MINIMUM POWER CONSUMPTION ROUTING USING HIERARCHICAL FUZZY LOGIC CLUSTERING FOR INTERNET OF THINGS

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Abstract. The Internet of Things (IoT) is a very famous network because of its many applications. IoT network has an integration of large-scale IoT devices that generate data. These IoT devices are very low power computing devices due to which they have a low level of communication. These devices construct data and transmit the data to the base station via intermediate IoT devices. The base station gathers and integrates the data and sends it to the administrator for further processing. The data attains the base station using various routing algorithms with the goal of low power consumption. When discussing low power IoT devices, power efficiency is an important performance measurement when creating a routing algorithm. This paper proposes a Minimum Power Consumption Routing (MPCR) algorithm using Hierarchical Fuzzy Logic Clustering (HFLC) algorithm for IoT networks. The MPCR with HFLC algorithm is an energy-efficient algorithm because of its lower power consumption for the cluster by aggregating the data within the cluster head and decreasing the number of data transmissions to the base station. In this paper, the cluster formation and cluster-head selection are explained, and a simulation has been conducted. In addition, the proposed algorithm is compared with the existing algorithms based on different metrics such as throughput, packet delivery ratio, and energy consumption of the network. The experimental results show that the proposed MPCR with the HFLC algorithm provides high throughput and packet delivery ratio and reduces energy consumption more efficiently than other existing algorithms.

Keywords: Clustering, Routing, Energy consumption, hierarchical clustering and fuzzy logic.

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1 Introduction

The Internet of Things (IoT) is currently discovering a broad range of applications in different fields, such as smart home, smart city, healthcare, industrial automation, disaster management, agriculture, etc. The IoT network generally uses IoT devices that are wirelessly linked together to accomplish a specific intelligent task [10]. One thing that distinguishes the IoT network from the conventional wireless sensor network (WSN) is that, unlike the latter, the devices on the IoT network dynamically connect to the internet and perform a task in conjunction with other similar devices [12]. Like the classical WSN network, IoT devices typically periodically send the gathered event data to the base station (BS). Followed by the base station transmits the attained data to the admin. IoT utility devices typically contain transceivers, batteries, and microprocessors to perform key functions [2].

Because of its feature, the IoT network has numerous applications, from monitoring to surveillance and remote access to automation. The IoT network has numerous applications and is more famous in nearly all technology fields. For example, industrial process monitoring, health care monitoring, battlefield monitoring, border field monitoring, smart city traffic monitoring are important applications [7]. The application is also used for remote access and automation, which contains Smart Water Supply System, Smart Grid, Smart Traffic Management, Smart Hospital, Smart Home and industry 4.0 and more. A few applications of IoT networks include IIoT, water control monitoring and leakage reduction system, disaster detection system, smart farming to increase productivity, smart traffic monitoring and smart health monitoring. The major need to attain all applications is to gather and send data. Data transfer from any IoT device can be done up to a specific distance because of its low communication capability. To send data from the IoT device to the base station, the other intermediate device must cooperate. The IoT device acts as both a source device and a relay device. The data should arrive at the base station with less latency; higher reliability by utilizing less power is the motivation for proposing any routing algorithm [6]. In most battery-powered applications, such as IoT devices, we place more emphasis on power consumption.

To address these types of problems, this paper proposes a Minimum Power Consumption Routing (MPCR) algorithm using the Hierarchical Fuzzy Logic Clustering (HFLC) algorithm for IoT networks that will be more energy efficient. Using the MPCR algorithm, we could decrease the number of data broadcasted to the base station by aggregating the data in the cluster head, decreasing the transmission cost and preserving the battery power. The MPCR algorithm further decreases the overheads in the network for keeping the routing path. Cluster formation implements based on Hierarchical clustering. Hierarchical clustering makes a hierarchy of clusters by either frequently combining two smaller clusters into a larger one or partitioning a larger cluster into smaller ones. Cluster head formation implements based on the Fuzzy Logic technique. Fuzzy logic is one of the computational intelligence techniques that could be utilized in applications with uncertainties. The formation of clusters in IoT may not be appropriate if it is based on fixed rules since the competence is based on overlapping metrics like energy, the density of devices, the distance between devices and base station etc. Thus, Fuzzy Logic is appropriate in cluster head selection solving the uncertainties.

The rest of the paper has been prearranged: In section 2, the related work in cluster-based routing has been explored. In section 3, the proposed Minimum Power Consumption Routing (MPCR) algorithm using the Hierarchical Fuzzy Logic Clustering (HFLC) algorithm developed in this work has been comprehensive. In section 4, the evaluation of the proposed work and the results with appropriate comparative analysis. At last, we concluded this paper in section 5.

2 Related Work

Sankar et al. [10] presented a multi-layer cluster-based energy-aware routing protocol for Low Power and Lossy Networks, splitting the network region into equivalent length rings. The intra-ring clustering procedure splits a ring into equivalent-sized clusters, and inter-cluster routing chooses the most excellent route for data transfer. As a result, it raises the network lifetime and packet delivery ratio by 18 to 22 % and 5 to 8 %, respectively.

Sujanthi et al. [12] develop a Secure Deep Learning (SecDL) technique for dynamic cluster-based WSN-IoT networks to give power competence to high stage security. To enhance power competence, the network is implemented to be Bi-Concentric Hexagons together with Mobile Sink technology. Dynamic clusters are constructed within the Bi-Hex network, and the best cluster heads are chosen by Quality Prediction Phenomenon (QP2) to ensure QoS and other power competence. Data aggregation is allowed in each cluster and managed by a Two-way Data Reduction then Elimination scheme. A One Time-PRESENT (OT-PRESENT) cryptography algorithm is implemented to attain high-stage security for aggregated data. After that, the ciphertext is sent to the mobile sink by best route to ensure high-stage QoS. For the best route chosen, a Crossover based Fitted Deep Neural Network (Co-FitDNN) is provided. This work further focused on IoT-user security because IoT users could use the sensory data. This work used the concept of data mining to validate the IoT users. All IoT users are authenticated through an Apriori-based Robust Multi-factor Validation algorithm that maps the perfect authentication feature set for all users. In this method, the SecDL technique attains energy efficiency, QoS and security.

Aranzazu-Suescun et al. [2] presented a development of the reactive, anchor-based routing protocol by limited flooding and dynamic clustering. The authors presented an event-based clustering method and a dynamic clustering method. This enhancement results in decreased power expenditure also a high number of packets process effectively through the base station. Data gathered by the mobile sink are distributed to the end-users by the IoT infrastructure.

Maheswar et al. [7] presented a cluster-based Backpressure routing (CBPR) method that has been proposed, which goals to extend the lifetime of the network and improve the data transmission dependability utilizing the power load-balancing method. For every cluster of the sensor device, the CBPR method chooses a cluster head with the highest power level. In addition, the CBPR routing method also uses a more strong data aggregation algorithm to checkmate avoid the flow of redundant data packets in the network while further utilizing the Backpressure scheduling machine for data packets queuing and for the path chosen, which permits it to choose the next-hop sensor device using the queue length value of the sensor devices.

Jilong Liet al. [6] provided routing protocol using clustering. In this protocol, the author's major focus is to balance the load between the sensor devices to attain an improved network lifetime and decrease the end-to-end delay.

Muhammad Asad et al. [4] provided a novel variety of clustering protocols. The entire network is separated into two parts; in the first part, the centralized technique was utilized, and in the second part, the disseminated technique was utilized. The author presumes that in the network both heterogeneous and homogeneous kind of sensor does not exist, the position of the sink is static, and it will be in the centre of two divisions of the network.

Raj Kumar et al. [9] presented a cluster-based routing protocol for WSN-Assisted IoT. In this routing protocol, primarily three stages exist; in the first stage, the zone in the network will be formed for the communication. In the second stage, the zone cluster will be created, and at the last stage, the zone head will be chosen utilizing the power and location. The transmission between the zone head and the base station will be single-hop or multi-hop based on the circumstances.

S. K. Sathya et al. [8] presented a modified fuzzy-based clustering protocol for IoT enabled WSN. For choosing the cluster head in this algorithm, a fuzzy multi-criterion most excellent technique is utilized. The cluster head criterion contains residual power, quality of services (QoS), and the sensor device position.

Muhammad Arshad et al. [3] presented a multi-tier routing protocol for IoT enabled WSN. In this protocol, numerous clusters are constructed using randomly chosen cluster heads. Then, the cluster head forwards the data to the base station using an intermediate cluster head. Therefore ultimately, it executes like a multi-hop routing protocol.

S. M. Amini et al. [1] presented a Two-Level Distributed Clustering (TLDC) protocol for massive IoT networks. In this, two cluster heads are chosen, known as primary and secondary cluster heads. Sensor devices transmit their data by any cluster head, which provides more dependability to the network.

Xinxin Du et al. [5] presented routing protocol using the conception of compression. The core conception of this protocol is to decrease duplicate data and merely transmit the unique data to the base station. It is also utilized for predicting the data created through the sensor network.

Anurag Shukla et al. [11] proposed a Scalable and Energy Efficient routing Protocol known as SEEP, a multi-hop cluster-based routing protocol that separates the entire network into various zones. Each zone contains numerous clusters known as sub-zones. The number of clusters close to the base station raises. The sensor devices would be chosen like the relay device and cluster head. Any sensor devices transmit their data to the base station by the relay device or the cluster head in a multi-hop manner.

3 Minimum power consumption routing (MPCR) algorithm using hierarchical fuzzy logic clustering (HFLC) algorithm

In the routing algorithm for the IoT network, if any source IoT device desires to transmit the data, it could send the data to the base station if the distance between the source IoT device and the base station is one-hop. Otherwise, the source IoT device sends the data to its neighbour device; that device acts as a relay device and sends it to the base station via other intermediate relay devices. Many routing algorithms are based on how data is sent from any source IoT device to the base station. The cluster-based routing algorithm is famous among all varieties of routing algorithms because of its benefits over the low power IoT network. The benefits of cluster-based routing algorithms are because of the base station's decreased number of data packets. However, because of the dense deployment of IoT devices into the networks, the base station obtains the same type of data which raises the overhead into the network and surely does not make any sense for building the decision. In the cluster-based routing algorithm, the cluster head obtains the data from the cluster members, and it aggregates the data; after that, it will transmit only one aggregated data to the base station, which severely decrease the number of data packets obtained by the base station and ultimately guide to power proficient network.

Clustering in IoT networks is trendy among scientists and researchers because of its benefits on constructing the network more power proficient. In the clustering, the cluster head is chosen, and other members obtain the data about the cluster head. The members who desire to be the cluster element may request the cluster head to join the cluster; this is Type-1 for cluster formation. The cluster will be created first, and then one cluster head will be chosen; this is Type-2 for creating the cluster.

This work proposed a Minimum Power Consumption Routing (MPCR) algorithm using Hierarchical Fuzzy Logic Clustering (HFLC) algorithm for IoT network has been proposed. This HFLC algorithm forms clusters using Type-2. Cluster formation executes based on Hierarchical clustering. Hierarchical clustering makes a hierarchy of clusters by either frequently combining two smaller clusters into a larger one or partitioning a larger cluster into smaller ones. Cluster head selection executes based on the Fuzzy Logic technique. Fuzzy logic is one of the computational intelligence techniques that could be utilized in applications with uncertainties. Algorithm 1 explained the proposed Minimum Power Consumption Routing (MPCR) algorithm.

Algorithm 1: Minimum Power Consumption Routing (MPCR)

Input : Admin, Base Station (BS), IoT Devices (IoTDs) with initial battery power, Packet Aggregation Threshold (PAT)

Output : Minimum power consumption

Step 1: Admin creates the IoT Network using IoT devices and base station

Step 2: Admin clusters IoT Network based on Hierarchical Fuzzy Logic Clustering (HFLC) algorithm **// Algorithm 2**

Step 3: For each cluster head CH from IoTDs

Step 4: DR = BS discovers all available routes between CH to the BS using intermediate cluster heads

Step 5: SR = Sorts DR from the shortest route to the longest route

Step 6: BS inform its SR to each CH

Step 7: CH keeps its SR to its Routes List

Step 8: End For

Step 9: Source IoT device SI sense, and construct a packet P

Step 10: Transmit P to its cluster head CH

Step 11: Set AP is equal to empty

Step 12: If the number of the received packet is not equal to PAT, Then

Step 13: AP = AP + P

Step 14: Send acknowledgement message to SI

Step 15: Else

Step 16: AP = AP + P

Step 17: Select SR from its Routes List

Step 18: Find next cluster head NCH from SR

Step 19: Transmit AP to NCH

Step 20: If NCH is not equal to BS

Step 21: Repeat Step 17 to Step 19

Step 22: Else

Step 23: Forward AP to admin

Step 24: End If

Step 25: End If

Step 26: Admin received AP from BS

Step 27: Extract each packet P from AP

First, the admin constructs the IoT network using IoT devices and base station (Step 1). Then the admin cluster the IoT network for routing purposes using the HFLC algorithm (Step 2). The base station then discovers all available routes between each cluster head using intermediate cluster heads (Step 4). It then sorts all the routes for each cluster head from the short route to the long route (Step 5). Followed by it informs each cluster head with its sorted route details (Step 6). Then, each cluster head stores its sorted route details to its Routes List (Step 7).

If an IoT device (cluster member) senses anything, it constructs a packet (Step 9). Followed by it transmits this packet to its cluster head (Step 10). Now cluster head aggregates all received packets until the number of the received packet is equal to the packet aggregation threshold (Step 11 - 14). If the number of received packets equals the packet aggregation threshold, it will transfer aggregated packets to the next device (cluster head or base station) in its shortest route (Step 19). If the next device is a cluster head, it repeats the above step (Step 21). But next device is the base station; it forwards the aggregated packet to the admin (Step 23). After received aggregated packet, the admin extracts each packet from the aggregated packet (Step 27). In case of any failure from any shortest route, all cluster heads take the next shortest route from their route list. The main advantage of this algorithm is battery power consumption reduction and successful packet transmission. Figure 1 shows the flow diagram of the proposed MPCR algorithm.

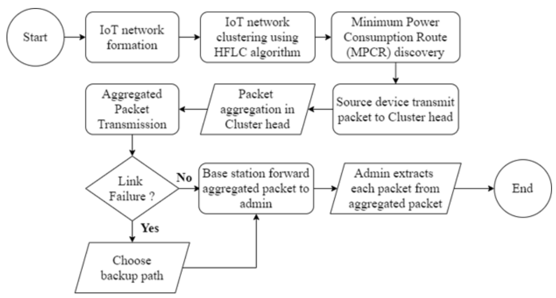

Figure 1: The flow diagram of the proposed MPCR algorithm

3.1 Hierarchical Fuzzy Logic Clustering (HFLC) algorithm

The main significant aim of the proposed MPCR algorithm is to improve the lifetime of the IoT network. So, this work proposes a Hierarchical Fuzzy Logic Clustering (HFLC) algorithm to generate minimum power consumption routing, leading to the extension of network lifetime. In the HFLC algorithm, cluster formation executes based on Hierarchical clustering. The hierarchical clustering algorithm is an unsupervised clustering algorithm that involves building clusters with main ordering from top to bottom. For instance, all folders and files on our hard disk are prearranged in a hierarchy. Then, the algorithm group's equivalent objects into groups known as clusters. The endpoint is a set of clusters, where each cluster is different from the other cluster, and the objects within each cluster are generally equivalent to each other. Hierarchical clustering builds a hierarchy of clusters by either frequently combining two smaller clusters into a larger one or partitioning a larger cluster into smaller ones. This clustering method is separated into two types: 1) Agglomerative Hierarchical Clustering 2) Divisive Hierarchical Clustering. The Agglomerative Hierarchical Clustering is a "bottom-up" clustering approach.

Conversely, Divisive Hierarchical Clustering is a "top-down" clustering approach. Therefore, the proposed HFLC algorithm is a "top-down" clustering approach. Figure 2 shows HFLC algorithm cluster formation.

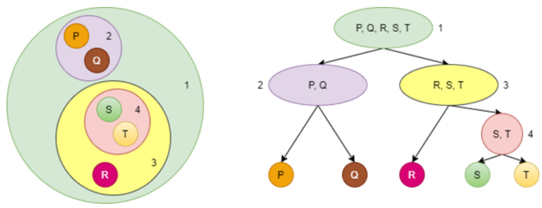

Figure 2: HFLC algorithm cluster formation

In the HFLC algorithm, the admin allocates all IoT devices to a single cluster (mentioned as 1 in Figure 2) and then splits the cluster into two least equivalent clusters (mentioned as 2 and 3 in Figure 2). At last, the admin proceeds partition recursively on each cluster until there is one cluster for each IoT device (mentioned as 4 in Figure 2).

In addition, in the HFLC algorithm, cluster head selection executes based on the Fuzzy Logic technique. Fuzzy logic is one of the computational intelligence techniques that could be utilized in applications with uncertainties. Three fuzzy parameters, namely the current energy level of the IoT device, the distance between the IoT device and base station, distance between cluster members and the IoT device, are utilized for efficient cluster head selection. The levels utilized for each of the fuzzy parameters are as follows,

- **IoT device current energy** – Less, medium less, medium, high medium and highly
- **Distance between IoT device and base station** – Closer, medium closer, medium, medium distant and distant
- **Distance between IoT device and cluster members** – Closer, medium closer, medium, medium distant and distant

The distance between the IoT device (ID) to the base station (BS) (or to cluster member) is determined based on the Euclidean distance. The distance computation is given in Eq.(1)

$$\text{Distance(ID, BS)} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (1)$$

For choosing the best cluster head in this work, nine levels have been utilized: very much weak, weak, less weak, less medium, medium, high medium, less strong, strong; the fuzzy logic-based IF-THEN rules utilized in the HFLC algorithm are shown in Table 1.

Table 1: Fuzzy Logic-based IF-THEN rules for cluster head selection

IoT device current energy	**Distance between IoT device to the base station**	**Distance between IoT device to each cluster members**	**Fuzzy Logic Result (FLR)**
Less	Distant	Distant	Very Much Weak
Less	Distant	Distant	Weak
Less	Distant	Distant	Less Weak
Less	Distant	Distant	Less Medium
Less	Distant	Distant	Medium
Medium Less	Medium Distant	Medium Distant	Weak
Medium Less	Medium Distant	Medium Distant	Less Weak
Medium Less	Medium Distant	Medium Distant	Less Medium
Medium Less	Medium Distant	Medium Distant	Medium
Highly Medium	Medium Closer	Medium	Less Medium
Highly Medium	Medium Closer	Medium	Medium
Highly Medium	Medium Closer	Medium	Less Medium
Highly Medium	Medium Closer	Medium	Medium
Highly Medium	Medium Closer	Medium	Highly Medium
Highly	Closer	Closer	Medium
Highly	Closer	Closer	Highly Medium
Highly	Closer	Closer	Less Strong
Highly	Closer	Closer	Strong
Highly	Closer	Closer	Very Much Strong

From the above table, if a fuzzy logic result of an IoT device in a cluster is very much strong, it will be chosen as the cluster head. Algorithm 2 explained the proposed HFLC algorithm.

Algorithm 2: Hierarchical Fuzzy Logic Clustering (HFLC) algorithm

Input IoT Devices, Base station (BS)

Output Clusters with Cluster Head (CH)

Step :1 Assign all of the IoT devices to a single cluster

Step :2 Partition the cluster into two least similar clusters

Step :3 CL[] = Admin proceeds partition recursively on each cluster until there is one cluster for each IoT device

Step :4 For each cluster C from CL

Step :5 For each Member M from C

Step :6 CE = Get current energy of M

Step :7 DB = Compute the distance between M to BS

Step :8 DM = Compute the distance between M to other members

Step :9 FLR = Apply Fuzzy Logic-based IF-THEN rules for CE, DB and DM **// Table 1**

Step :10 If FLR is Very Much Strong Then

Step :11 CH = M // Cluster Head of Cluster C is M

Step :12 Break

Step :13 End If

Step :14 End For

Step :15 End For

4 Results and Discussion

This section provides the experimental results and analysis of the MPCR with the HFLC algorithm on the IoT network. This simulation presumes that many IoT devices are still distributed evenly and randomly in the forest. These IoT devices monitor smoke, rainfall, wind speed, light intensity, humidity, and temperature. Following these devices, readings are sent to the admin through the base station. Java was utilized to assess the MPCR with the HFLC algorithm. This section provides the results attained from the simulation of the proposed MPCR with HFLC algorithm alongside three existing routing schemes, for example, InFRA [7], DRINA [7] and CBPR [7] under various node density situations.

Parallels are drawn between the result performances of the MPCR with the HFLC algorithm and that of the other mentioned schemes on the following metric; throughput, packet delivery ratio, and energy consumption of routing schemes. In addition, critical study of obtained outcomes is further performed in this section as follows;

4.1 Throughput

Throughput refers to the total number of data packets that an algorithm can successfully deliver to the base station over a particular period. Table 2 demonstrates the throughput difference for MPCR with the HFLC algorithm, CBPR, DRINA, and InFRA under various network node densities.

Table 2: Throughput Comparison

Number of IoT devices	InFRA	DRINA	CBPR	MPCR with HFLC
50	72	81	93	104
100	74	86	108	113
150	79	96	115	121
200	88	112	132	139

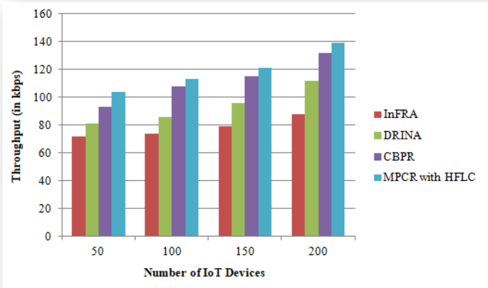

Figure 3: Throughput with the number of IoT devices in the IoT network

Figure 3 show that the MPCR with HFLC algorithm outperforms all the InFRA, DRINA and CBPR in the area of throughput for all network densities of device scenarios. Since MPCR with HFLC algorithm tends to choose merely the best routes while routing packets towards the base station. The route chosen by the MPCR with the HFLC algorithm is said to have the maximum residual power, low power consumption rate, and the shortest distance to the base station; thus, it presents link solidity and decreases packet drop during data transmission. Furthermore, the proposed MPCR with HFLC algorithm benefits from the Fuzzy Logic cluster head selection to dynamically discover the most excellent cluster head utilized for aggregated packet transmission. All of the above taken into consideration by MPCR with the HFLC algorithm resulted in a better throughput performance when compared to its counterparts.

4.2 Packet Delivery Ratio (PDR)

Packet delivery ratio is the percentage ratio between the total number of packets sent from the source IoT device and the number of packets obtained at the base station during the simulation time. A high PDR is an indication of the best aggregation and efficient routing scheme. As the number of devices rises in the network, the number of intermediate devices in the routing path further rises, thus creating numerous route choices between the source and destination devices. The MPCR with HFLC algorithm benefits from this multi-path factor to advance its performance by choosing the intermediate cluster head devices with higher residual power to build the best forwarding routes with fewer chances of a link failure in the network, guiding to proficient transmission and higher packets delivery ratio. Furthermore, the MPCR with HFLC algorithm organizes the packets based on the IoT device queue length status, providing priority to the devices with a smaller queue length to reduce the waiting time and minimalize congestion in the IoT network, improving the PDR score. Furthermore, MPCR with HFLC algorithm utilizes the proficient data aggregation that removes redundant data by collapsing all correlated event data into a solitary meaningful data unit compared to InFRA, DRINA and CBPR routings. Table 3 shows packet delivery ratio comparison.

Table 3: Packet Delivery Ratio Comparison

Number of IoT devices	InFRA	DRINA	CBPR	MPCR with HFLC
50	38	46	64	76
100	39	49	66	79
150	40	60	72	81
200	44	63	76	84

Figure 4 shows the PDR performances of the assessed schemes, indicating that each scheme's value raises as the number of devices rises.

4.3 Energy Consumption

Energy consumption is the amount of energy needed to send a unit of data from a source IoT device to a base

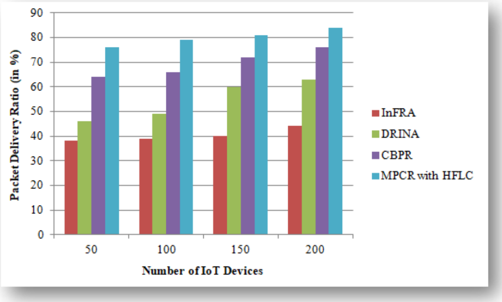

Figure 4: Packet delivery ratio with the number of devices in the IoT network

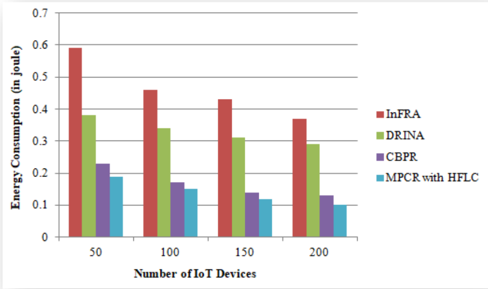

Figure 5: Energy consumption with the number of IoT devices in the IoT network

station in an IoT network. The energy consumption performance of the proposed MPCR with HFLC algorithm has been evaluated using varying network device densities and compared with the InFRA, DRINA and CBPR routing schemes, as demonstrated in Table 4 and Figure 5.

Table 4: Energy Consumption Comparison

Number of IoT devices	InFRA	DRINA	CBPR	MPCR with HFLC
50	0.59	0.38	0.23	0.19
100	0.46	0.34	0.17	0.15
150	0.43	0.31	0.14	0.12
200	0.37	0.29	0.13	0.1

The MPCR with HFLC algorithm forever selects the shortest route for decrease energy consumption. Furthermore, it chooses the best cluster head with high residual energy, closer to the base station and closer to all cluster members. Thus, it leads to reduce energy consumption. Followed by, it used packet aggregation technique. Therefore, it also leads to reduce unnecessary energy consumption. In addition, this algorithm also has a backup path. In case of any link failure, this algorithm automatically chooses another shortest route. This way saves a lot of energy. Therefore, compared with other existing algorithms proposed, MPCR with the HFLC algorithm reduce energy consumption efficiently.

5 Conclusion

This paper proposed a Minimum Power Consumption Routing (MPCR) algorithm using Hierarchical Fuzzy Logic Clustering (HFLC) algorithm for IoT enabled WSN network. The MPCR with HFLC algorithm is the power proficient algorithm because of its minimum power consumption for clusters through aggregating the data within the cluster head and decreasing the number of data transmissions to the base station. In this paper, the cluster formation is executed based on hierarchical clustering, the cluster-head selection is executed based on the Fuzzy Logic technique, and simulation has been performed. Also, the proposed algorithm is compared with the existing algorithms based on various metrics, for example, throughput, packet delivery ratio, and energy consumption of the network. The experimental results concluded that the proposed MPCR with HFLC algorithm provides high throughput and packet delivery ratio and reduces energy consumption more efficiently than other existing algorithms. In the future, we have planned to extend this work with more than one base station to decrease power consumption.

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