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An Efficient Precoding Method for Improved Downlink Massive MIMO System

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ABSTRACT This paper proposes an efficient precoding method based on Neumann series (NS) to improve error performances for already developed diagonal NS (DNS) in massive MIMO system. The conventional DNS has very low complexity compared to a zero-forcing (ZF) and any other NS based ZF precoding methods such as tri-diagonal NS (TNS) and eigenvalue based NS. However, the conventional DNS has very poor error performance in highly correlated massive MIMO system and performance degradations are severe as the used modulation is large. For an efficient precoding, diagonal plus columns NS (DCNS)-1, DCNS-k, and hybrid DCNS-1 and DCNS-U are proposed, and these precoding schemes are adaptively used according to the number of total diagonal dominant active users. The DCNS-1 is applied to fully diagonal dominant users and DCNS-k is applied to non diagonal dominant users, and finally, hybrid DCNS-1 and DCNS-U is applied to partially diagonal dominant systems. For improved DCNS-k, k active users which cause the largest post interference power are selected by simple calculations. The simulation results show that bit error rate (BER) performance for the proposed scheme is very higher than the conventional DNS and is nearly approximated to the BER performance for the conventional optimal ZF with very low complexity.

INDEX TERMS DCNS-1, DCNS-k, DNS, Massive MIMO, ZF.

I. INTRODUCTION

Multi-user (MU) massive multiple input multiple output (MIMO) which is called as very large-scale MIMO provides tremendous spectral efficiency in wireless communication systems without additional bandwidth and transmit power compared to conventional MU-MIMO systems [1]–[7]. The downlink massive MIMO where the base station (BS) which is equipped with hundreds of transmit antennas communicates with several active users in a cell increases overall system performances by suppressing MU interference (MUI) and small-scale fading. One of attractive advantages for the downlink massive MIMO is that it can obtain nearly optimal performance by using only linear precoding at the BS compared to the conventional MU-MIMO which has to use very complex nonlinear precoding for optimal performance. The linear precoding based massive MIMO provides very high beamforming gain due to extreme number of transmit antennas and it leads energy efficient systems. Among several linear precoding methods, a zero-forcing (ZF) suppresses the MUI completely with perfect channel state information (CSI) and it does not require any baseband signal processing at receivers for decoding transmit symbols [8]–[12]. However, the ZF has very high complexity when the number of active users is large since the ZF calculates inversion of gram matrix and its complexity is cubic order with respect to the number of active users. For low-complexity ZF, Neumann series (NS) based approximate ZF was developed in [13]–[19]. The NS calculates inverse matrix approximately by using matrix multiplications and summations, and the order of complexity for calculating inversion of gram matrix is significantly reduced compared to the ZF. Although the NS based ZF avoids exact inversion of gram matrix, the inversion of initial matrix is required. The initial matrix in the NS can be differently set according to system requirements such as cost and target error performance. For efficient implementation of the NS based ZF, two challenges of the initial matrix are considered. First, the initial

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matrix has to be reliable for fast convergence of the NS since the length of NS L is reduced. Second, the calculation for inversion of initial matrix has to be easy. In [13], a tri-diagonal NS (TNS) based ZF was developed where the initial matrix is composed of diagonal and off-diagonal entries of the gram matrix. The convergence rate for the TNS is increased as a large number of off-diagonal entries are included and it decreases L. However, the complexity for the inversion of initial matrix is very high for practical implementations where its complexity is nearly the same as complexity for the ZF as a large number of off-diagonal entries are included. For more lower complexity, a diagonal NS (DNS) based ZF was developed in [14] where the initial matrix is composed of only diagonal entries of the gram matrix. One of main properties for the massive MIMO is that the gram matrix is diagonal dominant when the number of transmit antennas is very larger than the number of active users. The conventional DNS exploits the property of massive MIMO system well and has very low complexity since the inversion of diagonal matrix is very easy. However, the DNS has serious performance degradations in highly correlated massive MIMO system where the number of transmit antennas to active users ratio is small since diagonal entries for the gram matrix are not dominant compared to off-diagonal entries. Also, the error performance is nonlinearly degraded as the used modulation order is increased. The more serious problem is that performance degradations cannot be solved by merely increasing L for the NS and transmit power at the BS.

For performance improvements and practical implementations, this paper proposes an efficient precoding method. According to the correlation of massive MIMO systems which is the same as diagonal dominance of active user, the proposed scheme uses a diagonal plus columns NS (DCNS)-k adaptively where the initial matrix is composed of diagonal entries and k-best columns of the gram matrix. The proposed scheme applies the DCNS-1 to fully diagonal dominant active users for low complexity and applies the DCNS-k $(2 \leq k \leq N_u)$ to non diagonal active users for improving the error performance. In the DCNS-k, k columns which minimize post interference power are selected for minimizing performance degradations. The detailed algorithm is represented in Section IV.

II. DOWNLINK MASSIVE MIMO SYSTEM CONFIGURATION

Fig. 1 shows system configuration for the downlink massive MIMO where the number of transmit antennas at the BS is N_t and the number of single antenna equipped active users is N_u $(N_t \gg N_u)$. The received symbol y_i at the i-th active user is as follows,

$$y_i = \sqrt{P}\mathbf{g}_i^T \frac{\mathbf{w}_i}{\|\mathbf{W}\|_F} x_i + \sum_{j=1, j\neq i}^{N_u} \sqrt{P}\mathbf{g}_i^T \frac{\mathbf{w}_j}{\|\mathbf{W}\|_F} x_j + n_i, \quad (1)$$

where P is downlink transmit power, $\mathbf{W}$ is $N_t \times N_u$ precoding matrix, $\mathbf{w}_i$ is the i-th column of $\mathbf{W}$, x_i is the i-th zero-mean and

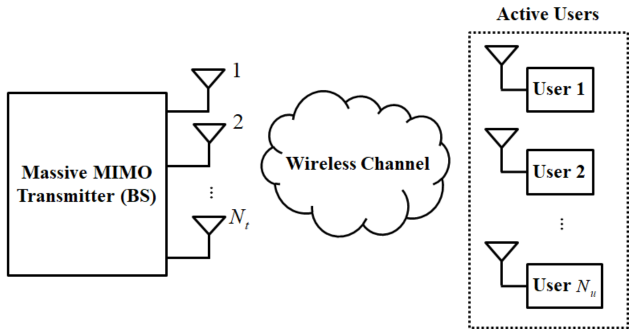

FIGURE 1. The system configuration for downlink massive MIMO.

unit variance transmit symbol, n_i is the i-th zero-mean and unit variance additive white Gaussian noise (AWGN), and $\mathbf{g}_i$ is the i-th column vector of $\mathbf{G}^T$ where $\mathbf{G}$ is Rayleigh fading channel matrix which is composed of channel coefficients from all transmit antennas to all active users as follows,

$$\mathbf{G} = \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1N_t} \\ g_{21} & g_{22} & \cdots & g_{2N_t} \\ \vdots & \vdots & \ddots & \vdots \\ g_{N_u1} & g_{N_u2} & \cdots & g_{N_uN_t} \end{bmatrix}, \quad (2)$$

where g_{ij} is zero-mean and unit variance channel coefficient from the j-th transmit antenna to the i-th active user.

III. CONVENTIONAL DOWNLINK PRECODING METHODS

This section expresses conventional downlink precoding methods, i.e. ZF and DNS.

A. ZF PRECODING

The ZF aims to suppress MUIs perfectly. The condition of precoding vector for perfect suppression of MUIs is as follows,

$$\begin{cases} \mathbf{g}_i^T \mathbf{w}_i = 1 \\ \mathbf{g}_i^T \mathbf{w}_j = 0 \, (\forall i \neq j) . \end{cases} \quad (3)$$

From (3), the ZF precoding matrix is as follows,

$$\mathbf{W} = \mathbf{G}^H \left(\mathbf{G}\mathbf{G}^H\right)^{-1}. \quad (4)$$

The ZF is well operated in interference dominant environments. However, the complexity for the ZF is very high since exact inversion of gram matrix $\mathbf{G}\mathbf{G}^H$ has to be calculated. Although the ZF is linear precoding scheme, the complexity order for calculating exact inverse matrix increases exponentially with respect to the number of linearly increased active users.

B. DNS PRECODING

For simple notation, the gram matrix $\mathbf{Z}$ is defined as follows,

$$\mathbf{Z} \triangleq \mathbf{G}\mathbf{G}^H = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1N_u} \\ z_{21} & z_{22} & \cdots & z_{2N_u} \\ \vdots & \vdots & \ddots & \vdots \\ z_{N_u1} & z_{N_u2} & \cdots & z_{N_uN_u} \end{bmatrix}. \quad (5)$$

For calculating $\mathbf{Z}^{-1}$ with low complexity, the NS based approximate ZF is used. For an invertible matrix $\mathbf{Z}$, the NS has to be satisfied with convergence condition as follows,

$$\lim_{n\to L}\left(\mathbf{I}_{N_u}-\Phi^{-1}\mathbf{Z}\right)^n=\mathbf{0}, \quad (6)$$

where Φ is initial matrix which has to similar with $\mathbf{Z}^{-1}$ for fast convergence of the NS and $\mathbf{I}_m$ is $m\times m$ identity matrix. The approximate $\mathbf{Z}^{-1}$ by using the NS is as follows,

$$\mathbf{Z}^{-1}\approx\sum_{n=0}^{L-1}\left(\mathbf{I}_{N_u}-\Phi^{-1}\mathbf{Z}\right)^n\Phi^{-1}. \quad (7)$$

In this paper, L is fixed to 2 for practical implementations. Again, methods for implementing efficient NS are summarized as two points. First, the convergence rate for the $L=2$ based NS in (6) has to be fast. Second, the complexity order for calculating Φ^{-1} has to be low. The DNS selects Φ as diagonal entries of $\mathbf{Z}$ and it is represented as $\mathbf{D}$ as follows,

$$\mathbf{D}\triangleq\begin{bmatrix} z_{11} & 0 & \cdots & 0\\ 0 & z_{22} & \cdots & 0\\ \vdots & \vdots & \ddots & \vdots\\ 0 & 0 & \cdots & z_{N_uN_u}\end{bmatrix}. \quad (8)$$

For the DNS, above two points are satisfied since one of main properties for the massive MIMO is diagonal dominance of $\mathbf{Z}$ due to law of large numbers, and the calculation of Φ^{-1} is very easy. However, the DNS has serious performance degradations in highly correlated massive MIMO system since diagonal entries for the gram matrix are not dominant compared to off-diagonal entries. Also, the performance degradations are more severe when the high order modulation is used.

IV. PROPOSED DOWNLINK PRECODING METHOD

In section III, main disadvantages for the conventional downlink precoding methods are described where the ZF has very high complexity and the DNS has serious performance degradations in highly correlated massive MIMO system. For solving problems of conventional downlink precoding methods, an efficient downlink precoding method based on the NS is proposed. The proposed scheme uses different precoding adaptively according to the number of diagonal dominant active users. The condition for diagonal dominance of the i-th user is as follows,

$$|z_{ii}|>\sum_{j=1,j\neq i}^{N_u}|z_{ij}|. \quad (9)$$

The number of total diagonal dominant active users V is summation of users which are satisfied with (9). According to V, the proposed scheme is divided into three scenarios (a) $V=N_u$, (b) $V=0$, (c) $0<V<N_u$. For the scenario (a), i.e. all active users are fully diagonal dominant, the proposed scheme applies the DCNS-1 which is specific form of general DCNS-k. Reversely, for the scenario (b), i.e. all active users are not fully diagonal dominant, the proposed scheme applies the DCNS-k. For detailed expression of the proposed DCNS-k, hollow matrix $\mathbf{E}$ is defined as follows,

$$\mathbf{E}\triangleq\mathbf{Z}-\mathbf{D}=\begin{bmatrix} 0 & z_{12} & \cdots & z_{1N_u}\\ z_{21} & 0 & \cdots & z_{2N_u}\\ \vdots & \vdots & \ddots & \vdots\\ z_{N_u1} & z_{N_u2} & \cdots & 0\end{bmatrix}. \quad (10)$$

The DCNS-k makes Φ^k which is general notation of Φ with respect to k in (7) as follows,

$$\Phi^k=\mathbf{D}+\mathbf{E}^k, \quad (11)$$

where $\mathbf{E}^k$ is composed of the k columns of $\mathbf{E}$ and N_u-k zeros columns. For easy understanding, an example for $N_u=3$ and $k=1$ is considered, and it is assumed that the first column of $\mathbf{E}$ is extracted. Then, $\mathbf{E}^1$ and Φ^1 are as follows,

$$\mathbf{E}^1=\begin{bmatrix} 0 & 0 & 0\\ z_{21} & 0 & 0\\ z_{31} & 0 & 0\end{bmatrix},\quad \Phi^1=\begin{bmatrix} z_{11} & 0 & 0\\ z_{21} & z_{22} & 0\\ z_{31} & 0 & z_{33}\end{bmatrix}. \quad (12)$$

The Φ^1 is decomposed into $\mathbf{D}$ and atomic matrix which is very easy to calculate the inverse matrix as follows,

$$\Phi^1=\mathbf{D}\begin{bmatrix} 1 & 0 & 0\\ z_{21}/z_{22} & 1 & 0\\ z_{31}/z_{33} & 0 & 1\end{bmatrix}. \quad (13)$$

Then, $\left(\Phi^1\right)^{-1}$ is as follows,

$$\left(\Phi^1\right)^{-1}=\begin{bmatrix} 1 & 0 & 0\\ -z_{21}/z_{22} & 1 & 0\\ -z_{31}/z_{33} & 0 & 1\end{bmatrix}\mathbf{D}^{-1}. \quad (14)$$

Equation (7) includes matrix multiplication $\left(\Phi^k\right)^{-1}\mathbf{Z}$ and the first column of $\left(\Phi^k\right)^{-1}\mathbf{Z}$ is unit vector where all MUIs to the first user are perfectly suppressed. For improving error performance, the proposed scheme selects k active users for the DCNS-k which cause the largest post interference power. Therefore, k columns which have the largest k squared Euclidean norm of $\mathbf{E}$ are selected. The simple selection improves error performance significantly and its results are shown in Section V. Also, for low complexity DCNS-k ($k>1$), the proposed scheme uses iterative Sherman Morrison formula (ISMF) for calculating $\left(\Phi^k\right)^{-1}$. For more general explanation, an example for N_u active users and $k=K$ is considered. It is assumed that the first column to the K-th column of $\mathbf{E}$ is extracted. For calculating $\left(\Phi^K\right)^{-1}$, $\left(\Phi^1\right)^{-1}$ is firstly calculated. Since $\mathbf{D}$ is invertible, $\left(\Phi^1\right)^{-1}$ is represented as follows,

$$\left(\Phi^1\right)^{-1}=\left(\mathbf{D}+\mathbf{e}_1\mathbf{v}_1^T\right)^{-1}=\mathbf{D}^{-1}-\frac{\mathbf{D}^{-1}\mathbf{e}_1\mathbf{v}_1^T\mathbf{D}^{-1}}{1+\mathbf{v}_1^T\mathbf{D}^{-1}\mathbf{e}_1}, \quad (15)$$

where $\mathbf{e}_j$ and $\mathbf{v}_j$ are the j-th column of $\mathbf{E}$ and $\mathbf{I}_{N_u}$ respectively. By using (15), $\left(\Phi^2\right)^{-1}$ is represented as follows,

$$\left(\Phi^2\right)^{-1}=\left(\Phi^1\right)^{-1}-\frac{\left(\Phi^1\right)^{-1}\mathbf{e}_2\mathbf{v}_2^T\left(\Phi^1\right)^{-1}}{1+\mathbf{v}_2^T\left(\Phi^1\right)^{-1}\mathbf{e}_2}. \quad (16)$$

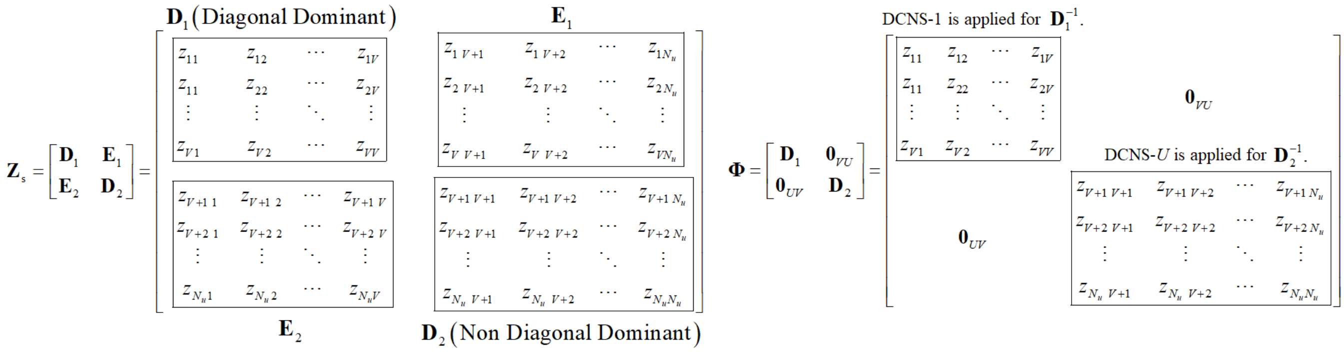

FIGURE 2. The detailed expressions of $\mathbf{Z_s}$ and Φ for the proposed hybrid DCNS-1 and DCNS-*U*.

In this way, $\left(\Phi^k\right)^{-1}$ is calculated at the k-th iteration loop and an algorithm for the ISMF ends at the K-th iteration loop. The trade-off relationship between the error performance and the complexity is noticeable according to k, i.e. the error performance is improved as k increases but, the complexity is also increased.

Finally, for the scenario (c), the proposed scheme applies the hybrid DCNS-1 and DCNS-U where $U = N_u - V$ is the number of non diagonal dominant active users when V is greater than 0 and less than N_u. The DCNS-1 is applied to diagonal dominant V active users and the DCNS-U which uses full columns for the ISMF for minimizing the loss of performance degradations is applied to non diagonal dominant U active users. For applying different precoding scheme according to diagonal dominance of active users, diagonal and non diagonal dominant active users have to be separated. For separation, rows of $\mathbf{G}$ are sorted as descending order according to diagonal dominance, i.e. the row which has the largest diagonal dominance moves to the first row, and the row which has the smallest diagonal dominance moves to the last row. It is assumed that the first row to the V-th row of $\mathbf{G}$ is diagonal dominant active users, and all rows are sorted as descending order according to diagonal dominance for simple notation. Therefore, $\mathbf{Z}$ in (5) can be used as sorted gram matrix. However, $\mathbf{Z}$ is replaced with $\mathbf{Z}_s$ for highlighting sorted gram matrix. Fig. 2 shows $\mathbf{Z}_s$ and block diagonal initial matrix Φ where $\mathbf{0}_{ij}$ is $i \times j$ zeros matrix. In $\mathbf{Z}_s$, $\mathbf{D}_1$ is diagonal dominant matrix and $\mathbf{D}_2$ is non diagonal dominant matrix. Also, $\mathbf{E}_1$ and $\mathbf{E}_2$ are block off-diagonal matrix. By using (7) with $L = 2$, $\mathbf{Z}_s^{-1}$ is approximated as follows,

$$\mathbf{Z}_s^{-1} \approx \sum_{n=0}^{1} \left(\mathbf{I}_{N_u} - \Phi^{-1}\mathbf{Z}_s\right)^n \Phi^{-1} = 2\Phi^{-1} - \Phi^{-1}\mathbf{Z}_s\Phi^{-1} = \begin{bmatrix} \mathbf{D}_1^{-1} & -\mathbf{D}_1^{-1}\mathbf{E}_1\mathbf{D}_2^{-1} \\ -\mathbf{D}_2^{-1}\mathbf{E}_2\mathbf{D}_1^{-1} & \mathbf{D}_2^{-1} \end{bmatrix}, \tag{17}$$

where it uses property of block diagonal matrix as follows,

$$\Phi^{-1} = \begin{bmatrix} \mathbf{D}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{D}_2 \end{bmatrix}^{-1} = \begin{bmatrix} \mathbf{D}_1^{-1} & \mathbf{0} \\ \mathbf{0} & \mathbf{D}_2^{-1} \end{bmatrix}. \tag{18}$$

For obtaining $\mathbf{Z}_s^{-1}$, $\mathbf{D}_1^{-1}$ and $\mathbf{D}_2^{-1}$ have to be calculated. The proposed scheme applies the DCNS-1 such as (14) for calculating $\mathbf{D}_1^{-1}$ since $\mathbf{D}_1$ is diagonal dominant matrix for low complexity. However, the proposed scheme applies the DCNS-U such as (15) and (16) for calculating $\mathbf{D}_2^{-1}$ since $\mathbf{D}_2$ is non diagonal dominant matrix to minimize the loss of performance degradations.

In this way, methods for calculating approximate Φ^{-1} of all scenarios of the proposed scheme are considered. With Φ^{-1}, (7) and (4) are applied for calculating the precoding matrix. Finally, $\mathbf{Z}_s^{-1}$ is modified to $\mathbf{Z}^{-1}$ by sorting in reverse order.

Fig. 3 shows a flow chart for the proposed scheme. In Fig. 3, matched filter (MF) denotes multiplication of $\mathbf{G}^H$ to $\mathbf{Z}^{-1}$ in (4).

Table 1 expresses required multiplications for the conventional ZF, DNS, and proposed scheme. It is assumed that one complex multiplication costs one floating-point operations (flops). The total complexity for the massive MIMO system is nearly dependent on $O\left(N_u^n\right)$ $(n > 0)$. Therefore, $O\left(N_u^0\right)$ terms are omitted for simple expressions. The conventional ZF, DNS, and proposed scheme require calculations of $\mathbf{Z}^{-1}$ and $\mathbf{G}^H\mathbf{Z}^{-1}$. However, $\mathbf{G}^H\mathbf{Z}^{-1}$ is commonly required for all precoding schemes. So, the complexities for only calculating $\mathbf{Z}^{-1}$ are considered. In Table 1, the complexity for the proposed DCNS-1 is required to calculate diagonal dominance of all users, selection for the best user, inversion of initial matrix, and NS. The proposed DCNS-K is calculated like the DCNS-1 but selection of the best user is replaced with selection of the largest K users, and the ISMF is used for calculating inversion of initial matrix.

V. PERFORMANCES EVALUATION

For performances evaluation of the proposed scheme, BER performances and complexities are measured. The simulation results for the conventional ZF and DNS are also shown for comparisons. In all simulation results, the number of transmit antennas is fixed to 200 for practical massive MIMO systems. The downlink channels are modeled by Rayleigh fading where all MIMO channel coefficients are zero-mean and unit variance. Also, the AWGN at all active users is zero-mean and unit variance. Finally, time division

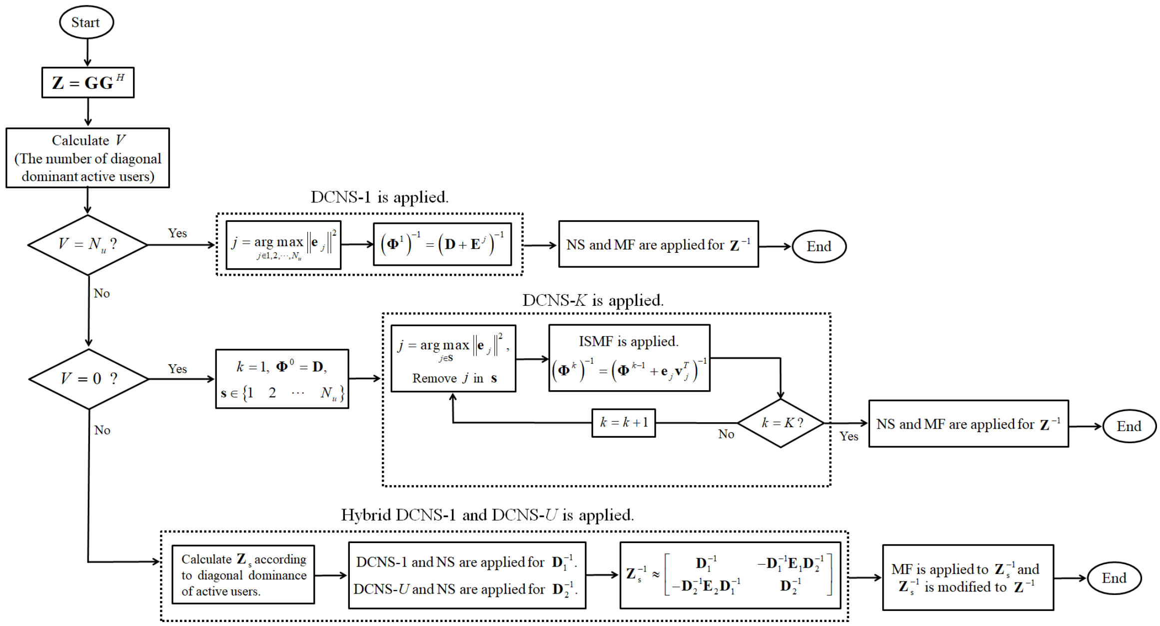

FIGURE 3. **The flow chart for the proposed scheme.**

TABLE 1. **The number of complex multiplications for calculating gram matrix of the conventional ZF, DNS, and proposed scheme.**

Scheme	The number of complex multiplications
Exact ZF	$N_u^3 + N_u^2$ with Gauss elimination in [13]
NS with DNS	$2N_u^2$
NS with proposed DCNS-1	$5N_u^2 + 7N_u$
NS with proposed DCNS-K	$5N_u^2 + (K^2 + 4K)\, N_u + \left(\frac{K^2 - 5K}{2}\right)$
NS with proposed hybrid DCNS-1 and DCNS-U	$\left(U^3 + \frac{9U^2 - 5U}{2}\right) + (5V^2 + 7V)\ (U < N_u)$

duplex (TDD) system is assumed where the coherence interval of wireless channel is sufficient that the uplink channel matrix is transpose of downlink channel matrix. The downlink channels are estimated by transmitting orthogonal pilot sequences at all active users. The length of pilot sequence τ is N_u for minimizing an effect of pilot contamination to adjacent cells. The received pilot sequence $\mathbf{Y}_p$ at the BS is as follows,

$$\mathbf{Y}_p = \sqrt{\tau P_u}\mathbf{G}^T\mathbf{X}_p + \mathbf{N}_p, \tag{19}$$

where P_u is uplink transmit power, $\mathbf{X}_p$ is $N_u \times \tau$ unitary orthogonal pilot matrix which is satisfied with $\mathbf{X}_p\mathbf{X}_p^H = \mathbf{I}_{N_u}$, and $\mathbf{N}_p$ is $N_t \times \tau$ AWGN where all entries have zero-mean and unit variance. The estimated channel matrix $\hat{\mathbf{G}}$ at the BS which is used for downlink precoding is as follows,

$$\hat{\mathbf{G}} = \frac{\mathbf{X}_p^*\mathbf{Y}_p^T}{\sqrt{\tau P_u}} = \mathbf{G} + \bar{\mathbf{N}}_p, \tag{20}$$

where $\bar{\mathbf{N}}_p = \frac{\mathbf{X}_p^*\mathbf{N}_p^T}{\sqrt{\tau P_u}}$ is modified AWGN.

Fig. 4 shows mean square error (MSE) performances of channel estimation in 200×10, 200×20, and 200×30 massive MIMO systems with respect to uplink transmit power where P_u is 3dB less than P. The theoretical MSE performances for the channel estimation are calculated by using the (i, j)-th

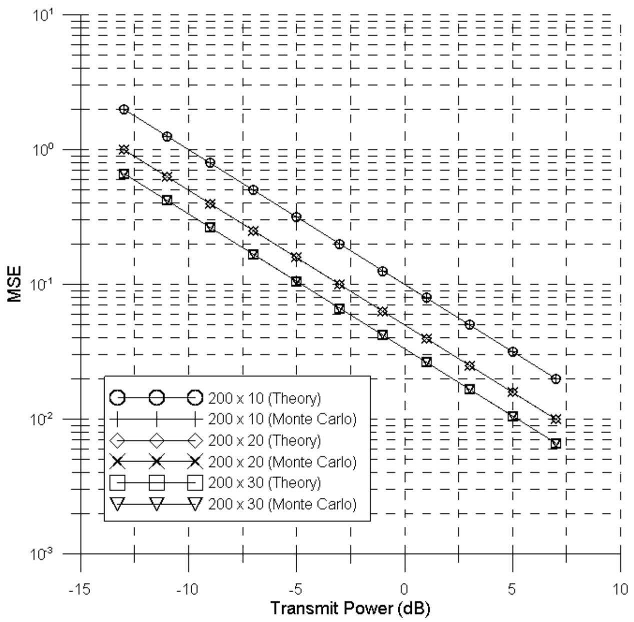

FIGURE 4. The MSE performances of channel estimation in 200 × 10, 200 × 20, and 200 × 30 massive MIMO systems.

component of $\tilde{\mathbf{G}} = \mathbf{G} - \hat{\mathbf{G}}$ as follows,

$$E\left[\left|\left[\tilde{\mathbf{G}}\right]_{ij}\right|^2\right] = E\left[\left|[\bar{\mathbf{N}}_p]_{ij}\right|^2\right] = \frac{1}{\tau P_u}, \tag{21}$$

where theoretical results are the same as Monte Carlo based results. The MSE performance is improved as the number of active users increases since transmit power of pilot sequence is proportional to τ.

Fig. 5 shows utilization rate among the proposed DCNS-1, DCNS-k, and hybrid DCNS-1 and DCNS-k with respect to the number of active users. The proposed DCNS-1 is almost used when the number of active users is less than 13 since the massive MIMO system is nearly diagonal dominant. However, the proposed hybrid DCNS-1 and DCNS-U is almost used when the number of active users is more than 13 and less than 21 since the massive MIMO system is partially diagonal dominant. Finally, the proposed DCNS-k is almost used when the number of active users is more than 21 since the massive MIMO system is highly correlated. The results in Fig. 5 help to understand other simulation results from Fig. 6 to Fig. 10 well.

Fig. 6, Fig. 7, and Fig. 8 show BER performances for the conventional ZF, DNS, and proposed scheme in 200 × 10, 200 × 20, and 200 × 30 massive MIMO systems respectively by using quadrature phase shift keying (QPSK) and 16-quadrature amplitude modulation (QAM). In simulation results, the number of active users is chosen as 10, 20, and 30 according to results in Fig. 5 where these numbers are proper values to show performances for the proposed scheme variously with respect to diagonal dominance of active users. The transmit power at the BS has range from -10dB to 10dB since the massive MIMO system seeks high energy efficiency.

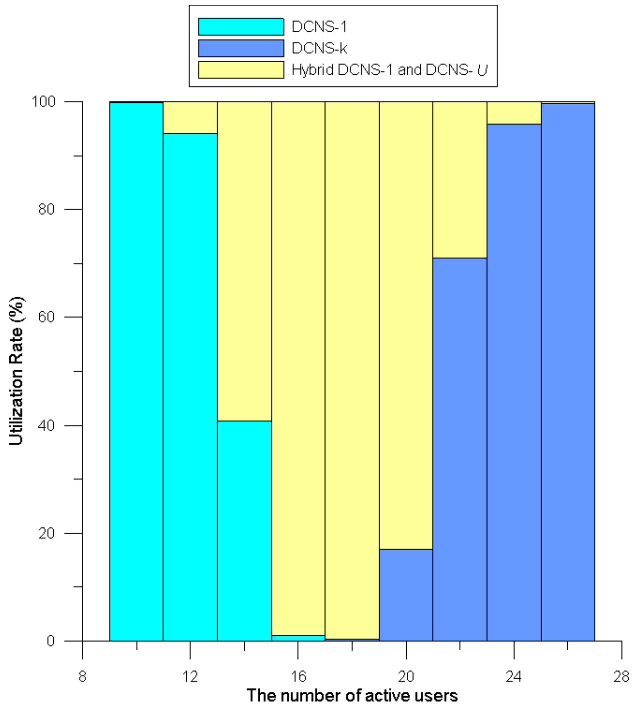

FIGURE 5. The utilization rate among the proposed DCNS-1, DCNS-*k*, and hybrid DCNS-1 and DCNS-*k* with respect to the number of active users.

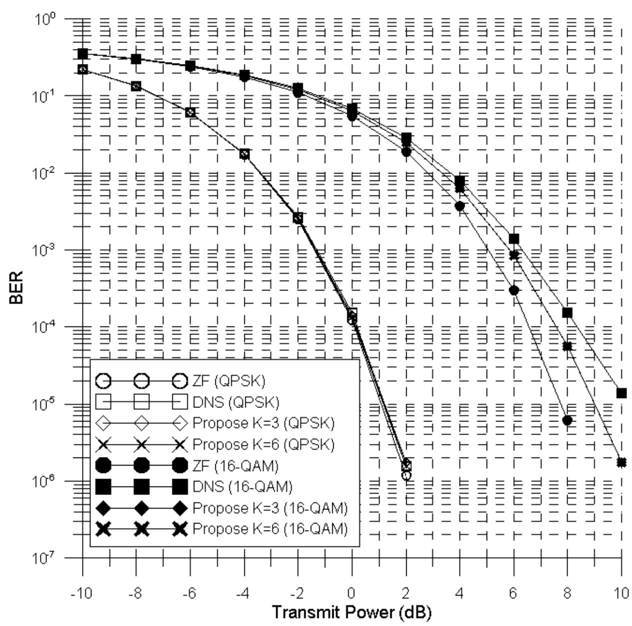

FIGURE 6. The BER performances for the conventional ZF, DNS, and proposed scheme in 200 × 10 massive MIMO system.

The parameter K for the proposed DCNS-K is fixed to $K = 0.3N_u$ and $K = 0.6N_u$ for various results of the proposed scheme. Again, the ZF has nearly optimal BER performance in massive MIMO systems and it is good reference to evaluate the proposed scheme.

In Fig. 6, the conventional DNS and proposed scheme which use the QPSK have nearly the same BER performance as conventional ZF since the massive MIMO system is fully

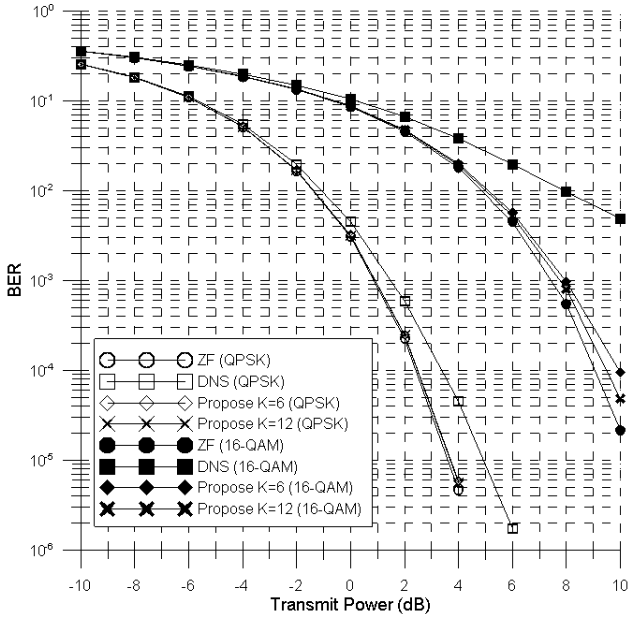

FIGURE 7. The BER performances for the conventional ZF, DNS, and proposed scheme in 200 × 20 massive MIMO system.

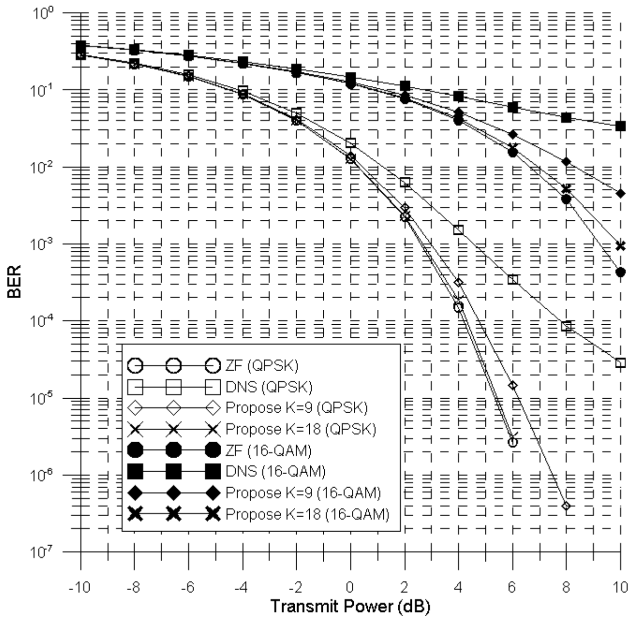

FIGURE 8. The BER performances for the conventional ZF, DNS, and proposed scheme in 200 × 30 massive MIMO system.

diagonal dominant (see Fig. 5) and modulation order is not large. The increased K cannot improve the BER performance for the proposed scheme since the only DCNS-1 is used due to fully diagonal dominant massive MIMO system. The conventional DNS and proposed scheme which use the 16-QAM suffer from slight BER degradations compared to the conventional ZF. However, the BER degradation for the proposed scheme is less than the conventional DNS since an active user which causes the largest post interference power is suppressed.

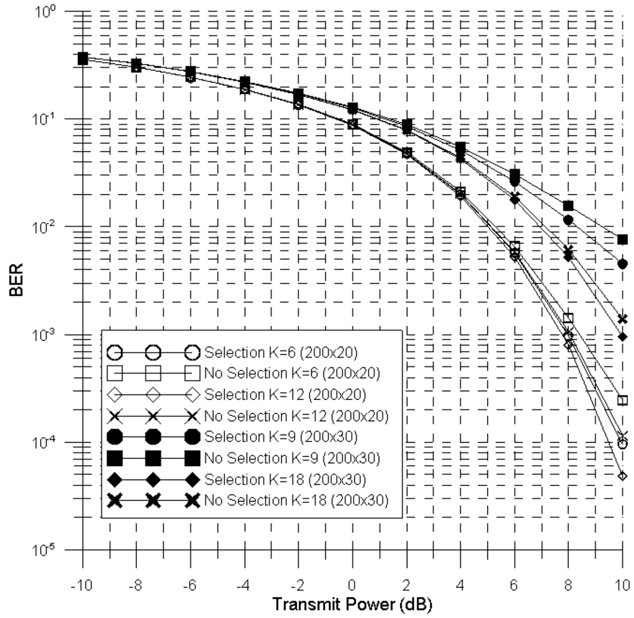

FIGURE 9. The BER performances for the proposed scheme with respect to selection of DCNS-K in 200 × 20 and 200 × 30 massive MIMO systems.

In Fig. 7 and Fig. 8, the conventional DNS has BER degradations compared to the conventional ZF regardless of used modulation scheme since the massive MIMO is partially diagonal dominant in 200 × 20 system and is not fully diagonal dominant in 200 × 30 (see Fig. 5). The performance degradations are more severe as the number of active users and used modulation order are large. However, contrary to results in Fig. 6, the increased K can improve BER performances, and proposed schemes with $K = 12$ in 200 × 20 system and $K = 18$ in 200 × 30 system have nearly the same BER performances as conventional ZF.

Fig. 9 shows BER performances for the proposed scheme with respect to selections of the proposed DCNS-K by using the 16-QAM in 200 × 20 and 200 × 30 massive MIMO systems. The simple selections which require only squared Euclidean norm of column vectors in hollow matrix can improve BER performances since K active users which have the largest post interference power are suppressed.

Fig. 10 shows the required number of multiplications of gram matrix for the conventional ZF, DNS, and proposed scheme with respect to the number of active users. The number of multiplications for proposed schemes regardless of K is nearly the same as conventional DNS when the number of active users is 10 since the massive MIMO system is fully diagonal dominant and it leads very slight addition of multiplication for selection of only one active user. However, the number of multiplications for the proposed schemes regardless of K is slightly higher than the conventional DNS when the number of active users is 20 since a large number of hybrid DCNS-1 and DCNS-U are used. The utilization rate of the DCNS-k is about 19% and the complexity for the proposed scheme with $K = 0.6N_u$ is very slightly higher than the proposed scheme with $K = 0.3N_u$. Also,

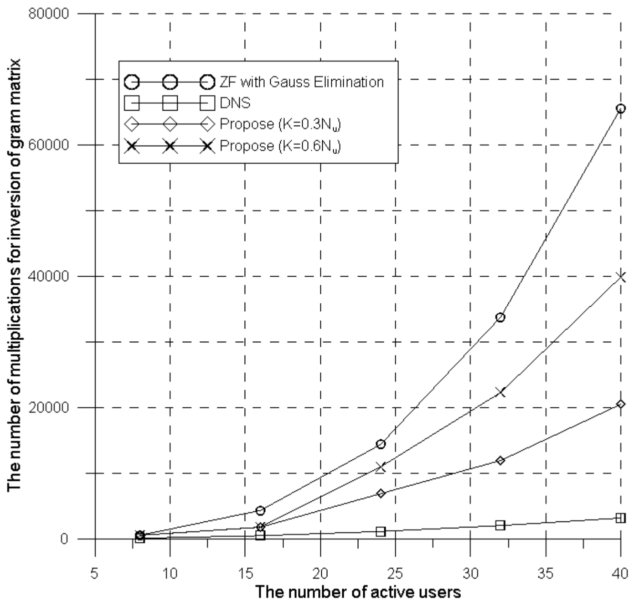

FIGURE 10. The required number of multiplications for the conventional ZF, DNS, and proposed scheme with respect to the number of active users.

the differences of complexities between proposed schemes are increased with respect to K when the number of active users is more than 20 since the utilization rate for the DCNS-k is increased as the massive MIMO system is more correlated.

VI. CONCLUSION

This paper proposes an adaptive downlink precoding method to solve one of main problems for the conventional DNS which has poor BER performance in highly correlated massive MIMO system. For an efficient precoding, the proposed scheme selects one of the DCNS-1, DCNS-k, and hybrid DCNS-1 and DCNS-U adaptively according to the number of total diagonal dominant active users. The proposed scheme applies the DCNS-1 to diagonal dominant active users and reversely, applies the DCNS-k to non diagonal dominant active users for efficient usage of the property of massive MIMO system. The proposed DCNS-k selects k active users which cause the largest post interference power and these simple calculations improve the BER performance. In simulation results, the proposed scheme has nearly the same BER performance as conventional optimal ZF despite of small K of the DCNS-K, and has very higher BER performance than the conventional DNS in highly correlated massive MIMO system with some additions of complexity.

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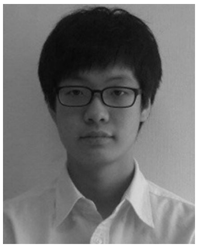

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