SIMPLIFIED COMPUTATION OF LOG-LIKELIHOOD RATIO VALUES FOR HIGH-ORDER MODULATIONS

[1]IN-WOONG KANG, [2]KYU-SOON OK, [3]YOUNGMIN KIM, [4]JAE HYUN SEO, [5]HEUNG MOOK KIM, [6]HYOUNG-NAM KIM

[1,2,6]Dept. of Electrical and Computer Engineering, Pusan National University, Busan, Korea
[3,4,5]Electronics and Telecommunications Research Institute, Daejeon, Korea
E-mail: hnkim@pusan.ac.kr

Abstract- This paper proposes a method to approximately compute log-likelihood ratio (LLR) values with reduced complexity. Conventionally, the maximum-likelihood (ML) method is used as the optimum LLR computation method in terms of reception performance. However, the ML method has a drawback that its computational complexity increases exponentially with the modulation order of the system. Although this complexity issue may not significantly affect the reception time with low modulation orders, when high order modulations such as 4096-quadrature amplitude modulation (QAM) are used the ML method may not be used due to its enormous amount of computations. In this respect, this paper proposes an approximation to compute the LLR values. The proposed method requires only M one-dimensional (1D) Euclidian distances for one modulated symbol while the ML method needs 2M 2D distances which may not be implementable with high order modulation. As a cost of the complexity reduction, the proposed method shows an acceptable performance degradation.

Keywords- High Order Modulation, Log-likelihood ratio, Maximum-Likelihood Estimation.

I. INTRODUCTION

As high-quality digital multimedia services, such as 3-dimensional television (3DTV) and ultra-high definition television (UHDTV) services, are going to be transmitted, the necessity for the enhancement of the transmission data rate of the systems has been highlighted.

As one of prospective approaches, adopting the high order modulation schemes, such as a 4096-QAM, has been studied As modulated symbols carry more bits, receivers suffer from increased complexity to demodulate the received symbols into soft values, such as LLRs, whose sign and magnitude denote the hard decision result and its reliability. As a conventional method to compute the LLRs, the ML method can be used whose complexity increases exponentially with the modulation order. With this high complexity, high order modulation schemes will cost impractical reception time to receivers unless a less complex method replaces the slow conventional method. In order to reduce decoding complexity, there have been some approaches to modify the conventional ML method.

However, such strategy merely tries to reduce a part of the ML method's complexity. When the large modulation order is used, the elimination of some of total computations may not be enough because the amount of the residual computations is still enormous.

In order to achieve a significant reduction of the LLR computation complexity, this paper proposes an algorithm to compute approximated LLRs which requires linearly increasing complexity with modulation order.

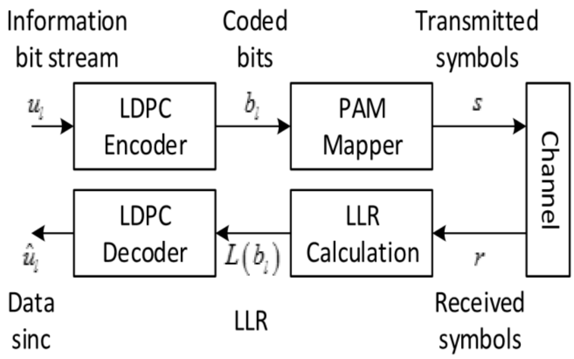

Figure 1. System model

II. SYSTEM MODEL

In Fig. 1, a block diagram of the system model considered in this paper is presented. The information bit stream is encoded by low-density parity check code (LDPC) encoder and at the output of the encoder the forward error correction (FEC) frames are generated. The M coded bits in the FEC frames are grouped and the groups of coded bits are mapped into symbols by the pulse amplitude modulation (PAM) mapper.

The PAM modulation symbols are transmitted over wireless channel and the symbols are distorted by the channel fading. After receiving the distorted symbols, the LLR calculation block demodulates a received symbol into M LLR values. With this soft values, the LDPC decoder performs error correction. The correction performance deeply depends on how to compute the LLR values.

The optimal method to compute the LLRs is the ML method which is expressed as follows

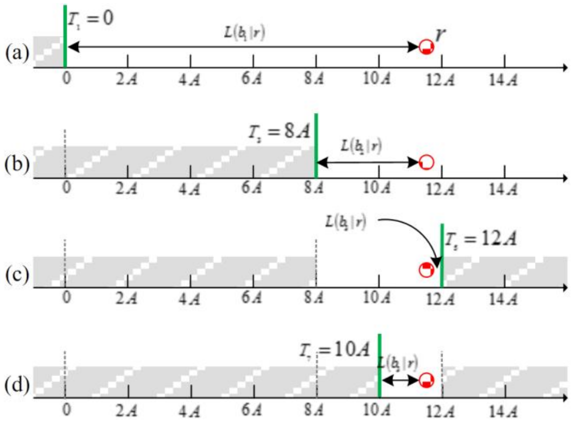

Figure 2. The LLR values are approximated by the Euclidean distances between hard decision threshold (T) and the received symbol (r).

$$L(b_l) = \log \frac{\sum_{s\in\Lambda_l^1} f(r|s)}{\sum_{s\in\Lambda_l^0} f(r|s)} \approx \frac{1}{\sigma^2}\left[\min_{s\in\Lambda_l^1}|r-s|^2 - \min_{s\in\Lambda_l^0}|r-s|^2\right], \tag{1}$$

where, and f(r|s) denotes the LLR value for lth bit in the received symbol r, the subsets of symbols whose lth bit is b(0 or 1), and likelihood function of s with r.

According to (1), the ML method computes the two-dimensional Euclidean distances between the received symbol r and all of the symbols in set whose number of elements is 2M. In fact, if M is not big (e.g., 2) the computational complexity does not make a severe decoding complexity issue. However, with a big M (e.g., 8 or 10) the exponentially increased number of computations for obtaining all of the Euclidean distances result in a big burden at the receiver. In this respect, this paper proposes an approximation to compute the LLRs and its implementation in the next section.

III. PROPOSED LLR COMPUTATION ALGORITHM

The proposed method approximates the LLR computations as follows

$$L(b_l) = \phi(l)\frac{|r-T_l|}{\sigma^2} \tag{2}$$

where $\phi(l)$ and $|r-T_l|/\sigma^2$ are the sign and the magnitude of the resultant approximation values. The magnitudes are simply one-dimensional Euclidean distances between hard decision thresholds (T_l) and the received symbol (r) as graphically depicted in Fig. 2. From Fig. 2(a) to (d), the circle and the vertical bar denote the received symbol (r) and the hard decision threshold for lth modulation level, respectively.

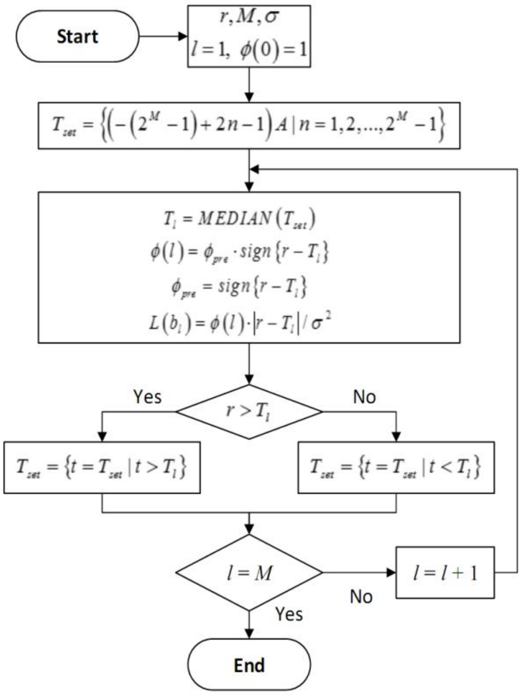

Figure 3. Flow chart of the proposed LLR computation algorithm.

Table 1. Comparison of computational complexity for one LLR value the modulation order M

Computation	ML Method	Proposed Method
$\lvert\cdot\rvert^2$	2^M	0
$\lvert\cdot\rvert$	0	1

Including sign computations, the overall proposed algorithm is described in a flow chart in Fig. 3. With the received symbols (r), the modulation order (M), and the noise power (σ^2) are given, the modulation index (l) of the algorithm is set as 1 and the initial value of the sign ($\phi(0)$) is also set as 1, respectively. Then, the initial set (T_{set}) of the decision thresholds is defined. With T_{set}, the T_l is determined by finding the median element out of T_{set}. The T_l value is used to compute the magnitude and the sign of the approximated LLR values ($L(b_l)$) for lth modulation level. After obtaining $L(b_l)$, the algorithm updates T_{set} as a final step of the algorithm for lth modulation level. The algorithm recursively performs the same procedure until l reaches its maximum modulation level, M.

The computational complexities of two method, the ML and the proposed methods, are compared in Table 1. While the ML method requires 2^M two-dimensional Euclidean distance computations ($|\cdot|^2$) for one LLR value, the proposed method approximates a LLR value with only a one-dimensional distance ($|\cdot|$).

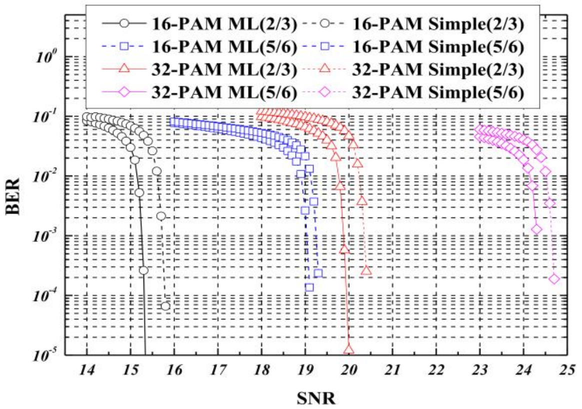

Figure 4. Coded BER performance.

IV. SIMULATION RESULTS

The simulation results of bit error rate (BER) is given in Fig. 4. The performance of the ML and the proposed method with 16-PAM and 32-PAM modulations, and 2/3- and 5/6-rate LDPC codes are evaluated over AWGN channel. It was shown that the reception performance of the proposed method is degraded less than 0.5 dB of SNR compared to the ML method as a cost of the dramatic complexity reduction. It should be noted that since the ML method may require too long computation time to be implemented at the receiver especially with high order modulated symbols. In this respect, the proposed simple method can be regarded as one of efficient alternative methods to compute soft values of the received symbols in spite of its performance degradation.

CONCLUSION

This paper proposes a simplified method to compute the LLR values with drastically reduced complexity. By modifying the conventional ML method equation to a simpler one, the computation of LLRs becomes much faster enough to be implemented at DTV receivers. Although there exists BER performance degradation, it is less than 0.5 dB of SNR which can be decreased in the future and the reduced complexity is considered to be compensated by its significantly reduced complexity.

ACKNOWLEDGMENT

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