EEHCCP: An Energy-Efficient Hybrid Clustering Communication Protocol for Wireless Sensor Network

Rohit Pachlor(✉) and Deepti Shrimankar

Department of Computer Science and Engineering, Visvesvaraya National Institute of Technology, Nagpur, India
`rohit.pachlor@gmail.com`

Abstract. Depending upon the application type, wireless sensor network has to work for months to years with a finite energy source. During this time, sensor nodes sense useful information from their surrounding and transmit it to the Base Station. Due to the sensor's finite energy source, accumulation and transmission of sensed information in an energy efficient manner is very significant. Therefore, energy efficient communication protocols are a major research concern in a wireless sensor network to prolong the network lifetime. This paper presents an Energy-Efficient Hybrid Clustering Communication Protocol (EEHCCP). It is an improved LEACH protocol. It evenly distribute the energy load among all the sensor nodes. It uses a novel parameter average cluster-member energy ($ACME$) to delay the re-clustering time. The experimental results show the effectiveness of the proposed protocol over prominent Low Energy Adaptive Clustering Hierarchy (LEACH) and its descendant protocols in terms of network lifetime and energy consumption.

Keywords: Clustering · Network lifetime · Data aggregation
Energy efficient routing · Scalability · Communication protocols
Wireless Sensor Network

1 Introduction

Wireless Sensor Network (WSN) consist of hundreds to thousands of sensors (nodes) deployed over a target area for environment monitoring or event tracking. The job of nodes is to gather the information about the events occurring in their close surrounding, and periodically communicate it to the Base Station (BS) for further processing [1]. The nodes are energy constrained and possibly deployed in such a manner that the replacement of the energy source is not possible always. Therefore, it is utmost important for a node to efficiently utilize its energy so as not to quickly run out of energy and hence prolongs the network's lifetime. Network lifetime is the time elapsed until the last node (or the first node or prefix percentage of nodes) in the network run out of its energy (dies) [2].

The simplest technique to reduce energy consumption during transmission is to send packets in a multi-hop fashion rather than single-hop to the BS [3].

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In the literature clustering based [4–7], chain based [8,9] and tree based [10,11] techniques are discussed to achieve multi-hop communication. In a cluster-based network, fixed percentage of sensor nodes are elected as leader called the cluster head (CH) based on a preset CH selection criteria. CH serves as a BS for cluster members and transmits the aggregated data to the actual BS [4]. Rest of the sensor nodes join one of the CHs based on a preset cluster joining criteria. Each cluster member periodically sends its data to the cluster head, which in turn aggregates the received data before transmitting it to the BS.

The rest of the paper is organized as follows: Sect. 2 describes LEACH and its descendant protocols. Section 3, introduces the proposed EEHCCP protocol. Section 4, presents the performance evaluation of EEHCCP. And finally, Sect. 5 concludes the findings.

2 LEACH and Its Descendant Protocols

LEACH [4] is the most renowned cluster-based communication protocol for WSN. LEACH uses a randomized rotation of cluster heads to evenly distribute the energy load among nodes in the network. The election of cluster head is based on the number of times the node has served as a cluster head and the desired number of cluster heads, determined apriori, for the network. LEACH divides the communication process into rounds. Each round is composed of setup phase and steady-state phase. In the setup phase, each node independently selects a random number between 0 and 1 and if the chosen number is less than a threshold (T) given by Eq. 1, then, the node selects itself as a cluster head for current round.

$$T(n) = \begin{cases} \frac{p}{1-p*(r mod p^{-1})} & \forall n \in G \\ 0 & \forall n \notin G \end{cases} \tag{1}$$

Where n is a random number between 0 and 1. p is the desired percentage of cluster heads. G is the set of nodes that weren't the cluster heads in the last $1/p$ rounds.

Each cluster head, then, broadcasts an advertisement message to share their status with other sensor nodes. Each node chooses a cluster to which they belong by choosing a cluster head that requires least communication energy. The decision is based on received signal strength of the advertisement message. The one with the largest received signal strength is the cluster head that can be reached using least communication energy. After cluster formation, head of each cluster creates a TDMA schedule for associated cluster members and broadcasts it back to them. In the steady-state phase, each cluster member node transmits its sense data to the corresponding cluster head in their allocated transmission slot and turns off the radio components for rest of the time to reduce the energy dissipation. Once cluster heads receive the data from associated cluster members, they perform aggregation on it before transmitting it to the BS.

LEACH-C [5] is the centralized version of LEACH. The only difference lies in the fact that LEACH-C uses the BS to decide the cluster heads for each round. In the beginning of each round, all nodes send their IDs, location information, and energy status to the BS. The BS then analyzes the received data and selects energy-rich nodes as cluster heads to form optimal clusters using the simulated annealing algorithm. LEACH-F [6] is also the centralized version of LEACH. The only difference lies in the fact that LEACH-F uses Static clusters. The clusters formed in the first round are static and used throughout the network lifetime. In each cluster, the role of cluster head rotates among the associated cluster members.

VCH (Vice cluster head) [12,13] is very much identical to LEACH but it delays the re-clustering time by prolonging the steady-state phase duration. In VCH [13], clusters are static for two consecutive rounds and re-clustering occurs at the end of every second round. In steady-state phase, the current cluster head selects a VCH among cluster members and thus, reduces the clustering setup overhead for next one round.

LEACH and LEACH-C have no control over the clustering frequency. The setup phase is an overhead over the actual transmission of sensed data. Performing clustering in each communication round increases this overhead. LEACH-C suffers from high energy dissipation of nodes due to long distance because at the beginning of each round, each node sends its ID, location, and energy information to the BS. In LEACH-F, clusters are static and only the cluster heads are rotated according to the rotation order given by the BS. Therefore, it may happen that a new cluster head for the next round is located far away from a member node compared to other cluster heads. Consequently, the node has to use the large communication energy cluster head when there is another clusters cluster head nearby.

In this paper we extend the concept of VCH protocol and use a novel average cluster-member energy ($ACME$) parameter to increase the number of rounds that uses the same clusters. Therefore, it delays the re-clustering time to save the setup phase overhead cost.

3 Energy-Efficient Hybrid Clustering Communication Protocol (EEHCCP)

EEHCCP divides the communication process into several rounds. Each round composed of setup and steady-state phase. In each round, EEHCCP rotates cluster heads based on the residual energy of the nodes. EEHCCP incorporates both static and dynamic formation of clusters and selects either of these methods based upon a user control parameter average cluster-member energy ($ACME$). In the very first round of EEHCCP, each node sends its ID, location, and energy information to the BS station. The BS then selects the desired number of cluster heads, determined apriori, and their associated cluster members. The CH selection is based on the location and energy status of all the nodes. The BS, first, divides the network into k-cluster using k-mean clustering, where k, is equal to the desired number of cluster heads. The BS then finds the highest residual energy node for each cluster and appoints them for the job of cluster heads. At last, the BS forgets the cluster formed using k-mean clustering and then, performs re-clustering for chosen cluster heads and determines cluster members for each cluster head using minimum distance criterion so as to minimize the within-cluster sum of squares. The k-mean clustering is used just to find initial cluster heads and not the initial clusters. The k-mean ensures good distribution of cluster heads. After the formation of initial clusters, the BS calculates the $ACME$ and set $ACME$ threshold ($ACME_{th}$) using Eqs. 2 and 3. The $ACME$ parameter decides when to form new clusters: if $ACME$ is below $ACME_{th}$ then new clusters are formed by passing remaining energy status of nodes to the BS. Otherwise, the clusters are static and used for subsequents rounds with new CHs.

$$ACME = \frac{\sum_{i=1}^{K} E(i)_{remE}}{K} \quad \forall i \in C_m \tag{2}$$

$$ACME_{th} = \frac{ACME * P}{100} \tag{3}$$

Where $E(i)_{remE}$ is the residual energy of node i belongs to m^{th} cluster. K is the total number of cluster members in m^{th} cluster. P is the user control parameter varies from 0 to 100.

The BS then broadcasts a message in the network which includes (cluster head) CH's ID for each node, $ACME_{th}$ for each cluster and the TDMA schedule for each cluster. Upon receiving the message each node compares its own ID with the CH's IDs part of the broadcast message to find its role in the cluster. If the CH's ID matches the node's ID, the node becomes the CH and reads the $ACME_{th}$ for its cluster, otherwise, it reads its TDMA slot and goes into sleep mode, to save its energy, till its slot comes. In the data transmission phase, each node sends its data to corresponding CH in its respective TDMA slot. Once the CH receives data from all cluster members, it aggregates the data and sends it to the BS. After the data transmission, each cluster member sends its current energy status to the corresponding CH. The CH of each cluster then calculates the $ACME$ and selects the cluster head for next round using following rules:

1. If the $ACME$ is above the $ACME_{th}$, for all clusters, then the current CH of each cluster selects new CH for the next round from the associated cluster members based on the residual energy such that
   (a) The residual energy of new CH must be greater than current $ACME$ and residual energy of others CMs of the cluster.
2. If no such node is found or the $ACME$ is below the $ACME_{th}$ of any cluster then call for re-clustering.

3. The cluster head whose $ACME$ is below its $ACME_{th}$ broadcast a re-clustering message in the network.
   (a) Each node then sends the same information to the BS as the one sent in the first round.
   (b) BS forms the new clusters and cluster heads as the one formed in the first round.

   After the selection of new CH, the current cluster head of each cluster waits for the re-clustering message. If no such message occurs then the current CH informs all cluster members about the new CH, new TDMA schedule for the next round, and becomes the normal node of the cluster. After this, steady-state phase takes place in order to complete data transmission process.

4 Performance Evaluation

This section presents the performance evaluation of the proposed EEHCCP protocol to show its effectiveness in terms of network lifetime and average energy consumption per round. The performance of EEHCCP has been evaluated using MATLAB simulation and compared with prominent LEACH [4] and its decedent protocols namely, LEACH-C [5], LEACH-F [7], VCH [12]. The BS is located at (50,175) in a 100∗100 m field. The value of network parameters during simulation is specified in Table 1.

Table 1. Network model parameters

Network parameter	Value
Network area	100*100 m^2
Total numbers of nodes (n)	100
CH percentage (p)	0.05
Initial energy of nodes (E_{init})	0.5 J
P (to set ACM_{th})	80
Coefficient for free-space fading (ξ_{fs})	10 pJ/bit/m^2
Coefficient for multi-path fading (ξ_{mp})	0.0013 pJ/bit/m^2
Data packet size	6400 bits
Control packet size	200 bits
Idle state energy ($E_{T,X} = E_{R,X}$)	50 nJ/bit
Data aggregation energy	5 nJ/bit

We ran the simulations to determine the number of rounds of communication when 1%, 10%, 25%, and 50% of the nodes are dead using LEACH, LEACH-C, LEACH-F, VCH and EEHCCP with each node having the same initial energy.

Once the energy of a node goes below zero it is considered dead for the rest of the simulation. Our simulation results, as shown in Fig. 1, show that EEHCCP achieves:

- Approximately 2.2× the number of rounds compared to LEACH when 1%, 10%, 25%, and 50% of the nodes dead.
- Approximately 1.5× the number of rounds compared to LEACH-F when 1%, 10%, 25% and 50% of the nodes dead.
- Approximately 1.3× the number of rounds compared to LEACH-C when 1%, 10%, 25% and 50% of the nodes dead.
- Approximately 1.05× the number of rounds compared to VCH when 1%, 10%, 25% and 50% of the nodes dead.

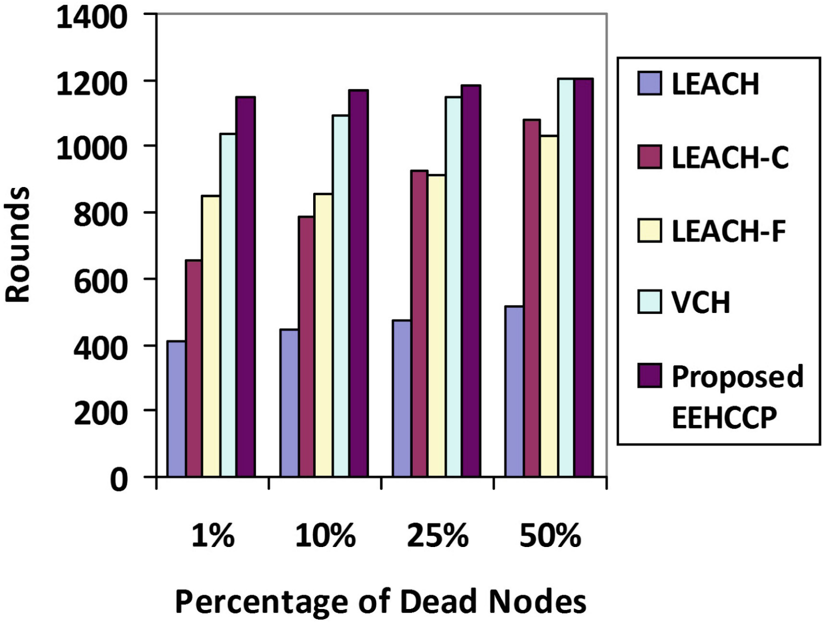

Fig. 1. Network's lifetime

Table 2 shows the number of rounds when 1%, 10%, 25%, and 50% of the nodes dead for different values of P:

Figure 2 shows the number of nodes alive over simulation rounds. The simulation results demonstrate that numbers of active nodes after 1200 rounds are 81, in

Table 2. Performance of EEHCCP for different values of P

P	1%	10%	25%	50%
10	1100	1133	1162	1209
30	1089	1139	1171	1215
50	1099	1145	1169	1214
70	1139	1160	1177	1206
90	1156	1171	1180	1188

EEHCCP protocol, but in the cases of LEACH, LEACH-C, LEACH-F, and VCH, the number of active nodes are 0, 46, 24, and 68 respectively. Figure 3 shows Energy consumption over simulation rounds. The simulation results demonstrate that the energy usages till 700 simulation round are 99.9800%, 60.5197%, 66.7439, 56.3459%, and 55.2500% of the total energy for LEACH, LEACH-C, LEACH-F, VCH, and EEHCCP respectively.

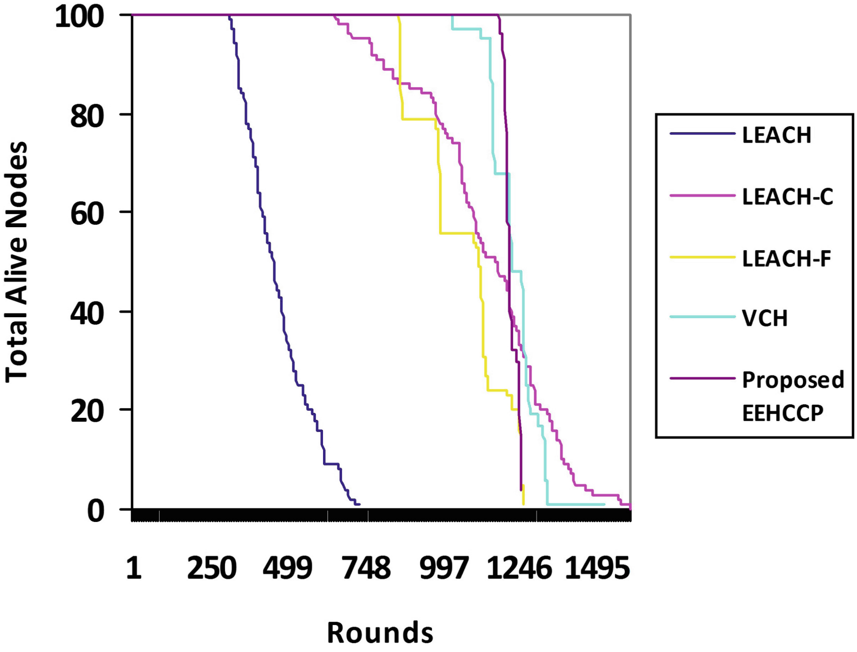

Fig. 2. Number of nodes alive over simulation rounds.

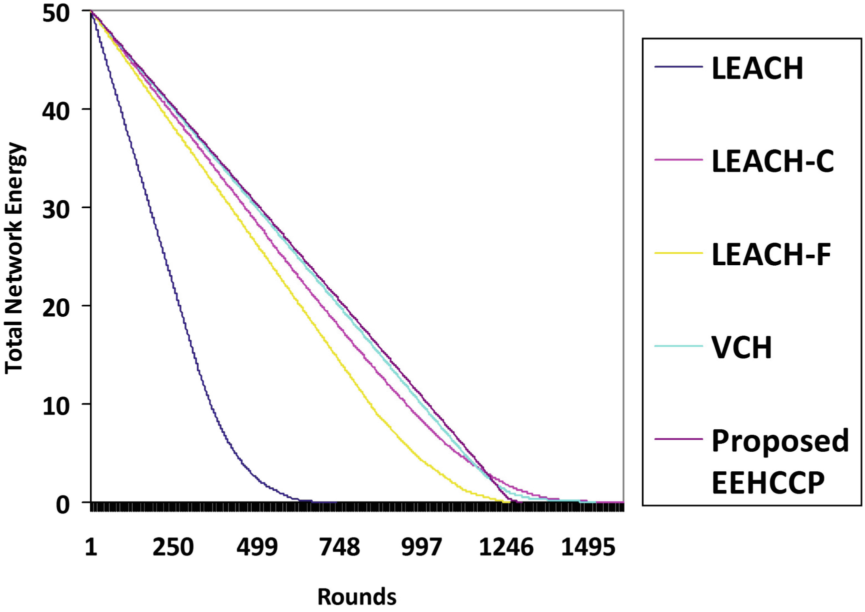

Fig. 3. Energy consumption over simulation rounds.

5 Conclusions

In this paper, we present EEHCCP, a self-organizing protocol which uses static as well as dynamic clusters to evenly distribute the energy load among all nodes to essentially balance the energy consumption on long distances within and outside the cluster. EEHCCP uses k-mean clustering to find well-distributed CHs. EEHCCP uses these CHs to find initial clusters and uses these clusters for communication purpose with a new cluster head for each communication round until their $ACME$ goes below a threshold thus, delays the re-clustering time. As soon as the $ACME$ goes below a threshold for any of the clusters the new cluster heads are selected once again using k-mean.

Our simulation results show that the EEHCCP outperforms LEACH, LEACH-C, LEACH-F and VCH.

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