Optimizing the Operational Time of IoT Devices in Cloud-Fog Systems

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Abstract. With the increasing number of connected devices, sensors, data generated need to be analyzed. The current cloud computing model, which concentrate on computing and storage resources in a few large data centers, will inevitably lead to excessive network load, end-to-end service latency, and overall power consumption. This leads to the creation of new network architectures that extend computing and storage capabilities to the edge of the network, close to end-users. The emerging problem is how to efficiently deploy the services to the system that satisfies service resource requirements and QoS constraints while maximizing resource utilization.

In this paper, we investigate the problem of IoT services deployment in Cloud Fog system to provide IoT services with minimal energy consumption. We formulate the problem using a Linear Programming (LP) model to maximize the operational time of Cloud-Fog system as well as the IoT services specific requirements [1]. We propose a new heuristic algorithm to simplify the problem. We compare the lifetime of the proposed algorithm with the optimal solution solved by Linear Programming. The experimental results show that our proposed solution is very close to optimum solutions in terms of energy efficiency.

Keywords: IoT · Cloud-Fog system · Battery constraint · Operation time · Linear Programming

1 Introduction

Along with the development of connected devices and smart environments, the Internet of Things (IoT) has been receiving attention for years because of the growth in the number of devices.

Recently, Cisco has introduced Cloud Fog computing as a new paradigm which takes advantage of the extensive resources in the cloud while being able to expand computing power to the edge of the network, close to end-users. Figure 1 illustrates the architecture of a Cloud-Fog system with three hierarchical layers. At the edge most of the network is the device layer which contains numerous sensor devices. They can be widely distributed at various public infrastructures to monitor the environment over time. Each node either collects data (i.e., video, temperature, noise) or performs a certain function (i.e., sprinkle, smart light). Data generated by IoT devices can be sent to and processed and deployed at the fog nodes near by the data sources. The fog nodes can be micro clouds, access network devices or even user devices, which located in a

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wide-spread geographical area, together they form the fog layer that lies between the device layer and the cloud layer. Each fog node is connected to and responsible for a group of IoT devices, performing data analysis in a timely manner. On top of the architecture is cloud layer consists of a number of powerful servers allocated in a few data centers. The cloud layer is considered as an unlimited resource pool providing an ability to process computational-intensive tasks, store a massive amount of data [2, 3].

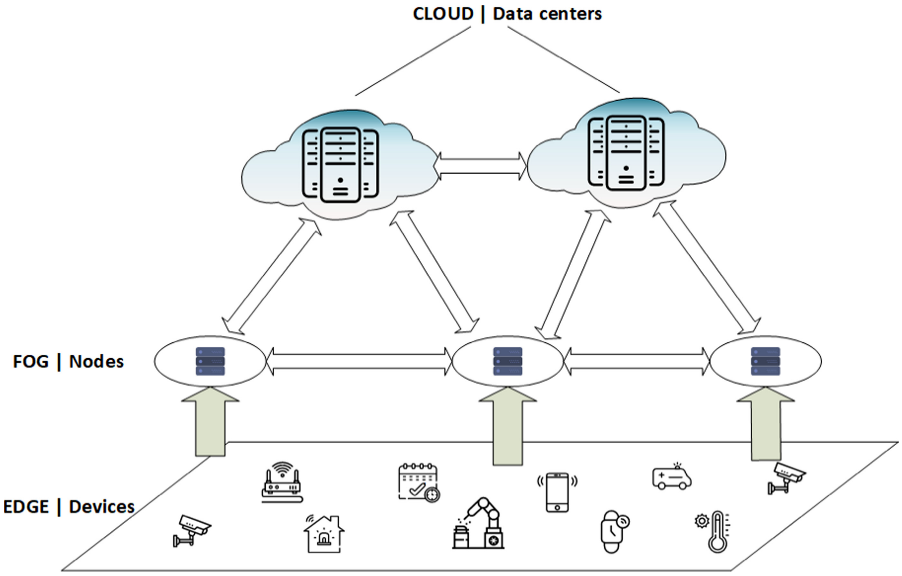

Fig. 1. Three-layer Cloud-Fog system paradigm.

The Cloud-fog system is considered to be an efficient solution for providing resources to handle newly emerging IoT services with tightly QoS constraints. However, the computing intensive functions of IoT services can not be deployed to the devices due to its limitations on computing power and battery life.

2 Linear Programming Model for Optimizing the Operational Time of IoT Devices with Multiple Fog Nodes (Fns)

To model the energy consumption of the FN problem, the full wireless radio energy dissipation model is not used. A very simple energy usage model is given below. The validation of the simulation results is not affected.

$$E(S) = d^2, E(D) = 0 \tag{1}$$

where S is the energy to transmit data, D is the destination node. In other words, the energy to transmit a unit of data is equal to the square of the distance to a destination, and the energy to receive data is equal to zero [5].

We define a round of operation of a IoT device as the time the device must transmit a unit of data to the closest FN. It is also assumed that only k FNs from N FNs ($k < N$) as the FNs in each round of transmission and the role is reallocated among all FNs so the system lifetime is maximized. The linear programming model needs to calculate the optimal usage of FNs under the battery constraint of every IoT device [5–7].

Given a Cloud Fog network with k Fog Nodes (FNs) in the set of N FNs, each IoT device connect to the closest FN of the k FNs provides the optimal lifetime for the Cloud Fog network.

In more detail, we have n IoT devices located in the Cloud Fog system. We define W as the set of ways to choose k FNs in the given set of N FNs. If every FN is different to the remaining $N - 1$ FNs, the number of items in W is $\binom{N}{k}$. The energy c_i^j is equal to the energy dissipation of Device j to send a unit of data to the closest FN in the i^{th} element in W. We define n_i as the number of rounds, the i^{th} item in W is chosen as the active FNs. We define E_j as the initial energy of Device j. We also define O as the optimal solution of the following Linear Programing problem:

Maximize:

$$\sum_{i=1}^{\binom{N}{k}} n_i$$

Subject to:

$$\sum_{i=1}^{\binom{N}{k}} n_i c_i^j \le E_j : \forall j \in [1\ldots n] \tag{2}$$

$$n_i \in Z^+ : \forall i \in [1\ldots\binom{N}{k}]$$

3 Proposed Heuristic Algorithm

The solution given by the above LP model for the IoT devices networks is not simple for calculation. Each time, there is a change in the network, the solution needs to be recalculated. Also, IoT devices are too small to solve the LP model. Furthermore, it is infeasible to calculate an optimum solution for the big cloud fog network. We need to find out a heuristic algorithm to calculate the FN pattern.

In the heuristic algorithm, the FNs pattern needs to be reallocated among the IoT nodes so that the minimum residual energy of all IoT device is maximized. As the process is rerun in every round, the energy consumption of active FNs is reasonably distributed among all FNs so that the operational time lasts until a IoT device dies. The heuristic method is called Modified-LEACH (M-LEACH) and can be stated as below [4, 8, 9].

M-LEACH:

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In every round, select $k$ FNs randomly from all $N$ FNs in Cloud Fog networks.
Given:
$N$ The number of FNs indexed from 1 to $N$
$s$: The current FN pattern
For every round of data transmission
$i$ = Random (1..N) Repeat for $k$ different FNs
Result: $s$ is the FNs pattern for the current round
Repeat until the first IoT device dies
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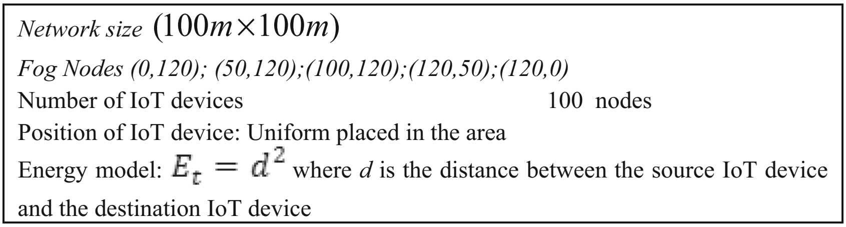
4 Simulation Results

Visual Studio C++ is used to simulate the efficiency of M-LEACH. For the calculation of the optimum solution, we use the LP solver mentioned in [10]. The coefficients of the analytical model for different Cloud Fog topologies are generated from a C++ application. In the program, every possible combination of k *FN*s from N FNs is generated and the energy usages of sending data from all IoT devices to each combination active FNs are calculated.

In our experiments, 100 random 100-node IoT networks are generated. Initially, each node has 3,000,000 units of energy. The algorithm M-LEACH is run over the network topologies while the number of FNs k is set to 3 and N is set to 5, and the operational time is calculated for every Cloud Fog topology. The Cloud Fog networks are given below. The IoT device positions and the FNs position are described as in Fig. 2 and Fig. 3.



Network size $(100m \times 100m)$

Fog Nodes (0,120); (50,120);(100,120);(120,50);(120,0)

Number of IoT devices 100 nodes

Position of IoT device: Uniform placed in the area

Energy model: $E_t = d^2$ where d is the distance between the source IoT device and the destination IoT device

Fig. 2. IoT devices and Fog Nodes.

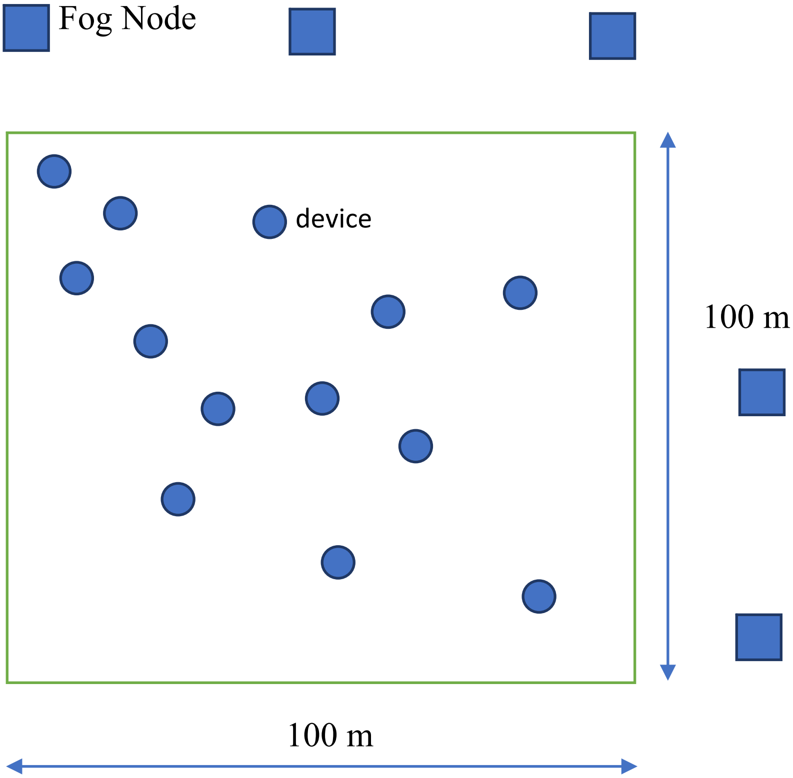


Fig. 3. Cloud Fog network topologies.

The performance of the heuristic M-LEACH and the optimum solution from the analytical model is compared. For the optimum solution, the analytical model in Sect. 2 is used where k is set to 3 and N is set to 5. Both methods are run over the above 100 network topologies and the ratio between the lifetime of M-LEACH and the optimum is calculated. Figure 4 shows that M-LEACH simulation result is very close to the optimum solution (Table 1).

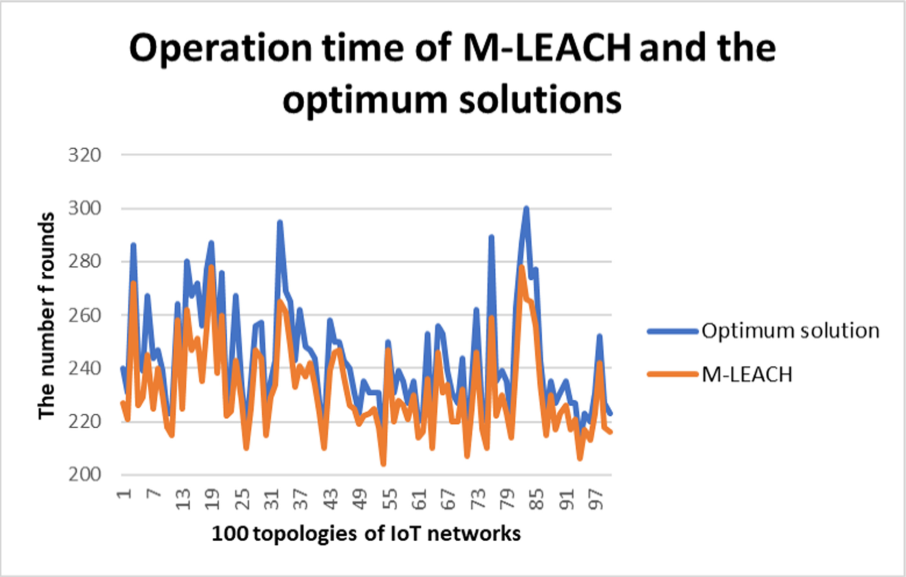


Fig. 4. Simulation results compared M-LEACH and the optimum solution.

Table 1. Results for Fig. 4.

Statistics	M-LEACH/Optimum solution
Mean	**0.89**
Variance	**0.0005**

5 Conclusion

In this paper, we model the IoT services deployment in Cloud Fog system using a Linear Programming (LP) model taking into account the characteristics of energy resources in Cloud-Fog system and IoT devices. However, it is impractical to find the solution of large Cloud Fog network. Therefore, heuristic algorithms are needed to solve the problem. A new heuristic method M-LEACH is then proposed. 100 random 100-node networks are used to evaluate the performance of the methods. Simulations show that M-LEACH provides performance very close to the optimum solutions.

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