DUCA: An Approach to Elongate the Lifetime of Wireless Sensor Nodes

S. B. Bore Gowda and G. Nayak Subramanya

Abstract Clustering the wireless sensor network (WSN) is a persuasive methodology for increasing the sensor nodes' lifetime. The clustering algorithms normally selects nodes as a cluster head only if the node has abundant remaining energy and quick energy depletion in the nodes is balanced through rotating the cluster heads at regular intervals. Mostly, the WSN is divided into small areas of identical size called clusters, which lead to non-uniform energy loads among the heads of the cluster and member nodes of the cluster. The head nodes of the cluster closer to the sink have a larger burden of the energy load. In order to prolong the premature node failure, it is very much essential to manage the energy load of the nodes. We propose a Distributed Unequal Clustering Algorithm (DUCA), which addresses hotspot issues and imbalanced energy consumption. In the proposed algorithm, the energy load balancing is dealt with by making the cluster size small which is near to sink against the nodes farthest from the sink. For inter-cluster communication and direct routing with the sink, the multi-hop routing technique is implemented. The behavior of the proposed protocol is simulated against the LEACH protocol. The simulation results prove that the proposed unequal clustering method balances uniform depletion of energy in the network and also effectively addresses the hot spot issues. The proposed DUCA enhances the greater improvement in the lifespan of the WSN.

Keywords Clustering · Energy · Routing · Lifetime · Energy efficiency
Wireless sensor network

1 Introduction

The technical advancements in the field of communication and sensing lead to the developments of devices with communication capability to monitor continuously

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K. Ray et al. (eds.), *Engineering Vibration, Communication and Information Processing*, Lecture Notes in Electrical Engineering 478,
https://doi.org/10.1007/978-981-13-1642-5_30

some physical phenomena results in the evolution of WSNs. WSN as a promising domain of networked systems contains a huge number of low-powered wireless nodes with certain constraints in CPU and an on-chip memory employed to gather the certain physical attributes from the environment. The wireless nodes are tiny, less expensive, multi-operational devices deployed in the sensor field. The environment being sensed by the sensor nodes shapes the data through the processor to convert it to a more readable form and also transmit the sensed attribute to the neighbouring nodes or to the head nodes. The sensor nodes communicate with the nodes situated at different distances using the wireless channel. The WSNs are primarily employed to take participation to perform assigned jobs, for example, administering the environs, safety monitoring, analysis of the battleground, security and health care.

The WSN is one of the promising technologies that can be used for gathering information. The WSN is capable of creating a universal environment suitable for distant sensing, observing and regulating a media or environmental state. The goodness of WSN is quite evident that it is capable of realizing adequate tracking of events occurring at a faraway locality that may or may not be inaccessible.

2 Literature Review

The data dissemination in WSN is primarily dependent of the kind of routing paths used to transmit the data to the intended destination from the source of information. The WSNs are highly constrained in energy, processing and communication. Many challenges raised during the routing process are addressed by plenty of the proposed algorithms in the literature to manage the many challenges raised during routing. Basically, the routing protocols for WSN are grouped depending on two factors: network structure and network operation. In a hierarchical network topology, certain factors and specific preconditions play important roles in the organization of sensor nodes in the field into clusters. Different tasks are being executed by different nodes in the WSNs [1].

Clustering is a process of organizing the sensing devices called nodes into a hierarchical structure, which exists in their relative vicinity. The lifespan of the nodes is boosted by the well-known scheme called clustering. Basically, the clustered WSNs consist of two kinds of heterogeneous or homogenous nodes in each individual cluster namely: cluster head and member nodes of the cluster. The member nodes of the cluster sense the data from the surrounding sensing area at a specified interval and finally, forward it to the cluster head (CH). Depending on the type of the application, the data aggregation of collected one from the members of the cluster is performed by the cluster heads. The aggregated data is forwarded to the sink either by single-hop or multi-hop mode of communication technique.

Hybrid Energy-Efficient Distributed Clustering (HEED) [2] is one of the most popular power conservative protocol. HEED is an example of a hierarchical clustering protocol in which member nodes and cluster heads communicate by single-hop mode, whereas between cluster heads and sink employs a multi-hop mode of communication. The basic factors used for selection of cluster heads are each node's remaining battery power and the energy expense involved in intra-cluster communication.

One of the distributed hierarchical clustering algorithms, which employs k-hop communication for elongating the lifetime of the WSN is an energy-efficient hierarchical clustering (EEHC) [3]. The EEHC protocol operation begins as follows: all sensor nodes with probability "*p*" are chosen as cluster heads. These nodes broadcast their selection to the nearby nodes that fall into their communication range. The cluster heads selected this manner are termed as the volunteer cluster heads.

The PEGASIS [4] is a communication protocol for WSN. The nodes form the chain, which is initiated by the farthest node. In PEGASIS, nodes communicate only with adjacent neighbouring nodes. The node gets a chance to become a cluster head sequentially for data communications to the sink. Some of the features of PEGASIS are: random node placement, performing data fusion and the ability of the nodes to detect the vital data, supporting the wireless media of communication.

TEEN [5] is another protocol, which employs hierarchical-and cluster-based routing. TEEN forms small clusters by grouping the deployed sensor nodes. The clusters are managed by a particular cluster head. The member nodes send their sensed data to the respective cluster heads. The aggregated data is routed to a next level cluster head for the sink.

The most popular protocol in WSNs, Low-Energy Adaptive Clustering Hierarchy (LEACH) [6] is a hierarchical routing protocol. The succeeding cluster and routing protocols for WSN are inspired by LEACH. The primary goal of LEACH in the clustering process is that it rotates the selection of sensor nodes as cluster heads periodically. The criteria used for the election of cluster head depend on: set threshold and node should not be a cluster head in any of the previous rounds, i.e. the lifetime of the network. The threshold values set for the election of cluster head is based on the nodes probability. The randomly elected cluster heads form the clusters by broadcasting the information through advertisement message to the neighbouring nodes. In order to ensure the almost uniform distribution of energy load, the protocol selects the eligible node as new cluster heads at each and every round.

3 Proposed DUCA Protocol

3.1 Energy Model for Sensor Nodes

A simple radio energy hardware model is considered to calculate the energy expenditure to execute the receive/transmit electronics [6]. The radio energy model for the WSN is given in Fig. 1. The proposed protocol is simulated either by considering free space (fs) or multi-path (mp) fading model depending upon the remoteness of the receiver and transmitter. For the less threshold distances, the free space model is suitable and for higher threshold distances multi-path model is used [6].

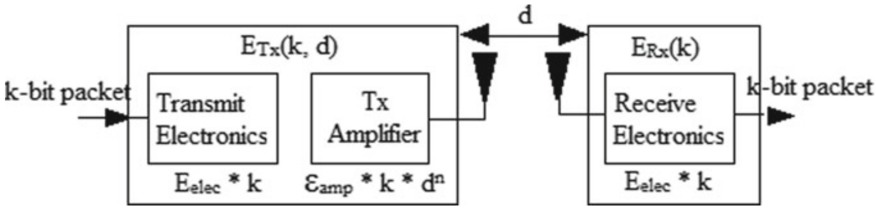

Fig. 1 Typical radio energy model of the sensor nodes [6]

If the distance from the transmitter to receiver node is d, the amount of power dissipated to send a message of length *k-bit* is computed as follows:

$$E_{Tx}(k; d) = E_{Tx\_elec}(k) + E_{Tx\_amp}(k; d) \quad (1)$$

where E_{Tx_amp} *and* E_{Tx_elec} are the energy dissipation incurred to run power amplifier and transmit electronics, respectively.

Based on the distance from the transmitter to the receiver, the transmitter energy dissipation can be controlled by setting the power amplifier. The radio energy model to compute the power dissipation of multi-path fading (d^4 power loss) and free space (d^2 power loss) channel are given as follows:

$$E_{Tx}(k, d) = \begin{cases} kE_{elec} + k \in_{fs} d^2, d < d_0 \\ kE_{elec} + k \in_{mp} d^4, d \geq d_0 \end{cases} \quad (2)$$

The energy expended by the receiving sensor node to receive a message of length k-bit is computed as follows:

$$E_{Rx}(k) = E_{Rx\_elec}(k) = kE_{elec} \quad (3)$$

$$d_0 = \sqrt{\frac{\in_{fs}}{\in_{mp}}} \quad (4)$$

where E_{elec} is the electronics energy dissipation and it depends on the following factors: filtering type, digital coding, spreading of the signal, modulation technique. The acceptable bit error rate (BER) and the separation between the receiver and the transmitter decide the amplifier energy dissipation, $\in_{fs} d^2$ or $\in_{mp} d^4$. The threshold transmit distance for the amplification circuit is represented by the symbol d_0.

3.2 Methodology of the Proposed Protocol

The proposed protocol employs competent distributed approach for maximizing the lifespan of the network. The clusters are created such that the energy load distribution is uniform across the deployed sensor nodes. To choose a node as a cluster head, the proposed protocol considers the residual energy of the node as the primary criteria. This helps in network scalability and data compression to decrease the quantity of sensed information to be transmitted to the main collecting centre, i.e. base station. Large amount of energy is conserved by employing data fusion locally and multi-hop transmission. The TDMA type of access technique minimizes the during inter and intra-cluster communication. These strategies employed in the proposed algorithm enhance the energy conservation by a greater extent, thereby maximizing the network life time.

The proposed DUCA protocol operation is classified into four different phases: Cluster setup phase, Cluster head advertisement phase, Scheduling phase and Data transmission phase.

Cluster setup phase: The sink collects the necessary information of every node through the dissemination of *REQ* message into WSN. The information includes: node ID and localization details such as (x, y) coordinates of the node's position in the WSN. Every node in the sensor field reacts to the sink by transmitting the requested information. The WSN is partitioned into the desired number of unequal clusters by sink depending on the localization information gathered from the nodes in the network. In unequal clustering, smaller sized clusters are formed which are near to the sink as compared to clusters created farthest from the sink. The sink computes the cluster radius RC_i to form clusters of unequal size using the maximum cluster radius R_i [7].

$$RC_i = \left[1 - C \cdot \frac{d\text{max} - d_i(c_i, S)}{d\text{max} - d\text{min}}\right] R_i \quad (3)$$

where d_{max} represents the maximum distance to cluster from the sink and d_{min} is the minimum distance, $d(C_i, S)$ is the separation from the cluster centre C_i to the sink, a constant coefficient C value range between 0 and 1, and the maximum cluster radius is R_i. By varying the constant C, the cluster radius can be varied. The cluster radius decreases, if the C value is increased from 0 to 1. The sink partition the complete sensor network into a predetermined number of clusters of unequal size.

After the completion of network portion, the sink broadcasts the cluster information *CLUST* which contains the cluster centre to every node in WSN and ID of the cluster. The decision of joining the cluster they belong to is made by obtaining the cluster ID information in the message *CLUST*. The cluster ID is very much useful to group the nodes into the cluster.

Cluster head advertisement phase: During this phase, selection of node as a cluster head for every cluster formed is processed. The critical parameter to be considered to decide the cluster head for the subsequent round is the remaining energy of the node battery. In the beginning of every new round of protocol operation, node with more residual energy and very near to the cluster centre is elected as the head of cluster. Subsequently, all the member nodes of the cluster will receive an advertisement message *CH_ADV* from the elected cluster head. The *CH_ADV* message from the adjacent clusters is also being received by the nodes. Every node determines their probability to be the member of the cluster or not depending on the strength of the signal being received. If the nodes are inside the communication range of the cluster head, then the cluster heads receive *JOIN* message from them. Through this process, nodes intimate their willingness to be the member of that cluster to the closest cluster head. The cluster head gathers all the *JOIN* messages from the member nodes.

The collisions due to intra- and inter-cluster communication are avoided by employing TDMA scheduling technique. In this TDMA scheduling technique, each is allotted the specific time slot and is free to transmit only during their specific time slot and other nodes will be in the sleep or idle state.

TDMA Scheduling phase: Depending on the number of cluster members, the distance to the cluster head, the cluster head creates TDMA schedule. The cluster head creates TDMA time slot by taking the number of nodes and distances into account. These TDMA time slots convey the information when they can transmit the data to the cluster head. When the TDMA time slot of all the member nodes is decided by the cluster head, then it broadcasts the time schedule to the cluster member nodes.

Data Transmission phase: The member nodes of the cluster send their sensed information to the cluster heads in their allotted TDMA time slots. The member nodes can turn off their transceiver and can enter into sleep mode

The member nodes of the cluster can communicate only with the respective cluster heads and transmit their data to the immediate cluster head during the assigned TDMA time slots. After knowing their TDMA time slot assigned to them, the member nodes turn off their transceiver and goes to sleep mode. The energy of the nodes is greatly conserved by putting them in sleep mode untill their TDMA time slot. The node enters into wake up mode when their time slot arrives, and collects the data by sensing the media and transmits it to the cluster head. The data being sent by the member node during their time slot is collected by the cluster heads and data aggregation is performed for transmission. The redundant data being sent to the sink is reduced by the data aggregation techniques. This technique greatly contributes towards the conservation of energy in the sensor nodes.

Data from the network reaches the sink node by the multi-hop mode of transmission. In multi-hop mode, the data from the farthest cluster head reaches the sink through the nearest intermediate next level cluster head in the path of the sink. The data being received by all the intermediate cluster heads from higher cluster levels and as well as its own data undergoes data aggregation by every intermediate cluster heads and send the same to the next level cluster head. Finally, the data is forwarded to the sink by the mode of multi-hop transmission.

4 Simulation Results

The proposed protocol's performance is evaluated using MATLAB. The energy depletion in each node is calculated by considering the energy expended during transmission and aggregation. The performance of the DUCA is analyzed with the LEACH protocol. The simulation parameters [6] considered for the proposed protocol are listed in Table 1. The protocol was simulated by deploying 200 nodes in 100 m × 100 m square region. The nodes in the LEACH deplete their energy quickly, since the CHs reach the base station in one hop, which is more energy-consuming process. Also, in LEACH, at the end of every round, the nodes make fresh negotiation to elect CH nodes. This increases the communication overhead and consumes more node energy. The nodes deplete their energy quickly and die faster in LEACH than UDCA. From Table 2, it is evident that the first node died during round 755 in LEACH, but in the proposed DUCA protocol it is reported in the round 891. The nodes death rate is prolonged in UDCA, since it uses energy-efficient techniques to extend the network lifetime. From Table 3, it is observed that last node died early in the LEACH. i.e. during the round 1358, but in proposed DUCA protocol it is in the round 1439.

In WSN, network longevity is one of the important measures for the performance evaluation of the whole network. If the node depletes the battery power very slowly without compromising the network operation, this increases the lifetime of the WSN. The network lifetime is measured by taking the number of nodes that are alive in each round into considerination and it is shown in Fig. 2. From Fig. 2, we observed that

Table 1 Simulation parameters

Parameter	Symbol	Values
Simulation area	M × M	100 m × 100 m
Total number of nodes	N	200
Base station position	(x, y)	(50, 175)
Packet size	P	500 bytes
Propagation delay	Td	50 μ s
Transmit/Receive electronic	Eelec	50 nJ/bit
Amplifier constant	$\in_{fs}$	10 pJ/bit/m2
	$\in_{fs}$	0.00013 pJ/bit/m2
Initial energy	E0	0.5 J
Energy for data aggregation	EDA	5 nJ

Table 2 First node death

Protocol	Round number
LEACH	755
DUCA	891

Table 3 Last Node Death

Protocol	Round number
LEACH	1358
DUCA	1439

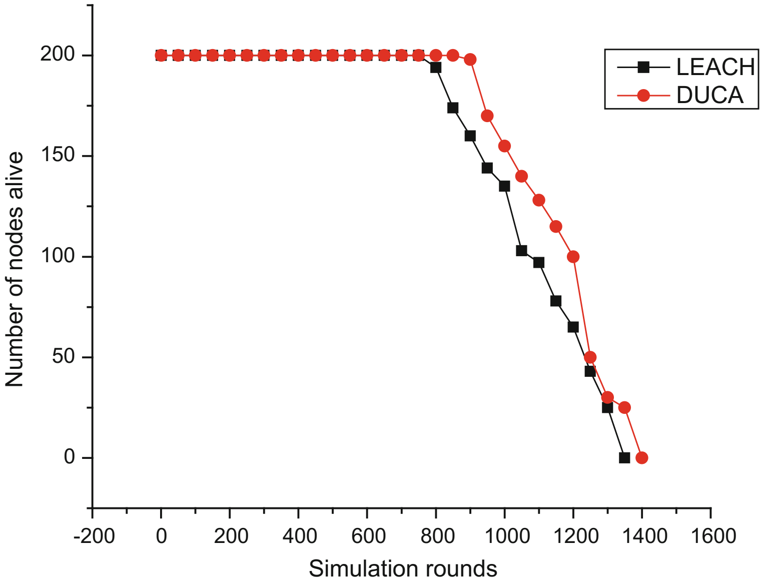

Fig. 2 Network lifetime

the proposed DUCA protocol maximizes the network life by controlling the death rate of the nodes. The algorithm employs distributed CH selection methodology as compared to the LEACH.

5 Conclusion

In this research work, a novel distributed unequal clustering protocol is presented. The distributed unequal cluster formation and multi-hop communication greatly contribute in extending the network lifetime. The hot spot problem is common in WSN with equal cluster size and also energy load among the nodes is also non-uniform. The hot spot problem is taken care by the method of unequal clustering, which also distributes the energy loads almost uniformly among the nodes.

In the presented DUCA algorithm, the cluster size is smaller near to the sink node compared to faraway clusters. This enables the CHs near to base station will have less energy loads from the member nodes of the cluster. In addition, these nodes will have more loads from the faraway CHs. Since the energy load is spread evenly among the sensor nodes, so the nodes will have a lower death rate in the proposed algorithm compared to LEACH.

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