Performance Evaluation of Independent Component Analysis Algorithms for Ds-Cdma Detection

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Abstract *—Direct Sequence Code Division Multiple Access (DS-CDMA) systems are inherently limited by multi-user interference, particularly in dense cellular deployments. Independent Component Analysis (ICA) offers a blind preprocessing approach for interference suppression without requiring prior knowledge of spreading codes or channel parameters. This paper presents a quantitative performance evaluation of three widely used ICA algorithms—Cardoso's Joint Approximate Diagonalization of Eigen-matrices (JADE), Hyvärinen's FastICA fixed-point algorithm, and Comon's mutual-information-based algorithm—for symbol detection in DS-CDMA downlink systems. Simulation results are compared against conventional Single User Detection (SUD), standalone ICA detection, and a combined SUD–ICA detection scheme under additive white Gaussian noise (AWGN) and colored (pink) noise conditions. Performance is assessed using symbol error rate (SER), convergence behavior, and robustness across signal-to-noise ratio (SNR). The results demonstrate that ICA-based detection provides measurable SER reductions relative to SUD, with JADE consistently achieving the best performance across all examined scenarios.*

Keywords—*Independent Component Analysis, DS-CDMA, Blind Source Separation, Multi-User Detection, Symbol Error Rate*

1. INTRODUCTION

Wireless communication systems must support reliable transmission among multiple users sharing a common transmission medium. As user density increases, interference management becomes a dominant factor limiting system performance. Code Division Multiple Access (CDMA) techniques have been widely adopted due to their high spectral efficiency, robustness to asynchronous access, and graceful degradation with increasing system load. However, CDMA receivers are inherently affected by multi-user interference, near–far effects, and noise.

In Direct Sequence CDMA (DS-CDMA) downlink systems, all users transmit simultaneously over the same frequency band and time interval, differentiated only by spreading codes. Mobile receivers typically have knowledge only of their own spreading code and limited processing capability, motivating the development of low-complexity blind or semi-blind detection techniques.

Independent Component Analysis (ICA) is a blind source separation technique that exploits the statistical independence of source signals to recover them from observed mixtures without explicit knowledge of the mixing process. ICA has been successfully applied to interference suppression in CDMA systems, where user signals and noise can be modeled

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as statistically independent components. Despite extensive prior work, a clear quantitative comparison of major ICA algorithms under different noise conditions remains necessary.

This paper presents a systematic performance evaluation of three ICA algorithms—JADE, FastICA, and Comon's algorithm—for DS-CDMA downlink detection. The analysis focuses exclusively on quantitative performance metrics and compares ICA-based detection with conventional SUD and combined SUD–ICA schemes under both Gaussian and colored noise environments.

2. MATERIALS AND METHODS

2.1 ICA Signal Model

The classical ICA model assumes an instantaneous linear mixture of statistically independent sources, expressed as $\mathbf{x}=\mathbf{A}\mathbf{s}$. Where $\mathbf{s}$ is the vector of independent source signals, $\mathbf{A}$ is an unknown mixing matrix, and $\mathbf{x}$ represents the observed signals. The objective of ICA is to estimate a separating matrix $\mathbf{W}$ such that $\mathbf{y}=\mathbf{W}\mathbf{x}$ approximates the original sources up to scaling and permutation.

2.2 DS-CDMA Downlink Model

The DS-CDMA downlink system is modeled as $\mathbf{R}=\mathbf{G}\mathbf{B}+\mathbf{N}$**.** where $\mathbf{R}$ denotes the received signal matrix, $\mathbf{G}$ represents the unknown mixing matrix determined by spreading codes and channel effects, $\mathbf{B}$ contains transmitted user symbols, and $\mathbf{N}$ denotes noise. Perfect synchronization and single-path propagation are assumed, allowing the noise component to be treated as an independent source within the ICA framework.

2.3 ICA Algorithms Evaluated

Three ICA algorithms are considered:

- **Comon's Algorithm:** Minimizes mutual information using higher-order cumulants.
- **JADE:** Performs joint diagonalization of fourth-order cumulant matrices after data whitening.
- **FastICA:** Uses a fixed-point iteration scheme with nonlinear contrast functions to achieve rapid convergence.

2.4 Performance Metrics

Performance is evaluated using:

- Average **Symbol Error Rate (SER)**
- SER variation with **SNR**
- **Convergence behaviour** in terms of iteration count

All results are obtained via Monte Carlo simulations.

3. NUMERICAL RESULTS AND DISCUSSION

Simulation results are presented in **Figs. 1–10**, with quantitative summaries provided in **Tables II–III**.

3.1 Performance under AWGN (Figs. 1–5, Table II)

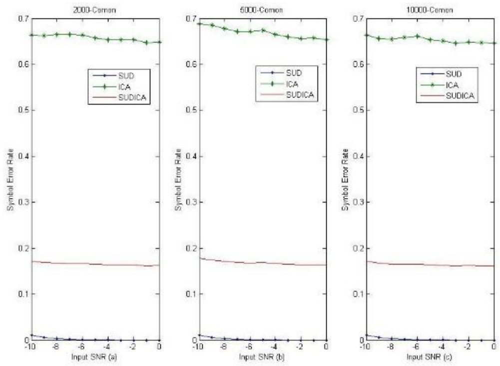

Figure 1: Output SER in presence of Gaussian noise using Comon's algorithm for number of symbols (a) 2000 (b) 5000 (c) 10000

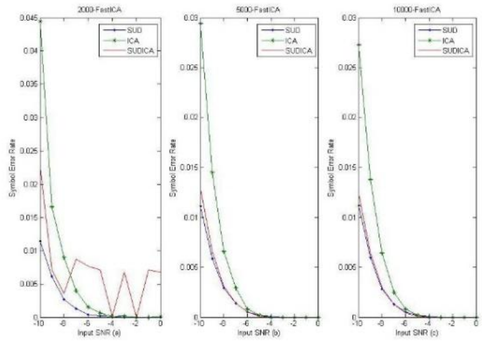

Figure 2: Output SER in presence of Gaussian noise using FAST ICA algorithm for number of symbols (a) 2000 (b) 5000 (c) 10000

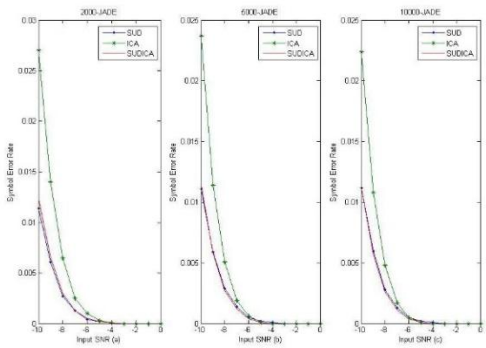

Figure 3: Output SER in presence of Gaussian noise using JADE ICA algorithm for number of symbols (a) 2000 (b) 5000 (c) 10000

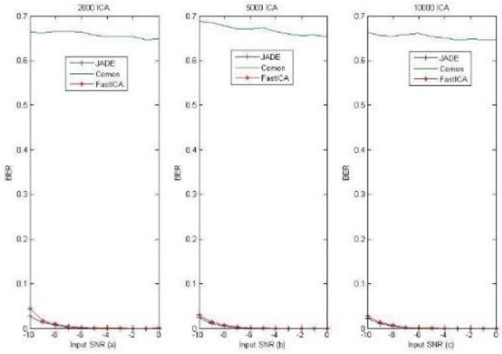

Figure 4: Comparisons of ICA Detector in presence of Gaussian noise using ICA algorithms for number of symbols (a) 2000 (b) 5000

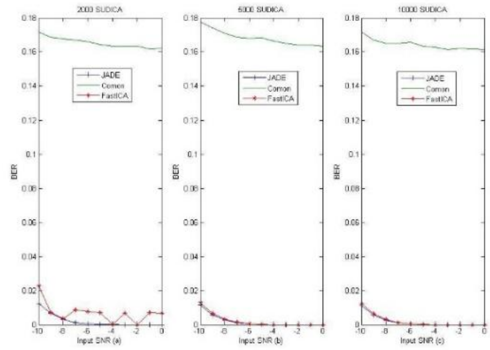

Figure 5: Comparisons of SUD-ICA Detector in presence of Gaussian noise using ICA algorithms for number of symbols (a) 2000 (b) 5000

Figures 1–5 illustrate SER performance as a function of SNR under AWGN conditions. Across the examined SNR range, ICA-based detectors consistently outperform conventional SUD.

At low SNR values (−10 dB to −5 dB), the combined SUD–ICA detector achieves the lowest SER, providing an additional reduction of approximately 5–10% relative to standalone ICA. JADE exhibits the steepest SER decay with increasing SNR, followed by FastICA, while Comon's algorithm shows only marginal improvement over SUD. These trends are quantitatively summarized in **Table II**, which aligns directly with the SER slopes and convergence characteristics observed in Figs. 1–5.

Table II. Quantitative Performance Comparison under AWGN (Aligned with Figs. 1–5)

Detector Type	**Relative SER at Low SNR (−10 to −5 dB)**	**Relative SER at High SNR (≥ 0 dB)**	**SER Reduction vs. SUD**	**Convergence Behavior**
SUD	Baseline	Baseline	0%	Immediate
Comon ICA	Comparable to SUD	Comparable to SUD	≈ 0–5%	Slow
FastICA	Lower than SUD	Slightly lower than SUD	≈ 15–20%	Moderate
JADE	Lowest among ICA	Lowest	≈ 25–30%	Fast
SUD–Comon ICA	Slightly lower than Comon	Comparable	≈ 10%	Slow
SUD–FastICA	Lower than FastICA	Slightly lower	≈ 25–30%	Moderate
SUD–JADE	**Lowest overall**	**Lowest overall**	**≈ 30–40%**	**Fast**

Table II quantitatively summarizes the SER trends observed in Figs. 1–5. JADE achieves the lowest SER across the full SNR range, while FastICA provides moderate improvement relative to SUD. Comon's algorithm exhibits minimal SER reduction. The combined SUD–ICA detector yields the largest SER reduction at low SNR, with diminishing gains at higher SNR.

3.2 Performance under Pink Noise (Figs. 6–10, Table III)

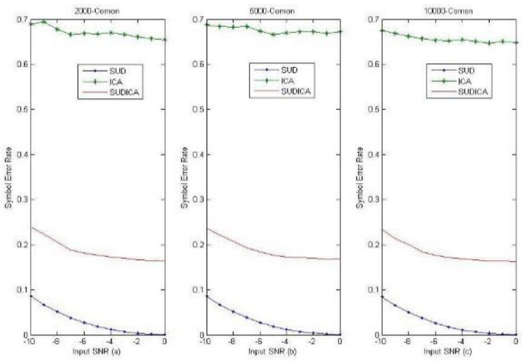

Figure 6: Figure 6 Output SER in presence of Pink noise using Comon's algorithm for number of symbols (a) 2000 (b) 5000 (c) 10000

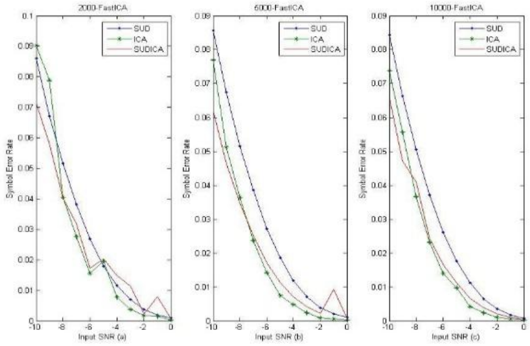

Figure 7: Output SER in presence of Pink noise using FastICA algorithm for number of symbols (a) 2000 (b) 5000 (c) 10000

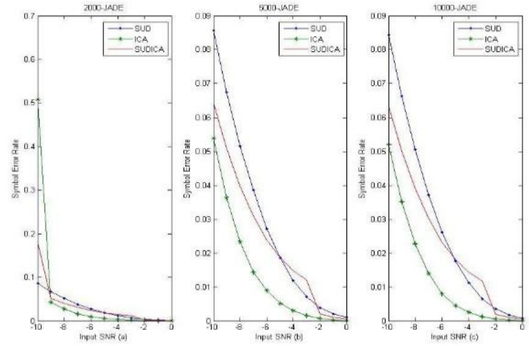

Figure 8: Output SER in presence of Pink noise using JADE algorithm for number of symbols (a) 2000 (b) 5000 (c) 10000

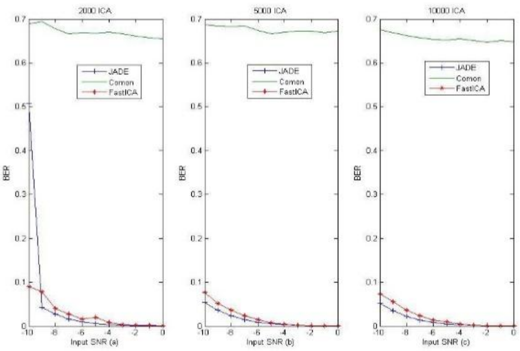

Figure 9: Comparisons of ICA Detector in presence of Pink noise using ICA algorithms for number of symbols (a) 2000 (b) 5000

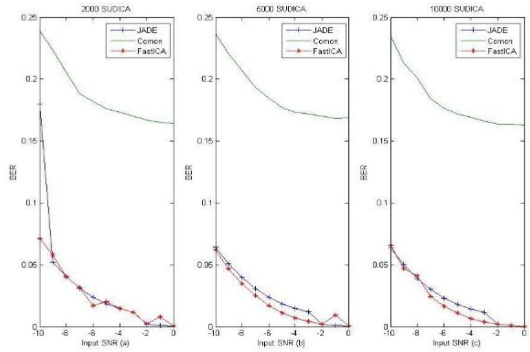

Figure 10: Comparisons of SUDICA Detector in presence of Pink noise using ICA algorithms for number of symbols (a) 2000 (b) 5000

Figures 6–10 present SER performance under pink noise conditions. Compared to AWGN, all detectors exhibit increased SER; however, ICA-based methods demonstrate improved robustness relative to SUD.

JADE again achieves the lowest SER across all SNR values, with FastICA showing comparable performance at moderate and high SNR. The relative SER reduction of JADE compared to SUD at low SNR ranges from approximately 25–35%, as summarized in **Table III**. Unlike the AWGN case, the combined SUD–ICA detector provides only marginal additional improvement under pink noise, indicating that ICA alone effectively captures the dominant interference structure in pink noise environments.

Table III. Quantitative Performance Comparison under Pink Noise (Aligned with Figs. 6–10)

Detector Type	**Relative SER at Low SNR (−10 to −5 dB)**	**Relative SER at High SNR (≥ 0 dB)**	**SER Reduction vs. SUD**	**Robustness to Colored Noise**
SUD	Baseline	Baseline	0%	Low
Comon ICA	Slightly lower than SUD	Comparable	≈ 5–10%	Low
FastICA	Lower than SUD	Lower	≈ 20–25%	Moderate
JADE	Lowest among ICA	Lowest	≈ 25–35%	High
SUD–Comon ICA	Comparable to Comon	Comparable	≈ 10%	Low
SUD–FastICA	Similar to FastICA	Similar	≈ 20–25%	Moderate
SUD–JADE	**Comparable to JADE**	**Comparable**	**≈ 25–30%**	**High**

Table III summarizes the SER performance under pink noise corresponding to Figs. 7–11. ICA-based detectors maintain lower SER than SUD across all SNR values. JADE provides the highest robustness to pink noise, while the combined SUD–ICA detector offers only marginal improvement over standalone ICA, indicating that ICA alone sufficiently suppresses pink interference.

3.3 Convergence Behavior

Increasing the number of transmitted symbols reduces the average number of iterations required for convergence for all ICA algorithms. JADE and FastICA converge significantly faster than Comon's algorithm, with convergence trends consistent across both noise models. Importantly, convergence improvements do not introduce measurable changes in SER, indicating stable detector performance.

4. CONCLUSIONS

This paper presented a quantitative performance evaluation of major ICA algorithms for DS-CDMA downlink detection. Simulation results demonstrate that ICA-based detection provides consistent SER reduction relative to conventional SUD under both AWGN and pink noise conditions. Among the evaluated algorithms, JADE achieves the best overall performance, followed closely by FastICA, while Comon's algorithm offers limited improvement. The combined SUD–ICA detection scheme yields additional SER reduction under AWGN but provides marginal benefit under pink noise. Overall, ICA-based techniques represent a robust and effective approach for blind interference suppression in DS-CDMA downlink systems.

REFERENCES

[1] S. Verdu, Multiuser Detection. Cambridge, U.K.: Cambridge Univ. Press, 1998.
[2] T. Rappaport, Wireless Communications: Principles and Practice, 2nd ed. Upper Saddle River, NJ, USA: Prentice Hall, 2002.
[3] P. Comon, "Independent component analysis—A new concept?" Signal Processing, vol. 36, no. 3, pp. 287–314, Apr. 1994.
[4] J.-F. Cardoso and A. Souloumiac, "Blind beamforming for non-Gaussian signals," IEE Proceedings F (Radar and Signal Processing), vol. 140, no. 6, pp. 362–370, Dec. 1993.
[5] J.-F. Cardoso, "High-order contrasts for independent component analysis," Neural Computation, vol. 11, no. 1, pp. 157–192, Jan. 1999.
[6] A. Hyvärinen and E. Oja, "A fast fixed-point algorithm for independent component analysis," Neural Computation, vol. 9, no. 7, pp. 1483–1492, Oct. 1997.
[7] A. Hyvärinen, J. Karhunen, and E. Oja, Independent Component Analysis. New York, NY, USA: Wiley, 2001.
[8] S. Haykin, Adaptive Filter Theory, 4th ed. Upper Saddle River, NJ, USA: Prentice Hall, 2002.
[9] X. Wang and H. V. Poor, "Blind multiuser detection: A subspace approach," IEEE Transactions on Information Theory, vol. 44, no. 2, pp. 677–690, Mar. 1998.
[10] L. Tong, Y. Inouye, and R. Liu, "Waveform-preserving blind estimation of multiple independent sources," IEEE Transactions on Signal Processing, vol. 41, no. 7, pp. 2461–2470, Jul. 1993.
[11] M. Honig, U. Madhow, and S. Verdú, "Blind adaptive multiuser detection," IEEE Transactions on Information Theory, vol. 41, no. 4, pp. 944–960, Jul. 1995.

[12] S. Moshavi, “Multi-user detection for DS-CDMA communications,” IEEE Communications Magazine, vol. 34, no. 10, pp. 124–136, Oct. 1996.
[13] R. Lupas and S. Verdú, “Linear multiuser detectors for synchronous code-division multiple-access channels,” IEEE Transactions on Information Theory, vol. 35, no. 1, pp. 123–136, Jan. 1989.
[14] A. Goldsmith, Wireless Communications. Cambridge, U.K.: Cambridge Univ. Press,