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A Novel Cluster Arrangement Energy Efficient Routing Protocol for Wireless Sensor Networks

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Abstract

Background: Wireless sensor networks are application-based networks designed by large number of sensor nodes. Utilizing the energy in efficient way is the one of the main design issue in Wireless Sensor Network (WSN). Limited battery capacity of sensor nodes makes energy efficiency a major and challenging problem in wireless sensor networks. **Methods:** In order to improve Network lifetime, Energy efficiency and Load balance in Wireless Sensor Network, a Cluster Arrangement Energy Efficient Routing Protocol CAERP is proposed. It mainly includes efficient way of node clustering and distributed multi-hop routing. In the clustering part of CAERP we introduce an un-even clustering mechanism. Cluster head which are closer to the Base Station (BS) have smaller cluster size than those farther from BS, so in here they can preserve some energy in the time of inter-cluster data communication. Our protocol consists of cluster head selection algorithm, a cluster formation scheme and a routing algorithm for the data transmission between cluster heads and the base station. **Findings:** Each sensor node should effectively handle its energy in order to keep the WSN at its operation state. In each time duration Q-leach is consume more energy than the CAERP. CAERP eliminate the initial dead node problem. During the initial stage the message overhead between the Q-Leach and CAERP have somewhat similar, but after the uneven clustering formation the CAERP message overhead is reduced comparing with the Q-LEACH. In CAERP protocol it mainly focuses for utilizing the energy in efficient way. This improvement is accomplished because the nodes remain alive due to the efficient way of cluster arrangement. CAERP has mainly five cluster Head so each cycle the Cluster Head varying based on the CAERP CH selection algorithm. Due to efficient CH selection algorithm the CAERP have high network life time compared to Q-LEACH. The simulation result shows that CAERP significantly increasing the network lifetime and minimizes energy consumption of nodes compared with Q-leach protocol. **Conclusion:** The performance of the proposed protocol is compared with that of Q-LEACH using different parameters with the help network simulators. Our protocol CAERP has significantly improved in average energy consumption, survival rate and the extended the network life cycle which means the energy efficiency of the CAERP network is improved.

Keywords: Clustering Methods, Cluster Head Selection, Efficient Routing Protocol, Energy Network Lifetime, Uneven Clustering, Wireless Sensor Network

1. Introduction

Wireless Sensor Network[1] is a network composed with hundreds of sensor devices that communicate wirelessly with limited energy consuming routing protocols. Nowadays the applications of sensor networks are varied like target tracking environment monitoring, air pollution monitoring, detecting fires in forest, health monitoring with the use of advanced machines, detection of landslides and in battlefield surveillance etc. In such applications, there is a high need of secure communication among sensor nodes. One of the main challenges in WSN is the utilizing the energy in efficient way for extending the lifetime of the WSN. Nowadays many researchers have

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tried to overcome this problem[3-5]. A wireless network consisting of very small devices that monitor physical or environmental conditions such as temperature, pressure, motion or pollution etc. at different areas. Such sensor networks are expected to be widely deployed in a vast variety of environments for commercial and military applications such as surveillance, tracking, climate and health monitoring, intelligence and data gathering. The key limitations of wireless sensor networks are the power and processing of the data. The architecture of the sensor nodes and their limitation lead us to design energy efficient routing protocols. The inexpensive sensor networks is accelerated by the advances in MEMS technology, combined with low power, low cost digital signal processors and radiofrequency circuits[4,6]. Sensor nodes are spatially distributed throughout the region which has to be monitored. They self-organize into a network through wireless communication and coordinate with each other to accomplish the common task.

Basic features of sensor networks are self-organizing capabilities, dynamic network topology, limited power, mobility of nodes, node failures, multi-hop routing and large scale deployment[6].

The key challenge in sensor networks is to maximize the lifetime of sensor nodes due to the fact that it is not feasible to replace the batteries of thousands of sensor nodes. So the computational operations of various sensor nodes and their routing protocols must be made as energy efficient as possible. Among these energy efficient routing protocols data transmission protocols have much more importance in the aspect of energy, as the energy required for data transmission takes 70% of the total energy consumption of a wireless sensor network[3]. Area coverage and data aggregation[1] techniques can greatly help conserve the scarce energy resources by eliminating data redundancy and minimizing the number of data transmissions.

Security in data communication is another important issue to be considered while designing wireless sensor networks, as they may be deployed in hostile areas such as battlefields[4,9].

1.1 Sensor Network Challenges

Wireless sensor network uses a wide variety of application and to impact these applications in real world environments, we need more energy efficient routing protocols and algorithms. Designing a new protocol or algorithm address some challenges, which are need to be clearly understood[13]. These challenges are summarized below.

1.1.1 Physical Resource Constraints

The most important constraint imposed on sensor network is the limited battery power of sensor nodes. The effective lifetime of a sensor node is directly determined by its power supply and hence the lifetime of a sensor network is also determined by the power supply. The main design issue of energy efficient routing protocol is their energy consumption. Limited computational power and memory size is another constraint that affects the amount of data that can be stored in individual sensor nodes. So the energy efficient routing protocol should be simple and light-weighted. Communication delay in sensor network can be high due to limited communication channel shared by all the peer nodes within each other's transmission range.

1.1.2 Ad-hoc Deployment

Many applications require the ad-hoc deployment of sensor nodes in the specific region. Various sensor nodes are randomly deployed over the region without any infrastructure and prior knowledge of topology. In such a situation, it is up to the nodes to identify its connectivity and distribution between the nodes.

1.2 Classification of Routing Protocols in WSN

Different routing protocols are designed to fulfill the shortcomings of their source constraint nature of the WSNs. The deployed WSN can be differentiated according to the network structure or intended operations. Therefore, routing protocols for WSN needs to be categorized according to the nature of WSN operation and its network architecture's routing protocols can be subdivided into two broad categories such as network architecture based routing protocols and operation based routing protocols[8].

1.2.1 Architecture based Routing Protocols

Protocols are divided according to the structure of network, which is very crucial for the required operation. The protocols included into this category are further divided into three subcategories according to their functionalities. These protocols are[18]

- Flat-based routing.
- Hierarchical-based routing.
- Location-based routing.

1.3 Clustering

Based on the applications clustering arrangement mainly classified into homogenous and heterogeneous, static and dynamic, centralized and distributed[2]. Every cluster nodes transmit the sensed data to the Cluster Head for sending the data directly to the Base Station via single hop or multi hop format[6]. So uses of the clustering in WSN have lot of advantages in the time of energy conservation, data aggregation, and network load balancing. This paper presents a new Clustering Arrangement Energy Efficient Routing Protocol (CAERP).

This paper is organized as follows. Section 2 describes the details of the related work, Section 3 describes CAERP routing protocol, Section 4 evaluates simulation results and Section 5 briefs the conclusion and future work.

There's a considerable research effort for the development of energy efficient routing protocols in Wireless Sensor Networks. The development of energy efficient routing protocols is based on the particular architecture of the peer nodes forming the network and their applications. We need to consider several factors that should be taken into account when designing energy efficient routing protocols for WSNs. Energy efficiency is the most important factor, as it directly affects the lifetime of the network. There have been considerable efforts in the literature pursuing energy efficiency in Wireless Sensor Networks. In[16] Low Energy Adaptive Clustering Hierarchy (LEACH), a hierarchical protocol in which most nodes transmit to cluster heads, is presented.

Here the node selects the random number 0 and 1, if the numbers below the threshold then the node become cluster head[6]. In LEACH protocol select the Cluster Head (CH) randomly based on the received signal strength in the network.

$$T(u) = \{ p/(1 - p(r \bmod 1/p)), \text{ if } n \in G \quad (1)$$

Otherwise

In steady state phase mainly having the transferring the data's in between the CH and the Base Station. In steady state phase the cluster nodes other than the CH sense the data and transmitted to the CH's, these CH aggregates the data and sending to the base station or sink[7-9]. The time of inter and intra cluster formation LEACH uses TDMA (Code Division Multiple Access) and CDMA for avoiding the collisions[6].

LEACH protocols having some drawbacks like this protocol cannot applicable for large network because LEACH is a single hop network so the energy unbalance is happening.

In the Quadrature LEACH (Q-LEACH)[8] is a Clustering based protocol for a homogenous network. For a better clustering the given network is partition into four quadrants. Doing such a partition the network achieving the better coverage and load balancing[9]. LEACH applies the random cluster head election, which will result in higher energy consumption. So this shows that effective selection of cluster head could reduce the usage of consumption energy. Initially the nodes distribute randomly in network, and then the nodes send their location information to the base station. According to the location information the network is partition into four quadrants. In the CH selection process node select a random number 0 and 1. When the number is less than the threshold value T(n) then the node becomes the CH. Similarly the same process is repeating in the entire network.

The selection of the clusters based on the RSSI (Received Signal Strength Indicator)[1,8]. After selection of the clusters the node informs the CH details to their surrounding nodes. Then the nodes assigned TDMA[3] time slots for an intra-cluster communication. When the all nodes transmit the sensed data to the CH then, the CH aggregate the data and send to BS or sink.

In LEACH, a node becomes a cluster-head based on stochastic algorithm. This can produce unbalanced energy level reserves among the peer nodes and increasing the total energy dissipated in the network. In the case of PEGASIS, the cluster head selection does not take into consideration of the residual energy of the nodes and the location of the base station. PEGASIS has good performance compared to LEACH[17], but the nodes are grouped into chains by the sensor nodes which may result in redundant data transmissions.

3. CAERP

In here CAERP (Cluster Arranged Energy Efficient Routing Protocol) having mainly four phases: clustering, CH selection, routing and Data transmission. Initially the network partition into different uneven clusters. The cluster which are nearer to the base station have smaller size than those farther from base station because of conserve the energy during the data transferring time. Besides maximizing the lifetime of the sensor node, there is a need to distribute the energy dissipated throughout the wireless sensor network in order to minimize maintenance and maximize overall system performance. Any routing protocol that involves synchronization of all the nodes needs some message overhead for setting up the communication. So we study the various energy-efficient routing algorithms and compare among them. We take into account the number of packets to BS and analyze the energy-efficiency and the useful lifetime of the system. In order to have better understanding of the characteristics of each algorithm and how well they really perform with their peer nodes, we also compare their performance with an optimum clustering algorithm.

We propose a cluster arrangement routing protocol for minimum energy consumption during the data communication time. In Q-Leach the network is partition into four quadrants. During data communication time the energy unbalancing occurs and this protocol cannot be applicable for large networks. We consider a sensor network consisting of N sensor nodes uniformly deployed over a vast field to continuously monitor the environment.

We impose some assumptions about the sensor nodes for the underlying network model.

- There is a base station which is located far from the sensing field.
- Sensors and base station are all stationary after deployment.
- All nodes have similar processing/communication capabilities with equal significance
- Nodes are left unattended, after once they are deployed.
- Sensors can operate in an active mode or a low-power sleeping mode.
- Sensors uses power control to vary the transmission power according to the distance to the desired recipient.
- Sensor nodes are location-unaware, but a sensor node can compute the approximate distance to another node based on the received signal strength, if the transmitting power is known.

3.1 Problem Statement

The number of nodes deployed in the network area is large. The overall dataflow in the network is considerable and large dataflow incur significant energy dissipation for nodes. The densely deployed nodes incur highly correlated data. Since the nodes are energy constrained the routing protocol is required to be energy efficient. The energy consumption is different from node to node due to various functions and positions in the network, the routing protocol should be able to balance the energy dissipation of nodes.

The distances from nodes to the base station are usually long in a wireless sensor network. Long distant data transmission will incur considerable energy dissipation. The routing protocol should be able to minimize the energy consumption of data transmission from nodes to the base station. The problems that need to be addressed in the design of energy efficient routing protocol for wireless sensor networks can be summarized as how to efficiently organize numerous nodes in the network in order to reduce the energy dissipation of nodes, how to balance the energy consumption of nodes and how to minimize the energy dissipation of data transmission from sensor nodes to the base station.

3.2 Proposed Solution

The central theme of the above problem is energy-efficiency in a large wireless sensor network where the data is highly correlated and the end-user requires a high-level function of the data which describes the events occurring among the peer nodes in the given network model. A novel cluster arrangement is a sensible approach for a large network that can efficiently organize communication among the peer nodes, aggregate data communication and reduce energy dissipation of nodes.

The protocols that use centralized clustering where the base station utilize the global information of the network for cluster head selection and cluster formation can produce better clusters that require less energy for data transmission[6]. The cluster head forward aggregated data to the base station and the distance between the cluster heads and the base station is long. Using an efficient multi-hop routing can minimize the energy dissipation of data transmission from cluster heads to the base station[9].

The good performance of these efficient methods leads us to develop a novel Clustering Arrangement Energy Efficient (CAERP) routing protocol for wireless sensor networks. The novel clustering arrangement consist of a centralized cluster head selection algorithm, a cluster formation scheme that aims at balancing energy load among cluster heads and an energy efficient multi-hop routing algorithm for data transmission from cluster heads to the base station.

3.2.1 Clustering

Initially all nodes in the network choose a random number 0 and 1 for node identification. Although the base station assigns energy levels for each node based on the random number in the network. As per our concept, the data should be travel across the network without any congestion. So each node having some energy level for data transmission. This energy level is assigned by base station. After completing the energy allocation the base station checks each and every node energy level.

$$R = \left(1 - c\frac{d\max - d(si, BS)}{d\max - d\min}\right) R\max \qquad (2)$$

Equation 2 describing the clustering formation method. In here for a better coverage and the load balancing the uneven clustering method is introduced. Initially we randomly distribute the nodes in 100m×100m field. The size of the uneven cluster is based on the competition Range 'R'. Consider Rmax is the predefined maximum range. Assume dmax and dmin are the maximum and minimum distance between the Base station and the CH. Consider C is the constant coefficient between 0 and 1. R is the candidate cluster head (n1) range.

3.2.2 .Cluster Head Election

In CAERP the CH selection based on the residual energy and distance from the base station. Based on the CH selection algorithm in each cluster head chooses its next-hop neighbor independently according to the distance to BS. Initially, any cluster head chooses a neighbor, which is nearest to BS within communication range and higher energy level. The CH distance from the BS is varying according to the size of the Clusters.

Algorithm 1. The cluster head election algorithm.
1: The base station providing RE, NODE ID (0 AND 1)
2: Completing the energy distribution
3: n1. CH =min. Dis (n1←BS)
4: n2. CH =min. Dis (n2 ←BS)
5: if min. Dis (n1) = min. Dis (n2)
6: RE (n1←BS) < RE (n2←BS)
7: Final CH ←n2
8: else Final CH ←n1

Consider the cluster head selection algorithm; in here initially the base station distribute residual energy and node id to every node in the network like n1 and n2. Consider these nodes which having the minimum distance between the BS and that node be consider as CH. When the n1 and n2 having the same distance between the BS, then we consider the Residual energy. IF the node n2 having higher residual energy compare with n1, then the node n2 is the final CH. The communication between the CH and base station is made by multi hop so they can reduce the transmission cost among all the clusters.

Every time that a node changes neighbors, the sender will require an acknowledgement for its first message which will ensure that the receiving node is still alive. If a time out occurs, the sending node will choose another neighbor to transmit to and the whole process repeats as mentioned above. Once the communication among the node is initiated, there will be no more acknowledgements for any messages. Besides data messages, there is a need for exception messages that serve as explicit synchronization messages. Receivers have the capability to issue exception messages and used to tell the sending node to stop sending, so that the sender chooses a different neighbor. An exception message is generated in only three instances: the receiving node's queue is too large, the sender's power is more than the receiver's power, and the receiver has passed a certain threshold which means that it has very little power left. The main advantage of this algorithm is the distribution of power dissipation achieved by randomly choosing the group heads among the various nodes that yields a random distribution of node deaths. In our simulation results, we used rounds of 20 iterations between choosing new cluster heads.

As a whole, the system does not live very long and has similar characteristics to direct communication. We can only notice the difference in its perceived performance from direct communication is that it randomly kills nodes throughout the network rather than having all the nodes die on one extreme of the network.

The nodes that are farther away would tend to die earlier because the cluster heads that are farther away have much more work to accomplish than cluster heads that are close to the base station in a network. The random clustering algorithm has a wide range of performance results that indicates its performance was directly related to the random cluster election; the worst case scenario had worse performance by a factor of ten in terms of overall system lifetime.

3.2.3 Routing

In energy efficient routings, to rout a packet to the base station sometimes we do not need to know the exact positions of all the sensors. Only relative positions will do the work for us, that is, for each sensor, information about its neighbors and its distance from base station will suffice. For each sensor, exploring its neighbors and its distance from base station is a two-step task: 1. First each sensor will estimate its distance from the base station. For this base station will send a signal which would give its location and also which should cover all sensor network region, then all sensors receiving this signal will estimate their distance from the base station depending upon the signal strength received by them. 2. Now all sensors know their radial distance from the base station. They are ready to find their neighborhood. For this each sensor will release a signal, which will contain information about their radial distance from base station and ID, to their neighbors. Similarly they can estimate which sensors are their neighbors. Based on this information each sensor can figure its neighbor which is nearest to the base station among its neighbor.

Each node is assumed to be within communication range of the base station and that they are all aware of which node acts as a base station. When the nodes do not know about the base station, the base station could broadcast a message announcing itself as the base station. Then all nodes in their range will send to the specified base station, so each node sends its data directly to the base station. Consequently, each node will deplete its limited power supply and die. The system is said to be dead when all the nodes are dead. The main advantages of this algorithm lie in its simplicity. There is no synchronization to be done between peer nodes, and a simple broadcast message from the base station would suffice in establishing the base station identity in a network. The disadvantages of this algorithm are that radio communication is a function of distance squared, and the nodes should opt to transmit a message over several small hops rather than one big one; nodes far away from the base station will die before nodes that are in close proximity of the base station.

In WSN the routing is mainly considering for data communication between the nodes and Base station. Mainly the clustering communication is mainly two levels like intra-cluster and inters cluster communication. In intra cluster communication the cluster nodes other than the CH wanted to transfer their sensed data to CH by using the TDMA scheme as shown in the Figure 1.

During the time of intra cluster each node have its own time slots for data communication with cluster head and keep these nodes in listen mode.

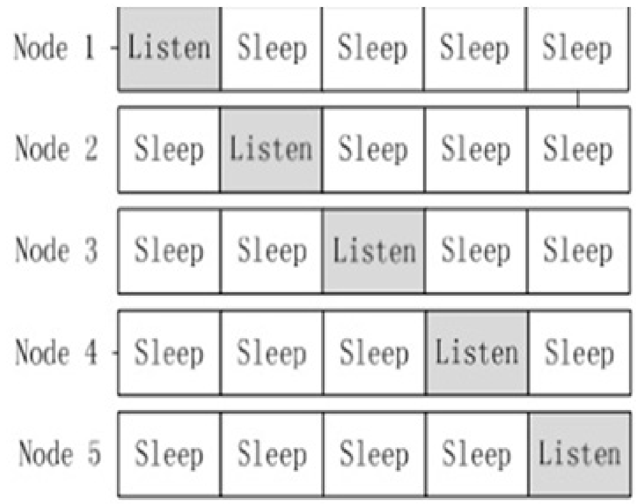

Figure 1. TDMA scheme applied to five nodes.

Algorithm 2. **Multi-hop routing choosing algorithm.**

1. current CH←ci
2. neighboring CH's ← cj, ck
3. if Min.Dis (cj ← ci)>Min.Dis (ck ← ci)
4. cj ← next hop
5. else ck ← next hop
6. Min.Dis (cj ← ci) = Min.Dis (ck ← ci)
7. if RE (cj) >RE (ck)
8. Next hop ←cj
9. else Next hop ←ck

In the inter cluster communication we use multi hop routing technique[9]. Before delivering their data to base station the CH aggregate the data from cluster members and transfer the data via multi hop path. Here consider the current cluster head ci and cj, ck are neighboring cluster heads. When completing the data aggregation in ci, its check the minimum distance neighboring CH. If the cj and ck having the same distance, then ci select the next hop based on the available energy. After completing all the every three rounds the network recycling the entire network and select the new CH's. The various states involved in CAERP are given as a flowchart in the Figure 2.

4. Performance Evaluation

We simulated proposed protocol using NS2 with 100 nodes randomly deployed in 100m × 100m field.

The various simulation parameters are given in the

Table 1. The simulation results of the nodes show that CAERP is more energy efficient than Q-LEACH. In this paper mainly focused on energy efficient clustering arrangement routing protocol. The Q-leach is a self-organized clustering arrangement protocol, so we use this protocol for comparison.

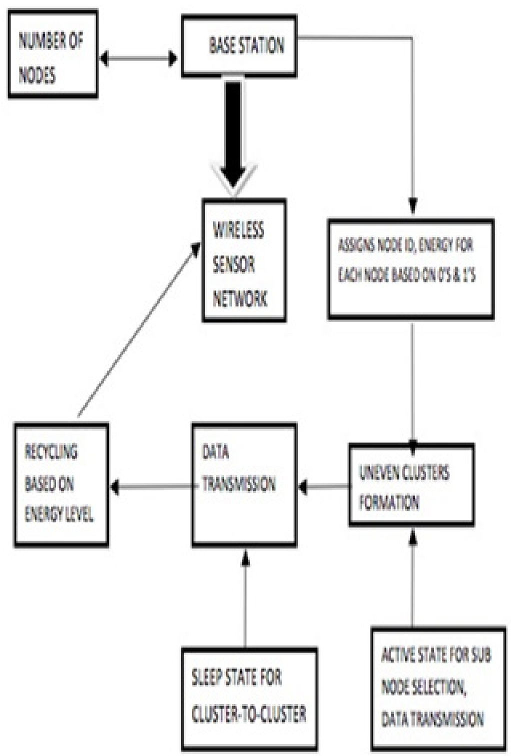

Figure 2. Flow chart of CAERP.

In CAERP the CH selection is based on the residual energy and distances from the base station. Based on the CH selection algorithm in each cluster head choses its next hop neighbor independently according to the distance to BS. Initially, any cluster head chooses a neighbor, which is nearest to BS within communication range and higher energy level. The CH distance from the BS is varying according to the size of the clusters in the network. CH in the cluster spent more energy than the other nodes in the cluster.so energy load balancing is necessary for this situation so the role of the CH should be rotate after three rounds. In the network number of nodes varying based on the size of the clusters. Less number of nodes in the cluster can do more work compare to the large clusters in the network. By efficient cluster arrangement in the wireless sensor network we can maintain the load balancing in the networks.

The simulation result shows the comparison between existing routing protocols Q-LEACH with CAERP. The wireless sensor network life varying based on the size of the network. The reason is that a large-scale network usually has more available communication paths, so the node energy was varying in each round due to the data transferring. When the BS

finishes collecting all data, one cycle is completed. When the BS completing three rounds the network is recycling by the help of BS. The number of nodes alive of proposed CAERP method becomes better performance than the Q leach method. CAERP clearly improves the network lifetime (both the time until the first node dies and the time until the last node dies) over Q–LEACH as shown in the Figure 3. CAERP also eliminate the initial dead node problem versus.

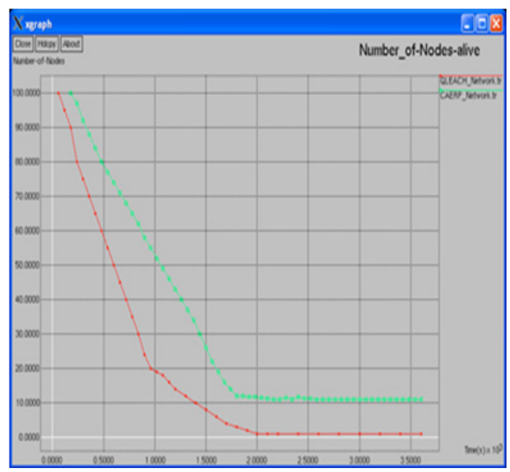

Figure 3. Number of nodes versus time.

In CAERP we can control the message overhead during the intra cluster and inter cluster communication. Based on the completion radius the network is separated by uneven clusters, so in here the cluster that is nearer to the base station have smaller size. So CAERP have only very less message overhead during the data transferring compare to Q-LEACH as shown in the Figure 4.

Table 1. Simulation parameters

Number of sink	1
Number of nodes	200
Topography of X-axis	2100 m
Topography of Y-axis	1700 m
Initial energy assign	100 J
Protocol	CAERP and Q LEACH
End of simulation time	50 mins

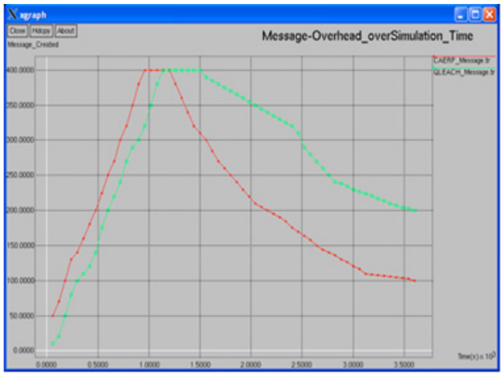

Figure 4. Message overhead versus time.

Each sensor node should effectively handle its energy in order to keep the WSN at its operational state. In each time duration Q-leach is consume more energy than the CAERP. The efficient wireless sensor protocol should be reducing the dead node problems. In CAERP protocol mainly focused for utilizing the energy in efficient way. We note that the protocol CAERP extended significantly the network lifetime compared to Q-LEACH as shown in the Figure 5. This improvement is accomplished because the nodes remain alive due to the efficient way of cluster arrangement.

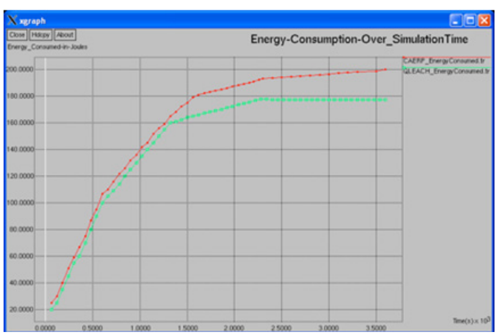

Figure 5. Energy consumption versus time.

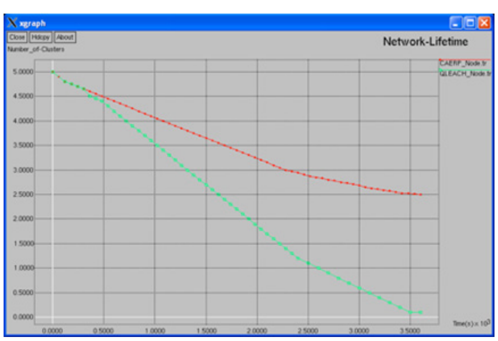

Figure 6. Number of clusters versus time.

In CAERP have mainly five cluster Head so each cycle the cluster Head varying based on the CAERP CH selection algorithm. Due to efficient CH selection algorithm the CAERP have high network life time compared to Q-LEACH as shown in the Figure 6.

5. Conclusion and Future Work

In this paper, a cluster arrangement energy efficient routing protocol has been proposed. The performance of the proposed protocol is compared with that of Q-LEACH using different parameters with the help of NS-2 simulator. The simulation results show that compared with Q-LEACH, our protocol has significantly improved in average energy consumption and survival rate, and extended the network life cycle that improves the energy efficiency of the CAERP network is improved.

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