JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. 17 No 3, 03015(6pp) (2025)
ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том 17 № 3, 03015(6cc) (2025)

REGULAR ARTICLE

# Massive MIMO Signal Detection Using Cascaded OQRD-PMD Method

J.P. Patra[1,*] ✉, R.K. Mahapatra[2], S.B. Prusty[3], K. Babooji[4], G.S. Satapathi[5], V.-K. Samudrala[6]

[1] *Department of Electronics and Communication Engineering, C. V. Raman Global University, Bhubaneswar-752054, Odisha, India*

[2] *Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Founda-tion, Vaddeswaram-522302, AP, India*

[3] *School of Electronics and Communication Engineering, REVA University, Bengaluru-560064, Karnataka, India*

[4] *Department of Electronics and Communication Engineering Sri Vasavi Engi-neering College, Tadepalligudem-534101, AP, India*

[5] *Department of Electronics and Communication Engineering, A J Institute of Engineering and Technology, Mangaluru-575006, Karnataka, India*

[6] *Department of Electronics and Com-munication Engineering NRI Institute of Technology (A) Agiripalli, 521212, AP, India*

(Received 01 April 2025; revised manuscript received 20 June 2025; published online 27 June 2025)

The minimum mean square error (MMSE) is adopted widely as a signal detection technique for massive MIMO (mMIMO) systems; however, it needs matrix inversion with complexity of cubic or-der. Therefore, several signal detection techniques were adopted, including successive over relaxation, Richardson, Jacobi, and Gauss Seidel (GS) to avoid matrix inversion. Although these techniques offer lower complexity, their performance remains inferior to MMSE. Therefore, in this paper, we propose four signal detection techniques namely QR decomposition (QRD), QRD-parallel multi-stage detection (QRD-PMD), ordered QRD (OQRD), and OQRD-PMD. In this work, at first, the QR decom-position is applied to the channel matrix followed by backward substitution method to obtain the transmitted signal. After that, the ordered QRD (OQRD) method is applied to avoid the error propagation problem arises in QRD method. Furthermore, the parallel multistage detection (PMD) method is cascaded with QRD and OQRD to estimate more accurate transmitted signal at the receiver side. The performances of conventional and proposed signal detection techniques are evaluated based on bit error rate (BER) and complexity. The simulation results show that the proposed techniques significant achieve superior performance as compared to MMSE while maintaining comparable complexity.

**Keywords**: Signal detection, Massive MIMO, Parallel multistage detection, Ordered QRD.

DOI: 10.21272/jnep.17(3).03015 PACS number: 84.40.Ba

## 1. INTRODUCTION

The massive multiple input multiple output (mMIMO) is a promising technique for 5G communication, known for its high spectral efficiency, simple transceiver design and higher diversity gain [1-2]. In mMIMO system, the base station (BS) is deployed with massive antennas. During uplink transmission, signals from multiple user terminals are superimposed at the BS, leading to interference and thus reduces data rates. Although, the minimum mean square error (MMSE) is a widely used detection techniques, but it involves matrix inversion. To avoid matrix inversion, several detection methods were proposed by exploiting Gram matrix. These methods include Neumann series (NS) [3], successive over relaxation techniques (SOR) [4-5], Jacobi method [6], Gauss Seidel (GS) [7], conjugate gradient (CG) [8], Richardson (RI) [9], multiple search direction conjugate gradient (MSD-CG) [10]. The Neumann series technique has lowest complexity however its performance is poor as compared to other methods. Gauss-Seidel (GS) detector with Jacobi iteration (CJ) (CJGS) method was presented in [11]. This method provides faster converges with increasing in computational complexity. An iterative hybrid pseudo-stationary algorithm was proposed in [12]. This method achieves performance close to zero-forcing (ZF) method. Based on the Cayley Hamilton theorem two signal detection techniques were proposed in [13].

An improved Newton iterative based mMIMO signal detection was prosed in [14]. Extrapolation principles incorporate with SOR method was proposed for mMIMO

* Correspondence e-mail: jyotiprasannapatra@gmail.com





Cite this article as: J.P. Patra, et al., *J. Nano- Electron. Phys.* 17 No 3, 03015 (2025) https://doi.org/10.21272/jnep.17(3).03015

system in [15]. The performance of extrapolation based SOR is close to MMSE method with lower complexity.

Since, all the signal detection methods [3-15] are developed by approximating the MMSE Gram matrix, their performances are limited to MMSE method. Therefore, in this work, we propose four signal detection techniques such as QR decomposition (QRD), ordered QRD (OQRD), QRD-parallel multistage detection (QRD-PMD), and OQRD-PMD. The performance of these methods is compared with conventional techniques based on bit error rate (BER) and complexity. Since, these methods are obtained by directly by exploiting the channel matrix, their performances are superior as compared to the MMSE method and the complexity is one order lower than MMSE as they do not require matrix inversion.

The remaining part of the paper is organized as: The uplink mMIMO system is described in Section 2. In Section 3, we review several existing techniques. The proposed techniques are discussed followed by complexity calculations in Section 4 and Section 5 respectively. The simulation results were presented based on bit error rates in Section 6. Finally, the work is concluded in Section 7.

## 2. SYSTEM MODEL

This paper considers uplink mMIMO system which deploys $M$ base station (BS) antennas and $N$. Let the symbol $\boldsymbol{x}$ represents $N \times 1$ transmitting signal vector simultaneously transmit signals to $M$ number of base stations. Thus, the received signal vector $\boldsymbol{y}$ is written as

$$\boldsymbol{y} = \boldsymbol{Hx} + \boldsymbol{w} \tag{1}$$

where $\boldsymbol{H}$ denotes $M \times N$ dimensions channel matrix. The signal detection using MMSE can be expressed as

$$\hat{\boldsymbol{x}} = \left( \boldsymbol{H}^{H}\boldsymbol{H} + \frac{\boldsymbol{N}}{\boldsymbol{SNR}}\boldsymbol{I}_{N} \right)^{-1} \boldsymbol{H}^{H}\boldsymbol{y} = \boldsymbol{A}^{-1}\boldsymbol{y}_{MF} \tag{2}$$

where $\boldsymbol{A} = \boldsymbol{H}^{H}\boldsymbol{H} + \frac{\boldsymbol{N}}{\boldsymbol{SNR}}\boldsymbol{I}_{N}$, $\boldsymbol{y}_{MF} = \boldsymbol{H}^{H}\boldsymbol{y}$. Thus, MMSE method requires matrix inversion with cubic complexity.

## 3. CONVENTIONAL SIGL METHODS

To avoid matrix inversion, several signal detection techniques were proposed by exploiting the Gram matrix such as JA, RI, GS, SOR for uplink mMIMO systems.

### 3.1 Jacobi Method

The signal detection in Jacobi method is performed iteratively as described below:

$$\hat{\boldsymbol{x}}^{(i)} = \boldsymbol{D}^{-1}\left[ \boldsymbol{y}_{MF} + (\boldsymbol{D} - \boldsymbol{A})\hat{\boldsymbol{x}}^{(i-1)} \right] \tag{3}$$

$$\lim_{i \to \infty}\left( \boldsymbol{I} - \boldsymbol{D}^{-1}\boldsymbol{A} \right)^{i} = 0 \tag{4}$$

The diagonal matrix $D$ is obtained from matrix $\boldsymbol{A}$. For simplicity, the initial estimated signal is considered as

$$\hat{\boldsymbol{x}}^{(0)} = \boldsymbol{D}^{-1}\boldsymbol{y}_{MF} \tag{5}$$

### 3.2 Richardson Method

The Richardson method performs the signal detection iteratively by exploitation of regularized matrix $\boldsymbol{A}$.

$$\boldsymbol{x}^{(i+1)} = \boldsymbol{x}^{(i)} + \boldsymbol{\omega}\left[ \boldsymbol{y} - \boldsymbol{Hx}^{(n)} \right] \quad i = 0,1,2,\cdots \tag{6}$$

The initial estimate of the signal is taken as $\hat{\boldsymbol{x}}^{(0)} = \boldsymbol{D}^{-1}\boldsymbol{y}_{MF}$ Typically, $\omega$ is taken in the range of $0 < \omega \le \frac{2}{\lambda}$, with $\lambda$ is the largest eigenvalue of $\boldsymbol{H}$.

### 3.3 Gauss-Seidel method

In Gauss-Seidel method, the Gram matrix ($\boldsymbol{A}$) is decomposed into lower triangular ($\boldsymbol{L}$), diagonal ($\boldsymbol{D}$), and a upper triangular ($\boldsymbol{U}$) matrices as follows:

$$\boldsymbol{A} = \boldsymbol{L} + \boldsymbol{D} + \boldsymbol{U} \tag{7}$$

The detection is performed iteratively as

$$\hat{\boldsymbol{x}}^{(i)} = [\boldsymbol{D} + \boldsymbol{L}]^{-1}\left[ \boldsymbol{y}_{MF} - \boldsymbol{U}\hat{\boldsymbol{x}}^{(i-1)} \right], \quad i = 1,2,\cdots. \tag{8}$$

the initial estimate of the signal is $\hat{\boldsymbol{x}}^{(0)} = \boldsymbol{0}_{N}$.

### 3.4 Successive Over Relaxation Method

The successive over relaxation technique enhances the accuracy of the Gauss-Seidel method by introducing a parameter $\omega$. The estimated signal is obtained as

$$\hat{\boldsymbol{x}}^{(i)} = \left[ \frac{1}{\boldsymbol{\omega}}\boldsymbol{D} + \boldsymbol{L} \right]^{-1}\left[ \boldsymbol{y}_{MF} + \left[ \left[ \frac{1}{\boldsymbol{\omega}} - 1 \right]\boldsymbol{D} - \boldsymbol{U} \right]\hat{\boldsymbol{x}}^{[i-1]} \right] \tag{9}$$

The relaxation parameter $\omega$ is typically taken in the range between $0 < \omega < 2$.

## 4. PROPOSED SIGNAL DETECTION METHODS

This section discusses four proposed detection techniques: QRD, OQRD, QRD-PMD, and OQRD-PMD.

### 4.1 QRD Method

The QRD method perform signal detection using following steps as given below.

[Step 1] The relationship between transmitted and received signals can be expressed in the matrix form as:

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_M \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N} \\ h_{21} & h_{22} & \cdots & h_{2N} \\ \vdots & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & \vdots \\ h_{M1} & h_{M2} & \cdots & h_{MN} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_M \end{bmatrix} \tag{10}$$

[Step 2] The $\boldsymbol{H}$ matrix is factorized using QR method as $\boldsymbol{H} = \boldsymbol{QR}$. The received signal vector becomes

$$\boldsymbol{y} = \boldsymbol{Hx} + \boldsymbol{w} = \boldsymbol{QRx} + \boldsymbol{w} \tag{11}$$

where $\boldsymbol{Q}_{M\times N}$ and $R_{N\times N}$ are orthonormal and upper triangular matrices respectively.

[Step 3] Multiplying $\boldsymbol{Q}^H$ with $\boldsymbol{y}$, we have

$$\tilde{\boldsymbol{y}} = \boldsymbol{Q}^H(\boldsymbol{Hx} + \boldsymbol{w}) = \boldsymbol{R}\tilde{\boldsymbol{x}} + \tilde{\boldsymbol{w}} \tag{12}$$

$$\begin{bmatrix} \tilde{y}_1 \\ \tilde{y}_2 \\ \vdots \\ \tilde{y}_N \end{bmatrix} = \begin{bmatrix} R_{11} & R_{12} & \cdots & R_{1N} \\ 0 & R_{22} & \cdots & R_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & R_{NN} \end{bmatrix} \begin{bmatrix} \tilde{x}_1 \\ \tilde{x}_2 \\ \vdots \\ \tilde{x}_N \end{bmatrix} + \begin{bmatrix} \tilde{w}_1 \\ \tilde{w}_2 \\ \vdots \\ \tilde{w}_N \end{bmatrix} \tag{13}$$

[Step 4] Backward substitution algorithm is performed to obtain for estimation of the transmitted signal as

$$\hat{x}_N = \boldsymbol{\Pi}\left[\frac{\tilde{y}_N}{R_{NN}}\right] \tag{14}$$

$$\hat{x}_k = \boldsymbol{\Pi}\left[\frac{\tilde{y}_k - \sum_{j=k+1}^{N} \tilde{y}_{kj} x_j}{R_{kk}}\right], k = N-1:-1:1 \tag{15}$$

### 4.2 OQRD Method

The QR decomposition may experiences error propagation when the initial signal is not obtained accurately. To mitigate this problem, the ordered QRD (OQRD) method arranges the columns of channel matrix $\boldsymbol{H}$ in ascending order based on the column norms using the following steps as given below. The received signal, is represented in column form, as follows:

$$\boldsymbol{y} = \boldsymbol{Hx} + \boldsymbol{w} = \boldsymbol{h}_1 x_1 + \boldsymbol{h}_2 x_2 + \cdots + \boldsymbol{h}_N x_N + \boldsymbol{w} \tag{16}$$

where $\boldsymbol{h}_k$ denotes $k$-th column of $\boldsymbol{H}$ matrix. To arrange column of $\boldsymbol{H}$ in ascending order, the norms of column vector need to be calculated and is given by

$$norm_k = \|\boldsymbol{h}_k\| \quad k = 1,2,.....,N \tag{17}$$

Then, the column vectors are sorted in ascending manner using their ***index*** as

$$\boldsymbol{index} = sort(\boldsymbol{norm}) \tag{18}$$

The modified channel matrix $\boldsymbol{H}_o$ is given by

$$\boldsymbol{h}_{o,k} = \boldsymbol{H}_o(:,k) = \boldsymbol{H}(:,index_k) \tag{19}$$

where $\boldsymbol{h}_{o,k}$ refers to k-th column of $\boldsymbol{H}_o$ matrix. The transmitted signal vector also needs to be ordered as

$$x_{o,k} = \boldsymbol{x}(index_k) \tag{20}$$

After substituting $\boldsymbol{H}_o$ and $\boldsymbol{x}_o$, received signal $\mathbf{y}$ becomes

$$\boldsymbol{y} = \boldsymbol{H}_o \boldsymbol{x}_o + \boldsymbol{w} \tag{21}$$

By performing QR factorization $\boldsymbol{H}_o = \boldsymbol{QR}$ and multiply $\boldsymbol{Q}^H$ with $\boldsymbol{y}$, it becomes

$$\tilde{\boldsymbol{y}} = \boldsymbol{Q}^H(\boldsymbol{H}_o \boldsymbol{x}_o + \boldsymbol{w}) = R\tilde{\boldsymbol{x}}_o + \tilde{\boldsymbol{w}} \tag{22}$$

Finally, the transmitted signals are detected using backward substitution algorithm.

### 4.3 QRD-PMD Method

To further enhance the performance, the QRD method is cascaded with parallel multistage detection (PMD) [16], resulting in the QRD-PMD approach. In this method, at first, the $N$ auxiliary symbol vectors are constructed from initial estimate of QRD output such that each time k-th element is set to zero as

$$\breve{\boldsymbol{x}}_k = \boldsymbol{J}_k \tilde{\boldsymbol{x}}_k \tag{23}$$

where $\boldsymbol{J}_k$ is a $N \times N$ identity matrix with all ones e cept the $k$-th element is zero. Then, the interference free signal for $k$-th user can be obtained by subtracting the contribution of all the interference signal as

$$\boldsymbol{y}_k = \boldsymbol{y} - \boldsymbol{H}\breve{\boldsymbol{x}}_k \tag{24}$$

The $k$-th estimated signal can be obtained as

$$\hat{\boldsymbol{x}}_k = \boldsymbol{\Pi}[(\boldsymbol{h}_k^H \tilde{\boldsymbol{y}}_k)/(\boldsymbol{h}_k^H \boldsymbol{h}_k)] \tag{25}$$

### 4.4 OQRD-PMD Method

The OQRD-PMD method is exactly same as QRD-PMD except the OQRD is used in place of the QRD.

## 5. COMPUTATIONAL COMPLEXITY

This section analyzes the complexity of proposed QRD, OQRD, QRD-PMD, and OQRD-PMD methods in terms of real multiplications. The QR decomposition of channel matrix $\boldsymbol{H}$ needs $N^{2.529}$ [17]. Multiplication of $\boldsymbol{Q}^H\boldsymbol{y}$ has $N^{2.529} + 4NM^2 + 2N(N-1)$ real multiplications. The backward substitution as outlined in [step 4] needs $N^2 - N$. Hence, the QRD method requires $N^{2.529} + 4NM^2 + 2N(N-1)$ complexities. The OQRD method involves calculating the column vector norm, which requires $4MN$ additional multiplications. Thus, OQRD method requires $4MN + N^{2.529} + 4NM^2 + 2N(N-1)$ real multiplications. The QRD-PMD method first obtain rough estimates using QRD operation which requires $N^{2.529} + 4NM^2 + 2N(N-1)$ real multiplication. Multiplication of diagonal $\boldsymbol{J}_k$ matrix of size $2M \times 2M$ real matrix with signal vector $\tilde{\boldsymbol{x}}_k$ with size $2M \times 1$, has complexity of $2M$. The matrix-vector multiplication operation in Eqn. (24) of size $2N \times 2M$ with $2M \times 1$ has complexity of $4NM$ and Eqn. (25) involves vector-vector multiplication with complexity $2N$. Therefore, the number of real multiplications of PMD method from all users has complexity of $(2M^2 + 4NM^2 + 2NM)$. Thus, proposed QRD-PMD method has complexity $N^{2.529} + 8NM^2 + 2N(N-1) + 2NM$. Similarly, the OQRD-PMD method has a total computational complexity of $N^{2.529} + 8NM^2 + 2N(N-1) + 6MN$. Table 1 presents the computational complexity of the proposed and conventional techniques.

**Table 1** – Computational Complexity of various methods

| Methods | Complexity |
|---|---|
| MMSE | $2MN^2 + (10/3)N^3 + 4MN + 4N^2$ |
| RA | $(4M + 4I)N^2 + 2NM$ |
| JA | (4M+4I+1) $N^2$+2NM |
| SOR | $(4M + 4I - 2)N^2 + 2(M - I + 1)N$ |
| GS | $(4M + 4I - 2)N^2 + 2(N - 2I + 1)N$ |
| QRD | $N^{2.529} + 4NM^2 + 2N(N-1)$ |
| OQRD | $N^{2.529} + 4NM^2 + 2N(N-1) + 4MN$ |
| QRD-PMD | $N^{2.529} + 8NM^2 + 2N(N-1) + 2MN$ |
| OQRD-PMD | $N^{2.529} + 8NM^2 + 2N(N-1) + 6MN$ |

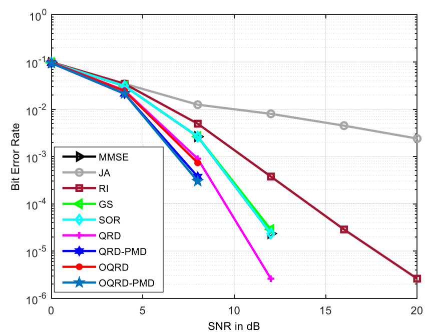


**Fig. 1** – BER vs SNR performance proposed and conventional methods for $M \times N = 64 \times 24$ antenna

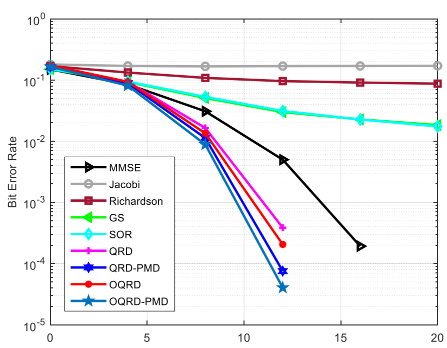


**Fig. 2** – BER vs SNR performance of proposed and conventional methods for $M \times N = 64 \times 32$ antenna

## 6. SIMULATION RESULTS

This section analyzes the bit error rate (BER) performances of proposed and conventional methods for uplink mMIMO system. The following parameters value are taken for simulation: the modulation technique is 16QAM, the antenna sizes are $24 \times 64$, and $48 \times 64$. The channel is modeled as an uncorrelated flat fading Rayleigh channel. The BER performance of proposed and conventional signal detection techniques for $24 \times 64$, $36 \times 64$,and $48 \times 64$ number of users are illustrated in the Fig. 1, Fig. 2, Fig. 3 respectively.

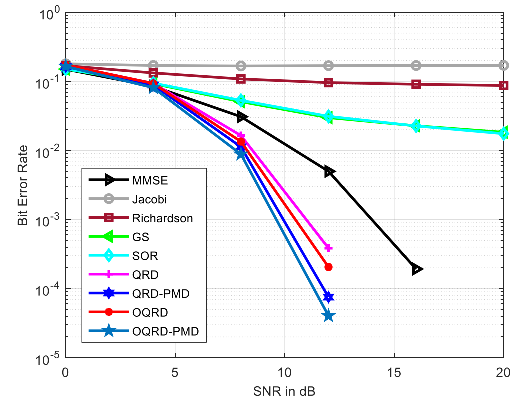


**Fig. 3** – BER vs SNR performance of proposed and conventional methods for $M \times N = 64 \times 48$ antenna

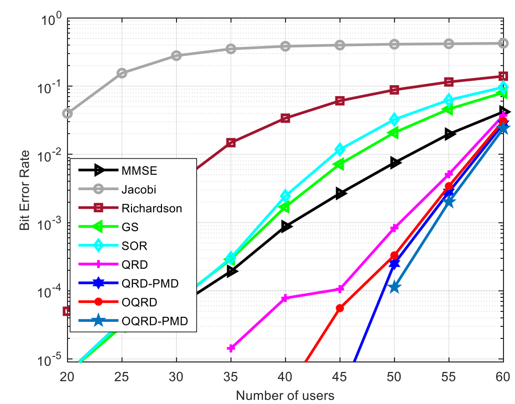


**Fig. 4** – BER vs several user ($N$) performances of proposed and conventional methods at 12 dB SNR

The results indicate that the Jacobi, Richardson methods exhibit substantially lower performance. The performance of GS method outperforms Jacobi, Richardson methods and slightly worse than MMSE method. The SOR method provides similar performance as GS method. Since these signal detection techniques are derived from MMSE, their performances are generally lower than MMSE method. From simulation results, it is observed that QRD method outperforms the MMSE method. The OQRD outperforms QRD method because it orders the channel matrix prior to signal detection. The QRD-PMD gives better result than QRD method as it performs the signal detection in two stages. This method first estimates the initial signal using QR method and then cancels the interference in parallel manner to obtain more refined data signal. The QRD-PMD and OQRD-PMD outperform their corresponding QRD and OQRD as they have additional MPD unit. The various signal detection methods are listed in descending order of performance, are as follows: OQRD-PMD, QRD-PMD, OQRD, QRD, MMSE, SOR, GS, Richardson, and Jacobi. The BER performance comparison for various number of users and different signal detection techniques at 12 dB SNR is shown in the Fig. 4. From the simulation result, it can be shown that, the BER performances of several detection techniques significantly degrade as number of user terminals increases. The Richardson and Jacobi methods demonstrate satisfactory performance for less number users; however, their performances significantly decline with increasing number of users. The SOR and GS perform comparably to the MMSE method with a smaller number of users, however the performance gap widens as users' increases. Notably, the proposed QRD, OQRD methods outperform the MMSE method. Furthermore, the QRD-PMD and OQRD-PMD methods achieve better performance compared to the QRD and OQRD methods.

## 7. CONCLUSIONS

In this research, we propose four signal detection methods: QRD, OQRD, QRD-PMD, and OQRD-PMD for mMIMO uplink systems. The performances of proposed and conventional signal detection techniques, including MMSE, Richardson, Jacobi, Gauss-Seidel, and SOR are compared with respect to their BER performance and complexity. The results indicate that the proposed signal detection techniques outperform the conventional methods while maintaining comparable complexity. Additionally, the proposed QRD-PMD and OQRD-PMD methods achieve significant performance gain over the MMSE method. Based on the simulation results and complexity analysis, the proposed OQRD-PMD method emerges as promising options for signal detection in uplink mMIMO systems.

## REFERENCES

1. M. Agiwal, A. Roy, N. Saxena, *IEEE Communications Surveys and Tutorials* **18** No 3, 1617 (2016).
2. M.A. Albreem, W. Salah, A. Kumar, M.H. Alsharif, A.H. Rambe, M. Jusoh, A.N. Uwaechia, *IEEE Access* **9**, 45 740 (2021).
3. C.N. Cuong, T.T. Hong, L.D. Khai, *International Conference on Computing and Communication Technologies* (RIVF), 1 (2019).
4. X. Qin, Z. Yan, G. He, *IEEE Communications Letters* **20** No 2, 276 (2015).
5. Y. Hu, Z. Wang, X. Gaol, J. Ning, *International conference on communication systems*, 477 (2014).
6. B. Kang, J.-H. Yoon, J. Park, *ETRI Journal* **39** No 3, 326 (2017).
7. L. Shao, Y. Zu, *Mathematical Problems in Engineering* (2016).
8. Z. Albataineh, *Wireless Personal Communications* **116**, 2549 (2021).
9. M.K. Hasan, et.al., *Computers and Electrical Engineering*, **101**, 108045, (2022).
10. K. Khurshid, M. Imran, A. Wakeel, *Transactions on Emerging Telecommunications Technologies* **34** No 9, e4826 (2023).
11. D. Shen, L. Chen, H. Liang, *Applied Sciences* **13** No 23, (2023).
12. S. Shafivulla, A. Patel, 26th *International Workshop on Computer Aided Modeling and Design of Communication Links and Networks* (CAMAD), 1 (2021).
13. N. Jain, V.A. Bohara, A. Gupta, *IEEE Open Journal of Signal Processing* **1**, 135 (2020).
14. Imran, A. Khoso, Xiaofei Zhang, Hayee Shaikh Abdul, A. Khoso Ihsan, Ahmed Dayo Zaheer, *Journal of Systems Engineering and Electronics* **35** No 3, 549 (2024).
15. I.A. Khoso, C.G. Kang, *IEEE Wireless Communications Letters* **13** No 5, 1419 (2024).
16. W.H. Chin, A.G. Constantinides, D.B. Ward, *Electronics Letters* **38** No 12, 1 (2002).
17. C. Camarero, arXiv preprint arXiv:1812.02056, 2018.

## Виявлення сигналу в масивних MIMO-системах методом каскадованого OQRD-PMD

J.P. Patra[1], R.K. Mahapatra[2], S.B. Prusty[3], K. Babooji[4], G.S. Satapathi[5], V.-K. Samudrala[6]

[1] *Department of Electronics and Communication Engineering, C. V. Raman Global University, Bhubaneswar-752054, Odisha, India*

[2] *Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Founda-tion, Vaddeswaram-522302, AP, India*

[3] *School of Electronics and Communication Engineering, REVA University, Bengaluru-560064, Karnataka, India*

[4] *Department of Electronics and Communication Engineering Sri Vasavi Engi-neering College, Tadepalligudem-534101, AP, India*

[5] *Department of Electronics and Communication Engineering, A J Institute of Engineering and Technology, Mangaluru-575006, Karnataka, India*

[6] *Department of Electronics and Com-munication Engineering NRI Institute of Technology (A) Agiripalli, 521212, AP, India*

У масивних системах MIMO (mMIMO) метод MMSE (мінімальної середньоквадратичної похибки) широко застосовується для виявлення сигналів, однак вимагає обернення матриці зі складністю кубічного порядку. Щоб уникнути цього, застосовувалися методи Річардсона, Якобі, Гауса-Зейделя, які мають меншу обчислювальну складність, але гірші результати за точністю. У даній роботі пропонується чотири покращені методи виявлення сигналу: QR-декомпозиція (QRD), паралельне багатоступеневе виявлення на основі QRD (QRD-PMD), упорядкована QR-декомпозиція (OQRD), OQRD з паралельним багатоступеневим виявленням (OQRD-PMD). Спочатку застосовується QR-декомпозиція до матриці каналу, після чого методом зворотної підстановки відновлюється переданий сигнал. Для усунення накопичення помилок у QRD вводиться упорядкування (Ordered QRD). Для підвищення точності на стороні приймача додатково застосовується метод паралельного багатоступеневого виявлення (PMD), каскадовано з QRD та OQRD.

**Ключові слова:** Виявлення сигналу, Масивні MIMO, Багатоступеневе виявлення, QR-декомпозиція, Упорядкована QRD.