Mengyu ZHANG, Zhenxue HE, Yijin WANG, Xiaojun ZHAO, Xiaodan ZHANG, Limin XIAO, Xiang WANG, 2025. A power optimization approach for mixed polarity Reed–Muller logic circuits based on multi-strategy fusion memetic algorithm. *Frontiers of Information Technology & Electronic Engineering*, 26(3):415-426.
https://doi.org/10.1631/FITEE.2400513

A power optimization approach for mixed polarity Reed–Muller logic circuits based on multi-strategy fusion memetic algorithm

Key words: Power optimization; Multi-strategy fusion memetic algorithm (MFMA); Mixed polarity Reed–Muller (MPRM); Combinatorial optimization problem

Corresponding author: Zhenxue HE
E-mail: hezhenxue@buaa.edu.cn
ORCID: https://orcid.org/0000-0001-7041-8582

Motivation

1. With the rapid development of the integrated circuit industry, technological innovation and chip integration continues to improve. However, the existence of the chip power consumption problem is also increasingly significant. The increase in chip power consumption not only leads to a variety of portable equipment power difficulties and chip overheating problems, but also has a certain effect on the cost of heat dissipation and packaging costs.

2. The existing power consumption optimization methods for MPRM logic circuits based on traditional swarm intelligence optimization algorithms suffer from issues such as low convergence speed and susceptibility to local optima.

Main idea

1. An MFMA is proposed. It comprises a global exploitation optimizer using the chimp optimization algorithm (ChOA), a local exploration optimizer based on the coati optimization algorithm based on the optimal position learning and adaptive weight factor (COA-OLA), and a population selection optimizer employing a truncation selection algorithm. The MFMA expedites convergence, enhances search accuracy, and prevents the algorithm from succumbing to local optima.
2. A power optimization approach for MPRM logic circuits is introduced, employing the MFMA to search for the optimal polarity configuration with minimal power. Notably, this paper marks the pioneering application of the ChOA and COA to RM logic circuit optimization, enhancing the search capabilities and solution quality in this domain.
3. Experimental results conducted on power using the Microelectronics Center of North Carolina (MCNC) benchmark circuit validate the efficacy and superiority of the proposed power optimization approach.

Method

Due to the random selection of prey positions in the initial phase of the original algorithm, the search accuracy is relatively poor. This paper proposes an optimal position learning strategy. This strategy calculates the fitness values of the remaining coati individuals and updates the prey position by combining the best fitness individual with two randomly selected individuals. This approach enables the coati individuals to approach the prey more quickly and enhances their attack efficiency, thereby improving the algorithm’s search speed.

Method

1. Global exploitation optimizer——ChOA

Khishe and Mosavi (2020) proposed the ChOA, a novel meta-heuristic algorithm that simulates the behaviors of chimpanzee groups in attacking, driving away, obstructing, and pursuing prey. Due to its strong global search capabilities and ease of implementation, it is suitable for various optimization problems. Therefore, the ChOA is selected as the global optimization algorithm to enhance convergence speed.

Method

2. Local exploration optimizer——COA-OLA

Due to the random selection of prey positions in the initial phase of the original algorithm, the search accuracy is relatively poor. This paper proposes an optimal position learning strategy. This strategy calculates the fitness values of the remaining coati individuals and updates the prey position by combining the best fitness individual with two randomly selected individuals. This approach enables the coati individuals to approach the prey more quickly and enhances their attack efficiency, thereby improving the algorithm's search speed.

$$\begin{aligned}\mathrm{Iguana}^{G}:\ \mathrm{Iguana}_j^{G}&=x_{i,j}^{1}+R_d\left(x_{i,j}^{1}-x_{i,j}^{2}\right)\\&\quad+\left(x_{i,j}^{3}-\mathrm{Iguana}_j^{G}\right),\\ i=1,2\ldots,N_2,\ j&=1,2,\ldots,m,\end{aligned}$$

Method

2. Local exploration optimizer——COA-OLA

In the original algorithm’s stage of escaping from predators, coati individuals randomly select a position nearby to flee. This random escape does not effectively cover the entire search space and fails to guide the coatis to explore significantly different areas, making it difficult to balance exploration and exploitation. As a result, the algorithm is prone to stagnation in local optima. We propose an adaptive weight factor strategy. By adjusting the inertia weight, coati individuals can choose new positions based on the distance from the predator, thereby enhancing the algorithm’s local search capability.

$$w=\sin\left(\frac{\pi i}{2N_2}+\pi\right)+1,$$

$$X_l^{P_2}: x_{i,j}^{P_2}=wx_{i,j}^{4}+(r^2x_{i,j}^{5}-x_{i,j}^{6}),$$

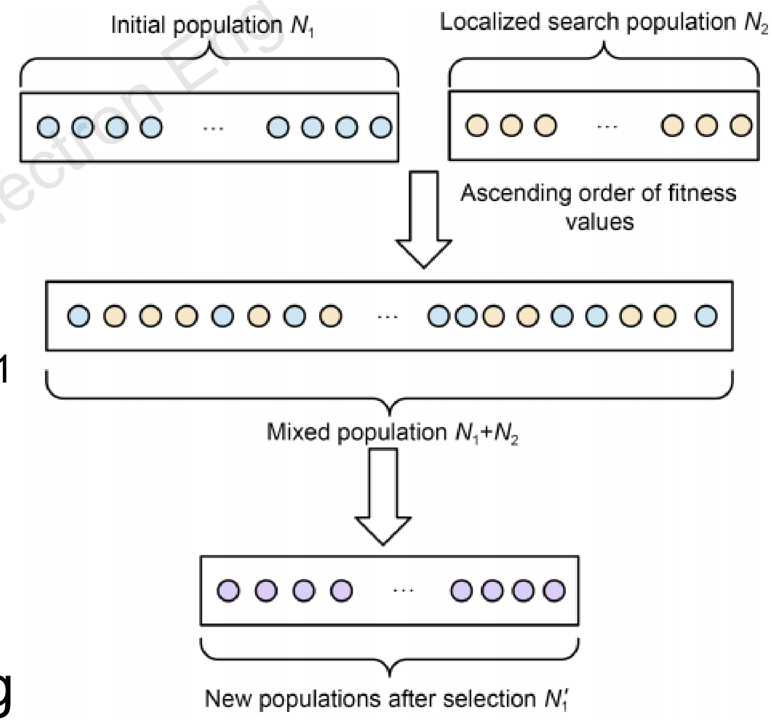
$$i=1,2\ldots,N_2,\ j=1,2,\ldots,m,$$

Method

3. Population selection optimizer

——Truncation selection algorithm

In truncation selection, the fitness values of the population are first calculated and sorted from best to worst, allowing only a fixed number of individuals to advance to the next iteration. The initial population N_1 is generated using a global optimization algorithm, and a local search algorithm subsequently optimizes the population to create a new population N_2. After merging and sorting the two populations, the top N_1 individuals with better fitness are selected for further iterations.



Major results

Orthogonal experiment parameters

Level test	N_2	N_1	T	Average result
1	26	30	35	769.22
2	26	35	45	776.68
3	26	40	40	759.58
4	28	30	45	770.47
5	28	35	40	737.27
6	28	40	35	778.21
7	30	30	40	782.99
8	30	35	35	764.89
9	30	40	45	774.34

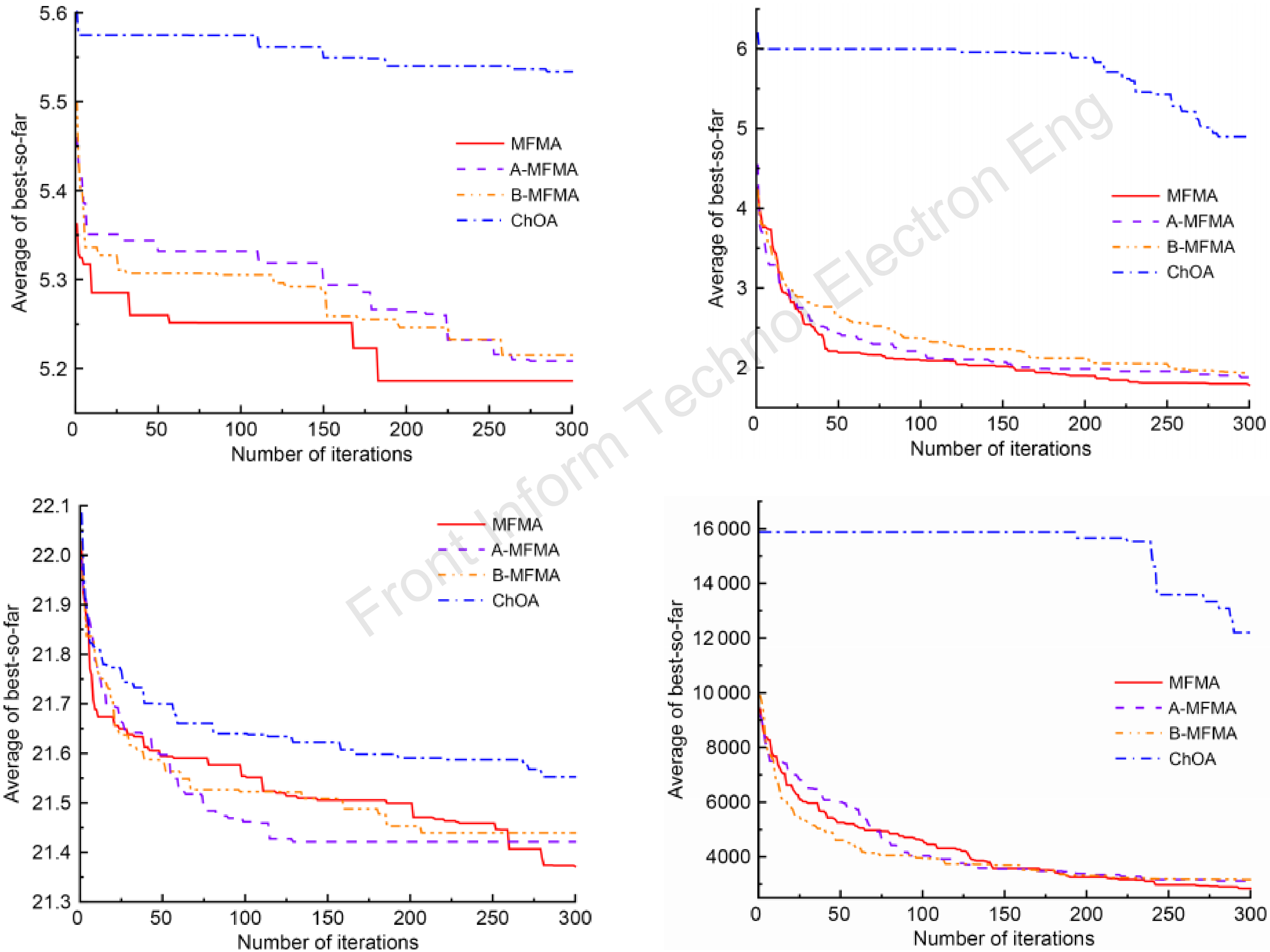
Major results

Ablation experiments

Set	Function	Standard	Value			
			ChOA	A-MFMA	B-MFMA	MFMA
2019	F3	Ave	10.1527	9.4022	7.5436	7.1943
		Best	5.3731	5.2293	3.2485	4.0357
	F6	Ave	10.8505	10.0401	9.8551	9.7078
		Best	10.1586	8.4792	8.5220	8.3931
	F8	Ave	5.3669	4.9212	4.7368	4.5605
		Best	5.0513	3.8661	4.5148	4.2269
	F9	Ave	1.5225	1.5078	1.4192	1.4077
		Best	1.2841	1.4432	1.2163	1.2949
	F10	Ave	21.4411	21.3696	21.3297	21.3272
		Best	21.3136	21.2078	21.1823	21.1388
2022	F3	Ave	660.4345	644.1511	641.4526	640.2807
		Best	640.0812	630.4283	632.6393	628.2525
	F4	Ave	930.71	891.5244	874.839	903.7881
		Best	911.9187	901.8239	884.5712	882.1141
	F5	Ave	2924.664	2143.449	2046.742	2015.967
		Best	2624.837	1792.98	1742.162	1715.962
	F9	Ave	2764.985	2571.001	2556.346	2539.089
		Best	2617.578	2492.277	2491.055	2488.957
	F10	Ave	6708.998	6282.002	5402.276	3450.28
		Best	5447.077	5374.694	2784.491	2513.652

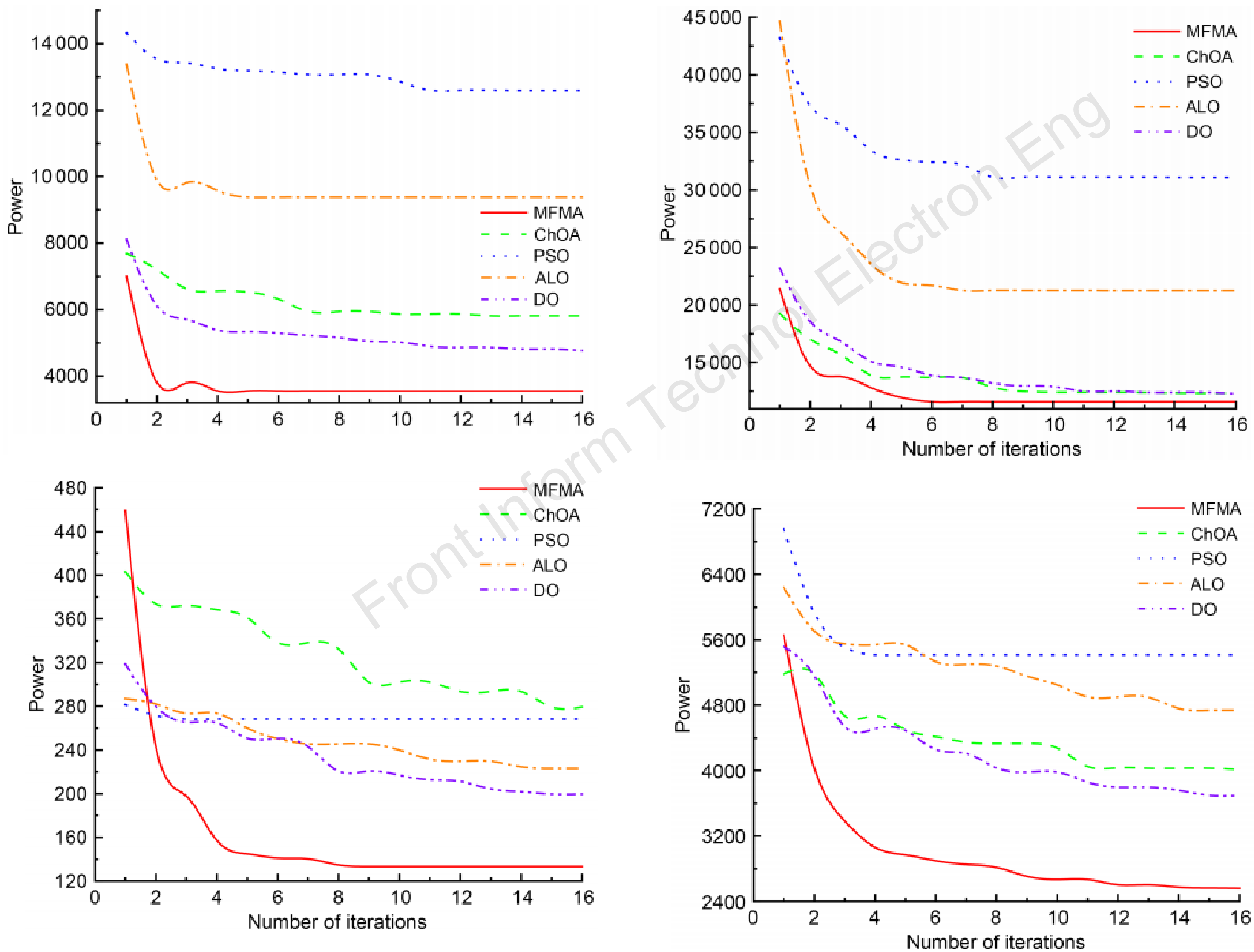
Major results

Convergence performance for ablation experiments



Major results

Convergence performance for power comparison



Conclusions

The XNOR/OR-based power optimization for MPRM logic circuits belongs to a typical three-valued optimization problem. To address challenges in existing MPRM logic circuits, such as inaccurate searches and susceptibility to local optimization, we propose a power optimization approach based on the MFMA; it not only accelerates convergence process but also enhances search accuracy, effectively resolving the three-valued combinatorial optimization problem in RM logic circuit power optimization. Experimental results conducted on the MCNC benchmark circuits and the IEEE CEC function test set demonstrate that MFMA outperforms existing optimization algorithms by converging faster and identifying optimal solutions more accurately.

Mengyu ZHANG is a graduate student at Hebei Agricultural University. Her research interests include XNOR/OR-based area optimization of Reed–Muller circuits, power optimization, low-power integrated circuit (IC) design, computer-aided design, and intelligent optimization algorithms.

Zhenxue HE received the Ph.D. degree in computer architecture from Beihang University, Beijing, China, in 2018. He is currently a full Associate Professor with Hebei Agricultural University, Baoding, China. He has authored or coauthored more than 40 articles in peer-reviewed journals and proceedings, such as *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, *IEEE Transactions on Services Computing*, *IEEE Sensors Journal*, and *Journal of Computer Science and Technology*. His research interests include low power IC design and optimization, multiple-valued logic circuits, combinatorial optimization, and intelligent algorithm.