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Simulation Analysis and Comparative Study of MOSGT with Other Techniques

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Abstract: - This paper presents a comparative study of the Multi-Objective Symmetric Game Theory (MOSGT) for task offloading in cloud robots with existing techniques such as Genetic Algorithm 4 Collaborative Computation Offloading (GA4CCO) and Approximation Collaborative Computation Offloading (ACCO). The study employs a simulation analysis to evaluate the performance of the proposed MOSGT model in a cloud robotics context. The results of the simulation study reveal that the MOSGT model reduces system cost by approximately 35% compared to GA4CCO and by 20% compared to ACCO. Furthermore, the MOSGT model exhibits a reduced rate of 30% less than GA4CCO and 25% minimal than ACCO in terms of iteration. These findings underscore the potential of MOSGT as a promising solution for efficient task offloading in cloud robots, offering significant improvements in computational complexity and service quality in edge computing.

KeyWords: Simulation Analysis, Task Execution Iteration Time, Comparative Study, Genetic Algorithm, Collaborative Computation, offloading (GA4CCO), Approximation Collaborative Computation Offloading (ACCO).

I. INTRODUCTION

In the era of edge computing, efficient utilization of resources with reduced energy consumption is considered crucial for minimizing task execution time. However, the challenge of offloading tasks and sub-tasks in cloud robots remains significant. This paper introduces a novel solution, the Multi-Objective Symmetric Game Theory (MOSGT), designed to address this issue. By converting offloading into a game-type scenario and performing computations for task offloading, MOSGT reduces the load on the central cloud with multi-objective optimization. This approach notably reduces system cost and iteration, thereby lowering the computational complexity of Cloud Robots.

Simulation analysis of the proposed MOSGT exhibits reduced system cost and iteration, which reduces the computational complexity of Cloud Robots. The performance of the proposed MOSGT is comparatively examined with existing techniques such as Genetic Algorithm 4 Collaborative Computation Offloading (GA4CCO) and Approximation Collaborative Computation Offloading (ACCO). The proposed MOSGT system cost is improved by approximately 35% of GA4CCO and 20% for ACCO. In iteration analysis, MOSGT exhibits a reduced rate of 30% less than GA4CCO and 25% minimal than ACCO. The reduced system cost and iteration reduce the computational complexity of Cloud Robots with improved service quality in edge computing.

II. RELATED WORK

Based on the information provided, here is a suggested structure for the "Related Works" section for Part 2 of your paper. In the realm of multi-robot systems and cloud services, several studies have been conducted to address the challenges of task offloading.

Dai et al. [9], for example, evaluated the multi-user robotics system and various offloading techniques. Their analysis showed that the allocation of offloading data resource within sub-channel energy consumption was reduced. Similarly, Chen et al. [10] developed a Lagrange multiplier method-based offloading strategy for reducing energy consumption. The proposed strategy optimized the offloaded data and allocated resources, resulting in effective computation of tasks on intensive deployment servers. In another study, Kattepur et al. [11] presented an offloading framework with a two-tier computation process. The proposed two-tier scheme aimed to resolve issues in load balance with multiple servers and reduced energy consumption. The two-tier scheme involved an optimization process in user association, allocation of resources, offloading task computation, and power allocation. Guo et al. [12] proposed an algorithm for real-time task assessment in a centralized cloud and

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edge cloud. The proposed scheme, known as the Genetic Algorithm 4 collaborative computation offloading algorithm (GA4CCO), aimed to reduce total task processing time.

Li et al. [13] developed a hybrid-fiber wireless structure for resolving coordinate offloading. The proposed scheme was based on an optimization strategy with reduced total energy consumption. The developed scheme was based on the integration of an approximation collaborative computation offloading (ACCO) scheme and a distributed computation offloading algorithm (DCOA). In recent years, several researchers focused on the development of game theory for computation offloading in the cloud. Anton et al. [14] discussed multi-robot offloading problems in a multi-wireless environment. The proposed scheme incorporated an offloading strategy with a distributed computational offloading process. Liu et al. [15] developed a game model for communication between users and edge cloud. The proposed scheme used an efficient optimization scheme with an efficient strategy. The proposed scheme significantly reduced the cost and pricing of the communication system. Kim et al. [16] proposed an edge computing model with the integration of Stackberg game theory for data transmission between edge cloud and mobile users. The proposed scheme significantly improved task calculation, energy efficiency, and reasonable energy utilization.

Xu et al. [17] developed a Stackberg equilibrium for resource storage and bandwidth allocation in edge cloud. The proposed scheme did not focus on the offloading decision strategy and utility function of the network.

Aujla et al. [18] evaluated the Stackelberg game model with consideration of multiple dominant and followers for job scheduling and offloading. The analysis stated that the deployed model improved the performance of the network with reduced energy consumption and delay. These studies provide valuable insights into the challenges and solutions of task offloading in multi-robot systems and cloud services. However, they primarily focus on general concepts and do not specifically consider the use of symmetric game theory in task offloading. Our proposed Multi-Objective Symmetric Game Theory (MOSGT) addresses this gap by transforming task offloading into a game-like situation and performing computations for task offloading. This approach offers a novel perspective on task offloading in cloud computing, potentially leading to more efficient management of tasks in cloud robots.

I. PROPOSED MOSGT FOR TASK OFFLOADING

To improve task scheduling with minimal utilization of energy in edge computing this research proposed a multi-objective symmetric game theory (MOSGT). The proposed MOSGT is involved in the formulation of a multi-objective problem base on the cloud robot workload and converts those tasks into a game. Based on the estimation of game tasks are offloaded from the cloud robot. In figure 1 overview of task offloading is presented.
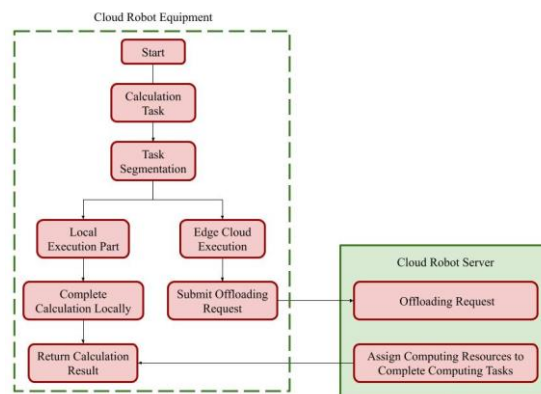

Figure 1: Cloud Robot task offloading process

Regarding figure 1 proposed MOSGT perform the calculation of task and segment those task as local execution and edge cloud execution. The overall process of task allocation with proposed MOSGT is illustrated in figure 2.
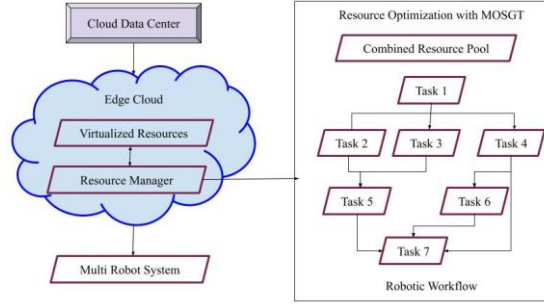
Figure 2: Task allocation in Robot Cloud

3.1 Multi-objective optimization problem formulation

In the proposed MOSGT, the first phase is about the allocation of optimal resources to workflow in robotics for multi-objective problem formulation. The network is involved in characteristics such as constraints of sensitivity, the requirement of resources, and latency. Based on this, the multi-objective problem in the Cloud robot is formulated for task completion, resource energy consumption, and total cost execution. In edge Cloud robot for completing a particular task total time is defined as s_i^k, with time $t \in T$ over the resources $r \in R$. The implemented processing speed is defined as β_i for allocated resources and each task is represented as η_k, which is shown in equation (1)

$$s_i^k = \frac{\eta_k}{\beta_i} \qquad (1)$$

Similarly, for execution of task $t \in T$ and resources $r \in R$ are considered for calculating energy consumption level b_i^k. For the resources calculated energy consumption for per unit is denoted as $\hat{b}_i$ with required time s_i^k for task execution. Energy constraints is calculated using equation (2)

$$b_i^k = \hat{b}_i \times s_i^k \qquad (2)$$

Similarly, for calculating monetary cost g_i^k for task execution $t \in T$ with resources $r \in R$, cost g_i^k is calculated. $\hat{g}_i$ defines the unit cost per time for allotted resources and time. The s_i^k represents total task execution time as defined in equation (3)

$$g_i^k = \hat{g}_i \times s_i^k \qquad (3)$$

$$\min(S(I,K), B(I,K), G(I,K)) \qquad (4)$$

Where,

$$S(I,K) = \sum_{i \in I, k \in K} x_{ik} \times s_i^k$$

$$B(I,K) = \sum_{i \in I, k \in K} x_{ik} \times b_i^k$$

$$G(I, K) = \sum_{i \in I, k \in K} x_{ik} \times g_i^k$$

From equation (1) - (3) proposed multi-objective optimization problem formulation is presented for Edge Cloud. In equation (4) represents the overall multi-objective computational framework for proposed MOSGT is stated. In the available resource environment set of tasks T in Cloud robotics are computed minimal representation of total makespan as $S(I, K)$, $B(I, K)$ denotes total consumption of energy and $G(I, K)$ represents total cost.

3.2 Multi-objective Symmetric Game theory for Computing

Based on the constructed multi-objective scenario derived in equation (4) computational intensive tasks are computed with the game theory model. This paper adopts the symmetric game theory model, which based on the strategy adopted by one player other player defense strategy will be modified. Consider N= {1, 2, 3, ..., n} users in cloud robot and each robot performed in intensive task computation. The set of tasks is divided into subtasks defined as M = {1, 2, 3, ..., m} for unloading each task. In industrial robots, the tasks that need to be performed are categorized into sub-tasks such as pre-processing of sounds, extraction, and classification of features, loading acoustic model, decoding of the speech signal, and searching. Based on constraints, MOSGT does not allow the execution of subtasks before the completion of the predecessor subtask. In figure 3 task execution process in the industrial robot system is illustrated.
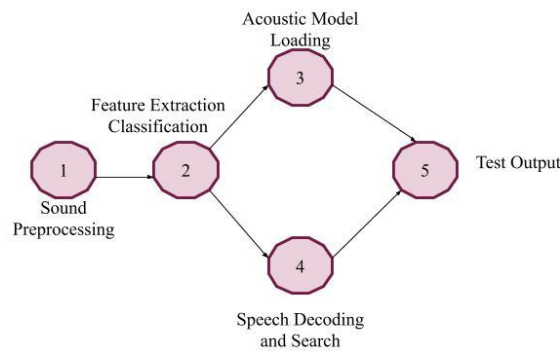

Figure 3: Subtask in Cloud Robot

Cloud robot communication is based on edge computing cloud technology with consideration of communication method energy consumption and task completion time, Based on the computation of those parameters communication model is derived in the cloud based on local computing and edge computing. In figure 4 constructed MOSGT communication model is presented.
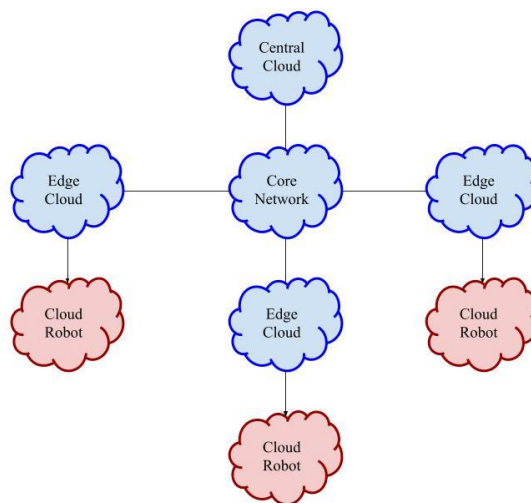

Figure 4: MOSGT Cloud Robot Architecture

The figure 4 provides the interaction of cloud robot for edge cloud computer through wireless communication. To calculate the game theory of edge computing consider I = {1, 2, ..., i}, this provides number of servers in edge cloud, where cloud offloading is stated as $a_{m,n} = i$ with offloading n and task is defined as $a_{m,n} = 0$ for task execution in m devices with local execution. The task decision set is denoted in matrix form A stated in equation (5).

$$A = \begin{bmatrix} a_{11} & a_{12}......... & a_{1n} \\ a_{21} & a_{22}......... & a_{2n} \\ a_{m1} & a_{m2}......... & a_{mn} \end{bmatrix} \tag{5}$$

According to Shannon's computation law, data transmission rate of cloud robot user n offloading is defines by equation (6) as follows:

$$S_k^i(B) = w \log_2 \left(1 + \frac{a_k^i Los_k^i}{\omega + \sum_{k=1}^{k} a_k^i Los_k^i} \right) \tag{6}$$

a_k^i - transmission power for offloading task n in edge cloud.

Los_k^i - channel gain with consideration of interference

w - Channel Bandwidth

ω - gaussian level included in channel

3.2.1 Local computing model

As $N, C_{i,k}, S_{i,k}, B_{i,k}^{local}, B_{i,k}^c, W$ stated, proposed MOSGT involved in task computing for local and edge. For locally executed task cloud robot calculate consumed energy and task completion time. Here, B data amount are represented as B with sub-task offloading of cloud m and robot n. To perform sub-task completion $C_{i,k}$ estimate the number of CPU cycles. The local computing model in cloud is stated in equation (7) as follows:

$$B_{i,k}^{loc} = VC_{i,k} \tag{7}$$

Where, the energy consumed with each CPU cycle is defined a V, involved in linear proportional process.

3.2.2 Edge Computing Model

In cloud edge server cloud robot tasks are executed for data transmission between the cloud. To complete particular task time for data transmission involved in server computing, edge cloud, and waiting time. Based on this, MOSGT involved in the offloading of edge computing. The edge computing process involved in task offloading stated as follows:

The data transmission process in cloud robot for consumption of energy is stated in equation (8)

$$B_{i,k}^c = p_{i,k}^j \times \frac{B_{i,k}}{S_i^k} \tag{8}$$

The time taken for data transmission is stated in equation (9)

$$T_{i,k}^{tra} = \frac{B_{i,k}}{S_i^k}$$
(9)

In equation (10), task execution time for edge server is defined as follows:

$$T_{i,k}^c = \frac{g_{i,k}}{s_i^k}$$
(10)

Time involved in cloud task offloading is computed using equation (11) as follows:

$$CT_{i,k}^c = T_{i,k}^{tra} + T_{i,k}^c$$
(11)

In subsequent cloud environment wait time for sub-tasks are defined in equation (12) as follows:

$$WT_{i,k}^c = \max\left\{ T_{i,k}^{tra}, \max_{k \in reap(m)} CT_{i,k}^c \right\}$$
(12)

Here,

$$CT_{i,k}^c = T_{i,k}^{tra} + WT_{i,k}^c$$

The proposed MOSGT model for offloading edge cloud is stated in equation (13) as follows:

$$C_{i,k}^c = \eta^e B_{i,k}^c + \beta^t CT_{i,k}^c$$
(13)

This paper involved in task offloading scenario with consideration of energy consumption and task completion in Cloud Robot execution in local machine. The proposed MOSGT model weighted factor energy consumption and time for completion is denoted as CG. The computed MOSGT offloading is defined in equation (14) as follows:

$$CG = \begin{bmatrix} a_{11} & a_{12}......... & a_{1n} \\ a_{21} & a_{22}......... & a_{2n} \\ a_{m1} & a_{m2}......... & a_{mn} \end{bmatrix}$$
(14)

The game strategy for players are defined in decision set. Hence, the cost function is computed using equation (15) as follows:

$$C_n = \eta^e \sum_{m=1}^{m} B_{i,k} + \beta^t \sum_{m=1}^{m} T_{i,k}$$
(15)

Where, $0 \le \eta^b \le 1, 0 \le \eta^t \le \eta^b + \eta^t = 1$

To evaluate the cloud robot user requirement users select different weighting factor. In which, η^b is higher in cloud robot for low battery level, while η^t involved in reduction of delay. To perform reduced offloading strategy objective function evolved is estimated using equation (16) as follows:

$$CG_n(a_n) = \min\left\{ C_n^{loc}, C_n^c \right\}$$
(16)

Based on the computed equation (16) offloading in Cloud Robot is estimated. The algorithm for proposed MOSGT is presented as follows:

Algorithm 1: Proposed MOSGT for task Off-loading
Input: $N, B_{i,k}, S_{i,k}, B_k^{loc}, B_{i,k}^c, W$
Output: $C_{i,k}^c, C_n$
Initialization: Initiate Cloud Robot locally where, $a_{m,n} = 0$

For
  Each iteration t do;
{
  For each cloud robot k, $k \in K$
{
  Compute each state offloading factor based on local and edge computing
      Estimate the cost of each cloud robot using equation (15)
      Select minimal cost path from equation (16)
}
      Update the estimated set to Cloud Server
{
   Check for opportunity of each cloud robot to perform particular task
   Compare the cloud robot with higher cost and update the policy in equation (16)
}
   Else
     Break;
}
  Update the set of S_i^k

III.   SIMULATION RESULTS

The simulation of proposed MOSGT is implemented in the OpenStack Cloud platform for edge cloud. The analysis uses Virtual machine 2 with a memory of 12 GB with an operating frequency of 5GHz. The analysis is based on location distributed are of 100 meters with a randomly selected frequency of {0.5, 0.7, 1.0} GHz. In table 1 presented simulation parameters to evaluate proposed MOSGT.

Table 1: Simulation Setting

Parameters	Values
Size of Population	100
Iteration Count	500
Rate of Mutation	0.5
Rate of Crossover	0.5
Number of Overflow task	50
Number of computing resources	45
Processing Speed of virtual resources	20,0000MIPS
Processing Speed of local resources	10,000MIPS
Virtual Resource energy consumption	100W
Local Resource energy consumption	60W
Size of Task	8000MI

In table 2 system costs for varying numbers of Cloud Robots are presented with a comparison of existing techniques such as GA4CCO and ACCO. In figure 5 comparative illustration of the system, cost is presented.

Table 2: Comparison of System Cost

Number of Cloud Robots	GA4CCO (cent)	ACCO (cent)	Proposed MOSGT (cent)

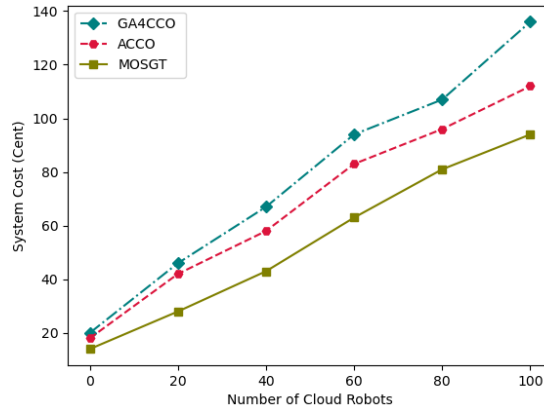| 0	20	18	14
20	46	42	28
40	67	58	43
60	94	83	63
80	107	96	81
100	136	112	94

Figure 5: Comparison of System Cost

The experimental analysis of the proposed MOSGT tested with a channel bandwidth of W = 5MHz, internal Gaussian Noise ω = -100dBm, and transmission power of Pn = 100mW. The simulation is evaluated with the computation of the offloading strategy of cloud robot with a data size of 1MB and 5MB. The system task computation of proposed MOSGT with existing technique GA4CCO and ACCO. The simulation results stated that GA4CCO consumes a higher system cost than ACCO. The system cost is measured in cents for the identification of variation. However, the proposed MOSGT reduces the system cost by approximately 35% of GA4CCO and 20% for ACCO. In table 3 comparative analysis of task execution iteration time with existing GA4CCO and ACCO with MOSGT is presented.

Table 3: Comparison of Cloud Robot task execution iteration time

Number of Cloud Robots	GA4CCO (times)	ACCO (times)	Proposed MOSGT (times)
0	0	0	0
20	54	48	29
40	97	92	76
60	146	137	97
80	208	198	123
100	317	256	175

The analysis of proposed MOSGT with existing GA4CCO and ACCO are examined. In figure 6 graphical representation of proposed MOSGT with existing technique iteration count are stated.
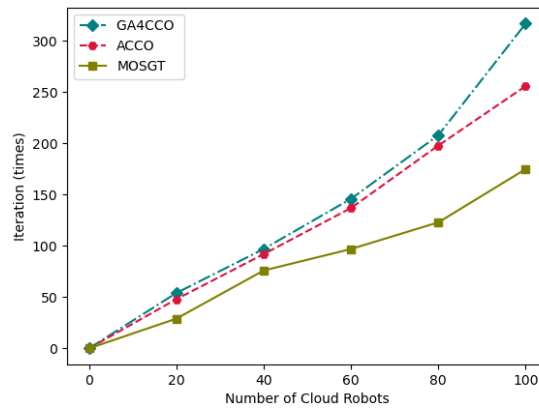
Figure 6: Comparison of Iteration

The simulation analysis expressed that the proposed MOSGT exhibits minimal iteration count rather than existing GA4CCO and ACCO technique. The proposed MOSGT uses a game theory model with multi-objective optimization which significantly converts the resources optimal values and increases the computation process in MOSGT. This provides minimal iteration count for proposed MOSGT which is approximately 30% less than GA4CCO and 25% minimal than ACCO. In table 4 proposed MOSGT offloading strategy for various distances is provided. The simulation coverage range is set as 100 meters based on those optimal value is tabulated.

Table 4: Comparison of Cloud Robot Offloading for proposed MOSGT

Number of Cloud Robots	50m	60m	70m
0	25	21	16
20	32	29	22
40	48	37	33
60	57	44	42
80	68	59	51
100	80	72	67

The simulation analysis of proposed MOSGT with varying distances of 50m, 60m, and 70 m is represented in figure 7. Based on the number of Cloud Robots performance of the proposed MOSGT is examined.
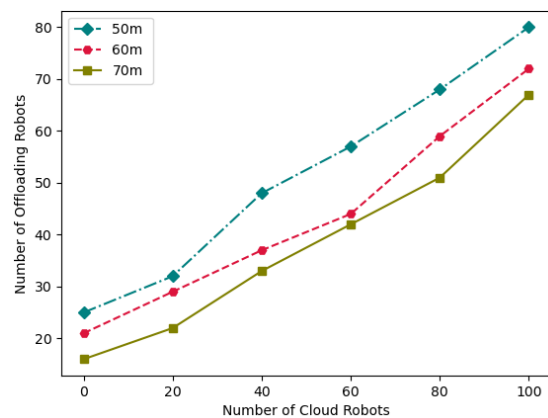

Figure 7: Offloading in Cloud Robot

The analysis of the offloading strategy in Cloud Robot provides significant performance for varying Cloud Robot. From the analysis, it is observed that the proposed MOSGT the offloading of Cloud Robot with distance is decreased. However, for assigned 100 meters the performance is significantly improved with higher convergence speed and higher offloading efficiency. This implies that the proposed MOSGT perform effective task offloading with minimal task execution time.

IV. CONCLUSION

In this paper, proposed a multi-objective model with symmetric game theory MOSGT is developed. The proposed MOSGT is based on the mathematical computation of multi-objective formulation with symmetric game theory. The incorporation of a multi-objective function with a cloud Robot considers each task as game players. The performance of the proposed MOSGT is comparatively examined with existing GA4CCO and ACCO. The simulation analysis stated that the proposed MOSGT provides reduced system cost and iteration count than the existing GA4CCO and ACCO. The system cost is reduced by approximately 35% of GA4CCO and 20% for ACCO. In terms of iteration, the proposed MOSGT reduces the game theory rate of 30% less than GA4CCO and 25% minimal than ACCO. The decreased system cost and iteration improve the performance with varying distance of cloud Robot.

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