Suboptimal Decoding Scheme Based on Parallel Detection for ATSC 3.0 MIMO System

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***Abstract*—This paper proposes a suboptimal decoding scheme based on QR-decomposition which means a decomposition of a matrix A into a product A=QR of an orthogonal matrix Q and an upper triangular matrix R and Parallel Detection (PD) for Advanced Television Standard Committee (ATSC) 3.0 Multiple-Input Multiple-Output (MIMO) system. The 2x2 complex-valued channel model of ATSC 3.0 MIMO system can be transformed into a 4x4 real-valued channel model. For the 4x4 real-valued channel model of ATSC 3.0 MIMO, PD-based decoding can reduce the decoding complexity with a negligible performance loss compared with the maximum-likelihood decoding.**

Keywords-ATSC 3.0; real-valued representation; MIMO precoding; parallel detection.

I. INTRODUCTION

In Advanced Television Standard Committee (ATSC) 3.0, Multiple-Input Multiple-Output (MIMO) is optionally supported and can provide spatial diversity and multiplexing gains [1]. The ATSC 3.0 MIMO system additionally includes MIMO demultiplexer and precoder compared to ATSC 3.0 baseline system. Each output of the MIMO demultiplexer is mapped to constellation symbols in the mapper which is identical to ATSC 3.0 Single-Input Single-Output (SISO) [2]. In ATSC 3.0, Non-Uniform Constellations (NUCs) are defined and the shape of NUCs is specified for each combination of modulation order and code rate [3]. Also, the MIMO precoder consists of the stream combining, I/Q (In-phase/Quadrature) polarization interleaving and phase hopping. Here, the precoder outputs can be divided into the in-phase and quadrature components and then the 2x2 complex-valued channel model of ATSC 3.0 MIMO system can be transformed into a 4x4 real-valued channel model [4].

This paper proposes a suboptimal decoding scheme based on QR-decomposition [5] and Parallel Detection (PD) [6] using the 4x4 real-valued channel model for ATSC 3.0 MIMO system. Since NUCs are used in ATSC 3.0, the shape of NUCs should be considered for the proposed decoding scheme. However, NUCs were not considered in previous works for real-valued channel models [7][8]. The proposed decoding scheme can reduce the decoding complexity with a negligible performance loss compared with the Maximum-Likelihood (ML) decoding.

The rest of the paper is organized as follows. Section II introduces the MIMO precoder and NUCs of ATSC 3.0. In Section III, the real-valued received signal model for ATSC 3.0 MIMO is described and the proposed decoding scheme is presented. The simulation result is provided in Section IV and finally, this paper is concluded in Section V.

II. MIMO PRECODER AND NUCS OF ATSC 3.0

The received signal vector of ATSC 3.0 MIMO system can be represented as follows:

$$\begin{bmatrix} U_{2i} \\ U_{2i+1} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} S_{2i} \\ S_{2i+1} \end{bmatrix} + \begin{bmatrix} n_{2i} \\ n_{2i+1} \end{bmatrix} \tag{1}$$

where $\mathbf{u}_i = [U_{2i} \quad U_{2i+1}]^T$ denotes the received signal for the i-th cell pair. And, $\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$ denotes the 2x2 complex-valued channel gain matrix and h_{mn} means the complex-valued channel gain between the n-th transmit antenna and the m-th receive antenna. Also, $\mathbf{N}_i = [n_{2i} \quad n_{2i+1}]^T$ denotes the Additive White Gaussian Noise (AWGN) vector for the i-th cell pair. Here, $\mathbf{s}_i = [S_{2i} \quad S_{2i+1}]^T$ denotes the output vector of the MIMO precoder for the i-th cell pair where the input

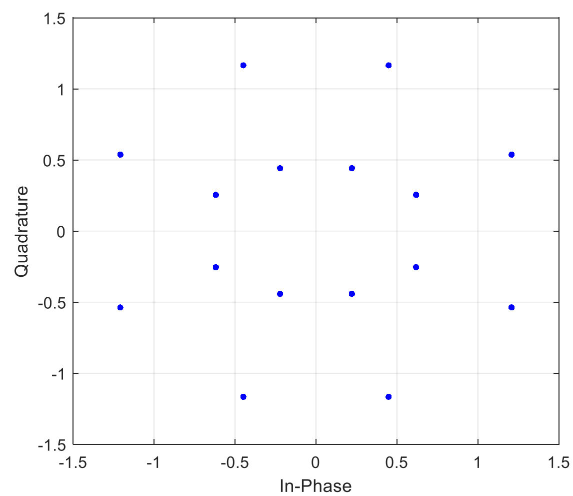

Fig. 1. Example of NUC for 16-ary modulation with code rate of 10/15

vector $\mathbf{x}_i = [X_{2i} \quad X_{2i+1}]^T$ is input into the MIMO precoder and passes through the stream combining, I/Q polarization interleaving, and phase hopping blocks in turn.

In ATSC 3.0, NUCs are used in the mapper. Fig. 1 shows an example of NUC for the combination of 16-ary modulation and code rate of 10/15 [1]. Unlike uniform 16-ary Quadrature Amplitude Modulation (QAM), the number of candidates of in-phase or quadrature components is 8. In general, for *M*-ary 2 dimensional (2D)-NUC defined in ATSC 3.0, the number of all possible real-valued candidates in each dimension is *M*/2 [3] where *M* denotes the modulation order. Hence, several component bits of a given complex symbol in 2D-NUC are not separated into in-phase and quadrature components unlike uniform QAM.

III. PD-BASED DECODING SCHEME FOR ATSC 3.0 MIMO

The real-valued received signal vector for ATSC 3.0 MIMO system can be represented as follows [4]:

$$\begin{aligned}\mathbf{u}_i' &= \begin{bmatrix}\mathrm{Re}\{\mathbf{u}_i\}\\ \mathrm{Im}\{\mathbf{u}_i\}\end{bmatrix}\\ &= \begin{bmatrix}\mathrm{Re}\{\mathbf{H}\} & -\mathrm{Im}\{\mathbf{H}\}\\ \mathrm{Im}\{\mathbf{H}\} & \mathrm{Re}\{\mathbf{H}\}\end{bmatrix}\begin{bmatrix}\mathrm{Re}\{\mathbf{s}_i\}\\ \mathrm{Im}\{\mathbf{s}_i\}\end{bmatrix} + \begin{bmatrix}\mathrm{Re}\{\mathbf{N}_i\}\\ \mathrm{Im}\{\mathbf{N}_i\}\end{bmatrix} \\ &= \mathbf{H}' \cdot \mathbf{C} \cdot \mathbf{P} \cdot \mathbf{T} \cdot \mathbf{x}_i' + \mathbf{N}_i' \\ &= \mathbf{H}_e' \cdot \mathbf{x}_i' + \mathbf{N}_i'\end{aligned} \tag{2}$$

where $\mathbf{H}' = \begin{bmatrix}\mathrm{Re}\{\mathbf{H}\} & -\mathrm{Im}\{\mathbf{H}\}\\ \mathrm{Im}\{\mathbf{H}\} & \mathrm{Re}\{\mathbf{H}\}\end{bmatrix}$, $\mathbf{s}_i' = [\mathrm{Re}\{\mathbf{s}_i^T\} \quad \mathrm{Im}\{\mathbf{s}_i^T\}]^T$, and $\mathbf{N}_i' = [\mathrm{Re}\{\mathbf{N}_i^T\} \quad \mathrm{Im}\{\mathbf{N}_i^T\}]^T$. Here, $\mathrm{Re}\{\cdot\}$ and $\mathrm{Im}\{\cdot\}$ denote the real and imaginary parts, respectively. Additionally, the output of the MIMO precoder can be rewritten by using the real-valued input vector, $\mathbf{x}_i' = [\mathrm{Re}\{\mathbf{x}_i^T\} \quad \mathrm{Im}\{\mathbf{x}_i^T\}]^T$, of the MIMO precoder and the real-valued transformation matrices, $\mathbf{T}$, $\mathbf{P}$, and $\mathbf{C}$, for the stream combining, I/Q polarization interleaving, and phase hopping, respectively. Also, $\mathbf{H}_e' = \mathbf{H}' \cdot \mathbf{C} \cdot \mathbf{P} \cdot \mathbf{T}$ denotes the real-valued equivalent channel gain [4].

By using the real-valued signal representation for ATSC 3.0 MIMO, suboptimal decoding algorithms based on QR-decomposition can be considered. As mentioned in the previous section, several component bits of NUC in ATSC 3.0 cannot be separated into in-phase and quadrature parts and such bits are related across two layers, i.e., real and imaginary parts. Therefore, each inseparable bit has to be jointly considered with both of real and imaginary parts. However, uniform constellations were considered in previous works for real-valued channel models, this property of the NUC shape was not considered [7][8]. In this paper, a PD-based decoding scheme for ATSC 3.0 MIMO using NUCs is presented. The PD considers all possible transmitted symbols for the first layer which is the last element of the received vector [6]. Next, the cancellation for the second layer is performed for each possible candidate symbol. Note that the first layer means the last element of the real-valued received signal vector in reverse order. Similarly, all possible real-valued candidates for the first layer, i.e., the imaginary part of the second complex symbol, are considered in the proposed PD-based decoding for ATSC 3.0 MIMO. Note that the number of all possible real-valued candidates is *M*/2.

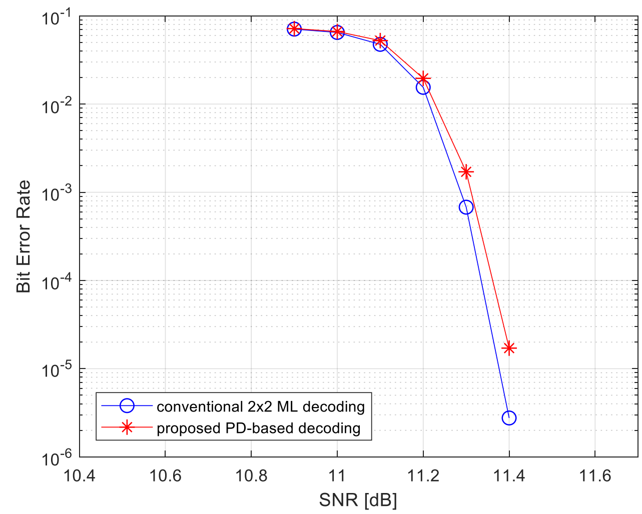

Fig. 2. The performance of ML decoding for 2x2 complex-valued channel model and proposed PD-based decoding scheme under AWGN channel

This paper assumes that the perfect dual-polarized antennas are used. Therefore, the in-phase component vector $[X_{2i,I} \quad X_{2i+1,I}]$ and the quadrature component vector $[X_{2i,Q} \quad X_{2i+1,Q}]$ in the real-valued signal vector can be decoupled for MIMO decoding. However, each real symbol $X_{2i,I}$ and $X_{2i+1,I}$ for in-phase components or each real symbol $X_{2i,Q}$ and $X_{2i+1,Q}$ for quadrature components cannot be decoupled. Hence, for the second layer, i.e., the imaginary part of the first complex symbol $X_{2i+1,Q}$, the cancellation for the symbol of the first layer has to be performed. However, for the third and fourth layers, i.e., $X_{2i,I}$ and $X_{2i+1,I}$, the cancellations for the symbols of the first and second layers are not performed.

On the other hand, inseparable bits for a complex symbol are related with both real and imaginary parts of the complex symbol. The first and third layers are related for 2*i*-th complex symbol and the second and fourth layers are related for (2*i*+1)-th complex symbol. For the separable bits, the hard decision for each candidate can be independently performed by computing Euclidean distance between the received signal for a given layer and each candidate symbol. For inseparable bits, on the other hand, the hard decision for each candidate is not performed in the first and second layers. Next, for the third layer, all candidates of the first layer are jointly used with all candidates of the third layer. Also, for the fourth layer, all candidates of the second layer are jointly used with all candidates of the fourth layer in a similar manner. After that, the Log-Likelihood Ratio (LLR) for each bit in a given complex symbol is calculated by using obtained candidate vectors.

Note that the complexity of the ML decoding is proportional to M^2. For the proposed PD-based decoding, on the other hand, the second layer can consider $(M/2)^2$

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candidates. Next, the third and fourth layers can consider M and $M/2$ candidates, respectively. Therefore, the complexity of the proposed decoding is proportional to $(M/2)^2 + (3M/2)$ and it is lower than the complexity of the ML decoding.

IV. Simulation Result

Fig. 2 shows the performance of the ML decoding for 2x2 complex-valued channel model and proposed PD-based decoding scheme under AWGN channel. This paper assumes that the receiver perfectly knows the channel gain and uses the perfect dual-polarized antennas. Also, 16-ary NUC and code rate of 10/15 are used for the simulation. Due to the use of perfect dual-polarized antennas, the upper triangular matrix $\mathbf{R}$ by QR-decomposition of $\mathbf{H}_e^{\prime}$ becomes a diagonal matrix. Then, the interference cancellation at each layer can be negligible. The proposed decoding scheme shows a negligible performance loss compared with the ML decoding. Note that the complexity of the proposed PD-based decoding scheme with NUC is higher than the original PD scheme with uniform QAM due to the inseparable property of several bits in NUC.

V. Conclusion and Future Work

In this paper, a suboptimal decoding scheme based on the QR-decomposition and PD for ATSC 3.0 MIMO system was proposed. In order to apply the concept of PD to ATSC 3.0 MIMO, the 4x4 real-valued channel model and the non-uniformly distributed shape of the constellation, i.e., NUC, in ATSC 3.0 were utilized. The complexity for the proposed decoding scheme can be reduced with a negligible performance loss compared with the ML decoding.

In the future work, more realistic channel models including multipath and time-varying channels should be considered to further analyze the performance and verify the availability of the proposed decoding scheme. Also, numerous sub-optimal decoders for MIMO decoding can be studied to compare the performance and complexity. Note that the inseparable property of NUCs should be considered for these further studies.

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