New Hierarchical Modulation Scheme Using a Constellation Rotation Method

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***Abstract*—In this paper, we propose a new hierarchical modulation scheme for DVB-NGH to improve the performance of LP (Low-Parity) signals by applying a conventional constellation-rotation method to the LP signals with virtually no loss of performance in the HP (High-Parity) signals. The improvement of the LP signals is mainly due to the increased diversity gain caused by the constellation-rotation method which barely affects the performance of the HP signals. For the new scheme, we also propose a hardware-efficient ML (Maximum-Likelihood) detection algorithm that first decodes the HP signals using a conventional HP receiver, followed by simply decoding the precoded LP signals based on the pre-detected HP signals.**

Keywords-hierarchical modulation; constellation rotation; maximum likelyhood decoding; DVB-NGH; broadcasting Systems

I. INTRODUCTION

Current broadcasting services provide high definition (HD), 3-Dimensions (3D) and Ultra HD (UHD) in commercial services. Research on high capacity and efficient frequency usage is also ongoing for a variety of content transfer and higher order modulations have been continuously studied [1]. However, higher order modulations are not effective in terms of maintaining backward compatibility. Thus a technique to increase the transmission rate while maintaining backward compatibility is required. Hierarchical modulation is one of the best ways to achieve these conditions [2-3]. Hierarchical modulation adopt in the variety broadcasting standard such as Digital video broadcasting - terrestrial (DVB-T) [4], terrestrial – digital multimedia broadcasting (T-DMB) [5], advanced T-DMB (AT-DMB) [6] and Digital Video Broadcasting - Next Generation broadcasting system to Handheld (DVB-NGH) [7].

Hierarchical modulation is a technique for increasing the effective data according to the channel environment and conditions by inserting additional data. Hierarchical modulation applied to a next generation mobile broadcasting standard is modulated with low priority (LP) signals around high priority (HP) signals. Hierarchical modulation can be used to effectively transmit data to other users. For a good-channel status, the user receives all of the data in the HP signal and LP signal, which provides a high-performance service. Bad-channel status users receive only the data from the HP signal resulting in a low-performance service.

However, it is difficult to optimize due to the performance trade-off between the HP signal and the LP signal. Performance degradation is inevitable in the HP signal of the conventional receiver because the LP signal is too noisy.

So, the power of the HP signal is assigned to at least three times that of the LP signal power to minimize the degradation of the HP signal for backward compatibility in the DVB-NGH standard. However, performance degradation of the LP signal occurs due to the relatively low transmission power of the LP signal. Therefore, in this paper, we propose a new Hierarchical modulation applying to the constellation rotation (CR) method to enhance the performance of the LP signal and minimize the performance of the HP signal [8-9].

The rest of the paper is organized as follows: In chapter II, we briefly review the conventional Hierarchical modulation scheme; in chapter III, the new Hierarchical modulation scheme applied to the CR method is presented; and lastly, the simulation results and conclusions are presented in chapters IV and V, respectively

II. CONVENTIONAL HIERARCHICAL MODULATION SCHEME

The block diagram for the conventional hierarchical modulation is depicted in Fig. 1.

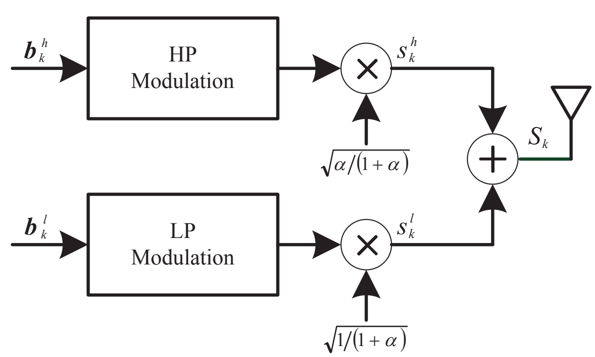

Figure 1. Transmitter block diagram for hierarchical modulation.

First, in the transmitter, the kth input bit vectors $\boldsymbol{b}_k^h$ and $\boldsymbol{b}_k^l$ are modulated by the QAM constellation. The power of the HP signal s_k^h and the LP signal s_k^l is determined by the hierarchical modulation coefficient α, respectively, and α is the power ratio of the HP and LP signals. Then, a single

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hierarchical modulated signal s_k is transmitted to the transmission antenna. Here, α is a coefficient that determines the power ratio for the HP and LP signals.

Fig. 2 presents one example of the hierarchical modulated constellation when using s_k^h and s_k^l signals set to the 4QAM with $\alpha = 3$.

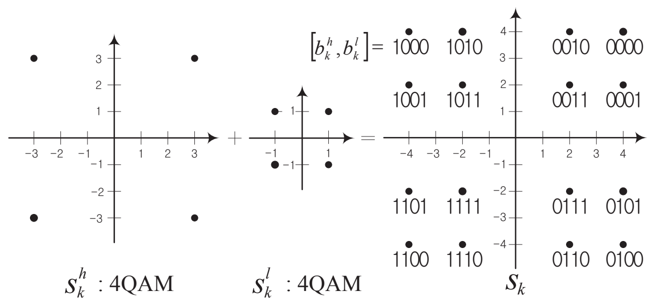

Figure 2. Constellation of hierarchical modulation with $\alpha = 3$.

This transmitted hierarchical modulated signal passes through the fading channel and the received signal is decoded by an ML decoder. The matched filter output y_k can be expressed as below;

$$y_k = h_k\left\{\sqrt{\alpha/(1+\alpha)}\, s_k^h + \sqrt{1/(1+\alpha)}\, s_k^l\right\} + n_k \quad (1)$$
$$= h_k s_k + n_k\ , \quad (2)$$

where, h_k is a Rayleigh fading-channel gain that is modeled as an independent and identically distributed (i.i.d.) complex Gaussian random variable with a zero mean and a unit variance, and n_k denotes an i.i.d. complex white Gaussian noise sample with a zero mean and a variance of $2\sigma^2$. The hierarchical modulation ML detection of (2) can be written as

$$\hat{s}_k = \arg\min_{s_k} |y_k - h_k s_k|^2 \quad (3)$$
$$= \arg\min_{s_k(s_k^h, s_k^l)} \left| y_k - \sqrt{\tfrac{\alpha}{1+\alpha}}\, h_k s_k^h - \sqrt{\tfrac{1}{1+\alpha}}\, h_k s_k^l \right|^2 . \quad (4)$$

However, ML detection such as in (4) is possible in the new receiver to demodulate both the HP and LP signals, and the conventional receiver capable of receiving only the HP signal assumes the LP signal to be noise. So, the conventional receiver can decode only s_k^h as below;

$$\hat{s}_k^h = \arg\min_{s_k^h} \left| y_k - \sqrt{\tfrac{\alpha}{1+\alpha}}\, h_k s_k^h \right|^2 . \quad (5)$$

In other words, s_k^h decoding of performance degradation in (5) is due to the assumption of s_k^l as additional noise. Compared to ML decoding in (4), there is a problem with backward compatibility. For this reason, in systems using hierarchical modulation, such as DVB-NGH [7], the constellation of the LP signal is adjusted by α to prevent the decision bounding of the HP signal as shown in Figure 2. Therefore, the s_k^h signal detection method in (5) has the same performance as ML detection in (4). Decoding of the LP signal can easily be performed as below

$$\hat{s}_k^l = \arg\min_{s_k^l} \left| y_k' - \sqrt{\tfrac{1}{1+\alpha}}\, h_k s_k^l \right|^2 , \quad (6)$$

where, $y_k' = y_k - \sqrt{\alpha/(1+\alpha)}\, h_k \hat{s}_k^h$. In other words, (6) the decoded signal $\hat{s}_k^h$ is first eliminated in (5), and the final ML decoding proceed based on the newly received signal y_k'.

This hierarchical modulation is a technique that can be expected for higher transmission efficiency in a good channel environment. The hierarchical modulation can be independently decoded in the HP and LP signals and thus can be effectively applied to backward compatibility critical systems. As mentioned earlier, due to the relatively low signal power, the LP signal requires a high signal to noise ratio (SNR) and the threshold of visibility (ToV) is not satisfied in many areas. Therefore, in this paper, we propose a new hierarchical modulation scheme to enhance the performance of LP signal.

III. New Hierarchical Modulation Applied Constellation Rotation Method

In this chapter, we propose new a hierarchical modulation scheme applied CR method [8-9] to improve the performance of the LP signal while minimizing the performance degradation of the HP signal.

A. Conventional Constellation Rotation Method

The CR method [8], [9] generates a rotated vector $\boldsymbol{r} = [r_1, r_2]^T$ by using a precoder of the QAM modulated signal vector $\boldsymbol{s} = [s_1, s_2]^T$ for twice the symbol duration, where $[\cdot]^T$ is the transpose operator. In this paper, we use the real precoder and the rotated vector generated by the real precoder can be expressed as below

$$\boldsymbol{r} = \boldsymbol{\Theta s} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} . \quad (7)$$

The CR signals are assumed to pass through the ideal independent erasure fading channel with the ideal symbol interleaving. Therefore each of the real and imaginary components of every rotated symbol is guaranteed to undergo independent erasure fading. Hence if at least one of the two components arrives without error at the receiver, the demodulator can recover the symbol perfectly. Consequently, throughout the CR method, the transmission scheme has an additional diversity gain of two, resulting in further performance improvement. The optimized CR angles for a variety of modulation types under the erasure Rayleigh-fading channels are shown in Table I [8].

TABLE I. OPTIMUM ROTATION ANGLE FOR EACH MODULATION [8].

Mod.	4QAM	16QAM	64QAM	256QAM
θ	29.0^o	16.8^o	8.6^o	3.6^o

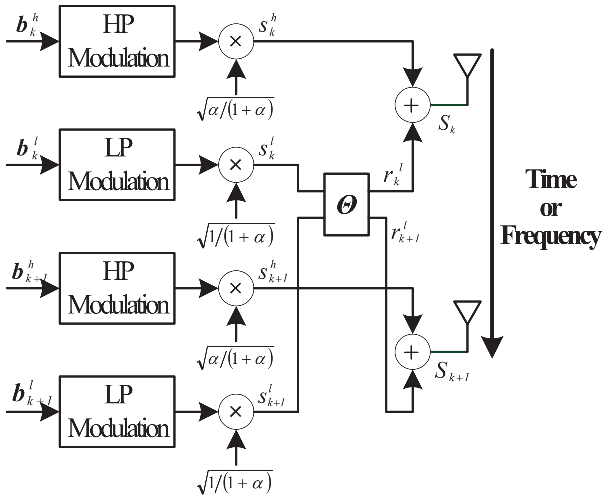

Figure 3. Block diagram for new hierarchical modulation adapted in CR modulation method.

B. New Hierarchical Modulation Scheme

The block diagram for the proposed new hierarchical modulation adapted in the CR method is depicted in Fig. 3.

At first, the new hierarchical modulation shown in Fig. 3 generates two rotated LP (R-LP) signals by using the real precoder $\boldsymbol{\Theta}$ from (7) with incoming LP signals of $\boldsymbol{s}_k^l = \sqrt{1/(1+\alpha)}\left[s_k^l\ s_{k+1}^l\right]^T$ over twice the symbol duration as below;

$$\boldsymbol{r}_k^l = \boldsymbol{\Theta}\boldsymbol{s}_k^l = \begin{bmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{bmatrix}\begin{bmatrix}\sqrt{1/(1+\alpha)}\,s_k^l\\ \sqrt{1/(1+\alpha)}\,s_{k+1}^l\end{bmatrix} \quad (8)$$

Two HP signals $\boldsymbol{s}_k^h = \sqrt{a/(1+\alpha)}\left[s_k^h\ s_{k+1}^h\right]^T$ over twice the symbol duration as well as R-LP signals are hierarchically modulated as in the conventional hierarchical modulation scheme. And then, the hierarchical modulated signals $\boldsymbol{s}_k = [s_k\ s_{k+1}]^T$ are transmitted through independent fading channels.

Fig. 4 depicts one example of the new hierarchical modulated constellation adapted in the CR modulation method when using s_k^h and s_k^l signals set to the 4QAM with $\alpha = 3$. The matched filter output of the received signals $\boldsymbol{y}_k = [y_k\ y_{k+1}]^T$ at the receiver is shown as below;

$$\boldsymbol{y}_k = \begin{bmatrix}h_k & 0\\ 0 & h_{k+1}\end{bmatrix}\left\{\begin{bmatrix}\sqrt{a/(1+\alpha)}\,s_k^h\\ \sqrt{a/(1+\alpha)}\,s_{k+1}^h\end{bmatrix} + \begin{bmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{bmatrix}\begin{bmatrix}\sqrt{1/(1+\alpha)}\,s_k^l\\ \sqrt{1/(1+\alpha)}\,s_{k+1}^l\end{bmatrix}\right\} + \begin{bmatrix}n_k\\ n_{k+1}\end{bmatrix} \quad (9)$$

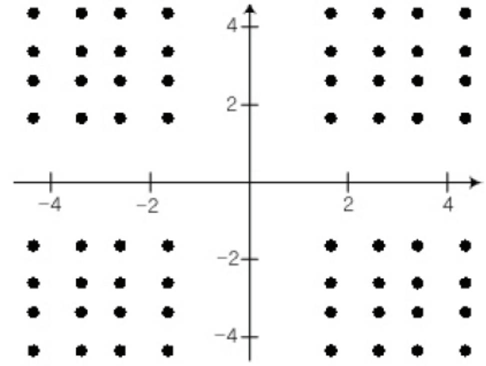

Figure 4. Constellation of proposed hierarchical modulation adapted in CR method with $\alpha = 3$.

$$= \boldsymbol{H}_k\left(\boldsymbol{s}_k^h + \boldsymbol{\Theta}\boldsymbol{s}_k^l\right) + \boldsymbol{n}_k = \boldsymbol{H}_k\left(\boldsymbol{s}_k^h + \boldsymbol{r}_k^l\right) + \boldsymbol{n}_k \quad (10)$$

$$= \boldsymbol{H}_k\boldsymbol{s}_k + \boldsymbol{n}_k\,. \quad (11)$$

The ML detection of the proposed new hierarchical modulation of (11) can be expressed as below;

$$\hat{\boldsymbol{s}}_k = \arg\min_{\boldsymbol{s}_k}\|\boldsymbol{y}_k - \boldsymbol{H}_k\boldsymbol{s}_k\|^2\,. \quad (12)$$

ML detection with the proposed method increases the decoding complexity significantly because of the need to perform combined ML decoding to see all of the received signals from $\boldsymbol{y}_k$ and $\boldsymbol{y}_{k+1}$. Additionally, the ML decoding performance for the HP signals are the same as that of the HP ML receiver, as shown in (5). The HP signal for the new hierarchical modulation also does not undergo any performance loss when the decision region of the HP signals is maintained as below;

$$\hat{\boldsymbol{s}}_k^h = \arg\min_{\boldsymbol{s}_k^h}\left\|\boldsymbol{y}_k - \boldsymbol{H}_k\boldsymbol{s}_k^h\right\|^2 \quad (13)$$

$$= \arg\min_{\boldsymbol{s}_k^h}\left\{\begin{bmatrix}y_k\\ y_{k+1}\end{bmatrix} - \begin{bmatrix}h_k & 0\\ 0 & h_{k+1}\end{bmatrix}\begin{bmatrix}\sqrt{a/(1+\alpha)}\,s_k^h\\ \sqrt{a/(1+\alpha)}\,s_{k+1}^h\end{bmatrix}\right\}^2 \quad (14)$$

$$= \begin{bmatrix}\arg\min_{s_k^h}\left|y_k - \sqrt{a/(1+\alpha)}\,h_k s_k^h\right|^2\\ \arg\min_{s_{k+1}^h}\left|y_{k+1} - \sqrt{a/(1+\alpha)}\,h_k s_{k+1}^h\right|^2\end{bmatrix}. \quad (15)$$

Next, in order to detect R-LP signals, the new received signal vector $\boldsymbol{y}'_k$ is calculated as below

$$\boldsymbol{y}'_k = \boldsymbol{y}_k - \boldsymbol{H}_k\hat{\boldsymbol{s}}_k^h \quad (16)$$

$$= \begin{bmatrix}y_k\\ y_{k+1}\end{bmatrix} - \begin{bmatrix}h_k & 0\\ 0 & h_{k+1}\end{bmatrix}\begin{bmatrix}\sqrt{a/(1+\alpha)}\,\hat{s}_k^h\\ \sqrt{a/(1+\alpha)}\,\hat{s}_{k+1}^h\end{bmatrix}. \quad (17)$$

ML decoding of the LP signals $\boldsymbol{s}_k^l$ based on the new received signal vector $\boldsymbol{y}'_k$ is presented as below;

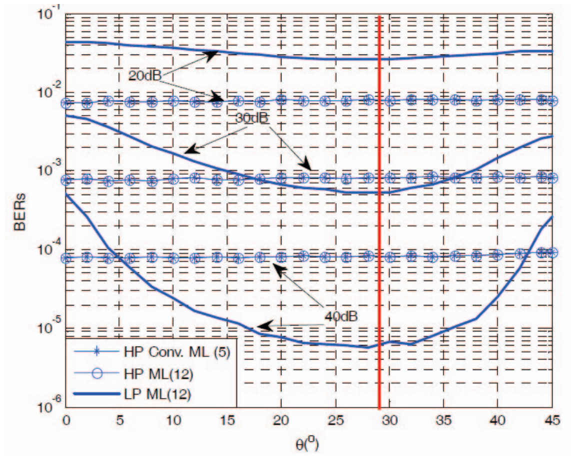

Figure 5. Performance of HP, LP ML detector (12) and the conventional HP detector (5) at $\alpha = 3$.

$$\hat{\boldsymbol{s}}_k^l = \left[\hat{s}_k^l\ \hat{s}_{k+1}^l\right]^T = \arg\min_{s_l^k} \left\| \boldsymbol{y}_k' - \boldsymbol{H}_k \boldsymbol{r}_k^l \right\|^2 \quad (18)$$

$$= \arg\min_{s_l^k} \left\| \boldsymbol{y}_k' - \boldsymbol{H}_k \boldsymbol{\Theta} \boldsymbol{s}_k^l \right\|^2 \quad (19)$$

$$= \arg\min_{s_l^k} \left\| \begin{bmatrix} y_k' \\ y_{k+1}' \end{bmatrix} - \begin{bmatrix} h_k & 0 \\ 0 & h_{k+1} \end{bmatrix} \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} \sqrt{1/(1+\alpha)}\, s_k^l \\ \sqrt{1/(1+\alpha)}\, s_{k+1}^l \end{bmatrix} \right\|^2 \quad (20)$$

The ML detection of $\boldsymbol{s}_k^l$ is performed with the joint ML decoding method for the simultaneous decoding of s_k^l and s_{k+1}^l. However, the increment of the ML decoding complexity is not large because only the joint ML decoding of LP signals is performed.

The LP signals of the new hierarchical modulation adopted in the CR method can recover the symbol perfectly, if at least one of the two R-LP signals arrives without error at the receiver. The new hierarchical modulation achieves a diversity gain of two for LP signals maintaining backward-compatibility with the HP signals. And, the CR angle easily matches the conventional CR angle as shown in table 1.

Fig. 5 depicts the performance for the HP and LP signal with HP ML detection compared to the conventional HP detector. As shown in Fig. 4, we can easily set the optimum CR angle to 29.0^o for 4QAM. This is because the LP signal forms an R-LP signal using the 4QAM constellation. In that case, the performance of the conventional HP signal is barely less than in the non-CR case ($\theta = 0^o$).

IV. Simulation Results

In this chapter, we compare the performance of conventional hierarchical modulation in Fig. 1 with a new hierarchical modulation adopted in the CR modulation scheme under the i.i.d. Rayleigh fading channel. We decode the HP detector to (15) and the LP detector to (20).

Fig. 6 and Fig. 7 present the BER performances of HP and LP signals for conventional hierarchical modulation and the proposed hierarchical modulation. In the case of Fig. 6, we use the HP signal and LP signal to the 4QAM constellation and $\alpha = 3$. As shown in Fig. 6, we can easily find that the LP signal for the proposed hierarchical modulation(29.0^o) achieves high performance gain without loss of the HP signal. Especially, it is seen that the performance gap between the two schemes is much larger for higher SNR values. This is because the proposed scheme enjoys a diversity gain of 2.

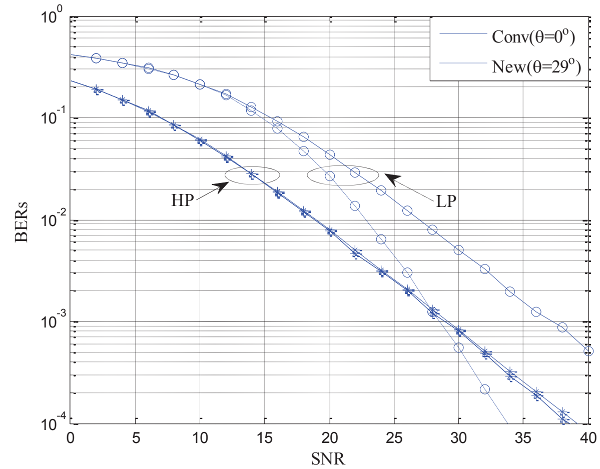

Figure 6. BERs of hierarchical modulation (HP : 4QAM, LP:4QAM, and $\alpha = 3$).

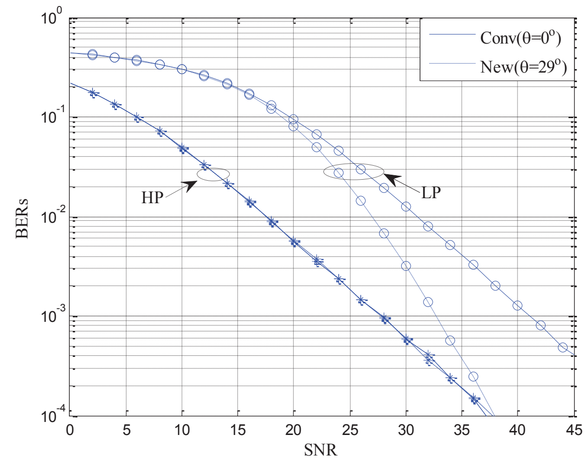

Figure 7. BERs of hierarchical modulation (HP : 4QAM, LP:4QAM, and $\alpha = 5$).

In the case of Fig.7, we use the HP signal and LP signal to the 4QAM constellation, $\alpha = 5$ and use same constellation rotation angle $\theta = 29^o$. Fig. 7 also shows that the LP the signal significantly improves the performance without loss of the HP signal.

As shown in Fig. 5 and Fig. 6, degradation of the HP signal may be seen that rarely occur in the low SNR region and the increasingly fine-occurring high SNR region. Due to the CR modulation of the LP signal, the minimum Euclidean distance is reduced inevitably. Therefore, the proposed hierarchical modulation has slight performance degradation in the high SNR region. And the higher α reduces the performance degradation of the HP signal. Because of the higher α increases the HP signal power and receives less affected of the CR modulation.

V. CONCLUSIONS

In this paper, we propose a new hierarchical modulation scheme to enhance the performance of LP signals by using a constellation-rotation method to the LP signals without virtually a loss in performance for the HP signals. The enhancement of the LP signals is mainly due to the diversity gain caused by the constellation-rotation method. Additionally, we also propose a hardware-efficient ML detection algorithm that first decodes the HP signals by using a conventional HP receiver, and then simply decodes the CR modulated the LP signals after eliminating the detected the HP signal. Therefore, the decoding complexity of the proposed hierarchical modulation scheme is only slightly increased.

ACKNOWLEDGMENT

This work was supported by the Human Resource Training Program for Regional Innovation and Creativity through the Ministry of Education and National Research Foundation of Korea(NRF-2014H1C1A1066568)

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