Journal of Theoretical and Applied Information Technology
15th January 2025. Vol.103. No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

RELIABLE MULTIHOP VORONOI LEACH FOR EFFICIENT WIRELESS SENSOR NETWORK

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ABSTRACT

Energy efficient processes are substantially important in Wireless Sensor Networks, especially in communication processes. In order to lower energy utilization on *LEACH*, Voronoi diagram-based clusters were presented that can bring a distance relationship among the given set of nodes. Multihop Voronoi *LEACH* was proposed to further reduce the communication energy expenditure between sensor nodes and cluster heads within Voronoi region. However, the method may often experience communication interruptions if the data to be transferred from sensor node to cluster head in high volumes or frequent data transfers. In this article, we propose an energy efficient wireless sensor network protocol called Reliable Multihop Voronoi *LEACH*, which is suitable for bulk data transfer in sensor network applications. Simulation results determine the performance of proposed method.

Keywords: *Sensors, Wireless Sensor Networks, Energy Saving, LEACH, Voronoi Diagrams.*

1. INTRODUCTION

In the last decades, Wireless Sensor Network (*WSN*)s have been used in many surveillance applications. These applications include in the area of mining industry, defense systems, military applications, chemical plants, security surveillance, and nuclear plants. Due to the nature of the environment for these applications, the sensors are randomly scattered on the surveillance area and observe the geographic area. Due to the conditions of the environment in deployment area, the WSN poses many challenges, especially limited battery power. Once the battery power is depleted, the sensor mote is considered dead, and communication network structure is changed. Hence, the energy efficient communication infrastructure is needed for WSN. In the literature, many energy efficient methods are proposed for *WSN* [5][6][12][13]. The first cluster-based methodology for *WSN* is the Low Energy Adaptive Clustering Hierarchical (*LEACH*)[4]. In this method, the Sensor Nodes (*SN*) forms clusters and it includes a Cluster Head (*CH*), see Figure 1.

The election of cluster head in *LEACH* is based on the following formula

$$T(n) = \begin{cases} \dfrac{P}{1 - P * \left(r \bmod \frac{1}{P}\right)} & if\ n \in G \\ 0 & Otherwise \end{cases} \quad (1)$$

P=The value of probability to become *CH*
G= List of nodes, which were not *CH*
r= the present node

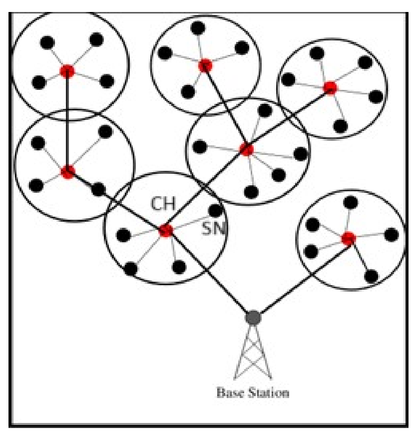

Figure 1: The Cluster Based WSN Model

In order to optimize the energy expenditure for the data transfers in WSN, the researchers used a computational geometry structure the Voronoi diagram for forming sensor network clusters, see Figure 2. All the sensors within Voronoi region need to transfer the environmental data to the Voronoi Vertex, i.e. cluster head. The basic objective of the method is to optimize the distances between the sensor nodes and their cluster head [19]. The method optimizes energy consumption and increase the lifespan of the network WSN.

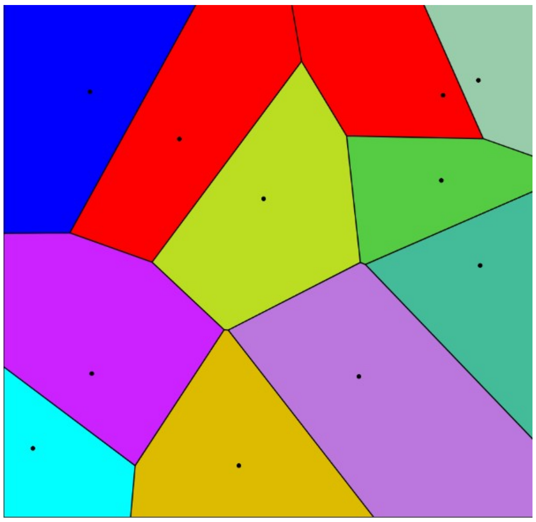

Figure 2: Voronoi Diagram with eleven vertexes

Energy consumption is directly proportional to the distance travelled by the data through the network. The distance here is the Euclidean distance among the sensors. The *Multihop Voronoi LEACH* (MV-LEACH) [23] considers the distance between a pair of sensors and improves energy efficiency of *VOR-LEACH*[19]. The basic idea of the *MV-LEACH* is that the multihop communications between a sensor and cluster head consume less communication energy compared to a single-hop long distance transmission, which has high energy consumption. However, the method does not consider the real conditions of the sensor nodes in the multihop transmissions. In general, the surveillance systems continuously send data from sensing area to the cluster head. In other words, bulk data transfers may lead to energy depletion from any of the sensor nodes in *MV-LEACH* path. This type of problem may cause problems such as network topology changes, and unreachability of sensor's data to the *CH* from the sensor's surveillance area. There is few clustering algorithms proposed in the literature for *WSN* [21][24][25]. All these methods focus on identifying the set of cluster heads to establish the stability of network. However, these methods face same problem of communication disruptions from *SN* to *CH*. By focusing on these problems, we propose a new method called Reliable Multihop Voronoi *LEACH* (*RMV-LEACH*), which is robust for high volumes of data transfers in WSN, and it is common in WSN applications.

The remaining portion of the paper is arranged as follows; Section II reveals literature review on the paper. Section III proposes a new methodology *RMV-LEACH*. Section IV presents simulation outcomes, whereas Section V concludes the paper.

2. RELATED WORK

The straightforward objective of the research work is to minimize the energy consumption of the wireless sensor network. In the literature, various protocols exist for energy efficient communications [10][11][12][13][18][22]. Among them, the protocol *LEACH* is the first cluster constructed communication protocol for energy efficiency in *WSN* [4]. A *WSN* collects environmental data through sensor devices and transmits the data to a specified place by the communication system [14]. In general, sensor devices have limitations on energy resources [15]. Hence, it is important to explore and do the research on energy efficient communication systems for *WSN*. The operational process of *LEACH* method is broadly split into two phases [4]. In Phase I, the clusters are selected. Phase II of *LEACH* protocol is committed to transfer data from sensor node to its cluster head, which aggregates data of the cluster and retransmits it to the base-station.

In the literature, a few improvements of the *LEACH* protocol are made to enhance the lifespan of *WSN* and provide stable communication at the same time. The researchers in [1] proposed a sequential *LEACH* (*S-LEACH*) protocol. This method maintains the sufficient number of cluster heads at every iteration till the first node spends all its energy. Another method, the *E-LEACH* protocol chooses the cluster head based on the outstanding energy levels of sensor devices in the network [16]. In the *E-LEACH* method, the sensor having maximum outstanding energy is chosen as the *CH*, which improves network lifespan. In the *K-LEACH* protocol, the K-medoids algorithm is used to choose the *CH*s. This protocol enhances the network lifetime by balancing the load of the sensor network [15].

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

An author proposed a *D-LEACH* protocol, in which the probability functions are used in deciding for the transmission of data coming from the sensor nodes [2]. In Hierarchical *LEACH* protocol, three types of nodes exist in the network [17]. The level 1 nodes collect surveillance data from the environment and the level 2 nodes exist beyond the communication range of the base-station, whereas the level 3 nodes are found inside a predefined range of the base-station [17]. An author proposed *CS-LEACH* protocol, which uses Intelligent sleeping mechanism (*ISM*) procedure to turn a certain percentage of sensor nodes to go to the sleep mode for saving battery power of the sensor nodes [3]. Another method on reducing energy expenditure in wireless sensor networks is based on reducing data redundancy during the intra-cluster data transmission [22]. This method computes the intersection areas of the sensor nodes and avoids sending the same data by the more than one sensor node to the cluster head.

A Voronoi diagram is a computational geometry structure, which specifies the distance relation among given points [7]. The formal procedure for creating Voronoi diagram is specified in [7]. However, this is a centralized algorithm, and it is very difficult to use in wireless sensor network due to the limitations of the network. The localized procedure for constructing Voronoi diagram for wireless networks is specified in [5][6].

A method called Voronoi Leach (*Vor-LEACH*) was proposed to optimize the communication energy efficiency based on the distance parameter between a sensor and its cluster head [19]. In this method, first it computes cluster heads based on the criteria given in the *LEACH* protocol [4]. After the cluster heads are elected, it constructs the Voronoi diagram with the elected set of cluster heads using the algorithm provided in the paper [5][6]. Once the Voronoi regions are constructed, all the sensors within the Voronoi region need to send the environmental information to the Voronoi vertex, that is the cluster head in *WSN* terminology. This method always optimizes the communication links from a sensor node to the cluster heads and it is very useful for saving communication energy because the communication energy expenditure is directly proportional to the distance travelled by the data packets.

The *Multihop Voronoi LEACH* (*MV-LEACH*) was presented to enhance the *Vor-LEACH* in terms of reducing the communication energy expenditure [23]. The primary idea of this method is to use the multi-hop nature of communication between sensor nodes and their relevant cluster heads within the Voronoi region. It computes direct link cost value of a path and the multihop cost value of the path. The value of *MC* must be always lesser than or equal to *DC* value. There could be multiple paths between *SN* and *CH* that satisfies the condition *DC* ≤ *MC*. However, the *MV-LEACH* chooses a path, which has the lowest *MC* value among the multiple paths for the transmission of data. Nevertheless, the method may not sustain high volume of data transfers if the battery power of any sensor node in the path contains low level. In the next section, the paper proposes a new method that enhance the longevity of data transfers between *SN* and *CH*.

3. CONTRIBUTIONS

The lifetime of the *WSN* depends on the residual energy in network's sensors. Hence, energy efficient methodologies are given higher significance in the research area of *WSN*. The energy consumption during communications is much higher compared to the energy consumption during computations in *WSN* [8][9][20]. There are few works focused on reducing the communication energy consumption [10][11][23]. Contrary to the traditional works, the author proposed a structural change in clusters of WSN by introducing the Voronoi region [5][19]. A paper introduces the multihop transmissions between an *SN* and its *CH* within Voronoi region [23]. However, the method may not perform well for high volume of data to be transferred from a sensor node to the cluster head. To address this problem, in this section, we present a new method called Reliable Multihop Voronoi *LEACH (RMV-LEACH)*, which is a robust and the method avoids communication disruptions due to the low battery power levels in the sensors during the data transmissions between a sensor to *CH*.

The proposed method *RMV-LEACH* assumes that all the sensors are homogeneous and contain the same characteristics on the communication and sensing functions. The coverage of sensing and communication areas of an *SN* are Omni directional. Algorithm 1 shows the methodology used for *RMV-LEACH*.

Algorithm 1: *RMV-LEACH*

1. With the eq. (1), identify cluster heads as mentioned in *LEACH*.
2. For all the cluster heads, identify the 2-hop neighborhood information and broadcast it.
3. Construct the Voronoi diagram using localized algorithm given in [5][6] with the set of cluster heads identified in *Step 1*.
4. Using *Algorithm 2*, find the robust path from an *SN* to its *CH*.
5. Transfer environmental data of a sensor node to *CH* through the robust path obtained from *Step 4*.
6. At every specific period, a new set of *CH*s are computed and repeat steps from *Step 2* to *Step 5*.

Algorithm 1 uses the procedures of electing the cluster heads given in the *LEACH* protocol [4]. Once the cluster heads are opted, the equivalent Voronoi diagram needs to be constructed with the given set of cluster heads obtained from the *step 1*. The *RMV-LEACH* uses the localized algorithm for constricting the Voronoi diagram given in the paper [19]. The Voronoi diagram optimizes the distances between sensor nodes and cluster heads. Here, all the sensor nodes within the Voronoi region transfer the sensing information to the Voronoi vertex, i.e. cluster head. The *RMV-LEACH* used Algorithm 2 to identify the robust path from SN to its cluster head. The robust path avoids communication disruptions and assures high volumes data transfers between *SN* and *CH* within the Voronoi region. The *step 6* of *RMV-LEACH* adopts the dynamics of the cluster heads by recomputing a new set of *CH*s followed by repeating the steps from step 2 to step 5.

Algorithm 2 is used to identify a robust path of every sensor node to its *CH*. In the beginning, it initializes *Reliable_Path_Vector* for every sensor node and the *Residual_Energy_Threshold* values. The *Reliable_Path_Vector* stores all the paths from a sensor node to its *CH* with certain conditions. Every sensor node calculates the Direct-link Cost (*DC*) value. The *DC* value is termed as square value of Euclidean distance from a sensor node to its *CH*.

$$DC = dist(x, CH)^2 \quad (2)$$

Algorithm 2: Robust Path Identification

1. Initialize *Reliable_Path_Vector* and *Residual_Energy_Threshold* values.
2. For every sensor node *x* in the Voronoi region with cluster head CH, compute the direct link cost
   $DC = dist(x, CH)^2$
3. For every sensor node x, which belongs to the Voronoi vertex CH, identify the intermediate node set K_i, where $K_i \notin \{x, CH\}$.
4. Compute the MC value
   $$MC_x = \sum_{i=1}^{n} inter\_dist(x, K_i, CH)^2$$
5. If the *MC* value is less than the DC value, then store the entire path in the *Reliable_Path_Vector.*
6. For every set of intermediate sensor nodes, repeat *step4* and *step5* and store all paths in *Reliable_Path_Vector*.
7. For every path $\overleftrightarrow{xV_iCH}$ in the *Reliable_Path_Vector* with the sequence of intermediate sensor nodes $V_1, V_2, V_3, \ldots$, remove the path from *Reliable_Path_Vector* if any of the sensor nodes $RE\{V_i\}$ < *Residual_Energy_Threshold* .
8. Identify the Average Residual value for every path in the *Reliable_Path_Vector*
   $$AR = \left(\sum_{k=1}^{n} RE_x + RE_{ki} + RE_{CH}\right) \Big/ (n+2)$$
9. Select the highest AR value path from the *Reliable_Path_Vector* and store it in *Robust_Vector* as robust path.
10. Return *Robust_Vector*

For every sensor node, identifying the Multihop Cost (MC) for paths from sensor node 'x' to its cluster head 'CH' within the Voronoi cluster.

$$MC_x = \sum_{i=1}^{n} inter\_dist(x, K_i, CH)^2 \quad (3)$$

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Here, the $\boldsymbol{K_i}$ represents intermediate sensor node within their communication range. For example, Figure 3 shows the $\overline{K_1K_2}$, $\overline{K_2K_3}$, $\overline{K_3K_4}$, and $\overline{K_4K_5}$ as edges of intermediate nodes in the communication range of each other. The notation $\overline{K_1K_2}$ indicates communication link between sensors K_1 and K_2, which is the Euclidean distance between them. Hence, $MC_{x,CH}$ value calculated from equation (3) as

$$\boldsymbol{MC_{x,CH} = dist(x,K_1)^2 + dist(K1,K2)2 + dist(K_2,K_3)^2 + \ldots dist(K_5,CH)^2} \quad (4)$$

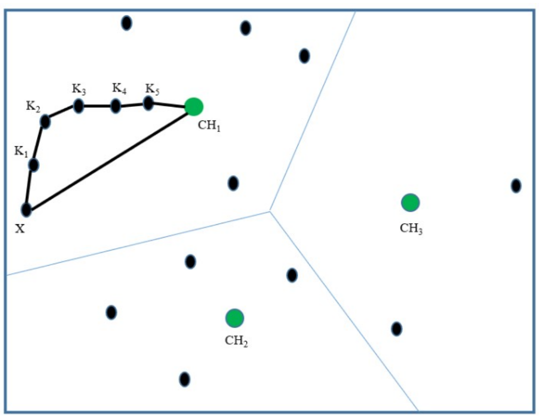

Figure 3: Multihop within a Voronoi region

After calculating the *MC* values, the sensor nodes verify whether the *MC* value is less than the *DC* value. If it is lesser then it stores the path in the *Reliable_Path_Vector.* The process is repeated for all the possible paths from sensor 'x' to the cluster head '*CH*' with the intermediate sensor nodes within a Voronio region. After all the paths are gathered in *Reliable_Path_Vector,* it identifies the *Robust_Vector* from the *Reliable_Path_Vector.* To compute the *Robust_Vector,* it deletes all paths from the *Reliable_Path_Vector* if any sensor node in the path has lower residual energy than the threshold value Residual_*Energy_Threshold*. These paths are considered weak paths as the node's battery power may deplete sooner if bulk data transfer occurs. After deleting the weaker paths from the *Reliable_Path_Vector,* for every path, it calculates the Average Residual (*AR*) value. The average residual value is defined as

$$AR = \left(\sum_{k=1}^{n} \boldsymbol{RE_x} + \boldsymbol{RE_{ki}} + \boldsymbol{RE_{CH}}\right) \Big/ (\boldsymbol{n} + \boldsymbol{2}) \quad (5)$$

Here, $\boldsymbol{RE_x}$, $\boldsymbol{RE_{ki}}$, and $\boldsymbol{RE_{CH}}$ represents the residual energy of sensor 'x', intermediate mediate SNs, and the *CH*, respectively. *AR* value exists for every path in the *Reliable_Path_Vector.* Once the *AR* value is available, then it selects the highest AR value path as the robust path and stores it in *Robust_Vector*. The robust path is used for transfer of environmental data from *SN* to its *CH*. The robust path increases the network lifetime without any communication interruptions during the sensor data transfer from *SN* to *CH*.

4. SIMULATIONS

The simulations have been conducted with the tools network simulator (*ns2*) and the python programming. The *ns2* generates different node scenarios in a square grid of 100x100 m^2. The random distribution of sensor nodes for different numbers of nodes is considered for simulations. These set of nodes are of sizes 20, 25, 30, and 35. The communication range of a sensor node is 25 meters. In the proposed method, it is assumed that all sensor motes have the same communication range and sensing range. The *RMV-LEACH* considered a *Residual_Energy_Threshold* value as 50% of its total battery power. Each sensor node is provided with a maximum of 100 Joules of energy at the beginning of the simulation. There are few experiments conducted to analyze the performance of *RMV-LEACH* protocol.

The first experiment is conducted to analyze the robustness of the path, which is used to transfer sensed information from a sensor *SN* to its cluster head *CH* within its Voronoi region. In the analysis of the simulation, it considers only one Voronoi region, *CH*, *SN*, and multiple relay sensor nodes, which are neighbors of the *CH*. The reliable path vector collects all the paths from the *SN* to *CH*. The robust path vector is computed by selecting the maximum average residual energy of sensor nodes existing in the path between *SN* and *CH*. Figure 4 shows the lowest residual energy of any sensor node between *SN* and *CH* in the robust path. From the graph, it indicates that the proposed method path contains higher values on residual energy of sensors compared to *MV-LEACH*'s path and it can guarantee a higher amount of data transfers without any communication interruptions. Similarly, Figure

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

5 shows average residual energy in the robust path of *RMV-LEACH* and low-cost path of *MV-LEACH*. From the graph, it shows that *RMV-LEACH* contains higher levels of residual energy compared to *MV-LEACH*, and it can be used for a higher volume of data transfers.

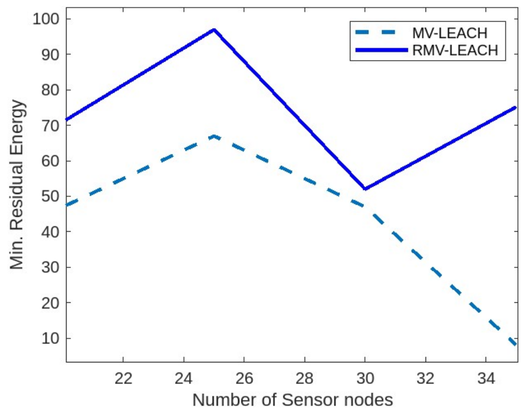

Figure 4: Minimum Residual Energy

The next experiment is conducted to analyze the *multihop cost* and *direct-link cost* of a path from *SN* to *CH* within a Voronoi cluster for three protocols *Vor-LEACH*, *MV-LEACH*, and *RMV-LEACH*. The *Vor-LEACH* contains only *DC* values, whereas *MV-LEACH* and *RMV-LEACH* use both *DC* and *MC* values in the protocol. From Figure 6, it shows that the path cost is highest for *Vor-LEACH* protocol. However, the path cost for protocol *RMV-LEACH* is higher than *MV-LEACH* because *MV-LEACH* does not consider residual energy levels, instead it greedily extracts lower distance values in MC calculations. Nevertheless, the *RMV-LEACH* takes care of the possibility of intermediate node failures in the path, which provides robustness to the communication path.

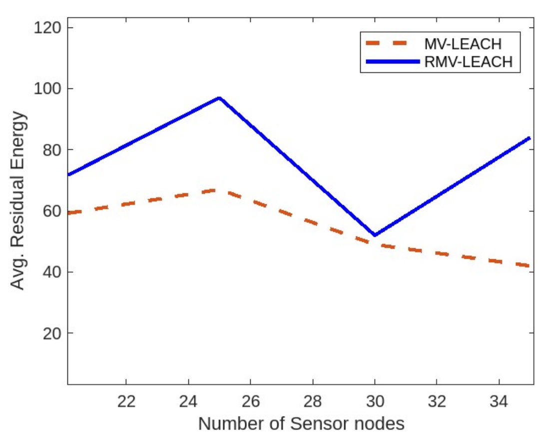

Figure 5: Average Residual Energy

Figure 7 shows the hop count of the path while transferring the information from *SN* to its *CH*. From the figure, it is observed that *Vor-LEACH* contains the hop count as always one, whereas *RMV-LEACH* and *MV-LEACH* may contain more than one hop count value because of its multihop nature. Sometimes, *RMV-LEACH* contains lower hop count values than *MV-LEACH* as it avoids some nodes in the path due to the lower residual energy levels in the battery. Figure 8 shows the number of neighbors while building the *RMV-LEACH* protocol. Note that the number of neighbors considered only for one cluster. From figure, it is observed that the number of neighbors are directly proportional to the total number of sensors within same area of node distribution. Note that the number of neighbors are important in identifying multiple paths for the *Reliable_Path_Vector*. In general, more neighbors lead to higher number of paths in path vector.

Another experiment is on finding the maximum data to be transferred on the paths of *MV-LEACH* and *RMV-LEACH* without communication interruptions, which occur due to the low energy levels in the sensor motes. The energy consumption model considers transmission energy consumption (*ETx*) as 4.602 µJ/bit and receiving energy consumption (*RTx*) as 2.34 µJ/bit [26]. Note that if any node in the path reaches zero battery power, then it cannot transfer the data, and the path is considered invalid. In the experiment, it has taken one *SN*, its assigned *CH*, and all the intermediate sensor nodes in the path between *SN* and *CH*. For *RMV-LEACH*, it considers all the nodes in the robust path and transfers the data through these nodes. For *MV-LEACH*, it considers low-cost *MC* path for transferring the data. We have plotted the graph for maximum data that can be transferred through robust path for *RMV-LEACH* and low-cost MC path for *MV-LEACH*. Figure 9 shows that the *RMV-LEACH* can transfer higher volumes of data compared to *MV-LEACH* because the *RMV-LEACH* eliminates the sensors with low battery levels, whereas the *MV-LEACH* does not consider it.

The next experiment is on identifying the maximum number of transmissions for packets (blocks) of different sizes 512 bytes, 1024 bytes, 2048 bytes, 3072 bytes, and 4096 bytes. The experiment considers 35 sensor nodes in the simulation with *ETx* and *RTx* values as 4.602 µJ/bit and 2.34 µJ/bit, respectively. From *Table I*, it shows that the *RMV-LEACH* can sustain a higher number of transmissions compared to *MV-LEACH*. This could happen because the robust path in *RMV-LEACH*

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

has higher levels of residual energy and can transit more data compared to *MV-LEACH*. Another observation from *Table I* is that the number of transmissions is reduced by increasing the data block size.

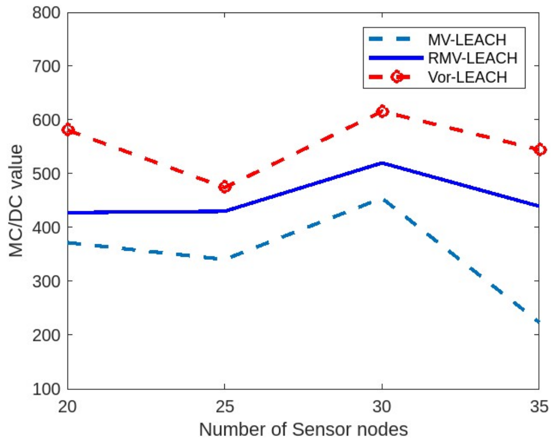

Figure 6: The MC and DC values

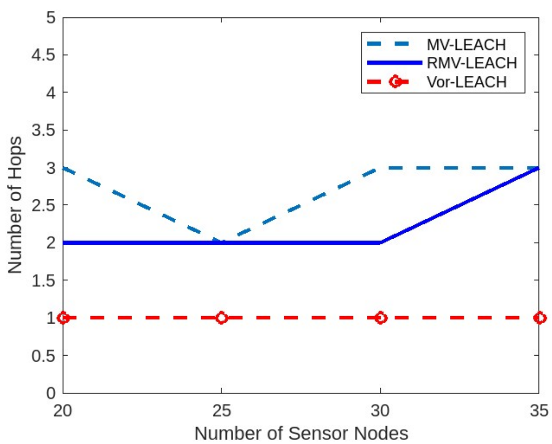

Figure 7: Hope count of the path

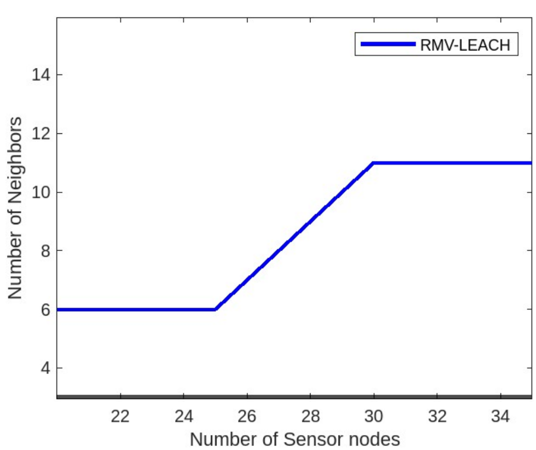

Figure 8: Number of Neighbors Within the Cluster

Table 1: Number of Transmissions vs Data Blocks

Data Block Size (Bytes)	MV-LEACH	RMV-LEACH
512	48	398
1024	24	200
2048	12	100
3072	8	67
4096	7	57

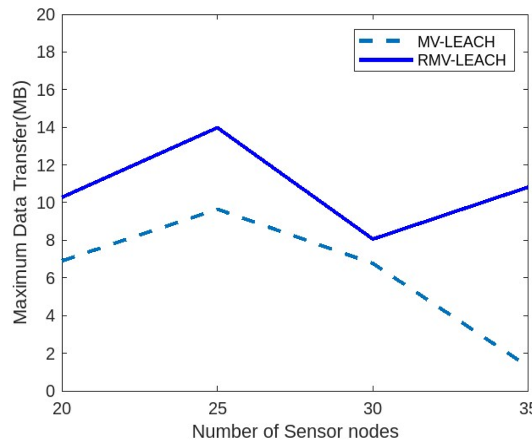

Figure 9. Maximum Data Transfer

5. CONCLUSIONS

In *WSN*, the sensors have limited energy in their battery and a sensor is considered dead if its battery power is exhausted. Hence, the research community of *WSN* gives high priority for energy saving mechanisms in network. In the literature, several energy efficient clustering mechanisms for *WSN* are reviewed to describe how they enhance energy consumption in the network for various *LEACH* protocols. In the article, a new energy efficient clustering method *RMV-LEACH* is proposed. The proposed method identifies a robust path within the Voronoi region from an SN to its *CH*. This robust path can sustain higher volumes of data transfers between *SN* and *CH*, which is common in many sensor network applications. The simulation is carried out for the proposed method and the results show the performance of the *RMV-LEACH*.

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