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ENERGY EFFICIENT AND CONNECTIVITY BASED CLUSTERING SCHEME FOR MULTICAST ROUTING IN WIRELESS SENSOR NETWORKS

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ABSTRACT

Wireless sensor networks s(WSNs) are the key technology for monitoring and communicating with the physical environment. Data aggregation is the key challenge to make energy constraints of sensor node to increase network life time. Since sensor nodes are densely deployed, redundant data may occur. Clustering the network provides effective solution for such issues and is an important way of managing large number of sensor nodes. We proposed a new Energy Efficient and Connectivity based Clustering scheme for multicast routing in wireless sensor networks named as E2C4. In E2C4, the cluster heads are elected by a probability based on the ratio between ensemble energy consumption of each node and the average energy of the network. The cluster-heads' period will be different according to their initial and consumption energy rate. The nodes with high initial energy and less energy consumption rate will have more chances to be the cluster-heads than the nodes with low initial energy and high energy consumption. In the conclusion, the experimental result shows that E2C4 achieves longer lifetime and more effective messages than current important clustering protocols like LEACH and HEED

Keywords: *Clustering algorithm, Data aggregation, Efficient energy consumption, Multicast routing, Wireless sensor networks*

1. INTRODUCTION

Recent advances in miniaturization and low-power design have led to the development of small-sized battery-operated sensors with limited on-board signal processing and wireless communication capacities. WSNs become increasingly useful in various critical applications including ecological monitoring, smart offices, homes, Warfield surveillance, and transportation traffic monitoring. In order to achieve high quality and fault-tolerant capability, a sensor network composed of hundreds or thousands of unattended sensor nodes, which are often randomly deployed inside the interested area [1].Since WSNs is usually exposed to dynamic and unattended in harsh environments, it is possible to loss of connectivity of individual nodes. Conventional centralized algorithms need to operate with global knowledge of the total network and transmission failure of a critical node that cause a severe protocol failure. On the contrary, distributed algorithms are only executed locally within partial nodes, thus can prevent the failure caused by a single node. It is realized that localized algorithms are more scalable and robust than centralized algorithms. As each sensor node is tightly power-constrained and one-off, the lifetime of WSNs is limited. In order to prolong the network lifetime, energy-efficient protocols should be designed for the characteristic of WSNs. Sensor nodes are organizing into clusters which reducing energy consumption [2]. Many energy-efficient routing protocols are designed based on the clustering structure [3]. The clustering technique can also used to perform data aggregation [4], which combines the data from source nodes into a small set of meaningful information. Under the condition of achieving sufficient data rate specified by applications, the fewer messages are transmitted, the more energy is saved. Localized algorithms can efficiently operate within clusters and need not to wait for control messages propagating across the whole network. Therefore localized algorithms bring better scalability to large networks than centralized algorithms, which are executed in global structure. Clustering technique

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can be extremely successful in multicast and data query [5-8][15]. Cluster-heads are collecting the interested data within their own clusters and minimize the broadcast control messages among the nodes. The performance of the novel energy saving clustering algorithms for WSNs was studied and evaluated. Each node can transmit sensing data to the base station through a cluster-head. The cluster-heads are elected periodically by clustering algorithms, aggregate the data of their cluster members and send it to the base station. All the nodes of the sensor network are equipped with different amount of energy [9]. Following the views of LEACH, the proposed E2C4 allows each node expend energy uniformly by rotating the cluster-head role among all nodes. The cluster-heads are selected by a probability based on the ratio between ensemble energy consumption of each node and the average energy of the network. The number of round the rotating period of each node is varied according to its initial and consumption energy rate. The nodes with high initial and less energy consumption rate have more chances to be the cluster-heads than the nodes with low initial energy and high energy consumption that led to prolong the network lifetime and make stable networks Simulation shows that E2C4 achieves longer network lifetime and more effective data aggregation than other classical clustering algorithms.

The remainder of the paper is organized as follows. Section2 review the related work. Section3 describes the proposed solution. Section 4 shows the performance of E2C4 by simulations and compares it with LEACH and HEED. Finally, Section 5 gives concluding remarks.

2. LITERATURE REVIEW

In general, two kinds of clustering schemes are applied in homogeneous networks are called homogeneous schemes, and the clustering algorithms applied in heterogeneous networks are referred to as heterogeneous clustering schemes. It is difficult to devise an energy efficient heterogeneous clustering scheme due to the complicated energy configure and network operation. Thus most of the classical clustering algorithms are categorized such as LEACH [10], PEGASIS [11], TEEN [12], APTEEN [13], SEP [14] and HEED [15].

W. R. Heinzelman, A. P. Chandrakasan and H. Balakrishnan [10] proposed Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. It is one of the most popular hierarchical routing algorithms for sensor networks. The idea is to form clusters of the sensor nodes based on the received signal strength and use local cluster heads as routers to transmit the data to sink. This save energy since the transmissions will only be done by such cluster heads rather than all sensor nodes. Optimal number of cluster heads is estimated to be 5% of the total number of nodes.

S. Lindsey and C. Raghavendra [11] introduced Power Efficient Gathering in Sensor Information Systems (PEGASIS) protocol. It is an improved version of LEACH. Instead of forming clusters, it is based on forming chains of sensor nodes. One node is responsible for routing the aggregated data to the sink. Each node aggregates the collected data with its own , and then passes the same to the next ring. It employs multi hop transmission and selects one node allows to transmit the data. Since the overhead caused by dynamic cluster formation is eliminated, multi hop transmission and data aggregation is employed, PEGASIS outperforms the LEACH. However excessive delay is introduced for large networks and single leader can be a bottleneck.

A. Manjeshwar and D. P. Agarwal [12] proposed Threshold sensitive Energy Efficient sensor Network Protocol (TEEN) protocol. Closer nodes form clusters with separate layers. Cluster heads are allowed to transmit the collected data to one upper layer. Cluster heads are formed based on broadcast two threshold values including hard threshold and soft threshold. Hard threshold is a minimum possible value of an attribute to trigger a sensor node. Hard threshold allows nodes transmit the event, if the event occurs in the range of interest. Therefore a significant reduction of the transmission delay occurs. Unless a change of minimum soft threshold occurs, the node does not send a new data packet. Employing soft threshold prevents from the redundant data transmission. Since the protocol is to be responsive to the sudden changes in the sensed attribute, it is more suitable for time-critical applications.

A. Manjeshwar and D. P. Agarwal [13] proposed Adaptive Threshold sensitive Energy Efficient sensor Network Protocol (APTEEN) protocol. The protocol is an extension of TEEN aiming to capture both time-critical events and periodic data collections. The network architecture is same as TEEN. After forming clusters the cluster heads broadcast attributes, the threshold values,

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and the transmission schedule to all nodes. Cluster heads are also responsible for data aggregation in order to achieve minimal energy consumption it decreases the size data transmitting. According to energy dissipation and network lifetime, TEEN gives better performance than LEACH and APTEEN because of the decreased number of transmissions. The main drawbacks of TEEN and APTEEN are overhead and complexity of forming clusters in multiple levels, implementing threshold-based functions and dealing with attribute based naming of queries.

In 2004, G. Smaragdakis, I. Matta and A. Bestavros [14] proposed Stable Election Protocol (SEP). It is a heterogeneous aware protocol that considered on weighted election probabilities of each node to become cluster head according to their respective energy. This approach ensures that the cluster head election is randomly selected and distributed based on the fraction of energy of each node which make uniform use of the node's energy. They considered the two types of nodes and two level hierarchies.

O. Younis and S. Fahmy described[15] Hybrid Energy Efficient Distributed clustering Protocol (HEED) protocol which extends the basic scheme of LEACH by using residual energy as primary parameter and network topology features like Node degree, distances to neighbors to achieve power balancing. The clustering process is divided into a number of iterations, and in each iterations, nodes which are not covered by any cluster head double their probability of becoming a cluster head. Since these energy-efficient clustering protocols enable every node to independently and probabilistically decide on its role in the clustered network, they cannot guarantee optimal elected set of cluster heads.

3. PROPSED WORK

4.2 Network model and cluster formation algorithm

This section describes the network model and cluster formation. The following assumptions are made to form the clusters; there are N_{nodes} sensor nodes, which are uniformly deployed within a MXM sized region, the nodes always have data to transmit to a base station, which is often far from the sensing area. This kind of sensor network can be used to track or monitor remote environment. Without loss of generality, it assumes that the base station is located at the middle of the MXM sized region. The network is organized into clustering hierarchy, and the cluster-heads execute fusion function to reduce the correlated data produced by the sensor nodes within the clusters. The cluster-heads transmit the aggregated data to the base station directly. To avoid the frequent change of the topology, network model is designed the way that the nodes are micro mobile or stationary as supposed. This network model considers the two types of sensor nodes including superior nodes and normal nodes. The total initial energy of the networks is calculated by Eq.(1)

$$E_{td} = NE_I(1-p) + NpE_I(1+C) = E_I(1+cp) \qquad (1)$$

Where E_{tot} – Total Energy of the network, N_{nodes} - Number of nodes, E_I – Normal node's Initial energy covers the radius R, p – fraction of the superior node, c times more energy than normal nodes, p N superior nodes equipped with initial energy of E_I(1 + c), and (1 - p) N_{nodes} normal nodes equipped with initial energy of E_I. The energy consumption of N_i can be calculated based on the ensemble energy consumption for sensing, processing, communication and coverage estimation per bit transmission to multiple groups. The cluster is formed based on the ensemble energy consumption rate. In multicast routing each packet transmitted by a source to one or more receivers in its neighborhood, the energy is calculated as according to Eq.(2)

$$E_{N_i} = E_S + E_R G + (NC - G)E_D + E_{CC} + E_C \qquad (2)$$

Where E_S and E_R represent the amount of energy required to send and receive packets respectively, G is the group of nodes which should receive the packet, and NC is the total number of cluster neighbors in the transmission range R. ED quantifies the amount of energy required to decode the packet header. E_{CC} denote the energy required for determining the connectivity conscious and E_C is the communication cost of $node_i$. The connectivity awareness can be calculated through the metrics of total packets send to group of receiver and the number of packets received by the destination group. The cost of a link between node S_i and group of receivers R_I to R_G is equal to the energy spent by these nodes to transmit and to receive one data packet successfully. Coverage and connectivity established between two sensors, a proper routing metric is needed which guides to form the reliable connection between the sensors. The connectivity conscious can be calculated using Eq.(3)

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$$E_{CC} = \left[\frac{E_i^{PD}}{\sum_{j=1}^{G} E_S(S_i, R_j) + \sum_{j=1}^{G} E_R(S_i, R_j)} X \frac{1}{R} \right] \quad (3)$$

In this section, ensemble energy consumption and coverage and connectivity aware clustering mechanism was formulated that binds all the nodes operating in a particular region. Each sensor has initial energy $E_I(1+cp)$ with coverage metric R. Sensor consumes energy E_C for communicating with one hop neighbors. Single cluster is formed based on the constraints Eq.(4) to Eq.(7) which are used for finding a subset of the sensors that provides complete coverage of the region. Ensemble energy consumption for communicating with one hop neighbors and maximum power consumption of any node in the network can be limit as follows

$$\sum E_{N_i} \leq E_i \quad (4)$$

$$\sum E_{C_i} \leq E_{tot} \quad (5)$$

Efficient routing metric is used for updating the periodic status of each node automatically when the node leave or join the network. The proposed algorithm has defined the additional clustering metric in equation (6) for the dynamic environment. and also find the best sequence of coverage to maximize the life of the network and minimize the energy consumption.

$$CA \subset \prod_{S_I \varepsilon C_i = 1} J(S_i) \quad (6)$$

Where CA is coverage area, J is energy consumed. A point in an area CA is said to be covered if it lies within the sensing range of at least one sensor. Amount of data to be transmitted between source to a group of clusters have constrained as follows

$$0 \leq D_{RG} \leq D_{Si} \quad (7)$$

Constraint (7) limits the amount of data to be transmitted from the source S_i to group of receiver (D_{RG}) that reduce the energy consumption.

4.2 Proposed Algorithm for Cluster Formation

Input : E_{Ni}, E_{CC}, R, S, R;
Output : C_i;
1: Classifying the sensing range R and deployed location into CA disjoint regions
2: Correlate each sensor with a set of sub regions based on ensemble energy consumption, residual energy and connectivity conscious
3: While all the sensors are not covered do
4: Calculate the efficient sub region as C = min $\sum_{S_i \in C_j} E_{CC}$
5: From the covering region C choose the maximum value of residual energy Ere_i
6: For each sensors in the current coverage do
7: $Ere_i = Ere_i - EN_i$
8: If ($Ere_i < EN_i$) then
9: Drop the sensor from current coverage set
10: End
11: End
12: Update the values of the sub regions and their relationships.
13: End

4.2 Cluster Head Selection

In this network model, all the nodes cannot possess the equal residual energy. The proposed protocol chooses different n_i based on the residual energy E_{re} of nodes Si at round r. Let $p_i=1/n_i$, as average probability to be a cluster-head during n_i rounds. n_i denote the number of rounds to be a cluster-head for the node S_i, and it referred as the rotating period. When nodes have the same amount of energy at each rotating period, choosing the average probability pi to be p_{opt} can ensure that there are p_{opt} N cluster-heads in every round. Nodes with different amounts of energy, pi of the nodes with more energy should be larger than p_{opt} . Let denote the average energy at round r of the network, which can be find out by Cluster-head is selected by average probability average energy at n_i rounds

$$E = \frac{1}{N} \sum_{i=1}^{N} E_{re} \quad (8)$$

This guarantees that the average total number of cluster-heads per round per epoch is equal to Eq.(9)

$$\sum_{1}^{N} p_i = \sum_{1}^{N} p_{opt} \frac{E_{re}}{\bar{E}_{re}} \quad (9)$$

It provides the optimal cluster-head number. The probability threshold of each node S_i used to determine whether itself to become a cluster-head in each round or not. It can be calculated by Eq. (10)

$$T(S_i) = \begin{cases} \dfrac{pi}{1 - p_i^{(r*n_i)}} & if\ S_i \varepsilon G \\ 0 & otherwise \end{cases} \quad (10)$$

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Where G is the set of nodes that are eligible to be cluster-heads at round r. If node S_i has not been a cluster head during the most recent n_i rounds. In each round r, node S_i itself eligible cluster head which choose a random number between 0 and 1. If the number is less than threshold T (S_i), the node S_i becomes a cluster-head during the current round. The nodes with high residual energy take more turns to be the cluster-heads than lower ones

4.2 Optimized route selection

Multipath Routing(MP) denote the maximum number of routes that exist between each source to destination pair, and l is the selected of in MP. Pow(Si,l) denotes the power consumed by node S_i for transmitting data to the next node on route l . Routing parameter depends only on the distance between the transmitting and the receiving node. Then, it associate with each route l an energy cost routing metric defined in Eq.(3). The proposed algorithm scans all the routes in MP and determines the least expensive route to reach the base station. A source node selects the route which has the least energy consumption. In order to obtain the optimal routes, base station broad cast a route discovery message to entire network. Upon receiving the broadcast message, each sensor node introduces a delay proportional to its cost and forwards the discovery message to the base station. In this way a message arrives at each node by minimum cost path. The cumulative cost of the routing path between base station and the node obtained which taken as energy aware routing cost as described in Eq.(3). Given MP available paths, the overall energy consumption per packet, E, can be calculated as

$$E = \sum_{i=1}^{MP} E_i D_L \qquad (11)$$

Where E_i is the energy consumption for one bit and D_L is the packet length in bits. The algorithm for route selection is as follows

Algorithm

Input : EN_i, E_{CC}, R, S_i, R_G;
Output : Optimal routes from Si to RG that have the least energy consumption;
1: initialize the path counter to 1
2: initialize $E_{CC} = 0$
3: For each path from S_i to R_G do
4: Repeat
5: Calculate E_{new} is use to store the minimal energy consumption per bit with m paths and is assigned maximum value initially
6: Repeat
7: Calculate equation (3) and get the corresponding optimal energy distribution with respect to constraints defined in equations (4), (5), (6), (7).
8: Calculate equation (11)
9: Calculate the value of E_{CC} and E_{CC} new = E_{CC}
10: Until (E_{CC} new - E_{CC}) < Φ1 //threshold value1
11: Update the values of energy for each route discovery process as E_{new} = E
12: Until (E_{new} = E)< Φ2 //threshold value 2
13: End
14: j = j+1
15: Compare all paths using Ecc metric and select the smallest one

4.2 Multipath data Transmission

This phase is mainly concerned about the multipath data transmission after route selection process is over. The optimal path chosen in section 3.3 which consumes less energy and maximum coverage. But the potential problem in the conventional protocols is that once the optimal route is determined, it will be used for every transmission. Using the optimal path frequently leads to energy depletion of the nodes along selected path and may lead to network partition. To counteract this problem, the proposed algorithm used multipath data transmission along different paths. These paths are chosen by means of a probability based on low the energy consumption of each path. Due to the probabilistic choice of routes, it continuously evaluates along different routes and optimal paths are chosen accordingly as defined in section 3.3. Si, SR, Ni, Nj are the source, destination and intermediate nodes respectively while ECC is the routing metric. Initially the value of routing cost ECC is set to zero but it is updated as the data transmission takes place along the optimal path.

4. SIMULATION RESULTS

This system considers the heterogeneous sensor network with 100 sensor nodes are randomly distributed in the 100mX100m area. The base station is located at the centre (50, 50). Initially minimum probability of nodes becoming a cluster head (p_{min}) to 0.0001 and set the cluster head probability for all the nodes is 0.05. The parameters used in our simulation are listed in the Table 1.

Table 1: Simulation parameters.

Parameter	Value
Area	100x100
Base station	At(50,50)
Number of Nodes	100

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Node sensing range	25m
Initial node Energy	1J
Node aggregation Energy	5 nJ/bit/signal
Energy consumed to transmit at a longer distance	0.0013 pJ/bit/m^4
Energy consumed to transmit at a shorter distance	10 nJ/bit
Energy consumed to transmit or receive the data	50 nJ/bit
Size of a data packet	4096 bits
Data transmission rate	4096 bits
p_{opt}	0.1

4.1 Efficient Energy Consumption

Figure 1 shows the energy consumption of the proposed scheme with well known LEACH clustering protocol and HEED when the maximum transmission range is 25 m. The results demonstrate that the energy consumption of proposed neural network based clustering is smaller than HEED and LEACH. This is due to the fact that in the proposed scheme the cluster formation and routes are chosen according to the routing cost metric defined. This routing cost metric chooses only those routes those having least value of this metric and preserve the coverage and connectivity. Hence the mean residual energy in the proposed scheme is more than existing one that is the proposed scheme prolongs the network lifetime. Figure 2 shows that the total remaining energy of the network in each round. In this both LEACH and HEED, the energy depletes very fast at constant rate than proposed one

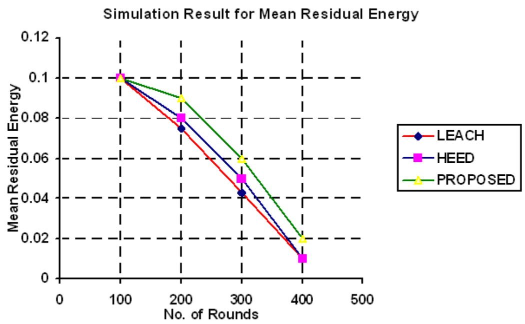

Figure 1:Energy Consumption Rate

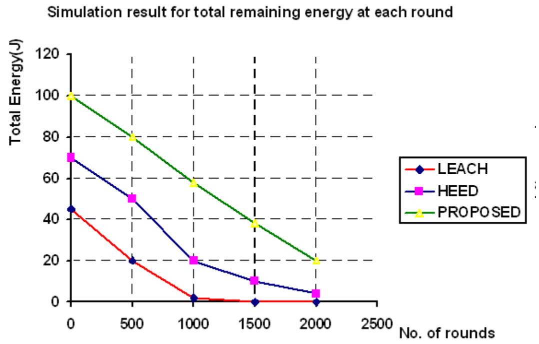

Figure2: Total Remaining Energy at each round

4.2 Packet Delivery Ratio with network coverage ratio

The impact of network coverage ratio on packet delivery fraction is plotted in Figure 3. The proposed scheme achieved 95% of packet delivery fraction with varying network coverage ratio compared to other schemes. This is due to the fact that routing paths are chosen depending upon the routing cost metric. The numbers of active nodes have direct impact on packet delivery fraction. Hence packet delivery fraction also increases in the proposed scheme compared to other schemes.

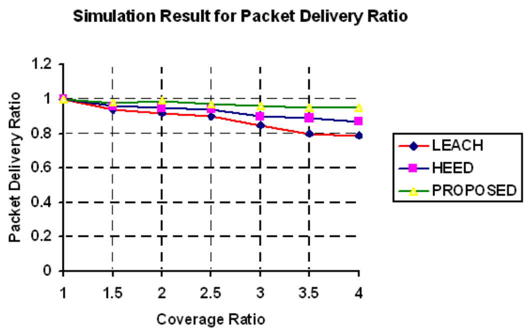

Figure 3: Packet delivery ratio vs. coverage ratio

4.3 Number of Packets Sent to the Base Station in each Round

Figure 4 displays the number of packets sent to the base station in each round. In this, more number of packets is sent in the proposed in comparison with LEACH, as superior nodes will be having more probability of becoming the cluster heads, due to more residual energy so more number of packets will be sent to the base station. Thus, the proposed sends data packets more effective to the base station.

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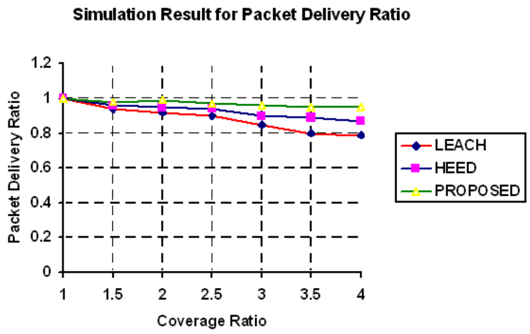

Figure 4: Coverage Ratio

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