Analysis of Multiuser Detectors and Performance improvement in DS-CDMA system using Multistage Multiuser Detection Techniques

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Abstract: - The Direct Sequence Code Division Multiple Access (DS-CDMA) system faces several disruptions, this is most crucial of which is the Multi Access Interference (MAI) caused by its users. The efficiency of the system gradually declines as every quantity rises, and the MAI rises, especially in faded environments. This work proposes a multiple-phase multiuser identification approach called Differencing Partial Parallel Interference Cancellation (DPPIC), which improves the overall efficiency. The methods known as Differencing Parallel Interference Cancellation (DPIC) and Partial Parallel Interference Cancellation (PPIC) are combined in this methodology. Current solutions for Parallel Interference Cancellation (PIC) and PPIC have enhanced overall effectiveness; however, this has come at the expense of increasing the complexity of computation. As the variety of consecutive stages grows, the MAI falls. Using the DPIC approach may reduce the computational burden without improving system functionality. The use of the Partial Differencing Parallel Interference Cancellation (PDPIC) technique can enhance system performance while lowering the level of complexity. According to the simulation findings, Bit Error Rate (BER) vs normalized signal strength (i.e., Eb / N0) performs more effectively for the suggested DPPIC approach than for PIC, the PPIC, and PDPIC.

Key-Words: - Multiuser Detection, MAI, PIC, PPIC, DPIC, PDPIC, DPPIC.

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1 Introduction

Multiple access techniques can be included in modern mobile radio networks to maximize efficiency while minimizing cost and better using the available bandwidth and radio cell infrastructure. Code Division Multiple Access (CDMA) and Multi-Carrier Code Division Multiple Access (MC-CDMA) are the two multiple access methods. CDMA is now a fundamental component of mobile phone networks. It uses communication methods to transfer information among a single base station and many endpoints. Although it presents a difficulty to accommodate lots of users in a limited region, the CDMA technology has significant potential to function as an air gateway for future high-rate mobile communication systems, [1], [2], [3].

More recently, in collaborative multiuser identification, multiuser disturbance is seen as data instead of sound, [4]. Previous work on multiuser identification has concentrated on creating less-than-ideal recipients in the synchronized CDMA paradigm, which have a lower computing complexity while functioning greater than linearity detectors, [5]. Owing to an MAI issue, multiuser detection for the symbol-synchronous Gaussian CDMA channel acted as the major factor in numerous multiuser communications systems during the last fifteen years. By taking employ of the known pattern of multiple-user disruption, multiuser identification may effectively demodulate customers' non-orthogonal transmissions and solve a variety of issues. When compared to traditional matched filter (MF) reception, it may be employed to lower MAI in direct sequence CDMA (DS-CDMA) systems, which greatly enhances the efficiency inside the structure, [6], [7], [8].

Every user of DS-CDMA technology has simultaneous access to the whole spectrum allotted to them. This is made feasible by the dispersion of a series and the brief chip period used to disperse user data across the whole spectrum that is available speed. It also acts as a unique user ID, offering various degrees of immunity from simultaneous disruption, [9], [10].

2 Literature Review

Code division multiple access (CDMA) is a well-designed contender to handle the downstream of cell phone connections to achieve high data speeds. Nonetheless, the CDMA system's efficiency is significantly impacted when sending any kind of signal across an intermittent range. To ensure that overcome the disruption and characterize the channel, multiuser detection (MUD) and channel estimation are crucial. Reducing the user's signal transmission error rate is the aim of the BBO algorithms. The most effective answer to the detection problem is selected by the criteria rates of arrival and departure. As a result, both the user sending signal disruption with the task that person identification have been solved.

As MAI is a significant issue in DS-CDMA systems due to its users, promising methods like Multiuser Detection reported can be employed to accomplish improved performance, [7]. The ideal multiuser identifier for information discovery in different access non-Gaussian stations has been determined in, [10], [11]. When comparing optimal multiuser identification in noisy conditions to achieve the best multiuser identification possible using a Gaussian distortion presumption, it was demonstrated that significantly improved performance may be achieved. A reduced complexity Multiuser sensor built around the M-estimator was developed and analyzed in, [12], as the optimal technique is extremely CPU-intensive. Specifically, the writers of, [12] exhibit that the proposed multiuser detector offers a substantial performance gain over the linear decorrelating device when the ambient channel noise is non-Gaussian. Additionally, an alternative M-estimator-based multiuser detector that ensures a reduced performance decrease in comparison to the ideal multiuser identification was devised in, [11] if the background noise is relatively reactive.

It is of relevance to build recipients to account for this band's behavior, as DS-CDMA broadcasts often occur across fade bands.

For submarine audio connections, [13], have introduced a blind adaptive multi-user identification technique based on Kalman filtering. In multi-user communication underwater acoustic networks of sensors, this method successfully improves system ability, lowers the cost of transmission and control of power expenses, increases the multi-user interaction separation, and decreases or eliminates ISI, MAI, and the near-far effect. All of these benefits result in the efficient use of the accessible restricted frequency band.

On reviewing the existing relevant literature, the following observations are being made:

i. Different spreading sequences have been investigated.
ii. Among all the multi-user detectors, the overall BER performance was found better in the maximum likelihood detector/the optimum detector at the cost of very high computational complexity and thus not realistic for implementation.

iii. Though the computational complexity is found less in decorrelating detectors and MMSE detectors, the calculation of the inverse cross-correlation matrix is difficult in these linear detectors.

iv. When the number of users rises, the computing cost grows exponentially in SIC, PIC, HIC and PPIC techniques. Each type of interference cancellation detector has its level of complexity, processing time and BER performance.

In view of the above observations, there exists a need to make studies to enhance visual DS-CDMA system performance and reduce the difficulty of computing. Further, interference cancellation methods other than the existing ones are to be explored for DS-CDMA systems.

The CDMA signal and channel model are covered in the following chapter. Standard single-user and multiuser detection methods are covered in Section 3. The fourth section describes multiple phases of detection techniques and noise. Simulation results on the performance comparison of several multistage multiuser identification approaches are presented in Section 5. An overview of the results is provided within Chapter 6's results.

3 CDMA Signal and Channel Model

Any user will issued an authentication series of time Tb, and Tb is the sign interval, in a K-user synchronous DS-CDMA system using the low pass comparable architecture, [12]. One way to describe the kth user's signing series is as

$$S_k(t) = \sum_{n=0}^{L-1} \alpha_n \, p(t-nT_c) \qquad 0 \le t \le T_b \qquad (1)$$

where

α_n, $0 \le n \le L-1$ is a series of pseudo-random noise (PN) with L wafers which can have numbers in the range of $\{+1,-1\}$. The length of the pulse, p(t), is Tc, where Tc is the chip interval and Tb = LTc. It is reasonable to presume that all K signature sequences contain units of energy without losing variety.

, i.e.

$$\int_0^{Tb} S_k^2(t)dt = 1$$

The cross-correlation for any two signature sequences S_j and S_k is defined as

$$\rho_{jk} = \int_0^{Tb} S_j(t) S_k(t)\ dt \quad j \ne k \qquad (2)$$

To keep things simple, we'll suppose that each user transmits their data via basic antipodal impulses. Since the transmission is synchronous, the data or delay related to the transfer of a single bit must be taken into account.

For K users, the combined broadcast message's corresponding low pass can be written simply:

$$x(t) = \sum_{k=1}^{K} A_k b_k S_k(t) \qquad (3)$$

Where A_k, b_k, and $S_k(t)$ are the transmitted amplitude, data bit, and signature sequences, respectively, of the k^{th} user.

The received signal via a fading channel can be expressed as:

$$r(t) = h(t)x(t) + n(t) \qquad (4)$$

where

$n(t)$ is the noise with power spectral density $N_0/2$ and h(t) is complex fading coefficient given by

$$h(t) = \alpha(t) e^{j\phi(t)} \qquad (5)$$

where

$\alpha(t)$ is Rayleigh distributed channel gain and

$\phi(t)$ is the phase shift uniformly distributed between 0 to 2π.

4 Conventional and Multiuser Detection Schemes

4.1 Conventional Single-User Detection

Figure 1 shows the conventional single-user detection system,

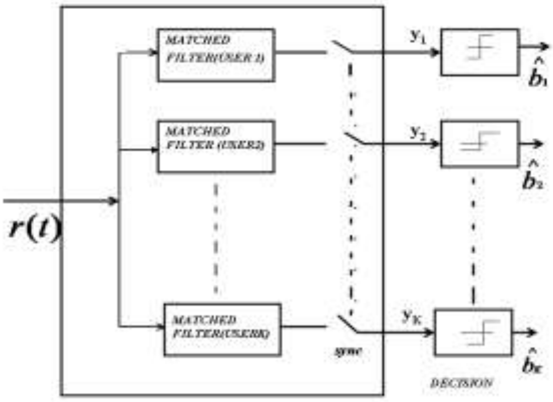

Fig. 1: Matched filter bank

K distinct single-input (continuous time) and single-output (discrete time) filtering are used to create the sensor without any joint processing. Despite considering the presence of other (K-1) active users in the system, every individual gets demodulated independently, [8], [9], [10], [11]. The kth matching filter's sample result is given by:

$$y_K = \int_0^{T_b} r(t) s_K(t) dt \qquad (6)$$

The decision is made by:

$$\hat{b}_K = \mathrm{sgn}(y_k) \qquad (7)$$

4.2 Multiuser Detection Scheme

All user information is simultaneously detected by the multiuser sensor. Another name for it is ligament identification. In the absence of MAI, It addresses the process of demodulating digitally encoded signals. One needs to be apt for suboptimal multiuser detectors as it is too complex to use this detector in practical applications like DS-CDMA systems, [8], [9].

Figure 2 depicts the multiuser detecting method's architecture. It utilizes an appropriate filter-branch that transforms the discrete-time sampled at the chip from the constant time signal that arrived rate, allowing it to recognize all of the sent signals from what was received without obscuring any communicated data necessary for decoding, [10],[11].

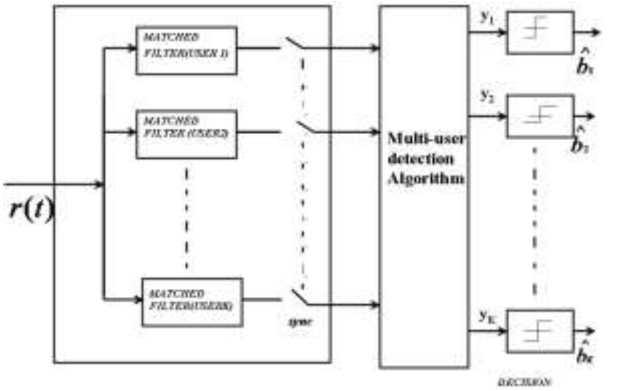

Fig. 2: Multi-user detector

4.2.1 MMSE Method

For identification, the decorrelating sensor just needs to distribute events' correlations matrices R's information, [8]. Multi-user identification relying on the Minimum Mean Square Error (MMSE) criteria has garnered an abundance of attention lately, [8]. Figure 3 depicts the MMSE sensor. The choice for the kth user is determined by the linear mapping that minimizes the mean-squared error between the actual information and the result of the traditional detection.

$$\hat{b}_k = \operatorname{sgn}\left(((\mathbf{R} + \sigma^2 \mathbf{A}^{-2})^{-1} y_k) \right) \tag{8}$$

where

σ^2 - Normalised cross-correlation
A - Amplitude of the signal

5 Interference Cancellation Schemes

Generally, speaking there are three types of interfering cancellations strategies: hybrid interference cancellation (HIC), parallel interference cancellation (PIC), and successive interference cancellation (SIC). It is discovered that the PIC detector performs better than the SIC detector, [8]. Here isn't a justification for a single signal to be given preference over the others under efficient power regulation as all signal strengths are of the same order. A parallel interference cancellation (PIC) detector may be employed in these circumstances. The PIC detector measures each bit of the information and deducts based on the intended user's signal the MAI imposed by all interfering participants.

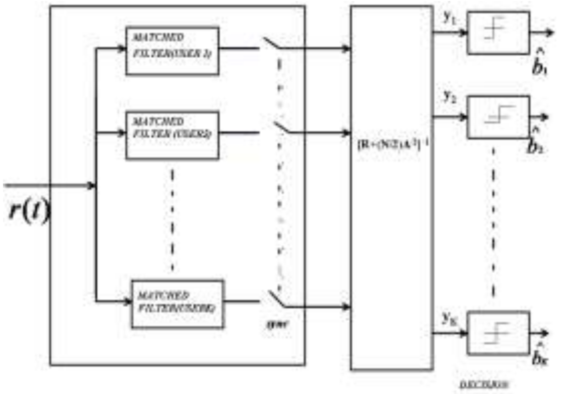

Fig. 3: MMSE Detector

5.1 Multistage Multiuser Parallel Interference cancellation

To identify the data bits and eliminate disruption, the PIC sensor goes through several iterations. The information bits are initially calculated using the MMSE. The subsequent phases execute signal reconstructions for every user and remove the estimated interference from every other user, [8]. The estimations of the information fragments plus the previously determined user cross-correlations are utilized throughout multiple-stage multiuser PIC detectors to cancel out any interference in the results of the MMSE detectors or results of previous phases. Figure 4 depicts the multiple-stage PIC. The choice for stage s+1 in the PIC detector's Sth stage may be stated as, [8]:

$$\hat{b}_k^{(s+1)} = \operatorname{sgn}(z_k^{(s+1)}) \tag{9}$$

where

$$Z_k^{(s+1)} = y_k - \sum_{j \neq 1} A_j \rho_{kj} \hat{b}_j^{(s)} \tag{10}$$

and

$$z_k^{(1)} = y_k \tag{11}$$

The peak amplitudes of each user's signals received must be known by the PIC detector. The receiving magnitudes must be calculated because the device that receives it lacks immediate communication with this data. The multistage PIC will function effectively if the magnitude of the signal is correctly assessed in the preceding stage. Nevertheless, the PIC is unable to ensure that efficiency would increase in subsequent phases, [8].

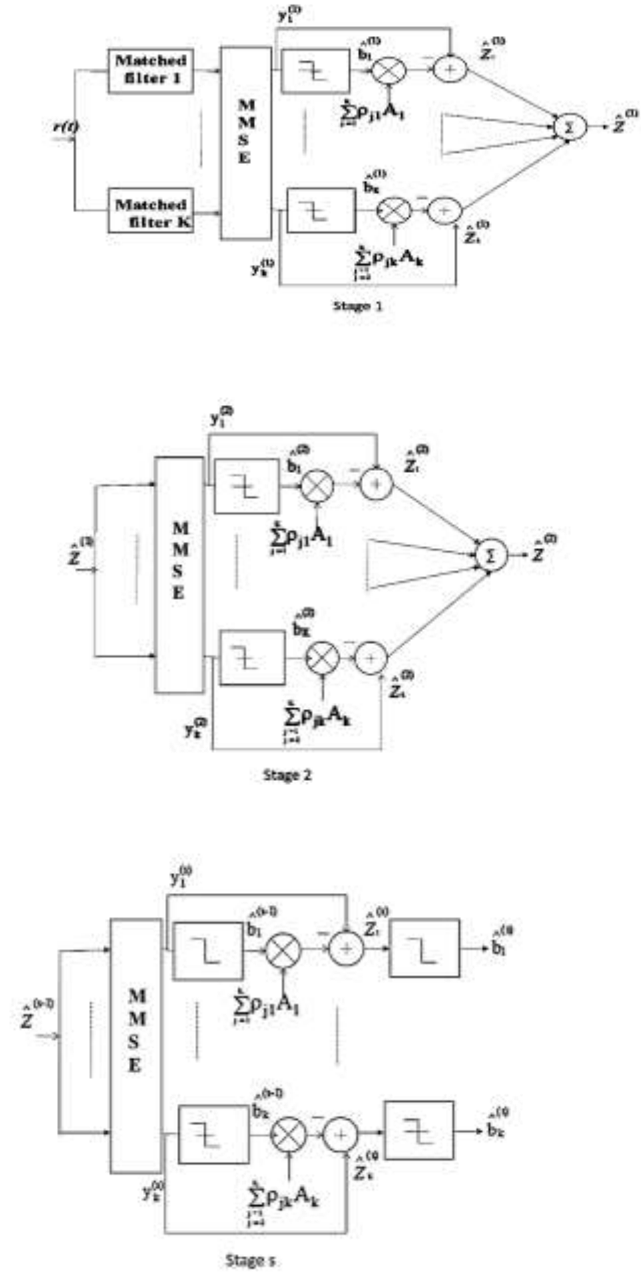

Fig. 4: Multistage PIC detector

5.2 Multistage Multiuser Partial Parallel Interference Cancellation

A biassed judgment statistics is produced by the Multistage Multiuser PIC detector execution, which is based on the subtraction of the interference estimations. The bias has less impact on the latter phases of noise elimination than it does on the initial stage. Nonetheless, the impact of these inaccuracies may be seen at subsequent stages if the bias causes erroneous cancellation at the initial step, [8], [9]. By dividing the magnitude predicted by a partial-cancellation aspect (range: 0 to 1) that changes depending on the stage of postponements and system load K, one can easily avoid the impact of the biassed decision statistic and enhance the performance of multistage parallel interference termination. A multi-stage PPIC is displayed in Figure 5. In this method, the partial factors 0.3, 0.4, and 0.5 are used in first, second, and third stages.

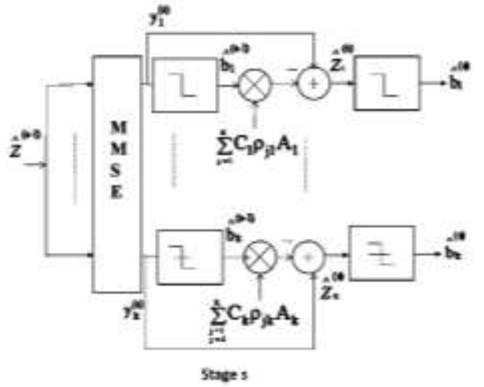

Fig. 5: Partial PIC detector

Before subtracting the impact from the magnitude estimations, the division must be completed. This may be understood as adding a partial cancellation factor to the solution (10) and rearranging the results to, [8], [9], [10], [11].

$$Z_k^{(s+1)} = y_k - \sum_{j \neq k} C_k^{(s)} A_j \rho_{kj} \overset{\wedge(s)}{b}_j \tag{12}$$

where

$C_k^{(s)}$ is a partial cancellation factor ranging from 0 to 1

5.3 Multi-stage Difference PIC (DPIC)

When detecting PICs multiple-stage if one observes $b_k^{(s)} = b_k^{(s-1)}$, then it represents the incremental technique's completion. The differencing of the estimated bits can be computed in two steps, rather than addressing each projected bit array as in formula (10). As seen in Figure 6, the input of each step becomes what is known as the distinction approach, [1]. $x_k^{(s)} = b_k^{(s)} - b_k^{(s-1)}$, which is called the differencing technique, [1], as shown in Figure 6.

$$Z_k^{(s)} = Z_k^{(s-1)} - \sum_{j \neq k} A_j \rho_{kj} \overset{\wedge(s)}{x_j} \qquad (13)$$

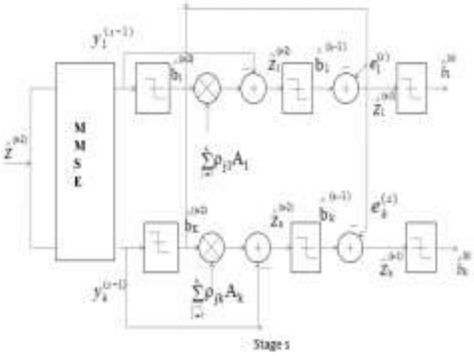

Fig. 6: Difference PIC detector using MMSE

5.4 Proposed Multi-stage Multiuser Difference Partial PIC technique (DPPIC)

The choice of statistics-based impact affects the PIC approach. However, this issue can be lessened, particularly by using the partial parallel interference cancellation in the early phases of the anticipated multiple access interference. The lowering of the computational burden in a PIC approach is its most significant and intriguing feature. A considerable performance boost is provided by the partial PIC. Either difference partial PIC (DPPIC) or partial difference PIC (PDPIC) will be produced by combining difference PIC (DPIC) and partial PIC (PPIC). Figure 7 and Figure 8 display the DPPIC and PDPIC diagrams. Except the fact that partial components are multiplied before as well as following differencing (in DPPIC and PDPIC), these schematics are nearly identical.

$$Z_k^{(s)} = \left(Z_k^{(s-1)} - C_k^s \sum_{j \neq k} A_j \rho_{kj} \overset{\wedge(s)}{x_j} \right) \qquad (14)$$

where

$$x_j^{(s)} = \hat{b}{}_k^{(s)} - \hat{b}{}_k^{(s-1)}$$

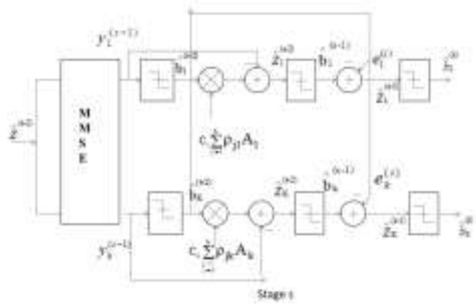

Fig. 7: Multi-stage PDPIC detector

$$Z_k^{(s)} = \left(Z_k^{(s-1)} - C_k^s \sum_{j \neq k} A_j \rho_{kj} \overset{\wedge(s)}{b_k} - C_k^s \sum_{j \neq k} A_j \rho_{kj} \overset{\wedge(s-1)}{b_k} \right) \qquad (15)$$

Algorithm for PDPIC

```
For s = 2 to S
    For k = 1 to K
        $\overset{\wedge(1)}{b_1} = \mathrm{sgn}(y_{MMSE})$
        $z_k^{(2)} = y_{MF} - \sum_{j=1}^{K} A_j (R_{ij} - diag(R_{ij})) b_j^{\wedge(1)}$
        $\overset{\wedge(2)}{b_1} = \mathrm{sgn}(Z_1^{(2)})$
    End
    $x_k^{(s)} = b_k^{(s)} - b_k^{(s-1)}$
    $Z_k^{(s)} = Z_k^{(s-1)} - C_k^s \sum_{j \neq k} A_j R_{jk} \overset{\wedge(s)}{x_k}$
End
    $\overset{\wedge}{b}{}_k^{(s+1)} = \mathrm{sgn}(Z_k^{(s+1)})$
End
```

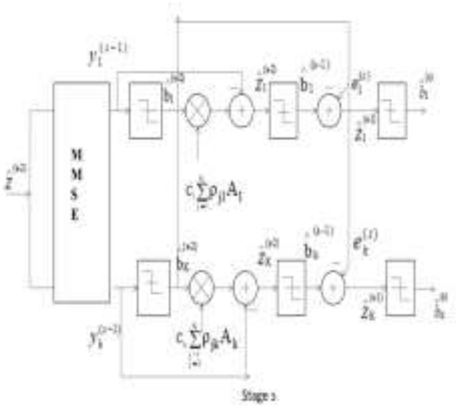

Fig. 8: Multi-stage DPPIC detector

Algorithm for DPPIC

```
For s = 2 to S
    $\hat{b}_1^{(1)} = \mathrm{sgn}(y_{MMSE})$
    For k = 1 to K
    End $z_k^{(2)} = y_{MF} - \sum_{j=1}^{K} A_j (R_{ij} - diag(R_{ij})) \hat{b}_j^{(1)}$
        $\hat{b}_1^{(2)} = \mathrm{sgn}(Z_1^{(2)})$
        $Z_k^{(s)} = Z_k^{(s-1)} - C_k^s \sum_{j \neq k} A_j R_{jk} \hat{x}_k^{(s)}$
        $x_k^{(s)} = b_k^{(s)} - b_k^{(s-1)}$
        $Z_k^{(s)} = \left( Z_k^{(s-1)} - C_k^s \sum_{j \neq k} A_j \rho_{kj} \hat{b}_k^{(s)} - C_k^s \sum_{j \neq k} A_j \rho_{kj} \hat{b}_k^{(s-1)} \right)$
        $\hat{b}_k^{(s+1)} = \mathrm{sgn}(Z_k^{(s+1)})$
    End
End
```

6 Simulation Results

The DS-CDMA basic multistage multiuser discrete time paradigm was applied. The customer's data is disseminated via BPSK modulation and Kasami odd spreading sequence techniques.

The system performance of multistage PIC, PPIC, PDPIC, and DPPIC with the MMSE multiuser detectors for different phases is displayed in Figure 9, Figure 10, Figure 11 and Figure 12. There are just three actions done into consideration herein for clarity. Stage 3 system efficiency surpasses both Stage 1 and Stage 2 system efficiency.

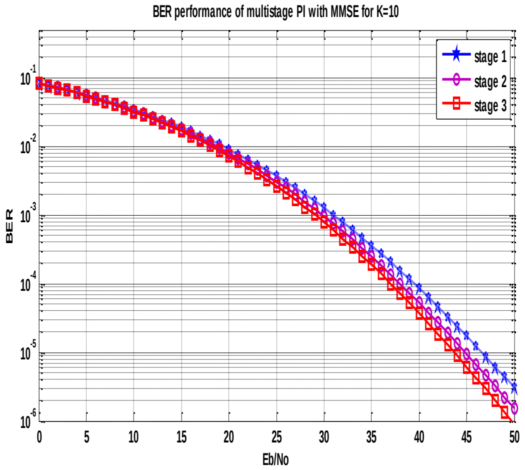

Fig. 9: BER performance of multistage PIC with MMSE, K=10 for three different stages

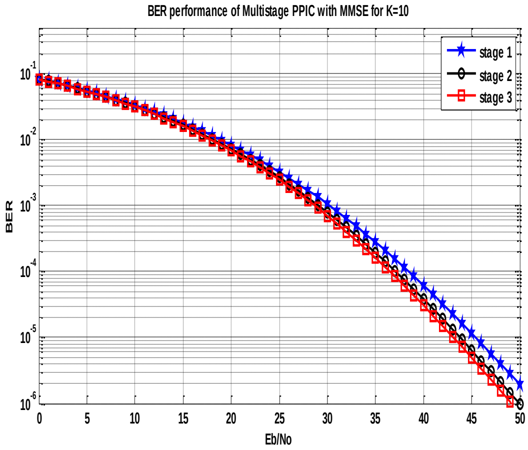

Fig. 10: BER performance of multistage PPIC with MMSE, K=10 for three different stages

Generally, speaking system efficiency improves as the number of phases rises, but the computing cost also does. As seen in Figure 13, Figure 14, Figure 15 and Figure 16, the system's reliability rapidly declines if the number of users grows along with the BER.

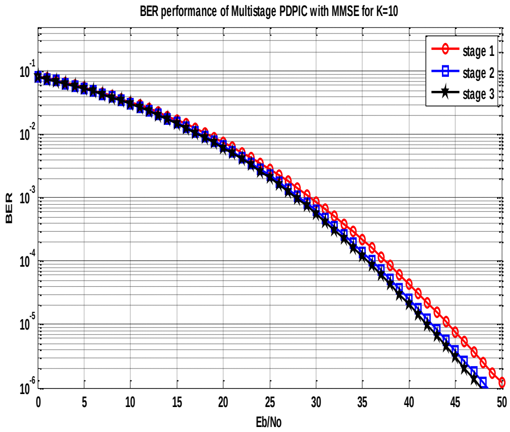

Fig. 11: BER performance of PDPIC with MMSE K=10 for three different stages

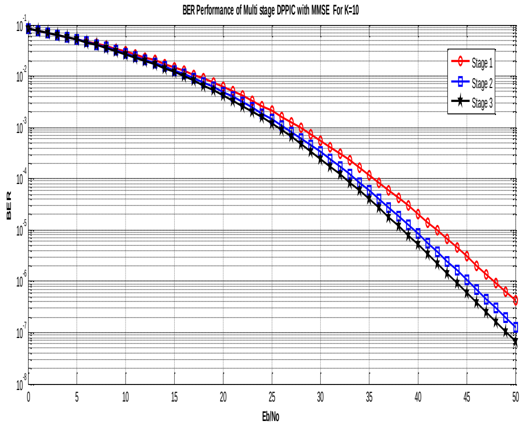

Fig. 12: BER performance of DPPIC with MMSE K=10 for three different stages

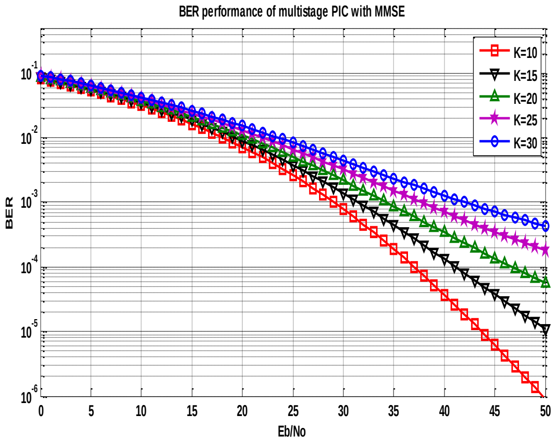

Fig. 13: BER performance of 3rd stage PIC with MMSE for K= different users

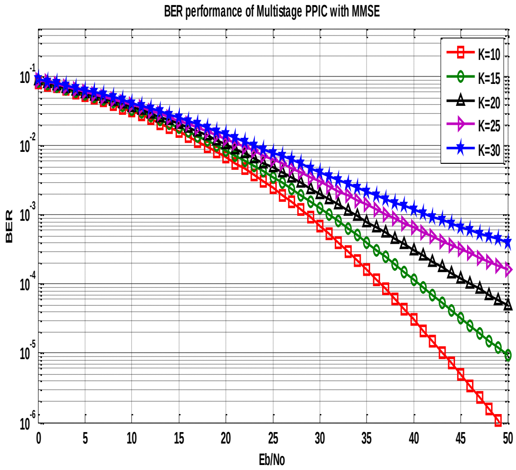

Fig. 14: BER performance of 3rd stage PPIC with MMSE K= different users

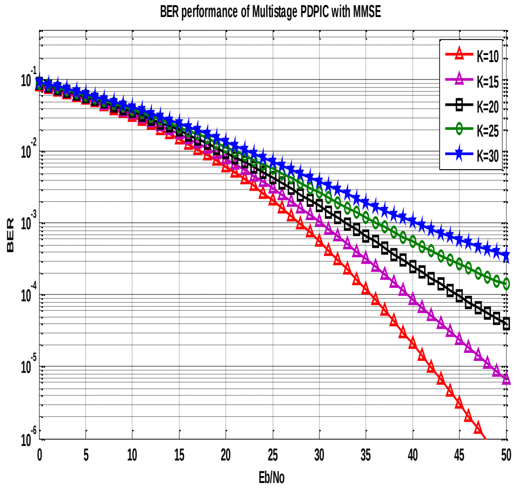

Fig. 15: BER performance of 3rd stage PDPIC with MMSE K= different users

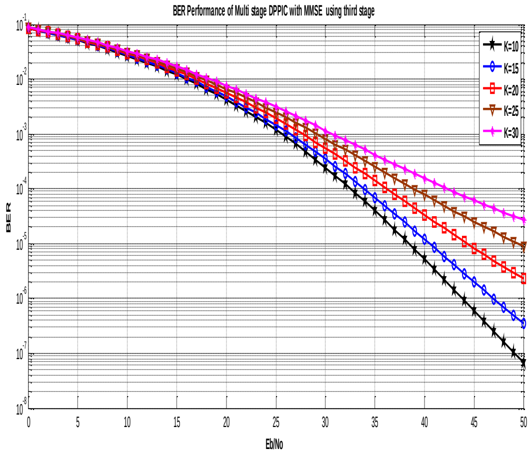

Fig. 16: BER performance of 3rd stage DPPIC with MMSE K= different users

A comparison of the simulated system performance of PIC, PPIC, PDPIC, and DPPIC at the third stage is shown in Figure 17. This chart makes it clear that the suggested multiple phases

DPPIC outperforms the others. The contrast of PDPIC and DPPIC's computational difficulty is displayed in Figure 18. The computational complexity of DPPIC is somewhat higher in this figure compared to that of PDPIC.

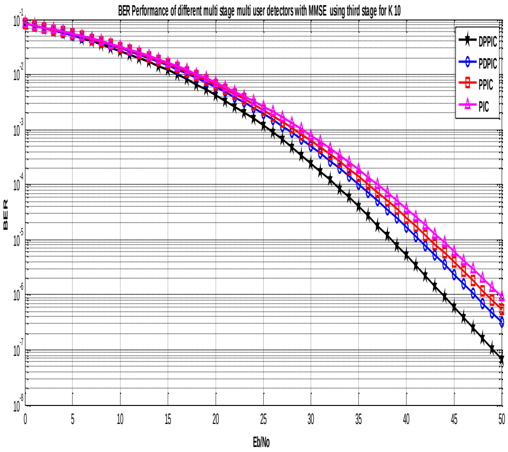

Fig. 17: BER performance comparison of multi-stage multi-user detectors at the third stage for K=10

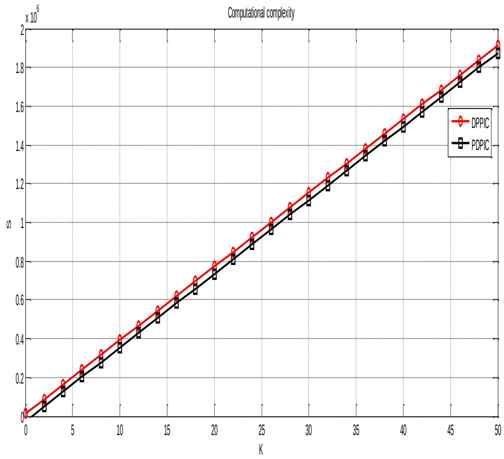

Fig. 18: Computational complexity between DPPIC and PDPIC.

7 Conclusions

Employing multiple-stage multiuser approaches in DS-CDMA systems can also minimize the complexity of computation and Multiple Access Interference. In the multistage PIC approach, bit error rate (BER) drops and detection becomes more dependable as the number of stages rises. The ability to increase in subsequent phases cannot be guaranteed by the PIC. In a DS-CDMA system, the effectiveness of the Partial Parallel Interference Cancellation (PPIC) technique is assessed. Multistage PDPIC and DPPIC approaches can be used to achieve both cost decrease and efficiency enhancement simultaneously. Ultimately, it may be concluded that DPPIC outperforms PIC, PPIC, and PDPIC approaches, yet has a little higher computational demand than PDPIC.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- J. Ravindra Babu, D. Swathi Identified the problem statement and done the mathematical Analysis.
- J. V. Ravi Teja, J. V. Ravi Chandra have implemented the Algorithms in section 4.4.
- N. Pranavi Sri, Arshiya carried out the simulation in section 5 using MATLAB.

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Conflict of Interest

The authors have no conflicts of interest to declare.

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