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Optimization of Data Recovery using Non-Linear Equalizer in Cellular Mobile Channel

셀룰라 이동통신 채널에서 비선형 등화기를 이용한 최적의 데이터 복원

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Abstract

In this paper, we have investigated the CDMA(Code Division Multiple Access) Cellular System with non-linear equalizer in reverse link channel. In general, due to unknown characteristics of channel in the wireless communication, the distribution of the observables cannot be specified by a finite set of parameters; instead, we partitioned the m-dimensional sample space into a finite number of disjointed regions by using quantiles and a vector quantizer based on training samples. The algorithm proposed is based on a piecewise approximation to regression function based on quantiles and conditional partition moments which are estimated by Robbins Monro Stochastic Approximation (RMSA) algorithm. The resulting equalizers and detectors are robust in the sense that they are insensitive to variations in noise distributions. The main idea is that the robust equalizers and robust partition detectors yield better performance in equiprobably partitioned subspace of observations than the conventional equalizer in unpartitioned observation space under any condition. And also, we apply this idea to the CDMA system and analyze the BER performance.

요 약

본 논문에서 역 방향 링크 채널에 대해 비 선형 등화기를 이용하여 CDMA 셀룰라 시스템을 연구하였다. 일반적으로 무선 통신에서 불확실한 채널 특성 때문에 Observable 들의 확률분포는 유한 세트의 파라미터로 규정될 수 없다. 대신에 training 샘플에 기반을 둔 Quantile과 Vector Quantizer를 사용함으로서 유한 수의 disjoint된 영역으로 m차 샘플 공간으로 분할하였다. 제안된 알고리듬은 RMSA 알고리즘에 의해 예측된 Quantile와 조건부 분할 모멘트에 따른 regression function의 부분적인 근사에 근간을 두고 있다. 본 논문의 등화기와 검출기는 잡음 분포의 Variation에 민감하지 않다는 관점에서 상당히 강한 특성을 보여 준다. 주요 아이디어는 Robust equalizer와 Robust partition detector가 어떤 환경의 무선 채널 하에서도 partition되지 않은 Observation space의 일반적인 등화기보다 Observation의 등 확률로 분할된 부 공간에서 더 낳은 성능을 보여 준다. 또한 이런 개념을 CDMA 시스템에 적용하여 BER 성능을 분석하였다.

Key Word : Equalizer, Vector Quantizer, RMSA

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I. Introduction

The research presented here is motivated by the need of providing reliable and efficient digital communications services over cellular mobile radio channels. The particular characteristics of the multipath channel are generally unknown. Thus, the objective of the receiver is to identify the channel characteristics in order to reduce the inter-symbol interference (ISI) component and additive noise. The use of statistical methods of detection and estimation theory has provided powerful signal processing techniques for communication system design, image processing and many other systems where noise and other forms of interference occur. In most practical situations, the channel characteristics are not known beforehand, so the assumption of gaussian environment will lead to poor detector and equalizer designs. In this paper, we consider the design of a (non-linear)equalizer having the ability to suppress problems caused by dependent noise. The structure of the equalizer is chosen to minimize the mean square error (MSE) with respect to the transmitted information. The equalizer is based on piecewise approximations to a regression function involving only quantiles and partition moments which are estimated by a Robbins Monro stochastic approximation (RMSA) algorithm [1]. For each partition, the coefficients of the equalizer are evaluated by using the conditional MMSE criterion. In this paper, we employed a postdetection phase combining scheme for the dual diversity reception of quadrature phase shift keying (QPSK) signaling system. The main idea is to combine diversity reception, known to combat fading in radio transmission, with adaptive equalization, known for suppressing the effects of ISI and additive noise, resulting in a robust receiver. As the multiple access of code division multiple access (CDMA) reverse link, the reverse link channelization is based on a conventional spread spectrum PN code division multiple access scheme in which different mobile users are distinguished by distinct phase offsets of the long PN code, which serve as a user addresses. In addition to the long code, the reverse link data stream is direct sequence modulated in quadrature by the same two short PN codes. We employed the QPSK modulation scheme. And also, the reverse link uses convolutional coding with Viterbi decoding and interleaves code streams before transmission in order to protect against possible burst error patterns. The remainder of this paper is organized as follows. Section II gives the system model including channel model under the CDMA Systems. In the next section, nonlinear equalizer using RMSA is derived. Performance analysis and simulation result is given in Section IV, followed by some concluding remarks in Section V.

II. Description of System Model

2.1 Coding System

For both the forward and reverse link in CDMA system, convolutional coding and Viterbi decoding schemes [2]-[4] are used for forward error control (FEC) purpose to achieve reliable communications and use the minimum possible signal power. The idea of using FEC is to help recover from errors that occur during the transmission over the channel. There are many types of FEC. But, the convolutional coding scheme with a large coding gain is employed in order to maximize the user capacity of the CDMA cellular system. In the previous section, we noticed that the reverse link of CDMA system employ the orthogonal modulator as the role of (n,k) block channel encoder which follows the block interleaver. The output of the orthogonal encoder is Walsh coded symbols. A set of Walsh functions [1] consist of N member functions, and they are ordered according to the number of zero crossing (sign changes).

2.2 Characteristics of Channel

We use a diversity reception (i.e., since ISI due to delay spread becomes larger as the signal becomes weaker, diversity combining can reduce the effect of the delay spread) providing a viable solution, because of the presence of a diversity path. Among various combining method, we choose the maximal ratio combining method in this system and use the rectangular type of signaling pulse shape, i.e., windows pulse.

$$p(t) = \begin{cases} 1, & (n-1)T \le t \le nT \\ 0, & Elsewhere \end{cases} \quad (1)$$

At the detector, the received signal of the k *th* branch(k=1,2) in diversity scheme can be expressed by

$$r_k(t) = r_{fk}(t) + n_{dk}(t)$$

$$r_{fk}(t) = \frac{1}{\beta} \sum_{n=-\infty}^{\infty} a_n\, c(t)\, q(t-nT) \times \cos(2\pi f_c t + \theta(t)) \quad (2)$$

$$n_{dk}(t) = \textit{additive dependent gaussian noise}$$

where $q(t) = h(t) * p(t)$, $h(t)$: *channel filter.*

When the effect of multipath delay spread can not be ignored, fading is termed frequency-selective for which complex stationary, zero mean gaussian random process which has a Rayleigh amplitude distribution and an uniformly distributed phase. β is a normalized constant defined for pulse a given shape so that the two following conditions are met [5]-[6] ;

$$E = \frac{1}{2}\int_0^T |p(t)|^2 dt, \quad \beta = \frac{1}{T}\int_0^T p(t) dt \quad (3)$$

And also, $r_k(t)$ can be expressed by inphase and quadrature components representing the input to the detector of the signal ;

$$\begin{aligned} r_k(t) &= r_{ki}(t)\cos 2\pi f_c t - r_{kq}(t)\sin 2\pi f_c t \\ &= \sqrt{r_{ki}^2(t) + r_{kq}^2(t)}\cos[2\pi f_c t + \tan^{-}(\frac{r_{ki}(t)}{r_{kq}(t)})] \quad (4) \\ &= R_k(t)\cos[2\pi f_c t + \tan^{-}(\frac{r_{ki}(t)}{r_{kq}(t)})] \end{aligned}$$

As we mentioned, we employ the dual diversity system, so the resultant combiner output with the phase detection output ($\widehat{\theta}_k$) is given by

$$\widehat{\theta} = w_1\widehat{\theta}_1 + w_2\widehat{\theta}_2, \quad w_1 + w_2 = 1 \quad (5)$$

where the weight, w_k, must be chosen to minimize

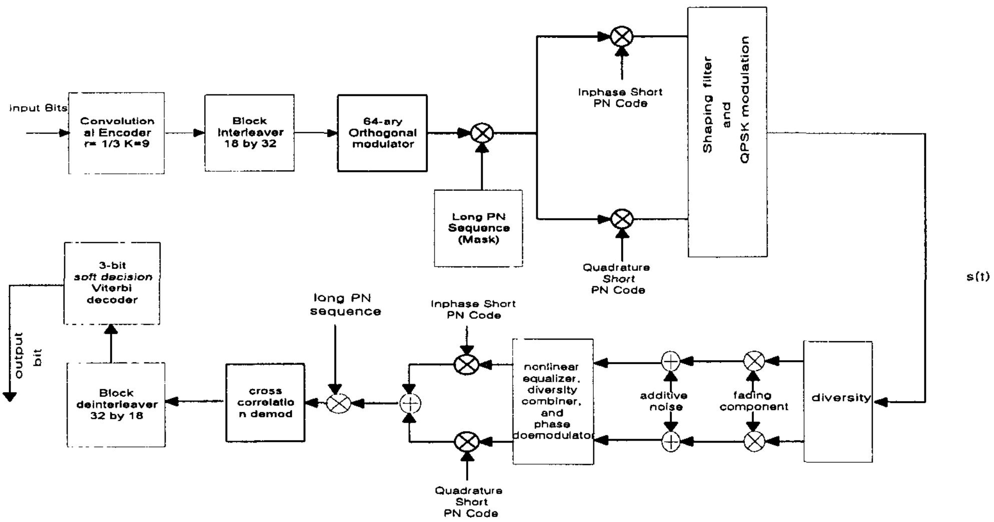


그림 1. 시스템 모델의 블록도
Fig.1. Block diagram of system model

the contribution of the weaker signal because the phase of noise becomes large when the received signal fades. Here, we use the weight proportional to the m th power of $R_k(nT)$,

$$w_k = \frac{R_k^m(nT)}{R_1^m(nT)+R_2^m(nT)}, \quad k=1,2 \qquad (6)$$

III. The Structure and Operations of Non-Linear Equalizer

The quantization process entails the partitioning of the observation space and the determination of optimal scores for each element of the partition. Using the training mode, we estimate quantiles, which are used in vector quantizer (VQ), and partition the observation space into m regions. For each partition, the partition moments which are required to calculate the coefficients of MMSE are estimated by RMSA. We can examine the quantiles by using the following recursive estimation

$$e_{n+1} = e_n - q_n[u(e_n-\tau_{n+1})-p], \; n=0,1,2,\ldots \qquad (7)$$

where $u(x)$ is Heaviside step function and q_n is the sequence of positive numbers having the following conditions

$$q_n = 0 \;\; as \;\; n\rightarrow\infty; \quad \sum_{n=0}^{\infty} q_n = \infty; \quad \sum_{n=0}^{\infty} q_n^2 < \infty \qquad (8)$$

Now, we are considering of establishing a recursive estimation scheme for estimating the partition moments defined by

$$m_i(a,b] = E[\chi_{(a,b]}(y)\; y^i], \quad i=1,2,\ldots \qquad (9)$$

where $\chi_{(a,b]}$ is the indicator function of the interval (a,b], and $\chi_{(a,b]}(y)y^i$ will be denoted by H. From the available sequence $[x_n]$, n=0, 1, 2,...., the proposed partition moments are

$$\mu_{n+1} = \mu_n + q_n[H_{n+1}-\mu_n] \qquad (10)$$

where $H_{n+1} = \chi_{(a,b]}(y)y^i$ and q_n satisfies the previous conditions described. Lomp[8] showed that the recursive estimation of partition moments (10), converges with probability 1. Let us consider MMSE estimation of the signal to be measured, a_n, from $(m+1)$ present and past received signals. The optimal estimate is the well known regression function and this function is non-linear, $E[a_n|y_n, y_{n-1}, y_{n-2}, \ldots, y_{n-m}]$.

Using Taylor series expansion, we approximate this function in the neighborhood of a point $(y_n^*, y_{n-1}^*, y_{n-2}^*, \ldots, y_{n-m}^*)$ as

$$\begin{aligned} & E[a_n|y_n, y_{n-1}, y_{n-2}, \ldots, y_{n-m}] \\ & = \beta(y_n^*, y_{n-1}^*, y_{n-2}^*, \ldots, y_{n-m}^*) \\ & + \sum_{k=0}^{m} a_k(y_n^*, y_{n-1}^*, y_{n-2}^*, \ldots, y_{n-m}^*) y_{n-k} \end{aligned} \qquad (11)$$

We replace the condition vector $(y_n, y_{n-1}, y_{n-2}, \ldots, y_{n-m})$ by the output of a VQ, i.e., $\Omega = \rho_1, \rho_2, \ldots, \rho_l$,where Ω is a finite set with elements called pseudo-states of $(y_n, y_{n-1}, y_{n-2}, \ldots, y_{n-m}) \in S$. Using the estimated quantiles and VQ, we can express the MSE such as

$$\begin{aligned} & MSE \\ & = E[(a_n - (\beta_{qk} + \gamma_{qk} y_n + \sum_{i=1}^{m} a_{qk,i} e_{n-i}))^2 \mid S_k] \end{aligned} \qquad (12)$$

where $e_{n-k} = y_{n-k} - a_{n-k}$ and a_{n-k} is detected symbol and k=1, 2, 3,...,m.

Using the orthogonality principle and RMSA algorithm and solving the partition moments by (10), we can get the coeffcients $(a_{qk}, \beta_{qk}, \gamma_{qk})$ for each partitioned sets, i.e.,

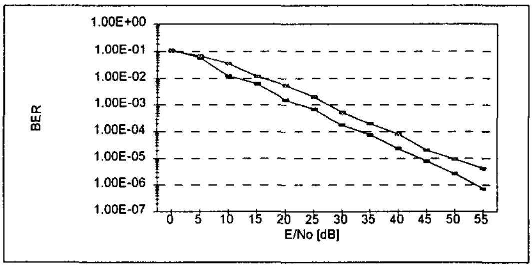
$$E\{a_n|y_n, e_{n-1}, e_{n-2}, \ldots .e_{n-m}\}$$

$$= \sum_{k=1}^{m} \chi_{S_k}[y_n, e_{n-1}, e_{n-2}, \ldots .e_{n-m}] \qquad (13)$$

$$\cdot [\beta_{qk} + \gamma_{qk} y_n + \sum_{i=1}^{m} a_{qk,i} e_{n-i}]$$

Ⅵ. Discussion of Results

In this paper, we use the dependent noise model generated by the auto regressive(AR) model as a noise component and take the 6 *th* order Chebychev filter to generate ISI. We choose a component having a Rayleigh amplitude distribution as a fading component. In Fig.2, we can see that the channel used in this paper is much more complex than the pure Rayleigh fading component. After setting the quantiles for using non-linear equalizer, we apply the real data to those quantities then the outputs of the non-linear equalizer pass through a single sample detector. We use 1125, total number of partitions, and 10^7 training samples. This non-linear MMSE equalizer performance is shown in Fig.3 including the maximal ratio diversity combining scheme according to SNR(signal to noise ratio). And also, we can save approximately 21dB at BER 10^{-5}



■ : Rayleigh fading(under line)

□ : Rayleigh fading + Additive dependent Gaussian noise(upper line)

그림 2. 가산성 종속 가우시안 잡음을 포함한 페이딩 잡음의 분석

Fig. 2. Evaluation of fading noise including the additive dependant Gaussian noise

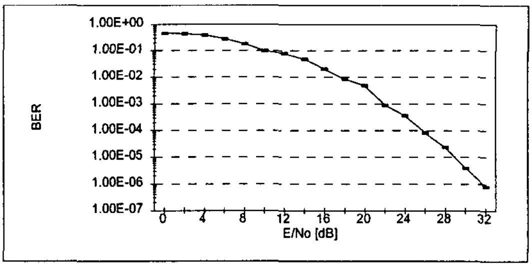
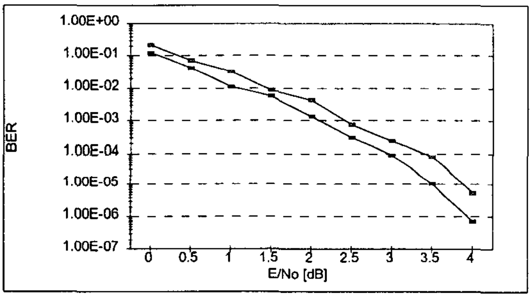


그림 3. Ratleigh 페이딩과 가산성 비독립 가우시안 잡음하에서 비선형 MMSE 등화기의 성능

Fig. 3. Performance of nonlinear MMSE equalizer under the Rayleigh fading and additive dependent Gaussian noise



■ : Performance of 3-bit soft decision Viterbi decoder under the Gaussian noise(upper line)

□ : Performance of system shown in Figure 1(under line)

그림 4. 본 논문에서 사용된 시스템의 성능

Fig. 4. Performance of system used in this paper

under the more complex fading channel and know that a BER of a non-linear equalizer is improved significantly as compared to a single sample detector and to the conventional decision feedback equalizer (DFE) [9]. Fig.4 shows that the performance of 3 bit soft decision Viterbi decoder(r=1/3 K=9) is almost near the bound known to us. And also, using BPSK as a quick reference, we know that the coding gain of soft decision Viterbi decoder(r=1/3, K=9) is almost 7dB in unfading channel and 24dB in Rayleigh fading channel. But in this paper, in spite of more complex channel, we can see the just small difference (0.6 dB at BER 10^{-5}) of performance in Fig.4 when we employ the non-linear MMSE equalizer.

V. Concluding Remarks

The overall performance of CDMA system using this equalizer is evaluated under the channel caused by multipath delay spread and corrupted by additive dependent noise. The use of statistical methods of detection and estimation theory has provided powerful signal processing techniques for communication system design. In this paper, we know the design of a non-linear equalizer having the ability to suppress problems caused by both gaussian and dependent gaussian noise and know that the structure of the nonlinear robust equalizer can be chosen to minimize the mean square error(MSE) with respect to the transmitted information. And also, we know that this equalizer can get approximately 21dB power gain at BER 10^{-5} under the more complex fading channel and know that a BER of a non-linear equalizer is improved significantly as compared to a single sample detector and to the conventional decision feedback equalizer (DFE).

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