Cooperative Co-evolution Strategies with Time-dependent Grouping for Optimization Problems in Smart Grids

Junpeng Su
South China University of Technology
Guangzhou, China
sujp.scut@gmail.com

Han Huang
South China University of Technology
Guangzhou, China
hhan@scut.edu.cn

Zhifeng Hao
Foshan University
Foshan, China
zfhao@fosu.edu.cn

ABSTRACT

The rapid development of smart grids provides end-users numerous services, like energy transactions and load management. Meanwhile, it raises new optimization problems worthy to explore. To solve these problems, cooperative co-evolution strategies with time-dependent grouping are proposed in this paper. Compared with five advanced methods, the proposed algorithms are applied in GECCO 2021 competition on evolutionary computation in the energy domain.

CCS CONCEPTS

• **Theory of computation** → **Evolutionary algorithms**.

KEYWORDS

cooperative co-evolution, time-dependent grouping, mixed-integer nonlinear programming, smart grid

ACM Reference Format:
Junpeng Su, Han Huang, and Zhifeng Hao. 2021. Cooperative Co-evolution Strategies with Time-dependent Grouping for Optimization Problems in Smart Grids. In *Proceedings of the Genetic and Evolutionary Computation Conference 2021 (GECCO '21 Companion)*. ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3449726.3463298

1 INTRODUCTION

A number of real-world optimization problems are still outstanding in the energy domain [1]. For example, the bidding optimization problem in day-ahead local energy markets aims at the minimization of end-users' costs [3]. Moreover, the flexibility management of home appliances can be modeled as a mixed-integer nonlinear programming problem[2]. To solve these optimization problems, cooperative coevolution strategies with time-dependent grouping (CCS-TG) are proposed in this paper.

GECCO '21 Companion, July 10–14, 2021, Lille, France

ACM ISBN 978-1-4503-8351-6/21/07.
https://doi.org/10.1145/3449726.3463298

Algorithm 1 CCS-TG-I

$groups \leftarrow time\_dependent\_grouping(n, lbs, ubs)$;
/* lbs and ubs are variables boundaries, n represents the problem dimension */
Generate an initial solution X randomly;
Evaluate X and record the best-ever solution X^*;
while termination criterion is not met **do**
    $\xi \leftarrow randi(size\,(groups))$;
    $indicies \leftarrow groups[\xi]$;
    $X_c \leftarrow quantity\_search(X, indicies)$;
    $X_c \leftarrow price\_search(X_c, indicies)$;
    Evaluate X_c and record the best-ever solution X^*;
    $X \leftarrow elitist\_selection(X_c, X)$;
end while
return the best-ever solution X^*;

2 THE PROPOSED ALGORITHMS

2.1 CCS-TG-I for optimal bidding strategy in local energy markets

Algorithm 1 presents the search procedure of cooperative co-evolution strategy with time-dependent grouping for optimal bidding strategy in local energy markets. Inspired by

Algorithm 2 CCS-TG-II

$groups \leftarrow time\_dependent\_grouping(n, lbs, ubs)$;
Randomly generate an initial population P of size N_p;
Evaluate each solution X in P and record the best-ever solution X^*;
while termination criterion is not met **do**
    for each solution X in P **do**
        $X_c \leftarrow starting\_period\_search(X)$;
        for $i \leftarrow 1$ *to size* $(groups)$ **do**
            $indicies \leftarrow groups[i]$;
            $X_c \leftarrow intensity\_search(X, indicies)$;
        end for
        Evaluate X_c and record the best-ever solution X^*;
        $X \leftarrow elitist\_selection(X_c, X)$;
    end for
    Reduce the population size when the number of fitness evaluations exceeds the threshold ζ;
end while
return the best-ever solution X^*;

Table 1: Experimental Results on the Bidding Strategy Optimization Problem in Local Energy Markets

Algorithm	Avg Fit	Std Fit	Var Fit	Min Fit	Max Fit	Avg Profit	Avg Time	Ranking Index
CCS-TG-I	**1.48E+00**	**2.12E-02**	**4.50E-04**	**1.47E+00**	**1.54E+00**	**-1.75E+00**	**1.09E+02**	**1.48E+00**
CE-CMAES	6.85E+00	3.01E+00	9.08E+00	2.71E+00	1.48E+01	-3.50E+00	1.08E+02	6.85E+00
CUMDANCauchy	3.04E+00	1.01E-01	1.02E-02	2.85E+00	3.22E+00	-5.16E+00	9.08E+01	3.04E+00
GASAPSO	1.66E+00	7.56E-02	5.72E-03	1.55E+00	1.82E+00	-1.93E+00	1.11E+02	1.66E+00
AJSO	1.58E+00	6.37E-02	4.05E-03	1.50E+00	1.74E+00	-1.92E+00	1.14E+02	1.58E+00
HyDE-DF	1.95E+00	8.83E-02	7.79E-03	1.83E+00	2.19E+00	-2.23E+00	1.09E+02	1.95E+00

Table 2: Experimental Results on the Flexible Management Problem of Home Appliances

Algorithm	Avg Fit	Std Fit	Var Fit	Min Fit	Max Fit	Avg Profit	Avg Time	Ranking Index
CCS-TG-II	**4.35E+00**	**8.16E-02**	**6.66E-03**	**4.18E+00**	**4.49E+00**	**1.82E+00**	**6.61E+01**	**4.35E+00**
CE-CMAES	1.53E+01	5.47E-01	2.99E-01	1.41E+01	1.62E+01	5.34E+00	7.33E+01	1.53E+01
CUMDANCauchy	2.45E+01	4.86E-01	2.36E-01	2.37E+01	2.53E+01	1.19E+01	5.65E+01	2.45E+01
GASAPSO	8.09E+00	1.26E+00	1.59E+00	5.21E+00	1.01E+01	1.23E+00	6.51E+01	8.09E+00
AJSO	9.44E+00	5.52E-01	3.05E-01	8.55E+00	1.06E+01	1.65E+00	5.28E+02	9.44E+00
HyDE-DF	7.98E+00	5.94E-01	3.53E-01	6.78E+00	9.29E+00	1.75E+00	6.80E+01	7.98E+00

cooperative co-evolution frameworks [4], the grouping function $time\_dependent\_grouping(n, lbs, ubs)$ groups the decision variables into subcomponents based on the time period in the day-ahead market. The operator *quantity_search* adjusts the bid quantities, while the operator *price_search* searches for the optimal bid price.

2.2 CCS-TG-II for flexible management problem of home appliances

The pseudocode of CCS-TG-II for flexible management problem of home appliances is given in Algorithm 2. Different from CCS-TG-I, the grouping function in CCS-TG-II is not applied to all decision variables, but groups the intensity variables of real-time devices based on the time period. The search procedure of CCS-TG-II is divided into two stages. Specifically, CCS-TG-II first randomly modifies the starting period of shifting devices (*starting_period_search*), and then searches for the optimal intensities of appliances with reduction capabilities (*intensity_search*).

3 RESULTS AND DISCUSSION

CCS-TG-I and CCS-TG-II are applied to solve two tracks of GECCO 2021 competition on evolutionary computation in the energy domain. To verify the effectiveness of the proposed algorithms, five advanced meta-heuristics are selected for comparison. CE-CMAES, CUMDANCauchy, GASAPSO, and AJSO are outstanding participants in GECCO 2020 competitions, while HyDE-DF is an improved variant of Hybrid-adaptive differential evolution for single-objective optimization. Each method repeats 20 times independently.

Table 1 presents the average, minimum, and maximum fitness obtained by each algorithm in 20 trials for the bidding strategy optimization problem. Moreover, the computational results on the flexible management problem of home appliances are provided in Table 2. Since both tracks are modeled as minimization problems, the less the fitness value, the better the performance achieved by the algorithm. Tables 1 and 2 show that the proposed meta-heuristics outperform all the other algorithms in terms of the average fitness.

4 CONCLUSION

In this paper, cooperative co-evolution strategies with time-dependent grouping are developed for GECCO 2021 competition on evolutionary computation in the energy domain. Experimental results demonstrate that CCS-TG-I and CCS-TG-II are capable of obtaining high-quality solutions for the optimization problems under consideration.

5 ACKNOWLEDGMENTS

This work is supported by National Natural Science Foundation of China (61772225, 61876207) and Guangdong Province Key Area R&D Program (2018B010109003).

REFERENCES

[1] Keke Gai, Yulu Wu, Liehuang Zhu, Meikang Qiu, and Meng Shen. 2019. Privacy-preserving energy trading using consortium blockchain in smart grid. *IEEE Transactions on Industrial Informatics* 15, 6 (2019), 3548–3558.

[2] Fernando Lezama, Joao Soares, Bruno Canizes, and Zita Vale. 2020. Flexibility management model of home appliances to support DSO requests in smart grids. *Sustainable Cities and Society* 55 (2020), 1–12.

[3] Fernando Lezama, Joao Soares, and Zita Vale. 2019. Optimal bidding in local energy markets using evolutionary computation. In *2019 20th International Conference on Intelligent System Application to Power Systems (ISAP)*. IEEE, New Delhi, India, 1–6.

[4] Mohammad Nabi Omidvar, Xiaodong Li, Yi Mei, and Xin Yao. 2013. Cooperative co-evolution with differential grouping for large scale optimization. *IEEE Transactions on Evolutionary Computation* 18, 3 (2013), 378–393.