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CENTRALIZED CLUSTERING ALGORITHM TO ENHANCE ENERGY CONSUMPTION IN WIRELESS SENSOR NETWORKS

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ABSTRACT

A Wireless Sensor Networks (WSNs) composed of a large number of sensor nodes within a sensing geographical area. Energy consumption is considered a major WSNs issue. Therefore, a considerable number of researches have investigated various ways to reduce energy consumption. One of the best techniques used to reduce energy consumption is clustering. Clustering helps to improve the network performance through extending the battery lifetime. Our study improves the work on LEACH Enhancements for WSNs based on the energy model by introducing the K-means clustering approach to improve energy and increase network lifespan. The proposed approach divides the nodes into member nodes and cluster head nodes. The member nodes transmit data to the cluster head, whereas, the cluster head nodes are responsible for communication with the base station. This approach is a centralized election technique where the base station makes the decision for selecting the cluster heads based on the information received from each node. The advantage of the proposed technique is that the information of each node is only sent once to the base station during the initialization phase. The base station performs weightage calculation for all nodes and nodes with the highest weights are elected as cluster heads. The base station also decides the cluster members and the decisions are then transmitted to all nodes in the network. This research introduces weightage calculation based on three important parameters which are remaining energy, number of neighbor nodes and the node's distance to base station. The proposed technique consists of three phases: Initialization Phase, Setup Phase, and Selection Phase. The results of our proposed technique shows significant improvement of the residual energy, the total energy consumption, the total alive nodes, and total packets delivered compared to LEACH Enhancement for WSNs based on the energy model technique. In conclusion, the results of this study show improvements and achieved the objectives of this paper.

Keywords: WSNs, LEACH, cluster head, energy-efficiency.

1. INTRODUCTION

Wireless sensor networks (WSNs) have opened up modern, promising methods for creating several types of applications [1]. WSNs consist of many small sensing nodes that monitor their environment, process data if necessary (using microprocessors), and send and receive processed data from other sensing nodes. These nodes, which are distributed in their environment, are connected to a sink node through a centralized network or to other sensing nodes [2].

The distribution of nodes in the environment can be non-structural or structural. Non-structural distribution occurs when nodes are not controlled after distribution, and the only role of nodes is to monitor the environment, process data, and build a network by finding and connecting to their neighbors [3]. By contrast, in structural distribution, the position of each node (sensing and CH) is clear. Communication between nodes becomes programmable, making the management and maintenance of the nodes easier. The cost is also much lower because a lower number of nodes were issued in the environment.

Different ways can be used to select a path for traffic within a WSNs environment, a feature that contrasts with that for traditional methods in fixed networks [4]. Given that routing in a WSNs environment lacks infrastructure, unpredictably erratic wireless links occur frequently, sensor nodes have a high vulnerability index, and essential routing conventions are inefficient and inflexible where energy use is concerned [5].

WSNs consist of numerous inexpensive miniature devices called sensor nodes [6]. These nodes facilitate data transfer from one node to other nearby nodes until the data packet reaches the base station (BS) within the network. These data can be in the form of environmental data related to pressure, temperature, and sound.

2. LITERATURE REVIEW

The popularity of WSNs has increased considerably because of their remarkable capabilities (Mahmood *et al.* 2015). WSNs are now being used in an extensive variety of domains ranging from the military to farming. They can be applied to monitor and detect threats or enemies in military surveillance systems. In addition, WSNs can be used by farmers to control the humidity and temperature of crops in precision agriculture (Campobello *et al.* 2015).

WSNs are utilized for observing the actions and tracking the effects of small insects, birds, and animals on livestock and crops in different environmental settings, discovering forest fires, engaging planetary investigation, and monitoring the activities of the Earth, detecting floods, studying environmental pollution, and plotting environmental biocomplexity [7].

WSNs can be deployed in diverse environments for monitoring purposes, including military and civil applications [8]. The primary inspiration for the development of sensor networks was military applications, for example, monitoring military vehicle movements in the battlefield [9]. However, WSN applications are now

found in many industrial and consumer activities, such as process industry control, machine control, and health monitoring.

Depending on their application requirements, these sensors may be connected to multiple nodes or a single node [10]. The number of connected nodes can range from a handful to hundreds or even thousands. In the network sensor, each node consists of the following components: batteries, sensors, microcontroller and transceiver with either an internal or external antenna.

Usually, WSNs comprise a large number of low-power, low-cost, and multifunctional sensor nodes that are deployed in the target region [11]. Although these sensor nodes are small in size, they are geared with integrated radio receivers, microprocessors, and power components that facilitate computing, sensing, actuation, and communications. Any constraints in the cost and size of these sensor nodes affect the corresponding resources, such as memory, energy, communication bandwidth, and computational speed. Depending on the requirement, WSNs topology may be a simple or advanced multi-hop wireless mesh network [12]. Some of the applications of WSNs to improve the quality of life include the following:

a) Monitoring farms
b) Tracking vehicles
c) Healthcare monitoring
d) Environmental/Earth sensing
e) Industrial monitoring
f) Machine health monitoring
g) Water/wastewater monitoring

Energy efficiency is the major design problem with WSNs, because each sensor node depends on battery power for data acquisition, processing, reception, and transmission (Mijovic *et al*. 2015). Sensor nodes are usually small in size and powered by irreplaceable batteries, making energy a key concern that poses the most challenges in designing sensor networks. Each sensor node of a WSNs has a different energy consumption rate because of the distance from the BS and the disparities in event sensing, resulting in energy inequalities among the network sensor nodes and reducing the network's life cycle [13].

Meeting the QoS parameters is another pressing issue with WSNs. QoS parameters and energy conservation are key factors that determine the lifespan of sensor networks. Energy-efficient routing mechanisms are calculated to improve the performance of sensor networks [14]. The limitations of energy supply have led to numerous studies on WSNs in all levels of the protocol stack. Network architectures, such as the Internet and the Open Systems Interconnection, are essentially well-designed models structured as layers, where one layer delivers services to the one above it (e.g., the application layer delivers services to the end users).

Network evaluation is often carried out with respect to the QoS parameters, including throughput, delay, availability, jitter, security, and reliability. However, regarding to energy consumption, some difficulty always exists. In network optimization and evaluation, only a couple of comprehensive models take energy consumption into consideration. Normally, researchers tend to focus on the customary network architecture while trying to minimize elements of a single layer regardless of the other layers or components, in the hope that the network overall energy consumption will decrease. This approach is not ideal because no knowledge exists on how a component fits into the complete energy picture(s) of the whole WSNs [15].

Most existing energy minimization models emphasizes the transfer and receipt of data [16], but neglects other parameters. Wang and Yang studied the power consumption model [17], which focuses on the costs associated with sending and receiving data, and realized the energy efficiency upper limit for each single-hop distance. This method includes an intermediate node in the middle of the source and destination to save energy through transmission. Other methods assess the energy efficiency of WSNs through the power consumption model cited in [18].

Given that the specifications and challenges of wireless networks are different, applying the traditional network architecture to them does not work. This drawback necessitated the creation of a cross-layer idea that provides wireless networks with flexible network architecture [19]. The key idea behind the cross-layer design is enhancing information dependence and sharing among various protocol stack layers [20]. Utilizing a cross-layer design improves performance gains within wireless networks, with the resulting protocols being more appropriate for use with wireless networks compared to protocols developed for a strictly layered method [21]. For more critical review related works found in Table-1.

Table-1. Most critical related works.

Author/ Year	Problem	Methodology
[22]	WSNs-related energy issues	Authors suggested two approaches to reduce the energy consumption level, but investigations on the several drawbacks associated with the approaches are still needed.
[23]	Limited resources and energy consumption issues in WSNs	The authors suggested an enhancement on the LEACH protocol using their proposed algorithm, in which the network is logically partitioned into four zones.
[8]	Energy consumption issues and the distance between nodes	The authors proposed a new protocol called energy-efficient distance-based cluster head (DBCH) algorithm to improve energy consumption.
[6]	A major challenge is the energy consumption of sensor nodes	The authors suggested a hybrid protocol version of MR-LEACH and ant colony optimization
[24]	Short lifespan of residual energy, which basically amounts to the high-energy consumption of sensor nodes	The authors suggested the integration of multi-hop clustering protocols, such as MR-LEACH and MH-LEACH, and their modified version, which integrates the LEACH-1R protocol, to help stabilize the network at the point of clustering

3. PROPOSED METHOD

Shurman proposed two approaches based on an energy model to enhance the cluster head (CH) selection method by not only reducing overconsumption but also reduce the number of (CH) [22]. However, In the current study, we will redevelop the two approaches realted for Shurman works based on K-mean clustering.

a. Energy-based selection strategy (Approach 1)

In this approach, the number of clusters to be selected during the round is determined theoretically depending upon the communication radius and the area of the sensing field. The number of CHs to be selected is given by the equation below:

$$k = \frac{\sqrt{3}M}{2 * r^2 * \pi^2} \tag{1}$$

where k is the number of CHs, M is the sensing area, and r is the communication radius. In the next phase, to select the CH, the threshold for each node on each round is given by

$$T(n) = \frac{E_i * k}{E_{tot}} \tag{2}$$

This equation involves the remaining energy for selection of CHs. Hence, the nodes with high residual energy within a cluster will be selected as the CH for the next round. E_i represents the remaining energy of node I, and E_{tot} denotes the total energy of the node.

b. Modified energy-based selection strategy (Approach 2)

This strategy, which is also a modification of the original LEACH algorithm, appends a new parameter distance to calculate the threshold. The energy model and equation for calculating the number of CHs are kept similar, as shown in Equation (2). The threshold for each node is calculated using the equation below, where d is the distance between the node i and the other node:

$$T(n) = \frac{E_i * k}{E_{tot} + d} \tag{3}$$

c. Energy model

A first-order radio model for the energy model is considered for all the clustering algorithms implemented in our simulation at WSNs. Figure-3, illustrates the radio energy dissipation model in WSNs. In this model, to exchange a B bit of message between two sensor nodes, the energy consumption can be calculated by:

$$E_{tx}(d, x) = E_{elec} * B + \varepsilon_{amp} * B \tag{3.4}$$

$$E_{rx}(B) = E_{elec} * B \tag{3.5}$$

where d is the distance between nodes, E_{tx} is the transmitter energy consumption, and E_{rx} is the receiver energy consumption. E_{elec} is the electronics energy consumption per bit in the transmitter and receiver sensor nodes. ε_{amp} is the amplifier energy consumption in the transmitter node, which is given by:

$$\varepsilon_{amp} = \varepsilon_{fs} * d^2, d \le d_0 \tag{4}$$

$$\varepsilon_{amp} = \varepsilon_{mp} * d^4, d \ge d_0 \tag{5}$$

Where d_o is the threshold value. If distance d is less than d_o, then the free-space propagation model is used.

Otherwise, the multi-path fading channel model is used. ε_{fs} And ε_{mp} are communication energy parameters.

d. K-means weighted clustering algorithm

This study has introduced the design of the proposed K-means weighted clustering algorithm in terms of energy efficiency and increased network lifetime. We adopt a K-means clustering approach to divide the nodes into member nodes and CH nodes. The CH nodes are now responsible for communication with the BS, whereas the member nodes transmit data to the CH. This approach comprises a centralized system in which CH selection takes place in the BS and then announced to all the nodes. This outcome helps reduce the control overhead of sensor nodes and conserve energy.

e. Algorithm setting

A centralized clustering scheme is proposed to reduce the energy consumption and prolong the lifetime of battery in WSNs. In our approach, the BS divides the geographical area into k-number of clusters using K-means algorithm on the basis of each node's location. Thus, the sensor nodes are classified into clusters according to the minimal distance from the BS. The BS is assumed to have information about the residual energy, the distance and the number of neighbors of each node. Based on these information, the BS calculates the weight of each node. Hence, the node with the highest weight is selected as the CH for a given cluster. Our proposed algorithm consists of three phases:

- **Initialization phase**

In this phase, the BS broadcasts the request (REQ) message to all the nodes within a sensing area. After receiving the REQ, each node responds with a reply (REP) message.

The reply message from each node consists of the residual energy, the current location, and the number of neighbors. The packet format for the REQ and REP messages are shown in Figure-1 and Figure-2.

Type	BS ID	CRC	TTL

Figure-1. Format for REQ packet.

The first field contains the type of message (REQ and REP). The second field contains the address of the (BS ID). The third field contains the cyclic redundancy check (CRC) for error detection. The fourth field consists of time to live (TTL).

Type	Source Address	Address of Base station	Payload	CRC	TTL

Figure-2. Format of REP packet.

The first field consists of the type of message. The second field consists of the source address, which contains the address of node that sends the response to the REQ message. The third field consists of the destination address, which is the address of the sender of the REQ message. The fourth field consists of the payload, including information about the residual energy, the location of the node, and the number of neighbors. The fifth and sixth fields consist of CRC bits for error detection and for TTL respectively. The algorithm for initialization phase procedures can be summarized as follows:

a) The BS periodically broadcasts the REQ message to all the nodes within a network.
b) The BS then sets a timer and waits for a period of T seconds.
c) After receiving the REQ message, each node responds with a REP message.
d) The REP message consists of the sender address, the location of the sender, the residual energy, and the number of neighbor nodes.
e) Upon receiving the REP message, the BS stores it in its database.

- **Setup phase**

The main purpose of this phase is to find the number of CHs needed within a given geographical area and calculate the center location of K-clusters. Information on location and residual energy is received in the initialization phasewhere k is the number of clusters, and its value is decided at the beginning of the setup phase. This value is given by

$$k = \left[\frac{\sqrt{n}}{\sqrt{2\pi}} \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \frac{A}{d_{BS}^2} \right] \tag{6}$$

where A is the side of the square field, and d_{BS} is the average distance from the cluster nodes to the *BS*. However, the BS is assumed to have all the required information needed for the setup phase, which are narrowed as follows:

a) The total number of clusters to be selected in the network is calculated using Equation (6).
b) Base on calculation during setup phase in [22], they use five cluster head.

This is the result that will be used for selection phase.

- **Selection phase**

On the basis of the k-means algorithm, n number of nodes is partitioned into k-clusters, and each node belongs to the nearest cluster head to the BS. For k clusters, the k-means system can be expressed as follows:

$$avgs \min \sum_{i=1}^{k} \sum_{X_j \in S_i} | X_j - M_i |^2 \tag{7}$$

where S_i is the cluster i, X_j is the coordinate of sensor node j, and M_i is the coordinate of the mean point. The CH within a set is computed using the following formula:

$$W_i = w_1 * E_{rem} + w_2 * N_{neigh} + w_3 * d \quad (8)$$

$$w_1 + w_2 + w_3 = 1 \quad (9)$$

where w_1, w_2 ,and w_3 are the weights and are assigned in such a way that the total sum is equal to 1. We perform experiments for *(w1=0.6 , w2=0.2, w3=0.2)* to get our results.

W_i denotes the weight of the ith sensor node, E_{rem} denotes the residual energy, N_{neigh} denotes the number of neighbor nodes, and d denotes the distance between a node and the BS. Once the CH is selected on each cluster, this information is broadcasted by the BS to all sensor nodes and similarly updates the routing table. In this section, we analyze the performance of LEACH, APPROACH-1, and APPROACH-2 based on Shurman's work, which used a K-means clustering scheme based on metrics, namely, energy consumption, remaining energy, alive nodes, and packets delivered. The analysis shows that the performance of the K-means clustering scheme is better than that of other clustering schemes under similar conditions.

The energy model shows that the energy consumption during packet transmission depends upon the size of the packet and the distance. The nodes far away from the BS drain more energy compared to those near the BS. The nodes with distance less than reference distance assume the free space path loss with path loss exponent *e = 2*, whereas nodes with distance higher than reference distance assume a shadowing path loss with the path loss exponent *e = 4*.

Hence, to alleviate the problem of energy consumption, a clustering approach was introduced because the nodes must now transmit to their corresponding CHs, which are at lesser distance than those of BS and hence consume less energy. In clustering, nodes are organized into clusters that communicate with the local BS (known as CHs), and these local BSs transmit the data to the global BS.

This situation greatly reduces the distance because the member nodes do not need to transmit directly to their global BS but rather to the local CH. In turn, the reduced distance decreases the energy consumption, and clustering appears to be an energy-efficient communication protocol. The energy-efficient LEACH protocol and its variants, namely, APPROACH-1 and APPROACH-2, are compared with the k-means clustering approach. The algorithm for the CH selection phase is listed below:

a) The BS now separates the nodes into a k-cluster set. Each node is now associated with a cluster.
b) From each cluster set, a BS selects a CH based on the weighted scheme.
c) The weight of each node is calculated using Equation (8).
d) The node with the maximum weight is selected as a CH by the BS.
e) The BS then sends this information to all the nodes in the sensing area.

The proposed method is related with the following pesudo code options:

```
1. SET weights w1, w2, w3
2. FOR i = 1 : N
      a. CALCULATE distance
      b. GET E_rem (remaining energy)
      c. GET N_neigh = number of neighbors
      d. COMPUTE weight = w1 * distance + w2 * E_rem + w3 * N_neigh
3. END
4. FOR i = 1 : k
      a. SET Cluster members = [];
      b. FOR j = 1 : N
            i. IF ID == i
                  1. Concatenate Cluster member with j
            ii. END
      c. END
      d. SET weights = empty
      e. FOR l = 1 : no_of_cluster_member
            i. weights = [weight of each member node]
      f. END
      g. FIND node with maximum weight, note its ID
      h. ClusterHead = [ClusterHead ID]
5. END
```

f. Weight evaluation criteria

As introduced in proposed method, the clustering selection in K-means was based on the minimum distance from the CH position, the maximum energy, and the number of neighbors. Weights were used, and results were reported for 20 Iterations with W1, W2, and W3, where W1 is the distance, W2 is the remaining energy, and W3 is the number of neighbor nodes. Table-2. Illustrates these values, which are empirically used.

Table-2. Evaluation criteria.

Statistics concept	A	B	C
W1	0.6	0.2	0.2
W2	0.2	0.6	0.2
W3	0.2	0.2	0.6

Experiments were conducted with different values by the Table-2 and the results are as followed:

- Evaluation Criteria- Scenario A

After an in-depth empirical analysis of the results for W1, our proposed method is shown to be better than Shurman approaches [22] in terms of distance, alive nodes, total energy consumed, packets that have delivered and ramming energy. However, Figure-3 shows the possible results of our approach.

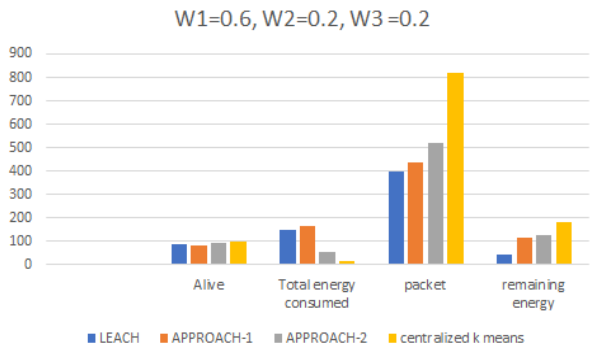

Figure-3. Empirical results for scenario-A with priority weightage for W1.

- Evaluation criteria- scenario B

Empirical analysis results for W2 show that our proposed method is better than Shurman [22] approaches in terms of remaining energy. In Figure-4, shows the possible results of our approach.

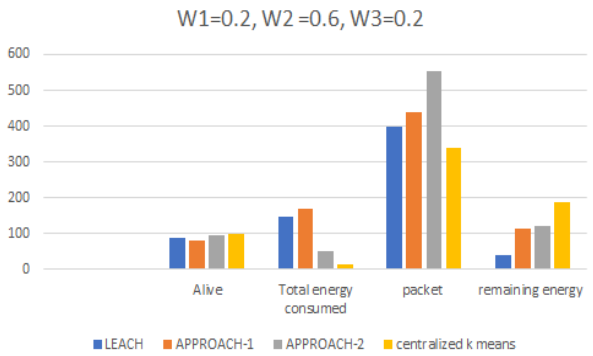

Figure-4. Empirical results for scenario-B with priority weightage for W2.

- Evaluation criteria- scenario C

In-depth empirical analysis of the results for W3 show that our proposed method is better than Shurman [22] approaches in terms of the number of neighbor nodes. In Figure-5 shows the possible results of our approach.

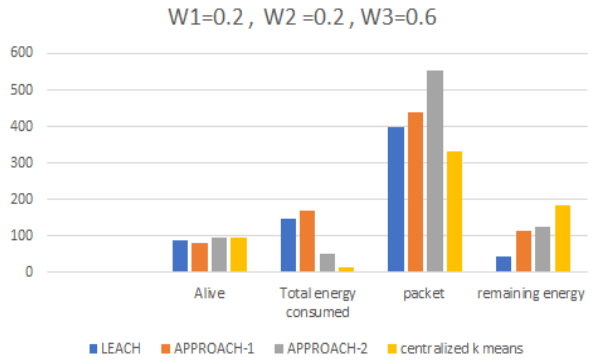

Figure-5. Empirical results for scenario-C with priority weightage for W3.

4. EXPERIMENTAL SETUP AND RESULTS

The sensor network consists of 100 nodes, which are placed randomly within a 100 m × 100 m area with a communication range of 30 m for each node. A total of 2000 bits of packet are sent by each node toward the BS through CHs, which are selected using the clustering algorithm simulation parameter, as shown in Table-3. Each node drains the energy per the first-order energy model. Each algorithm is run for 20 iterations. Performance analysis of each algorithm is conducted based on the total remaining energy, total energy consumption, number of alive nodes, and total number of packets delivered. The network is homogeneous and the nodes are distributed randomly around the sensing area. The BS is fixed. The analysis shows that the proposed algorithm is better in terms of performance metrics compared with traditional methods.

The number of nodes is fixed, and the results are analyzed under 20 iterations. In each iteration, the performance metrics are analyzed. Each node is implemented with all the four algorithms, and the results are stored under different variables for each algorithm. Each algorithm returns the number of CHs for the given round. The energy is calculated for each node based on the state (CH or member node) of the node.

Each member node only performs the transmission, whereas the CH nodes does both transmission and reception. Hence, the CH nodes drain more energy with respect to member nodes. In addition, the proposed algorithm balances the energy consumption and increases the lifetime of the network by selecting the CH on each round based on the k-means weighted approach.However, in Table-2 summrized all the parameters setting.

Table-3. Simulation parameters.

Parameters	Values
Number of nodes	100
Sensing area	100 m × 100 m
Transmission power/node	28 dBm
Communication radius	30 m
Electronics energy (E_{elec})	50 nJ/bit
Energy for data Aggregation (E_{da})	5 nJ/bit/signal
ε_{fs}	10 pJ/bit/m^2
ε_{amp}	0.0013 pJ/bit/m^2
Packet size	2000 bit
Clustering algorithms	LEACH, APPROACH-1, APPROACH-2, K-MEANS
Initial energy (E) for each node	2 J
Radiation pattern	Omni-directional
Path loss model	Shadowing path loss model
Total number of rounds k	20 5

Performance metrics are used to quantitatively evaluate the clustering algorithms in WSNs. Quantitative measurement is useful and necessary to evaluate network performance or to compare the evaluation of different clustering algorithms.

simulation begins with the network design in which the sensor nodes and the BS are placed in a network. All the nodes are assigned with fixed parameters (e.g., transmission power, communication radius, path loss model, etc.). An energy model is designed, which is run on each node, and residual energy is stored. Clustering algorithms are implemented and analyzed to verify the performance based on metrics. The analyzed results are then plotted for all algorithms. However, simulation will start to run 100 random node networks to prepare it for the K-means clustering.

The results were obtained from extensive simulations using MATLAB 2015. The nodes were deployed randomly, and each node had a fixed transmit power and communication range. Each node was run for 20 rounds, in which the energy model was applied from Shurman approaches to obtain the energy consumption of each node. The number of dead nodes, energy consumption, and packets delivered were analyzed. After the simulation was completed for scenario I, the evaluation of performance analysis was conducted using the evaluation metrics of residual energy, average energy consumption, alive nodes, and packets delivered. To show the effectiveness of the k-means weighted clustering scheme, a simulation was performed for 1 to 20 rounds.

A. Residual energy results

Figure-6 shows the total remaining energy on each round for each algorithm. The Figure depicts that the total remaining energy of the proposed algorithm is higher than that of the remaining three algorithms, showing that the energy consumption of our proposed algorithm is less than that of the other algorithms.

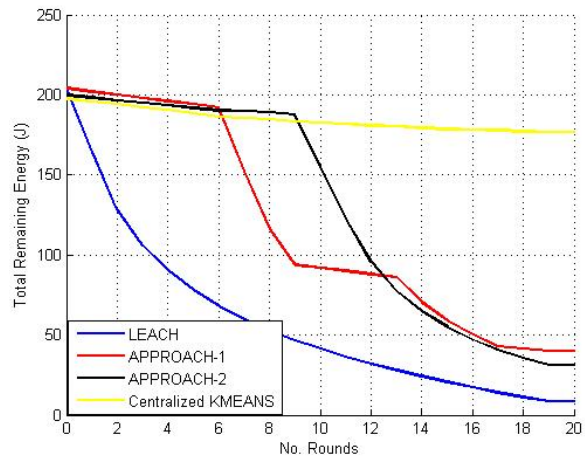

Figure-6. Remaining energy of a network.

B. Total energy consumption results

Figure-7, shows the energy consumption in each round. The simulation is run for each round, and the energy consumed in each round. For each node are added to obtain the total energy consumption. The analysis shows that the average energy consumption of clustering using k-means algorithm is cosniderablyy less than that of remaining algorithms. Low energy consumption helps increase the lifetime of the nodes and the entire network.

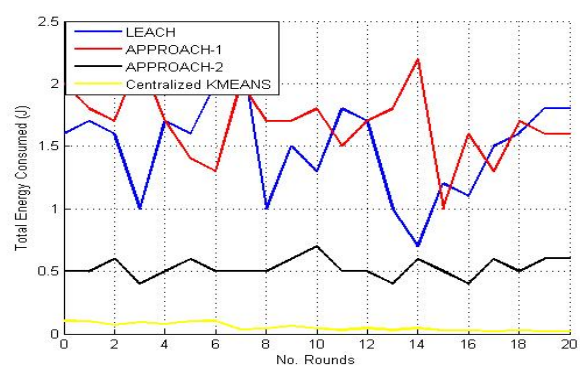

Figure-7. Total energy consumption.

C. Alive node results

Figure-8, shows the number of alive nodes in each round for each algorithm. The number of alive nodes was calculated based on the energy model. In each round, the residual energy of each node was checked. The nodes with energy higher than 0 were considered alive; otherwise, they were considered dead. The alive nodes

with our proposed algorithm are higher than those of remaining algorithms in each round. This result shows that the proposed algorithm is efficient in terms of energy consumption.

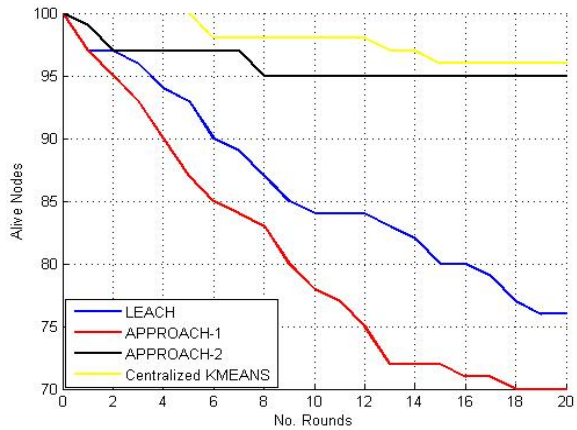

Figure-8. Total alive nodes.

D. Packet delivery results

A high number of alive nodes results in high packet delivery because a node is always available to relay the packet. A low number of alive nodes may result in network failure because a path to forward the packet to the BS may not exist. Figure-9 shows high packet delivery. The packet delivery increases as the number of rounds increases and becomes saturated at some point. Further increase in the number of rounds decreases the packet delivery because the nodes begin to die (less alive nodes available).

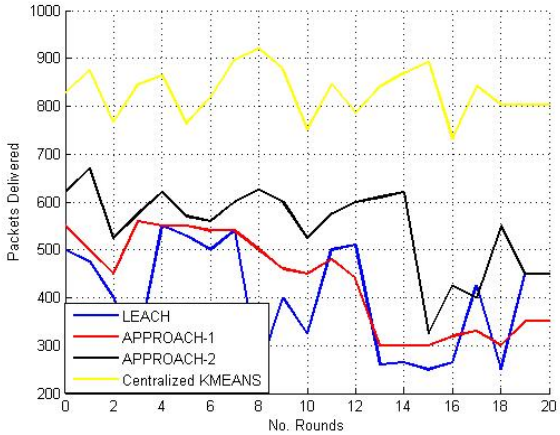

Figure-9. Packet delivery.

5. CONCLUSIONS

From this results, it showes evaluation criteria-scenario (A) is the best scenario and our experimants simulated using it. The results show that the proposed algorithm is energy efficient and has high packet delivery. The proposed algorithm provides an energy-efficient network by calculating the average distance between network nodes and the number of neighboring nodes, taking into account the residual energy. Finally, the weight for each node is calculated, and the node with the maximum weight is considered as the CH. This approach highly increased network lifetime by uniform cluster distribution and balanced the network loading among the clusters.

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