효율적 4세대 이동무선시스템을 위한 대수가능성비 기반의 인터리버 분할 다중접속기술의 성능 예측

정연호*

Performance Prediction of Interleave-Division Multiple Access Scheme based on Log-likelihood Ratio (LLR) for An Efficient 4G Mobile Radio System

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요 약

본 논문은 효율적인 4세대 이동통신 시스템을 위한 대수가능성율 기반의 인터리버분할 다중접속 시스템의 성능 예측 메카니즘을 제안한다. 기존 시스템에서는 대수가능성율을 수신기에 단순 전달을 통해 반복적으로 가능성값을 개선시켜 성능 향상을 얻는다. 본 연구에서는 대수가능성율의 단순 전달이전에 대수가능성율 값을 분석하여 비트오율을 예측한다. 이러한 예측을 통하여 수신기의 불필요한 반복 연산을 줄일 수 있으며 성능을 예측할 수 있어 효율적 시스템 설계가 가능하다. 다중 사용자 인터리버 분할 다중접속 시스템의 다양한 전송 시나리오를 구성하여 제안한 메카니즘을 분석하였는데 예측 메카니즘의 성능을 확인하였으며 향후 4세대 시스템중의 하나로 고려되고 있는 인터리버 분할 다중접속 시스템 개발에 유용하게 사용할 수 있을 것이다.

ABSTRACT

This paper presents a prediction mechanism of performance for an efficient interleave-division multiple access (IDMA) scheme that is being considered as 4th generation mobile radio system. The scheme is based upon log-likelihood ratio (LLR) to predict the performance of the IDMA. The conventional IDMA system simply passes the LLR values to a coarse estimation process in the receiver over a pre-defined number of iterations for an acceptable performance. The proposed IDMA system uses the LLRs to predict its BER performance and thus the iterative operation at the receiver can significantly be reduced when the performance attains an acceptable level. Performance evaluation shows that the proposed scheme of the IDMA with the LLRs used for the prediction provides a comparable BER performance. The use of the LLRs can facilitate an efficient design of the IDMA system that is a strong candidate system for 4G mobile radio systems.

키워드

Interleave-Division Multiple Access, Log-likelihood Ratio, Performance Prediction, Multiple Access

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Ⅰ. Introduction

Code division multiple access (CDMA) system is approved around the world to be the main access scheme in an increasing demand for system capacity of cellular communication systems. This is due to the fact that CDMA utilizes its spectrum efficiently with the help of interference rejection and power control. The performance of CDMA is often enhanced by using forward error correction coding (FEC). In multi-user CDMA transmission environments, iterative decoding and soft interference cancellation based on MMSE filter as part of multi-user detection (MUD) and decoding has been studied [1].

Recently, a CDMA-like system with a different user separation strategy based on interleaver has been proposed. This scheme is called interleave-division multiple access (IDMA) [2],[3]. This system employs a user-specific interleaver for each user and a chip-by-chip multi-user detection (MUD) is used at the receiver. By making use of log-likelihood ratio (LLR) decoding [4], the receiver performs iterative detection to achieve required performance. IDMA is proved to be superior to CDMA, due to simple but efficient detection structure.

Since IDMA requires to use the same number of random interleavers as the users, the base station has to use a considerable amount of memory to store these interleavers. Also, an information passing mechanism is necessary during the initialization process. To alleviate this problem, a power-interleaver is proposed [5].

LLR values are known to indicate a probability of detecting a transmitted symbol at the receiver. When the LLR values are used at the iterative operations of the receiver, detection error probability can be computed and thus a prediction mechanism of BER performance can be established. The predicted performance so obtained is useful for controlling the iterative receiver operation. In other words, an efficient IDMA system can be designed in terms of its reduced complexity of the receiver operation.

In this paper, we consider a prediction mechanism of IDMA performance based on LLRs. This mechanism is important and useful in that we can develop an adaptive IDMA in terms of the size of interleaving and/or code rate for an acceptable performance. An accurate prediction can be easily applied for a more practical IDMA system that is presently considered as a candidate for 4G wireless communication systems.

Section 2 describes a review of the IDMA system and is followed by the LLR-based prediction in Section 3. Section 4 shows the evaluation of the prediction performance and conclusions are drawn in Section 5.

Ⅱ. IDMA System

In multiple access schemes, a unique feature of user separation is necessary. For CDMA systems, signature sequences are used. By spreading the user data with each signature sequence, i.e. bandwidth expansion, user separation and interference rejection capability are achieved. In the IDMA, however, we employ an independent and random interleaver for each user. In other words, interleaver plays an important role in the IDMA scheme in view of reducing multiple access interference (MAI), while the chip-by-chip multi-user detection method enhances its performance. The transmitter and receiver structures are shown in Fig. 1 and 2, respectively. In the transmitter, the user data are first encoded by the convolutional encoder, followed by the repetition code. The repetition code is viewed as a spreader as in the CDMA, except for the fact that this code is common to all users. Therefore, each data bit is convolutionally coded and spread by this repetition code prior to the user-specific interleaver, thus the resultant data of the repetition code being aptly called chip. It can be viewed that the IDMA employs a chip-level interleaving process.

We consider BPSK modulated data and use the discrete-time baseband system to describe the operation of the transmitter. We assume that there are K simultaneous users. The data sequence of user k is then denoted by $d_k = [d_k(0), d_k(1), \cdots, d_k(N-1)]_T$, $k = 1,2,\cdots,K$. N is the length of data block. The coded sequence by a convolutional coder is c_k = [$c_k(0)$, $c_k(1)$, ⋯, $c_k(N_c-1)$]$_T$. That is, the code rate is defined as $R_1 = N/N_c$. As mentioned previously, this coded sequence is repeated by the simple repetition code with a rate of $R_2=1/N_r$, producing the chip signal. Thus, the overall code rate is R_1R_2. This sequence is then permutated by each interleaver generated independently and randomly for each user. Therefore, the interleaved data sequence is then x_k = [$x_k(0)$, $x_k(1)$, ⋯, $x_k(N_t-1)$]$_T$.

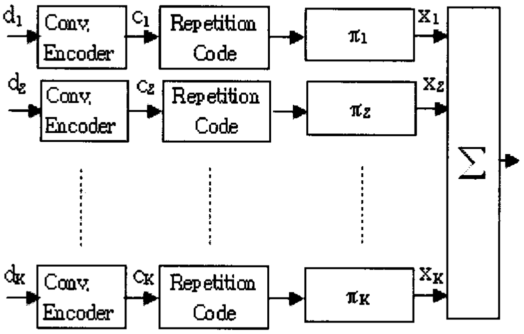

그림1. IDMA 시스템 전송부
Fig. 1. The IDMA transmitter structure

In the receiver, the multi-user detection is first performed. For user k, we can express the received signal as

$$y_k = h_k * x_k + n_k \tag{1}$$

where * denotes convolution, h_k is the channel coefficient for the user k, x_k is the transmitted signal for the user k and n_k is the additive white Gaussian noise. For a length N_t of the transmitted signal and L-multipath coefficients of the channel, the dimension of y_k is $(L+N_t-1)$ x 1.

In matrix form, (1) can be rewritten as

$$\mathbf{y}_k = \mathbf{H}_k \mathbf{x}_k + \mathbf{n}_k \tag{2}$$

where H_k is of dimension (N_t+L-1) x N_t. By defining each column of H_k as $h_k(m)$, we have

$$y_k = \sum_{m=0}^{N_t-1} h_k(m) x_k(m) + n_k \tag{3}$$

In the iterative multiuser detection employed in the IDMA, the a posteriori log-likelihood ratio (LLR) is used. That is,

$$L(d_k(i)) = \log \frac{P\{d_k(i)=1|y_k\}}{P\{d_k(i)=0|y_k\}}$$

$$= \log \frac{P\{y_k| d_k(i)=1\}}{P\{y_k|d_k(i)=0\}} + \log \frac{P\{d_k(i)=1\}}{P\{d_k(i)=0\}}$$

$$= L_e(d_k(i)) + L_a(d_k(i)) \tag{4}$$

The first term of Eq.(4) is channel information, whereas the second term denotes a priori information.

The first step in the IDMA receiver performs the MUD operation. That is, it produces the extrinsic LLRs. Assuming that n_k is Gaussian distributed with the variance of σ_n^2, this extrinsic LLR is found to be

$$L_e(d_k(i)) = \log \frac{P\{y_k|d_k(i)=1\}}{P\{y_k|d_k(i)=0\}} \tag{5}$$

$$= \frac{2h_k n_k}{\sigma_n^2}$$

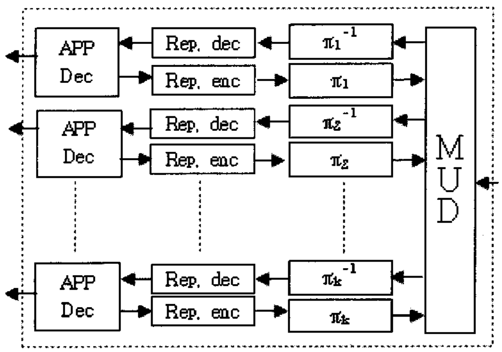

그림 2. IDMA 시스템 수신부
Fig. 2. The IDMA receiver structure

The extrinsic LLRs are deinterleaved and decoded using the repetition code as shown in Fig. 2.

The next step is to perform the a posteriori probability (APP) decoding based on the deinterleaved and derepeated extrinsic LLRs. The output of this operation, $L_e(c_k(i))$, is used to generate the following statistics [3]

$$E(x_k(i)) = \tanh\{L_e(c_k(i))/2\} \tag{6}$$

$$\sigma^2_{x_k}(i) = 1 - \{E(x_k(i))\}^2 \tag{7}$$

In producing $L_e(c_k(i))$, the input to the APP decoder can be subtracted from the output of APP decoder to ensure that the output of the APP decoder is truly extrinsic. However, this would require the storage of the output of the first step operation and more computation. This process can be avoided for reduced computational complexity and memory requirement at the expense of performance loss [3].

Ⅲ. LLR-based Prediction

In IDMA, the APP decoding is utilized to refine estimates of the convolutional decoder output as shown in Fig. 2. The APP decoder produces probabilities or LLR values that can be used for various purposes. In the presently study, we use these values to estimate the BER performance at each iteration. It is clear that the more we perform the iteration, the more accurate the estimates will be.

The average bit error rate (BER) is defined as

$$P_e = \lim_{N\to\infty} \frac{1}{N}\sum_{n=1}^{N} P_e^n \tag{8}$$

where N denotes the number of estimates. Obviously, P_e^n takes values based on error occurrence for the received bits. Instead of hard decision values, we use soft-decision values based on LLRs. That is, Eq.(8) can be rewritten as

$$P_e^n = \frac{1}{1+e^{|L_n|}} \tag{9}$$

Eq.(9) can easily be obtained from Eq.(4). In other words, the absolute values of the LLR values are used for the calculation of BERs. It is seen that the P_e^n values are exponentially symmetric.

For a particular symbol, Eq.(9) can be rewritten as

$$P\{d_n = -1\} = \frac{1}{1+e^{L(d_n)}} \tag{10}$$

This value can be used to observe the probability of being a particular symbol based on its likelihood function. Likewise, the other symbol, i.e. $P\{d_k=+1\}$, can be obtained and its probability can be computed accordingly.

Let us consider P_e^n as a random variable and rewrite Eq.(9) as follows:

$$R = \frac{1}{1+e^{|L_n|}} = \frac{1}{1+e^{l}} \tag{11}$$

Therefore, the probability of error will be

$$P_e = E[R] = \int_r r f_R(r)dr \tag{12}$$

where E[·] indicates expectation operator and f(·) denotes probability density function. By change of variables, $f_R(r)$ is given by

$$f_R(r) = \frac{f_L(l)}{\left|\frac{dR}{dl}\right|} = \frac{1}{r(1-r)} f_L\left(\ln\frac{1-r}{r}\right) \tag{13}$$

In this study, the LLR-based performance prediction scheme has been investigated using the method described in Eq.(9). Also, the performance is compared with its BER performance obtained from the conventional method.

Ⅳ. Simulations and Results

In this section, performance of the IDMA based on the LLR prediction is presented. The parameters used in the simulation are as follows. The data length of each block is 256. For a forward error correcting (FEC) code and extrinsic LLRs described in Section II, we use the convolutional code of $(23,35)_8$ in the simulation. In addition, BPSK modulation scheme is used for data modulation throughout evaluation. The use of this simple modulation scheme is justified, since the present study focuses on the performance of prediction mechanism based on the LLRs.

As mentioned in Section 3, the computationally efficient method in computing extrinsic LLRs has been adopted. Although the use of full extrinsic LLRs computation would provide slightly higher performance gain, this alternative method is employed to reduce its computational complexity in conducting comparative performance analysis.

The proposed prediction system is developed on the platform of Matlab Simulink [7]. Fig.3 illustrates the top-level block diagram of the LLR-based performance prediction system with 2 simultaneous users present.

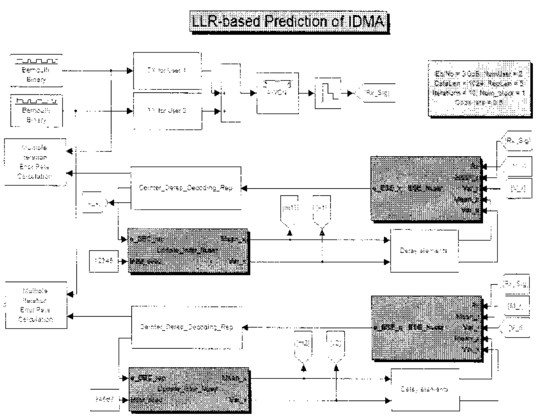

그림 3. 제안한 시스템의 최상위레벨 블럭도
Fig.3 Top-level block diagram of the proposed system

Fig. 4 shows the performance comparison between the proposed scheme and the conventional method for the IDMA system. For this comparison, we assumed 5 simultaneous users (K) with the repetition code length of 8 (Nr). Also, the number of iteration (R) was chosen to be 5. It can be seen that the two performances are very similar, so that the prediction mechanism based on the LLRs is in good agreement with the method we usually employ.

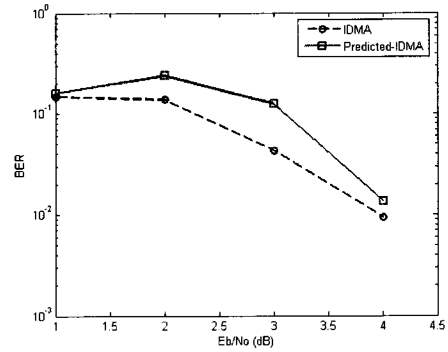

그림 4. 성능 비교 (K=5, Nr=8, R=5)
Fig.4 Performance comparison for K=5, Nr=8 and R=5

For investigating reliability of the proposed system further, a few more comparative studies were conducted with different system parameters. With 5 simultaneous users and the repetition length of 8, but an increased number of iteration of 10, the performances were compared.

Fig. 5 shows its performance comparative study result. As the number of iterations increases, the difference between the two systems becomes smaller. In other words, the more refined values of the LLRs are used in the prediction, so that the prediction becomes more reliable. This can be fairly anticipated that the performance with higher iteration would produce more refined LLR values, thus improving its performance as well as the performance prediction.

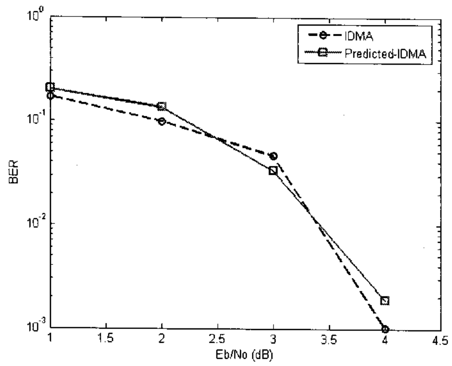

그림 5. 성능 비교 (K=5, Nr=8, R=10)
Fig.5 Performance comparison for K=5, Nr=8 and R=10

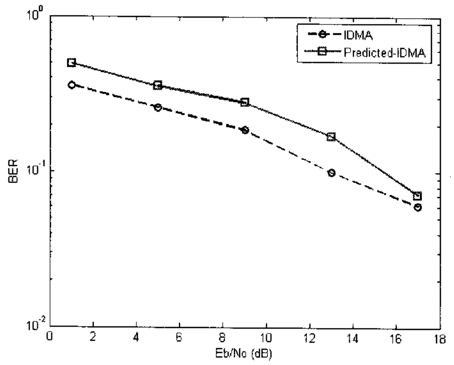

그림 6. 성능 비교 (K=10, Nr=8, R=5)
Fig.6 Performance comparison for K=10, Nr=8 and R=5

Fig.6 shows the performance comparison with different transmission scenarios. That is, we increase the number of simultaneous users (K) to 10, while other parameters remain unchanged.

It can be seen that the overall performance of the prediction mechanism shows a good agreement with the performance we often obtain by comparing between the transmitted bits and received bits.

Similarly, for the increased number of iteration of 15, we can observe the same phenomenon as the previous simulation scenarios in Fig.7. In addition, we note that we need to employ a relatively high number of iterations to obtain an acceptable BER performance as the number of users increases.

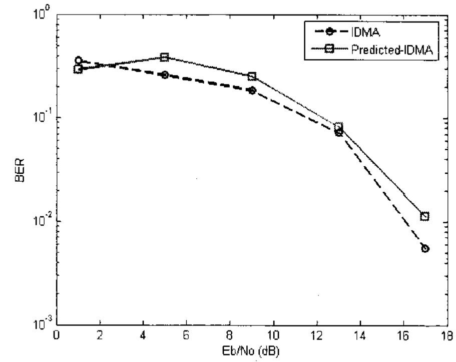

그림 7. 성능 비교 (K=10, Nr=8, R=15)
Fig.7. Performance comparison for K=10, Nr=8 and R=15

From the results of the comparative study, it can be concluded that the proposed prediction mechanism provides a reliable means of predicting the BER performance of IDMA, although it tends to produce slightly higher BER's than actual BER's. Therefore, this important finding can be used for designing an efficient IDMA system, either by controlling the iteration process for an acceptable performance or by avoiding unnecessary iterations once it reaches a desired performance.

V. Conclusions

An IDMA system with the prediction mechanism based on the LLR values at the output of APP decoding is proposed. Since the soft values of the likelihood functions indicate a detection probability, these values are directly used for predicting the BER performance. Simulation results show that the proposed mechanism works well and shows good agreement with the performances the conventional method provides. Therefore, an efficient IDMA system can be designed such that the number of iteration at the receiver can optimally be chosen for an acceptable performance. In addition, this reliable prediction method will eventually be able to pave the way for an adaptive IDMA system with various adaptation parameters. Further studies are being conducted for designing a highly efficient IDMA system, based on the present prediction method.

References

[1] Wang, X. and Poor H.V., "Iterative (Turbo) soft interference cancellation and decoding for coded CDMA," IEEE Trans. Comm. Vol.7, No.7, pp.1046-1061, July 1999

[2] Ping, Li, "Interleave-division multiple access and chip-by-chip iterative multi- user detection," IEEE Comm. Mag. Vol. 43, No.6, pp. S19-S23, June 2005

[3] Ping, Li, Liu, L., Wu, Keying and Leung, W.K.," Interleave-Division Multiple-Access, " IEEE Trans. on Wireless Comm., Vol.5, No.4, pp. 938-947, April 2006

[4] Li, C., Li, K., Wang, X. and Ping, L., "Optimal IDM-MISO transmit strategy with partial CSI at transmitter," Proc. 40thAnnual Conf. on Information Sciences and Systems (CISS'06), Princeton, N.J. Mar. 2006

[5] Wu, H., Ping L. and Perotti A., "User- specific chip-level interleaver design for IDMA systems," IEE Elec. Lett. Vol.42, No.4, Feb. 2006

[6] Kusume, K. and Bauch, G., "Simple construction of multiple interleavers: cyclically shifting a single interleaver," IEEE Trasn. Comm. Vol.56, No.9, pp.1394-1397, Sept. 2008

[7] http://www.mathworks.com

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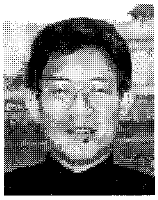

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