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Using the Cuckoo Algorithm to Optimizing the Response Time and Energy Consumption Cost of Fog Nodes by Considering Collaboration in the Fog Layer

Shakoor Vakilian
Department of Electrical and Computer Engineering
Isfahan University of Technology, Isfahan, Iran
Email: s.vakilian@ec.iut.ac.ir

Seyed Vahid Moravvej
Department of Electrical and Computer Engineering
Isfahan University of Technology, Isfahan, Iran
Email: vahid.moravvej@gmail.com

Ali Fanian
Department of Electrical and Computer Engineering
Isfahan University of Technology, Isfahan, Iran
Email: a.fanian@iut.ac.ir

Abstract—**With the growth of the Internet of Things (IoT) technology, Fog computing has moved the processing capability of generated data near IoT devices and objects. Therefore, fog nodes able to reduce the response time to high volumes of generated data. As fog nodes extend from the edge of the network to the cloud, their cooperation in workload processing can lighten processing queues and further reduce response time. On the other hand, by increasing processing data in fog nodes, the fog layer's energy consumption cost is increased. Therefore, to investigate this issue, in this paper, an optimization problem for collaboration between fog nodes is presented to reduce the response time and energy consumption cost. In this work, the goal is to make a balance between these two parameters. Then, the proposed problem is solved using the Cuckoo evolutionary algorithm. The evaluation results show that the proposed solution in solving the problem has been able to have significant impacts in reducing response time and energy consumption cost compared to competing works.**

Keywords: Fog Computing; Optimization; Cuckoo Evolutionary Algorithm; Collaboration in Fog Layer.

I. INTRODUCTION

Today, with the growth and expansion of Internet of Things (IoT) technology, the data generated in IoT devices like sensors, actuators are increasing [1]. Growing the produced data requires a powerful platform for processing. Therefore, cloud infrastructure with powerful servers is one option for processing enormous volumes of generated data [2]. The number of IoT devices is predicted to reach more than 75 billion by 2025 [3]. As the number of IoT devices increases, the cloud as an infrastructure can't meet this huge generated data volume. The distance between the cloud and IoT devices and the limitation of communication links are other problems. Therefore, time-sensitive applications can't use the cloud as a powerful processing resource because of time limitations for processing data [4, 5]. Thus, edge computing was proposed by processing generated data at the edges of the network [6]. However, due to the high volume of produced data and the making long queue in edge devices, new mechanisms to investigate these issues is necessary. Therefore, fog computing was proposed by Bonomi to address these issues in [7]. In fog computing, processing nodes expand from the edge of the network to the cloud and have the useful ability to process high volumes of processing workloads quickly.

In this paper, the collaboration among fog nodes to reducing response time and energy costs considering fairness between fog nodes has been proposed. This collaboration is investigated to decide how much workload is processing in the fog layer without the cloud. Therefore, the fog nodes must decide what percentage of the arrival workload they should process locally and what percentage they should send to other fog nodes for processing. Therefore, the average response time and energy consumption cost are modeled in the beginning, and then an optimization problem is introduced. In the following, The proposed problem should be able to make a balance between both response time and energy consumption cost. Finally, the proposed problem is solved using the cuckoo evolutionary algorithm.

The organization of this paper is adjusted as follows. In the second section, the related work in collaboration between the fog nodes is introduced. In the third section, the modeling of goals considering the fog layer's fairness is presented, and an optimization problem is proposed. Then, the proposed problem is solved using the cuckoo evolutionary algorithm. In the fourth section, the performance evaluation by comparison with competing works is presented. Finally, in the last section, a conclusion from the paper is given.

II. RELATED WORK

In the scope of collaboration between fog nodes, some works like [8-12] have been done. In all of this, minimizing response time is considered a key goal. Further, energy also plays an important role in most of these works. In the following, more details of the related work, the objective function and constraints, and solving methods are investigated.

In [13], fog computing has been used in the Internet of Things to reduce service time and the renting cloud resources cost. In the continuation of this work in [14], the reduction of applications lost was also added along with service time and the cloud renting resources cost. In these works, an online algorithm named Unit-Slot was proposed in order to decide on offloading the arrival workload considering only one fog node.

In [15], the influence of energy consumption and renewable energy capability in the Internet of Things has been used in fog computing. In [16], fog computing has been considered to reduce energy consumption in mobile devices. For this purpose, In this paper, a multi-objective problem to minimize time, the average cost of devices in cloud and fog node, and energy consumption in devices with only one fog node are presented. In [17], the offloading workload by the combined computations between cloud and fog is introduced considering the limitation for time. In this work, the necessity of a balance between energy and time is discussed. Therefore, a combined computational offloading problem is presented with the aim of offloading the workload to cloud and fog servers. In none of them, the collaboration between fog nodes to reducing response time is not considered.

In [8, 9], Yang Xiao and Marwan Krunz addressed the subject of offloading workload in the network with the aim of cooperating in the fog layer and cloud to improve the experimental quality of service for users. In this paper, a subset of fog nodes can send a portion or all of their workload to other fog nodes and cloud. In this paper, improving the experimental quality of service as average response time means that the amount of processing workload in the fog layer is increased. They conclude that reducing the average response time can increase the energy and data processing in the fog layer. But in this work, reducing energy consumption has not been studied as an effective constraint or objective function. Moreover, in [11], an analytical study in workload offloading among fog nodes without considering energy consumption was presented. In[10], the collaboration among fog nodes regarding the response time and energy consumption without the cloud is studied. In this paper, a convex optimization problem is introduced and solved using the Lagrangian method as a mathematical method. In [12], a convex optimization problem is presented in order to minimize the response time and cost of energy consumption and is evaluated using SCS as a convex solver tool without providing an algorithm to solve it.

In the reviewed papers, the problems in the two groups of workload offloading with considering only one fog node and also collaboration in the fog layer in order to offload the workload to the cloud have been investigated using mathematical methods. As it is clear, the collaboration among fog nodes can further reduce response time. But in these works, the cuckoo evolutionary algorithm has not been used as a practical method for solving multi-objective optimization problems. In the next section, in the first step, the system model is offered; later, an optimization problem is formulated, and the cuckoo evolutionary algorithm is used to solve this problem.

III. INTRODUCING THE SYSTEM MODEL, PROBLEM FORMULATION, AND USING THE CUCKOO EVOLUTIONARY ALGORITHM

In this paper, the proposed system model is introduced based on the average response time and energy consumption cost. In the following, the problem formulation is presented as a single-objective problem and then solved by a cuckoo evolutionary algorithm [18].

A. *System model*

As discussed in the previous sections, the average response time and the energy consumption cost are two very important goals in the fog layer. The tendency is to use the collaboration among the fog nodes to reduce the average response time and energy consumption cost in the fog layer. This collaboration can lead to the use of idle fog node resources and thus reduce processing time. Therefore, in a decision process, fog nodes must be able to calculate the amount of processing workload locally as well as send the remaining workload to other fog nodes. Therefore, it is assumed that N nodes collaborate with each other as $F = \{1, \dots, N\}$Error! Bookmark not defined.. For the decision process, the fog nodes send their arrival workload and service rate to a central coordinator to decide how much workload each node will process. We consider the amount of arrival workload for each fog node i as λ_i and also ϕ_{ij} as the percentage of arrival workload that must be sent from fog node i to j. We consider that the amount of transferring workload from fog node i to other nodes is less than or equal to the amount of arrival workload in fog node i. Therefore, we have

$$\sum_{j\epsilon F} \phi_{ij} \leq 1, \qquad \forall i \in F \tag{1}$$

In this work, it is assumed that a percentage of the workload that can't be processed in the fog layer is sent to the cloud for processing. In the following, the modeling of the average response time and the energy consumption cost are presented by considering the fairness factor.

B. *Average response time and energy consumption*

In the collaboration between fog nodes for workload processing, the average response time is divided into two segments. The first segment is about the workload, which should be processed locally in the fog node i, so in this segment, we only have the average processing time. The second segment of the average response time is about the workload that must be processed in the other fog nodes except fog node i. Therefore, in this segment, the average response time will include the round trip time between fog node i and the other fog nodes, as well as the processing time in node destination fog node. In each fog node, we assumed to have the $M / M / 1$ queue model. by considering the service rate μ_i for each node i ($i \in F$), the average response time can be calculated as follows:

$$T_i = Fair_{ii} \times \phi_{ii} \times \left(\frac{1}{\mu_i - \phi_{ii}\lambda_i}\right) + \sum_{j\in\delta_i} Fair_{ij} \times \phi_{ij} \times \left(\frac{1}{\varphi_{ij}\lambda_i} + T_{ij}^{rtt} + \frac{1}{\mu_j - \sum_{k\in F}\phi_{kj}\lambda_k}\right), \tag{2}$$

In this relation, $Fair_{ii}$ and $Fair_{ij}$ are the fairness coefficients considered for workload processing locally and also the workload processing coefficient for other fog nodes, respectively. If $Fair_{ii}$ is equal to the amount of fog node i resources divided by the total resources in the fog layer, we can be considered $Fair_{ij} = 1 - Fair_{ii}$. The higher value for the $Fair_{ii}$ coefficient means that the lower the workload processing at fog node i. Also, in this relation, the set δ_i refers to all fog nodes except fog node i. Also, considering that the amount of workload sent to node i is less than the service rate of that node, this condition will be considered as a condition of queue stability as follows:

$$\sum_{j\in F} \varphi_{ji}\lambda_j + \varepsilon_i \le \mu_i \quad (3)$$

In this relation, ε_i is considered in order to prevent saturation of the workload on the fog node i. By considering p_i as the energy consumption cost per unit time, the energy consumption cost can be determined as follows:

$$E_i = Fair_{ii} \times \phi_{ii} \times p_i \times \left(\frac{1}{\mu_i - \phi_{ii}\lambda_i}\right) + \sum_{j\in \delta_i} Fair_{ij} \times \phi_{ij} \times \left(\frac{1}{\varphi_{ij}\lambda_i} \times p_i + T_{ij}^{rtt} \times p_i + \frac{1}{\mu_j - \sum_{k\in F}\phi_{kj}\lambda_k} \times p_j\right), \quad (4)$$

C. Problem Formulation

Collaboration among fog nodes can reduce the average response time. Simultaneously, this collaboration can lead to increased workload processing in the fog layer and so increased the energy consumption cost. In this work, the purpose of the collaboration is to minimize the average response time and energy consumption cost. Then, according to the modeling done for the response time and energy consumption cost, using the coefficient w, which is a positive value, the problem of minimizing the average response time and energy consumption cost can be written as follows:

$$Problem\ 1\!: \min_{\Phi} cost = \left(\sum_{i\in F} w \times T_i + E_i\right) \quad (5)$$

$Subject\ to$:

$$\sum_{j\in F} \phi_{ij} \le 1, i \in F \quad (6)$$

$$\sum_{j\in F} \varphi_{ji}\lambda_j + \varepsilon_i \le \mu_i, i \in F, \lambda_j \ge 0, \mu_i \ge 0 \quad (7)$$

$$0 \le \varphi_{ij} \le 1, i, j \in F \quad (8)$$

$$p_i \ge 0, i \in F \quad (9)$$

$$0 \le Fair_{ii} \le 1, 0 \le Fair_{ij} \le 1, i, j \in F \quad (10)$$

In problem 1, constraint 6 guarantees that the percentage of arrival workload that remains in the fog layer for processing from fog node i will be less than the amount of workload arriving the fog node i, and the remaining workload can be sent to the cloud for processing. Constraint 7 indicates that the amount of workload that enters a fog node for processing will be less than the service rate of that node. Based on constraint 8, variables in the problem will have a value between 0 and 1. Also, constraint 9 shows that the unit cost of energy per time will be a positive value. According to constraint 10, the coefficients of fairness have a value between 0 and 1.

D. using the cuckoo evolutionary algorithm to solve the proposed problem

In this work, to find the optimal value of the average response time and energy consumption cost, the cuckoo evolution algorithm in [18] is used. Cuckoo Algorithm is a heuristic and population-based algorithm. This algorithm is inspired by the cuckoo spawning process. In problem 1, the variable for optimization is $\varphi = <\phi_{ij}>$ $for\ i, j\epsilon F$. This variable consists of an $N \times N$ matrix known in the proposed algorithm as a cuckoo. Therefore, the cuckoo means the matrix φ. For simplicity, the $N \times N$ matrix is considered as a row representation ($1 \times N^2$), which actually shows the habitat of the cuckoo (N^2). In this algorithm, in the first step, n initial populations of cuckoos are made by considering constraints 6 and 8 as the initial solution of the problem. Then for each answer i in n, a new solution j is created randomly using Levy flight. Next, the quality of the answer j is compared with i and replaced if it is better. Levy flight is a special type of random trajectory that the length of the steps in it follows the distribution of levy. Then the elements of each solution change with a probability of pa equal to 25 percent, and if its quality improves, it is replaced, and these steps are repeated until the optimal solution is reached. It should be noted that in all iterations, the population remains constant, and only better solutions are substituted. The cuckoo algorithm works better than other random algorithms by generating random steps with the help of Levy flight. Another feature of this algorithm is its elitism. The nature of elitism is that the worst answer replaces the best answer. Algorithm 1 shows the pseudo-code of the proposed cuckoo algorithm to solve problem 1.

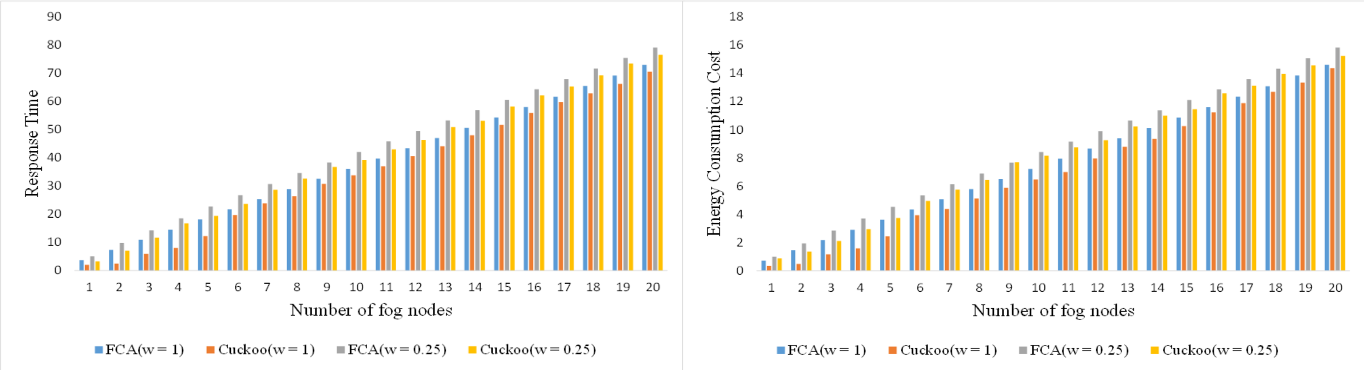
Algorithm 1: Solution of Problem 1 with the Cockoo evolutionary algorithm

Initialization: Create an initial population of n-sized cuckoos called Nests and fill them with random values considering conditions 6 and 7, along with an array for the n-length objective function called fitness.

```
Calculate the objective function for the initial population,
according to (10), and put it in fitness[1]
For( i = 1, i ≤ Max_iteration, i++)
    For(j = 1, j ≤ n, j++)
        Create a new solution φ_new based on Levy flight and
        conditions 6 and 7 and calculate its objective function,
        and put it in cost_new
        if cost_new < fitness[j]
            Nests[j]= φ_new and fitness[j]= cost_new
    For(j = 1, j ≤ n, j++)
        With a probability of pa = 25%, change the Nets data
        [j] randomly with a random value between 0 and 1
        and name it φ_new and put its objective function to
        cost_new
        if cost_new < fitness[j]
            Nests[j]= φ_new and fitness[j]= cost_new
Sort fitness and choose the best solution from Nests
```

IV. Evaluation

In this work, the efficiency of the proposed cuckoo algorithm to solve problem 1 is considered. For this purpose, the proposed algorithm is first compared with competing work based on the total response time and the energy consumption cost by raising the number of fog nodes. In the next step, the percentage of the other fog nodes' workload is investigated by raising the fairness factor for fog nodes. Then, with the increasing workload in the special fog node, the response time and energy cost in that node are evaluated.



(a) (b)

Fig. 1. (a) Response time (b) Energy consumption cost with rising the number of fog nodes with the several coefficients for the proposed method compare to FCA algorithm.

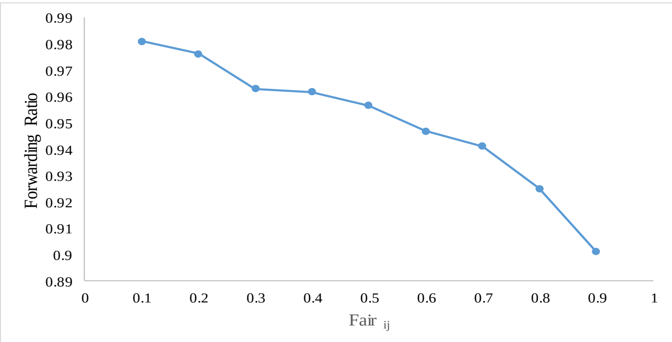


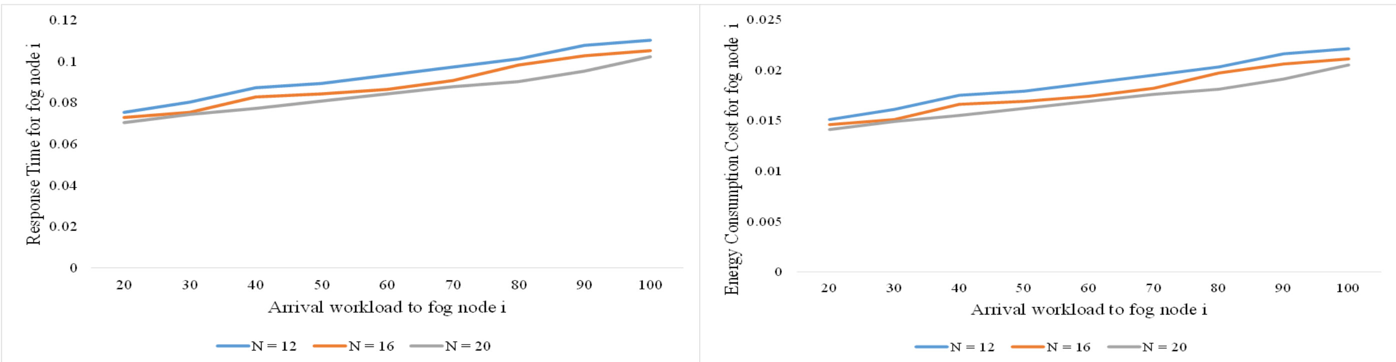
Fig. 2. The forwarding ratio for one fog node by different fairness $Fair_{ij}$ with the Cuckoo algorithm via 12 fog node collaboration

First, to compare the proposed cuckoo algorithm in solving the collaboration problem among fog nodes, we consider the arrival rate of all fog nodes equal to 40 Mb/s. We also assume that the service rate of all fog nodes is 30 Mb/s. In this work, the round trip time between fog nodes is constant and equal to 20 ms. As shown in Fig. 1(a), considering $w = 1$ and $w = 0.25$, the average response time in the proposed work for the number of fog nodes from one to 20 fog nodes is less than the FCA for both cases. Also, the energy consumption cost, according to Fig. 1(b) for fog nodes from one to 20 in both cases $w = 1$ and $w = 0.25$, is less than FCA [10]. As can be seen in both figures, if $w = 1$ is considered, the average response time is less than $w = 0.25$, and on the other hand, the cost of energy consumption will be higher. Therefore, it can be concluded that increasing the value of w can lead to a further decrease in the average response time.

Fig. 2 shows the percent of workload send from fog node i to other nodes for Cuckoo algorithm with 12 fog nodes collaboration. As shown in this figure, increasing the amount of $Fair_{ij}$ can be expected to reduce the amount of workload transferred to other fog nodes. Therefore, increasing $Fair_{ij}$ will mean that in optimization, the importance of the local

workload processing will be less on the fog node i, so more workload can be expected to be sent to the other nodes.

Now we consider the arrival workload for all fog nodes equal to 20. We now investigated what changes will occur between the average response time and the energy consumption cost as the workload increases in a fog node. For this purpose, we assume that we increase the arrival workload of fog node i from 20 Mb/s to 100 Mb/s. As shown in Fig. 3(a), the average response time will increase by considering 12, 16, and 20 nodes, but with increasing the number of nodes, the amount The average response time will be reduced on fog node i. The same result can also be seen in Fig. 3(b) about the energy cost in fog node i.



(a) (b)

Fig. 3. (a) Response Time (b) Energy Consumption Cost for fog node i with increasing arrival workload to fog node i

V. Conclusion

In this paper, the fog layer's collaboration is investigated to reduce response time and energy consumption cost. As the workload increases in the fog node, the response time rises due to increased queue length. Therefore, other fog nodes with a low processing workload can significantly reduce the queue length and response time. On the other hand, increasing the processing workload in the fog layer can raise energy consumption costs. For this purpose, an optimization problem to balance between the two introduced objective functions is presented. Next, the proposed problem is solved using the cuckoo evolutionary algorithm. The evaluation results show that the proposed method, compared to competing works, can significantly decrease response time and energy consumption cost.

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