

EAHCP: ENERGY AWARE HYBRID CLUSTERING PROTOCOL FOR MOBILE IOT NETWORKS

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ABSTRACT

With the rise in availability of smart devices, IoT applications have shown massive increase with time. This contributes to increase in energy consumption and carbon footprints. The work proposes an Energy Aware Hybrid Clustering Protocol (EAHCP) to overcome the challenges of energy aware IoT networks where sensor-based nodes can be mobile in nature. A novel energy aware clustering protocol based on boundary detection and probability-based clustering technique is introduced for green IoT networks. The aim of EAHCP is to increase the network lifetime by reducing energy usage of individual IoT nodes. EAHCP selects the Cluster Heads strategically due to which the results of EAHCP outperforms clustering algorithms like ETM-IoT, DEEC etc. concerning network's stability, network lifetime, residual energy, and number of packets sent to Base Station. The protocol works in two main phases: In the first phase, convex hull algorithm is applied to create boundary around nodes to determine nodes that are farther from base station. In order to further make the protocol energy efficient, the second phase introduces novel clustering algorithm. Using proposed strategy, mobile nodes are diverted back towards the BS, which is suitable for applications like patient monitoring, vehicle tracking, animal tracking etc.



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1. INTRODUCTION

The technology Internet of Things (IoT) shown remarkable popularity during recent years. IoT refers to interconnecting devices that are used in everyday life and with the help of internet, they are used to connect, collect and act upon the data. It has revolutionized different aspects of our lives and industries. IoT nodes can be mobile as well as static. Applications like security surveillance cameras, devices planted in lighting, temperature control, and automatic opening/closing of doors are examples of static IoT applications. While

mobile applications include smart wearables, mobile phones, vehicle/animal tracking, remote monitoring and environmental monitoring etc. With the advent of 5G connectivity and the decreasing cost of hardware, the number of IoT devices deployed worldwide is experiencing exponential growth. According to some estimates, there will be 15.14 billion connected IoT devices by the end of this decade (Alam et al., 2018).

Generally, IoT nodes are deployed in unfavorable regions like mountains, industries, forests, etc. where to replace or recharge batteries is extremely tough. In addition,

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forests and mountainous region often suffer from poor or limited connectivity, leading to unreliable data transmission and delayed response time. Adverse environmental conditions such as heavy rainfall, snowfall and strong winds can challenge the durability and functionality of nodes. This research introduces an innovative energy aware clustering protocol based on boundary detection and probability-based clustering technique IoT networks. The aim of EAHCP is not only to extend the network lifespan but also to reduce the energy expended by individual IoT nodes. Over the years, different clustering-based methods have been suggested for energy efficient Wireless Sensor Networks (WSNs) that were based on static networks or mobile networks (Khediri et al., 2014).

Energy Aware Hybrid Clustering Protocol not only simplifies the mathematical complexity but also aims to lessen the number of “dead” nodes i.e., the nodes having energy below minimum required threshold and thus extending the network lifetime. The communication among IoT nodes that are distant from Base Station presents several disadvantages including signal attenuation, power consumption, interference, noise, limited coverage, high cost, complex network planning and various security risks. Additionally, challenges like increase in end-to-end delay, packet loss, increased handover failure probability, latency and high signaling cost also exists in mobile IP based IoT network (Yassein et al., 2017). To resolve these issues, this work introduces an optimized algorithm to enhance network performance and reliability. Figure 1 shows the applications where such algorithm may be applicable and Figure 2 highlights the issues in such type of IoT network and various risks involved in communicating with the far away IoT nodes.

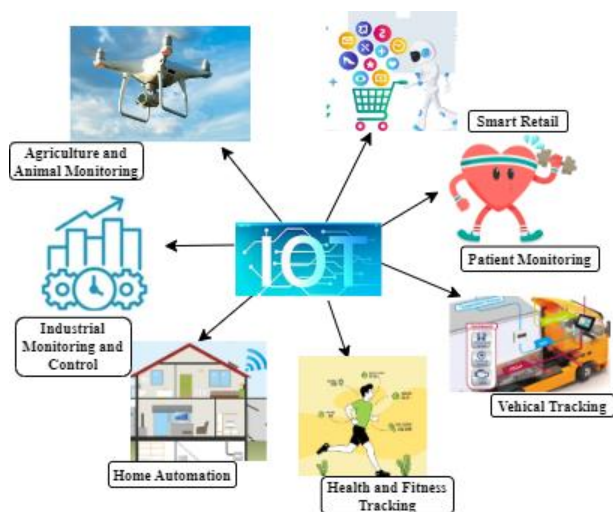


Figure 1. Applications of mobile IoT network

EAHCP protocol groups the active nodes using convex hull algorithm (Sharif, 2011) and then forms clusters using a novel clustering algorithm. Convex hull algorithm groups the network nodes on grounds of their distance from the Base Station and also according to the velocity of nodes with which they move around in the

network field. All the Cluster Heads (CHs) communicate with mobile nodes by following EAHCP algorithm and transmits the data to the BS. EAHCP significantly reduces network power consumption, extending the network lifetime, and optimally utilizes available bandwidth.

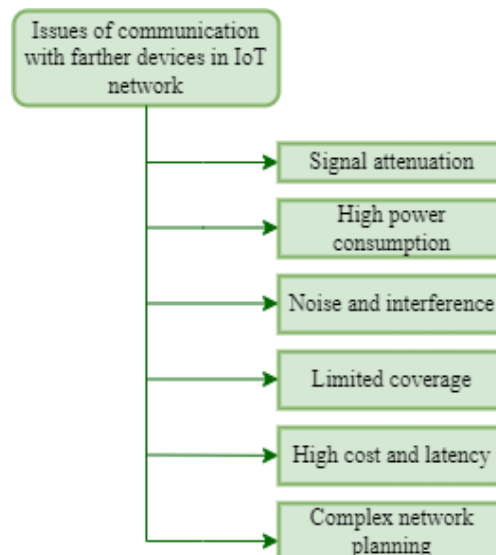


Figure 2. Issues of communication with devices far from BS in IoT network

1.1 Highlights of EAHCP

- A novel advanced clustering algorithm is proposed for hybrid IoT network, aiming to select best Cluster Heads. The use of an advanced election mechanism triggers to reselect Cluster Heads only after meeting specified conditions, contributing significantly to energy efficiency.
- Mobile nodes are tracked with the help of convex hull algorithm and redirected back towards BS. This approach extends the lifespan of the network, and makes it favourable for applications where mobile nodes travel beyond transmission range of BS.
- Mobile nodes in IoT networks consume more energy than stationary nodes. This is due to data collection from continuously nodes. Since, most of the mobile devices are battery powered, increasing the network lifetime in such a scenario becomes challenging. The proposed protocol EAHCP, constructs the boundary for the moving nodes with the help of convex hull algorithm, then forms the clusters based on nodes’ energy levels and their distance from the Base Station.
- The various metrics for performance including number of packets sent to BS, number of dead and alive nodes, total clusters formed and residual energy are assessed and compared with existing algorithms.

EAHCP algorithm is designed for hybrid IoT networks, specifically focussing on mobile nodes that are situated

away from BS. With the help of intelligent routing strategies, mobile nodes are diverted back towards BS. Its objective is to prolong the networks' lifetime while enhancing overall network performance. Furthermore, such advancements hold the potential to unlock new possibilities in various IoT applications, including remote monitoring, environmental sensing, and industrial automation.

Section 2 presents literature review that delves into existing research and related work. The working of the proposed protocol is provided in section 3. Section 4 presents results and analysis. Section 5 concludes the paper with potential areas of future research and development.

2. LITERATURE REVIEW

Various researchers have been working on energy-efficient deployment of IoT nodes to make environment green by reducing carbon emissions. Most of the earlier works have been done on reducing the energy consumption in IoT/WSN where nodes are stationary in nature. There are numerous algorithms which are based on cluster formation. An Energy-Aware technique for IoT networks that consists of mobile stations have been proposed (Saleh, 2023). Authors have employed a power-management technique that is dynamic in nature. The strategy which reduces the power consumption involves dynamically regulating the energy levels of every station and the IoT node, as per the combined techniques.

A distributed routing and multiple level clustering algorithm have been proposed for WSN based IoT networks (Turgut & Altan, 2021). Authors have proposed intra and inter-cluster multiple-level scheme for reducing energy consumption. Algorithm divides the network into very small clusters, each having CH, which is responsible to communicate with BS. Further, for reducing the energy usage of the network, different routing paths are considered and distance is calculated, according to which the communication has been established between the CH and BS. Authors in (Li et al., 2022) have proposed the scheme to save energy in IoT networks with the help of deep learning as well as edge computing. They have used the techniques for increasing the data transmission rate and decreasing delay in the mobile computing networks, while ensuring security in the network. They have also adopted the deep learning technique to predict the load and computed the results at the edge of the network using data centres deployed at the edge of the network. The accuracy of the algorithm can be improved, as in case of light load the results given are not found to be accurate enough.

SEP protocol (Smaragdakis et al., 2004) used the concept of heterogeneous nodes, where each has unequal energy. CH is selected based on energy level present in the nodes. The algorithm results in better stability of network as compared to previously proposed protocols, but the protocol can only be used in a network where the nodes that are stationary in nature. DEEC i.e., Distributed Energy-Efficient Clustering (Qing et al., 2006) also uses

the concept of heterogeneity in nodes with respect to energy for further reducing the power consumption in sensor networks. The CH selection is done according to the remaining energy of the nodes. DEEC is effective for multilevel heterogeneous networks, but it has the limitation that once the advanced nodes energy level becomes same as that of normal nodes than they tend to die faster as compared to the normal nodes.

(Hussain & Howayek, 2020) provided 2-D under water Wireless Sensor Network for faster detection of oil leakage in oceans and a sleep scheduling protocol for saving the energy. Construction of path to increase the lifetime of network and for reducing the energy consumed by WSN has been discussed in (Wen et al., 2018). Authors have considered network with mobile sink and shown that it can help in reducing energy consumed by visiting the sensors nodes and collecting data while moving along the specified path, instead of receiving data from each node. The protocol constructs the minimum spanning tree, which has Base Station as its root. The protocol constructs a path with the help of collection points and collects data from highly burdened program collection points. The main limitation of the work is that, it also does not work on mobile environments and does not cater to the challenges of mobile IoT networks. In (Bagga et al., 2019) fuzzy logic is applied to select the most appropriate nodes for the Cluster Head and based on the heterogeneous network where the nodes are stationary in nature. Network lifetime, number of packets delivered have been increased as compared to the previous algorithms and energy consumption has been reduced. But again, limitation lies in the nodes' nature which are stationary here.

Authors in (Faisal, 2013) have given Z-SEP Protocol for the heterogeneous web having two levels. Network is shown to be in division of three zones, and deployed the normal nodes in the zone where nodes are near to the BS in order to conserve energy. Results show that Z-SEP protocol outperforms SEP protocol, and achieved an increase in network lifetime. However, there is room for improvement especially concerning mobile nodes.

Threshold model (ETM-IoT) for communication between heterogeneous nodes has been proposed for energy aware IoT networks (Krishna & Leema, 2021). The work focusses on the clustering techniques and on the selection of Cluster Heads. Three different types of nodes, from normal, intermediate to advance exists in the IoT network based on energy levels of the nodes. The proposed protocol has shown an improvement over SEP and other heterogeneous networks but still has the drawback that it is not applicable to mobile IoT networks, where the environment is dynamic in nature.

The aforementioned algorithms including the one proposed in (Abdullah et al., 2020) focussed on enhancing energy efficiency in stationary environments. None of these algorithms have considered the mobile nature of nodes in IoT networks.

3. ENERGY AWARE HYBRID CLUSTERING PROTOCOL

IoT nodes are categorized into different types according to their nature and energy levels:

1. Standard node: Nodes that are actively engaged in sensing, processing and transmitting data to CH. They are operational in nature with energy level more than threshold.
2. Superior nodes: Nodes having energy level β times higher than standard nodes and considered as good candidates for Cluster Heads.
3. Mobile nodes: Nodes moving with constant velocity within the network.
4. Stationary nodes: Nodes that have zero velocity and remain stationary.
5. Sleepy nodes: For energy conservation, some of the nodes are put into sleepy mode. By putting nodes in the said mode, devices can operate for longer times that eliminates need of frequent battery replacement or charging.
6. Dead nodes: Dead IoT nodes are referred to as devices that are no longer operational due to any hardware failure, or depleted energy resources, or other issues.

3.1 Mobile Node

A mobile node in data communication network has ability to change its position with time, and moving in the network with some velocity. The position of a mobile node $X(t)$ can be represented by equation (1):

$$X(t) = X_0 + \int_0^t V(\tau) d\tau \quad (1)$$

Where X_0 is the initial position of a node, and $V(\tau)$ is the velocity vector of the mobile node, which is changing with respect to time. Use of different symbols used in the work with their meanings are given in Table 1.

3.2 Network Model of EAHCP

The existing protocols proposed earlier focusses on energy computation in networks where operating nodes do not move, particularly considering residual energy of the Cluster Heads (CH). However, the newly proposed energy aware hybrid model considers the impact of mobility on an IoT network. Nodes concurrently communicate with the CHs, which are capable of transferring data to the BS.

For EAHCP, network model is presumed to be heterogeneous in nature, where radio dissipation occurs. The energy consumed for running transmitter or receiver circuit is denoted by E_{elec} . Fraction of nodes are superior nodes denoted by 'L', which have energy greater than standard nodes. The representation of the standard nodes, P, set is shown by equation (2):

$$P = \{ P_i \mid P_i \in NS, 0 \leq i \leq Nn \} \quad (2)$$

Superior nodes have λ times more power than the standard nodes. This helps in increasing the survival time of the nodes. The time of first node get dead is very important for such critical applications where the location of nodes is continuously changing. Further assuming that there are 'L' superior nodes which are represented by equation (3):

$$L = \{ L_j \mid L_j \in NS, 0 \leq j \leq Nn \} \quad (3)$$

The presence of Base Station in the network, corresponds to greater likelihood of message delivery, as they possess larger storage capacity. Base Station is fixed and centrally located within the network as shown in Figure 3. All the IoT nodes inside network boundary act as relay nodes. The nodes having energy below the required threshold enter sleepy state and all other nodes remain in active mode. As shown in Figure 4, initially all IoT nodes are randomly distributed in the x-y region. At the start, all nodes have same energy and are presented in blue color. A boundary is established using convex hull algorithm, separating the nodes.

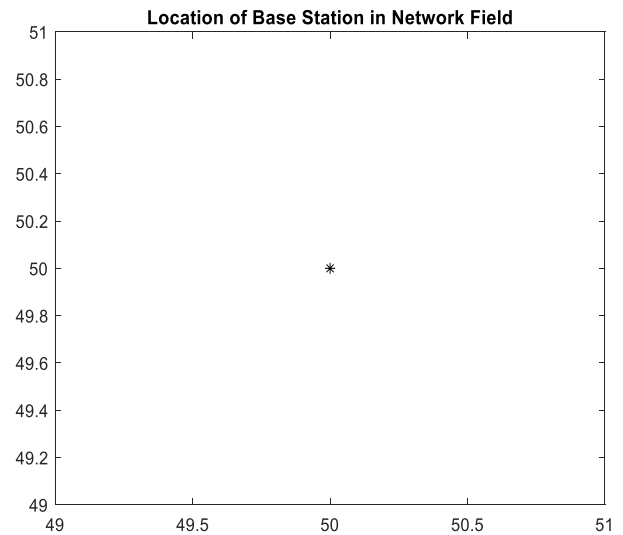


Figure 3. Placement of Base Station within the network

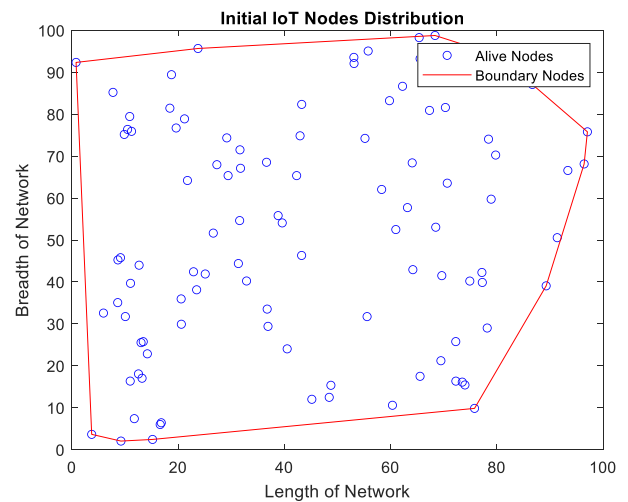


Figure 4. Initial IoT nodes distribution

Nodes that are far from the BS are inactive nodes as these nodes may not be able to send and receive message to the BS. High consumption of energy in communication is a limiting factor. Distance between the nodes v and s is calculated with the help of Euclidean distance formula as shown by equation (4). Equation (5) gives Distance threshold value, p_t

$$di(v, s) = \sqrt{(s_1 - v_1)^2 + (s_2 - v_2)^2} \quad (4)$$

$$p_t = \sqrt{\frac{E_{fs}}{E_{mf}}} \quad (5)$$

In equation (4), if $di(v, s)$ comes less than p_t , than it means that two nodes are very close to each other

(Chenait et al., 2015). In equation (5), E_{mf} is the energy loss in network because of signal transmission via multiple paths. It can also lead to fluctuation in signal strength, degrading the quality of communication. E_{fs} represents the free space loss of energy. This reduces the signal strength primarily due to geometric spreading of the wavefront. If both the sensors are too close to each other, they will transmit the data to one point say, Z , then they unnecessarily waste battery power. In such a case, the nodes are paired up and consider as one node for transmission. Similarly, if distance between a node and the BS is above a predefined threshold, then the nodes are bounced back towards the convex wall and moves towards the BS.

Table 1. Nomenclature.

Symbol	Meaning	Symbol	Meaning
NS	Network region	di	Distance between the nodes
p_t	Distance threshold value	EE^k	Total energy consumed by k^{th} node
$di(v, s)$	Distance between node v and s	CH	Cluster Head
E_t^k	Energy dissipation of k^{th} node in transmitting bits	BS	Base Station
E_r^k	Energy dissipation of k^{th} node in receiving bits	$L_0(k_{x_i, y_i})$	Location of k^{th} node in (x,y) region
n_b	Number of bits	$distCHB$	Square of average of distance among the CHs and BS
E_{totr}	Overall energy consumption in a network in a particular round	$E_{res}(i)$	Residual energy of IoT network
Nn	Number of nodes in IoT network	p_{CH}	Initial probability of a node being selected as CH=0.1

Equation (6) and equation (7) represents the dissipation of energy in k^{th} node while transmitting and receiving the data in IoT network. The nodes are assumed to start with same initial energy, EE , which keeps on decreasing as the nodes move and transfer/receive data (Behera et al., 2020).

$$E_t^k = \begin{cases} EE^k * n_b + E_{mf} * n_b * di^4; & if di \geq p_t \\ EE^k * n_b + E_{fs} * n_b * di^2; & if di < p_t \end{cases} \quad (6)$$

$$E_r^k = EE^k * n_b \quad (7)$$

Total energy consumption on k^{th} node can be calculated by adding energy consumed in transmission and receiving of the data packets, shown by equation (8). If energy level of k^{th} node, E_t^k is below minimum limit set or zero than they are assumed to be dead nodes.

$$EE^k = E_t^k + E_r^k \quad (8)$$

EAHCP model works in five phases:

Phase I: Convex hull creation

Phase II: Cluster creation

Phase III: Routing

Phase IV: Mobile nodes tracking and diverting

Phase V: Data transmission

3.3 Clustering model

For reducing the energy consumption of IoT networks, clustering is vital. The work considers sensor based IoT

network model. The nodes have highest amount of energy and proximity to the BS are made CHs. Since nodes are mobile, the probability of change of Cluster Head in each simulation round is high. As mobile nodes move, their energy decreases. To reduce the cost of communication, the nodes that are closest to the Cluster Heads communicate and transfer data if required to the CHs, which in turn relay the complete information to the BS for further processing. In this work, we have assumed that the nodes are moving with constant speed. Further, assuming speed of mobile nodes at time t_0 to be V_i , location of k^{th} node in IoT network can be represented in (x, y) region, in angular direction δn by equation (9) (Yadav & Tripathi, 2017):

$$L_0(k_{x_i, y_i}) = V_i * t_0 * \cos(\delta n) \quad (9)$$

As the location of IoT nodes are changing with time due to mobility, and they are moving in different locations, so the distance between them is also changing (Dhumane & Prasad, 2020). Location ($h1'$, $m1'$) of IoT node $n2$ w.r.t. node $n1$ with location ($h1$, $m1$) can be calculated according to the equation (10) and equation (11):

$$h1' = h1 + \omega n2 \times t \times \cos(\delta n2) \quad (10)$$

Similarly,

$$m1' = m1 + \omega n2 \times t \times \cos(\delta n2) \quad (11)$$

The ω_2 represents the velocity of node with time t . Number of CHs selection can be done ideally according to equation (12). The optimal number of CHs, P_{opt} , is determined using equation (12). The probability of choosing optimal number of CHs depends on NS, p_t as calculated using equation (5), and $distCHB$. α and γ are the weights having value less than 1 and Nn is the no. of nodes in network. $distm$, the distance between cluster member and CH is calculated using equation (13):

$$P_{opt} = (NS \times \sqrt{\alpha \times Nn \times \frac{p_t}{P_{sup}}}) / (distCHB)^2 \tag{12}$$

$$distm = NS / \sqrt{(\gamma \times P_{sup} \times p_{opt})} \tag{13}$$

P_{sup} is the probability of superior node being selected as a Cluster Head and P_{std} is the probability of standard node to be selected as a Cluster Head. If $E_{res}(i) > 0$ of i th node and if it is a superior node than its probability to become CH, is shown by equation (14) and probability of i th standard node is given by equation (15):

$$P_{sup} = \{p_{CH} \times Nn \times E_{res}(i) \times (1 + fpi)\} * V_i / (Nn + A) \times E_{res}(i) \tag{14}$$

$$P_{std} = (p_{CH} \times E_{res}(i)) / (1 + fpi) \tag{15}$$

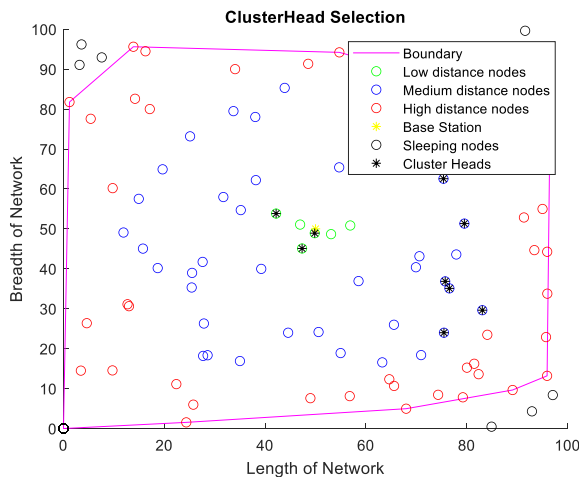


Figure 5. Position of Cluster Heads and Base Station

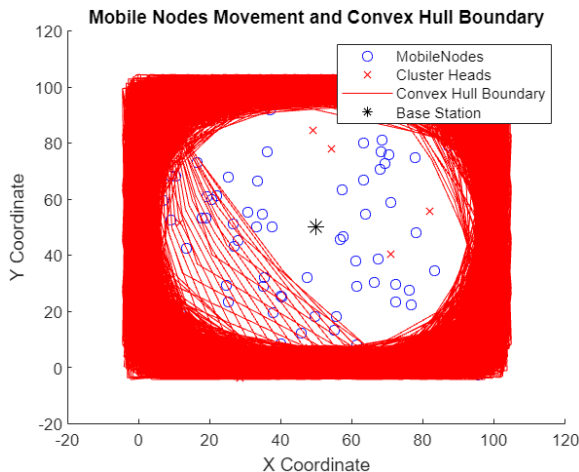


Figure 6. Convex hull creation

Where fpi represents fraction of advancement in energy of superior nodes and $E_{res}(i)$ is residual energy of each node and can be calculated using equation (20). Figure 5 shows the plot of selection of Cluster Heads on the basis of location and their residual energy and position of BS. Figure 6 displays creation of convex hull, for the mobile nodes that are going far from the BS.

3.4 Energy Consumption Analysis

The nodes communicating with CHs are sending say ' n_b ' number of bits to CHs, after processing the data and removing the duplicates and unwanted data, CHs send the data to the BS for further processing. After the distribution of nodes, their initial total energy can be calculated using equation (16):

$$E_{ini} = \sum_{i=0}^n Nn \times EE(1 + \beta) \tag{16}$$

So, energy consumption in the network can be summed up for a particular round using equation (17):

$$E_{otr} = n_b \times (2 \times Nn \times E_t^k + Nn \times E^{agg} + p_{opt} \times E_{mf} \times dist^4 to BS) + Nn \times E_{mf} \times dist^2 to CH \tag{17}$$

In the above equation (17), E^{agg} is data aggregation energy, $dist^4 to BS$ represents the distance between Cluster Head and BS and $dist^2 to CH$ represents the distance between members of clusters and their corresponding CHs. The distance between cluster members and their CHs and distance from CH to BS can be calculated using equation (18) and (19) respectively.

$$dist^2 to CH = \frac{N}{\sqrt{2\pi \times p_{opt}}} \tag{18}$$

$$dist^4 to BS = (0.765 \times N) / 2 \tag{19}$$

In the network, Residual Energy in each round is calculated using equation (20):

$$E_{res}(i) = E_{ini} \times (1 - \frac{Rr}{rmax}) / Nn \tag{20}$$

Where Rr is the r^{th} round and ' $rmax$ ' is the maximum number of rounds for which the simulation runs. In such a mobile IoT network, IoT nodes continuously change their positions resulting in wastage of energy. The work assumes that cluster members and CHs remain the same until the CH's energy is above its cluster members and it stays within the radio range of BS. This approach reduces the consumption of energy by minimising probability of selecting different CH and its members. When a CH is not able to listen or receive the messages from its members then there arises the need to reform cluster. New members join the cluster through request messages sent by mobile IoT node to the CH. Additionally, when a mobile node moves far from the radio range of the BS and other mobile nodes, then with the help of convex hull algorithm, they are redirected back towards the BS.

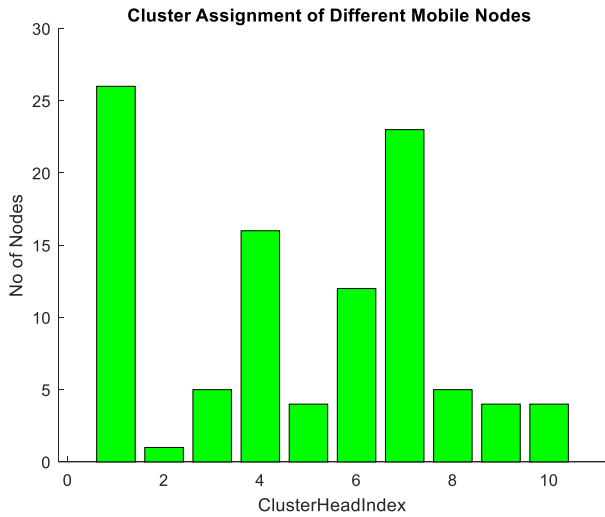


Figure 7. Cluster associated with different IoT nodes

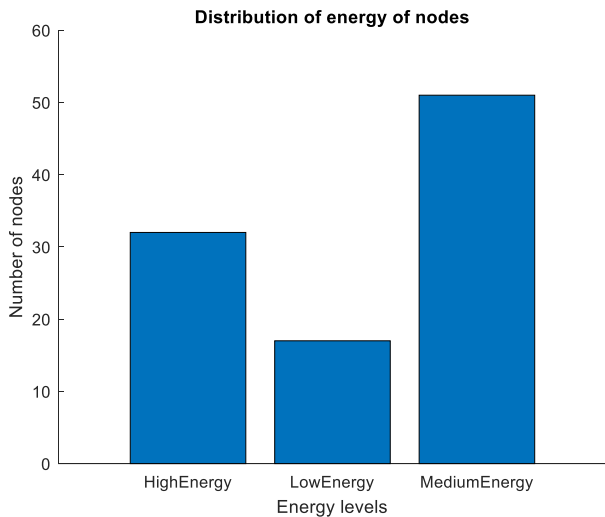


Figure 8. Energy levels of IoT nodes

Figure 7 shows associated CHs to corresponding IoT nodes after few rounds of simulation and Figure 8 shows distribution of different levels of energy to different IoT nodes in the network.

3.5 Routing phase

After the formation of the clusters, mobile nodes send data to the Cluster Heads. The Cluster Head selection procedure runs when the energy of the existing CH goes below the average energy of nodes associated with it. In this case, a new Cluster Head is chosen. The newly selected CH should also be in the close proximity of the BS. The cluster formation is done again only in case CH energy goes below a Decision Point and also if the topology of the network is changed because of mobility of IoT nodes and number of dead nodes in a cluster is increased. The Decision Point can be calculated using equation (21):

$$DpCH = \xi \times EavgCM \quad (21)$$

Here in above equation value of ξ varies from 0 to 1 and $EavgCM$ refers to the cluster members average energy. As the nodes move far from the BS, they need more energy to communicate with CHs. In some cases, they may not be able to communicate with other nodes due to interference. To address this, convex hull boundary is created for such nodes and they are diverted back towards the BS. The position of IoT node ($h1'$, $m1'$) is reversed based on equation (22) and equation (23):

$$h1' = -(h1') \times V_i \quad (22)$$

$$m1' = -(m1') \times V_i \quad (23)$$

3.6 Execution Flow of EAHCP

Figure 9 presents the execution flow of the proposed algorithm, EAHCP. Phase 1 starts with the process of establishment of an IoT network that consists of hybrid nodes. Nodes are configured according to the use case scenarios mentioned in the introduction section. Devices need to discover and join the network to participate in communication. A boundary for the nodes is created using convex hull algorithm. The algorithm involves acquiring location information from IoT devices. This data can be acquired either using GPS receivers or proximity sensors, depending on the type of devices present in the network.

In Phase 2, clusters are formed that consist of standard nodes and superior nodes. Nodes transfer data to the selected CHs. CH process the data and send the processed data to the BS. This phase continues till the IoT devices remain alive in the network.

Phase 3 begins when the CHs energy drops down the threshold level and it's the time to change the CH. A new CH is selected and handover process begins. In this state information is transferred to the new CH, routing tables are updated and neighbouring nodes are notified of the new CH.

4. RESULTS AND ANALYSIS

The simulations are done on MATLAB 2023a and experiments are executed on Intel (R) core (TM) i5-1155G7 @ 2.50 GHz system, 8 Gb of memory and a 64-bit Windows 11 system. The performance of EAHCP is compared with the existing protocols like SEP, Z-SEP, ETM-IoT and DEEC. While all aforementioned protocols are designed for heterogeneous nodes, but they assumed stationary nodes in a static IoT network. The simulation parameters considered in the work are given in Table 2. The performance is evaluated on parameters like network lifetime, number of packets transmitted to BS, number of clusters formed, residual energy and total energy consumption. Even though EAHCP protocol considers hybrid nodes (static and mobile), its results are better than the existing protocols.

The primary objective of this work is to evaluate the effectiveness of EAHCP in reducing the energy consumption within hybrid IoT network. Extensive simulations with varying parameters demonstrate that performance of EAHCP is significant in achieving energy efficiency.

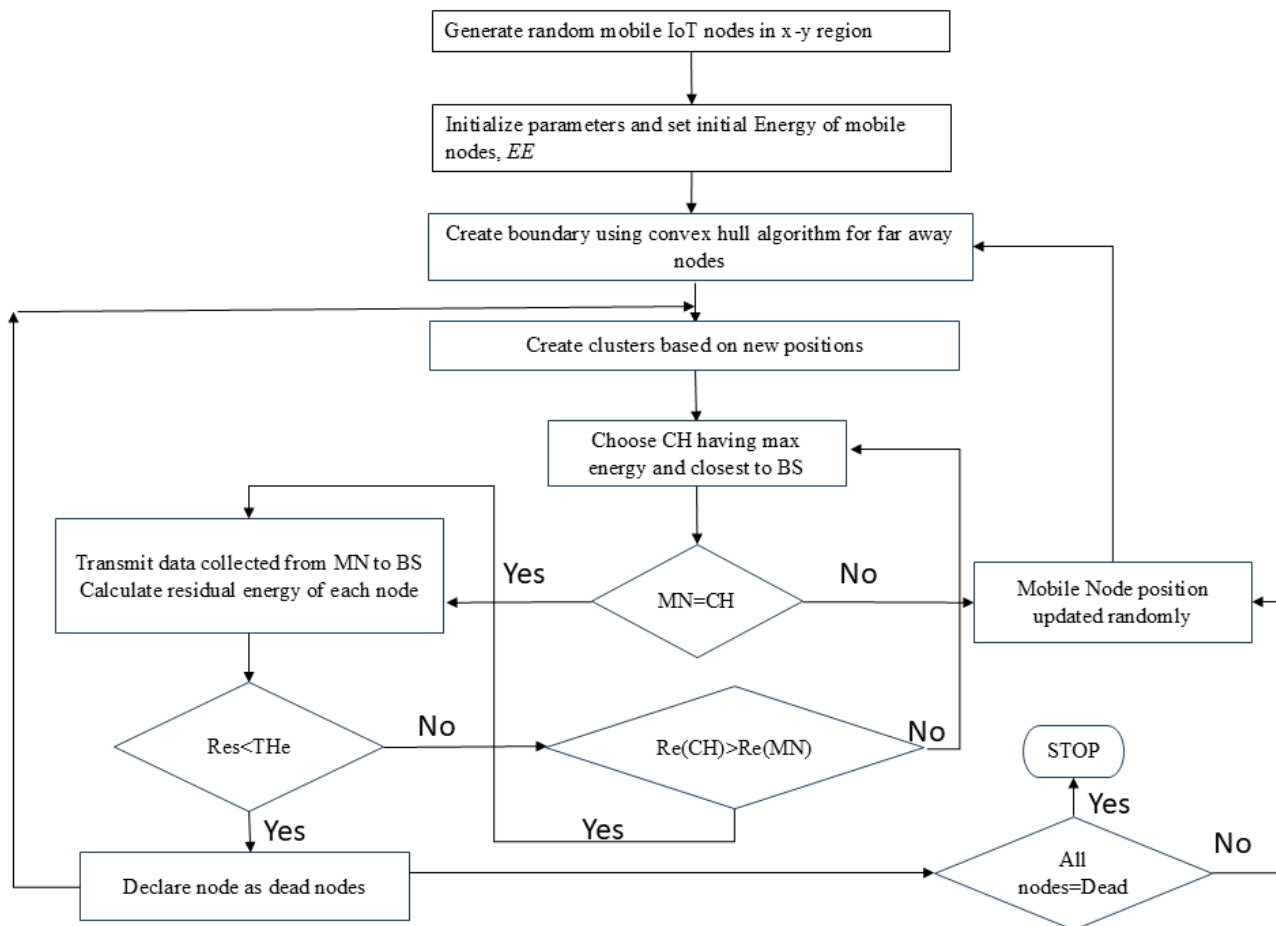


Figure 9. Flowchart of EAHCP

EAHCP can be deployed in any environment where tracking the locations of the IoT sensor-based nodes are required. Remarkably, EAHCP forwards data based on type of nodes, contributing to its improved performance. This also guarantees the reliable delivery of messages to destination node. The nodes are assumed to be scattered randomly in the defined area. The movement model is random while maintaining uniform velocities. Base Station have large coverage and ample memory capacity, making it capable to process all data. The simulation is done under two scenarios: one with 100 nodes and another with 200 nodes. In the proposed EAHCP more than 80% of the nodes are mobile in nature.

Table 2. Network parameters.

Parameter	Value
Network size	100m × 100m
Number of IoT nodes	100-200
Initial energy of nodes, EE	0.5 J
Transmission energy, E_t^k	$4e^{-8}$
Reception energy, E_r^k	$4e^{-8}$
Data Aggregation Energy, E^{agg}	$9e^{-9}$
Velocity of mobile nodes	5m/s
Pause time	0.01 s
Mobility Model	Random
Amplifier energy, Emf	$14e^{-16}$
Free space loss energy, E_{fs}	$14e^{-12}$

4.1 Performance analysis

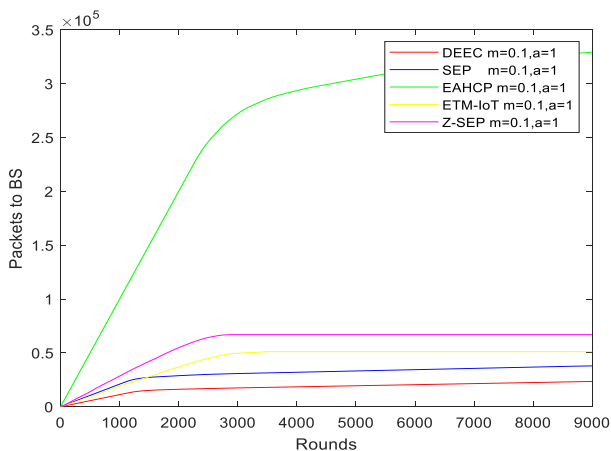
Energy Aware Hybrid Clustering Protocol EAHCP is proposed for a network that has dynamic changing topology. EAHCP has been evaluated and compared with different protocols based on network lifetime, number of packets transmitted to BS, number of clusters formed, residual energy and total energy consumption. Figure 10 shows the comparison of EAHCP with routing protocols like SEP, Z-SEP, ETM-IoT and DEEC based on number of packets transmitted to BS and number of alive nodes. Here, the comparison with varying value of ‘m’ i.e. fraction of advancement in superior nodes from value 0.1 to 0.2 (where m is the ratio of total number of superior advanced nodes to the total no. of nodes in the network) has been done. The simulations are performed on considering different energy levels of superior nodes i.e. ‘a’ set to 1 or 2.

4.2 Performance analysis based on Packets Transmitted

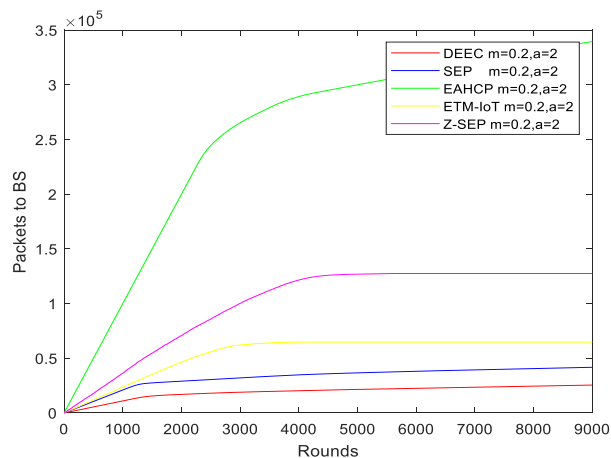
As the number of rounds increase, the number of packets transmitted using EAHCP eventually increases. As shown in Figure 10(a), number of packets transmitted are more than 75% when compared with DEEC, 50% more than Z-SEP, 40%

more than ETM-IoT and approx. 60% more than SEP, considering both the cases when number of IoT nodes is 100 and 200 (Figure 10(b)). The simulations results

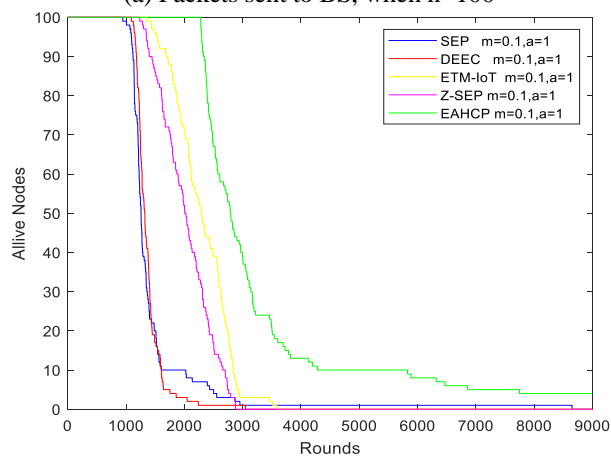
reveal that there is significant improvement in data transmission rates which helps EAHCP in effectively improving network performance.



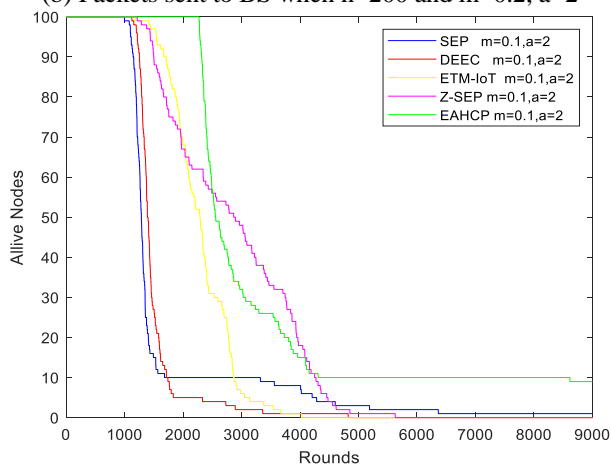
(a) Packets sent to BS, when $n=100$



(b) Packets sent to BS when $n=200$ and $m=0.2, a=2$



(c) Number of Alive nodes, when $n=100$



(d) Number of Alive nodes with increased energy level of superior nodes

Figure 10. Number of packets transmitted to BS and number of alive nodes.

4.3 Performance analysis based on Alive Nodes

As can be observed from Figure 10(c-d), Number of alive nodes using EAHCP is also more and alive till last rounds as compared to SEP, Z-SEP, ETM-IoT and DEEC protocol where number of alive nodes drop suddenly to 20 before 4000th round. The reason for this behaviour shown by EAHCP lies in the fact that EAHCP optimally selects the Cluster Heads. The load distribution is equally done among all the nodes associated with the CH that leads to efficient communication and resource utilization. It can be observed from the figure that number of alive nodes are increasing with the increase in number of IoT nodes as compared to the other algorithms.

4.4 Performance analysis based on Dead nodes

Figure 11 represents Number of dead nodes v/s Number of simulation rounds at different energy values. As can be observed from the figure, first node using EAHCP becomes dead at 2200th round as compared to SEP, DEEC, Z-SEP, ETM-IoT protocols, where the number of dead nodes started increasing after 1000th round only. The proposed protocol maintains stability and even after 8500 rounds, there are still few alive nodes, with the introduction of dynamism and heterogeneity in the IoT network. The results shown by Figure 11(a) and Figure 11(b) clearly state that even after increasing the energy level of superior nodes the protocol shows stable results as compared other protocols. According to the study on number of dead nodes, Table 3 lists the comparative analysis among SEP, Z-SEP, ETM-IoT, DEEC and EAHCP protocol on the basis of first and tenth dead nodes, network lifetime and number of packets transmitted and packets-energy ratio. Table 3 shows the resistance of network is increased using EAHCP protocol

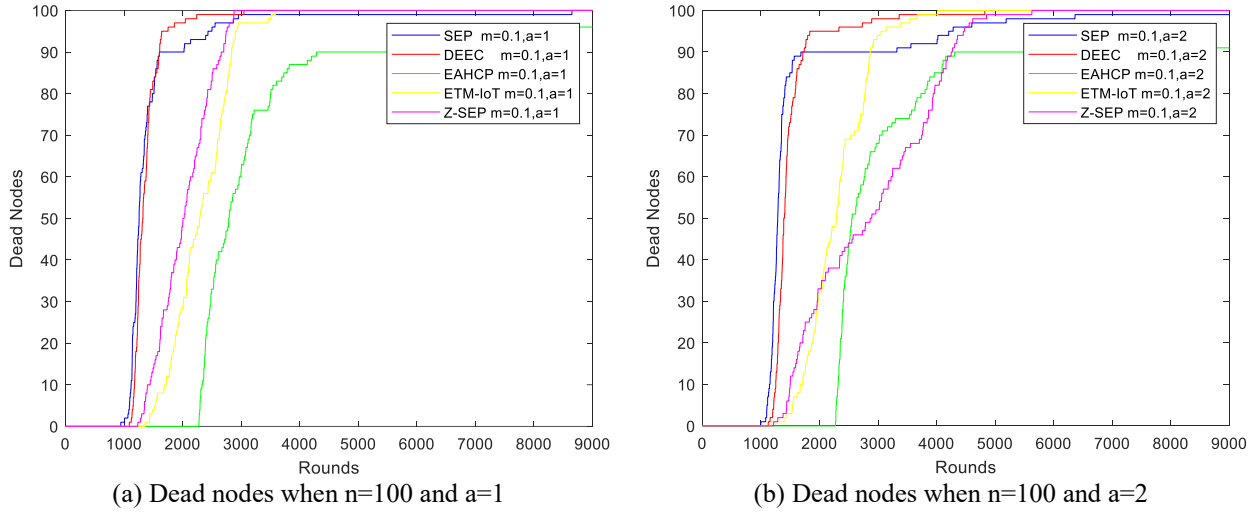


Figure 11. Number of dead nodes v/s Number of simulation rounds.

Table 3. Comparison analysis of EAHCP with SEP, Z-Sep, ETM-IoT and DEEC.

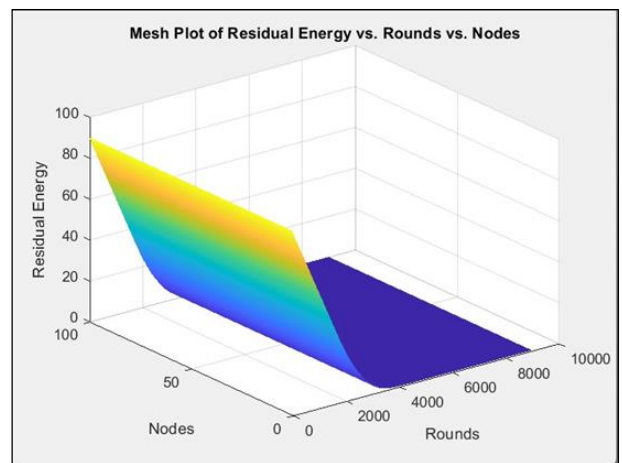
Protocol (When $Nn = 100$)	First node dead (Rounds)	Lifetime of network (Rounds)	Tenth nodes dead (Rounds)	No. of packets transferred to BS	Ratio of Number of packets transmitted to Energy Consumption (packets-energy ratio)
SEP	1010	5081	1090	144744	5.38×10^{-6}
DEEC	1080	7088	1122	148587	1.05×10^{-6}
Z-Sep	1112	2500	1312	254377	7.35×10^{-7}
ETM-IoT	1850	5500	1905	278448	5.03×10^{-7}
EAHCP	2200	8999	2212	445632	4.46×10^{-7}

From the results it becomes evident that the stability of EAHCP is more than other heterogeneous protocols. Besides mobile nature of IoT nodes, the first node dies very late and a large number of nodes stay alive for a greater number of rounds. This increases the stability period of the protocol. In comparison to other protocols, a greater number of packets are transmitted to BS using EAHCP. SEP and DEEC have higher packets-energy ratio value as compared to EAHCP, as they both save energy by limiting the no. of packets transmitted. On comparing EAHCP with Z-SEP and ETM-IoT, the proposed protocol achieves highest packets-energy ratio. This is due to optimal CH selection by the algorithm. The number of dead nodes in EAHCP increases at a very slow rate as compared to other protocols. This shows EAHCP ensures sustainable operation of IoT nodes in the network and doesn't require frequent replacement of batteries.

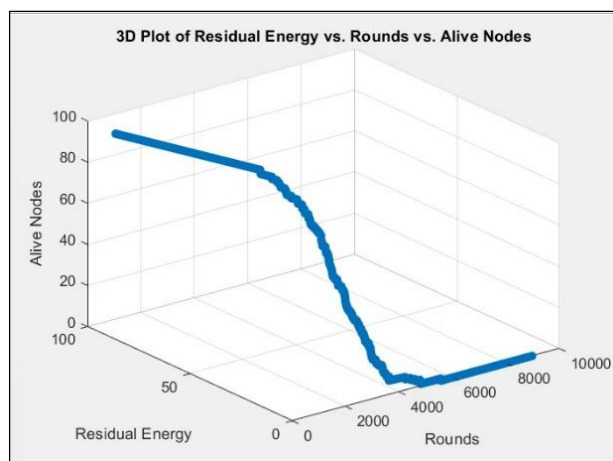
4.5 Energy Consumption Analysis

IoT nodes rely on battery, so energy reduction is one of the main challenges in these networks. In case of mobile nodes, as they move departing far from the BS, they consume more energy for transmitting and receiving data from the CHs. The proposed EAHCP is able to maintain the energy level till 4000 rounds as shown by Figure 12.

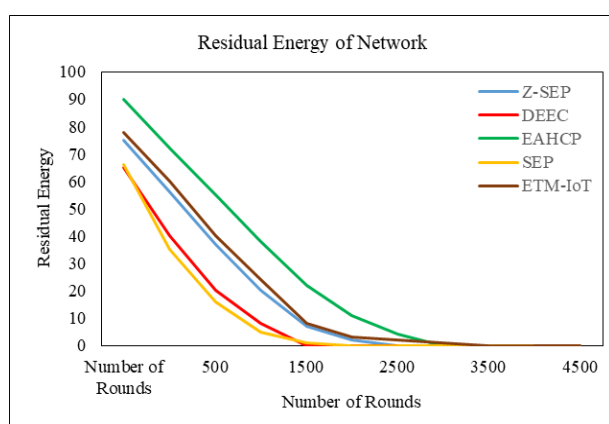
This is because all the alive nodes only communicate with their nearest CHs. It can be seen by the 3-D view of the results (Figure 12(b)), the nodes are alive for more time due to constant energy level maintained by EAHCP. Figure 12(c) also shows the comparison of residual energy of all three protocols with dynamic EAHCP. EAHCP is able to maintain high energy. EAHCP performance is almost 35% higher in comparison to SEP, 15% enhanced than Z-Sep and ETM-IoT and approximately 25% better than DEEC.



(a) Residual Energy of EAHCP



(b) Alive nodes vs Residual energy EAHCP



(c) Analysis of Residual Energy

Figure 12. Comparison of Residual Energy in the network

5. CONCLUSION

EAHCP is an innovative and novel protocol, which efficiently improves network lifetime in hybrid and heterogeneous IoT network, with the help of energy aware cluster formation technique. EAHCP cluster-oriented strategy increases the lifespan of IoT nodes by selecting nodes having higher energy level and that are nearest to the BS. As compared to other methods Z-SEP, DEEC, ETM-IoT and SEP; EAHCP is dynamic as the location of nodes is continuously changing. It is scalable because algorithm is not dependent on node position and completely heterogeneous in nature. Besides the nodes are mobile in nature, EAHCP outperforms other protocols in terms of Network robustness, Energy consumption and packets transmission. Results shows that the survival time of a network that uses EAHCP is more than the networks that uses SEP, Z-SEP, ETM-IoT and DEEC protocol.

We are currently working on extending EAHCP protocol to find a secure way to connect and transfer data having mobile IoT devices in the network (Dhingra et al., 2024). As in case of IoT network, the network is dynamic in nature so it is very difficult to secure it from DDoS attacks. Also, the number of message drops will further be reduced, which are very high in case of mobile IoT nodes. Further, to design and test, EAHCP under real time conditions is left as the future work.

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