Doppler effect geometry is shown in Figure 1

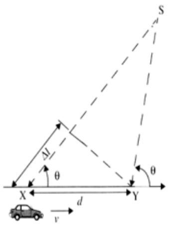

Figure 1. Illustration of Doppler effect Geometry

In cellular communication systems the radio channel is a function of both time and space and is illustrated in the Figure 2.

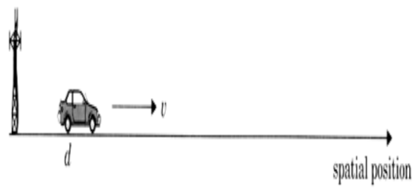

Figure 2. The Mobile Radio Channel as a function of Time and Space

The Space and Time variant nature of the channel or fading rapidity mechanism can be viewed in terms of two degradation categories namely fast fading and slow fading. The terminology "Fast Fading" is used to describe channels in which $T_O<T_S$, where T_O is the channel coherence time and T_S is the time duration of the transmission symbol. Fast Fading describes a condition where the time duration, in which the channel behaves in a correlated manner, is short compared to the time duration of a symbol. Small scale fading is also called Rayleigh fading, because the multiple reflective paths are large in number and there is no line of sight for signal components. Further, the envelope of the received signal is statistically described by Raleigh Probability Distribution Function (PDF). The Raleigh fading channel is modelled as a time varying channel. The model of the time varying channel is shown in Figure 3

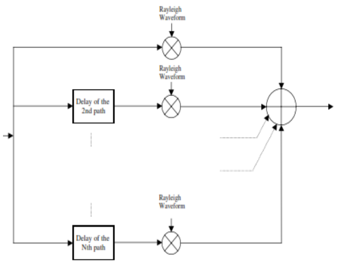

Figure 3. Model of Time Varying Channel

The Raleigh waveform in the above time varying channel is generated using modified Clarkes Model. Complex normal noise is obtained from Gaussian noise generators, which are uncorrelated in the time domain. The Gaussian noise is passed through Gaussian filters. The outputs of the Gaussian filters are multiplied by two sinusoidal waves with 180 degree phase difference and the resultant is summed at summer as shown in Figure 4. The waveform of the signal generated of the proposed Rayleighsignal generator is shown in Figure 5 which confirms with the theoretical model. The autocorrelation property and power spectral density of Rayleighwaveform are shown in Figures6 and 7 respectively, from the waveform it is clear that proposed scheme has a relevance and scope in the implementation of time varying channel.

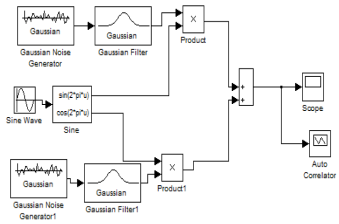

Figure 4. Proposed Rayleigh Waveform Generator

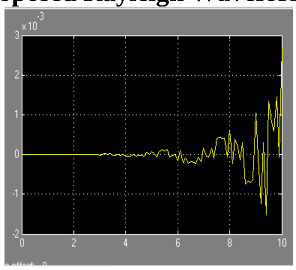

Figure 5. Waveform ofProposed Raleigh Waveform Generator

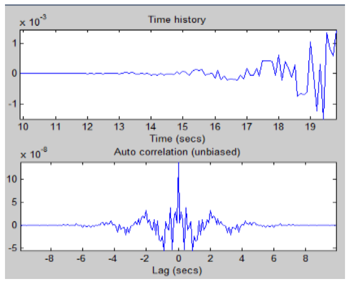

Figure 6. Auto correlation of the Proposed Rayleigh Waveform Generator

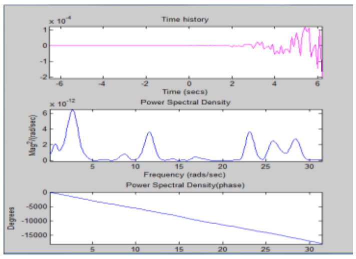

Figure 7.PowerSpectralDensity of Proposed Rayleigh Waveform Generator

4 Parallel Interference Cancellation (PIC) based Code Division Multiple Access (CDMA) transmission over Proposed Rayleigh Fading Channel

The schematic of the proposed scheme is shown in Figure 8. A random source having Gaussian (normal) distribution generated by Ziggurat method has been used to generate random message signals with different seed values and variance at the transmitting end. The outputs of two random sourcesare firstmultiplied with the two signature sequences $s_1(t)$ and $s_2(t)$. The outputs of the multipliers are combined by the summer,which is then transmitted over the simulated Time Varying Channel. The received signal is detected using two user PIC detectors, in which the received signal is signals tuned two signature sequences, similar to these utilized at the transmitting end. Another multiplier multiplies two signature sequences and generates an error signal $\rho_{(t)}$ which is used to mitigate the Multiple Access Interference (MAI) in parallel. The output of the tuned multipliers are passed through the integrators to produce two outputs $y_1(t)$ and $y_2(t)$. The $y_1(t)$ after passing through the decision device are multiplied with $\rho_{(t)}$, to produce another output $A_1(t)$. Similarly $y_2(t)$ after passing through the decision device is multiplied with $\rho_{(t)}$, to produce another output $A_2(t)$, then $A_2(t)$ is subtracted from $y_1(t)$ and $A_1(t)$ issubtracted from $y_2(t)$, which are then passed individually through threshold detectors to make decision in favour of either a binary 1 or 0. The performance of the proposed system has been verified by computing the Bit Error Rate (BER) using Error Rate Calculation counter which computes the error rate of the received data by comparing it to delayed version of the transmitted data. The error counter specifies the three element vector consisting of the error rate, followed by the number of errors detected, and total number of symbols compared as shown in the Figure9. For user1, the error rate comes to a 1, the number of errors detected is 5 and for user2 the error rate is 1, the number of errors detected is 6. The implementation of the proposed scheme is shown in Figure 9. The waveforms are shown in Figures10 to 13 respectively.

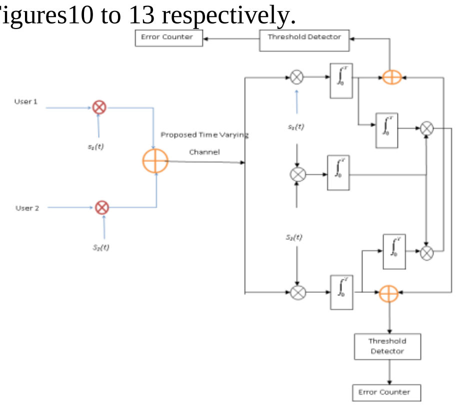

Figure.8.Schematic of Proposed Parallel Interference Cancellation based CDMA Scheme Transmitted over Time Varying Channel

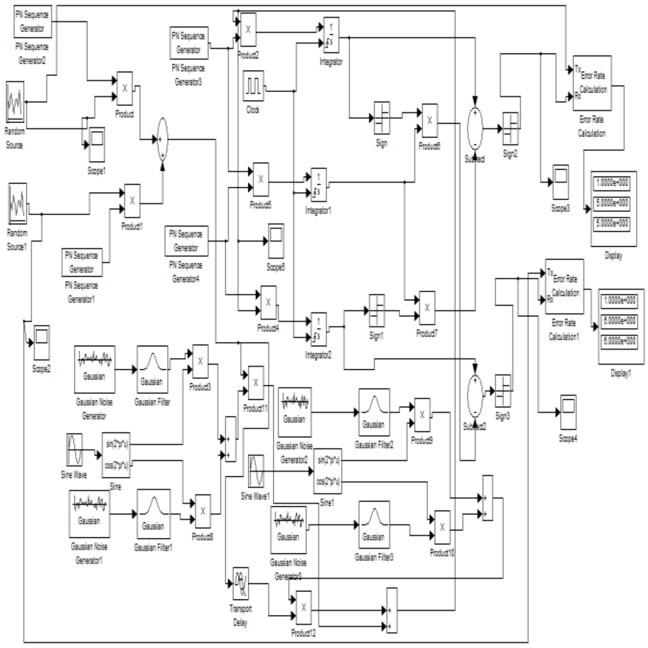

Figure 9. Implementation of Parallel Interference Cancellation based CDMA Scheme over Time Varying Channel

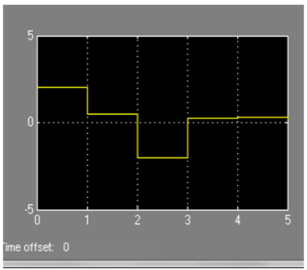

Figure 10. Waveform of User 1

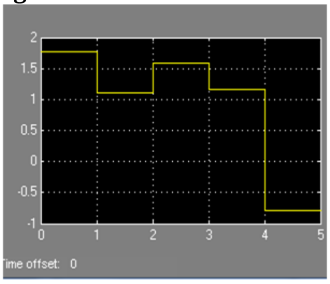

Figure 11.Waveform of User 2

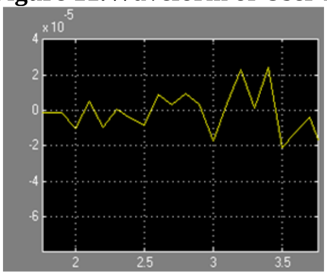

Figure 12. Output of Simulated Time Varying Channel

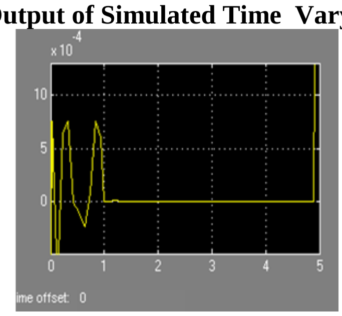

Figure 13. Waveform of Transmitting signal of both users over Simulated Time Varying Channel

Conclusion

In real world communication scenarios, the transmitter and/or the receiver may be in motion. In a mobile radio situation in which the transmitter is fixed in position while the receiver is moving, the direct line between the transmitter and the receiver may be obstructed by buildings. At ultra-high frequencies and above, the mode of propagation of the electromagnetic energy from transmitter to receiver is largely by way of scattering. The amplitude fluctuations of the received signal in such situations as have been shown to follow Rayleigh distribution.

A time-selective generalized Rayleigh fading model has presented that extends the Clarke's classical isotropic scattering model of mobile radio reception to general scattering environments. It turns out that the statistics of a generalized Rayleigh fading channel depend on the direction of mobile travel and the mean angle of arrival, and can be significantly different from those in an isotropic environment. In general, the autocorrelation is complex-valued and the power spectral density is asymmetric. In this chapter the Rayleigh fading channel has been simulated by taking into consideration the Doppler shift. The characteristics of the simulated channel have been verified by using various statistical methods. The performance of the proposed system has been checked bycomputing the BER at the output of the detector which has been found satisfactory.

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