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Energy efficient routing for improving lifetime in MWSN: A clustering approach

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Abstract

A Mobile wireless sensor network (MWSN) consists of mobile sensor nodes, which can be deployed in any specific environment, and due to its' mobility it can perform with rapid topological transformations of a network. The sensor nodes having limited battery power are used to collect specific data and this raw data is sent to a static sink node of the network. Under such a scenario, to avoid frequent disconnections due to topological change in the network and can avail more reliable data transmissions in energy awareness perspective, an energy efficient routing protocol for MWSNs to improve its lifetime is proposed here by utilizing a clustering approach. A MWSN with random number of sensor nodes are initially considered and then, clustering algorithm K-means is used to determine a predefined number of clusters with their initial cluster heads (CHs)and centroid locations of these clusters is also determined. The role of these CHs is to elect our DDBLACH (distance to sink and cluster centroid with battery level aware cluster head) nodes from each cluster, by sending and receiving intra-cluster messages among other member sensor nodes. A DDBLACH node is determined by using three factors, such as minimum distance from cluster centroid location, minimum distance from sink and the maximum battery level of the node from each cluster. These DDBLACH nodes are used to collect data from intra-cluster sensors and thereafter, send those towards sink node for further processing using tree-based hierarchical routes. Finally, an energy efficient routing technique for MWSNs is proposed for data transmission from DDBLACH nodes of clusters to sink of the network. Simulation results indicate the superiorityof our proposed scheme over other existing methods in various aspects, such as improving more data packet transmission by 14%-23%, presence of alive nodesand subsequently average network lifetime by5%-24%.

1. Introduction

Mobile wireless sensor networks (MWSNs) consists of mobile sensor nodes, those are able to move within a network. It is more flexible than a static WSN [1], as the sensors nodes can be deployed in any specific environment where it can operate with rapid topological transformations due its mobility [2]. The sensor nodes having limited battery power as energy sources [3], are used to collect specific data like temperature, humidity, pressure, light etc., from various environments [4,5]. This collected raw data is sent to a static sink node of the network [6], where the data is stored for future use. Hence, the design and development of MWSNs require efficient connectivity among the sensor nodes and sink node. It is noteworthy to mention here that the network topology has a considerable role in data routing [7] in MWSNs as it is varying in nature. Here, the network requires to be partitioned in such a systematic way, so that it can avoid frequent disconnections and subsequently, can avail more reliable data transmissions.

A hierarchical cluster based network [7] is most suitable one for data transmission in MWSNs over other possible network topologies, as it can support dynamically adaptation in a network without affecting its existing topological structure. Thus, the routing of collected data becomes much easier and it can take less time to accomplish [6]. The nodes in MWSNs dissipate its energy for such data transmissions under this clustered topological structure. Major factors of the energy utilization of a mobile sensor node are considered as the battery power denoting the energy level of that particular node along with its variable positions in the network due to mobility. Hence, the energy consumption of a node must be a key concern for any energy efficient routing protocol, which can increase the network lifetime [7]. Hence, it encourages us to develop an energy efficient routing scheme in favor ofan MWSN to obtain an increased availability of the nodes, which in turn can determine an improved network lifetime [8].

An energy efficient routing protocol for MWSNs to improve its lifetime is proposed in this paper by utilizing a clustering approach. To achieve our objectives, a MWSN with random number of sensor nodes are initially considered and then, clustering machine learning [9] algorithm K-means [10,11] is used here to find a predefined number of clusters with initial cluster heads (CHs). The CHs elect DDBLACH (distance to sink and cluster centroid with battery level aware cluster head) nodes by sending and receiving intra-cluster messages among other member sensor nodes. These DDBLACH nodes from each cluster are determined by using a cost function based on three parameters, such as minimum distance from cluster centroid location, minimum distance from sink node and the maximum battery level of the particular node. A DDBLACH node is responsiblefor the data collection from intra-cluster member sensor nodes and thereafter, sends those towards sink node for further processing using tree based hierarchical routes. Hence, an energy efficient routing technique [12] for MWSNs is proposed for transmission of data from a DDBLACH node of any cluster to a sink node by reducing energy requirement of the nodes in the MWSN. Now-a-days an energy efficient routing is a major challenge for any MWSN due to availability of a limited energy resource. Our simulation results indicate the advantage of our proposed scheme over other existing methodologies in various aspects, such as the number of successful data packet transfer, improving the presenceof alive nodes [13] in MWSN and average network lifetime.

The rest of the paper is organized as follows: the related works are discussed in the Section 2 for completeness of the proposed work. Section 3 presents the system models and section 4 described the proposed methodology. Thesimulation results of the proposed work are shown in section 5 and finally this paper is concluded in the Section 6.

2. Related works

Nowadays, MWSNs are gaining importance in several application areas, like object tracking in health care; wheremobility in a MWSN is intentional [14]. Due the topology change in MWSN [15], the cluster architecture of the network is not fixed. Hence, the major challenge is to maintain communication links for providing an efficient routing technique to route data towards a sink node [16]. Mobile sensor nodes in MWSNs are low-powered devices, along with their capability of mobility. Therefore, energy efficiency is one of the most critical factors to design an energy efficient MWSN, as it is associated with lifetime of a network [17]. In a work [18], mobile low-energy adaptive clustering hierarchy(M-LEACH) routing procedure is used to achieve a better routing performance considering remaining battery power. An advanced enhanced cluster based routing protocol (ECBR-MWSN [19]) in MWSN is further introducedto identify the initial clusters and routing of collected data. A multipath routing protocol in [20] is presented for load balancing in MWSNs. In another work [21], an optimized clusteringusing genetic algorithm (GA) for routing in MWSNs is discussed. Ad hoc on-demand distance vector (AODV) routing scheme in application of MWSN is also utilized in an earlier work [22]. In someother review and survey articles for routing in MWSNs [23-25], different routing protocols are discussed in perspective of minimizing the energy usage; whereas a cluster based hierarchical routing procedure is mostly preferred to obtain higher communication reliability and lower energy requirement.Hence, a comprehensive narration along with limitations of the related works is summarized in Table 1forbetter readability of the paper, which canhighlight the suitability of the proposed approach.

Table 1. A summary of related works.

Existing works	Major highlights	Limitations
Nguyen, L. T., Defago, X., Beuran, R., & Shinoda, Y. (2008).	A clustering algorithm for MWSNs uses a scheme comprising both Low Energy Adaptive Clustering Hierarchy (LEACH) and LEACH-centralized (LEACH-C)to support mobility.	Thisworklacks in a suitablemethodfor CH selection and subsequent comparison in terms of sucessful data transmission.
Jambli, M. N., Zen, K., Lenando, H., & Tully, A. (2011).	The efficiency of Ad hoc On-Demand Distance Vector (AODV) routing protocol is used in various MWSNs scenarios to evaluate, in terms of packet loss and the energy utilization.	The energy requirement for data transmission is not considered under the changes in network topology.
Sara, G. S., Devi, S. P., & Sridharan, D. (2012).	To evaluate the power utilization of a mobile sensor node of MWSN, a GA based technique is used to determine an optimal residual energy to select a CH.	Comparing the different lifetime parameters in MWSN is beyond scope of this work.
Anitha, R. U., & Kamalakkannan, P. (2013).	An enhanced cluster based routing protocol by balancing the energy consumption of the nodes is discussed to extend the lifetime for MWSNs.	In this work, there is a lack in focus on energy requirement for sensor node mobility.
Chen, Z., Zhou, W., Wu, S., & Cheng, L. (2021).	An energy aware multipath routing protocol is presented for MWSN, where the energy awareness is expressed through a packet scheduling policy.	Efficiency in the network lifetime is not discussed.
Swapna, D., & Nagaratna, M. (2023).	A review is focused on the classification of different routing protocols applicable for MWSNs.	This review paper discusses routing protocols without considering clustering technique.

In a nutshell, observing from Table 1, several routing protocols are obtained to extend the MWSN lifetime by reducing energy utilization of the mobile sensor nodes of a network. However, the focus to maintain connectivity between the mobile sensor nodes along with sink node under changing network topologies is beyond the scope of those existing works. Here, a suitable energy efficient routing technique is required for a MWSN which can result into a reduced energy dissipation of the nodes during the topological transformation of the network. Hence, a dynamic clustering with alternation of network topology isalways in demand, which can determine an essential energy efficient path. So, our proposed work in this paper presents a cluster based hierarchical routing scheme to prolong the lifetime of MWSNs, which would be transparent from successive discussions.

3. System model

3.1. Network model

A MWSN is containing sensor nodes (S), which are distributed over the sensing area; whereas it is mapped into a two-dimensional (2D) Cartesian coordinate system. Here, each node is represented as (S_x, S_y), where S_x and S_y denote X and Y-coordinate respectively of the sensor node, respectively. For example, an initial arrangement of this network is shown in Figure 1, where multiple mobile sensor nodes are randomly distributed inside a sensing area along with a sink node.

In this network, it is assumed that every mobile sensor nodes are fully aware about their current location using a positioning service scheme [26]. The sink node is placed at a static location and that location is known to every all other nodes of this MWSN. Other assumptions are considered for our proposed work as follows.

- Mobile sensor nodes are homogeneous in nature.
- Initial energy in terms of battery level (battery power) stored in each node is equal and the nodes are aware about its' current energy level.
- Mobile sensor nodes can move in any directionon this 2D area.
- Sink node is only connected to some finite number of CHs, which are responsible for routing data.
- Number of cluster is fixed and predefined for the data routing in the network.

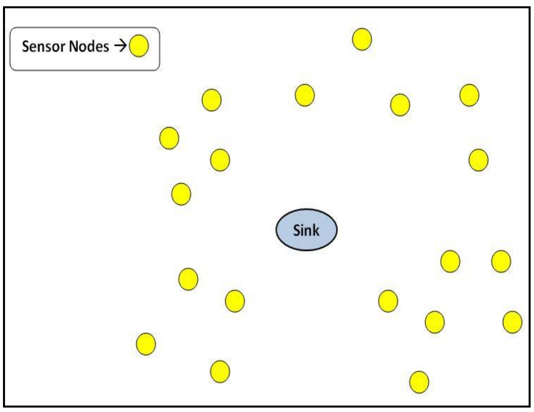

Figure 1. Initial MWSN topology.

A mobile sensor node is fully aware of its battery level (BL) which is represented as follows.

$$S_i = [S_{BL}, S_x, S_y] \quad (1)$$

Where, i = 1, 2, 3, ... , n andS_{BL} denotes the battery level information of the node S_i. Now, the distance from sink node is calculated after random placement of S_i. However, the sensor nodes with initial topology of the MWSN are represented by the following.

$$S_i = [S_{DS}, S_{BL}, S_x, S_y] \quad (2)$$

Here, S_{DS} denotes the distance between that mobile sensor and the network sink node. The distance S_{DS} is calculated by Euclidean distance [27,28] as follows.

$$Distance = \sqrt{(X_{SN} - S_x)^2 + (Y_{SN} - S_y)^2} \quad (3)$$

In (3), the location of sink node is denoted by (X_{SN}, Y_{SN}). However, for our work, the squared Euclidean distance [29,30] instead of Euclidean distance is considered, as it is convenient to exclude the final square root for a distance calculation. So, the value of $S_{DS}$is expressed by the following.

$$S_{DS} = (X_{SN} - S_x)^2 + (Y_{SN} - S_y)^2 \quad (4)$$

3.2. Energy model

It is already discussed that the battery level (BL) of a node plays an important role for transmitting the data in the network. Initially, the BL is identical for each mobile sensor nodes. However, later on, data collection and subsequent transmission by the nodes along with its displacement in a network are the major reasons of energy dissipation. Therefore, the total energy requirement by anymobile sensor node can be determined as follows.

$$E_T = E_{transfer} + E_{receive} + E_{idle} + E_{displacement} \quad (5)$$

Where, E_T denotes the total energy requirement of a sensor node and $E_{transfer}, E_{receive}$ are energy required for transmitting and receiving data and message by the node, respectively. While E_{idle} and $E_{displacement}$ denote energy requirement for staying as idle in the network and moving towards new location, respectively. For our proposed work, $E_{transfer}$ and $E_{receive}$ are calculated by the following.

$$E_{transfer} = \sum_{t=1}^{mt} E_{tm} + \sum_{t=1}^{dt} E_{td} \quad (6)$$

$$E_{receive} = \sum_{t=1}^{mr} E_{rm} + \sum_{t=1}^{dr} E_{rd} \quad (7)$$

Where in (6), mt and dt denote the count of message transfers and the count of data transfers, respectively; E_{tm} and E_{td} are energy requirement for message and data transfer, respectively and in (7), mr and dr denote the count of messages received and the count of data received, respectively; E_{rm} and E_{rd} are energy requirement for message and data receive, respectively.

Therefore, the energy requirement (E_{Comm}) for data communication in the proposed work is expressed by the following.

$$E_{Comm} = (E_{transfer} + E_{receive}) \quad (8)$$

Now, E_{idle} is considered as negligible for the sake of simplicity as it increases for a larger interval of time. Another parameter $E_{displacement}$ can be represented as follows.

$$E_{displacement} = distance(S_{CL} \sim S_{PL}) \times E_m \; where, S \in n \quad (9)$$

Here, S_{CL} and S_{PL} denote the current and previous locations of the S node, respectively. The parameter E_m in (9) is the energy requirement of a mobile sensor node to move a unit distance. Therefore, the residual BL is determined by the following.

$$S_{BL} = (S_{BL\_initial} - E_T) \quad (10)$$

Here, $S_{BL\_initial}$ is the initial amount of energy stored in the nodes before the topological change is initiated.

3.3. Network lifetime

Usually, the lifetime of a MWSN is determined by three aspects, such as first node dies (FND), half nodes dies (HND) and last node dies (LND) out of available sensor nodes [31-33]. The values of FND, HND and LND are determined in terms of the number of rounds necessary to complete the routing. If the initial number of sensors is considered as n, then the parameters FND, HND and LND can be defined by the following.

- First Node Die (FND): If the first sensor node out of $n$has died in $R1$ number of round, then the value of FND is R_1. Hence, after R_1 number of rounds, the count of alive nodes is $(n-1)$ and dead nodeis1 respectively.
- Half Node Die (HND): If $n/2$ numbers of sensor nodes are died in R_2 number of routing rounds, then the value of HND is R_2. Therefore, both the count of alive and dead nodes are $n/2$ at R_2 round.
- Last Node Die (LND): It denotes the aliveness of the sensor network till all sensor nodesare died. If all sensors are diedatR_3round, then the value of LND is R_3. In this regard, the count of alive nodes is 0.

Therefore, lifetime of that network is ended at the occurrence of LND in a MWSN.In our proposed work, the lifetime of MWSNs depend on the presence of alive nodes at any moment of time in the network. During routing, the energy dissipation is calculated as per (10); hence with dying BL, alive nodes are reducing, so the network lifetime is reduced accordingly. Thus, in the proposed work, these FND, HND and LND parameters are taking decisive roles in our proposed work.

4. Proposed methodology

The cluster based energy aware routing for MWSN is described in our work to improve the MWSN lifetime. In order to obtain such improvement, the proposed methodology is accomplished in three major sequential steps, such as – formation of clusters, election of DDBLACH and finally routing of collected data.

A workflow diagram of our proposed methodology is shown in Figure 2. With respect to this workflow, three major steps mentioned earlier are described next.

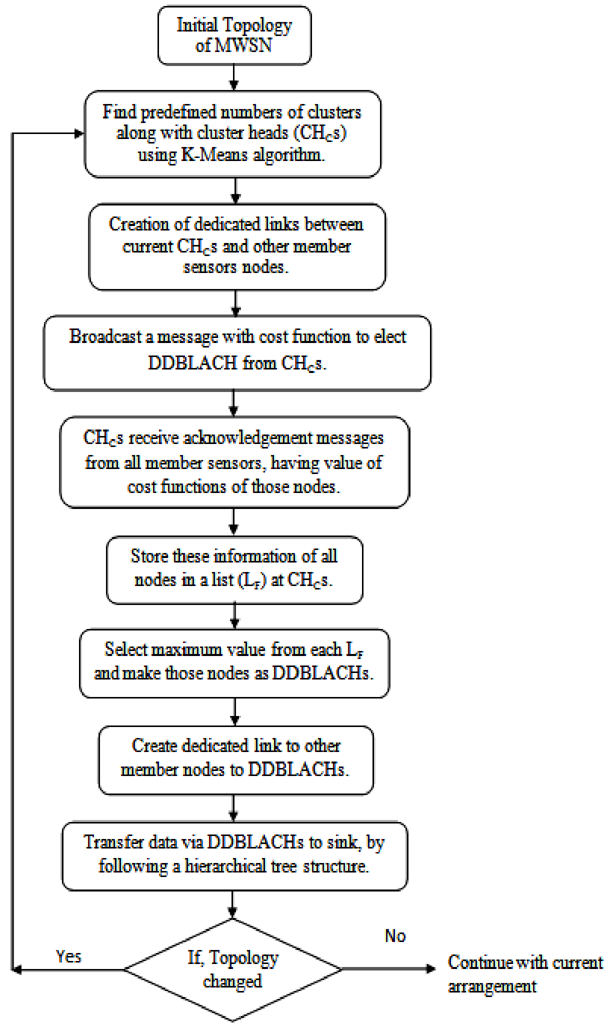

Figure 2. Workflow diagram of our proposed work.

4.1. Cluster Formation

To form the initial clusters, we have introduced K-means algorithm, which can provide K number of clusters with their K cluster heads (CH_{CS}). Here the number of clusters(k) is predefined as per earlier stated assumption.For the completeness of the proposed work, K-means clustering algorithm described by Algorithm 1, where one sensor node (*CNode*) initially selected to take responsibility of performing K-means algorithm on a finite set of sensors. In the proposed work, a node having highest BL is selected for being a *CNode* by the mobile sensors with their sensor information (S_i) from (2), through a distributed approach. Then this *CNode* get the responsibility to find CH_{CS} and centroid location of each cluster, as shown in Figure 3. Therefore, having a centroid location can highlight the utilization of the procedure used to determine S_{DC} as every sensor nodes are fully aware about their own location inside a sensing area.

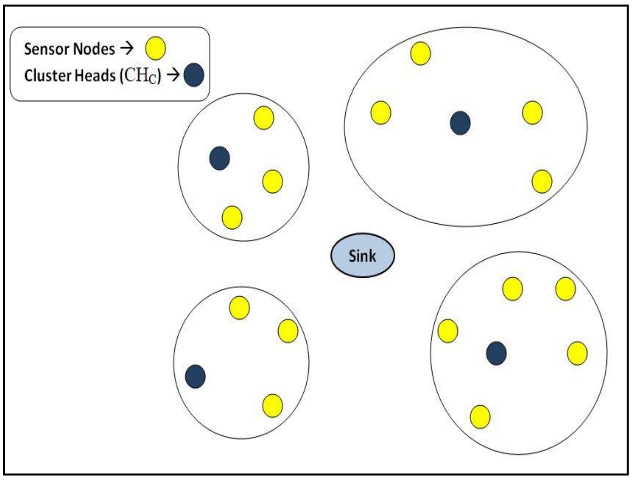

Figure 3. K number of clusters along with their CHCs.

Algorithm 1: Proposed clustering using K-Means

Step 1: Initialize,
K = number of clusters;
S = {S_1, S_2, ... , S_n} as set of n sensors;
where, K≤ n.

Step 2: Select a node having highest BL as *CNode* for clustering using (2).

Step 3: Choose, K number of sensors randomly from n as preliminary CHs, and inform locations of the CHs to the rest sensor nodes.

Step 4: Calculate, the distance between each sensor node and CHs using (4) as each node is aware about their location (S_x, S_y).

Step 5: Assign, the rest sensors to their nearest CH to form K numbers of clusters.

Step 6: Get, centroid location by finding mean (μ_K) from each cluster, by using-
$\mu_K = 1 / S_K \sum_{i=1}^{S_K} (S_x, S_y)$,
where, S_K represents the number of sensors in the K^{th} cluster.

Step 7: For all Cluster, reassign new CH which are closest to the μ_K.

Step 8: Recalculate, the distance between each sensor and newly obtained CHs.

Step 9: If, Member sensors are reassigned to clusters, repeat, from step 4.
else,
K clusters with K cluster heads (CHC)are achieved along with their centroid locations.

Step 10: Stop.

After performing K-means clustering algorithm we found the centroid location (mean) of a cluster which ultimately helps to find all the distances (S_{DC}) between that centroid to intra-cluster member mobile sensor nodes. After inclusion of this criterion, the sensor nodes for the proposed work are represented as:

$$S_i = [S_{DC},\ S_{DS},\ S_{BL}\ ,S_x\ ,S_y] \qquad (11)$$

This node information S_i is required along with the CHCs to proceed towards the next action for performing data routing towards the sink node.

4.2. Election of DDBLACH

After having the clusters with current CHCs, it needs to establish dedicated links between intra-cluster member sensors to each CHC as the member sensor nodes of the cluster and locations of each node is available after K cluster formation using Algorithm 1. In this context, Figure 4 shows the connectivity among the cluster members.

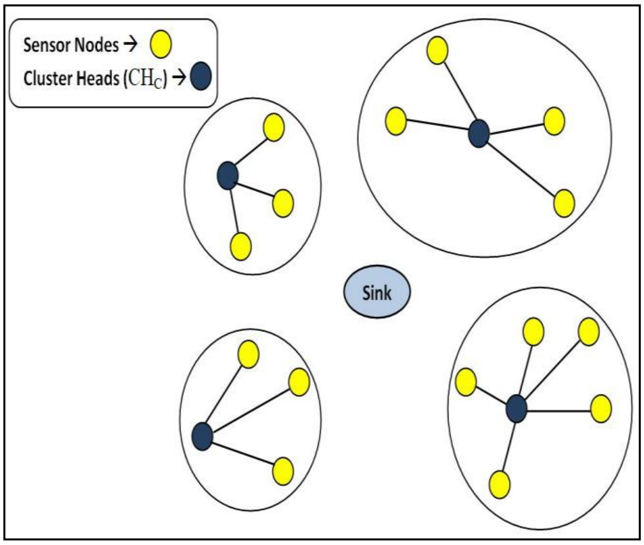

Figure 4. Clusters with connectivity between CHCs and member sensors.

Now, the election of DDBLACH includes S_{DC} , S_{DS} and S_{BL} as the set of criteria. Here, we consider maximum value of S_{BL}, as well as minimum values of S_{DS} and S_{DC}. The election of a new CH as a DDBLACH node is required for data transmission towards sink nodes. From an energy awareness perspective, a node having higher BL is preferred to be a DDBLACH node as this particular node is involved to collect sensed data from member sensor nodes of this cluster and subsequently, can be responsible to send data to sink. It means that a quite large amount of energy is exhausted for this data transmission. Instead of considering S_{BL} as a prime factor; it is important to mention here that, at initial topology of MWSN, the BL factor is identical for each node as they have initialized with equal BL values. During its initial phase, no displacement has been performed yet by any mobile node. However, the BL differentiation between homogeneous nodes is mostly dependent on the movement of sensor nodes in MWSN with topological changes. On the other hand, a minimum distance from sink node is also expected for making a reliable communication and energy efficient routing. Although a minimum distance from cluster centroid ensures that no member node is far enough to communicate. Therefore, a cost function (F_{DDBL}) is introduced in (12), where both the distances are inversely proportional to determine the value of F_{DDBL}.

$$F_{DDBL} = \alpha\times(1/S_{DC}) + \beta\times(1/S_{DS}) + \gamma\times S_{BL} \quad (12)$$

Here, α, β and γ are assigned weight to each individual parameters, whose values can vary between 0 to 1. Thus, after calculating the F_{DDBL} , the CH_C sends the value of the cost function to all other cluster member sensors with a broadcast message (MSG_F), while after receiving the message MSG_F other member nodes are also determined the value of F_{DDBL} and reply back their cost in an acknowledgement message (ACK_F). Then, a list (L_F) is maintained by CH_C, which can store all the intra-cluster F_{DDBL} values in it. Now, the node having maximum value of F_{DDBL} is elected as DDBLACH node. This entire procedure of election of DDBLACH node is described by the Algorithm 2.

Algorithm 2: Election of DDBLACH node

Step 1: Initialize, K clusters with K CH_Cs with locations.
Step 2: Set, C=1. // where, C is the current cluster.
Step 3: while, (C ≤ K)
    CH_C create dedicated links to other member nodes of the cluster.
    CH_C calculates F_{DDBL} using equation (12).
    CH_C broadcast a message (MSG_F) to every member nodes with own F_{DDBL}.
    After Receiving MSG_F,
    all member sensor nodes calculate F_{DDBL} using equation (12) and return their by cost function value (F_{DDBL}) by ACK_F message.
    Prepare, a list (L_F) of F_{DDBL} at CH_C for cluster.
    Find, the maximum value of F_{DDBL} in L_F.
    Elect, that node as new CH (DDBLACH) having maximum value of F_{DDBL}.
    C=C+1;
  end while;
Step 4: DDBLACHs are found.
Step 5: Stop.

4.3. Routing via DDBLACH nodes

In order to perform the routing, the dedicated connectivity between a DDBLACH and other member sensor nodes and subsequent links of DDBLACHs with the network sink can show the hierarchical routing paths in MWSN like Figure 5. Algorithm 3 is describing the proposed routing, where for an instance of initial network topology, algorithm 1 is used to find K clusters with their CH_C nodes. After that, Algorithm 2 is carried out to elect DDBLACH nodes from each cluster; those are responsible for data transmission from a cluster to a sink node of the network. To perform the data transmission towards sink node, the DDBLACH nodes communicates to all other member sensor nodes of its cluster and accumulate raw data collected by the sensor nodes from specific environment. Therefore, it is a major subject of concern that during the process of transferring collected data to a static sink node of the network, whether the topology of the MWSN has been changed or not due to mobility of the mobile sensors. In addition, number of alive nodes has to be checked before next iteration.

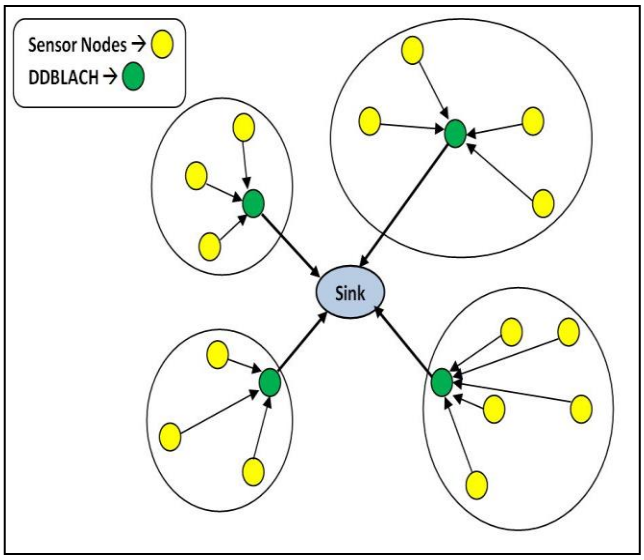

Figure 5. DDBLACHs and routes towards sink.

Algorithm 3: DDBLACH based Routing in MWSN

Step 1: Initialize, MWSN with topology ($NET_{Topology}$).
Step 2: Do,
    Algorithm 1;
    Algorithm 2;
    Establish, dedicated network links to DDBLACHs and intra-cluster sensor nodes.
    Create, network links to DDBLACHs to sink.
    Collect, data using mobile sensor nodes.
    Route, collected data towards sink node via DDBLACHs.
    Check, number of alive node (AN) in MWSN.
    Check, current network topology.
    if, ($NET_{Topology}$ is not changed) and (AN ≠ 0)
    Then, continue routing with current arrangement.
    else,
    while,($NET_{Topology}$ is changed) and (AN ≠ 0)
    Repeat step 2;
Step 3: Stop.

5. Simulation Results

For our work, the MWSN is initialized with n=100 mobile sensor nodes, those are randomly distributed on a 100x100 meter^2 network area; whereas a centrally located (x=50, y=50) sink node has been taken for the sake of simplicity. To carry out our simulations, the parameters are used as per Table 2 given below. It isnoteworthy to mention that, for the simulation work, any specific environmental condition or any potential sensor failures at the time of network initialization is not considered for the sake of simplicity of this work.

In our proposed work, α=0.5, β=0.5 and γ=1 are considered, as BL factor of a sensor node becomes more important in the proposed work as already mentioned. So, the weight for S_{BL} is 1 (γ), whereas the distances are the secondary parameters as per our consideration. As a consequence, for both of the distance factors S_{DC} and S_{DS}, the weight is used as 0.5 (α and β).Accordingly, the parameter F_{DDBL} is calculated as per (12). For more clarity of choosing the values for the weight, a sensitivity analysis has been shown in Table 3. Here, it is observed that the average successful data packet transmission is affected by declining value of weight γ. Therefore, for a preferable scenario, the maximum value for weight γ is chosen. The moderate values are considered for other two weights α and β as they are affecting evenly for the average count of successful data packet transfer in the proposed work.

Table 2. Parameters used for simulations.

Parameters	**Value**
Size of MWSN	(100 x 100) meter^2
Number of Nodes (n)	100
Initial energy at nodes	2 Joule
Number of Sink nodes	1
Sink location (X_{SN}, Y_{SN})	(50,50)
α	0.5
β	0.5
γ	1
Number of clusters (K)	5
Number of routing rounds	5000
E_m	10 Millijoule / meter
E_{Comm}	1 Millijoule /bit
Nodes displacement	Area inside MWSN
Size of packet	2000 bits
Number of iteration	10
Tool for implementation	MATLAB R2016a.

Table 3. A sensitivity analysis of weights (α, β, and γ).

Values of weight			**Average number of successful data packet transferusingF_{DDBL}**
α	**β**	**γ**	
1	0	0	2372.912
0.5	0	0	2309.143
0.25	0	0	2327.248
0.1	0	0	2245.058
0	1	0	2332.261
0	0.5	0	2318.188
0	0.25	0	2287.315
0	0.1	0	2292.74
0	0	1	2453.391
0	0	0.5	2251.322
0	0	0.25	2137.643
0	0	0.1	1892.259

Now, Figure 6 shows the placement of nodes for our initial topology of MWSN, where initially inside the network area, mobile sensor nodes are arbitrarily placed with a fixed sink node.

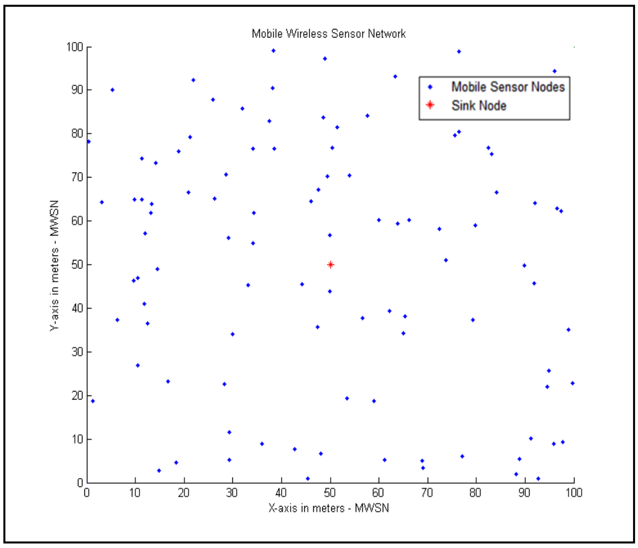

Figure 6. Initial placement of the sensor nodes along with a static sink node in MWSN.

In Figure 7, we can find that the percentage of residual BL (S_{BL}) of a sensor node for the proposed routing algorithm based on DDBLACH clustering technique in a hierarchical tree structure of MWSN, across the number of rounds. As topology changes frequently in a MWSN, each round considered as a single iteration of the Algorithm 3. Therefore, the $S_{BL}$is visibly decreasing with successive rounds of data routing for each node.

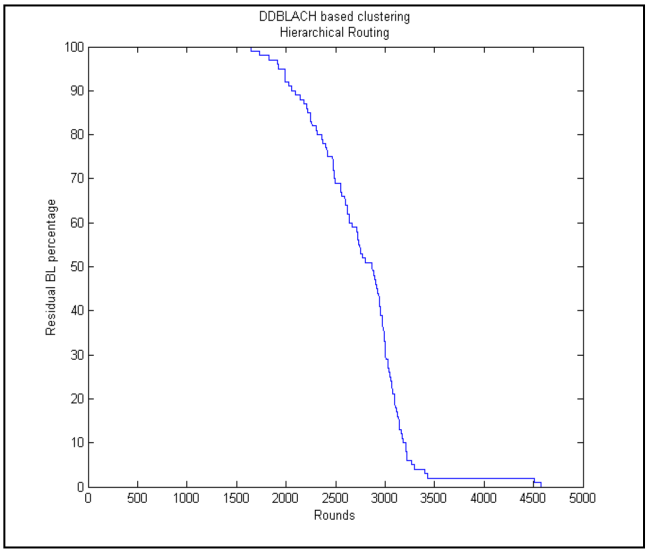

Figure 7. Percentage of residual energy of MWSN during simulation rounds using our proposed work.

The energy requirement in each round of our work must be considered as the accumulation of energy required for routing the data, sending and receiving massages as well as energy dissipation due to node mobility.

For our proposed work,the total energy requirement for each successful packet transmission during the lifetime of MWSN is shown in Figure 8. Here, it isobserved that network energy requirement for individual packet transmission is not uniformdue to mobility of sensor nodes inside the network. The energy requirement for node movement ($E_{displacement}$) is not identical as the movement of each node is not homogeneous inside the MWSN for each data packet transmission. Therefore, in Figure 9, only the total$E_{displacement}$ of proposed work is shown separately with successful data packet transmission; whereas Figure 10 shows us the total energy ($E_{transfer}$) required for each successful packet transmission of this simulation. Here, it shows the energy overhead that incurred due to passing position information between nodes, broadcasting messages for link establishment and broadcasting battery level information of nodes for each successful packet transmission. As $E_{displacement}$ varies for each packet transmission subsequently $E_{transfer}$ varies due to variable displacement of sensor nodes, which is shown in Figure 10.

Figure 11 shows a comparison of average energy used by routing techniques, between the proposed routing with other existing works on routing in MWSN, like M-LEACH [18], AODV-MWSN [22] and ECBR-MWSN [19]. Here, it is observed that, our model is performing considerably better than others existing works as energy requirement is in lower side than others.

A comparison with existing works, on average successful data packet transmission during the lifetime of the networks is shown in Figure 12. Here, it is observed that an advantage of our proposed work is obtained due to low energy consumption of network along with a higher number of active sensor nodes, which subsequently provides more successful data packet transmission during the simulation period.

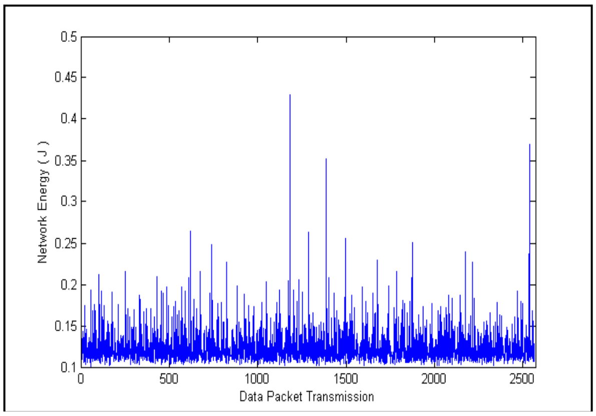

Figure 8. Total energy requirement for each successful packet transmission using proposed work.

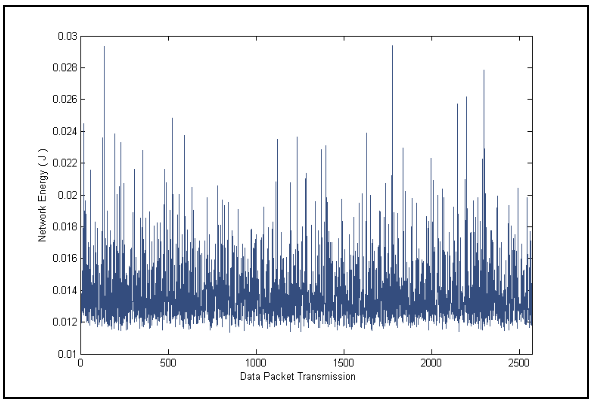

Figure 9. Energy requirement for total $E_{displacement}$ with respect to each successful packet transmission using proposed work.

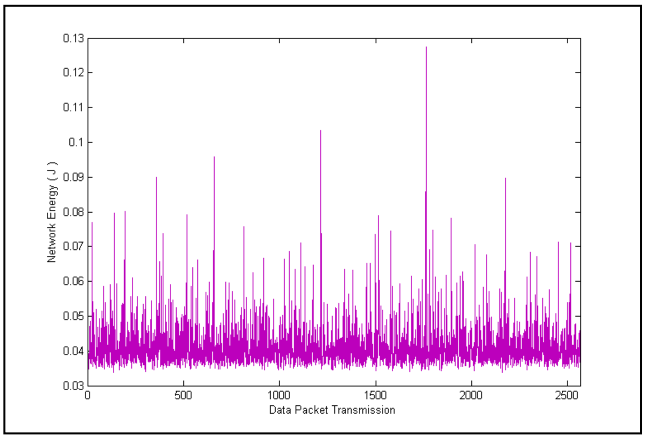

Figure 10. Energy requirement for total$E_{transfer}$ with respect toeach successful packet transmission using proposed work.

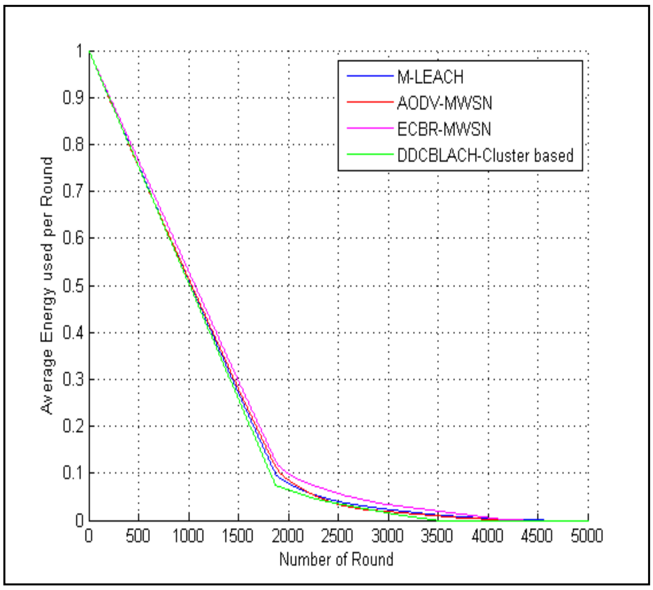

Figure 11. A comparison of average energy used per routing rounds with other existing protocols.

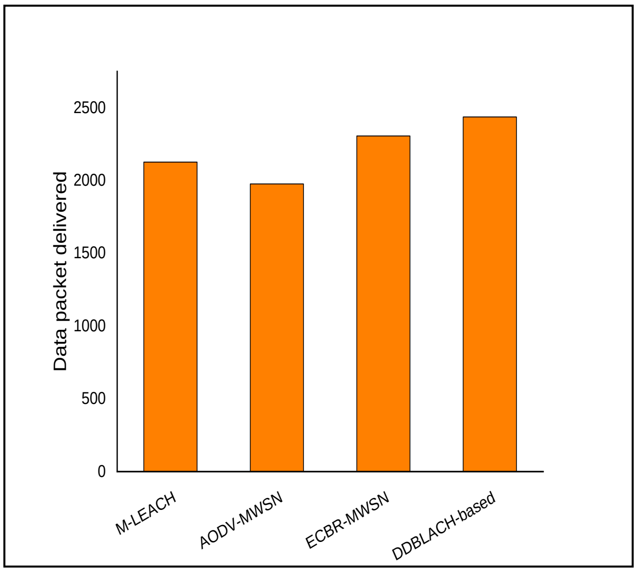

Figure 12. Comparison of average successful data packet transmissions with other existing protocols.

Therefore in Figure 13, a comparison of network lifetime with respect to routing rounds can show the numbers of alive nodes belonging on higher side with number of rounds during data routing. However, the FND is less than others. Hence, after exploration of multiple iterations, a comparison of our proposed work with other existing works,demonstrated in Table 4, where the values of individual FND, HND and LND is shown for all 10 iterations.

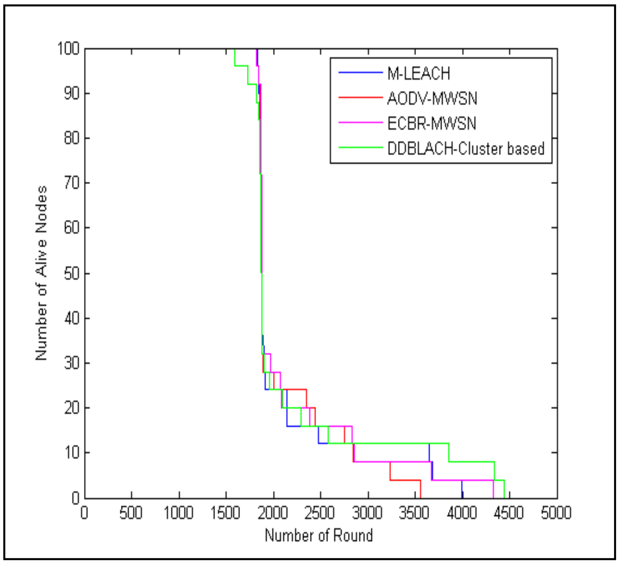

Figure 13. Comparison of alive nodes per routing rounds with existing protocols.

In Figure 14, a comparison of parameters like average of FND, HND and LND is shown for our DDBLACH-clustering based method with other existing methods. Here, it is shown that our model is having a low average FND than others, as our protocol initially has a high energy requirement for cluster formations and message passing with initial topology. On the other hand, the average HND and average LND are on higher side than other existing works, as the topological changes in every subsequent round due to sensor mobility is minimum. Thus, the proposed work obtains a higher lifetime of the MWSN as it is considerable till LND.

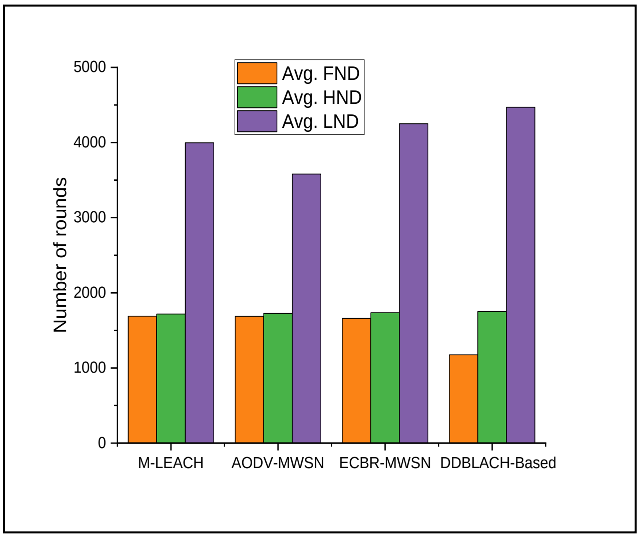

Figure 14. Comparison of average FND, HND and LND with existing protocols.

Table 4. Comparison of FND, HND and LND with other existing works.

Iteration	Methodology	FND	HND	LND
Iteration 1	**M-LEACH**	1699	1738	3959
	AODV-MWSN	1695	1733	3592
	ECBR-MWSN	1672	1770	4321
	DDBLACH-based	1188	1764	4489
Iteration 2	**M-LEACH**	1839	1891	4301
	AODV-MWSN	1837	1866	3705
	ECBR-MWSN	1749	1794	4351
	DDBLACH-based	1203	1768	4505
Iteration 3	**M-LEACH**	1582	1610	3721
	AODV-MWSN	1584	1634	3487
	ECBR-MWSN	1559	1647	4133
	DDBLACH-based	1087	1698	4358
Iteration 4	**M-LEACH**	1670	1701	3827
	AODV-MWSN	1664	1753	3597
	ECBR-MWSN	1668	1737	4245
	DDBLACH-based	1130	1743	4433
Iteration 5	**M-LEACH**	1737	1760	4121
	AODV-MWSN	1725	1744	3592
	ECBR-MWSN	1686	1765	4267
	DDBLACH-based	1196	1767	4469
Iteration 6	**M-LEACH**	1522	1549	3774
	AODV-MWSN	1528	1554	3428
	ECBR-MWSN	1587	1677	4173
	DDBLACH-based	1217	1779	4486
Iteration 7	**M-LEACH**	1630	1651	3902
	AODV-MWSN	1629	1652	3540
	ECBR-MWSN	1625	1686	4190
	DDBLACH-based	1141	1685	4517
Iteration 8	**M-LEACH**	1638	1656	3873
	AODV-MWSN	1641	1672	3577
	ECBR-MWSN	1657	1689	4218
	DDBLACH-based	1177	1744	4405
Iteration 9	**M-LEACH**	1755	1771	4129
	AODV-MWSN	1760	1789	3602
	ECBR-MWSN	1692	1773	4287
	DDBLACH-based	1198	1773	4512
Iteration10	**M-LEACH**	1831	1862	4358
	AODV-MWSN	1817	1878	3687
	ECBR-MWSN	1707	1812	4317
	DDBLACH-based	1214	1779	4527

The comparisons shown in Figures 11-14 and Table 4 can depict that our proposed work ishas betterenergy utilizationin a MWSN than other existing works. Therefore a high lifetime of network is also achieved than others by 5%-24%, along with better average successful packet transmissionsby 14%-23%. It indicates the superiority of the proposed work over existing approaches.

6. Conclusion

An energy efficient routing scheme for MWSNs is proposed in this paper to obtain an increased availability of the nodes, which in turn can determine an improved network lifetime. The proposed routing is presented by using a clustering approach in a hierarchical manner. In order to select the CH, three factors are considered which include energy utilization of the nodes along with node mobility. The data transmission between the DDBLACH node of a cluster and a sink node is obtained by reducing energy uses of the nodes in the MWSN. From the simulation results, it is clear that, after using a DDBLACH based clustering approach for routing data in a network, a better lifetime for a MWSN is obtained over other existing methods. Thus, instead of having limited battery powered devices, an increased lifetime of the network clearly indicate that the energy requirement for the proposed work is very much competent.

However, in our proposed work, thenumber of clusters is considered as static alongwith the movement of sensor nodes in the simulations. Therefore, the optimization on the number of clusters under topological changes in MWSN is still a scope of future research.

Appendix

Glossary of symbols

Symbols	Meaning
MWSN size	Sensing area (100 x 100) meter^2.
$NET_{Topology}$	Current network topology.
S	Sensor node.
S_i	Sensor node information.
(S_x, S_y)	Location of a sensor node.
S_{BL}	Battery Level of a sensor node.
S_{DS}	Sensor to Sink distance.
S_{DC}	Sensor tocentroid distance.
S_{CL}	Current location of sensor node.
S_{PL}	Previous location of sensor node.
(X_{SN}, Y_{SN})	Location of sink node.
K	Number of clusters.
CH_C	Initial cluster heads after K-Means algorithm.
S_K	Number of sensors in the K^{th} cluster.
C	Current cluster.
μ_K	Mean location of K^{th} cluster.
DDBLACH	Distance to sink and cluster centroid with battery level aware cluster head.
FND	First nodedie.
HND	Half node die.
LND	Last node die.
E_T	Total energy requiement of a sensor node.
$E_{transfer}$	Energy required for message or data transfer of a sensor node.
$E_{receive}$	Energy required for message or data receive of a sensor node.
E_{Comm}	Energy required by a sensor node for communication among nodes.
E_{idle}	Energy requirement for staying idle of a sensor node.
$E_{displacement}$	Energy required for dispacement of a sensor node.
E_{tm}	Energy required for message transfer of a sensor node.
E_{td}	Energy required for data transfer of a sensor node.
E_{rm}	Energy required for message receiving by a sensor node.
E_{rd}	Energy required for data receiving by a sensor node.
E_m	Energy required to move a unit distance by a sensor node.
mt	Number of message transfer.
mr	Number of message received.
dt	Number of data transfer.
dr	Number of data received.
α	Weight coefficient of (S_{DC}).
β	Weight coefficient of (S_{DS}).
γ	Weight coefficient of (S_{BL}).
n	Number of sensor nodes in simulation.
F_{DDBL}	Value of costFunction.
AN	Number of alivenode.
MSG_F	A message carrying F_{DDBL} from cluster head (CH_C) to other member senor nodes.
ACK_F	Acknowledgement message from member sensor nodes to cluster head (CH_C) carrying F_{DDBL}.
L_F	A list to store all the intra-cluster cost function values.

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Author contributions

Concept, designing and drafting of the manuscript: Ranadeep Dey and Parag Kumar Guha Thakurta; Model formulation, analysis, and interpretation of data: Ranadeep Dey; Supervision and editing: Parag Kumar Guha Thakurta.

Conflicts of interest

Authors sincerely declare there are no conflicts of interest.

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