A Low Complexity Detector For Two-Way Relay Stations in Wireless MIMO-SDM-PNC Systems

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***Abstract*—In modern wireless communication, Multiple-Input Multiple-Output (MIMO) takes advantage of spatial diversity to increase the capacity and spectrum efficiency effectively. This technology, however, poses many technical challenges for device implementation. Optimizing the computational workload with an acceptable bit error rate (BER) becomes the critical design problem for the MIMO relay station. This paper proposes a novel detection algorithm for the wireless MIMO in the two-way relay station (TWRS). We adopt the relay architecture that doubles the receive antennas for communication data between two MIMO terminals. The core processing block employs a variable K-Best detection (V-KBD). The simulation for 4×4 MIMO two-way relay results shows that our relay model could achieve BER close to the conventional SD algorithm systems with fixed and lower complexity.**

***Index Terms*—TWRN, TWR, MIMO-SDM-PNC, PNC, MIMO-PNC, K-Best, SD**

I. Introduction

To improve the capacity and coverage of cellular communication systems, wireless relaying has been considered a promising method and included in current broadband wireless standards [1]. Recent researches also showed that wireless relays could significantly improve quality of service (QoS) and system performance, reducing outage probability and transmission power [2]. However, conventional relaying schemes reduce bandwidth efficiency, system throughput and capacity as it requires multiple time slots for bidirectional data exchange. Network Coding (NC) has emerged as a powerful relaying solution because it can achieve significant throughput gains [3]. The conventional two-way relay station (TWRS), also known as bi-directional relaying, networks use the NC to reduce the number of data exchange time slots from four to three using appropriate symbol encoding at the relay. Further implementation of NC at the physical layer, which results in the physical-layer NC (PNC), can save one more time slot [4]. In the paper [5], Zhang demonstrated that the throughput of the PNC system could increase by 200% and 150% in comparison with the non-NC and the NC system, respectively.

Physical-layer NC was also introduced for applying in two-way relay Multiple-Input Multiple-Output (MIMO-PNC) systems [6]. In the MIMO-PNC, the network-coded symbols at the relay are created using the summation and difference components from the two terminal nodes. The MIMO-PNC scheme does not require strict synchronization for the carrier phase while producing higher performance than that in the conventional MIMO-NC schemes in the case of Rayleigh fading. In paper [7], the authors proposed channel coding and physical-layer network coding (CPNC) for a two-way relay MIMO system. The proposed method converts the received streams from two sources to the relay node into parallel streams, leading to a capacity achievement close to an upper theoretical bound. The eigen-direction alignment precoding for MIMO physical layer network coding (EDA-PNC) is proposed in [8]. EDA-PNC offers the solution to increasing the energy efficiency of the signal with noise. However, this work has not provided a solution to recover the transmitted signal from the source node at the destination node and has not evaluated the effect of the BER in the proposed scheme. Khani et al. in [9] proposed a V-BLAST-based PNC to improve the diversity in multiplexing gain by packet redundancy. But the simulation was reported only for the BPSK/QPSK modulations. In addition, the papers [10] and [11] proposed the space-division multiplexed (SDM)-PNC for the MIMO channel. The MIMO-SDM-PNC could operate without prior-knowledge of channel state information (CSI) but exhibits the same diversity order as the conventional MIMO-NC with double multiplexing gain. Nonetheless, those schemes adopted ZF and MMSE detection that result in very limited BER performance. Authors in [12] proposed PNC using ML detection that has been evaluated for the model with QPSK modulation. The scheme achieved a good level of BER but ML is a computational intensive with data-dependent complexity, hence, is not suitable for practical implementation.

In this paper, we propose a variable K-Best decoder (V-KBD) algorithm that takes advantage K-Best algorithm to achieve comparable BER while significantly reducing computational complexity compared to that of SD. Moreover, the proposed algorithm has fixed complexity and is ready for deployment in devices. Compared with the K-Best algorithm, we optimize the individual K-Best value for each SD search tree level (i.e., being variable K) based on the statistical analysis proposed in [13]. The proposed V-KBD has been implemented and evaluated in a wireless TWRS equipped with eight receive and four transmit antennas using 16-QAM modulation.

The remainder of this paper is organized as follows. Section II describes the system model, and we propose the novel algorithm of the detection at the relay node in Section III. In Section IV, the simulation of the proposed algorithm with several typical configurations is presented. And the conclusion in section V.

II. System model

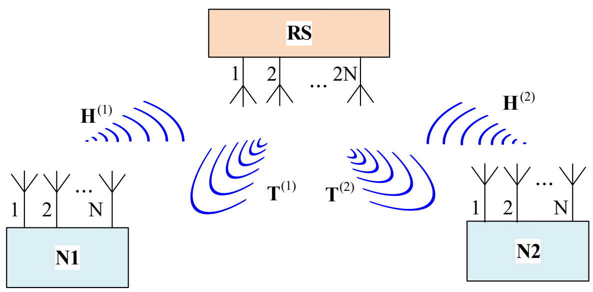

Fig. 1. System model of the MIMO-SDM-PNC two-way relay system.

Fig. 1 shows a two-way relay network (TWRN), where nodes N1 and N2 communicate via a relay RS. The nodes N1 and N2 are equipped with N antennas. The relay node has $2N$ antennas. The system operates in the same frequency band and modulation, and the channel is half-duplex. Thus, transmission and reception at a particular node happen in different time slots. We also assume that there is no direct link between node N1 and node N2. The system transacts the data signal in two phases. In the first phase, each element of two binary message packets $\boldsymbol{s}^{(i)} = (s_j^{(i)})^{N\times 1}, i \in (1,2), j = 1..N$ of node N_i are mapped ($\mathcal{M}-$function) to the M-ary modulation constellation set Ω, with $s_j^{(i)}$ is random in range from 1 to M. That are converted to the complex signal vectors $\boldsymbol{x}^{(i)} = (x_j^{(i)})^{N\times 1} = (\mathcal{M}(s_j^{(i)}))^{N\times 1} \subset (\Omega)^{N\times 1}, i \in (1,2), j = 1..N$ of two source nodes N1 and N2, respectively. The vectors $\boldsymbol{x}^{(1)}$ and $\boldsymbol{x}^{(2)}$ are transmitted from nodes N1 and N2 to the relay RS simultaneously. The received signal $\boldsymbol{y} = (y_j)^{2N\times 1} \subset \mathcal{C}^{2N\times 1}$ at relay node RS can be express as:

$$\boldsymbol{y} = \boldsymbol{H}^{(1)}\boldsymbol{x}^{(1)} + \boldsymbol{H}^{(2)}\boldsymbol{x}^{(2)} + \boldsymbol{n}, \tag{1}$$

where: $\boldsymbol{H}^{(i)} = (h_{km}^{(i)})^{2N\times N} \subset (\mathcal{C})^{2N\times N}, i \in (1,2), k = 1..2N, m = 1..N$ is channel matrix, which presenting the fading links between the the fading links between the source node Ni and the relay node RS, $\boldsymbol{n} = (n_k)^{(2N\times 1)} \sim \mathcal{CN}(0, \sigma^2\boldsymbol{I})$ is a complex Additive White Gaussian Noise (AWGN) vector. The equation (1) can be transformed as follow:

$$\boldsymbol{y} = \boldsymbol{H}\boldsymbol{x} + \boldsymbol{n}, \tag{2}$$

where $\boldsymbol{x} = [\boldsymbol{x}^{(1)}\boldsymbol{x}^{(1)}]^T$ is an equivalent transmitted signal vector from source nodes to relay node, and $\boldsymbol{H} = [\boldsymbol{H}^{(1)}\boldsymbol{H}^{(1)}]$ is equivalent channel matrix. Based on the superimposed signals that carry $\boldsymbol{x}^{(1)}$, $\boldsymbol{x}^{(2)}$ the relay processes and detects the transmitted signals vectors $\boldsymbol{x}^{(1)}$, $\boldsymbol{x}^{(2)}$ from received signal vector $\boldsymbol{y}$. The estimated signal vectors are expressed as $\widehat{\boldsymbol{x}}^{(1)}$, $\widehat{\boldsymbol{x}}^{(2)}$. The vectors $\widehat{\boldsymbol{x}}^{(1)}$, $\widehat{\boldsymbol{x}}^{(2)}$ are remapped to two messages $\widehat{\boldsymbol{s}}^{(1)}$ and $\widehat{\boldsymbol{s}}^{(2)}$, respectively, as

$$\widehat{\boldsymbol{s}}^{(i)} = \mathcal{M}^{-1}(\widehat{\boldsymbol{x}}^{(i)}) = \left(\mathcal{M}^{-1}(\widehat{x}_j^{(i)})\right)^{N\times 1}, i \in (1,2), j = 1..N. \tag{3}$$

The relay node performs XOR operation to combine two messages $\widehat{\boldsymbol{s}}^{(1)}$ and $\widehat{\boldsymbol{s}}^{(2)}$ into vector $\boldsymbol{s}^{(r)}$ by following equation:

$$\boldsymbol{s}^{(r)} = \widehat{\boldsymbol{s}}^{(1)} \otimes \widehat{\boldsymbol{s}}^{(2)} = \left(\widehat{s}_j^{(2)} \otimes \widehat{s}_j^{(2)}\right)^{N\times 1} \tag{4}$$

The $\boldsymbol{s}^{(r)}$ message is mapped to the M-ary modulation constellation set $(\Omega)^{N\times 1}$ as

$$\boldsymbol{x}^{(r)} = \mathcal{M}(\boldsymbol{s}^{(r)}) = \left(\mathcal{M}(s_k^{(r)})\right)^{N\times 1} \tag{5}$$

At the second time slot, the relay node broadcasts the $\boldsymbol{x}^{(r)}$ to two destination nodes N1, N2. The received signal $\boldsymbol{g}^{(1)} = \left(g_j^{(1)}\right)^{N\times 1}, \boldsymbol{g}^{(2)} = \left(g_j^{(2)}\right)^{N\times 1} \subset (\mathcal{C})^{N\times 1}$ with $j = 1..N$ at nodes N1 and N2 are, respectively, presented as following equation:

$$\boldsymbol{g}^{(i)} = \boldsymbol{T}^{(i)}\boldsymbol{x}^{(r)} + \boldsymbol{n}, \tag{6}$$

where $\boldsymbol{T}^{(i)} = \left(T_m^{(i)}\right)^{N\times N} \subset (\mathcal{C})^{N\times N}, i \in (1,2), m = 1..N$ is channel matrix between relay RS and destination node i, $\boldsymbol{T}^{(i)} = \left(T_m^{(i)}\right)^{N\times N} \sim \mathcal{CN}(0, \sigma^2\boldsymbol{I})$ is a complex AWGN vector. The destination node receives the broadcast signal from relay node RS then estimates and remap $\widehat{\boldsymbol{x}}^{(r)}$ into the binary-bit stream $\widehat{\boldsymbol{s}}^{(r)} = \mathcal{M}^{-1}(\widehat{\boldsymbol{x}}^{(r)}) = \left(\mathcal{M}(x_k^{(r)})\right)^{N\times 1}$. The destination nodes N1 and N2 restore the signal, which is transmitted from another source node, from its own signal and the estimated signal from the relay station as following equations:

$$\widetilde{\boldsymbol{s}}^{(2)} = \boldsymbol{s}^{(1)} \otimes \widehat{\boldsymbol{s}}^{(r)} = \boldsymbol{s}^{(1)} \otimes \widehat{\widehat{\boldsymbol{s}}^{(1)} \otimes \widehat{\boldsymbol{s}}^{(2)}}. \tag{7}$$

$$\widetilde{\boldsymbol{s}}^{(1)} = \boldsymbol{s}^{(2)} \otimes \widehat{\boldsymbol{s}}^{(r)} = \boldsymbol{s}^{(2)} \otimes \widehat{\widehat{\boldsymbol{s}}^{(1)} \otimes \widehat{\boldsymbol{s}}^{(2)}}. \tag{8}$$

The basis and proposal of the signal detection and processing algorithm at the relay station are presented in the next section.

III. Proposed the low complexity detection algorithm at wireless MIMO relay staytion

The computation and processing unit of the signal detectors at the relay stations in the communication system plays a significant role. Detectors in wireless MIMO systems are classified into two types: linear detectors and nonlinear detectors. The linear detector has a simple structure and is easy to apply in systems. However, the linear detector has the disadvantage in that the BER performance is much lower than the nonlinear detectors. Although nonlinear transmitters have a high BER performance, they require high complexity. Usually, they have a variable complexity that varies depending on the condition parameters. Therefore, implementing nonlinear detectors in practice is much more challenging than implementing linear detectors. In paper [11], we have presented studies on linear detectors (ZF, MMSE) at relay stations in the wireless communication system. This paper only analyzes and evaluates the sphere detector (SD) processing and computational techniques at the wireless MIMO communication relay station.

Like the ML detection method, the SD calculates the Frobenius norm for candidate points and chooses all points that are inside a hyper-sphere formed around the received signal vector with a predetermined radius r_{sph} as.

$$\widehat{\boldsymbol{x}}_{SD} = \arg\min_{\boldsymbol{x}\in\boldsymbol{S}} \|\boldsymbol{y} - \boldsymbol{H}\boldsymbol{x}\|^2, \tag{9}$$

where $\{\boldsymbol{S} \subset \boldsymbol{C}^{N_T\times 1} : \|\boldsymbol{y} - \boldsymbol{H}\boldsymbol{x}\| \leq r_{sph}\}$ is a set of all possible points in the lattice $\boldsymbol{Hx}$, whose distance to $\boldsymbol{y}$ is always smaller than the hypersphere's radius r_{sph}. Choosing the suitable value of r_{sph} is essentially important for determining the SD's computational complexity and BER performance. To further reduce the amount of computation in SD, equation (3) can be transformed into the identical problem applying the QR decomposition (QRD) to the channel matrix, that is $\boldsymbol{H} = \boldsymbol{QR}$ where matrix $\boldsymbol{Q}$ is a unitary matrix whose size is $2N \times 2N$ and $\boldsymbol{QQ}^H = \boldsymbol{I}$ while $\boldsymbol{R}$ is an $2N \times 2N$ upper triangular matrix. Replacing $\boldsymbol{H}$ by $\boldsymbol{QR}$ and after simple transformation, equation (9) becomes:

$$\widetilde{\boldsymbol{y}} = \boldsymbol{R}\boldsymbol{x} + \boldsymbol{Q}^H\boldsymbol{n}, \text{ with } \widetilde{\boldsymbol{y}} = \boldsymbol{Q}^H\boldsymbol{y}. \tag{10}$$

Note that $\boldsymbol{Q}^H\boldsymbol{n}$ has the same statistics as $\boldsymbol{n}$, hence equation (9) is equivalently characterized as

$$\widehat{\boldsymbol{x}} = \arg\min_{\boldsymbol{x}\in\mathbf{S}} ||\widetilde{\boldsymbol{y}} - \boldsymbol{R}\boldsymbol{x}||^2, \tag{11}$$

Equation (11) can be calculated through cost function as follows:

$$\mathcal{D}(\widetilde{\boldsymbol{y}}, \widehat{\boldsymbol{y}}) = ||\widetilde{\boldsymbol{y}} - \boldsymbol{R}\boldsymbol{x}||^2 \leq {r_{sph}}^2. \tag{12}$$

Since the matrix $\boldsymbol{R}$ is the upper triangular, the cost function $\mathcal{D}(\widetilde{\boldsymbol{y}}, \widehat{\boldsymbol{y}})$ is also a partial Euclidean distance that can be calculated recursively from one transmit antenna to another:

$$\mathcal{D}_m(\widetilde{\boldsymbol{y}}, \widehat{\boldsymbol{y}}) \triangleq \sum_{i=m}^{2N} \left(\widetilde{y}_i - \sum_{j}^{2N} R_{ij}x_{ij}\right)^2, \tag{13}$$

$$\mathcal{D}(\widetilde{\boldsymbol{y}}, \widehat{\boldsymbol{y}}) = \mathcal{D}_1(\widetilde{\boldsymbol{y}}, \widehat{\boldsymbol{y}}), \tag{14}$$

$$\mathcal{D}_{m-1}(\widetilde{\boldsymbol{y}}, \widehat{\boldsymbol{y}}) = \mathcal{D}_m(\widetilde{\boldsymbol{y}}, \widehat{\boldsymbol{y}}) + \left(\widetilde{y}_{m-1} - \sum_{i=m-1}^{2N} R_{m-1,i}x_i\right)^2, \tag{15}$$

where $\widetilde{y}_{m-1}$ is the $(m-1)$-th element of the received signal vector after multiplication of the received signal vector by $\mathbf{Q}^H$; $R_{i,j}$ is an entry of matrix $\boldsymbol{R}$ that belongs to the i-th row and the j-th column, and the cost function $\mathcal{D}_m(\widetilde{\boldsymbol{y}}, \widehat{\boldsymbol{y}})$ is a partial Euclidean distance of the candidate symbol $\boldsymbol{x}$ at the m-th search level. For all possible transmit symbol vectors that are satisfied $\boldsymbol{x} \in \{\boldsymbol{S} \subset \boldsymbol{\mathcal{C}}^{2N\times 1} : \|\boldsymbol{R}\boldsymbol{x} - \widetilde{\boldsymbol{y}}\| \leq r_{sph}\}$, we set $\mathcal{D}_{2N+1}(\widetilde{\boldsymbol{y}}, \widehat{\boldsymbol{y}}) = 0$, and have the following inequality:

$$\mathcal{D}_{m-1}(\widetilde{\boldsymbol{y}}, \widehat{\boldsymbol{y}}) \leq {r_m}^2 - \mathcal{D}_m(\widetilde{\boldsymbol{y}}, \widehat{\boldsymbol{y}}), \tag{16}$$

$${r_m}^2 = {r_{sph}}^2 - \sum_{i=m+1}^{2N} \mathcal{D}_i(\widetilde{\boldsymbol{y}}, \widehat{\boldsymbol{y}}), \tag{17}$$

where $m = 2N, 2N-1, ..., 1$. The major problem is choosing the value of r_{sph} that critically affects this method's computational complexity and high performance. If r_{sph} is large, it covers a large number of symbol candidates and highers the BER by the trade-off of more increased computation workload. In contrast, when r_{sph} is small, the correct solution is more likely to stay out of the chosen hyper-sphere. Hence, the initial search radius and the expected quantity of lattice points in the hypersphere must be judiciously selected to balance computational complexity and system performance. For hardware implementation, it is also more efficient to perform a Real-Valued Decomposition (RVD) of $\boldsymbol{H}$, which simplifies the computation of the Euclidean distance [13].

Through the evaluation survey at the project [13], we found that for each layer of the SD search tree, there will exist the number of valid node nodes on each level corresponding to the selected radius. The larger radius, the larger number of valid nodes in the considered sphere. In the proposed algorithm, take the idea that we have an SD detection with an infinite spherical radius. Then, we select the best nodes with the smallest Euclidean distance value for each class on the search tree based on the statistics in [13]. The algorithm does not need to check whether the node is within the sphere and updates the sphere radius after each search. Therfore, the proposed algorithm exhibit a fixed and much lower complexity compared to that of the conventional SD detection. The proposed algorithm is presented as Algorithm 1.

Assuming that the data is available in memory, the complexity of the proposed V-KBD algorithm can be analytically estimated as follow:

$$\mathcal{O}_{V-KBD}(M,N) \approx \sum_{i=1}^{4N} \left(K_i\sqrt{M}(4N-i+4)\right) + N, \tag{18}$$

where N is number of transmit antennas of terminal nodes, M is the order of modulation, K_i is the number of selected nodes at layer k-th of the search tree after sorting. The proposed V-KBD hence has fixed complexity as long as the configuration vector CV $= [K_{4N}, K_{4N-1}, \ldots, K_1]$ is determined.

IV. V-KBD ALGORITHM AND EVALUATION FOR 4X4 MIMO RELAY.

This section evaluates the BER system performances for a case study of 4×4 TWRS using V-KBD. According to the results from our previous work, we found that the number of survival search nodes (valid nodes) tends to be larger at some middle layers from $6 - 10$ (see Fig. 1 while the number of search nodes at top and bottom levels are small. We exploit this information for optimizing the configuration vector CV. For better comparison we have selected 3 groups of CV: group 1 has the number of workloads at first layers is large; Group 2

Algorithm 1 The V-KBD Algorithm

Input: $\widehat{\boldsymbol{y}}, \boldsymbol{R}, \boldsymbol{K}$
Output: $\boldsymbol{x}^{(r)}$
initial: $L = 4N$, $K = [K_L, K_{K-1}, ...K_1]$,
$C = [-(\sqrt{M}-1), -(\sqrt{M}-2), ..., (\sqrt{M}-1)]$
function $\boldsymbol{B}_{n\times K_c}$ =KBestSorting($\boldsymbol{A}_{n\times m}, K_c$)
Sort the columns of the matrix $\boldsymbol{A}_{n\times m}$ in order from smallest to greatest according to the values of the first row of the matrix $\boldsymbol{A}_{n\times m}$.
Store K_c first column of arranged $A_{m\times n}$ matrix to $B_{n\times K_c}$ matrix.
procedure LEV=L
lev=L
for $i = 1 : \sqrt{M}$ **do**
$\boldsymbol{x}^{(L)} = \mathcal{C}(i)$
$\boldsymbol{A}^{(L)}(1, i) = \left(\widetilde{y}_L - \sum_{i=L}^{L} R_{L,i}x_i\right)^2$
$\boldsymbol{A}^{(L)}(2 : L - lev + 2, i) = \boldsymbol{x}^{(L)}$
endfor
$\boldsymbol{B}^{(L)}$ =KBestSorting($\boldsymbol{A}^{(L)}, K_L$)
procedure LEV=L-1
lev=L-1
for $j = 1 : K(lev + 1)$ **do**
for $i = 1 : \sqrt{M}$ **do**
$\boldsymbol{x}^{(lev)} = [\boldsymbol{C}(i); \boldsymbol{B}^{(lev+1)}(2 : L - lev + 1, j)]$
$\boldsymbol{A}^{(lev)}(1, i) = \boldsymbol{B}^{(lev+1)}(1, j)+$
$\left(\widetilde{y}_{lev} - \sum_{i=lev}^{L} R_{lev,i}x_i\right)^2$
$\boldsymbol{A}^{(lev)}(2 : L - lev + 2, i) = \boldsymbol{x}^{(lev)}$
endfor
endfor
$\boldsymbol{B}^{(lev)}$ =KBestSorting($\boldsymbol{A}^{(lev)}, K_{lev}$)
Do the same above function for each level from level $(B-2)$-th down to level 3rd
procedure LEV=2
lev=2
for $j = 1 : K(lev + 1)$ **do**
for $i = 1 : \sqrt{M}$ **do**
$\boldsymbol{x}^{(lev)} = [\boldsymbol{C}(i); \boldsymbol{B}^{(lev+1)}(2 : L - lev + 1, j)]$
$\boldsymbol{A}^{(lev)}(1, i) = \boldsymbol{B}^{(lev+1)}(1, j)+$
$\left(\widetilde{y}_{lev} - \sum_{i=lev}^{L} R_{lev,i}x_i\right)^2$
$\boldsymbol{A}^{(lev)}(2 : L - lev + 2, i) = \boldsymbol{x}^{(lev)}$
endfor
endfor
$\boldsymbol{B}^{(lev)}$ =KBestSorting($\boldsymbol{A}^{(lev)}, K_{lev}$)
procedure LEV=1
lev=1
for $j = 1 : K(lev + 1)$ **do**
for $i = 1 : \sqrt{M}$ **do**
$\boldsymbol{x}^{(1)} = [\boldsymbol{C}(i); \boldsymbol{B}^{(2)}(2 : L, j)]$
$\boldsymbol{A}^{(1)}(1, i) = \boldsymbol{B}^{(2)}(1, j)+$
$\left(\widetilde{y}_1 - \sum_{i=1}^{L} R_{1,i}x_i\right)^2$
$\boldsymbol{A}^{(lev)}(2 : L + 1, i) = \boldsymbol{x}^{(1)}$
endfor
endfor
$\boldsymbol{B}^{(1)}$ =KBestSorting($\boldsymbol{A}^{(1)}, K_1$)
Map $B^{(1)}(2 : L+1, 1)$ to complex vector of the estimated $\widehat{\boldsymbol{x}}^{(1)}$, $\widehat{\boldsymbol{x}}^{(2)}$ vectors on modulation constellation
Remap $\widehat{\boldsymbol{x}}^{(1)}$, $\widehat{\boldsymbol{x}}^{(2)}$ to the binary symbol vector: $\boldsymbol{s}^{(i)} = \mathcal{M}^{-1}(\widehat{x}_j^{(1)})^{N\times 1}, i \in (1, 2)$
Calculate $\boldsymbol{s}^{(r)} = \boldsymbol{s}^{(1)} \otimes \boldsymbol{s}^{(2)} = \left(s_j^{(1)} \otimes s_j^{(2)}\right)^{N\times 1}$
Map $\boldsymbol{s}^{(r)}$ to $\boldsymbol{x}^{(r)}$: $\boldsymbol{s}^{(r)} = \mathcal{M}(\boldsymbol{s}^{(r)}) = \left(\mathcal{M}(s_j^{(r)})\right)^{N\times 1}$
Return: $\boldsymbol{x}^{(r)}$

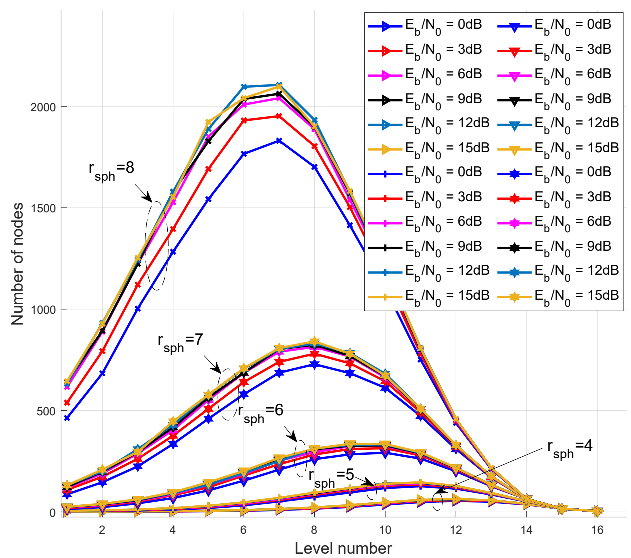

Fig. 2. The number of nodes corresponds to a coverage of $99,999\%$ number of valid nodes in the sphere, statistically evaluated for 8×8 MIMO systems run 1 million random input patterns with AWGN.

has the number of workloads at the last layers is large, Group 3 balances the workload at all layers. As shown in the Table I the complexity of the proposed V-KBD algorithm is much lower than the complexity of the conventional SD algorithm (by $4-30$ times lower). Here complexity of the SD is estimated for the case of normalized radius $r_{sph} = 7$, where the model statistically covers $99,999\%$ of the valid nodes. Furthermore, the BER performance has been evaluated for all configurations in Table I and presented in Fig. 3.

From the Fig. 3, the worse BER are observed for CV1$-$CV4 configurations, though they are still much better than MMSE and ZF by an order of magnitude. Among those, the high BER of CV1 and CV2 could be explained by the correspondingly low complexity. However, that is not the case for CV3, and CV4 which are reported as the second and the fourth computationally intensive CVs. CV7 and CV8 are the best among V-KBD and have a BER close to that of SD. However, those configuration requires a very high computational workload. The remaining configuration, including CV5, CV6 somewhat show the best balance between BER and complexity. For example, CV5 has the lowest complexity of 9.836 but exhibits the BER similar to CV7 and CV8. CV6 requires slightly higher

TABLE I
CONFIGURATION OF V-KBD ALGORITHM FOR 4×4 TWRS WITH 16-QAM MDULATION

Config. of V-KBD		**The level at search tree**																$\mathcal{O}(M,N)$ (flops)
		16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
Group 1	CV1	4	8	32	36	32	28	25	20	18	11	8	5	4	3	2	1	13.032
	CV2	4	16	64	32	24	16	12	8	4	4	2	2	2	2	24	1	11.836
Group 2	CV3	4	6	10	14	20	28	36	44	52	60	68	76	84	92	100	1	25.212
	CV4	4	10	16	32	44	56	68	80	92	104	116	128	140	152	164	1	44.660
Group 3	CV5	4	16	28	26	20	16	14	12	10	8	6	4	4	4	4	1	9.836
	CV6	4	16	28	32	36	32	28	24	20	16	12	4	4	4	4	1	14.356
	CV7	4	16	64	128	128	32	28	24	20	16	12	8	4	4	4	1	28.596
	CV8	4	16	64	256	256	256	128	128	128	64	64	32	32	32	16	1	78.212
SD : $r_{sph} = 7$		4	16	64	195	365	571	758	878	942	918	810	646	487	345	231	1	308.280

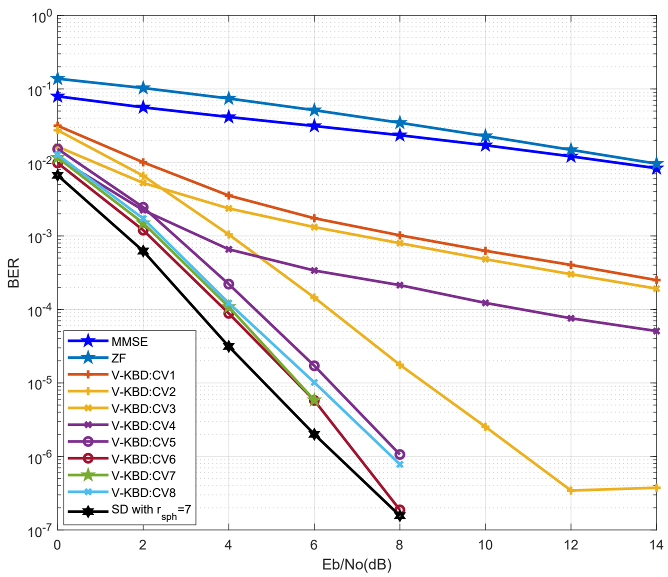

Fig. 3. TWRS BER performance comparison different CVs of the proposed V-KBD and the conventional ZF, MMSE, and SD algorithms for 16-QAM 4×4 MIMO TWRS, evaluated for 1 million random input patterns with AWGN.

complexity (14.356) than CV5 but shows fairly good BER performance among the presented configurations. Note that CV6 is $2-5$ times lower in complexity compared to those of CV7 and CV8.

V. CONCLUSION

In this paper, we propose an algorithm to detect signals at two-way MIMO wireless communication relay stations. The algorithm exploits the characteristic of the valid nodes distribution in the SD search tree to optimize the computational workload while maintaining comparable and good system BER. The evaluation for the V-KBD algorithm used in a 4×4 TWRS showed that a sub-optimal V-KBD configuration could achieve the BER closed to that of SD with almost 10 times lower in required computation. We have evaluated several configurations for the proposed algorithm with the transfer station model and analyzed the effects of configuration structure selection accordingly. Additionally, V-KBD is fixed in complexity and processing latency and is well suited for hardware implementations.

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