An efficient grey theory-driven path selection for energy efficiency control in the Internet of Things using fog and cloud computing

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Abstract

Due to the big data exchange on the Internet of Things, proper routing and selecting the best routes for fast data transmission improve network performance. There are major challenges, like high delay, when cloud computing is used. Therefore, one solution is to use other schemes, such as fog computing. In fog computing, all data is not sent to the cloud and the fog nodes close to objects are used for data processing. This reduces the network delay. In this paper, we propose an overlapping clustering method called MFCT-IoT to select the best cluster head nodes to guarantee the fast data transfer from objects to fog nodes. The selected cluster head nodes are responsible for sending the collected data to the closest fog nodes in the network edge. Upon receiving the data, the fog nodes process it, and if a response is ready, they respond immediately to the object. Otherwise, they merge and transmit the data to the cloud servers, which are considered as the root node of the proposed hierarchical tree. After processing, the merged data is sent to the object. We compare the proposed scheme with two schemes, including ERGID and EECRP. These schemes are evaluated based on various criteria, including the response time, packet delivery ratio, end-to-end delay, network lifetime, and energy consumption. The results indicate that the proposed method outperforms others in terms of all criteria.

Keywords Internet of Things (IoT) · Overlapping clustering method · Gray system theory · Fog and cloud computing

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1 Introduction

In the Internet of Things (IoT) networks, each node has limitations in energy consumption. It is very important that nodes are kept active and the best node is selected to send data. In the IoT, to reduce the energy consumption when collecting data from objects, one solution is to use the clustering-based routing methods. On the other hand, fog computing can meet the requirements of the IoT applications because it is close to end-users. Therefore, it is known as a suitable solution to reduce delay in the data transmission process [1,2].

In the cloud computing model, servers execute the application operation to process data sent from objects. However, when the networks are compressed and the servers are filled, it is necessary to manage a large volume of data sent from objects [3,4]. The fog computing model has been developed to improve the efficiency of IoT. In this case, the sub-processes of an application are executed not only on the servers but also on the fog nodes. Finally, the server receives the processed data from the fog nodes. Therefore, the fog computing model can reduce data traffic sent to servers for data processing and the number of data transmission in the networks [5,6].

Topology management is one of the most important issues in large-scale IoT networks. In this regard, one of the common topology management methods is clustering. Clustering techniques divide the network into several small groups. Each group includes a number of nodes. In the clustering process, the network operations are distributed among the group members to improve data collection, transmission operations, and resource management [7]. A cluster includes a number of nodes called cluster members (CMs) and one or more cluster head nodes (CHs). Clustering has many advantages, such as reducing resource consumption, balancing load, and tolerating fault. However, clustering is very challenging in IoT due to heterogeneity and mobility of nodes, as well as the integration of IoT with networking platforms and new computing techniques such as cloud computing, fog and edge computing [8,9]. These new techniques can change the nature of the network topology from multipoint-to-point mode to multipoint-to-multipoint mode. This makes new challenges when designing clustering-routing algorithms. It should be noted that clustering can improve the data collecting and processing processes in the fog environment and provide better data management. Clustering-routing techniques can significantly reduce energy consumption, but their implementation is difficult because routing protocols in the IoT should be able to support point-to-point, point-to-multipoint, multipoint-to-point, and multipoint-to-multipoint communications. On the other hand, the transmission of a huge volume of data generated in the IoT networks is a major challenge because of the energy [10], memory [11], and processing power constraints [12]. In addition, nodes can be joined or removed to/from the network at any time. Therefore, routing protocols designed in IoT networks should be scalable and energy-efficient. Moreover, they should consider heterogeneity and mobility of devices, periodic connections, limited resources, and topology changes [13,14].

The proposed method selects the optimal route in two phases. First, we use the gray system theory to select cluster head nodes (CHs) based on several criteria, including object energy, hop counts, the distance between objects and fog nodes, link expiration time, and signal to noise ratio. Eventually, a node, having highest rank, is selected as a CH. The second phase addresses the data transmission process between the fog and cloud servers. In the proposed scheme, we apply fog computing in which data is not directly sent to the cloud (unlike cloud computing). Compared to cloud computing, fog computing has more advantages. For example, it decreases network traffic, reduces delay, and improves scalability. The proposed approach is an improved version of the P-SEP protocol [15,16]. This protocol has been introduced to increase the network lifetime in the fog-based networks. In the proposed method, each fog node covers a region of the network. It is called the fog node coverage region. In the network, each region consists of sensors nodes. The main task of the sensor nodes is to collect environmental data and send the collected data to their CH. Also, the main task of cluster head nodes is to receive, aggregate, and merge data packets received from the nodes. Next, CHs send the collected data to the fog nodes. Furthermore, the main task of the fog nodes includes receiving the data from cluster head nodes, combining them, and delivering them to the cloud servers.

In the proposed method, the main contributions are:

- Choosing CH nodes using the gray system theory based on criteria such as object energy, number of hops, distance between the object and fog node, link expiration time, and signal to noise ratio.
- Using the overlapping clustering technique for clustering. In this clustering method, boundary nodes can simultaneously be a member of several clusters. This can reduce the packet loss rate in the network.
- Organizing fog nodes in a hierarchical tree for transferring data efficiently to the cloud server.
- Evaluating the proposed scheme in terms of packet delivery rate (PDR), delay, response time, and network lifetime.
- Comparing the proposed method with two schemes, including ERGID and EECRP in four scenarios with different data transmission rates.

The rest of the paper is organized as follows: Sect. 2 presents related work. The proposed MFCT-IoT approach is introduced in detail in Sect. 3. Section 4 presents the performance evaluation. In this section, the simulation results of the proposed method are compared with other schemes. Conclusion is presented in the final section.

2 Related work

In this section, we review the recent studies related to the research subject.

Qiu et al. in [17] presented an emergency-aware method called EARS, which is a lightweight approach. In this scheme, Qiu et al. consider the energy factor in the network to present an optimal scheme in terms of energy. Another advantage is that EARS can recover lost packets. Also, this scheme reviews the routes to obtain information about packet delivery emergency. This approach proposes an Implicit ACK mechanism, which utilizes the pre-hearing feature and wireless channels. Furthermore, this protocol selects suitable routes based on link quality.

Sobral et al. in [18] proposed a lightweight routing scheme called LOADng-IoT. This scheme is a reactive routing protocol. It means that, routes are created only when there is a route request. It uses the route request (RREQ) packet and the route reply (RREP) packet to find the best routes. This scheme includes three steps. (1) Internet route discovery process, (2) Internet route cache system (IRC), and (3) Improving the route error message (RERR). If a node (source node) wants to communicate with another node (destination node) and there is not any route between these nodes. Then, the source node starts the route discovery process. LOADng-IoT does this process similar to AODV [19]. After creating the desired routes in this process, the source node can safely transfer its data packet to the destination node via the routes. For this, the source node first searches the routing table stored in its memory to find its desired route to the destination and transfers its message to the next hop node at the route. Also, the source node updates the valid time corresponding to this entry in its routing table. After receiving the data packet by the intermediate node, the node searches its own routing table for transmitting this data packet to the next hop node in the route. This process continues until the data packet reaches the desired destination node.

Rahbari and Nickray in [20] offered a scheme based on fog computing, in which mobile devices can run their heavier computations on fog devices. It is an important challenge in terms of time and energy consumption to select the best fog devices for offloading. For choosing the best fog devices, they propose an suitable algorithm, which is called the module placement method by classification and regression tree algorithm (MPCA). This algorithm has two phases. Firstly, it evaluates energy consumed in the mobile devices and compares this value with an threshold i.e. the Wi-Fi energy consumption. Secondly, it resets the offloading process, when this energy value is more than the threshold. In MPCA, various parameters are considered such as authentication, privacy, availability, capacity, speed, and cost to select the best fog device. Network resources on offloading module is analyzed to optimize MPCA. The authors evaluate MPCA in terms of several parameters, including energy consumption, response time, and performance. These results show the successful performance of MPCA.

Naranjo et al. in [21] suggested a fog computing-based method called P-SEP. It improves the stable election protocol (SEP). It can balance energy consumption and improve the stable period of Fog-supported sensor networks. P-SEP presents a CH selection process and distributes uniformly the nodes in the network. It can elongate the network lifetime, especially FND. This method is presented for heterogeneous wireless sensor networks. Therefore, P-SEP considers two types of nodes, including advanced nodes (high-energy nodes) and normal nodes (low-energy nodes). The purpose of considering nodes with different energy levels is that nodes with very low energy cannot be selected as CH. Fog nodes collect information about the distance between nodes and communication links between them. This information is used in the clustering process. In P-SEP, both advanced and normal nodes can be selected as cluster head nodes. There are two limitations for selecting CH nodes: (1) The energy of the nodes should be more than a threshold value. (2) This node is not selected as CH node in the previous round.

Borujeni et al. in [22] proposed two routing algorithms, namely FEAR and FECR. These algorithms utilize fog computing. Also, they are inspired by P-SEP. In these schemes, a clustering algorithm is presented to select the best CH nodes in the network. This algorithm only considers the residual energy of nodes in the clustering process.

In the network, the task of fog nodes is to exchange data packets between the cloud space and the sensor network. FEAR and FECR determine how to send data packets to the cloud space. For this, FECR creates a chain between the nodes using the PEGASIS [23] algorithm to transmit data packets to the cloud. Whereas, FEAR creates routes using the ant colony optimization (ACO) algorithm. The main task of CHs is to collect data packets from sensor nodes and send them to the closest fog node. Finally, the fog nodes collect these data packets and upload the collected data packets in the cloud using FEAR and FECR.

Kar and Misra in [24] presented a routing scheme. Based on this approach, each sensor node can transfer its data packets to the cloud servers in the network. These servers are responsible for processing the data packets and sending activities to actuators. Fog computing is a useful tool for addressing the scalability problem in IoT. This scheme can handle the data flow in mobile edge network. Also, the base stations and fog nodes are connected to each other. Fog nodes are responsible for calculating the local resources and transmitting data to the cloud servers using software-defined networking (SDN).

Iwendi et al. in [25] suggested a clustering scheme in the Internet of Things to select the most suitable CHs for optimizing the energy consumption in the network. This clustering approach utilizes a hybrid meta-heuristic algorithm called WOA-SA. In the clustering process, CHs are selected based on several parameters, including the number of alive nodes, load balance, residual energy, and operation costs. This algorithm outperforms other schemes, including artificial bee colony (ABC) algorithm, genetic algorithm (GA), and compatible gravitational search (CGS) algorithm.

Chandnani and Khairnar in [26] offered a routing method, which is inspired by LEACH. This scheme is called MPR-LEACH and its aim is to improve the PR-LEACH method. In the routing scheme, the distance parameter is considered to reduce communication overhead between CHs and the sink node. As a result, it improves the energy consumption levels and increases the sensor node lifetime in the IoT. In this scheme, CHs are selected via evaluating a threshold value. This method only takes into account two parameters, including energy, and distance between CH and sink. However, considering other parameters, like packet delivery rate and throughput can improve this scheme.

Zhu et al. in [27] proposed a routing protocol. It is called the kernel tree routing protocol (KTRP). The routing process is done based on two parameters, including delay and reliability. This scheme applies an one-hop delay model for evaluating delay in the media access control (MAC) layer. Furthermore, the main properties of this protocol are defined. They include three strategies, including sending, maintenance, and efficiency. For more details, please refer to [27]. KTRP utilizes a machine learning technique i.e. deep learning theory. Firstly, the authors presented a direct transmission algorithm, which uses information of neighboring nodes. This algorithm seeks to reduce the number of hops. When the tree topology is created, sensor nodes can directly transmit their data packets to the destination node. Secondly, the authors presented a new stabilizing algorithm. This algorithm can prevent the duplicated connection requests. This algorithm uses a tree topology. Therefore, it can save energy in the network. In the third step, the authors try to enhance the link utilization using wired link priority policy. Furthermore, multicast mechanism was considered to reduce delay.

Jin et al. in [28] proposed the content-centric routing (CCR) method. CCR determines routes based on the available content. When the correlated data is sent to intermediate relay nodes for processing, the data aggregation ratio is increased. It can reduce network traffic. Therefore, the network delay is decreased. Furthermore, the data aggregation process can lower redundancy. CCR can help energy saving in the wireless data transmission process. This increases the lifetime of sensor nodes in the network. CCR can be integrated with the IETF RPL protocol. They work successfully on the network. This scheme has been implemented on the Contiki OS using the TelosB platform.

Qiu et al. in [29] offered an energy-efficient routing protocol in IoT. This scheme is called EECRP. The aim of EECRP is to improve network performance. EECRP presents a clustering algorithm. In the clustering process, CHs are rotationally selected to distribute uniformly energy consumption among all sensor nodes. Also, it presents a new mechanism to lower energy consumption in communication at long distances. This distributed clustering technique allows sensor nodes to locally self-organize themselves. Furthermore, EECRP uses the residual energy of the nodes to calculate the centroid position [30].

Shen et al. in [30] introduced a routing scheme called ERGID. It considers the delay in the routing process. They proposed a mechanism called the delay iterative method (DIM) to estimate delay. DIM solves issues, which are rooted in ignoring valid routes. DIM orders the nodes based on the estimated delay in the candidate set. At the same time, ERGID updates the routing table periodically. The updating process is done via communicating with neighboring nodes. ERGID can balance load during transferring data packets because it uses the residual energy probability choice (REPC) strategy. According to this strategy, sensor nodes, which have more energy, can be selected as a transport node [29].

Energy-efficient routing in Internet of Things (IoT) networks is critical for optimizing network performance, particularly when integrated with fog and cloud computing. Recent advancements have focused on enhancing security and fault tolerance to support efficient data transmission. Lightweight authentication methods in IoT-based medical care ensure secure and energy-efficient data exchanges, reducing overhead in routing protocols [32]. Hierarchical methods using fuzzy logic improve security in IoT, enabling robust cluster head selection for energy-efficient routing [33]. Fault tolerance improvements using residue number systems enhance ad-hoc networks' reliability, supporting stable routing under resource constraints [34].

These advancements collectively strengthen grey theory-driven routing protocols, integrating security and fault tolerance for optimized IoT performance.

3 Conclusion

In this paper, MFCT-IoT was introduced to find the best node as a cluster head based on the gray system theory according to several parameters, including E_{RE} , HC, D, LET, and SNR. In the next step, the fog nodes were organized hierarchically in a height-balanced tree to send the processed data to the server. In the proposed method, the optimum routing is a significant challenge to transfer data from objects to cloud servers to not only reduce energy consumption, but also improve other criteria such as latency and network lifetime. To this end, a method was proposed in which the best paths areselected from objects to cloud servers based on hierarchical routing and clustering. Thus, objects become members of clusters through overlapping clustering and send data to their own cluster head. The hierarchical routing was used to send data from fog nodes to cloud servers to reduce the path and response time. If the fog node can process data and produce a response, there is no need to send data to the cloud server, and the response is immediately provided to the object. Otherwise, the data is processed, merged, and sent to the cloud servers. This can reduce latency in sending and processing data. The simulation results of the proposed MFCT-IoT method are compared with ERGID and EECRP in terms of the response time, packet delivery ratio, end-to-end delay, network lifetime, and energy consumption. These results show that our scheme outperforms others. In addition to the issues mentioned in this research, it is very important to provide solutions for optimizing energy consumption, reducing delay, and increasing the quality of services in IoT. Therefore, some future research directions include presenting clustering schemes combined with the metaheuristic algorithms, using optimization techniques for selecting CH nodes, prioritizing according to the type of IoT requests or based on particular applications, and paying more attention to information security and its enhancement to resolve future requirements and new fields.

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