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Mobile-fog-cloud assisted deep reinforcement learning and blockchain-enable IoMT system for healthcare workflows

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Abstract

The Internet of Medical Things (IoMT) is increasingly being used to secure blockchain technology to operate healthcare applications in a distributed network. The applications are mobile and can move from one place to another with different wireless connectivity. However, there are a lot of challenges that are investigated further. For instance, dynamic content values changed during mobile applications during any business goal. The workflow healthcare applications are complex as compared to coarse-grained and fine-grained workload in IoMT. In this article, the study analyzed offloading and scheduling problems for healthcare workflows in IoMT fog-cloud network. Therefore, the study considered the problem as an offloading and scheduling problem formulated deep reinforcement learning as Markov problem. The study devises the novel deep reinforcement learning and blockchain-enabled system, consisting of multi-criteria offloading based on deep reinforcement learning policies and blockchain task scheduling with task sequencing and research matching methods for healthcare workloads in the IoMT system. The simulation results suggested strategies that reduced the communication and computation time for each application in the system.

1 | INTRODUCTION

The conventional healthcare system has been converting into digitalized healthcare mechanisms increasingly to facilitated patients with the user-friendly environment.[1] The Internet of Medical Things (IoMT) is a new network that provides a distributed healthcare infrastructure that can treat any illness from any place. To facilitate the distributed healthcare applications in the network, IoMT included mobile devices, cellular networks, fog nodes, and cloud nodes.[2] The emerging healthcare applications are divided into different classes such as fine-grained, coarse-grained, and workflows. The coarse-grained applications are data-intensive healthcare workloads that cannot be run locally on mobile devices with limited resources. As a result, devices might be able to offload the entire workload to a fog-cloud for execution. Healthcare applications' fine-grained workloads are compute-intensive and divided into small and large projects, which are then performed based on available resources.[3] The workflow healthcare systems, on the other hand, combine coarse-grained and fine-grained data with a precedence restriction criterion. As a result, workflow applications run on various nodes in the

IoMT network. The security (patient private-data), timeliness (delay-sensitive applications require immediate response), and deadlines of offloaded applications are all major issues.[4]

The new mobile-fog-cloud-assisted blockchain IoMT framework expands the stable distributed ecosystem by allowing healthcare applications to run on multiple nodes. Blockchain is an emerging technology to distributed data-ledger to the nodes based on validation and security rules. The goal is to minimize the tampering risk of data to any node in the IoMT system. The studies[3-8] suggested different IoMT ecosystem run the coarse-grained and fine-grained workload of healthcare applications in the distributed network. For security purposes, the blockchain-enabled network is widely implemented for coarse-grained and fine-grained applications. Many dynamic meta-heuristics based on dynamic programming, combinatorial methods, and supervised and unsupervised along with reinforcement are suggested to improve the performances of applications in the dynamic environment. In the dynamic environment, different wireless networks, computing nodes, and devices can face intermittent changes in resource values, for example, bandwidth utilization, available traffic, load balancing, server busy, etc. Therefore, content-aware offloading and scheduling are the key challenges in IoMT to satisfy the deadline of applications. While, existing studies[1-4] focused fine-grained healthcare applications in IoMT network and suggested blockchain-enable fog-cloud network. The workload has no dependency on each other they can run on different nodes during processing in IoMT. Furthermore, existing studies[6-11] focused on coarse-grained healthcare applications in the IoMT network and suggested blockchain-enabled fog-cloud network. The workload has no dependency on each other they can run on different nodes during processing in IoMT. However, these ecosystems cannot work for healthcare workflows when they run on different nodes at the same time.

The content-aware offloading and deadline-aware scheduling in blockchain-enabled mobile-fog-cloud assisted IoMT for healthcare workflows are formulated in this article. The goal is to shorten the time it takes for workflows to complete in the IoMT framework during offloading and scheduling. In the IoMT method, the makespan of each workflow sum of communication time and computation time. There are three types of tasks in each workflow: lightweight tasks, delay-sensitive tasks, and delay-tolerant tasks. Although lightweight tasks necessitate fewer resources for execution, delay-sensitive tasks necessitate a greater number of resources but with a shorter time delay. Delay-tolerant activities, on the other hand, are those that need a significant amount of resources.

There are many research questions related to healthcare workflows offloading and scheduling in the blockchain-enabled mobile-fog-cloud network. (i) The workflow decision manager does not know in advance, where to offload tasks for scheduling. There are many parameters that are required to make the decision such as execution time, communication time, deadline, available bandwidth, and available resources. These parameters are intermittently changed in the IoMT system. Therefore, it is a challenge on how to offload tasks in the dynamic based on different parameters. (ii) Due to the heterogeneous nature of resources, the workflows run in different locations. Therefore, to each makespan under the deadline constraint is a challenging job. (iii) To validate the transaction on different nodes for each application, the security maintenance to avoid tempering is challenging in the IoMT system. (iv) Workflow tasks topological ordering and dynamic scheduling in a heterogeneous environment always challenging job to obtain the optimal solution with the given constraints.

Mobile-fog-cloud assisted deep reinforcement learning and blockchain-enable IoMT system for healthcare. On the IoMT, the primary motivation is that aware applications consist of different tasks such as lightweight tasks, delay-sensitive tasks, and delay-tolerant tasks. Unfortunately, the existing mobile-only edge only and cloud-only cannot meet the requirements of IMoT workflow applications. Therefore, a collaborative fog-cloud environment some instant satisfy the needs of applications. The main problem is the security concern in the network. The blockchain widely implemented in the distributed network. However, existing heuristics cannot reach the objective in the dynamic environment. The deep reinforcement learning-enabled schemes adapt the dynamic changes in different states and perform the optimal actions with the agent. Therefore, mobile-fog-cloud assisted deep reinforcement learning and blockchain-enable IoMT system for healthcare must develop for the emerging and new healthcare applications.

Motivation: The study has the following contributions based on the state of the arts. The study formulated the offloading and scheduling problem in heterogeneous blockchain-enable mobile-fog-cloud IoMT for workflows applications. To find the solution to the aforementioned questions, the study divided the problem into sub-optimal offloading and scheduling problems. Initially, considered problem formulated as the Markov decision problem will be converted into the deep-reinforcement learning problem. The proposed consisted of different components: Offloading deep manager, task sequencing, and scheduling in the blockchain-enabled mobile fog-cloud network. The proposed system will explain in detail in the problem description part.

Contribution: The study devises the novel deep reinforcement learning and blockchain-enabled system which consists of multi-criteria offloading based on deep reinforcement learning policies and blockchain task scheduling with task sequencing and research matching methods for healthcare workloads in the IoMT system. The study has the following contributions based on the state of the arts.

- The study devises a novel multi-criteria aware system with deep reinforcement and blockchain network that can adapt to any dynamic changes in wireless communication values, resource availability, and failure of any resource during the process of applications.
- The study formulated the problem based on a suggested mathematical model which defines and optimized the problem in the dynamic and combinatorial form to achieve the feasible solution of applications under their quality of service requirements.
- The system can accept many random applications at a different time interval, which is called the Poisson process. Therefore, the priority of application to be set at the runtime of arrival in the system. It is a hard and critical job for the system. The study proposes the efficient task sequence rules to obtain the deadline, slack-time, and priority of each application efficiently and sort them according to their requirement before scheduling to nodes.
- To handle the dynamic tasks, the proposed scheduler is preemptive where execution tasks of applications can optimize at the runtime. This way, the makespan of applications to be minimized efficiently.
- The study implemented different kinds of offloading and scheduling algorithms and based on the mathematical model in the experimental part to achieve the effectiveness of the proposed system as compared to existing systems.

This article has different sections and to be ordered in the following way. Section 2 shows the efforts of existing studies with their methods and frameworks. Section 3 elaborates the problem description and formulation with the mathematical model. In Section 4, the study devised the proposed framework to solve the problem. Section 5 evaluated the performance of schemes with different experiments. Section 6 is about the conclusion and future work of the study.

2 | EXISTING WORK

These days, the IoMT aware applications have been growing progressively. The main reason behind the assistance of fog-cloud services and smart sensors that make healthcare services very convenient to patients. Many studies have suggested many IoMT ecosystems with different problem limits as shown in Table 1. The boundaries are parameters, decision, profiling, workload, problem, and network. For instance, study[1] considered the network, static, network, coarse-grained, offloading sides to solve the offloading problem in the IoMT ecosystem. The goal is to minimize mobile energy based on static offloading on coarse-grained workload. The full offloading technique has been implemented to migrate workload from mobile to cloud for execution.

The study[2] considered battery-level, static, network, fine-grained, static offloading, in the healthcare environment. The goal is to minimize mobile energy based on static offloading on a fine-grained workload. The fine-grained tasks are a

TABLE 1 Existing and proposed IoMT ecosystem

Study	Parameters	Decision	Profiling	Workload	Problem	Network
1	Network	Static	Network	Coarse-grained	Offloading	IoMT
2	Battery-level	Static	Network	Fine-grained	Offloading	Healthcare
3	Network	Dynamic	Resource	Coarse-grained	Offloading	IoMT
4	Delay	Dynamic	Network	Fine-grained	Resource allocation	IoMT
5	Delay	Hybrid	Network	Fine-grained	Scheduling	IoMT
6 and 7	Makespan	Hybrid	Network	Coarse-grained	Scheduling	IoMT
8, 10, and 11	Deadline	Dynamic	Network	Fine-grained	Scheduling	IoMT
12 and 13	Execution-time	Dynamic	Contents	Fine-grained	Offloading	IoMT
9, 14, and 15	Communication-time	Dynamic	Lateness	Fine-grained	Offloading	IoMT
Proposed	Multi-parameters	Hybrid	Makespan	Workflows	Offloading and scheduling	IoMT

mixture of lightweight and compute-intensive tasks which are executed on the mobile device and remote cloud. However, the static task partitioning is done at the design time, and compute-intensive tasks only offload to cloud computing for the computation which is blockchain-enabled in the network. The study solved the offloading problem based on the greedy static method during processing in the system. The study[3] considered network, dynamic, resource coarse-grained, offloading in IOMT network. The goal is to minimize the delay of coarse-grained applications. The offloading decision whether to offload tasks or not made at the runtime based on the dynamic offloading method. However, the dynamic task partitioning is done at run-time, and compute-intensive tasks only offload to cloud computing for the computation which is blockchain-enabled in the network. The study solved the offloading problem based on the greedy static method during processing in the system. The studies[4,5] investigated hybrid parameter aware offloading and resource with the following parameters: delay, dynamic, network, and fine-grained, Resource allocation in blockchain-enabled IoMT network. The goal is to minimize delay and security risk at the runtime and make design time and runtime offloading decisions.

The dynamic offloading aware problem for IoMT fine-grained and coarse-grained applications have been investigated in References 6-8 and 10. The hybrid blockchain such as private and public blockchain deployed in the IoMT network to reduce the security risk in the network. However, the content parameters such as bandwidth, resource, and deadline are not considered during offloading decisions in the study. The static scheduling aware problem for IoMT fine-grained and coarse-grained applications has been investigated in References 11-14. The hybrid blockchain such as private and public blockchain deployed in the IoMT network to reduce the risk of failure, latency, and security considered during offloading decisions. However, runtime changes and the deadline of applications did not consider in these studies. The dynamic scheduling aware problem for IoMT fine-grained and coarse-grained applications have been investigated in References 9 and 15. The hybrid blockchain such as private and public blockchain deployed in the IoMT network to reduce the security risk in the network. These studies did not focus on cooperative offloading and scheduling to optimize many things together.

The mobile healthcare and mobile-fog-cloud aware system suggested in these studies.[16-22] The goal is to offload healthcare tasks to the near available computing for further execution. Whereas, healthcare cancer disease, ECG, and blood-pressure aware workload include in their applications. Whereas, mobile-fog-cloud aware IoMT system suggested in References 23-28. The goal is to minimize security risks and improve the data accuracy in the system. The offloading and scheduling techniques are widely implemented in the literature studies.

To the best of our knowledge, the existing studies did not consider the mobile-fog-cloud assisted deep reinforcement learning and blockchain-enable IoMT system for healthcare workflows in the literature work. Offloading and scheduling are different techniques in the mobile cloud computing environment. Whereas offloading can only improve the performances of the devices such as the portable battery, response time, and lateness. However, in the current study, we improved the performance from the system side; therefore, instead of only offloading, we consider both offloading and scheduling techniques to achieve both user and system performances high in the system. This work is dynamic and different from existing studies, where dynamic changes in the system can adapt quickly without degrading the performance of applications. The blockchain is implemented at both client and management levels to avoid anomaly problems in the system. The dynamic offloading and scheduling can optimize the issue at the runtime and execution of applications from start to end. The existing studies only suggested either static or dynamic methods, but they did not consider the adaptive techniques that can easily handle immaturity. Mobile-fog-cloud assisted deep reinforcement learning and blockchain-enable IoMT system for healthcare workflows is a novel system in which deep learning can improve the performances of the state in the system.

3 | PROPOSED SYSTEM AND DESCRIPTION

The study devised mobile-fog-cloud assisted deep blockchain-enable offloading and scheduling IoMT system for healthcare workflows. These workflows have different kinds of tasks such as lightweight tasks, delay-sensitive tasks, and delay-tolerant tasks as shown in Figure 1. These workflow applications are directly submitted to the system agent which is the manager in the system and located at the client application layer. After submission of workflows, the system calls the deep parameter decision offloading method which makes the decision which tasks to be executed on the mobile device, fog node, and cloud computing based on different parameters (eg, execution time, deadline, bandwidth, resource availability). Different profiling technologies implement in the system to generate the values of the network, available resources, deadline, and execution time of applications and send the profiling to the deep offloading decision manager. After the offloading decision, the task sequence of tasks is necessary before scheduling to any node. The system agent calls the

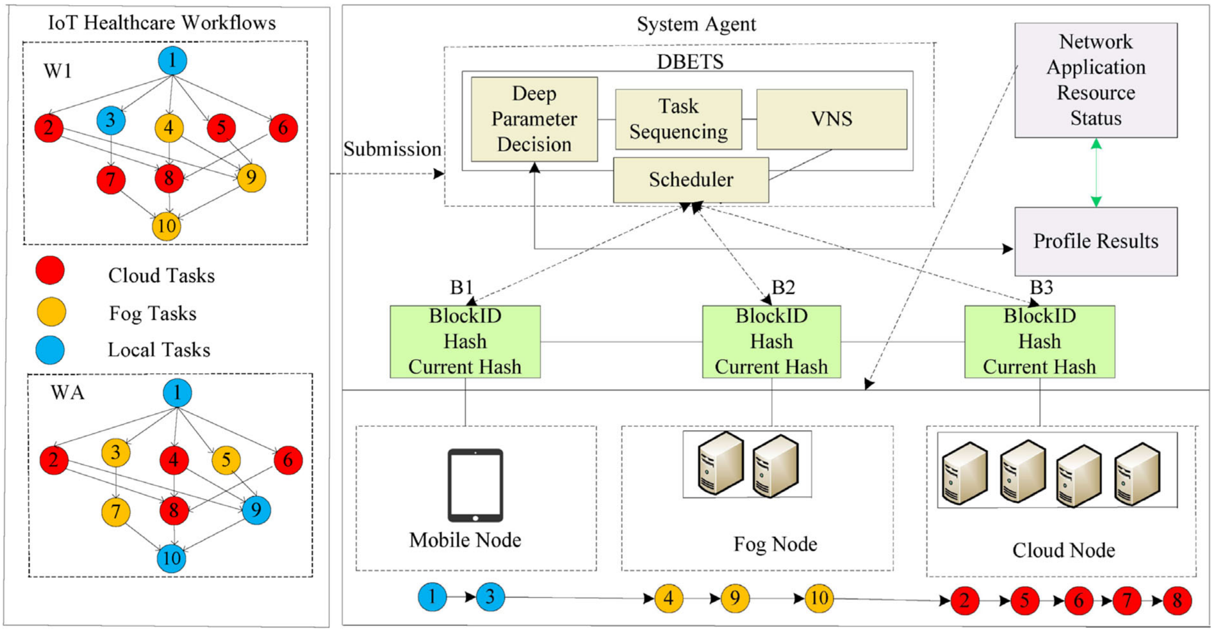

FIGURE 1 Mobile fog-cloud assisted deep blockchain-enable system for healthcare workflows

task sequencing method to arrange all tasks in topological order. The variable neighborhood structure (VNS) is the global search that finds optimal nodes to run the workflows on heterogeneous nodes. The scheduler is dynamic and preemptive which can handle tasks at the runtime of execution in the system. The IoMT consists of three types of resources such as mobile computing, fog node, and cloud computing. All nodes are connected to each other via the blockchain-enabled network and share the data of tasks between each other.

3.1 | Problem formulation

The study considers the A number of workflow applications. The G contains the V number of tasks and E edges between tasks. The workflow G has three types of tasks such as lightweight tasks $l_{vi} \in V$, delay-sensitive tasks $S_{v_i} \in V$, and delay-tolerant tasks $T_{vi} \in$. The deadline of each workflow represented by, for example, $G_D = \{D_1, D_2, \dots, DA\}$. Table 2 denotes the notations of the considered problem.

The study considers the M computing nodes (eg, mobile, fog, and cloud) is represented by $\{j = 1, \dots, M\}$. The set $\zeta_j\{j = 1, \dots, jM\}$ describes that each computing paradigm is equipped by a distinct computing speed. The variable $x_{ij}\{0, 1, 2\}$ elaborates the allocation of tasks to the particular nodes. Whereas, B represents the number of blocks in blockchain that are creating at different computing nodes, for example, $B_j \in M$. Whereas, T_i^e calculates the computation time of particular task on nodes.

$$T_i^e = \begin{cases} \frac{data_i}{\zeta_{j1}}, & x_i = 1, \\ \frac{data_i}{\zeta_{j2}}, & x_i = 2, \\ \frac{data_i}{\zeta_{j3}}, & x_i = 3. \end{cases}$$

In Equation (1), the variable value $x_i = 1$ denotes mobile device to run a task v_i with speed ζ_{j1}, when $x_i = 2$ the fog node selected to run a task v_i with speed ζ_{j2}. In the end when $x_i = 3$ the remote cloud selected to run task.

$$DT_{i,j} = \left(\frac{T^R_{data_i} + T^G_{data_{ij}}}{2(\theta - 1)B_{out} + (2 - \theta)B_{in}} \right). \tag{2}$$

TABLE 2 Mathematical notation

Mathematical notations	Descriptions
A	Set of workflow applications
G	Gth workflow application of A
G_D	The deadline of Gth application
V	All tasks of application G
v_i	ith task of application G
v_{di}	Deadline of a task v_i
$data_i$	Workload of a task v_i
$T^R_{data_i}$	Original transmission time of a task
$T^G_{data_{ij}}$	Transmission time precedence
DT_i	Round-trip time of a task v_i
FT_i	Finish time of a task v_i
ST_i	Setup time of a task v_i
M	All computing nodes in IoMT
j	jth paradigm in the M
x_ij	Assignment of task v_i to node j
ε_j	Resource of node j
ζ_j	Speed factor of jth paradigm
B_{in}	Uploading bandwidth of paradigm j
B_{out}	Downloading bandwidth of paradigm j
a_{nn}	Elements of each criteria 6×6
a_{mn}	Pair-wise comparison
X	A set of tasks matrix
ω	A vector of AHP comparison
λ_{max}	A prime values
RI	Reliability index
$k \in K$	A set of decision maker
J^+	Worst solution is obtained for a task
J^-	Ideal solution is obtained for a task
x	It is any real number
H_m	Highest task list
$PList[]$	Preference list of all tasks
B	The number of blocks in IoMT
B_{id}	The block id in blocks
B_j	Required resource to block at node j

In Equation (2), data sharing or communication time between different edges tasks.

$$ST_{v_i} = \max_{v_j \in pred(v_i)} \{FT_{v_j} + DT_{i,j}\}. \tag{3}$$

Equations (3) and (4) show the setup time and finish time of a task during scheduling in the IoMT

$$FT_{v_i} = \max_{v_j \in pred(v_i)} \{ST_{v_i} + T^e_i\}. \tag{4}$$

The makespan of all workflows to be determined in the following way.

$$X = \sum_{j=1}^{M} \sum_{v=1}^{V} \{FT_i(exit)\}, \quad \forall \{G = 1, \dots, A\}. \tag{5}$$

In Equation (5), the X is makespan of different workflows.

The minimized function of the study exploited as follows.

$$\min X. \tag{6}$$

Equation (6) shows objective function to be minimized for workflows

$$\text{Subject to} \sum_{G=1}^{A} X \leq \sum_{G=1}^{A} G_D \in GD. \tag{7}$$

All applications must be executed under their deadlines as defined in Equation (5).

$$\sum_{i \in G}^{A} data_i \leq \epsilon_j, \quad \forall j = 1 \in M. \tag{8}$$

The requested workload of applications must be less than the capacity of the resource of all computing nodes as defined in Equation (8).

4 | PROPOSED DBETS ALGORITHM FRAMEWORK

The study devises the deep-reinforcement-learning based efficient task offloading and scheduling (DBETS) algorithm framework which divided the main problem into sub problems such as offloading and scheduling and optimize jointly in the IoMT system.

Algorithm 1 is the main framework of proposed IoMT system. The framework consists of different methods which can optimize the problem via different steps. For instance, deadline division, offloading, task sequencing, and scheduling. All sub-parts to be defined in their subsections.

The following steps of Algorithm 2 explain below.

- Step 1: Created matrix of tasks and applications.
- Step 2: Normalized to form the matrix.
- Step 3: Create the optimal policy for different states in different time-interval.
- Step 4: Find the optimal solutions.
- Step 5: Euclidean distance matrix among all possible nodes.
- Step 6: Find the optimal decision of each task.
- Step 7: Offloading results of matched return to list.

4.1 | Blockchain-consensus method

Immutability, anonymity, protection, and transparency are all features of blockchain, a distributed decentralized network. Despite the lack of a central authority to validate and verify transactions, the blockchain considers each transaction fully secure and checked. Only the presence of the consensus protocol, which is a vital component of any blockchain network, enables this to happen. The study devises the blockchain-consensus algorithm to achieve blockchain network stability and create trust between unknown peers in a distributed computing system in this way. The proposed algorithm generates blocks, for example, $\{B_1, \dots, B\}$ with different components for each computing node, for example, $\{k_1, \dots, K\}$. The study perform the blockchain-enable on fog-cloud in the following steps.

Algorithm 1. DBETS algorithm framework

Input : All applications, resources and nodes ;
Output: $\min X$;
begin
  $MList[] = null$ Matching Tasks List with Resources;
  foreach *(Match.All.Applications)* **do**
    Divide deadline of applications into tasks;
    Call Deep Offloading Method;
    $ratio = \sum_{G=1}^{A} \frac{G_D}{Z}$,;
    $T_i'^e = T_i^e \times ratio$;
    $DT'_{i,j} = DT_i \times ratio$;
    $v_{di} = \min(\{v_{dj}\}) - T_i'^e(v_j) - DT'(ij)$;
    Order all tasks in topological form;
    foreach $(v_i \in V)$ **do**
      $Priority(v_i) = data_i + \max_{v_j \in succ(v_i)} Priority(v_j)$,;
      $Priority(v_i) = data_i, v_i \in exit - task.$
    Call Resource Matching Method;
    $PList[v_i \in V, j \in M]$ Preference List;
    Call preemptive Task Scheduling Method;
    $Z \leftarrow PList[v_i \in V \forall G, j \in M]$;
  return Z;
End-Loop;

Algorithm 2. Deep offloading decision process

Input : $G \in A, v_i \in G, n \in v_i, s, a, t \in S$;
Output: $\min T^{total}, s$;
begin
  foreach *($m \in K$ as resources)* **do**
    foreach *($n \in V$ as coefficients)* **do**
      Step-1: Create a matrix;
      Step-2: Normalised to form the matrix;
      Step-3 Create optimal Policy for states;
      $RR = \frac{RI}{(v_i \leftarrow j) \times RI}$;
      $s, a, t \leftarrow v_i \leftarrow j$;
      Step-4: Find the optimal solutions;
      Step-5: Euclidean distance matrix among all possible paradigms;
      $D_m^+ = \sqrt{\sum_{v=1}^{G}}(v_i \leftarrow j \leftarrow \pi)$;
      $D_m^- = \sqrt{\sum_{v=1}^{G}}(v_i \leftarrow j \leftarrow \pi)$;
      Step-6: Find the optimal decision of each task;
      $H_m = \frac{D_m^-}{D_m^+ + D_m^-}$;
    foreach $(G \in A \& j \in M)$ **do**
      Add $PList[v_i \in V, j \in M] \leftarrow H_m$;
  Matched with all applications;
End Main-Loop;

Algorithm 3. Blockchain-consensus scheme

Input : $\{v_i, \ldots, V\} \in G, \{j = 1, \ldots, M\}, \{B = 1, \ldots B\}$

1 **begin**
2 Declare two big integers p and q;
3 Initialize n;
4 Previous hash PH=null;
5 Hash h=current hash;
6 Enc Encryption;
7 Dec Decryption;
8 Timestamp ts=null;
9 Transaction Tns;
10 Initial Block B1;Status=0 or 1;
11 **foreach** $(v = 1\ to\ V) \varsigma j = 1\ to\ M)$ **do**
12 Calculate n=$p.q$;
13 Calculate $\theta(n) = (p-1)(q-1)$;
14 Choose public exponent key $e \in \{e = 1, \ldots, \theta(n) - 1\}$ based on encryption (e,$\theta(n)$) = 1;
15 Enc=$(e, \theta(n) \times v_i \leftarrow j)$;
16 Calculate the private exponent key based on $d.e = 1 \bmod \theta(n)$;
17 Dec=$d.e = 1 \bmod \theta(n)$.Enc;
18 **if** *(Status.B1=1)*$\leftarrow$ **then**
19 Enc=$(e, \theta(n) \times v_i \leftarrow j)$;
20 $h \leftarrow$ Enc;
21 Calculate the private exponent key based on $d.e = 1 \bmod \theta(n)$;
22 Dec=$d.e = 1 \bmod \theta(n)$.Enc;
23 **while** $(B \neq = empty)$ **do**
24 **foreach** $(B = 1\ to\ B)$ **do**
25 Tns=$v_i \in V \leftarrow j \in k \leftarrow B$;
26 Tns=$B_1 \in B \leftarrow k \in K \leftarrow \times ts$ Enc, Dec;
27 **if** $Tns \neq B_1\ to\ B$ **then**
28 Data Tempered at any B;
29 **else**
30 Tns.status=success;
31 End status condition;
32 End Blockchain Matching Condition;
33 End Assignment Condition;
34 End Encryption and Decryption Condition;
35 End Main Assignment Condition;
36 End Main Logic

To maintain the cryptography and security requirements for each transaction in fog-cloud, the blockchain process defines in Algorithm 3 as below.

- Initially, Algorithm 3 implements decentralized fog-cloud node with different blocks as the miner. The miners can have the capability to run different transactions of tasks inside the same block, for example, B1. All decentralized fog-cloud nodes working with each other and transfer their data between them. Each blockchain miner can send data to all miners to avoid any temper or fraud on the data. Algorithm 3 process the secure process in the following steps.
- Steps 1 to 10: All variables declared for the process such as two big integers (p, q) for key-generation during encryption and decryption. Initialization n is the permutation of key-generations during encryption and decryption. Previous has

Algorithm 4. Task scheduling

```
Input : {∑_{G=1}^{N}, ∑_{j=1}^{M}, PList[v_i ∈ V, j ∈ M] ← H_m};
begin
    while (PList[v_i ∈ V, j ∈ M] ← H_m ≠ empty) do
        foreach (v_i ∈ G) do
            Sort all tasks based deadline first scheme;
        foreach (j = 1 ∈ M) do
            Schedule all parents tasks first and then child tasks after parents tasks;
        if ({B_ij + F_ij ≤ vd_i) then
            min X* = ∑_{G=1}^{N} ∑_{v_i=1}^{V} ∑_{j=1}^{|M_i|} x_ij based on equation~(9);
            replace original function X ← X* based on equation~(9);
            Final available time slot for all tasks in selected services M_i^j is S_ij = {S_ij0, S_ij0, ..., S_ij(|S_ij|-1)} Call
             blockchain method Block-Method to save result in secure form;
            Optimize X;
    Repeat the process until all tasks map to the services;
End Main
```

and current hashing represented by *Ph* and *h* variables. The variable *Tns* and *ts* represented transaction and timestamp for encryption (Enc) and decryption (Dec). The blocks inside the blockchain represented by B with status 0 or 1.

- Steps 11 to 17: Algorithm performs encryption and decryption process on plaintext into ciphertext. In Step 11, each task and function list display before the scheduler. Calculate permutation and key-generations $n(p.q)$ in Steps 12 and 13. In Steps 14 and 15, algorithm performs encryption hashing for all tasks based on asymmetric technique. In Steps 16 to 18, the algorithm performs decryption to each block for computation.
- Practical byzantine fault tolerance (PBFT) is implemented in Algorithm 3 to handle the failure of block or computing node at the runtime application execution. Each decentralized miner in particular computing node connected and share data to avoid fraud of data. If the particular block B tempered the data, another block cannot process the request of application for further processing. Error handling or failure handing to be maintained based on the PBFT method and any fraud to be detected by proof of work (PoW) in the system. If the status of the block becomes 1, it means the stability is high of the transaction and free from any tampering of data in the decentralized system.

4.2 | Task scheduling

The proposed scheduler is non-preemptive, where the scheduler cannot suspend the running processes of tasks in the system. Therefore, it is non-preemptive in nature. Based on task sequencing, and composition matching list, the scheduler allocates all tasks to functions based on requirements. Algorithm 4 reads the composition list of tasks and functions, then schedule them based on tasks deadline and cost. This process iteratively carry on until tasks are allocated and executed to appropriate functions.

4.3 | Optimal objective function

Based on deep reinforcement learning, the study can optimize the original objective of each application during execution based on the following equation.

$$X^* = s, a, t \leftarrow H_m^* \times \pi. \tag{9}$$

Equation (9) determines the optimal offloading at different time interval during dynamic environment in IoMT system.

4.4 | Time and space complexity

The study calculated two kinds of the complexity of the problem. For instance, time complexity and space complexity. We define the time complexity via different components such as sorting based on $O(mlogn)$, where m is the number of tasks and n is the number of tasks, and log is the sorting sequence tasks. The resource matching and scheduling have the same sequences; therefore, the total complexity of the problem becomes $O(mlogn)^3$. Furthermore, the space complexity determined the available resources of the nodes to process the requests, for example, ϵ_k. Therefore, total complexity is equal to $O(mlogn)^3+\epsilon_k$.

5 | EXPERIMENTAL RESULTS

The experimental part is divided the experimental setup into subparts: deep reinforcement learning aware offloading, blockchain implementation, task sequencing, and task scheduling. Table 3 shows the implementation of the proposed with the given components. Table 4 elaborates the resources of the system. Whereas, Table 5 benchmarks or workload of workflows configured and considered in the study.

TABLE 3 Simulation parameters

Simulation parameters	Values
Languages	JAVA, Python, YAML
Simulation time	6 hours
Experiment repetition	50 times
Sensors	Lead-1, Lead-2, ECG
Fog node	Intel 5 laptop, AndroidX86
Public cloud	AndroidX86 Amazon t2.medium
Blockchain	Netifly Platform
Mobile-fog-cloud	EdgeX Foundry

TABLE 4 Nodes specification of resources

M	ϵ_j (GB)	Core	ζ_j (MIPS)
j_1	2 000 000	1	10 000
j_2	500 000	1	5000
j_3	1000	1	1000

TABLE 5 Workload analysis healthcare workflows

A	$data_i$ (MB)	l_{vi}	S_{vi}	T_{vi}
G1	800	100	500	200
G2	850	50	450	350
G3	1000	50	350	200
G4	900	40	400	200

5.1 | Resources of different computing paradigms

For each workflows, offloading of native tasks to the external servers is not beneficial and wasting of resources because they require very less resource to execution. Similarly, due to the stringent requirement of end to end latency, delay-sensitive tasks must be offloaded proximal fog node for execution. Offloading resource-hungry delay-tolerant tasks (eg, persistent data storage tasks) to the cloud is effective and efficient. Therefore, we consider the three types of resources to run the workflow applications, as shown in Table 4.

5.2 | Workload of mobile workflow applications

We downloaded the different workload of mobile workflow applications from play store and applied reverse-engineering on them. We found that different kinds of tasks with their characteristics and QoS requirements, and we set it in the input configuration file for the simulation. Each application consists of different array values such as application annotation, data size, required CPU per instruction (ms), the total number of tasks, native tasks, delay-sensitive tasks, and delay-tolerant tasks. This micro-workload are freely available on the play store platform. We have shown the detail of each workload in Table 5 for the experiment setup.

$$RPD\% = \frac{X - X^*}{X^*} \times 100\%. \tag{10}$$

5.3 | Blockchain-implementation

```
public class Block {

   private int previousHash;
   private String[] transactions;

   private int blockHash;

   public BlockChain(int previousHashing, String[] All-transactions) {
      this.previousHashing = previousHashing;
      this.All-transactions = All-transactions;
      this.j1.All-transactions;
      this.j2.All-transactions;
      this.j3.All-transactions;
      this.j4.All-transctions;
      Object[] contens = {Arrays.hashCode(Alltransactions), previousHashing};
      this.blockHash = Arrays.hashCode(contens);

   }

   public int getPreviousHashing() {
      return previousHash;
   }

   public String[] getTransaction() {
      return transactions;
   }

   public int getBlockHash() {
      return blockHash;
   }
}
```

The aforementioned source code defined the blockchain implementation in IoMT system with different steps. The study implemented the following baseline approaches in the experimental part which are closely similar to the proposed work and already discussed in related work part.

- Baseline 1: The scheduling methods are widely used in the IoMT network to obtain the optimal resource allocation of tasks during the process. These methods are static scheduling methods and non-preemptive methods and widely implemented in References 1-4.
- Baseline 2: The scheduling methods are widely used in the IoMT network to obtain the optimal resource allocation of tasks during the process. These methods are dynamic scheduling methods and non-preemptive methods and widely implemented in References 5-8.
- Baseline 3: The scheduling methods are widely used in the IoMT network to obtain the optimal resource allocation of tasks during the process. These methods are dynamic scheduling methods and preemptive methods and are widely implemented in References 10 and 11.
- Static blockchain: These blockchain methods offered the blocks with validations for each transaction to the different miners during the process in the IoMT. These blockchain methods are exploited in Reference 12.
- Dynamic blockchain: These blockchain methods offered the blocks with validations for each transaction to the different miners during the process in the IoMT and failure mechanism. These blockchain methods are exploited in Reference 13.
- Static offloading: The offloading makes offloading at the design time of application which is implemented in Reference 14.
- Dynamic offloading: The offloading makes offloading at the run time of application which is implemented in Reference 15.
- Deep offloading: This is the dynamic offloading with different time intervals with different parameters.

5.4 | Result discussion

The proposed mobile-fog-cloud assisted deep reinforcement learning aware system gained outperformed all existing mobile, fog, cloud-only schemes. The main reason is the identification of characteristics of tasks based on available resources according to their quality of service requirements. Mobile-fog-cloud assisted deep reinforcement learning and blockchain-enable IoMT system for healthcare. On the IoMT, the primary motivation is that aware applications consist of different tasks such as lightweight tasks, delay-sensitive tasks, and delay-tolerant tasks. Unfortunately, the existing mobile-only edge only and cloud-only cannot meet the requirements of IMoT workflow applications. Therefore, a collaborative fog-cloud environment some instant satisfy the needs of applications. The main problem is the security concern in the network. The blockchain widely implemented in the distributed network. However, existing heuristics cannot reach the objective in the dynamic environment. The deep reinforcement learning-enabled schemes adapt the dynamic changes in different states and perform the optimal actions with the agent. Therefore, mobile-fog-cloud assisted deep reinforcement learning and blockchain-enable IoMT system for healthcare must develop for the emerging and new healthcare applications. The deep reinforcement learning aware multi-criteria method for offloading is dynamic method where dynamic values in different time interval obtained the optimal offloading results.

Figure 2 shows the performances of different offloading schemes for different healthcare workflows in the IoMT network. Four cases are implemented based on different values in different criteria. Figure 2A, Case1 shows that the considered values such as execution time, deadline, bandwidth, resource availability, block leakage, and makespan show the performances of different methods during the variation in these values. In Figure 2B, Case2, two values changed that are execution time, bandwidth with time t in different states, and action during offloading due to resource-constraint issues and method complexity problem lead to lower RPD% of applications.

In Figure 2C, Case3, three values changed that are execution time, bandwidth, and deadline with time $t$in different states and action during offloading due to resource-constraint issues and method complexity problem lead to lower RPD% of applications. In Figure 2D, Case4, four values changed that are execution time, bandwidth, deadline, and block space with time t in different states and action during offloading due to resource-constraint issues and method complexity

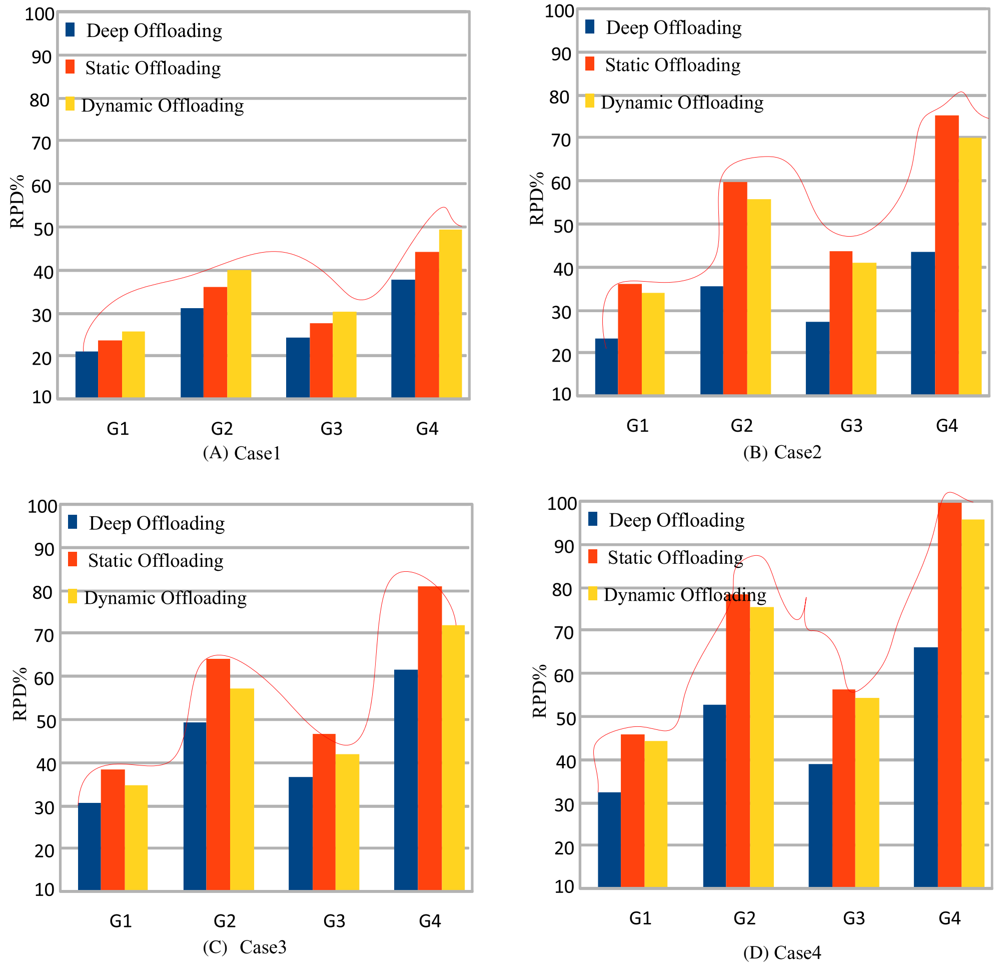

FIGURE 2 Multi-criteria offloading performances of schemes

problem lead to lower RPD% of applications. All cases in Figure 2 show that the proposed deep reinforcement learning aware offloading outperformed in terms of RPD% than all existing static and dynamic offloading during application partitioning between different computing nodes (mobile, fog, and cloud). The main reason is that deep reinforcement learning aware offloading adopts any dynamics changes with multi-criteria in different states. In this way, the offloading performance can improve. As the static offloading cannot adopt any dynamic changes as compared to dynamic offloading. Hence, the dynamic is better than static offloading. However, due to multi-criteria in runtime, the proposed deep offloading outperforms all offloading schemes.

The study considered four different scenarios when considering the proposed blockchain technology for offloading and scheduling performance. For instance, Figure 3A-D shows space leakage, validation, failure, and independency, respectively. These four criteria are ensured during offloading with the blockchain technology in the IoMT system. The static blockchain only makes the initial decision and handles only validation criteria of each transaction in a different network. The dynamic blockchain technology-aware method handles the failure of the blocks during processing in the system. However, they did not focus on space leakage and interdependency. Figure 3 shows the performance of different criteria in terms of blockchain technology performance. Hence, the proposed work is more optimal than all existing blockchain methods which ensure the space, failure, validation, and interdependency of nodes during processing in IoMT.

The simulation results in Figures 4 and 5 shows the methods performances in terms of makespan of healthcare and deadlines during scheduling in the IoMT. Each healthcare workflows has deadlines and from experimental results as shown in Figure 5, the proposed scheduling method DBETS meet all workflows deadline with minimum makespan as shown in Figure 4.

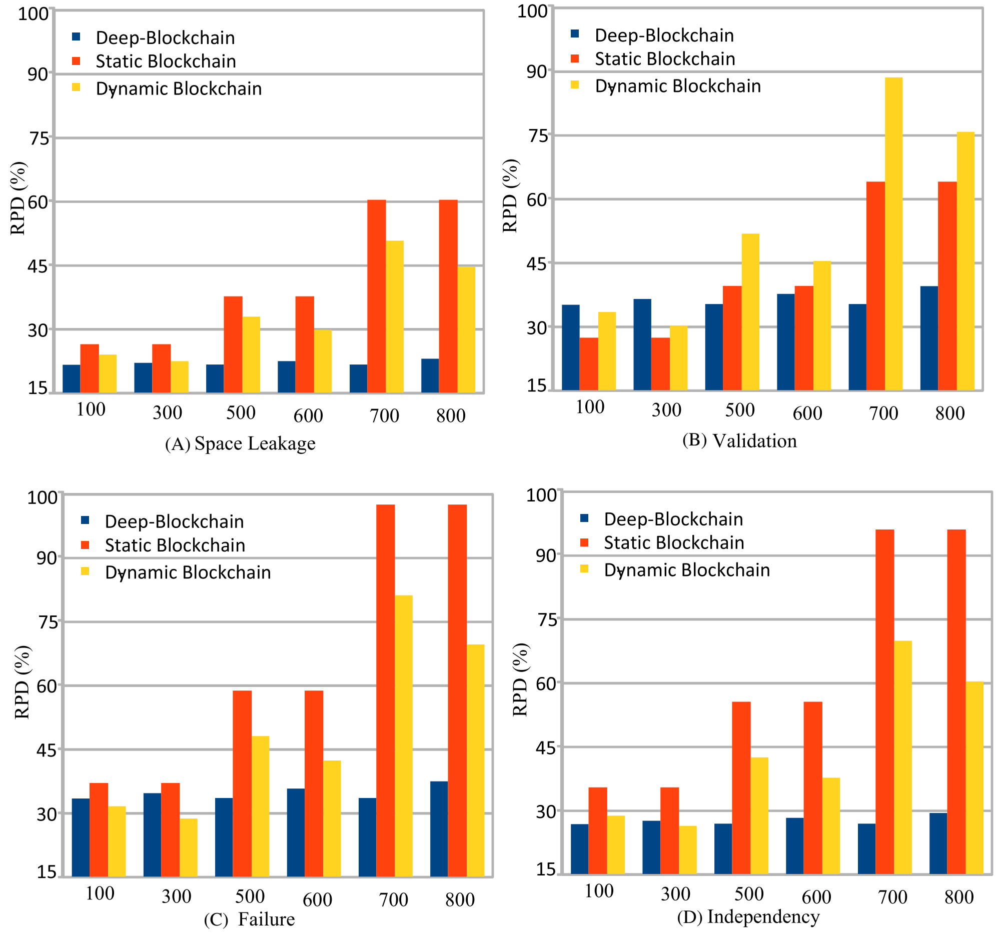

FIGURE 3 Blockchain-enable offloading performance

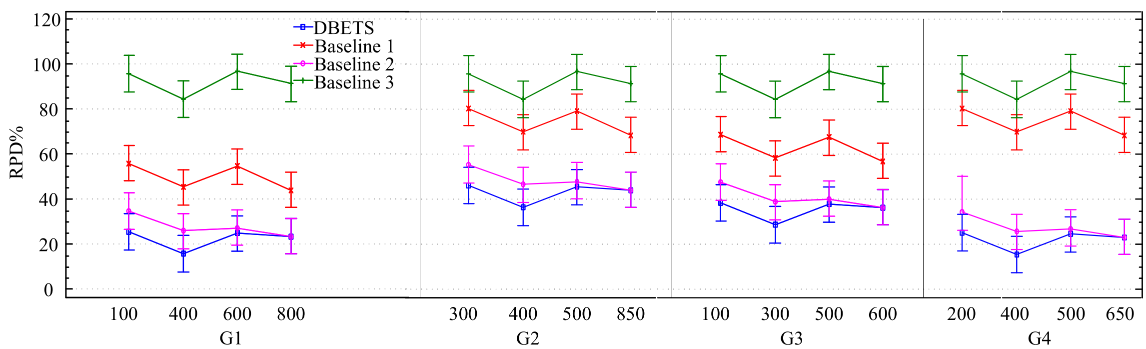

FIGURE 4 Scheduling under different strategies for workflows

5.5 | Current limitation of the study

In the current work, the study obtained dynamic results with the help deep learning technique in the current system. However, there are many challenges in the current system. For instance anomaly detection cannot be handled in the current system, but it is recent issue in the dynamic and distributed applications. Whereas, this model only handles one type workload such as workflow and ignore the coarse-grained and fine-grained workload of healthcare applications.

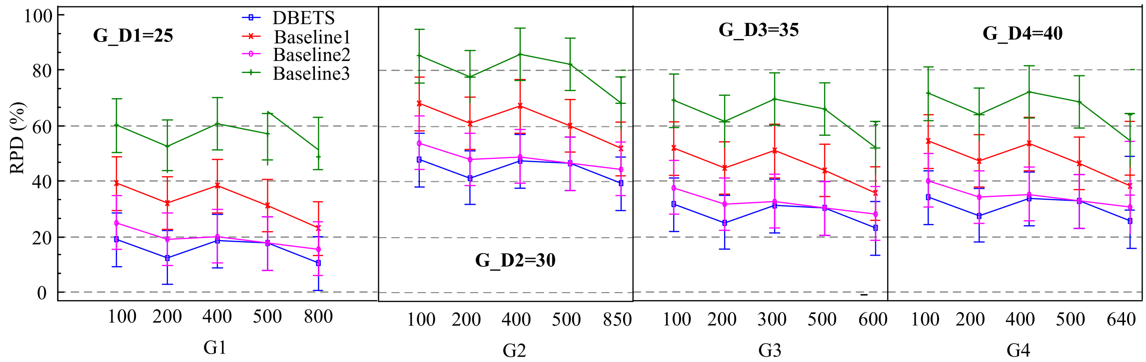

FIGURE 5 Task scheduling with different deadlines constraints

6 | CONCLUSION

In this article, the study analyzed offloading and scheduling problems for healthcare workflows in IoMT fog-cloud network. Therefore, the study considered the problem as offloading and scheduling problem that to be formulated deep reinforcement learning as Markov problem. The study devises the novel deep reinforcement learning and blockchain-enabled system which consists of multi-criteria offloading based on deep reinforcement learning policies and blockchain task scheduling with task sequencing and research matching methods for healthcare workloads in the IoMT system. The results discussion part demonstrates the strength of the proposed schemes for all workflows rather than existing scheduling schemes. In the future work, study will consider the hybrid healthcare workload with cost, energy, and delay constraints. Whereas, this study will improve current system with more security mechanism such as anomaly detection enabled blockchain is necessary in dynamic and complex environment.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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