International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Node Clustering and Cluster Head Selection in Multi-Channel Wireless Sensor Networks

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Submitted: 03/02/2024 **Revised:** 11/03/2024 **Accepted:**17/03/2024

Abstract: Hierarchical approach for overall management of a multi-channel wireless sensor network seems to be more practical in terms of stability, scalability and also reliability. Clustering of nodes in such a hierarchical network plays an important role. Moreover, appropriate selection of cluster head nodes can not only improve the network performance but it can result in prolonged lifetime of the network too. In this paper, a node clustering algorithm for multi-channel wireless sensor network is proposed along with a methodology for selection of the respective cluster head nodes. The node clustering algorithm may be executed at sink and nodes are clustered considering two different parameters namely geographic proximity and availability of common channels. The nodes inside a cluster are expected to be geographically close to each other and also they are desired to have access to maximum number of common communication channels. Access to common communication channels shall reduce the overhead due to channel switching. Again at the time of selection of the cluster head nodes, the principles of Analytic Hierarchy Process (AHP) are exploited and as per AHP principles, the most suitable node is selected as the cluster head for a cluster of nodes. The performance of the proposed protocol has been evaluated and compared with few benchmark techniques available in literature. The proposed approach outperforms other protocols in terms of energy efficiency, throughput, end-to-end delay, communication overhead, network lifetime, and re-clustering time. The future scopes of the work are outlined.

Keywords: *Wireless Sensor Networks, Multi-channel Wireless Sensor Networks, Analytical Hierarchy Process, Clustering, Mobility.*

1. Introduction

Over the last decade, there has been a significant advancement in both hardware and communication technology. Multi-channel communication-capable sensor nodes are now commercially available. Thus, in the environment of typical wireless sensor networks, there has been a trend to set up such sensor nodes that are able to communicate across several channels. Compared to single-channel Wireless Sensor Networks (WSN), the performance of multi-channel Wireless Sensor Networks (MWSN) is significantly improved. Multi-channel WSNs support several communication frequencies, simultaneously [1]. Because the nodes have access to many channels, they have a variety of possibilities in terms of channels for data communication [2]. As a result, the nodes have options for choosing the communication channels. It is important to remember that MWSNs expend more energy than single-channel WSNs [3]. Single channel WSN generally performs well in low traffic conditions; thus they perform efficiently especially when energy efficiency is taken into account [4]. However, in situations with high traffic loads, single channel WSN finds it challenging to manage the situation. Again, as compared to single channel WSN, MWSN performs better in situations with high traffic [5]. Many protocols for WSN have already been developed, but they are incompatible with the MWSN setup. The development of appropriate protocols and algorithms is required at every level, from the physical layer to the application layer, in order to fully utilize the potential of the MWSN system. The routing protocols and medium access control protocols are essential to the efficient operation of a MWSN system. Therefore, developing effective protocols for varied uses, using multiple protocol stack layers (i.e., cross layer approach) is an open research topic. Protocols and algorithms that have been developed for WSN are not effective in MWSN setup, especially when quality of services considerations are taken into account. There has been a trend for replacing traditional WSN by MWSN in various domains such as Industrial Internet of Things (IIoT). One of the reasons being the significant advancements in hardware technology that have taken place recently, MWSN is gradually gaining popularity. In present time, sensor nodes in particular are more efficient in terms of transmission, energy consumption, and support for multi-channel communications [6]. MWSN applications are generally found in various industries such as the military, building, healthcare, etc. [7] [8][16].

The operational efficiency of such a network is highly influenced by the logical organization of the sensor network. It has been understood that a hierarchical network setup is much more stable, scalable, robust and also efficient. Thus node clustering in a given WSN or MWSN setup is an important problem while hierarchical organization of the sensor network is considered. Nodes in a network set up are clustered considering different features such as proximity of the nodes in terms of geographical distance, or other similar attributes. Although, there are a few node clustering algorithms already developed for WSN (such as LEACH [26]), straightforward application of these algorithms in a MWSN setup is not advisable considering the unique characteristics of MWSN nodes. Access to multiple channels by the sensor nodes in a MWSN setup enables clustering of nodes with a distinct

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perception. For example, availability of common channels for communication, for different sensor nodes makes those nodes similar. Since similarity is the major parameter in choosing the cluster members for a particular cluster of nodes, this similarity measure in terms of common channel availability shall enable node clustering with a unique approach.

In this paper, node clustering along with cluster head selection has been the problem addressed.

A node clustering approach is proposed along with a cluster head selection algorithm. The cluster head selection is achieved by exploiting the principles of Analytical Hierarchy Process (AHP). AHP is a statistical tool that can be used for optimization purpose. After the sensor nodes are deployed, the sensor field is essentially clustered into several clusters. Although the clustering techniques available for WSN can be used to produce this sensor field clustering [22][23], it is felt that there is scope to have a different clustering approach as mentioned above that shall give importance to the parameter like availability of channels to the nodes.

For multi-channel WSNs, there aren't many cluster-based protocols available; these are detailed in [13][14]. When using a cluster-based strategy, there is always a hierarchical transmission structure. The data is transmitted from the regular sensor nodes to the corresponding cluster head node, which then forwards the data to the sink directly or via a multi-hop protocol that includes a few additional cluster head or relay nodes along the way. This method reduces the overall energy expenditure. Data from the sink is typically sent to and received by the cluster head node. Therefore, in a MWSN configuration, all intra-cluster communications between regular cluster member nodes and the corresponding cluster head node must use the proper communication channels. Furthermore, for the full multi-hop communication that begins with a certain cluster head node and finishes with the sink, the proper channels must be determined.

Conventional clustering strategy those are available can be found in literature [22][23]. In this work, a novel method is used to identify the cluster head nodes. An extremely effective approach for determining the best decisions is the Analytical Hierarchy Process (AHP) [17][18]. The cluster head node in each cluster has been chosen by utilizing AHP. An eligible node for cluster headship can be chosen to be the cluster head node by employing AHP. Since the cluster head node is in charge of communicating with the sink, the cluster head node must also be assigned the proper channels after it has been chosen.

Members of a cluster are other nodes that are part of that cluster. The number of nodes that will make up a cluster is not predetermined. Either a stationary or mobile node can serve as the cluster head node. Members of the cluster communicate with each other through the corresponding cluster head node rather than the base station directly. Every cluster in the specified configuration has a unique cluster ID. Similarly, every node has a unique ID. Thus a node is associated to two different IDs such as Node ID, and cluster-ID. An assumption made here is s follows: different channels are distinguished uniquely throughout the entire system, by their distinct colors [21]. When data transmission takes place, the cluster head node handles long-distance communication with the sink, while the cluster members use the designated channel to transfer data to the corresponding cluster head node. Various cluster head nodes may be allocated distinct time slots for the purpose of data transmission. The simulation results establish superiority of the proposed scheme in terms of various performance parameters over other contemporary schemes.

The rest of the paper is organized as follows: in section 2 related works are presented, followed by section 3 in which the proposed protocol is described in detail. Section 4 presents the simulation results and the paper is concluded in the section 5.

2. Related Works

In hierarchical wireless sensor networks, clustering is a crucial strategy for maintaining network consistency, stability, scalability, and energy economy. In such networks, clustering techniques are employed in order to form clusters of nodes. Even distributed clustering approaches have been developed to address various issues such as energy efficiency and network longevity, i.e., lifetime. In cluster based networks, forwarding nodes (gateway nodes) are used to forward the essential information to the rest of the network. Each cluster is made up of certain number of nodes known as cluster members, and a cluster head (CH). Data packets are forwarded to the CH by the ordinary cluster members. The CH collects data, and aggregates it, to save energy. Cluster members often communicate with the cluster head. On the way to the sink, the cluster heads may also create additional layers of clusters among themselves. This section describes a few such protocols that use clustering as a way to increase the effectiveness of the network.

A clustering algorithm that forms unevenly sized clusters of sensor nodes to broadcast data to the sink is proposed in [9]. To extend the lifespan of sensor networks, this distributed algorithm determines the number of nodes, distance from the sink, and remaining energy of each node. Cluster heads transmit data in a multi-hop manner to the sink. All other clusters' traffic is transmitted towards the sink by the cluster head that is the closest to the sink. Thus, in order to maximize the performance of WSNs, either none or very few members are chosen to form a cluster close to the sink. This algorithm performs better, improves the life of the network, and consumes less energy.

A cluster-based scheduling technique designed for Cognitive Radio Sensor Networks (CRSNs) has been proposed in [10]. Only mixed channels are assigned to the nodes that have one-hop neighbors outside of their clusters in order to prevent inter-cluster collisions. In order to prevent inter-cluster collisions, different channels are assigned to the entire set of neighboring clusters. Optimizing the spatial reuse and boosting network throughput while reducing sensor energy consumption are the goals. These are achieved by designating channels to those particular nodes exclusively. Each cluster head (CH) autonomously arranges the transmissions within its cluster after the inter-cluster collision issue has been resolved. The CH only provides time slots to its cluster members that are specified nodes, as the channel assignment has already been completed. For the cluster members (other than specific nodes), the pair of <channel, slot> is assigned by the CH. This study suggests two ways to schedule the cluster members. There are two algorithms used for this purpose, namely, Frame-ICMS (Frame Intra Cluster Multichannel Scheduling) and Slot-ICMS (Slot Intra Cluster Multi-channel Scheduling). The proposed method performs better than the benchmark, particularly in terms of energy efficiency.

As per the technique proposed in [11], each sensor node, or member node, continuously gathers data from the surrounding environment, stores it in a buffer, and then waits for the allotted timeslot to transfer the data to a chosen cluster head. Every node's buffer is subjected to one or more threshold values that have been predefined. The node begins to discard the collected data if the buffer occupancy level is higher than the threshold value. It is possible for a member node to continuously gather data. It may take longer than anticipated time duration to transmit data to the sink. In this situation, the underlying application's data may produce too much latency, and become unusable for additional analysis. The author here proposes a channel borrowing plan for each cluster's member nodes. Every member node keeps an eye on its buffer, and if occupancy rises over a predetermined threshold, a request for a channel borrowing is made. Every node keeps track of possible cluster leaders in a table. Based on signal intensity, a nearby cluster head is chosen for channel borrowing. The member node receives any available channels from nearby cluster heads. A threshold waiting time must be met before acknowledging the request to borrow a channel. The experimental findings demonstrate that the suggested approach improves throughput and network longevity while lowering packet loss, energy usage, and end-to-end latency.

An improved technique for cluster formation and cluster head (CH) selection for multi-cluster topologies based on fuzzy logic has been proposed in [12]. This technique offers an extended network lifetime. By reducing the interference and collision, the proposed technique titled as Multi-Cluster Multi-Channel Scheduling (MMS) algorithm enhances data collection in the network. Various components of the proposed technique are cluster formation, cluster head (CH) selection, and interference-free data transfer through appropriate channel scheduling. Simulation results demonstrates that the proposed method is appropriate for energy-constrained wireless sensor networks since it minimizes delays and prolongs network lifetime in addition to enabling interference-free transmission.

In [13], a cluster based multi-channel MAC (Medium Access Control) protocol called MPCB-HM (Multipath Cluster-Based Hybrid MAC) is proposed. It makes use of FDMA (Frequency Division Multiple Access) to enable simultaneous collision-free data exchange, TDMA (Time Division Multiple Access), and CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) to exchange data. In order to spread the heavy data flow across several channels, the nodes have multiple communication channels. By using this technology, collision-free transmission is obtained while minimizing energy usage and reducing node overhead. The MAC mode control is in charge of switching the mode from TDMA to CSMA and vice versa with the aid of intra- and inter-cluster communication. The use of the cluster-based architecture aids in increasing energy efficiency and scalability.

A unique Bayesian non-parametric channel clustering approach is presented in [14]. The proposed technique determines the QoS (Quality of Services) levels supported over license channels that are accessible. The bit rate, packet delivery ratio, and packet delay variation of licensed channels are used as features in the feature space of the proposed approach, which uses the infinite Gaussian mixture model and collapsing Gibbs sampler to determine the QoS levels. Furthermore, the effectiveness of the suggested system is assessed using actual measurements of wireless data traces, and compared with baseline clustering approaches.

MCCH (Multi-Channel Clustering Hierarchy) is proposed in [15]. The network can be modified by choosing the cluster head to be the channel reference, and splitting it up into multiple clusters. Spreading out 100 nodes and using the probability calculations to select one at random, yields the cluster head. In order to maximize efficiency and minimize energy consumption during data transmission, the cluster head and cluster members are kept not too far apart. The Euclidean method is used to calculate the distance between cluster leaders or cluster heads and cluster members. Using a single linkage approach, cluster heads and members are grouped by comparing their proximity and similarity to each other, calculating the distance matrix of the closest (most similar) cluster pair, and then merging the newly formed clusters.

Table1: Summary of literature review

Protocols	Quality of services parameters					
	Energy efficiency	End-to-end delay	Throughput	Packet delivery ratio	Network lifetime	Scalability
[09]	Yes				yes	
[10]	Yes					
[11]	Yes	yes	yes	yes	yes	
[12]		yes			yes	
[13]	Yes					yes
[14]			yes	yes		
[15]		yes	yes			

It has been noted that none of the protocols mentioned above takes into account the issue of node and sink mobility, either jointly or individually. Moreover, there is no prominent work available that can guarantee quality of services in MWSN.

3. Proposed Work

In this section, an approach for node clustering in a MWSN setup along with a technique for cluster head selection is detailed. The cluster head selection method is based on Analytical Hierarchy Process (AHP). Figure 1 depicts a deployed MWSN which is clustered. Here, the sink is located outside the sensor field.

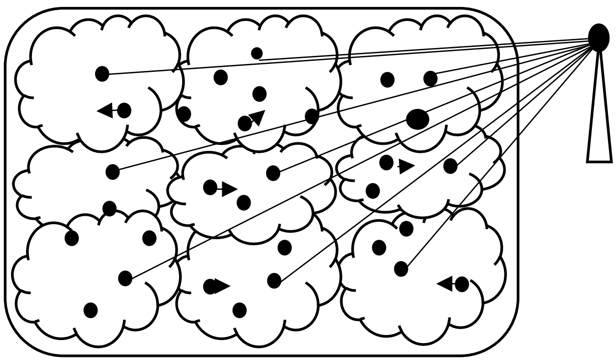


Fig 1 Cluster based MWSN

Initially, the multi-channel wireless sensor network (MWSN) is established. The sensor nodes which are multi-channel enabled are deployed randomly. The nodes possess multiple channels and are set up to communicate with these channels. Some of the sensor nodes are mobile, and others are stationary. The mobile sensor node can have mobilizer unit attached to it or it may be attached to other mobile objects, depending on the type of application. The node is predicted to have a maximum speed of two to three meters per second. Every node is uniquely identified by its unique identification number (ID). The network is inherently self-organizing and self-starting.

The entire operation of such a network may be described with the help of figure 2. As shown in the figure, various phases are to be crossed in order to achieve end-to-end data transmission.

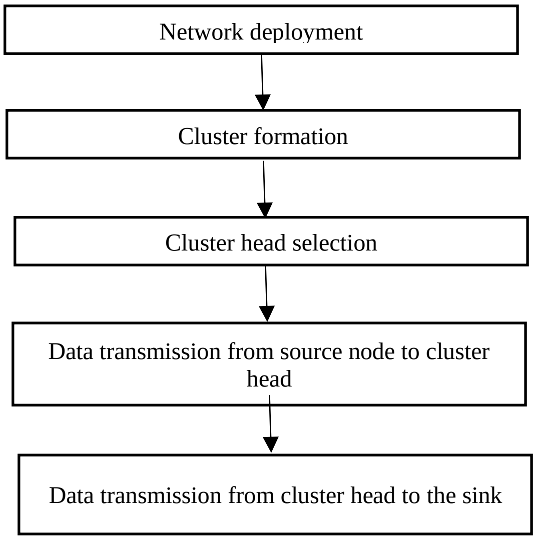


Fig 2 Phases covering entire operation of the network

In this work, major focus is on cluster formation and cluster head selection. Once the nodes are deployed, a node clustering algorithm may be invoked to form the clusters. The entire sensor field then shall be composed of multiple clusters. Depending on the kind of application, different sensor nodes may virtually be grouped together to form clusters considering certain factors like residual energy, position, etc. After the clusters are formed, the next important task is to choose the respective cluster head nodes.

Cluster formation:

In this section, a node clustering algorithm is proposed. In has been assumed that the sink is resourceful and it can compute at ease. Moreover, energy is not a constraint for the sink. For simplicity, the computational burden has been shifted toward the sink. It is also assumed that the sink is aware of the geographic locations of the nodes deployed in the sensor field. As the sensor nodes are multi-channel enabled, each sensor node shall have access to multiple channels depending on the network conditions.

While clustering, two parameters of each node are given maximum importance. Those are geographic location (Loc_i), and availability of common channels (CC). The sink is also assumed to be aware of the channel availability with each node in the field. Considering the type of application, these two parameters can be assigned different weights while making the clusters. Therefore, following quantities are computed before making the clusters.

Distance between two different nodes i and j at a given time instant $(D_{ij})_t$: Time instant is important to be considered as some of the nodes are mobile and thus the distance shall vary with respect to time. $(D_{ij})_t$ can be computed using Euclidian distance formula, which is trivial. The inputs for computation of $(D_{ij})_t$ are $(Loc_i)_t$ and $(Loc_j)_t$.

Availability of common channels between the two nodes i and j at a given time instant $(CC_{ij})_t$*:* The time instant is important as the channel availability may change with respect to time considering the dynamics of the network system.

Finally, weights w_1 and w_2 are decided considering the application type and assigned to $(D_{ij})_t$ and $(CC_{ij})_t$ respectively, in order to compute the total credit value as given below:

Total credit = $[w_1\ ((D_{ij})_t\ )] + [w_2\ ((CC_{ij})_t\ )]$ subjected to $(w_1 + w_2) = 1$.

The above mentioned two parameters are heterogeneous, as one is a distance value and the other is a number (of channel), therefore, these two parameters may be normalized and be compared with an appropriate threshold value at the time of making a decision whether to keep the nodes I and j inside the same cluster or not.

This process is repeated for either the entire set of nodes or for a subset of the nodes to form the clusters. As it is already mentioned the computational overhead is shifted to the sink considering its resource availability. The nodes are finally informed by the sink about their cluster information.

Cluster head (CH) selection:

For every cluster, a cluster head must be chosen. The cluster head node is expected to have a high level of residual energy as well as other attributes like channel availability, connectivity with other cluster members etc. The choice of cluster head may be influenced by mobility level as well. An optimization technique that can be used to make wise and efficient judgments is the Analytical Hierarchy Process (AHP) [17]. Thus, while choosing the cluster heads, the AHP principles have been utilized in this proposed approach. The application of AHP in cluster head node selection is described in this sub-section.

Thus optimization is accomplished across several parameters in accordance with the AHP principles. To arrive at the best choice, a number of factors are taken into account. In this instance, the more capable sensor node must be chosen to serve as the cluster head for a particular cluster. A sensor node's capability is defined by a variety of characteristics. The capability of a sensor node can be calculated using a number of unique factors, including available queue length (also known as the buffer), mobility, residual energy, and others. In specific, the following four highly significant parameters are considered in the cluster head node selection process.

Energy: it represents the amount of residual energy in a given sensor node.

Mobility: It indicates if a node is movable or stationary. If the position remains fixed, the distance from the base station may be determined. If the node is mobile, it is necessary to take into account its direction (i.e., approaching or moving away from the sink) also and its distance from the sink.

Node density: it represents the number of nodes present in a particular cluster.

Node status: it represents queuing buffer length available in a sensor node.

A node must have enough remaining energy within it to be chosen as the cluster head. Numerous iterations can be used to represent the sensor network's whole activity. The network configuration doesn't change for a specific iteration. Thus the cluster head node is fixed for an iteration of the network. This is one of the reasons for the following requirement: the cluster head node needs to have greater capabilities in terms of several factors, including available queuing buffer length, and residual energy.

Consumed **energy** (average) may be computed using expression (1).

Consumed energy= $\frac{Eo - \sum_{i=1}^{n} Ei}{n}$ (1)

It is possible to set the values for various parameters in a given network. For a few simulation trials, for example, the following values are taken into consideration in this work.

Initial energy in each node (Eo) = 10 Joule

Number of nodes (n) = 100

As it is already mentioned that the nodes can be stationary or mobile, the cluster head node that is going to be chosen can also be either stationary or mobile. The permanent position of the static nodes could be advantageous for communication between the nodes that make up the cluster. But this might not be the greatest option if the cluster head is far from the sink. It can be more advantageous to choose a mobile node as CH that is traveling towards the sink at a slower speed.

Mobility is expressed using the following expression.

$M = N(x, y) \mp Sn$ (2)

Here, M represents mobility and N(x,y) represents the current position (coordinates) of the node. Moreover, Sn represents the speed of the node ("+" if direction is towards the sink, "-" if away from the sink).

Node density has a significant impact on the node chosen to be the cluster head. Not every cluster has the same quantity of nodes in it. Furthermore, there is no pre-set quantity of nodes in any cluster. The node clustering algorithm determines this, dynamically. A node needs to be able to communicate with the sink on behalf of the entire cluster in order to be designated as the cluster head of a high density cluster. As a result, different cluster head node capabilities may be expected for average and low density clusters. For a given cluster, the node density (ND) is the combined number of static node (SN) and mobile node (MN), as given in expression (3).

ND=SN+MN (3)

Queuing length is the primary factor used to determine **node status**. The queuing duration is a crucial quantity for a cluster head node since, occasionally, all cluster member nodes communicate with it simultaneously. Again, the cluster head node keeps regular contact with the sink. The cluster head node needs to be able to hold onto the packets for that specific amount of time. A buffer overflow could result in packet loss, if the cluster head does not have enough queuing capacity. The average buffer capacity (Q) can be computed as follows (expression 4) [25]:

$Q = (Qmax - Qt)/Qmax$ (4)

Where, Qmax represents the maximum buffer size. In this work, the buffer size is set to 50. Qt represents the number of packets in the buffer queue at time t.

As it has already been mentioned, the cluster head nodes are chosen by utilizing the principles of AHP. Figure 3 shows the hierarchical organization of the multiple criteria and sub-criteria that were employed.

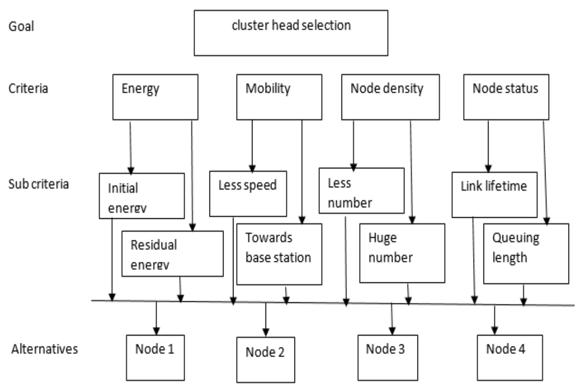


Fig 3 Hierarchical view of the cluster head selection process (as per AHP)

The cluster head node can be chosen once all requirements have been examined. The selection of the cluster head node with the highest priority is the final objective in this step. As per the AHP based method, matrix Zij is used to determine the nodes' priority. The relative significance of the criteria at each stage is represented by Zij [29]. Table 2 displays relative relevance along with various weights applied to these importance levels.

Table 2: The scale of relative importance

Weights	Description
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extremely importance value

1/3 1/5 1/7 1/9 are used for inverse calculation. 2, 4, 6, and 8 are intermediate values.

Table 3 represents a calculated Zij matrix; here the number of criteria is considered to be 4.

Table 3: Matrix Z=(Zij), representation

	Energy	Mobility	Node density	Node status
Energy	1	Zem	Zed	Zes
Mobility	Zme	1	Zmd	Zms
Node density	Zde	Zdm	1	Zds
Node status	Zse	Zsm	Zsd	1

As per the principle of AHP, Eigen vectors are computed; also the priorities are computed. Finally, the following values are computed: Consistency index (CI), Consistency ratio (CR), and Random consistency index (RI).

Consistency ration is computed using expression (5).

CR=CI/RI (5)

Explanation of the matrix $Z_{i,j}$**:** In the AHP based approach, the comparison matrix Z=(Z_{ij}), n×n is computed for all the decision criteria where, n is the total number of criteria at each level. $Z_{i,j}$

represents the relative importance of criteria i to j. Here, if $Z_{i,j}>0$, then it indicates the importance of criteria i to j, if $Z_{i,j}=1$, then it indicates i=j, and $Z_{i,j} = 1/ Z_{i,j}$, indicates the reciprocal importance of criteria j relative to criteria i. Here, the number of criteria is 4 (e.g., energy, mobility, node density and node status). For example, Zme represents the relative importance of mobility to energy metric and so on so forth, as shown in the above matrix (table 4).

Then, as per the AHP principle, Eigen vector is calculated; also the priorities are calculated, and finally, the followings factors are determined [19].

Consistency index (CI):

$$CI = \frac{\lambda max - n}{n-1} \quad (6)$$

λmax= maximum Eigen value of matrix $Z_{i,j}$

n= number of criteria.

Random consistency index (RI): The value of RI is related to the dimension of the matrix, and will be extracted from Table 4. It should be noted that consistency ratio lower than 0.10 verifies that the results of comparison are acceptable.

Table 4: The value of Random Consistency Index, Source: [20]

Dimension	RI
1	0
2	0
3	0.5799
4	0.8921
5	1.1159
6	1.2358
7	1.3322
8	1.3952
9	1.4537
10	1.4882

Lastly, the consistency ratio (CR) is computed using the formula CR = CI/RI in order to validate the outcomes of the AHP.

Various parameter configurations have been used, and a detailed analysis has been done to find the optimal set of parameters. The impact of the different factors is evaluated to ascertain the relative importance of the parameters (e.g., energy, mobility, node density, and node capacity) using a comparative matrix Zi,j as presented in Table 6. Following a comprehensive study, the resulting combination shows the relative relevance of the coefficients.

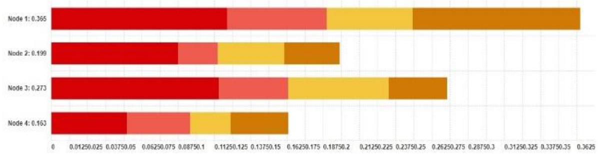
After a thorough examination, several parameter combinations have been tested to discover which set of parameters works the best. The impact of several metrics is evaluated to ascertain the relative significance of the following factors: energy, mobility, node density, and node status, using a comparative matrix Zi,j as presented in Table 5. Following a comprehensive performance study, the resulting combination is used to indicate the relative relevance of the coefficients. Table 5 is just an illustration.

Table 5 Weight value assumption (based on table 2)

	Energy	Mobility	Node Density	Node Status
Energy	1	7	6	1/5
Mobility	1/7	1	1/5	7
Node Density	1/6	5	1	3
Node Status	5	1/7	1/3	1

Four nodes, namely, N1, N2, N3, and N4 were taken into consideration in a series of experiments (simulations). As shown in table 6, it was discovered that Node 1 (i.e., N1), has the highest priority, as per the calculation described above.

Table 6 Overall weights of the four nodes



The relative ordering of the criteria is shown in Table 7. It is evident that, out of the four decision factors, mobility is the least significant, whereas the energy measure has a greater priority, and is also crucial in the cluster head selection process. Table 7 displays the relative value of each additional criterion.

Table 7: Relative ranking of the criteria

Criteria	Value	Importance
Energy	0.376	The most important criteria
Mobility	0.188	The least important criteria
Node density	0.202	The third important criteria
Node status	0.234	The second important criteria

Some more such examples are worked out in this sub-section to establish different cluster head selection process depending on priority of the criteria.

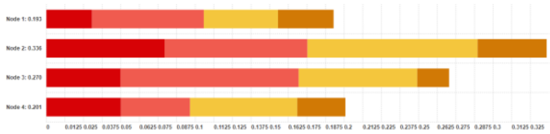
The mobility criterion, which is one of the chosen criteria for cluster head selection, is given the maximum weight. Table 8 illustrates other requirements that are presumed.

Table 8 Weight value assumption (based on table 2)

	Energy	Mobility	Node Density	Node Status
Energy	1	1/7	4	1/5
Mobility	7	1	1/5	7
Node Density	1/4	5	1	3
Node Status	5	1/7	1/3	1

We identified four nodes as N1, N2, N3, and N4 in a series of experiments (simulations). Following the calculations as mentioned above, it has been found that Node 2 (i.e., N2) has the highest priority, as shown in table 9.

Table 9 Overall weights of the four nodes



The relative ranking of the criteria is displayed in Table 9. It is noticed that, out of the four decision factors, node status is the least significant, whereas mobility metric has a higher value and influences the choice of cluster head. Every other criterion is given a weight according to table 10.

Table 10: Relative ranking of the criteria

Criteria	Value	Importance
Energy	0.210	The third important criteria
Mobility	0.337	The most important criteria
Node density	0.316	The second important criteria
Node status	0.137	The least important criteria

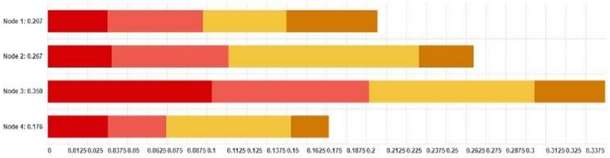
For the next example, we consider node density as the criteria having the highest importance level considering all other criteria. The assumptions regarding the weights are shown in table 11.

Table 11 Weight value assumption (based on table 2)

	Energy	Mobility	Node Density	Node Status
Energy	1	1/5	4	1/5
Mobility	5	1	1/5	4
Node Density	1/4	5	1	4
Node Status	5	1/4	1/4	1

In a set of experiment (simulation) we considered four nodes as N1, N2, N3 and N4. After calculating as described above, it was found that Node 3 (i.e., N3) has the highest priority, as depicted in table 12.

Table 12 Overall weights of the four nodes



The relative rankings of the criteria are presented in Table 13. Among the four choice factors, node status has the least significance, indicating that node density metric has the highest value, and influences the cluster head selection process. Table 13 displays the relative weights of all other criteria.

Table 13: Relative ranking of the criteria

Criteria	Value	Importance
Energy	0.207	The third important criteria
Mobility	0.267	The second important criteria
Node density	0.350	The most important criteria
Node status	0.176	The least important criteria

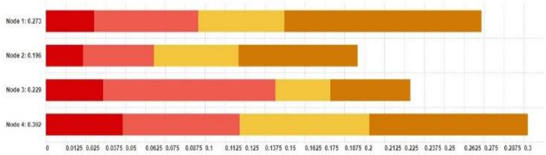
Another example is presented here. Node status is considered to be the most important criterion among all other criteria. The assumptions of the weighs are presented in table 14.

Table 14 Weight value assumption (based on table 2)

	Energy	Mobility	Node Density	Node Status
Energy	1	1/5	4	1/5
Mobility	5	1	5	1/4
Node Density	1/4	1/5	1	4
Node Status	5	4	1/4	1

Like before, four nodes, denoted as N1, N2, N3, and N4 are considered in a series of experiments (simulation). Table 15 shows that Node 4 (i.e., N4) received the highest priority.

Table 15 Overall weights of the four nodes



The relative ordering of the criteria is presented in Table 16. It is evident that, out of the four choice factors, energy is the least significant, while the node status measure has the highest priority and is crucial in choosing the cluster head node. Table 16 indicates the relative value of each additional criterion.

Table 16: Relative ranking of the criteria

Criteria	Value	Importance
Energy	0.138	The least important criteria
Mobility	0.291	The second important criteria
Node density	0.223	The third important criteria
Node status	0.348	The most important criteria

As a summary, Figure 4 illustrates the general procedure for calculating the weights needed to choose the cluster head nodes using AHP. Figure 3 displays the criteria, while Table 2 provides an explanation of the importance levels of the scale. Finally, a single node is chosen to be the cluster head node based on the consistency ration (CR) value.

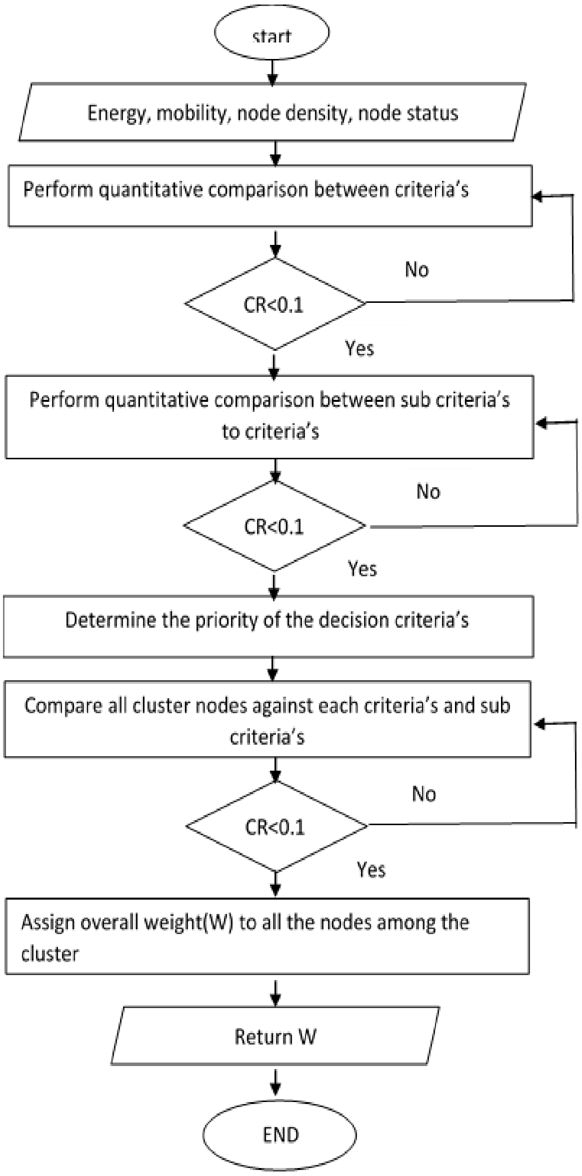


Fig 4 Use of AHP to compute the weights for cluster head selection

4. Simulation Results

The The proposed protocol has been simulated extensively using Matlab 7.1. AHP mechanism has been included to calculate the weights of the surrounding nodes. Each node irrespective of their mobility value (static/ mobile) will have a CR (Consistency Ratio) value. The node with highest CR value has the highest priority and gets selected as the Cluster Head for one round (iteration). Various simulation parameters are enlisted in table 17.

Table 17: Simulation parameters considered

Parameters	**Value**
Number of channels	8
Number of nodes	100 (75static node 25 mobile node) with one static sink (or base station)
Node velocity	2-5 meter/second
Initial energy of each sensor nodes	Eo= 10 Joule
Radio range	50 meters
Packet queue size	10 packets
Packet size	4000 bits
Simulation surface	100 X 100 (in meters)
Topology	Random
Packet generation rate	10 packets per second
Number of reading repetitions	10

During simulation, the proposed protocol is used to form the clusters and to select the respective cluster head nodes. Once the clusters are formed and cluster head nodes are selected, standard approach of cluster based communication has been adopted to measure the network performance [30]. This is note worthy that the hierarchical communication protocol proposed in [30] has been developed by this group only. Then various quality of service (QoS) parameters are evaluated under the influence of the proposed methods of clustering and cluster head selection, and similar but other benchmarks methods [26][27][28]. Different QoS parameters considered for comparative study are energy efficiency, end-to-end delay, throughput, overhead, network lifetime and re-clustering time. The proposed protocol is compared with well known algorithms like LEACH: Low Energy Adaptive Clustering Hierarchy [26] , ADCA: Adaptive Distributed Clustering Algorithm [27], and EAFCA: Energy Aware Fuzzy Clustering Algorithm [28].

Energy efficiency:

Nodes are expected to consume minimum energy during the network operation. The total amount of energy consumed (TE) may be expressed as given in expression (7).

$$TE= E_T + E_R + E_I \quad (7)$$

E_T= Energy consumed due to data transmission
E_R= Energy consumed due to data reception
E_I= Energy consumed against idle listening

If a k-bit data message is forwarded between two nodes separated by a distance of r (meters), then the energy expended due to transmission can be expressed as given in expression (8) as per [24].

$$E_{Tx}(k,r) = E_{Tx}(k) + E_{mp}(k,r) = \begin{cases} kE_{Tx} + ke_{fs}r^2, & r < r_0 \\ kE_{Tx} + ke_{mp}r^4, & r \geq r_0 \end{cases}$$

(8)

Similarly, energy expended against receipt ion of k bits may be expressed as given in expression (9).

$E_{Rx}(k) = kE_{Rx}$ (9)

E_{Tx} and E_{Rx} are the energy dissipations per bit for transmission and reception, respectively, e_{fs} and e_{mp} denote transmit amplifier parameters corresponding to the free-space and the two-ray models, respectively, and r_0 is the threshold distance given by

$r_0 = \sqrt{e_{fs}/e_{mp}}$ (10)

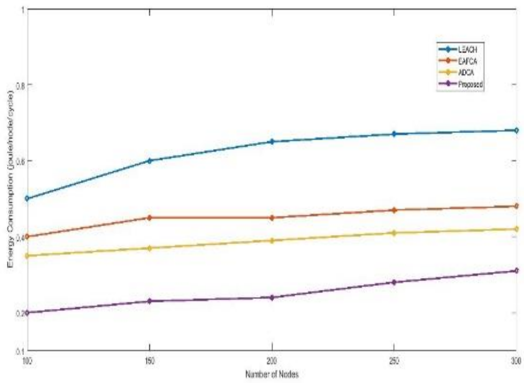


Fig 5: Energy efficiency

Energy efficiency analysis under the influence of various protocols is presented in figure 5. It is observed that the proposed approach consumes minimum energy. This is mainly due to better selection of cluster head node and better clustering of nodes.

Throughput (TH):

The network system is expected to offer maximum throughput under the influence of the proposed protocols. Throughput is defined in terms of percentage (%) calculated using the ratio between the numbers of packets received to the numbers of packets transmitted during a particular time interval.

TH = (P_R / P_T) × 100 (11)

Here, P_R= Packet received; and P_T= Packet Transmitted.
Throughput analysis under the influence of various protocols including the proposed one is presented in figure 6.

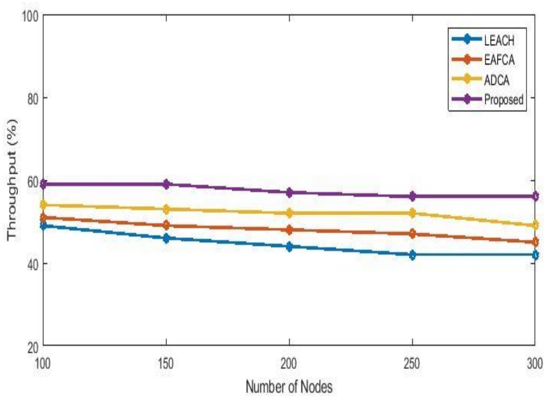


Fig 6: Throughput

Throughput of the network under the influence of the proposed protocol is maximum and it around 60%. This implies that there has been minimum loss of packets in comparison to the other protocols. This is due to again better selection of cluster head nodes and better grouping of the nodes in the form of clusters.

End-to-end delay (D):

Minimum end-to-end delay is desired. End to end delay is the time duration taken by a packet required in order to travel from source node to the destination node. For simplicity, without loss of generality, his duration is expressed in terms of two major parameters namely, travel time in various links and time required for processing (to forward) in various intermediate routers or relay nodes, as expressed in (12).

D= $\sum_{i=1}^{n} T_L + \sum_{j=1}^{m} T_R$ (12)

Here, T_L= time taken by link; T_R= time taken by router/hub.

End-to-end delay analysis under the influence of various protocols including the proposed one is presented in figure 7.

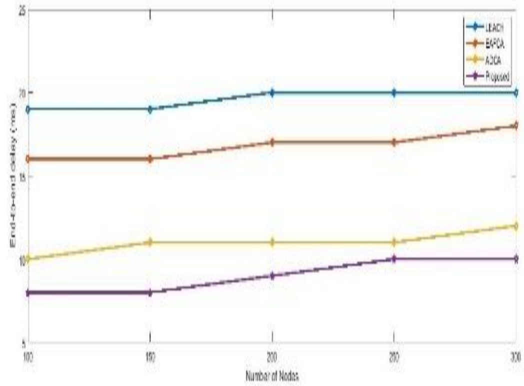


Fig 7: End-to-end delay

End-to-end delay is the minimum under the influence of the proposed protocol. This is so because of the fact that the queuing delay in the intermediate routers and other nodes are the minimum. This has connection to the fact that appropriate nodes were selected as the cluster head nodes under the influence of the proposed protocol.

Overhead (E_{OV}):

Minimum overhead is desired. This is the energy consumed due to the transmission and reception of control packets. As a part of the network management, the control packets move across the network and some of the intermediate nodes need to receive and forward such packets including the routers. Thus total overhead is the summation of the energy expended by various nodes due to the transmission and reception of the control packets. This is expressed in (13).

$E_{OV} = \sum_{i=1}^{n} e_i$ (13)

E_{OV} = overhead in a given duration; e_i=energy consumed by each node.
Moreover, e_i= E_{tx} + E_{tr} (14)
Here, E_{tx} = consumed energy for transmission; and E_{tr}= consumed energy for reception.

Overhead analysis under the influence of various protocols including the proposed one is presented in figure 8.

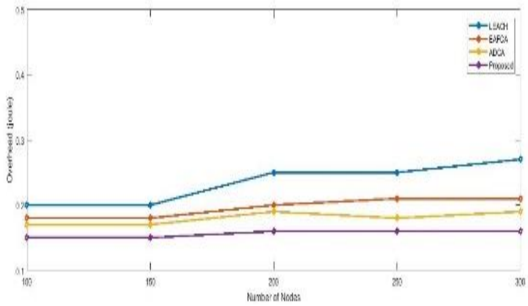


Fig 8: overhead

Overhead is again the minimum under the influence of the proposed protocol. The proposed protocol incurs minimum packet loss and therefore, minimum re-transmission. Thus overall expenditure against control packet transmission is the minimum.

Network lifetime:

Prolonged network lifetime is desired. In this work, network lifetime is considered to be the time elapsed till the death of 75% of the total nodes deployed in the network; here, time is measured in terms of rounds (n). Again, ten such rounds is considered to be equivalent to 1 cycle. N is the total number of nodes deployed then the number of nodes alive at round n <= .25(N); here n is the network lifetime.

Network lifetime analysis under the influence of various protocols including the proposed one is presented in figure 9

The network achieves prolonged lifetime due to the proposed protocol. This has link to the energy efficiency of the protocol as mentioned already. The nodes deplete energy slowly as overhead is minimum and the best node is selected as the cluster head node for each cluster.

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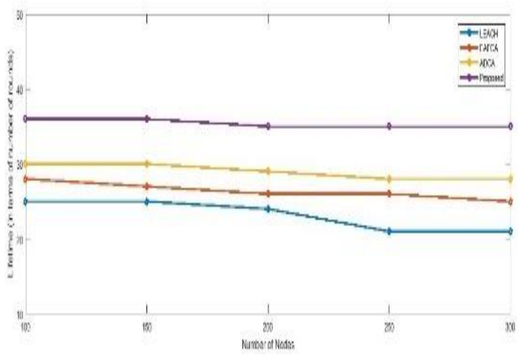

Fig 9: Network lifetime

Re-clustering time (RT):

Prolonged re-clustering time is desired. Re-clustering time is again the number of rounds after which the need of re-clustering arises. Need of re-clustering may arise due to various reasons such as network partition, excessive packet loss, or death of nodes etc.

RT=m (15)

Here, RT= re clustering time; m is the no of rounds in which re-clustering is initiated.

Thus at round m, the no of dead nodes >= .75(N); where N is the total number of nodes deployed in the network.

Re-clustering time requirements under the influence of various protocols including the proposed one is presented in figure 10.

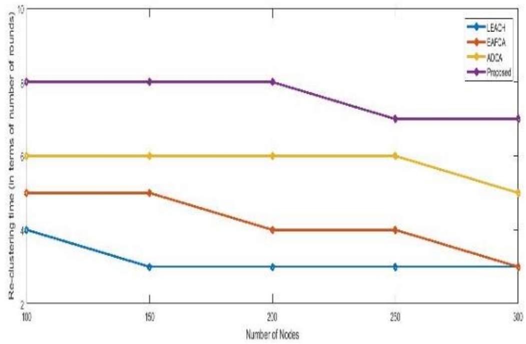

Fig 10: re-clustering time

It has been observed that the life each of the clusters is the maximum due to the proposed protocol. This has connection to other performance parameters such energy efficiency, overhead, and network lifetime. As better clusters are formed and most appropriate nodes are selected as cluster head nodes, the proposed protocol incurs minimum energy expenditure and thus the nodes live for longer time duration. Again, mobility of the nodes was considered, while forming the clusters as well as selecting the cluster head nodes under the influence of the proposed protocol, thus each cluster remains valid for a relatively longer duration.

5. Conclusion And Future Scope

A node clustering algorithm for multi-channel wireless sensor network has been proposed in this paper. The nodes in the network may be mobile also. Thus entire network is consisting of a mix of static nodes and mobile nodes. However, the sink is considered to be static. The node clustering algorithm considers two different parameters such as geographic location of each node, and availability of common channels for communication. These two parameters are given certain weights while clusters are formed. These weights may be decided at the time of implementation considering the application requirements. In each cluster, the nodes are expected to be geographically close to each other although it may not be the case always, and the nodes are expected to have access to certain number of common communication channels. After the clusters are formed, cluster head node for each cluster needs to be identified. Cluster head nodes are selected applying the principles of Analytic Hierarchy Process. The AHP principles facilitates in selecting the most suitable node as the cluster head node for each cluster, considering different objectives or parameters. The proposed clustering approach and the cluster head selection technique are extensively simulated in order to observe respective performances. Different performance parameters considered in this evaluation are energy efficiency, throughput, end-to-end delay, overhead due to the communication of control packets, network lifetime, and re-clustering time. The proposed protocol outperforms other similar protocols such as LEACH (Low Energy Adaptive Clustering Hierarchy), ADCA (Adaptive Distributed Clustering Algorithm), and EAFCA (Energy Aware Fuzzy Clustering Algorithm), in terms of all the above mentioned performance parameters.

In future, the proposed protocol may be evaluated for higher mobility values of the nodes including a mobile sink, as there shall be many applications having such characteristics. Moreover, security aspects in such environments may be investigated and if possible, effort may be put to integrate security with clustering as well as routing protocols.

References

[1] Sadeq, A. S., Hassan, R., Sallehudin, H., Aman, A. H. M., & Ibrahim, A. H. (2022). Conceptual framework for future WSN-MAC protocol to achieve energy consumption enhancement. Sensors, 22(6), 2129.

[2] Bhuyan B., Kar A, Mall R Sarma H.K.D. and Sarma N. (2010) : Quality of Service (QoS) Provisions in Wireless Sensor Networks and Related Challenges, Published Online November 2010, Wireless Sensor Network, vol: 2, pp: 861-868.

[3] Akyildiz I.F., Cayirci E., Su W., and Sankarasubramaniam Y.,(2002): Wireless sensor networks: a survey, Computer Networks, No: 38 pp. 393-422.

[4] Elson J. and Estrin D. (2004): Wireless Sensor Networks: A bridge to the Physical World, in Springer US, pages 3–20.

[5] Chen D. and Varshney P. K. (2004): QoS Support in Wireless Sensor Network: A Survey, Proceedings of the 2004 International Conference on Wireless Networks(ICWN2004), Las Vegas, Nevada, USA, Volume 1.

[6] Dulman S., Incel O.D., Jansen P. and MullenderS.(2006): Multi-channel interference measurements for wireless sensor networks, in LCN ’06: Proceedings of the 31st Annual IEEE International Conference on Local Computer Networks, pp. 694–701.

[7] Anderson J., Culler D., Mainwaring A., Polastre J. and Szewczyk R.(2002): Wireless Sensor Networks for Habitat Monitoring, in Proceeding WSNA '02 Proceedings of the 1st ACM international workshop on Wireless sensor networks and applications, Pages 88-97

[8] Estrin D., Govindan R., Heidemann, J., and Kumar S.,(1999) : Next century challenges: scalable coordination in sensor networks, ACM MobiCom’99, Washington, USA, pp. 263–270.

[9] Awan, K. M., Ali, A., Aadil, F., & Qureshi, K. N. (2018, February). Energy efficient cluster based routing algorithm for wireless sensors networks. In 2018 International Conference on Advancements in Computational Sciences (ICACS) (pp. 1-7). IEEE.

[10] Idoudi, H., Mabrouk, O., Minet, P., &Saidane, L. A. (2019). Cluster-based scheduling for cognitive radio sensor networks. Journal of Ambient Intelligence and Humanized Computing, 10, 477-489.

[11] Khan, H., Jan, M. A., Alam, M., &Dghais, W. (2019). A channel borrowing approach for cluster-based hierarchical wireless sensor networks. Mobile Networks and Applications, 24, 1306-1316.

[12] Alagarsamy, V., & Ranjan, P. V. (2019). Multi-Cluster Multi-Channel Scheduling (Mms) Algorithm for Maximum Data Collection with Delay Minimization in WSN. International Journal of Computer Networks & Communications (IJCNC) Vol, 11.

[13] Rambabu, C., Prasad, V. V. K. D. V., & Prasad, K. S. (2020). Multipath cluster-based hybrid MAC protocol for wireless sensor networks. International Journal of Wireless and Microwave Technologies (IJWMT), 10(1), 1-16.

[14] Ali, A., Yaqoob, I., Ahmed, E., Imran, M., Kwak, K. S., Ahmad, A., ... & Ali, Z. (2018). Channel clustering and QoS level identification scheme for multi-channel cognitive radio networks. IEEE Communications Magazine, 56(4), 164-171.

[15] Rizky, R., Mustafid, &Mantoro, T. (2022). Improved Performance on Wireless Sensors Network Using Multi-Channel Clustering Hierarchy. Journal of Sensor and Actuator Networks, 11(4), 73.

[16] Adhyapok, S., &Sarma, H. K. D. (2020, March). Review on QoS aware MAC protocols for multi-channel wireless sensor network. In 2020 International Conference on Computer Science, Engineering and Applications (ICCSEA) (pp. 1-5). IEEE.

[17] Saaty, Thomas L., 1999. "How to make a decision: the analytic hierarchy process. European journal of operational research 48.1 pp.9-26.

[18] Katsaros, K., Dianati, M., Sun, Z., Tafazolli, R. (2015). An evaluation of routing in vehicular networks using analytic hierarchy process. Wireless Communications and Mobile Computing.

[19] Taherdoost, H. (2017). Decision making using the analytic hierarchy process (AHP); A step by step approach. International Journal of Economics and Management Systems, 2.

[20] Golden, B. L. & Wang, Q. (1990). An Alternative Measure of Consistency. In: B. L. Golden, A. Wasil& P.T. Harker (eds.) Analytic Hierarchy Process: Applications and Studies, 68-81, New-York: Springer Verlag.

[21] Sarma, H. K. D. (2016, December). Grid Based Data Gathering in Multi-channel Wireless Sensor Network. In 2016 International Conference on Information Technology (ICIT) (pp. 114-117). IEEE.

[22] Gurupriya, M., & Sumathi, A. (2023). Multi-Faceted Clustering with Enhanced Multi-channel Allocation for Optimal Path Selection in Wireless Sensor Networks. Wireless Personal Communications, 129(1), 95-118.

[23] Debasis, K., Sharma, L. D., Bohat, V., &Bhadoria, R. S. (2023). An energy-efficient clustering algorithm for maximizing lifetime of wireless sensor networks using machine learning. Mobile Networks and Applications, 1-15.

[24] Zhao, L., Qu, S. & Yi, Y. A modified cluster-head selection algorithm in wireless sensor networks based on LEACH. J Wireless Com Network 2018, 287 (2018). https://doi.org/10.1186/s13638-018-1299-7

[25] Zhou, J., Xu, H., Qin, Z., Peng, Y., Lei, C., 2013. Ad hoc on-demand multipath distance vector routing protocol based on node state. Communications and Network,

5(03), pp.408.
[26] Heinzelman W, Chandrakasan A. and Balakrishnan H, Energy-Efficient Communication Protocol for Wireless Sensor Networks, Proceeding of the Hawaii International Conference on System Sciences, Hawaii. (2000) 1-10. Doi: 10.1109/HICSS.2000.926982.
[27] Manisekaran, S. V., Venkatesan, R., & Deivanai, G. (2011). Mobile adaptive distributed clustering algorithm for wireless sensor networks. International Journal of Computer Applications, 20(7), 2-19.
[28] Akila, I. S., & Venkatesan, R. (2016). A cognitive multi-hop clustering approach for wireless sensor networks. Wireless Personal Communications, 90, 729-747.
[29] Kumari, N. D., & Shylaja, B. S. (2019). AMGRP: AHP-based multimetric geographical routing protocol for urban environment of VANETs. Journal of King Saud University-Computer and Information Sciences, 31(1), 72-81.
[30] Adhyapok, S., Bhuyan, B., Sharma, U., Sarma, H. K. D. Sarma (2023, July). Analytical Hierarchy Process based routing protocol for Multi-channel Wireless Sensor Networks. In 2023 14th International Conference on Computing Communication and Networking Technologies