A Decentralized Multiagent-Based Task Scheduling Framework for Handling Uncertain Events in Fog Computing

Extended Abstract

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ABSTRACT

Fog computing, as an extension of the cloud, provides computing resources for Internet of Things (IoT) applications through communicative fog nodes located at the network edge. Fog nodes assist cloud services in handling real-time applications by bringing the processing capability to where the data is generated. However, the introduction of fog nodes increases scheduling openness and uncertainty. The scheduling issues in fog computing need to consider the geography, load balancing, and network latency between IoT devices, fog nodes, as well as the parent cloud. Besides, the scheduling methods also need to deal with the occurrence of uncertain events timely so as to ensure service reliability. This paper proposes an agent-based framework with a decentralized structure to construct the architecture of fog computing, with considerations of the scheduling, load balance, and rescheduling processes.

KEYWORDS

Scheduling; Fog Computing; Agent-based Simulation

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1 INTRODUCTION

Internet of Things (IoT) devices with embedded sensors and actuators have been widely applied in our daily life from personal use to industrial productions [1, 3, 4]. The extensive data streams generated by IoT devices require powerful computational resources to process [3, 4]. Nowadays, cloud computing delivers powerful computing resources for IoT applications through virtual technology in a centralized manner [2, 8, 9]. Fog computing is the evolutionary extension of cloud computing, which attempts to bring computing resources to where the data is generated instead of moving the data to cloud centres, so as to relieve the communication amount and latency [5]. Fog computing employs fog nodes to deliver computing services and shares the API and communication standard with active fog nodes. The fog topologies are based on the hierarchy of networks, the number of IoT devices, as well as the fog node capabilities.

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Task scheduling in fog computing refers to (**i**) configure the required computing resources in nodes, (**ii**) transfer task data from IoT devices to nodes, (**iii**) execute tasks in order, and (**iv**) return execution results to IoT devices. Three challenging issues need to be considered when processing task scheduling in the context of fog computing. (**i**) Considering the heterogeneity and wide geographic distribution of IoT devices and fog nodes, it is challenging to schedule global tasks on suitable computing resources with multiple real-world constraints in a centralized manner. (**ii**) In geographically distributed fog computing environments, due to the dynamic change of node load and the arrival of streams of tasks, it is challenging to autonomously make decisions on data migrations and enable nodes to reach agreements on data migrations quickly. (**iii**) It is challenging to deal with uncertain events with high efficiency and success rate because they are hard to detect, and decision-making on rescheduling in dynamic environments is time-cost.

This paper proposes an agent-based framework for task scheduling and rescheduling in fog computing with the consideration of essential real-world constraints to address the challenges mentioned above.

2 PROBLEM FORMULATION

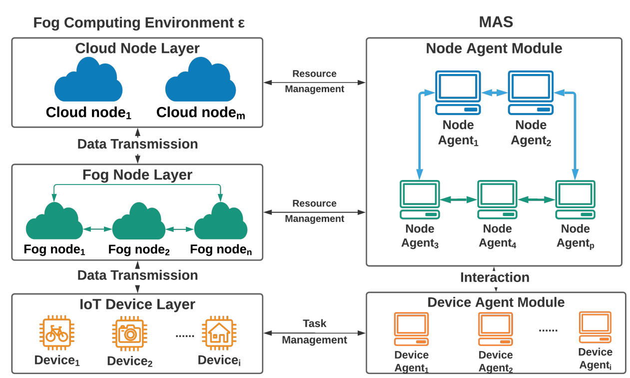

Figure 1: The Architecture of Fog Computing and Framework

Figure 1 shows the architecture of the fog computing environment and the proposed agent-based scheduling framework. This paper considers the *fog computing environment* with three layers $\epsilon = \{D, F, C\}$, where D denotes the *IoT device layer*, F denotes the *fog node layer*, and C denotes the *cloud node layer*.

As shown in **Figure 1**, the series of tasks generated by IoT devices (i.e., the sensor components) will be sent to fog nodes or cloud nodes to be executed using online computing resources. After task executions, the computation results will be sent back to IoT devices (i.e., the actuator components). All nodes are directly or indirectly connected through the network. The network topology can be represented by an undirected graph via a $p \times p$ adjacency matrix $A_{p,p}$.

$$A_{p,p} = \begin{pmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,p} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,p} \\ \vdots & \vdots & a_{i,j} & \vdots \\ a_{p,1} & a_{p,2} & \cdots & a_{p,p} \end{pmatrix}$$

where $a_{i,j} \in [0, 1]$. Here, $a_{i,j} = 0$ means there is no direct network connection between η_i and η_j, and $a_{i,j} = 1$ means η_i and η_j is directly connected.

Let $E = \{e_1, ..., e_j\}$ denote uncertain events. This paper mainly focuses on solving the following four types of uncertain events, i.e., (**i**) IoT device changes, (**ii**) task cancellations, (**iii**) node capability changes, and (**iv**) node disconnection.

In this paper, the main scheduling objectives are (**i**) to minimize the task makespan and (**ii**) to balance the load of fog nodes. Besides, the rescheduling objective is to maximize the task success rate.

3 THE PRINCIPLE OF AGENT-BASED SCHEDULING FRAMEWORK

This paper employs intelligent agents to model the scheduling framework for fog computing to facilitate the interplay between IoT devices and nodes. **Figure 1** shows the architecture of the proposed agent-based framework. Two agent modules are involved, including the (**i**) *device agent module* and (**ii**) *node agent module*.

3.1 The Procedure of Initial Task Scheduling

Initial task scheduling refers to allocating computing resources in cloud or fog nodes for tasks generated by IoT devices. This section gives the agent-based algorithm for task scheduling, which describes the agent interactions and decision-making for two types of agents. Initial task scheduling takes the geographic locations of devices and nodes, as well as the network topology, into consideration and tries to (**i**) minimize the makespan of tasks, (**ii**) balance the load of fog nodes, and (**iii**) minimize the conflicts among agents caused by their self-interests. The initial scheduling process consists of four steps: (**i**) *information access*, (**ii**) *node search*, (**iii**) *agent interaction*, and (**iv**) *task execution*.

3.2 The Procedure of Load Balance

Node agents mainly process the procedure of **load balance**. Because node agents only have the local views, they balance the fog load in a decentralized and ad-hoc manner. Each node only migrates data and balances the load with nearby connected nodes. This preference reduces the cost of data transmission, as well as minimizes agent decision-making and interaction time.

3.3 The Procedure of Task Rescheduling

Task rescheduling refers to the process of re-allocating computing resources for tasks when uncertain events occur, and tasks cannot be completed as pre-scheduled. Since there are no third-party agents with global information in our framework, device agents and node agents with local views implement the task rescheduling process. Due to the lack of global information, solutions for uncertain events must be found through agent interactions. In our framework, agents first try to resolve uncertain events peer-to-peer through ad-hoc communication. When uncertain events cannot be resolved in the local range, agents will try to expand the range of search until uncertain events are resolved. Since tasks considered in this paper are all independent, when uncertain events occur, agents only reschedule tasks that cannot be completed. In contrast, unaffected tasks continue to execute according to the settled schedule.

4 EXPERIMENTS

In the experiments, entities of fog computing were modelled by the iFogSim toolkit, including IoT devices, fog nodes, cloud nodes, and network topology. The proposed agent-based scheduling framework was implemented in JADE (Java Agent DEvelopment Framework). We tested the proposed scheduling framework in terms of *makespan*, *load balance*, and *network usage* [3]. The makespan refers to the task completion time of all IoT devices, which includes agent decision-making, data transmission, and task execution time. The load balance is evaluated by the load variance after the task completion. Network usage refers to the total number of bytes communicated by IoT devices and nodes.

To verify the benefits of the proposed framework, a traditional method *Round-Robin*, a heuristic algorithm proposed by Rehman et al. [7], and a geo-aware agent-based approach proposed by Niu et al. [6] were selected as the comparison models. Experimental results demonstrate that the proposed agent-based scheduling framework can achieve better performances than the three comparison models. Experimental results also show that the proposed framework can achieve a different performance by adjusting the agent preferences. Let θ denote the interaction scale of agents during the scheduling and rescheduling processes. The complexity of each agent is subject to $O(\theta)$, rather than $O(i * p)$, where i denotes the number of device agents and p denotes the number of nodes.

For the rescheduling purpose, the proposed framework has a quick response mechanism driven by distributed agents. Distributed agents can easily detect uncertain events by themselves and react to events autonomously. Our framework de-centrally solves uncertain events in a small range controlled by θ, where no central or coordinator agents are involved. In this case, executions of other tasks will not be affected. The experimental results also indicate that decentralized agent-based approaches have the potential to minimize the impact of unexpected events during task executions and solve uncertain events with high success rates and short response times.

5 CONCLUSION

This paper proposed an agent-based task scheduling framework for fog computing under the consideration of four types of uncertain events. Experimental results demonstrated that our framework could flexibly schedule IoT tasks in fog computing environments and handle uncertain events with a higher success rate and lower response time than that of comparison methods. Further work will extend the current framework to handle more types of uncertain events with more real-world constraints.

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REFERENCES

[1] Mohamed Abd Elaziz, Laith Abualigah, and Ibrahim Attiya. 2021. Advanced optimization technique for scheduling IoT tasks in cloud-fog computing environments. *Future Generation Computer Systems* (2021).

[2] Aida Amini Motlagh, Ali Movaghar, and Amir Masoud Rahmani. 2020. Task scheduling mechanisms in cloud computing: A systematic review. *International Journal of Communication Systems* 33, 6 (2020), e4302.

[3] Fadoua Fellir, Adnane El Attar, Khalid Nafil, and Lawrence Chung. 2020. A multi-Agent based model for task scheduling in cloud-fog computing platform. In *2020 IEEE International Conference on Informatics, IoT, and Enabling Technologies (ICIoT)*. IEEE, 377–382.

[4] Md Razon Hossain, Md Whaiduzzaman, Alistair Barros, Shelia Rahman Tuly, Md Julkar Nayeen Mahi, Shanto Roy, Colin Fidge, and Rajkumar Buyya. 2021. A scheduling-based dynamic fog computing framework for augmenting resource utilization. *Simulation Modelling Practice and Theory* 111 (2021), 102336.

[5] Perry Lea. 2018. *Internet of Things for Architects: Architecting IoT solutions by implementing sensors, communication infrastructure, edge computing, analytics, and security.* Packt Publishing Ltd.

[6] Meng Niu, Bo Cheng, and Jun-Liang Chen. 2020. GMAS: A Geo-Aware MAS-Based Workflow Allocation Approach on Hybrid-Edge-Cloud Environment. In *2020 IEEE 13th International Conference on Cloud Computing (CLOUD)*. IEEE, 574–581.

[7] Saniah Rehman, Nadeem Javaid, Sadia Rasheed, Kanza Hassan, Farkhanda Zafar, and Maria Naeem. 2018. Min-min scheduling algorithm for efficient resource distribution using cloud and fog in smart buildings. In *International Conference on Broadband and Wireless Computing, Communication and Applications*. Springer, 15–27.

[8] Girish Talmale and Urmila Shrawankar. 2021. Dynamic Multi-agent Real Time Scheduling Framework for Production Management. In *IOP Conference Series: Materials Science and Engineering*, Vol. 1085. IOP Publishing, 012001.

[9] Dimitrios Tychalas and Helen Karatza. 2020. A scheduling algorithm for a fog computing system with bag-of-tasks jobs: Simulation and performance evaluation. *Simulation Modelling Practice and Theory* 98 (2020), 101982.