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LEACH–V: A Solution for Intra-Cluster Cooperative Communication in Wireless Sensor Network

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Abstract

Objectives: A Wireless Sensor Network (WSN) plays an important role in the future wireless communication domain because of its properties, which includes intelligence, cheaper and smaller in size. With the wireless interfaces, these can communicate with each other in case of cooperative communication in a single or multiple networks. **Methods/Statistical Analysis:** As multiple nodes are required for cooperative communication, the Low Energy Adaptive Clustery Hierarchy (LEACH) Protocol is used for cluster formation. Further Vector Quantization (VQ) is used for analysis of low energy path for the nodes and clusters respectively. **Findings:** The main issue of inter-cluster node communication is carried out in earlier work using LEACH protocol. The proposed technique illustrates the LEACH-Vector Quantization (LEACH-V) protocol for intra-cluster communication in a cooperative communication network. **Application/Improvements:** As per the application point of view, LEACH-V performs the lowest energy path for intra-cluster communication. LEACH provides the optimum cluster size and their Cluster Head and using VQ, the minimum distance is calculated using Euclidean distance between the multiple cluster heads which creates the shortest path results in energy efficient technique. Further, the spectral distortion of the proposed technique has been analyzed for practical implementation.

Keywords: Cooperative Communication, Energy Efficient, LEACH, Vector Quantization, Wireless Sensor Network

1. Introduction

One of the subsets of Ad-hoc network[1] is Wireless Sensor Network (WSN). It especially consists of distributed autonomous sensors. A WSN system consists of sink node, sensor node and management node. Sensor nodes are located in monitored area, originating a network through the access of self-organizing mechanism. Sensor nodes transmit the monitored data through other nodes one after another[2]. The monitored data will be routed through various intermediary hops and will be passed to sink node. Then the sink node further passes the data to the management node. The storage capacities of the nodes in WSN along with the processing speed are limited. Sensor network creates a connection between real and computational world. A good network protocols have some properties, like,

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- Ease of Deployment, i.e. nodes is communicated in the absence of the network.
- Lifetime, this means networks are very much energy efficient.
- Latency, which means nodes and base station, communicates each other timely.
- The Quality of Service (QoS), all data are does not require the end users. So one of the major issues in QoS is data aggregation.

Wireless Sensor Network (WSN) has important application like remote environmental monitoring and target tracking. These sensors are highly energy constrained due to their limited battery, storage, processing power and communication capacity. By enhancing the sensor node lifetime we can reduce the power consumption and the energy efficiency is maintained, so that the data is delivered within the reasonable time. Clustering routing is basically used for information accumulation mechanism. In this process cluster heads reduce the data transmission and thus significantly save the energy. "LEACH" (Low Energy Adaptive Clustering Hierarchy)[3] adapts the dynamic clustering approach and thus complies its greater efficiencies in WSN. This is a first protocol of hierarchical routing which proposed data fusion. It is a self-adaptive and self-organised. In WSN LEACH was proposed as a single-hop clustering routing protocol[4]. Many clustering algorithm are composed based on the LEACH, like "PEGASIS" (Power Efficient Gathering in Sensor Information System), "HEED" (Hybrid Energy-Efficient Distributed Clustering) and "TEEN" (Threshold Sensitive Energy Efficient Sensor Network Protocol) etc[4–7]. In clustering technique cluster members directly cannot transmit collected data. In the beginning the Cluster Head is created. Then the data from the Cluster Head is transmitted to the base station directly or via multi-hop transmission. This Cluster Head are responsible for communicating to the cluster members. So, Cluster Head receives more packet data and utilized more energy forwarded data for a long range. The major disadvantage of LEACH is it assumes homogeneous distribution[8] of the sensor nodes for selected area. LEACH can increased the network lifetime by about 15% larger than the simulation results of multi-hop and slicing algorithm[9]. Vector Quantization (VQ) is a quantization technique that allows the modelling of probability density functions by the distribution of prototype vectors. It was generally used for data compression. The Vector Quantization algorithm is used and for reducing the transmission bit rate, density estimation and clustering. The proposed work illustrates the combination of LEACH and Vector Quantization (VQ) which results in a least and energy efficient path for intra-cluster cooperative communication. The rest of the paper is organised a follows: LEACH protocol overview for finding optimum clusters and their respective cluster head. Next section elaborates VQ, where the minimum distance between the cluster heads are found for cooperative communication. Finally the conclusion and future work is discussed regarding the proposed method for WSN.

2. LEACH Overview

LEACH is an energy conserving hierarchical routing protocol. It was suggested by[8]. The whole LEACH networks are divided into several clusters. The networks are broken into the several rounds in the run time. In every round, a Cluster Head is created according to their predefine criteria. All sensor nodes have same probability to make a cluster head. For that reason, energy consumption is balanced as well as network lifetime increases. LEACH has come with some changes in the family of proactive network protocols. To design a LEACH protocols have some techniques like:

- Randomized and self-configurability.
- Data aggregation.
- Local control on data transmission[10].

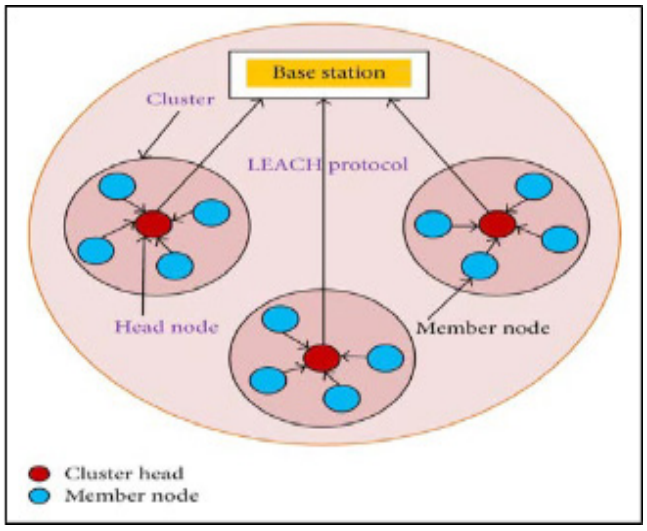

Figure 1. Schematic structure of the LEACH protocol[4].

Figure 1 shows that every cluster has various numbers of nodes. In each cluster we have one node which acts as the head node and other remaining nodes are referred as member nodes where the different member nodes in each cluster are connected to the head node. Also all the head nodes from all the various clusters are in turn connected to the base station. LEACH protocol[11,12] takes round as unit and each round is created by two stages. One is cluster setup stage and another is steady state stage. It is used for decreasing energy costs. Steady state stage should be greater than setup stage. Cluster Head initiates TDMA scheme for the nodes inside the cluster which enables radio components. This process is turned off always except at their transmit time. This process will occur for the non-Cluster Head nodes. This procedure is shown in Figure 2.

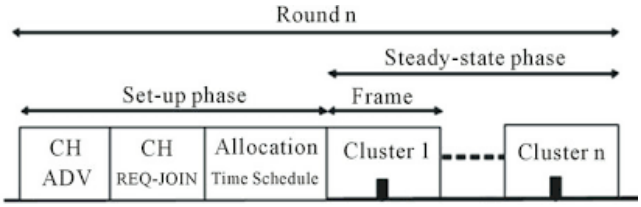

Figure 2. Timeline showing operation of LEACH[4].

Each node n is generated a random number between 0 to1, compared its predefined values of threshold, i.e. *t (n).t (n)* is greater than *n*, the Cluster Head (CH) is created in the round, otherwise it acts as a common node[8]. *t (n)* is obtained from the below Equation[11]:

$$t(n) = \begin{cases} \dfrac{p}{1 - p * \left(r \bmod \dfrac{1}{p}\right)} & if\ n \in G \\ 0 & if\ n \notin G \end{cases} \quad (1)$$

In Equation (1), *p* denotes the percent of Cluster Head (CH) nodes are in the selected path, *r* represents for number which is selected by the round. *G* is a set of nodes which yet not been head nodes selected in a first *1/p* rounds. The Cluster Heads are selected in randomly manner. The analysis is like that, every node act as Cluster Head (CH) with probability *p* when the round starts, which act as a head nodes in one round that will not be act as head node in the next *1/p* rounds, because the number of the head nodes will reduce, for these remain nodes act as head nodes that probability is increased. After (*1/p-1*) rounds, all nodes which yet haven't been selected as head nodes that probability is 1, when the *1/p* rounds over, all nodes will back to the same position.

When Cluster Heads were formed, then nodes send messages to other nodes to inform the status of the nodes. Then the non Cluster Head nodes participate in communicating the data and calculate the received signal strength. Thereafter the respective Cluster Heads are decided and accordingly communicated. Then these Cluster Heads generates schedules and sends to all nodes in clusters. For remaining part, the nodes send the data to respective head nodes. Then all the head nodes communicate to the base station.

After every process, Cluster Heads are reconstructed to form new clusters. Cluster Head circulation is allowed to network to equally distribute the energy between sensor nodes; therefore it can increase network life time[13,14].

2.1 Issues with LEACH

- LEACH is a homogeneous distribution of sensor nodes in given area. LEACH's cluster creation algorithm[15,16] will end by assigning more cluster member nodes. Due to this, the Cluster Heads loses continuous energy.
- LEACH can govern lower information overhead[17,18], but it cannot ensure that CH distribution is uniformed. Thus resulting in the division of entire network into the cluster and imbalance CH which makes network lifetime limited.
- LEACH assumes the nodes are isomorphic and also energy capacity is uniform for every round selection. This is an impractical in the application purpose.
- CH transfers their data to sink node by a single hop link. This single hop transmission is quite costly when CH is far away from the sink.
- LEACH[18] considers all sensor nodes have enough power to connect the sink node, it is necessary if nodes are might be resistant.

3. VQ Overview

Vector Quantization is the powerful quantization technique which is used for image compression. This technique[19,20] is used for decreasing the transmission data rate or storage has been broadly studied for image signals and speech signals and one of the cooperative communication technique has been used as power saving algorithm[21]. VQ has four stages: Vector formation, training set selection, codebook generation and quantization. The first step is that the input image is divided into the set of vectors. Then choose the subset of vectors as a training sequence. Then the code words are getting by a fixed clustering algorithm. At last, closest code words are determined by quantizing the input vector from the codebook and equivalent label of the codeword is transmitted. The data compression process is achieved in this manner.

Compression amount: Codebook size and dimension of vector is K and L respectively. It's informed to the decoder of which vector is chosen, we need to use $[log_2 K]$ bits. Each vector holds the improvement the value of L, $log_2 K / L$ is the bits per sample.

4. Proposed Methodology

As we have discussed the cluster formation is achieved through the LEACH protocol. It will be quite helpful in cooperative communications. We also propose to use the Vector Quantization methodology. The Vector Quantization methodology adapts the shortest distance as it is major and thus effective in communication by using the energy comparatively. So combining the above two mechanism our proposed method "LEACH-V" (LEACH-Vector Quantization) to be implemented in a co-operative network. Figure 3 illustrates the overview of the proposed LEACH-V protocol. Initially for WSN, an area dimension has been set with a fixed number of nodes. The various participating nodes are assumed to be randomly distributed working with two different unlicensed frequencies. Here we have implemented LEACH by setting a threshold for CH for formation of cluster vector. After formation of clusters and their respective CH, VQ is implemented for analysing the minimum distance between the CHs.

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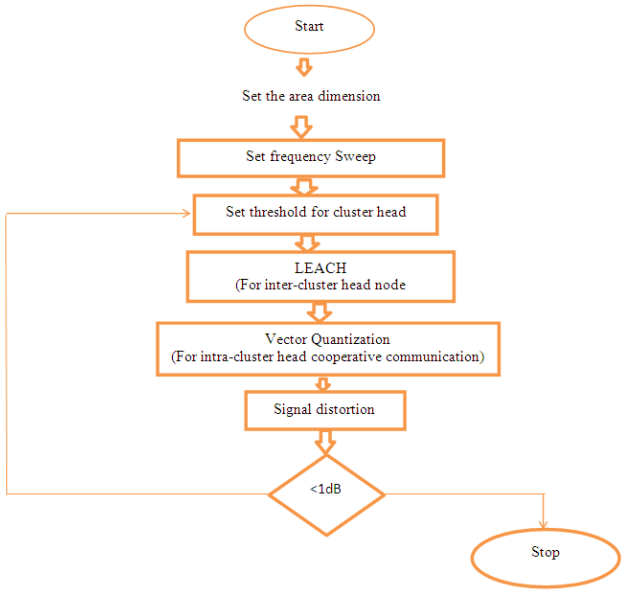

Figure 3. Algorithm of LEACH-V method.

5. Analysing Spectral Distortion of LEACH-V

In the LEACH algorithm we create the Cluster Head. When multiple Cluster Heads wants to communicate then with the help of Vector Quantization method found the shortage path (Euclidean distance). In this process we consume the power.

The major objective is to compute the distortion between unquantized frequency and quantized frequency outputs; this process is known as spectral distortion. It is used in especially for narrow band coding of speech signal. For i^{th} position spectral distortion (in dB), SDi is shown by the following Equation (2).

$$SD_i = \sqrt{\frac{1}{(f2 - f1)} \int_{f1}^{f2} \left[10 \log_{10} Si(f) - 10 \log_{10} \widehat{Si}(f)\right] df \ (dB)} \quad (2)$$

Where Si (f) and $\widehat{S}_i$ (f) are the Linear Predictive Coding (LPC) which is the power spectra of unquantized frequency and quantized frequency i^{th} position respectively. 'f' is the frequency, which unit is in Hz. The range of the frequency is f1 and f2. Spectral distortion SD is the mean. It is obtained by the following Equation (3):

$$SD = \frac{1}{N} \sum_{i=1}^{N} SD_i \quad (3)$$

Assuming, maximum probability of selecting higher frequency Cluster Head is 1 and lower frequency vale is zero, $\left[10\log_{10} Si(f) - 10\log_{10} \widehat{Si}(f)\right] = t(n)$ and $p = p(f2) - p(f1)$. Therefore,

$$\left[10\log_{10} Si(f) - 10\log_{10} \widehat{Si}(f)\right] = \frac{p(f2) - p(f1)}{1 - \left[(p(f2) - p(f1)) * \left(r \bmod \frac{1}{p(f2) - p(f1)}\right)\right]} \quad (4)$$

$$SDi = \sqrt{\frac{1}{(f2 - f1)} \frac{p(f2) - p(f1)}{1 - \left[(p(f2) - p(f1)) * \left(r \bmod \frac{1}{p(f2) - p(f1)}\right)\right]}}$$

Assuming, f1 = 3.36 GHz, f2 = 3.56 GHz, for, i = 1 and the maximum probability of selectivity high frequency CH p(f2) = 0.5, p(f1) = 0.1, spectral distortion becomes:

$SD_1 =$ 0.001414214

Similarly, for i = 2, assuming, p(f2) = 1, p(f1) = 0, SD_2 = 0.0022360.

Thus in general, the SD is calculated for all the frequencies of the nodes and shown in Table 1.

As shown in Figure 4, LEACH is been implemented based on 5 set of cluster vector. Corresponding CHs are highlighted in black colour. For simulation purpose, we have assumed 10.000 active nodes which are spread over a distance of 10 X 10 units (Km).

Table 1. Spectral distortion for all probable frequencies

$p(f_1)$	$P(f_2)$	SD_iSD_i	$p(f_1)$	$P(f_2)$	SD_iSD_i
0	1	0.0022360	0.4	0.7	0.0015
0.1	0.2	0.0022360		0.8	0.001414214
	0.3	0.001		0.9	0.0025
	0.4	0.0015	0.5	0.6	0.0022360
	0.5	0.001414214		0.7	0.001
	0.6	0.0025		0.8	0.0015
0.2	0.3	0.0022360		0.9	0.001414214
	0.4	0.001		1.0	0.0025
	0.5	0.0015	0.6	0.7	0.0022360
	0.6	0.001414214		0.8	0.001
	0.7	0.0025		0.9	0.0015
0.3	0.4	0.0022360		1.0	0.001414214
	0.5	0.001	0.7	0.8	0.0022360
	0.6	0.0015		0.9	0.001
	0.7	0.001414214		1.0	0.0015
	0.8	0.0025	0.8	0.9	0.0022360
0.4	0.5	0.0022360		1.0	0.001
	0.6	0.001	0.9	1.0	0.0022360

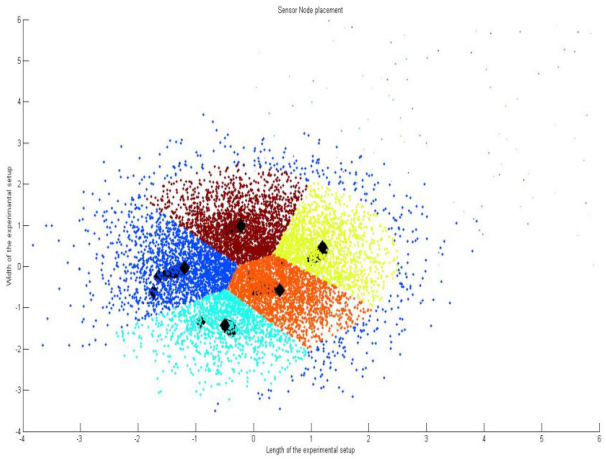

Figure 4. LEACH implementation for CH (inter-cluster communication).

As shown in Figure 5, as the probability of CHs communication is increasing, the energy is getting decreased as well as the spectral distortion approaches towards 1 dB. This shows the less usage of energy for multiple Cluster Head communication. In earlier research, the intra cluster communication has been taken into account but the authors have assumed the cluster vectors are adjacent, which may not be the practical case.

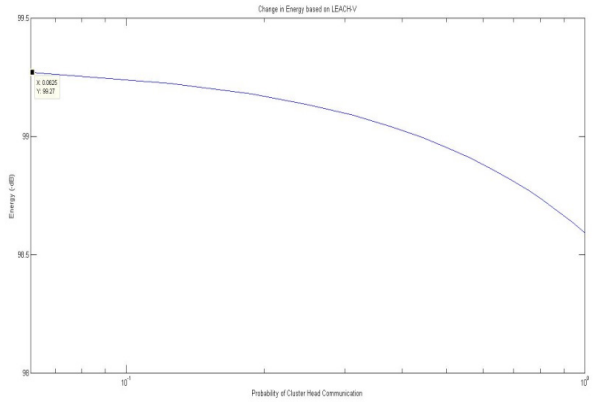

Figure 5. Probability of Cluster Head communication based on LEACH-V.

As shown in Figure 6, as the numbers of clusters are increasing, the energy consumption is decreasing based on the proposed technique.

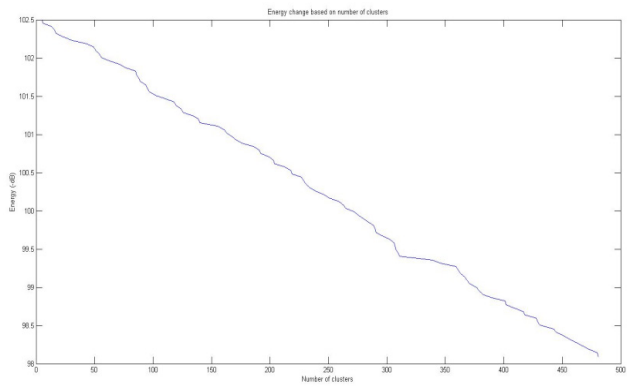

Figure 6. Number of clusters impact on energy consumption.

6. Conclusion

The proposed technique extends the LEACH protocol to LEACH VQ protocol (LEACH-V) for intra-cluster communication, in a co-operative communication network which performs the lowest energy path. Here, LEACH provides the optimum cluster size whereas by using VQ the minimum distance is calculated between multiple Cluster Head. As a result, it creates a shortest path result in energy efficient technique.

As discussed, the LEACH-V technique shows substantial power saving in case on cooperative communication in WSN. In our study, we have assumed 4 vectors, 10,000 nodes, 10 channels and 100 square kilometers. The simulations are performed based on scaling of area as 100 m^2 equivalent with 100 Km^2. The mathematical analysis shows the spectral distortion less than 1 dB, which concludes efficient cooperative communication. The work can further be extended by considering the selective node approach among the active nodes.

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