Adaptive energy efficient fuzzy: An adaptive and energy efficient fuzzy clustering algorithm for wireless sensor network-based landslide detection system

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Abstract
It is a well-known research outcome that clustering helps in increasing the network lifetime and the routing performance. This research thus aims to optimize the energy consumption of wide scale wireless sensor networks (WSNs) by proposing a novel and an adaptive energy efficient fuzzy (AEEF) clustering for a WSN. It is an improvement and modification on the traditional clustering of the cells of the network for Landslide Detection systems. It incorporates the concept of fuzziness and state machine in selecting the cluster heads, unlike previously clustering algorithms such as low-energy adaptive clustering hierarchy and so on. The proposed AEEF approach is validated by carrying out simulations and the results show that the average energy consumption per node under no-clustering is 0.5144892 mJ, whereas it reduces drastically to 0.084482 mJ using the proposed AEEF clustering algorithm. Hence, the proposed algorithm is approximately 83.5% more energy efficient and thus increases the lifetimes of the nodes deployed for sensing a landslide along with being adaptive to any changes in the ambient conditions.

1 | INTRODUCTION

Landslide, a type of mass wasting, includes a wide range of ground movements such as rock falls, deep failure of slopes and shallow debris flows, which can occur in offshore, coastal and onshore environments, under the influence of gravity [1]. Being sporadic in nature, it is a short-lived and yet potentially destructive phenomenon and causes a significant damage to society and nature.

The degree of unpredictability of landslides and rapid change of contributing parameters greatly impacts the complexity in design of an Early Landslide Warning System. The successful implementation of a landslide detection application requires handling massive amounts of data from the wireless sensor network (WSN), maintaining its accuracy, integrity and ensuring low-latency transmission of the sensed data with efficient utilization of energy [2].

Wireless sensors are one of the leading technologies that can record rapid changes in data such as detection of changes in slope moment of a mountain or tilt angle change and transmit the sensed data to a data analysis centre from the remote hostile regions. WSN technology has the capability to quickly capture, process and transmit the critical and high resolution data for real-time monitoring [3,4]. It also has the advantage of deploying sensors that require low maintenance, which is ideal for hostile environments but has energy constraints which limits the lifetime of the nodes.

Network lifetime is an inevitable consideration in WSN because sensor nodes are power constrained [3]. Since each sensor node has only limited energy and frequent battery replacement in the monitoring applications is impractical, hence in order to prolong the network lifetime, an energy-aware network design is desired. To address the aforementioned problems, clustering of sensor nodes is preferred. It improves the scalability of the network, has better data aggregation which dramatically reduces transmission data and saves energy. It also reduces latency and provides with collision avoidance along with ensuring high connectivity and fault tolerance. The stated features of clustering prevent the unnecessary bandwidth consumption by redundant data, which in turn avoids channel congestion. Hence, an adaptive energy...
efficient fuzzy (AEEF) clustering algorithm is presented that self-organizes itself to the changes in the deployed region properties and also increases the lifetime of network by improving the energy consumption by individual sensor nodes.

1.1 | Paper contribution

The main contributions of this paper are as follows:
- A modified fuzzy logic based clustering algorithm is proposed which is adaptive in nature as well as highly energy efficient
- Implementation of proposed clustering algorithm in landslide detection system
- Performance evaluation with both flat routing and clustering algorithm is presented to estimate the efficiency of the algorithm
- Exhaustive simulation for different scenarios viz. pre-landslide, during landslide and post-landslide scenarios is done

1.2 | Paper organization

The rest of the paper is organized as follows. A brief review of the application of WSNs in landslide monitoring and detection is presented in Section 2. Various clustering algorithms in WSN and their comparison is presented in Section 3 followed by the discussion on Fuzzy C-Means (FCM) clustering algorithm in Section 4. The proposed Adaptive Energy Efficient Clustering Algorithm for Landslide Detection System is elaborated and explained in detail in Section 5. Section 6 gives the Experimental Setup and Simulations to validate the proposed algorithm. Sections 7 and 8 discusses the results and conclusion of the paper respectively.

2 | ROLE OF WSN IN LANDSLIDE DETECTION

The evolution of WSNs has fostered development in real-time monitoring of critical and emergency applications. In Ref. [5], a Drought Forecast and Alert System has been proposed to collect and analyse the landslide data using sensor nodes and stream the alert notification to the people through mobile communication. Whereas, soil monitoring using WSN has been proposed in Ref. [6] to provide information about land deformations leading to a Landslide. It involves combination of remote sensing, automated terrestrial surveys and Global Positioning System (GPS) in combination for the monitoring purpose. Similarly, in Ref. [7] different types of sensors have been used in conjunction for the soil deformation monitoring.

In context to the surface slope monitoring, a sensor node has been developed in Ref. [8] to be employed in expandable WSNs for remote monitoring of slope stability failure susceptible areas, whereas in [9] landslide prediction is done using slip surface localization. A Multisensor Deep Earth Probe has been proposed in Ref. [10] for Rainfall-Induced Landslide Detection. It is a heterogeneous structure and consists of various geophysical sensors viz., Pore Pressure Piezometers, Dielectric Moisture Sensors, Rain gauges, Strain gauges and Tiltmeters placed at different positions.

In heavy rainfall and steep slopes areas, WSN based on clustering has been proposed for landslide detection in Ref. [11]. The network has been divided in two layers. In the lower layer, sensor nodes are attached with the sensor column to collect the data, whereas in the upper layer, cluster head (CHs) are placed that aggregate the data from sensors and transmits it to the sink node with minimal data packet loss. WSN has been used in Ref. [12] for accelerometer based detection and measurement of vibrations caused by landslides.

A Clustering and Multi-hop Protocol for landslide prediction has been proposed in Ref. [13]. It uses beacon to send the clustering algorithm to all nodes for selection of CHs and is triggered periodically to conserve energy. Data is routed to the base station (BS) by optimally satisfying the trade-off between number of hops and energy consumed per transmission. In Ref. [14] an autonomous landslide monitoring system based on WSNs has been presented, in which software agents are continuously collecting and analysing sensor data, such as record ground acceleration and the orientations of the sensor nodes along the slope.

A robust WSN in Ref. [15] has been proposed for landslide risk analysis. The data collected by sensors deployed is sent to remote unit/BS through the network to monitor various metrics such as battery lifetime, radio link and so on. Similarly, in Ref. [16] authors have proposed an energy efficient data acquisition technique for rainfall-induced landslide monitoring system. The main focus of Ref. [16] is to reduce energy consumed by sensor nodes which has been achieved using wavelet-based sampling approach for choosing optimized sampling rate of sensors.

3 | CLUSTERING APPROACHES IN WIRELESS SENSOR NETWORKS

Various clustering algorithms have been proposed till date, however some of the most commonly used approaches have been discussed next.

i. **Low-Energy Adaptive Clustering Hierarchy (LEACH)** [17,18]: LEACH is one of the most common and efficient clustering algorithm used in WSN. The basic idea on which LEACH works is to select the nodes as CH on rotation basis such that the energy dissipation and load involved in communication with BS gets distributed to all the nodes. Various variations of LEACH have been proposed till date to increase the efficiency of LEACH.

ii. **Hybrid Energy-Efficient Distributed clustering (HEED)** [19]: HEED is another energy efficient multi-hop clustering algorithm in WSN in which prime consideration is energy. Unlike LEACH, HEED does not select the CH randomly. Instead, intra-cluster communication cost and node's residual energy are used for the election of a CH.
| Clustering Routing Protocols | LEACH [18] | HEED [19] | DWEHC [20] | PANEL [21] | UCS [22] | EECS [24] | EEUC [25] |
|-----------------------------|------------|------------|------------|------------|------------|------------|------------|
| Cluster characteristics     |            |            |            |            |            |            |            |
| Variability of cluster count| Variable   | Variable   | Variable   | Fixed      | Variable   | Variable   | Variable   |
| Uniformity of cluster sizes | Even       | Even       | Even       | Even       | Uneven     | Uneven     | Uneven     |
| Intra-cluster routing        | Single-hop | Single-hop | Multiple-hop| Single-hop | Single-hop | Single-hop | Single-hop |
| Inter-cluster routing        | Single-hop | Single-hop multiple-hop | Single-hop | Multiple-hop | Multiple-hop | Multiple-hop |             |
| Cluster-head characteristics |            |            |            |            |            |            |            |
| Existence                   | Cluster-head based | Cluster-head based | Cluster-head based | Cluster-head based | Cluster-head based | Cluster-head based | Cluster-head based |
| Difference of capabilities   | Homogeneous | Homogeneous | Homogeneous | Homogeneous | Heterogeneous | Homogeneous | Homogeneous |
| Mobility                    | Stationary | Stationary | Stationary | Stationary | Stationary | Stationary | Stationary |
| Role                        | Relay aggregation | Relay aggregation | Relay aggregation | Relay aggregation | Relay aggregation | Relay aggregation | Relay aggregation |
| Clustering process           |            |            |            |            |            |            |            |
| Control manners             | Distributed | Distributed | Distributed | Distributed | Distributed | Distributed | Distributed |
| Execution nature            | Probabilistic | Iterative | Iterative | Probabilistic | Probabilistic | Probabilistic | Probabilistic |
| Convergence time            | Constant   | Constant   | Constant   | Constant   | Constant   | Constant   | Constant   |
| Parameters for CH election  | Adaptive   | Adaptive   | Adaptive   | Adaptive   | Adaptive   | Adaptive   | Adaptive   |
| Proactiveness               | Proactive  | Proactive  | Proactive  | Proactive  | Proactive  | Proactive  | Proactive  |
| Objectives                  | Load balancing | Load balancing | Load balancing | Load balancing reliability | Load balancing lifetime extension | Load balancing periodical data communications | Load balancing |
| Entire proceeding of the algorithm |            |            |            |            |            |            |            |
| Algorithm stages            | Cluster construction | Cluster construction | Cluster construction | Cluster construction | Cluster construction | Cluster construction | Cluster construction |

**Abbreviations:** CH, cluster head; DWEHC, Distributed Weight-based Energy-efficient Hierarchical Clustering; EECS, Energy Efficient Clustering Scheme; EEUC, Energy-Efficient Uneven Clustering; HEED, Hybrid Energy-Efficient Distributed clustering; LEACH, Low-Energy Adaptive Clustering Hierarchy; PANEL, Position-based Aggregator Node Election protocol; UCS, Unequal Clustering Size.
iii. **Distributed Weight-based Energy-efficient Hierarchical Clustering (DWEHC)** [20]: DWEHC protocol is another distributed Clustering algorithm used in WSN for the election of stable clusters. HEED and DWEHC shows similarity on some aspects like considering of residual energy for the CH election and not taking into consideration parameters like size and density of the network. DWEHC enhances the HEED by making balanced clusters sizes and bringing location awareness of nodes for improvement of intra-cluster topologies.

iv. **Position-based Aggregator Node Election protocol (PANEL)** [21]: PANEL is position and location based CH election algorithm used in WSN. Unlike majority of other clustering algorithms, PANEL has the support for both synchronous and asynchronous applications. PANEL which uses position of nodes for the CH election has one major limitation that not all the times position of a node can be determined and for finding the locations of the nodes, special GPS based hardware needs to be deployed on the nodes.

v. **Unequal Clustering Size (UCS)** [22]: UCS was designed to enhance the lifetime of the network by considering the energy consumptions of the CHs. In UCS, it is assumed that the position and locations of the CHs are defined and determined in advance only and all the CHs are arranged in symmetry in circle around the BS. The major limitation in UCS is that only fixed super nodes are appointed as CHs all the time.

vi. **Energy Efficient Clustering Scheme (EECS)** [24]: EECS is designed majorly for the applications that requires periodic collection of data. In this, CH are made by considering the residual energy of the nodes whose information is broadcasted by the contender CHs. EECS allows dynamic sized clusters on the basis of the distance of the cluster from the BS.

vii. **Energy-Efficient Uneven Clustering (EEUC)** [25]: EEUC algorithm is another distributed clustering algorithm in WSN in which CHs are elected by a localized competition. Multi-hop routing is used for communication between the clusters. For communicating with the destination node, CH chooses a intermediate node whose residual energy is greater than others.

The comparison of these clustering approaches for WSN in terms of clustering and cluster-head characteristics, clustering process and so on is given in Table 1.

### 4 | FUZZY C-MEANS CLUSTERING

Clustering involves the task of dividing data points into homogeneous classes or clusters so that items in the same class are as similar as possible and items in different classes are as dissimilar as possible. Clustering can also be thought of as a form of data compression, where a large number of samples are converted into a small number of representative prototypes or clusters. Depending on the data and the application, different types of similarity measures may be used to identify classes, where the similarity measure controls how the clusters are formed.

The FCM algorithm is one of the most widely used fuzzy clustering algorithms. This technique was originally introduced by Bezd [26]. The algorithm attempts to partition a finite collection of elements into a collection of c fuzzy clusters with respect to some given criterion. FCM is a method of clustering which allows one piece of data to belong to two or more clusters. It is based on minimization of the following objective function:

\[
J_m = \sum_{i=1}^{N} \sum_{j=1}^{C} u_{ij}^m \| x_i - c_j \|, \quad 1 \leq m < \infty
\]  

where,
- \( m \) is any real number greater than 1,
- \( u_{ij} \) is the degree of membership of \( x_i \) in the cluster \( j \),
- \( x_i \) is the \( i \)th of \( d \)-dimensional measured data,
- \( c_j \) is the \( d \)-dimensional centre of the cluster,
- \( N \) is the number of data points/nodes
- \( C \) is the number of clusters, and
is the Euclidean distance expressing the similarity between any measured data and the centre.

With the following constraints

\[ \sum_{i=1}^{N} u_{ij} = 1, \forall i. \]  \hspace{2cm} (2)

\[ 0 \leq u_{ij} \leq 1, \forall i,j. \]  \hspace{2cm} (3)

\[ \sum_{j=1}^{N} u_{ij} > 0, \forall k. \]  \hspace{2cm} (4)

The algorithm can be described using the flowchart shown in Figure 1.

5 | PROPOSED AEEF CLUSTERING

The main idea behind this paper is to develop an Adaptive Clustering approach for a Landslide Monitoring and Detection System which demands high performance metrics like throughput, end-to-end delay along with a prolonged network lifetime. To achieve this, an AEEF clustering algorithm has been proposed which works in three phases, pre-landslide phase, landslide phase and post-landslide phase.

5.1 | Pre-landslide phase

This phase involves setting up clusters prior to the Landslide. It has been sub-categorized into two phases viz., setup and cluster formation phase. In the setup phase, sensor nodes are assumed to be deployed in a Quasi Random manner. The first task is to transfer the location of all nodes to the sink node or BS. This is achieved using the routing protocols discussed in [4]. Based on their performance in the proposed scenario, one routing protocol is selected for routing the co-ordinates to the sink. Once the BS has the geographical location of all the sensor nodes, second phase, that is, Cluster

F I G U R E 2 State diagram representation of sensor nodes. CH, cluster head; FFD, full function device; RFD, reduced function device

F I G U R E 3 Flow chart illustrating operation of each reduced function device under mobility

F I G U R E 4 3D quasi random deployment of sensor nodes in MATLAB

Formation phase begins at the sink node. FCM Clustering algorithm is initiated for clustering of the nodes. When the termination criterion (c) of FCM is satisfied, it gives the clusters and their corresponding cluster centres. Since we are working with sensor network, we need a CH, but FCM
provides us with the cluster centre. So, a modification of FCM has been proposed in this paper, wherein, the distance of all the nodes in the cluster is calculated from their respective cluster centres and the node having minimum distance from cluster centre is elected as CH for that cluster. This CH appointment process can be very well summarized by Pseudo Code 1. Index gives the node number which is elected as the CH. This procedure is repeated till all the CHs are elected.

Another modification has been introduced in the FCM code related to the membership of the nodes with the cluster, to ensure that a node is associated with at least one cluster. This is achieved by introducing a de-fuzzification cut whose value is calculated by finding the minimum value among the maximum membership values of nodes with each cluster.

This scheme has been named as Modified Fuzzy C-Means (MFCM) Clustering. Hence, after completing the clustering process, sink has the information about the clusters and CHs. In case a node claims membership in more than one cluster, the node transmits its data to the CH having higher energy level but maintains association with both the CHs. If the two CHs have equal energy, then the node transmits its data to both the CHs.

An additional feature has been proposed in AEEF to increase the energy efficiency of the network. The CHs will be appointed as full function devices (FFDs) and the member nodes (MNs) will simply be reduced function devices (RFDs). This will be implemented using the concept of state machine as shown in Figure 2. Each node, after the completion of clustering process, will check if it is appointed as CH or not. If appointed, it will start operating as FFD else it will operate as RFD.
Next step in Cluster Formation phase is to disseminate the clustering information to all the nodes. To do this, some energy efficient dissemination strategy should be used. The information to be propagated includes the address of CHs, MNs and their functioning mode.

### 5.2 Landslide phase

The clusters have been organized to form a hierarchical routing for the designed network. As soon as any mass movement occurs or the surface begins to slide, the nodes will sense the movement. Let us assume a small area begins to slide. There will be two scenarios possible, first, only the MNs which are RFDs are sliding with the surface, break from their clusters. In this case, the RFDs cannot communicate with other CHs. So, a modification has been proposed at MAC layer to temporarily appoint a pseudo-FFD during movement of the RFD nodes such that these RFDs can communicate with other nodes and transmit the sensed data to sink. The flowchart of the proposed algorithm is shown in Figure 3.
5.3 | Post-landslide phase

Once the Landslide stops, some nodes will be displaced from their original position. Since we are designing an energy efficient network, the use of GPS for finding the location of nodes will not be suitable. Hence another technique has to be used for localization. Given the hardware availability and constraints, Uncertainty Analysis Method for RSSI-based estimation [27] can be used for distance measurement. In free space, other things being equal the RSS varies as the inverse square of the distance \(d\) between the transmitter and the receiver. However, in real environment propagation may not be direct Line of Sight. Hence authors in [27] have considered path loss power factor due to multiple reflection of the signal for estimation of distance given by:

\[
d = d_0 10^{(RSSI - P_0 - X_r)/n}
\]  

(5)

where \(X_r\) is Gaussian random variable with log normal distribution and \(n\) is path loss exponent. For reference power \(P_0\) at a distance \(d_0\), the received signal strength at any distance can be calculated as:

\[
RSSI = P_0 + X_r + 10n\log(d/d_0)
\]  

(6)

The path loss exponent covers various aspects such as such as height and design of antennas, reflections and multipath signal propagation and so on.

Once the displaced nodes have their approximate positions, their co-ordinates are then routed to the sink using the routing protocol selected for cluster initialization. The CHs again check the energy levels of their MNs after the movement stops. The concept of fuzzy based clustering has been adapted in this paper because once the Landslide occurs the nodes may get accumulated in close vicinity to each other. Thus, to prolong the lifetime of the nodes, scheduling is done of these nodes to change their mode of operation from sleep to transmit and receive and vice versa and then MFCM is applied once again to reform new clusters in the same manner as in pre-landslide phase.

| Cluster no. | Cluster head | X co-ordinate | Y co-ordinate | Z co-ordinate |
|-------------|--------------|---------------|---------------|---------------|
| 1           | Node 12      | 42.3758       | 22.6993       | 21.1395       |
| 2           | Node 16      | 121.2171      | 21.9807       | 21.7035       |
| 3           | Node 19      | 181.2308      | 21.0236       | 21.8086       |
| 4           | Node 24      | 80.0296       | 41.7042       | 40.0450       |
| 5           | Node 33      | 42.2404       | 62.8705       | 61.9305       |
| 6           | Node 37      | 121.2559      | 62.9392       | 61.2359       |
| 7           | Node 40      | 180.6079      | 62.6272       | 61.3198       |

**TABLE 2** Result of clustering process in pre-landslide phase

![Figure 10](image-url) | **FIGURE 10** Termination measure versus iteration count
6 | EXPERIMENTAL SETUP AND SIMULATION

To verify the proposed AEEF Clustering algorithm, 50 wireless sensor nodes are deployed in a Quasi Random Manner, in a geographical terrain of dimensions 250 × 120 × 150 m in MATLAB as shown in Figures 4 and 5. The node file is then generated in MATLAB and transferred into QualNet and the Quasi Random Scenario is generated. Node number 31, shown in Figure 5, is the sink node or BS node and the green lines depict a constant bit rate link from each node to BS. The first step in our proposed design is to send the location of every node to BS so as to initiate the clustering process. This is achieved by selecting the best routing protocol among AODV, DSR, OLSR and ZRP by simulating the network on a single channel two ray pathless model at 2.4 GHz channel frequency, for 60 s as presented in Ref. [4].

After selection of appropriate routing protocol for sending the location of all sensor nodes to the sink node, clustering algorithm initiates at BS as explained earlier. Figure 6 shows the nodes arranged in proper clusters in MATLAB and Figure 7 shows the same clustering in QualNet.

Now, when a landslide occurs, there will be a movement of some sensor nodes and these nodes will disassociate themselves from their corresponding clusters until the mass movement stops.

Figure 8 shows a scenario depicting a landslide. After the landslide has stopped, that is, in post-landslide phase of our proposed design, the nodes that have been displaced will find their new location using the UAM-RDE approach [27] and their new locations will be transferred to BS using the routing protocol selected for cluster initialization and new clusters will be formed as shown in Figure 9.

7 | RESULTS AND DISCUSSIONS

In order for successful cluster formation, the sink node needs to have the location of all the sensor nodes placed in the geographical terrain. To achieve this, some routing protocols are considered viz. AODV, OLSR, DSR and ZRP, for routing the location of all nodes to the sink. From the results obtained in Ref. [4], it can be concluded that if setup time and overhead has to be reduced regardless of the number of data packets received, OLSR gives the best performance among all the routing protocols but since for proper clustering we need the exact location of all the nodes, so we can overlook the overhead data and hence DSR is the suitable routing protocol for our Quasi Randomly Deployed nodes, as it gives maximum throughput and data packets reception at the sink.

With the help of DSR routing protocol, the location of nodes is provided to sink node which then initiates the FCM
clustering. The Termination Criteria ($\epsilon$) plot of FCM is shown in Figure 10. It can be seen from the figure that, as the iteration count increases the termination measure decreases and when it becomes smaller than a pre-defined threshold (0.0001 in our case), the FCM algorithm stops and we get the final clusters and their cluster centres.

The result of clustering process is shown in Table 2, which shows the CH node and its geographical location. The Euclidean distance based membership function, which is the association strength of sensor nodes with all the clusters in the network, after the termination criterion is satisfied and FCM algorithm stops is shown in Figure 11. After the occurrence of Landslide, some nodes are displaced from their original position and hence re-clustering is done. Table 3 shows the new CHs and their geographical locations.

The performance evaluation of our proposed clustering algorithm is done on the basis of energy efficiency. The energy consumption will depend on the various modes of operation of the radio viz. transmit, idle and receive mode. Figures 12–14 show the energy consumption comparison between the proposed adaptive energy efficient fuzzy (AEEF) clustering scenario and no clustering scenario.

| Cluster no. | Cluster head | X co-ordinate | Y co-ordinate | Z co-ordinate |
|------------|-------------|---------------|---------------|---------------|
| 1          | Node 9      | 182.4642      | -17.439       | -18.4105      |
| 2          | Node 12     | 42.3758       | 22.6993       | 21.1395       |
| 3          | Node 15     | 100.5288      | 22.4539       | 21.3833       |
| 4          | Node 29     | 180.8166      | 22.0837       | 21.3160       |
| 5          | Node 33     | 42.2404       | 61.8705       | 61.9305       |
| 6          | Node 36     | 101.3980      | 60.5189       | 62.1799       |
| 7          | Node 50     | 180.9139      | 80.5189       | 81.1114       |

**Table 3** Result of clustering process in post-landslide phase

**Figure 12** Transmission mode energy (in mJ) comparison of sensor nodes for proposed adaptive energy efficient fuzzy (AEEF) clustering scenario and no clustering scenario

**Figure 13** Receive mode energy (in mJ) comparison of sensor nodes for proposed adaptive energy efficient fuzzy (AEEF) clustering scenario and no clustering scenario
shows the energy consumption of all 50 sensor nodes in these modes of operation.

From the comparison graphs, it is validated that in AEEF approach, only the CHs consume the maximum energy and the MNs consume very small amount of energy, as should be the case in a clustering scheme. When there is no clustering in the network, all the nodes consume almost equal energies in the receive mode and same is the case for idle mode operation, in which all the nodes consume approximately same values as can be seen from Figures 13 and 14, respectively. Table 4 gives the comparison of the average energy consumption of the proposed clustering algorithm with a non-clustering approach. It can be calculated that the average energy consumption per node under no clustering is 0.5144892 mJ whereas, when the proposed AEEF Clustering algorithm is implemented the average energy consumption reduces drastically to 0.084482 mJ. Hence, the proposed algorithm is approx. 83.5% more energy efficient. In addition to this, average energy consumption per node of LEACH [17,18] is 0.0159 mJ. Hence, AEEF is 74.18% efficient than LEACH.

8 | CONCLUSION

In this paper, an AEEF Clustering approach has been proposed for a Landslide Detection System in order to simplify the routing path from nodes to sink and hence decreasing the end-to-end delay, which could be very useful in case a landslide occurs, as the sensed data could reach the sink node quickly. It incorporates the concept of fuzziness and state machine in selecting the CHs, unlike previously clustering algorithms like LEACH and so on, and works in three phases viz., pre-landslide, landslide and post-landslide phase. Based on the simulation results, it is concluded that AEEF Clustering is approx. 83.5% more energy efficient than simple flat routing technique and 74.18% more efficient than LEACH while being adaptive to the changes in the position and the environment and will thus prolong the network lifetime of the monitoring system.

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REFERENCES

1. Waikato Regional Council: Landslide types [Online]. http://www.waikatoregion.govt.nz/Services/Regional-services/Regional-hazards-and-emergency-management/Landslides/Landslide-types/
2. Kotta, H.Z., et al.: Wireless sensor network for landslide monitoring in nusa tenggara timur. TELKOMNIKA Indonesia. J. Electr. Eng. 9(1), 9–18 (2011)
3. Akyildiz, I.F., et al.: A survey on sensor networks. IEEE Commun. Mag. 40, 102–114 (2002)
4. Ahmed, S., Gupta, S., Suri, A.: An optimal selection of routing protocol for different sink placements in a wireless sensor network for landslide detection system. Proc. Of IEEE International Conference on Computational Intelligence and Communication Networks (CICN), Bhopal, India, pp. 358–363 (2014)
5. Liu, H., Meng, Z., Cui, S.: A wireless sensor network prototype for environmental monitoring in Greenhouses. In: Proc. WiCom, Shanghai, pp. 2344–2347 (2007)
6. Musaloue-E, R., et al.: Life under your feet: a wireless soil ecology sensor network. In: Proc. 3rd Workshop on Embedded Networked Sensors (EmNets 2006) (2006)
7. Hill, C., Sippel, K.: Modern deformation monitoring: a multisensory approach. In: Proceedings of FIG XXII International Conference, Washington DC (2002)
8. Garach, E.A.: Wireless, “automated monitoring for potential landslide hazards”. Master thesis, Texas A&M University (2007)
9. Terzis, A., et al.: Slip surface localization in wireless sensor networks for landslide prediction. In: Proceedings of IPSN’06 (2006)
10. Ramesh, M.V.: Design, development, and deployment of a wireless sensor network for detection of landslides. Ad hoc networks, pp. 1-17 (2012)
11. Kumar, S., et al.: Factors and approaches for energy optimized wireless sensor network to detect rainfall induced landslides. ICWN, CSREA Press, pp. 435–438 (2007)
12. Herry, Z.: Kotta, Kalvein Rantelobo, Silvester tena, Gregorius Klau, “wireless sensor network for landslide monitoring in nusa tenggara timur. TELKOMNIKA Indones. J. Electr. Eng. 9(1), 9–18 (2011)
13. Mehta, P., et al.: Distributed detection for landslide prediction using wireless sensor network. Proceedings of First IEEE Global Information Infrastructure Symposium, pp. 195–198. Marakech, (2–6 July 2007)
14. Georgieva, K., et al.: An autonomous landslide monitoring system based on wireless sensor networks. Proceedings of International Conference on Computing in Civil Engineering, pp. 145–152, Florida, (17–20 June 2012)
15. Giorgetti, A., et al.: A robust wireless sensor network for landslide risk analysis: system design, development and field testing. IEEE Sensor. J. 16(6), 6374–6386 (2016)
16. Prabha, R., et al.: Energy efficient data acquisition techniques using context aware sensing for landslide monitoring systems. IEEE Sensor. J. 17(18), 6006–6018 (2017)
17. Heinzelman, W.R., Chandrakasan, A., Balakrishnan, H.: Energy-efficient communication protocol for wireless microsensor networks. Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, Maui, HI, USA, pp. 10–19 (4–7 January 2000)
18. Miglani, A., et al.: An energy efficient and trust aware framework for secure routing in LEACH for wireless sensor networks. Scalable Comput. Pract. Exp. 18(5), 207–218 (2017)
19. Younis, O., Fahmy, S.: HEED: A hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. IEEE Trans. Mobile Comput. 3, 366–379 (2004)
20. Ding, P., Holliday, J., Celik, A.: Distributed energy efficient hierarchical clustering for wireless sensor networks. Proceedings of the 8th IEEE International Conference on Distributed Computing in Sensor Systems (DCOSS), Marina Del Rey, CA, USA, pp. 322–339 (8–10 June 2005)
21. Buttyan, L., Schaffer, P.: PANEL: Position-based aggregator node election in wireless sensor networks. Proceedings of the 4th IEEE International Conference on Mobile Ad-hoc and Sensor Systems Conference (MASS), Pisa, Italy, pp. 1–9 (8–11 October 2007)
22. Soro, S., Heinzelman, W.: Prolonging the lifetime of wireless sensor networks via unequal clustering. Proceedings of the 5th IEEE International Workshop on Algorithms for Wireless, Mobile, Ad Hoc and Sensor Networks (WMAN), Denver, CO, USA, pp. 236–243 (4–8 April 2005)
23. Liu, X.: A survey on clustering routing protocols in wireless sensor networks. Sensors. 12(8), 11115–11153 (2012)
24. Ye, M., et al.: EECS: An energy efficient clustering scheme in wireless sensor networks. Proceedings of the 24th IEEE International Performance, Computing, and Communications Conference (IPCCC), Phoenix, AZ, USA, pp. 535–540 (7–9 April 2005)
25. Li, C.F., et al.: An energy-efficient unequal clustering mechanism for wireless sensor networks. Proceedings of the 2nd IEEE International Conference on Mobile Ad-hoc and Sensor Systems Conference (MASS), Washington, DC, pp. 596–604 (7–10 November 2005)
26. Ross, T.J.: Fuzzy classification. Fuzzy Logic with Engineering Applications. 3rd edition, pp. 339–357. Wiley India Pvt. Limited, New Delhi, India (2012)
27. Yan, X., et al.: UAM-RDE: An uncertainty analysis method for RSSI-based distance estimation in wireless sensor networks. Neural Comput. Appl. 1–14 (2020)

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