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Solving Adaptive Distributed Routing Algorithm Using Crow Search Algorithm

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Abstract
Crow Search Algorithm (CSA) can be defined as one of the new swarm intelligence algorithms that has been developed lately, simulating the behavior of a crow in a storage place and the retrieval of the additional food when required. In the theory of the optimization, a crow represents a searcher, the surrounding environment represents the search space, and the random storage of food location represents a feasible solution. Amongst all the food locations, the one where the maximum amount of the food is stored is considered as the global optimum solution, and objective function represents the food amount. Through the simulation of crows' intelligent behavior, the CSA attempts to find the optimum solutions to a variety of the problems that are related to the optimization. This study presents a new adaptive distributed algorithm of routing on CSA. Because the search space may be modified according to the size and kind of the network, the algorithm can be easily customized to the issue space. In contrast to population-based algorithms that have a broad and time-consuming search space. For ten networks of various sizes, the technique was used to solve the shortest path issue. And its capability for solving the problem of the routing in the switched networks is examined: detecting the shortest path in the process of a data packet transfer amongst the networks. The suggested method was compared with four common metaheuristic algorithms (which are: ACO, AHA, PSO and GA) on 10 datasets (integer, weighted, and not negative graphs) with a variety of the node sizes (10 - 297 nodes). The results have proven that the efficiency of the suggested methods is promising as well as competing with other approaches.

Keywords: Crow Search Algorithm, SP Problem, Routing Algorithms, Swarm Intelligence

حل خوارزمية التوجيه الموزع التكيفية باستخدام خوارزمية بحث الغراب

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الخلاصة
يمكن تعريف خوارزمية (CSA) Crow Search كواحدة من خوارزميات ذكاء السرب الجديدة التي تم تطويرها مؤخرًا، ومحاكاة سلوك الغراب في تخزين واسترجاع الطعام الزائد عند الحاجة. في نظرية التحسين، يمثل الغراب الباحث، وتمثل البيئة المحيطة مساحة البحث، ويمثل التخزين العشوائي لموقع الطعام حلاً ممكنًا. من بين جميع مواقع الطعام، تم اعتبار الموقع الذي يتم فيه تخزين الحد الأقصى من الطعام هو الحل الأمثل

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العالمي، وتمثل الوظيفة الموضوعية كمية الطعام. من خلال محاكاة السلوك الذكي للغربان، تحاول CSA إيجاد الحلول المثلى لمجموعة متنوعة من المشكلات المتعلقة بالتحسين. تقدم الدراسة الحالية خوارزمية توجيه جديدة وموزعة تكيفية تعتمد على CSA. ويتم فحص قدرتها على حل مشكلة التوجيه في الشبكات المحولة: اكتشاف أقصر مسار في عملية نقل حزم البيانات بين الشبكات. تمت مقارنة الطريقة المقترحة مع 4 خوارزميات شائعة (وهي: ACO و AHA و PSO و GA) على 10 مجموعات بيانات (عدد صحيح، وموزان، وليست رسوم بيانية سلبية) مع مجموعة متنوعة من أحجام العقد (10–297 عقدة). وقد أثبتت النتائج أن كفاءة الأساليب المقترحة واعدة بالإضافة إلى التنافس مع الأساليب الأخرى.

1. Introduction

The bio-inspired algorithms of optimization had gained an increasing popularity in the last 10 years due to their robustness, implementation simplicity, and capability of the parallel computations [1]. Even though the procedures and principles of the bio-inspired algorithms of optimization vary, it is agreed on that an effective search techniques have to strike a balance between the exploration of new search space regions and exploitation of known potential regions [2, 3].

Optimization has played a critical part in many facets of many challenges in recent decades, including but not limited to engineering problems. Complicated objective functions, a large number of decision variables, and a large number of constraints are common in such issues, adding to the complexity of an already complex optimization problem. Traditional optimization strategies are limited by the aforementioned features. As a result of this search for an alternate strategy, Beni and Wang launched a new field of study in the late 1980s called swarm intelligence (SI). SI aspires to emulate the social intelligence of nature's group living animals in the end [4].

Each new algorithm aims to improve one of two key characteristics: (1) the gap between reported solutions and the actual global optima; and/or (2) the time it takes to find a solution. Although each proposed optimization algorithm has its own set of characteristics, each with its own set of benefits and downsides, it has been demonstrated that no single algorithm can beat all its competitors. As a result, a variety of alternative innovative optimization techniques have been presented, each with its own set of benefits [4].

The crow search algorithm (CSA), which was first proposed by Askarzadeh, is one of these newly developed algorithms (2016). CSA seeks to mimic the social intelligence and food collection procedure of a crow group. The key findings demonstrated that CSA outperformed numerous traditional optimization methods in terms of convergence time and accuracy, such as the genetic algorithm (GA), particle swarm optimization (PSO), and harmony search (HS). Finally, CSA is a viable alternative strategy for resolving complex engineering optimization problems [4].

The CSA, which has been suggested in 2016 by Askerzadeh [5], can be described as one of the newly developed algorithms that are inspired by strategic behaviors of the crows during their search for food, chasing behaviors and thievery. The CSA has been identified by less parameter settings, easy implementation, and strong capacity of development in the process of searching [6]. Nonetheless, the CSA suffers as well from low search precision, high likelihood to get into local optima, and premature convergences, particularly for the multi-dimensional problems of optimization [6] that could happen due to two significant characteristics in basic CSA [7, 8]: (a) there aren't any criteria for the selection of destination and this selection is carried out in a random manner between all of the crows; (b) the flight length amount represents a constant value that could result in the inappropriate search by crows in solution space, resulting in trapping in local optimum.

The fast advancement in communications and networks led to the networks being backbone of several applications and a variety of areas. With this continual acceleration and progression, challenges that face data and package transfer process increased as well, particularly in the packet-switched networks. The process of routing represents the calculation of a route between two nodes in a network— i.e., source and destination—to enable effective exploitation of the intermediate network between them [9]. Such process of routing happens in the layer of the network through the routing protocols. Every one of the protocols is dependent upon a certain strategy of routing, which utilizes an algorithm for building a routing table. There are 2 routing types: dynamic and static.

The static (also referred to as non-adaptive) method of routing is simple to implement, and the path is characterized between any two nodes in the table of static routing. It can build the route without considering the current condition of traffic [9]. In contrast, the dynamic (i.e., adaptive) method of routing is helpful for finding an alternative route in the case where the node of routing senses that the path that has been determined previously is now harder to route a packet through because of the changing conditions of the network. There is a number of algorithms that are utilized for solving the problems of routing. Every one of which has a specific approach for route calculation. Those approaches have been based on dynamic and static network metrics, like the bandwidth, hop count, reliability, cost, congestion or load, and routing delays [10].

The goal of the Shortest-path problem is to identify the shortest path between two pre-defined places, which could be the shortest distance, the least amount of time spent, or the lowest value of the path between those two sites. There are numerous applications available. Many fields of study consider SP problem primarily in its operation, such as automobile navigation systems, robotic systems route planning, Traveling Salesman's Problem (TSP), and routing in telecommunication networks, Because the act of transmitting data packets between networks necessitates finding the shortest way, which may be the shortest delivery time, bandwidth link, or lower cost, this research focuses on routing problems in a switched networks. Many well-known algorithms, including the Dijkstra algorithm, Floyd-Warshall algorithm, and Bellmen-ford algorithm, have investigated the SP problem. Each algorithm has its own method for determining the shortest path.

The fundamental goal of this research is to introduce a novel dynamic routing method by: a) Using the crow search algorithm to design and construct a high-speed routing algorithm. b)Investigating how well local search algorithms function in network routing. c) Demonstrating the differences in efficiency between two types of search algorithms (population-based and local-based) in relation to the size of the network dataset.

The following is how this article is structured: The literature review of CSA is presented in Section 2, while the motivation and mathematical model of CSA are provided in Section 3. The routing model is shown in Section 4. Section 5 presents an assessment and evaluation of CSA, followed by a discussion of the experimental outcomes in Section 6.

2. Related Works

In the past years, the majority of research have been focused on applying the algorithm in a variety of the scientific areas with the proper modifications. Sayyed et al. [3] combined the chaos with the CSA for the enhancement of convergence speed and performance, whereas Sahu & Chaudhuri [11] suggested a time varying flight length for the purpose of obtaining better results. Concerning the optimization of energy, Askerzadeh & Makhdoom [12] incorporated the adaptive probability of the chaotic awareness in the CSA for the optimization of the photo-voltaic/diesel hybrid energy systems' operation. For the purpose of overcoming the phases of unbalanced exploitation and exploration, Saxena & Shekawat [8] enhanced the algorithm through a cos function and a concept of the opposition-based learning. The variants of the CSA were classified to modified [13,14] as well as hybrid versions [15, 16].

Zied O. Et al. [17] proposed a biometric based scheme of key recreation due to the fact that the human ears are interrelated. Presently, the generation of the encryption keys is carried out using the swarm intelligence method. The collective intelligence of the simple autonomous agent groups emerged from the swarm intelligence. CSA had shown its potential in the generation of the keys from the biometrical characteristics and obtained random keys with fewer iterations.

A variety of methods and algorithms were suggested for the purpose of finding the shortest path in the network routing. Kammoun & Ali [18] suggested an approach for solving the problem of routing in the packet-switched network through the application of computational tools with the use of an enhanced NN version. Their approach focused on minimizing the mean time of the delay with the adaptability to the changes in the costs or changes of the topology of the network.

Gianni DiCaro [19] created an algorithm of mobile agent routing, which has been referred to as the AntNet. It operated in two stages (i.e., forward and backward) and has been based on Ant Colony algorithm (ACO). S.Sugden etal.[20] addressed the problem of the shortest-path through selecting a specific pre-computed paths' portion —the ones that are restricted to a certain number of the hops or capacity—and after that, changing those paths with the use of the algorithm of simulated annealing.

Ali & Nagib [21] advanced a genetic algorithm (GA) for solving the problem of the network routing protocol in a random 10-node topology. They performed a comparison of their proposed topology against Dijkstra algorithm that is considered a very popular algorithm for solving the routing problems. They have given similar results.

Ramakrishna & Ahn [22] proposed the variable-length genes to GA for the purpose of solving the problem of routing. They suggested a formula for the population-sizing that is based upon gambler's ruin model.

Casali etal. [23] suggested the use of Tabu Search as meta-heuristic algorithm for solving routing problem rather than the conventional algorithms requiring exhaustive computation operations, particularly in the networks that have high number of nodes. However, it is not an optimal solution to detect the shortest path.

A. K. Ardabili etal. [24] Introduced a new adaptive algorithm for a distributed routing that is based on Camel Herds Algorithm (CHA). The algorithm can be adapted easily to problem space since the search space may be regulated based on the network type and size unlike population-based algorithms, where the search space is time-consuming and large. CHA is one of the fastest algorithms since it can offer a wider diversity due to the fact that every one of the herds has the ability of providing an independent path.

In Shahbaa I. Khaleel's research [25], a new technique was proposed to compress color-images based on clustering of image data by swarm intelligence algorithms. These algorithms were advanced using fuzzy-logic to make the clustering process easy and flexible. Then, the huffman algorithm was applied to the clustered data to get a highly efficient compressed file with small storage. The results showed that the first technique, PSO provided a good result. The rebuilt image has a distortion so the second advanced technique FPSO was used to achieve the compression and provided better results than the first. Afterwards, another swarm algorithm was used for the clustering and then compressed the clustered data

3. Crow Search Algorithm

The CSA is a new population-based algorithm that was suggested by Askerzadeh, simulating the crows' behavior of food hiding [4]. The crows are intelligent birds capable of remembering faces and warning its species from the danger. Very important evidence of how clever they are is how they hide food and remember where they have hidden it. In addition to that, CSA exploitation and exploration has been illustrated in Figure1 [25]. In general, CSA pseudocode can be modelled as in Algorithm1, and its basic phases can be summarized below [26]:

1) Random initialization of the swarm of crows in d-dimensional.
2) Using a fitness function for the evaluation of every one of the crows, and its value is considered to be initial memory value. Every one of the crows stores the hiding place in the memory variable *mi*.
3) Crow updates the position through the selection of another random crow, in other words, *xj* and the generation of an arbitrary value. In the case where that value has been greater than Awareness Probability `*AP*', then the crow *xi* will follow *xj* to know *mj*
4) The crow updates its location through the selection of another random crow, *xj* and following it to know *mj*. After that, a new *xj* is computed from:

$$x_{i,iter+1} = \begin{cases} x_{i,iter} + r_i \times fl_{i,iter} \times (m_{j,iter} - x_{i,iter}) & r_j \geq AP_{j,iter} \\ \text{a random position} & otherwise \end{cases} \quad (1)$$

where $AP_{j,iter}$ indicates the awareness probability of crow *j*. i_{ter} indicates the number of the iteration. *ri*; *rj* indicate random numbers, and $fl_{i,iter}$ represents crow *i* flight length to represent the memory of crow *j*.
5) Updating memory

$$m_{i,iter+1} = \begin{cases} x_{i,iter+1} & f(x_{i,iter+1}) \leq f(m_{i,iter}) \\ m_{i,iter} & otherwise \end{cases} \quad (2)$$

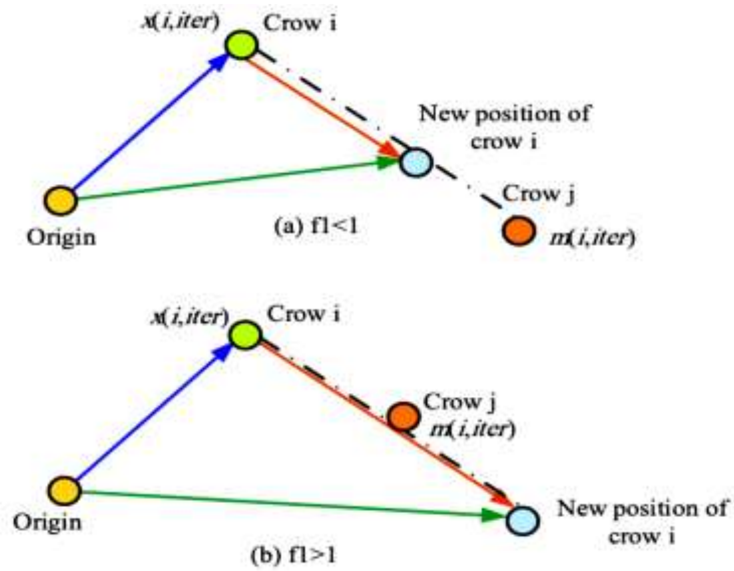

Figure 1: Exploration and exploitation of CSA [26].

```
Algorithm 1 CSA: Crow Search Algorithm
  Input: n Number of crows in the population.
  iter_max Maximum number of iteration.
  Output: Optimal crow position
  Initialize position of crows.
  Initialize crows' memory
  while iter < iter_max do
      for crow_i belong to crows do
          choose a random crow.
          determine a value of awareness probability AP
          Update x_{i,iter+1} using Eq.(1)
      end for
      Check solution boundaries.
      Calculate the fitness of each crow
      Update crows' memory using Eq.(2)
  end while
```

Figure 2: Crow Search Algorithm pseudocode [26].

4. Proposed Model of Routing

The present study proposes a new strategy for solving the problem of routing, that expands the existing CSA and optimizes its steps. It compares two deferent meta-heuristic optimization algorithm types (population-based and local searches) in efficiency of demonstrating the effects of the search space size on speed and accuracy of finding the shortest path. At first, the CSA generates the initial random positions of the crow, and the process of the generation is carried out with the use of the function of the logistic map.

Following the generation of the algorithm of the initial population, the fitness is calculated for the population to evaluate the crow position with the use of the fitness function, the value of the strength can be estimated in an individual manner for every one of the iterations. This value is computed based on the symbol that has been repeated most.

For every one of the crows, random value *ri* is generated. *ri* is compared to *AP* (i.e., awareness probability). In the case where *AP* < *ri*, then, the new position for the crow is randomly calculated, otherwise, a new position is calculated for the crow by using the levy-flight function. Then, the feasibility of the new position is checked, and the fitness is calculated for the new positions. Those steps are repeated to the point of reaching the maximum iteration.

This algorithm includes a list that stores the path for herds throughout/ after the process of the search. After running this algorithm, the final number of the solutions becomes equal to the number of the herds which have been launched from the starting point.

5. Experimental Results

For the purpose of demonstrating the Crow Search algorithm's performance, it was built with the use of the Python 3.8 environment as it powerful in dealing with the lists and has numerous functions and libraries thatmake code building simple. There were ten well-known graphs (integer, weighted, not negative) of a variety of the sizes (10 - 297 nodes) with several edges (up to 19,900 edges) utilized for testing the suggested algorithm of routing. There were 3 random paths utilized for every one of the graphs.

The results have been compared with the Camel Heard algorithm, ACO as a non-population-based method, and other population-based methods (GA, PSO) [24]. There is an importance for illustrating the differences between the two methods for solving SP problem. A special attention has been given to the effects of the search space of those two methods on the CPU time consumption and on the quality of the solution that is provided by those five approaches.

The first column in Table I, represents the graph name and size. The path source and the destination and its optimum costs are listed in column 2 & column 3. The remaining columns show the optimal execution time and cost for every one of the algorithms. Figure (3) shows differences in execution time between the suggested CSA and (ACO, GA, CHA, and PSO algorithms) for every path.

As presented in Table 1, results that have been obtained from CSA algorithm were better in comparison with those that were obtained from the rest of the algorithms that were compared with it.

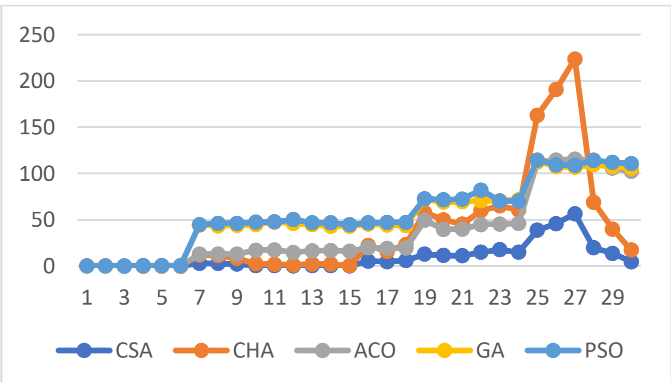

Figure 3: Execution Time values for every path in (sec)

Table 1: Comparison of the performance between the CSA and (ACO,GA, CHA, and PSO) Showing CPU consumption time (sec) and cost.

Dataset	Path	Optimum cost	Methods									
			CSA		CHA		ACO		GA		PSO	
			costs	time	costs	time	costs	time	costs	time	costs	time
1- Random (10-nodes)	(4 , 3)	9	9	0.020	9	0.037	9	0.062	9	0.327	9	0.243
	(8,1)	12	13	0.022	13	0.047	12	0.074	12	0.321	12	0.245
	(3,9)	9	11	0.017	12	0.047	9	0.062	9	0.319	9	0.241
2- NSFnet (14-nodes)	(0 , 13)	27	27	0.016	27	0.019	27	0.095	27	0.456	27	0.417
	(10,4)	22	22	0.021	22	0.016	22	0.092	22	0.459	22	0.425
	(3,9)	32	32	0.016	32	0.016	32	0.095	36	0.471	32	0.414
3- st70 (70-nodes)[23]	(3 , 44)	65	66	2.965	66	12.017	66	12.83	66	44.449	65	44.662
	(69,10)	78	79	2.845	78	11.184	79	13.02	86	43.466	79	46.174
	(48,49)	82	83	2.220	82	8.493	83	12.835	83	44.03	83	46.135
4- lesmis (77-nodes)[24]	(10 , 75)	3	3	0.537	3	2.481	11	17.151	9	44.815	3	47.417
	(26,70)	2	2	0.673	2	2.026	9	17.597	10	47.516	3	47.749
	(44,55)	4	4	0.345	4	1.28	4	14.75	16	46.197	4	50.122
5- sandi_authors (86-nodes)[25]	(29,76)	5	5	0.664	5	2.396	5	16.565	7	44.869	5	46.886
	(54,84)	5	5	0.58	5	2.162	5	16.868	5	42.837	7	46.637
	(32,2)	3	3	0.121	3	0.392	3	16.184	5	43.158	3	44.816
6- kroa100 (100-nodes)[23]	(8,88)	1827	1828	5.465	1827	22.247	1828	19.973	1828	45.409	1827	46.744
	(21,29)	3473	3474	4.846	3474	15.856	3474	19.204	3474	44.357	3474	47.162
	(99,98)	3759	3760	5.972	3759	23.343	3760	19.366	3769	43.775	3762	47.226
7- ch130 (130-nodes)[23]	(2 , 123)	368	369	12.893	369	57.858	369	49.451	369	72.281	369	72.775
	(65,8)	839	840	11.556	840	49.921	840	39.568	841	69.124	841	71.507
	(96,114)	421	422	11.216	421	45.36	422	39.965	432	69.449	427	72.381
8- Kroa150 (150-nodes)[23]	(1 , 135)	1843	1843	14.863	1843	59.89	1844	44.832	1844	70.46	1843	82.069
	(25,70)	4080	4081	17.64	4081	65.091	4081	45.519	4081	70.738	4081	70.403
	(143,142)	1877	1878	14.951	1877	60.415	1878	45.984	1998	71.509	1922	70.313
9- Kroa200 (200-nodes)[23]	(42 , 176)	2014	2015	38.724	2014	162.8792	2017	112.19	2014	112.862	2026	114.449
	(195,0)	2607	2608	45.776	2607	190.804	2608	114.468	2608	107.541	2614	109.345
	(153,77)	2800	2801	56.458	2801	223.587	2808	115.503	2804	106.818	2801	108.891
10-	(100,27	7	8	19.7	7	69.002	7	114.3	8	109.5	12	114.1

celegansneural (297-nodes)[24]	9)			19				55		46		86
	(0,250)	4	4	13.739	4	39.955	4	105.639	5	107.445	4	111.921
	(260,6)	4	4	4.831	4	17.341	4	102.389	5	105.735	4	110.637

6. Conclusion

The CSA is one of the recently developed algorithms that simulate the crows' behavior in food storage and retrieval. The researchers paid much interest towards the CSA as a result of its very good properties. CSA can be adapted easily to the problem space because the search space on the network type and size. On the other hand, in the population-based algorithms, where the search space is time-consuming and large, CSA is a fast algorithm that presents a higher degree due to the fact that every herd has the ability to provide an independent path. CSA has been run for solving the problem of the shortest path for 10 different-size networks. The results obtained show that this algorithm is efficient in comparison with other approaches (GA, PSO, CHA, and ACO).

References

[1] J. Del Ser, E. Osaba, D. Molina et al., "Bio-inspired computation: where we stand and what's next," Swarm and Evolutionary Computation, Elsevier B.V. All rights reserved, vol. 48, pp. 220–250, 2019.

[2] K. R. Harrison, A. P. Engelbrecht, and B. M. Ombuki-Berman, "Optimal parameter regions and the time-dependence of control parameter values for the particle swarm optimization algorithm," Swarm and Evolutionary Computation, Elsevier B.V. All rights reserved, vol. 41, pp. 20–35, 2018.

[3] G. I. Sayed, A. E. Hassanien, and A. T. Azar, "Feature selection via a novel chaotic crow search algorithm," Neural Computing and Applications, Elsevier B.V. All rights reserved, vol. 31, no. 1, pp. 171–188, 2019.

[4] Omid Bozorg-Haddad; "Advanced Optimization by Nature-Inspired Algorithms"; Springer Nature Singapore Pte Ltd. 2018

[5] A. Askarzadeh, "A novel metaheuristic method for solving constrained engineering optimization problems: crow search algorithm," Computers & Structures, Elsevier B.V. All rights reserved, vol. 169, pp. 1–12, 2016.

[6] C. Qu and Y. Fu, "Crow search algorithm based on neighborhood search of non-inferior solution set," IEEE Access, vol. 7, pp. 52871–52895, 2019.

[7] F. Mohammadi and H. Abdi, "A modified crow search algorithm (MCSA) for solving economic load dispatch problem," Applied Soft Computing, Elsevier B.V. All rights reserved, vol. 71, pp. 51–65, 2018.

[8] S. Shekhawat and A. Saxena, "Development and applications of an intelligent crow search algorithm based on opposition based learning," Isa Transactions, Elsevier B.V. All rights reserved, vol. 99, pp. 210–230, 2020.

[9] D. Medhi and K. Ramasamy, Network routing: algorithms, protocols, and architectures. Morgan Kaufmann 2017, pp.68–73.

[10] R. Baumann, S. Heimlicher, M. Strasser, and A. Weibel, "A survey on routing metrics," TIK Rep., p. 53, 2007

[11] A. Chaudhuri and T. P. Sahu, "Feature selection using Binary Crow Search Algorithm with time varying flight length," Expert Systems with Applications, Elsevier B.V. All rights reserved, vol. 168, 2020.

[12] S. Makhdoomi and A. Askarzadeh, "Optimizing operation of a photovoltaic/diesel generator hybrid energy system with pumped hydro storage by a modified crow search algorithm," Journal of Energy Storage, vol. 27, 2019.

[13] D. Gupta, J. J. P. C. Rodrigues, S. Sundaram, A. Khanna, V. Korotaev, and V. H. C. de Albuquerque, "Usability feature extraction using modified crow search algorithm: a novel approach," Neural Computing & Applications, vol. 32, no. 15, pp. 10915–10925, 2018.

[14] A. Javidi, E. Salajegheh, and J. Salajegheh, "Enhanced crow search algorithm for optimum design of structures," Applied Soft Computing, Elsevier B.V. All rights reserved, vol. 77, pp. 274–289, 2019.

[15] S. Arora, H. Singh, M. Sharma, S. Sharma, and P. Anand, "A new hybrid algorithm based on grey wolf optimization and crow search algorithm for unconstrained function optimization and feature selection," IEEE Access, vol. 7, pp. 26343–26361, 2019

[16] A. M. Anter and M. Ali, "Feature selection strategy based on hybrid crow search optimization algorithm integrated with chaos theory and fuzzy c-means algorithm for medical diagnosis problems," Soft Computing, Springer Nature Switzerland AG. Part of Springer Nature. vol. 24, no. 3, pp. 1565– 1584, 2020.

[17] Zied O. Ahmed, Abbas Akram Khorsheed, "Biometric key generation using crow algorithm", Indonesian Journal of Electrical Engineering and Computer Science Vol. 21, No. 1, January 2021.

[18] M. K. Mehmet Ali and F. Kamoun, "Neural Networks for Shortest Path Computation and Routing in Computer Networks," IEEE Trans. Neural Networks, vol. 4, no. 6, pp. 941–954, 1993.

[19] G. Di Caro, "Ant Colony Optimization and its Application to Adaptive Routing in Telecommunication Networks," University Libre De Bruxelles Faculty Des Sciences Appliques, vol. 41, p. 374, 2004 .

[20] S. J. Sugden, M. Randall, G. Mcmahon, and S. Sugden, "A Simulated Annealing Approach to Communication Network," Artic. J. Comb. Optim., Springer Nature Switzerland AG. Part of Springer Nature vol. 6, no. 1, pp. 55–65, Mar. 2002 .

[21] G. Nagib and W. G. Ali, "Network routing protocol using Genetic Algorithms," Int. J. Electr. Comput. Sci. IJECS-IJENS, vol. 10, no. 02, pp. 40–44, 2010 .

[22] C. W. Ahn and R. S. Ramakrishna, "A genetic algorithm for shortest path routing problem and the sizing of populations," IEEE Trans. Evol. Comput., vol. 6, no. 6, pp. 566–579, 2002 .

[23] D. Casali, G. Costantini, and M. Carota, "A tabu search based routing optimization algorithm for packet switching networks," Proc. 11th Conf. Proc. 11th WSEAS Int. Conf. Circuits, pp. 180–184, 2007.

[24] Ahad Khaleghi Ardabili, Zied Othman Ahmed, Ali Layth Abbood, "Solving The Routing Problem Using The Improved Camel Herds Algorithm", International Journal on Perceptive and Cognitive Computing (IJPCC) Vol 6, Issue 2, 2020.

[25] Shahbaa I. Khaleel, "Image Compression Using Swarm Intelligence", International Journal of Intelligent Engineering and Systems, Vol.14, No.1, 2021

[26] Abdelazim G. Hussien, Mohamed Amin, Mingjing Wang, Guoxi Liang, Ahmed Alsanad, Abdu Gumaei, And Huiling Chen, "Crow Search Algorithm: Theory, Recent Advances, and Applications", IEEE Explorer, October 1, 2020.