Graph Assisted Resource Allocation for Energy Efficient IoT Computing

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Summary
Resource allocation is one of the top challenges in Internet of Things (IoT) networks. This is due to the scarcity of computing, energy and communication resources in IoT devices. As a result, IoT devices that are not using efficient algorithms for resource allocation may cause applications to fail and devices to get shut down. Owing to this challenge, this paper proposes a novel algorithm for managing computing resources in IoT network. The fog computing devices are placed near the network edge and IoT devices send their large tasks to them for computing. The goal of the algorithm is to conserve energy of both IoT nodes and the fog nodes such that all tasks are computed within a deadline. A bi-partite graph-based algorithm is proposed for stable matching of tasks and fog node computing units. The output of the algorithm is a stable mapping between the IoT tasks and fog computing units. Simulation results are conducted to evaluate the performance of the proposed algorithm which proves the improvement in terms of energy efficiency and task delay.
Keywords:
Internet of Things, Fog computing, Energy efficiency, Task deadline.

1. Introduction

Internet of Things (IoT) connects the everyday devices and tablets that we use with the Internet and cloud servers [1-3]. This system gives us many applications that can change everyday lives and provide comfort to the end users. For example, a patient can have a sensor-based device placed in his arm which can measure different parameters of the body such as temperature, heart rate and other signals. As a result, patients can regularly measure their parameters and can also notify the doctors and staff in the hospital. This can reduce the load on the hospital network and also improve the real-time monitoring of patients. Similarly, remote patient monitoring can be implemented where patients can consult their doctors based on their real-time body related data. If the patient changes doctor or visits a different hospital, this system can track the history of patients.

Another application of the IoT technology is the smart transportation system. Road congestion and traffic issues are common in large metropolitan areas. Accidents on highways and urban roads are also a big cause of deaths in cities. Safe driving is critical and requires sensors and communications between different cars. IoT technology can provide sensors installed on cars and they can communicate with other cars [4-8]. Cars can drive safely without any issue of collisions and notifications can be generated in case of a danger. Autonomous vehicles can also upgrade transportation safety and it will lead to safer driving. It will provide congestion-free roads and traffic management can be done in an efficient manner. Vehicles can autonomously select the most optimal route considering factors such as accidents, road closures, traffic jams etc. It can also provide priority routes to emergency vehicles such as ambulances, and fire fighter cars. Similarly, it can provide communication with infrastructure nodes installed on road areas and also base stations. Many applications for advertisements and new business models can be developed based on IoT in transportation systems [9-14].

IoT devices are small sized and hence their battery is limited. Similarly, its storage and computation capacity are limited. They also have limited communication capability. To overcome these issues, there are two important things which need to be done. The first is the use of cooperative devices such as fog nodes and cloud servers which can assist in computing tasks and handling big data. The second is the use of algorithms which can conserve energy and transmit power of IoT devices. As a result, IoT devices with limited capabilities can run for a longer duration and adds to system reliability [15-23].

Data in IoT is generated by the sensors placed on the IoT devices. These sensors have many types such as health sensors (such as temperature and heart rate), air quality sensors, proximity sensors used in transportation etc. This data generated by IoT is handled by IoT devices but when the data is huge, it may require assistance. In IoT, these assisted devices are called fog nodes which are placed near the edge of the system. Compared to cloud computing, this technology offers less delay and efficient use of bandwidth [24-27].

This work is focused on the aspect of resource allocation of fog and IoT devices. As discussed before, efficient resource allocation can add to durability of IoT system, it is important to develop efficient algorithms. The major issue

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this work focuses on is the allocation of computing units at the fog nodes. The goal of the algorithm is to promote green communications and computing whereby the system energy is conserved and minimally used. The system energy involves both the IoT device energy and the fog computing energy.

This paper proposed a graph theory based algorithm to allocate computing unit resources on the fog nodes and conserve system energy. The paper transforms the problem into a bipartite graph and uses stable matching algorithm to find optimal mapping between tasks and computing units. A stable output is generated, and it results in optimal selection of computing resources. With the help of simulation results in MATLAB, the performance is evaluated in detail. Metrics such as system energy and delay of the tasks are evaluated, and comparisons have been conducted.

The paper organization is given as the following. Section 2 gives a brief literature review of the technology and techniques. This is followed by the system model in the next section. The algorithm is given in Section 4. Results are presented in Section 5 whereas section 6 provides the conclusions.

2. Related Works

2.1 Fog computing

Fog computing is the next generation computing system in which small servers are placed near the end users. This has many advantages as compared to the traditionally used cloud-based system as given in Table 1. Fog computing has less computing capacity as compared to the cloud but has many other advantages. For example, the delay in fog computing is low and also the bandwidth utilization is better. This is because the fog computing devices are near to the end users. Cloud on the other hand is far away and it takes lot of time to reach the cloud. Thus, transmission of tasks and data to the cloud is not efficient. In terms of cost, cloud computing is not as efficient as the fog system. Fog has less cost for installation and maintenance. Fog also had distributed topology due to installation of many fog nodes in the system. As compared to it, cloud has centralized topology system. This results in low reliability as out of order single cloud server can result in system outages. As fog nodes are in more quantity, if one fog server is down, the other one can work and handle the data and task requests. This makes the fog system much more reliable and easier to maintain. If one fog system is out for maintenance, the others can share the load and manage the working of IoT in the meantime. Fog nodes can also cooperate with each other to manage aspects such as task sharing in case of device mobility. If the device is moving, the fog node which is nearest to the end user can handle the task computing request so that transmission of task output is easier, and bandwidth can be efficiently utilized.

Table 1: IoT computing technologies.

Metric	*Cloud*	**Fog**
Computing capacity	High	Medium
Delay	High	Low
Bandwidth utilization	High	Low
Distance to end user	High	Low
Cost	High	Medium
Topology	Centralized	Distributed
Reliability	Low	High

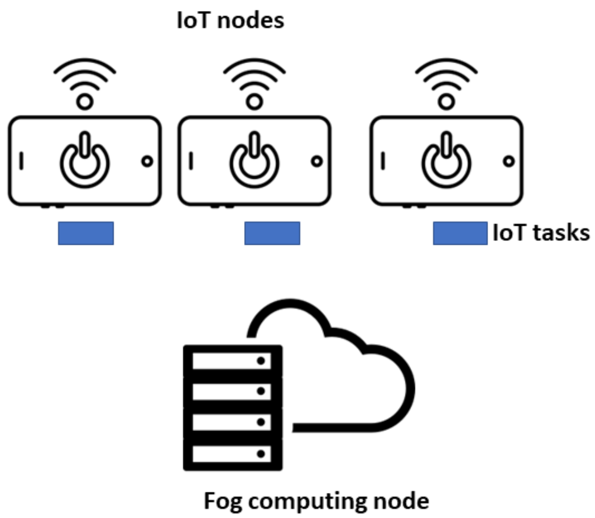

Fig. 1 IoT computing system model.

2.2 Literature Review

Several techniques related to resource allocation in fog computing and IoT networks have been proposed in recent years. The work is related to offloading of tasks to the fog nodes in which best fog nodes are selected based on different parameters. Some techniques focus on the energy of the system whereas other techniques focus on the delay of the tasks. The goal of all the techniques is to maximize the utilization of the resources in the IoT and fog nodes and keeping the metrics of importance up to a desired value.

In [23], the work is focused on delay efficient transmission of tasks to the fog nodes. In the work, the authors propose a matching technique to improve the delay and system outages. System outage is advocated to be an important metric as it results in tasks to be missed by the fog nodes. The idea of the work is to develop preference profiles and maximize the utilization of fog node resources such that maximum tasks are handled by each fog node. The results are provided which show that the technique performs better than other techniques for system outages.

Another technique in the literature focuses on parallel transmission of tasks to several fog nodes by dividing tasks into smaller subtasks [24]. The problem is converted to a matching problem and parallel transmissions are carried out from IoT nodes to the fog nodes. The goal of the technique is to minimize the task delay with the help of parallel computations of portions of tasks at different task nodes concurrently. The work uses one-to-many matching to achieve the above goal. Results have shown improvement achieved by the proposed technique for improving the task delay.

The technique related to energy efficiency is given in [21] where authors utilize a matching theory proposal and multiple criteria weighted scheme. The work ranks the tasks based on the defined criterion and offloads tasks based on it. Results have shown that the energy of the system is improved when using the proposed technique.

The missing issue in the literature is that the remaining energy of IoT devices to improve their battery life is not considered. It is critical to consider the total system energy comprising IoT energy and fog computing energy. This work focuses on a stable mapping based on overall energy of the system including remaining battery value of IoT nodes which is the novel part of the proposed technique.

3. System Model

The considered system model is shown in Fig. 1. The work considers an IoT scenario where IoT sensors are deployed at different places and fog nodes are placed to handle tasks of many IoT devices. The IoT nodes transmit a task completely to a fog node. The fog node computes it using its computing capacity. If the current computing capacity of the fog nodes is full, the task is placed in the queue. The task is considered to be atomic while transmission and no division occurs.

The IoT consumes energy while transmitting the task to the fog nodes. This energy depends on the size of the task, distance of the fog node from the IoT device, and transmit power of IoT device. The following equation is used to compute the energy of the IoT devices.

$$E_i = p^t \times t^{tran} \quad (1)$$

Here p^t is the transmit power used by the IoT device, and t^{tran} is the time taken to transmit the task from IoT device to the fog node. The transmission time is dependent on the data rate and task size. The data rate is dependent on factors such as bandwidth, distance and channel gain and can be given as follows.

$$D(i,f) = B \times \log_2(1 + \frac{p_i \times h_{i,f}}{No}) \quad (2)$$

Here, B is the bandwidth of the wireless link used for transmission, p_i is the transmit power of IoT device, $h_{i,f}$ is the channel gain between IoT device and fog node, and No is the background noise.

The fog node energy can be given as follows.

$$E_f = p^i \times t^{rcv} + E_{comp} \quad (3)$$

Here p^i is the IoT transmit power, t^{rcv} is the reception time of the tasks, and E_{comp} is the energy needed to compute the task. E_{comp} depends on factors such as processing speed of the fog node in cycles/s and the number of bits per cycle it can compute.

The total system energy can be given as the sum of both IoT node energy consumption and fog node energy consumption.

$$E_{total} = E_i + E_f \quad (4)$$

4. Proposed Technique

The proposed technique transforms the problem of minimizing energy consumption into a graph problem. The goal of the proposed technique is to

$$\min E_{total} \quad (5)$$

The problem is solved by using a bipartite matching algorithm. The two agents in the given problem are IoT tasks and fog computing units. The bi-partite graph is shown in the Fig. 2.

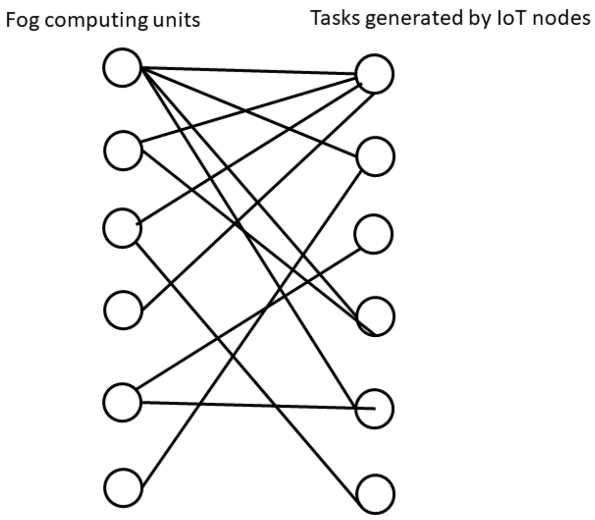

Fig. 2 Bi-partite graph of IoT tasks and fog computing units.

The first step of the proposed technique is preference generation as shown in Fig. 3.

Preference Profile of fog nodes			
F1	I2	I1	I3
F2	I1	I2	I3
F3	I3	I2	I1

Preference Profile of IoT nodes			
I1	F1	F2	F3
I2	F2	F3	F1
I3	F1	F3	F2

Fig. 3 Preference Profile Generation.

Each IoT task generates its preference profile of the fog nodes based on the distance and transmit power required to reach the fog node. The logic of this selection is that each IoT node prefers fog nodes to which it requires least energy to transmit the task. Therefore, each IoT task prepares a preference table based on Fig. 3 depending on the transmission energy needed.

Similarly, fog nodes also prepare a preference profile table including preference values to IoT tasks. Based on this preference profile, the fog nodes rank the incoming IoT tasks and makes selection of which IoT task to accept for computation. The preference profile of fog nodes is based on the IoT task size and also on the IoT remaining energy value in its battery. Each IoT node shares its remaining energy value with the fog nodes after certain time intervals. Based on this remaining energy, the fog nodes rank the IoT tasks and select IoT tasks which have lowest remaining energy for highest preference. The remaining battery life of IoT nodes is a novel metric that lets fog node make intelligent decision for offloading of tasks.

Once preference profile is generated by the nodes, the stable matching algorithm is used to map the IoT tasks to the fog computing units. The stable matching provides an optimal output of mapping by considering both preference profiles at IoT and fog end. The output is stable in the sense that every agent is offered the best possible resource and mapping. The proposed algorithm for mapping of tasks to the fog computing units is shown in Fig. 4.

Algorithm 1: Fog computing unit allocation Algorithm

1 Generate preference profile of IoT tasks based on distance of fog nodes and transmit power needed to reach the fog node
2 Generate preference profile of fog nodes based on task size and remaining batter life of IoT nodes
3 Run stable matching algorithm between IoT tasks and fog computing units based on generated preference profile
4 Transmit the tasks from IoT nodes to the fog computing units

Fig. 4 Proposed Algorithm

5. Simulation Results

The simulations are conducted in MATLAB simulator. The system model considered in the paper is generated in MATLAB. The number of IoT nodes varies from 10-30 and each are generating a single task after 1 second. The number of fog nodes are taken to be 5 and each of them have varying computing capacity. The processing speed of the fog nodes is taken as 2 GHz. The task sizes are varied from 100-500 bytes. The transmission range of IoT nodes is taken as 300m. The fading model used is Nakagami-m. The computing units of fog nodes are taken as 3-5. The IoT and fog nodes are uniformly distributed in the region of 500m by 500m. The queue size at fog nodes is taken to be infinite.

Table 2: Simulation Parameters

Simulation Parameter	***Value in the simulation***
Number of IoT nodes	10-30
Number of tasks	1 per second by IoT node
Number of fog nodes	5
Processor speed of fog nodes	2GHz
Task sizes	100-500 bytes
Transmission Range	300m
Fading Model	Nakagami-m
Computing units of fog nodes	3-5

The comparison of the results of the proposed technique is done against two other algorithms. The first is the matching theory-based algorithm in which task size is considered as preference profile to conserve energy [21]. The second is the one in which delay is considered as the preference profile to improve delay [23].

In Fig. 5, the results related to energy are presented and it can be seen that the proposed technique is better than both other approaches of energy-based profiling and delay-based profiling. The reason for this improvement is that the proposed technique considers remaining batter life of IoT nodes which is missing in other work. As a result, the overall energy consumption of the system is reduced. For example, the proposed technique only results in 120J of energy at the highest number of IoT nodes. This is much less than other techniques that can take up to 200 J. As a result, the proposed technique is much more efficient in terms of energy consumption.

Results in Fig. 6 show that the task delay of the proposed technique is also improved at different number of IoT nodes. Initially, when load of tasks is less, the delay based profiling performs slightly better. But when the load is increased, the proposed technique is the best option in terms of delay. The tasks can be computed well within 13s. The energy-based profiling takes 18s to compute and delay-based profiling takes 14s. This shows that the proposed technique is much better in terms of delay at high load of tasks. This is the scenario where task offloading is critical and the proposed technique performs better.

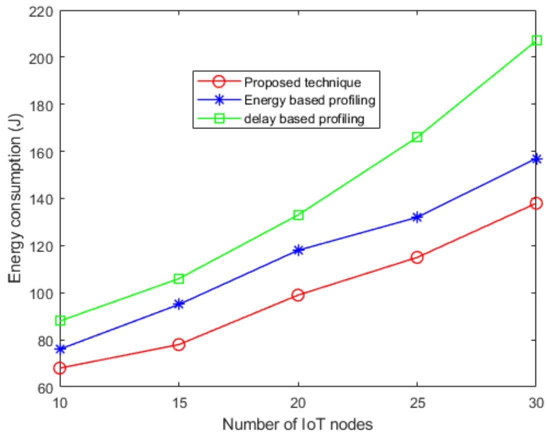

Fig. 5 Energy consumption vs number of IoT nodes

In Fig. 7, the results are plotted for percentage of task outages against the number of IoT nodes. The task outage happens if the task cannot be computed within the deadline due to waiting in the queue. This is a measure of inefficiency of the algorithm and can result in application to fail. The results show that task outages are much more for the energy-based profiling as it does not focus on the delay. The delay-based profiling performs good initially, but its performance is slightly bad as compared to the proposed technique.

In Fig. 8, the plot of remaining battery life of the IoT tasks at end of simulation is given. This is an important metric as remaining battery life is necessary for longevity of IoT nodes. Hence, nodes with high battery life will sustain for more time and will be active for longer duration. It is quite clear from the results that the proposed technique focuses on battery life and has the highest performance in this metric. The other techniques fail to capture this metric in their algorithm, and it can be seen clearly in the results. For the proposed technique, more than 70% battery remains intact as compared to other protocols whose battery fall to 40%.

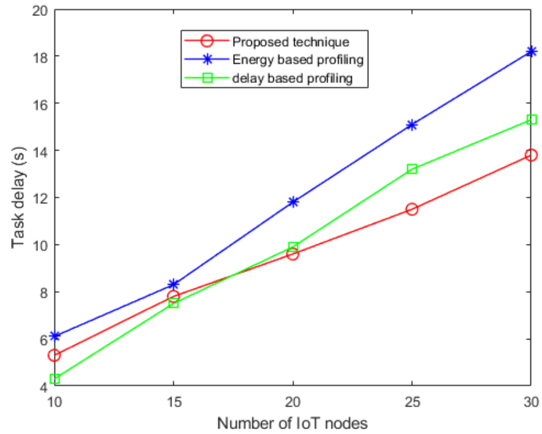

Fig. 6 Task Delay vs number of IoT nodes

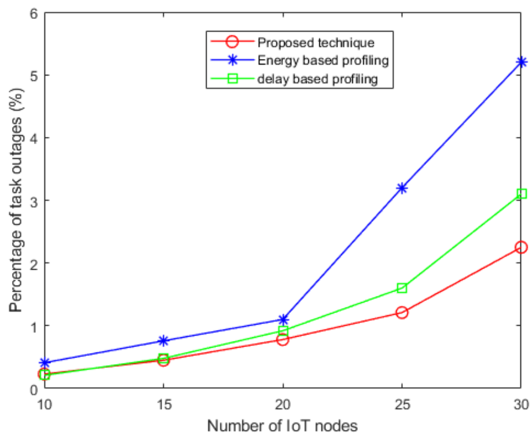

Fig. 7 Percentage of task outages vs number of IoT nodes

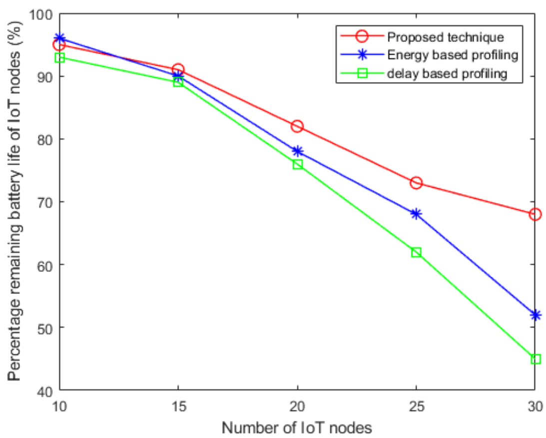

Fig. 8 Percentage of battery life of IoT nodes vs number of IoT nodes

6. Conclusion

The paper focuses on energy efficient allocation of fog computing units to the IoT nodes. The paper proposes a novel algorithm that considers remaining battery life of the IoT nodes, distance of fog nodes, transmit power of IoT nodes and task sizes to develop a resource allocation algorithm. The preference profiles of both sides are developed using the above factors related to energy. The stable matching algorithm is used to manage the mapping of the computing units with the tasks. Extensive simulation results are plotted and can highlight the performance improvement of the proposed technique as compared to delay-based profiling and energy-based profiling.

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