COMPARATIVE ANALYSIS OF ENERGY EFFICIENT DISTRIBUTED CLUSTERING SCHEMES FOR WIRELESS SENSOR NETWORKS

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Abstract
Wireless sensor networks are network of sensor nodes with a set of processors and small memory unit embedded in it. Unfailing routing of packets from sensor nodes to its base station is the most significant function for these networks. The conservative routing protocols cannot be applied here due to its battery powered nodes. To provision energy efficiency, nodes are frequently clustered in to non-overlapping clusters. This paper gives a brief overview on clustering process in wireless sensor networks. In this paper, the results of Capacity based Clustering Low Energy Adaptive Clustering Hierarchy (CC-LEACH) and Integrated Distributed Clustering Algorithm (IDCA) has been compared with Low Energy Adaptive Clustering Hierarchy (LEACH) and Hybrid Energy-Efficient Distributed Clustering (HEED). The performance assessment has been made in terms of Packet Delivery Ratio, Packet loss, Energy Consumption, Throughput and Network Lifetime of all these four clustering algorithms.

Keywords: Wireless sensor network (WSN), distributed clustering algorithm, comparison, throughput and network lifetime.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) can be defined as a self-configured and infrastructure-less wireless networks to monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants and to cooperatively pass their data through the network to a main location or sink where the data can be observed and analysed. A sink or base station acts like an interface between users and the network. One can retrieve required information from the network by injecting queries and gathering results from the sink. Typically a wireless sensor network contains hundreds of thousands of sensor nodes. The sensor nodes can communicate among themselves using radio signals. A wireless sensor node is equipped with sensing and computing devices, radio transceivers and power components. The individual nodes in a wireless sensor network (WSN) are inherently resource constrained: they have limited processing speed, storage capacity, and communication bandwidth. After the sensor nodes are deployed, they are responsible for self-organizing an appropriate network infrastructure often with multi-hop communication with them. Then the onboard sensors start collecting information of interest. Wireless sensor devices also respond to queries sent from a “control site” to perform specific instructions or provide sensing samples. The working mode of the sensor nodes may be either continuous or event driven. Global Positioning System (GPS) and local positioning algorithms can be used to obtain location and positioning information. Wireless sensor devices can be equipped with actuators to “act” upon certain conditions. These networks are sometimes more specifically referred as Wireless Sensor and Actuator Networks. Clustering follows some benefits like network scalability, localizing route setup within the cluster, uses communication bandwidth proficiently and makes the best use of network lifetime. Since clustering uses the mechanism of data aggregation, needless communication between the sensor nodes, CH and BS is avoided [1].

II. LITERATURE SURVEY

Low Energy Adaptive Clustering Hierarchy (LEACH) is a clustering mechanism which distributes energy consumption all along its network, the network being parted into minor clusters and CHs which are purely distributed in manner and the randomly elected CHs, collect the data from the nodes which are coming under its cluster. The LEACH protocol contains four chief steps for each round: the advertisement phase, the cluster set-up phase, the schedule creation phase and the data transmission phase [2]-[4]. During the first step, the advertisement phase, the eligible CH nodes will be delivering an announcement to the nodes coming under them to become a cluster member in its cluster. The nodes will be accepting the offer based on the received signal strength (RSS). In the cluster set-up phase, the sensor nodes will be answering to their selected CHs. In schedule creation step, as the CH accepts response from nodes it have to make a TDMA scheme and send it back to its cluster members to intimate them when they have to pass the data to it. In data transmission step, the data composed by the individual sensors will be given to the CH during their respective time intervals. The foremost restraint here is that, the radio of the cluster members will be turned off to diminish the energy consumption after the data transmission during particular slot is ended. Here in LEACH clustering protocol, multi-cluster interference problem was solved by using single CDMA codes for each cluster.

The energy drain is prohibited for the same sensor nodes which have been elected as the cluster leader using randomization, for each time CH would be altered. The CH is responsible for collecting data from the cluster members and fusing it. Finally, each CH will be forwarding the fused information to the base station. LEACH shows a substantial improvement mainly in terms of energy-efficiency. Hybrid Energy-Efficient Distributed Clustering (HEED) is a distributed procedure which selects the CH based on both residual energy and communication cost. Basically, HEED was suggested to avoid the random selection of CHs. Though LEACH protocol is much more energy efficient when compared with its antecedents (discussed below), the primary disadvantage of this method is the random selection of CH. In the worst case, the cluster head nodes may not be consistently distributed among the nodes and it will have its consequence on data gathering. Linked Cluster Algorithm (LCA) is a distributed clustering algorithm that avoids communication collisions among sensor nodes and uses TDMA frames for inter-node communication, with each frame having a time slot for each node in the network for communication. Suggesting cluster formation and CH election algorithms, several papers focuses on single-hop clustering and thereby guarantees that no node will be more than one hop away from leader [5]-[8]. In LCA, every nodes necessitates 2n time slots, where n is the number of nodes in the network, to have consciousness of all nodes in its neighborhood.

CLUBS algorithm uses the advantage of local communication to proficiently aggregate the nodes into clusters, in which the time reserved for convergence is proportional to the local density of nodes. In order that the clusters to be advantageous for resource allocation and self-organization, the clustering phenomenon in CLUBS is described by the following: First, every node in the network must apt to some cluster. Second, every cluster should be of equal diameter. Third, a cluster should have local routing, which means that every node inside the cluster should be able to communicate with each other using only nodes within that same cluster. The CLUBS algorithm forms coinciding clusters, with the maximum cluster diameter of two hops. Every nodes starts competing to form a cluster by choosing random numbers from a fixed integer range [0, R]. Each node counts down from that number silently. If it traces zero without being interrupted, the node becomes a CH and recruits its local neighborhood in to its cluster by broadcasting the recruit message. Energy Efficient Hierarchical Clustering (EEHC) is a distributed and randomized clustering algorithm for WSNs, in which the CHs gather the data about the individual clusters and forward the aggregated report to the base-station. Their method is based on two phases: initial and extended. The initial phase which is also named as single-level clustering, in which each sensor node proclaims itself as a cluster head with a probability p to the neighboring nodes within its communication range. These CHs are named as volunteer CHs. All the nodes that are within k hops range of a CH receive this announcement either by direct communication or by forwarding. Any node that receives that announcements and is not itself a CH becomes the member of the closest cluster. Forced CHs are sensor nodes that are neither CHs nor fit in to a cluster. If the announcement does not reach to a node within the preset time interval t that is calculated based on duration for a packet to reach a node that is k hops away, the specific node will become a forced CH supposing that it is not within k hops of all volunteer CHs. In the second phase, the technique is prolonged to permit multi-level clustering and commonly builds h levels of cluster hierarchy. Thus, the clustering method is recursively repeated at the level of CHs to form an additional tier. The procedure guarantees h-hop connectivity between CHs and the base-station. Fast Local Clustering Service (FLOC) is a distributed clustering technique that produces non-overlapping clusters and around equal-sized clusters. FLOC achieves locality: effects of cluster formation and faults or changes at any part of the network within almost two units distance. FLOC shows a double-band structure of wireless radio-model for communication. A node can communicate unfailingly with the nodes that are in the inner-band (i-band) range and unreliable communication with the nodes in its outer-band (o-band) range. Hence, the i-band nodes suffer very miniature interference communicating with the CH, thus it is a reliable communication. Messages from o-band nodes are unreliable during data communication and therefore it has the maximum probability of getting vanished during communication. FLOC is fast and scalable, therefore it achieves clustering in O(1) time irrespective of the size of the network. It also displays self-healing capabilities, since the o-band nodes can switch to i-band node in another cluster. It also completes re-clustering within constant time and in a local manner. It also achieve locality, in that each node is only influenced by the nodes within two units [9]-[12].

These structures inspire FLOC algorithm to be suitable for large scale WSNs. Algorithm for Cluster Establishment (ACE) is an extremely uniform cluster formation, self-organizing, slighter overlapping, efficient coverage and emergent cluster forming algorithm for WSNs, which is scale-independent and finishes in time proportional to the deployment density of the sensor nodes irrespective of the overall number of nodes in the network. ACE demands no knowledge of geographic location and necessitates only negligible amount of communication overhead. The important idea of ACE is to assess the potential of a cluster node as a CH before becoming a CH and steps down if it is not the best CH at the moment. The two balanced steps in ACE algorithm is spawning of new clusters and migration of the existing clusters. Spawning is the procedure by which a node becomes a CH. During spawning, when a node approves to become a cluster head, it broadcasts an invitation message to its neighbors. The neighboring nodes agree such invitation and become a follower of new CH. The principal distinctive feature of ACE is that, a node can be a follower of more than one CH. During migration, best candidate for being CH is selected. Each CH will periodically check all its neighbors to regulate which node is the best candidate to become a cluster head for the cluster. The finest candidate is the node which, if it were to become a cluster head, would have the greatest number of follower nodes with minimum amount of overlap with the prevailing clusters. Once the best cluster head is determined by the current cluster head, it will uphold the best candidate as the new CH and steps down from its CH position.

III. PROPOSED CAPACITY BASED CLUSTERING LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY (CC-LEACH) ALGORITHM

The proposed clustering algorithm is well distributed, where the sensor nodes are positioned randomly to sense the target environment. The nodes are distributed into clusters with each cluster having a CH. The nodes forward the information during their

TDMA timeslot to their respective CH which fuses the data to avoid redundant data by the process of data aggregation. The aggregated data is forwarded to the BS. Compared to the existing procedures, the proposed procedure has two distinguishing features. First, the proposed algorithm uses variable transmission power. Nodes nearer to CH use lesser transmission power and nodes far away from CH use extra power for transmission from nodes to CH or vice versa, which can decrease considerable power. Second, CH sends one message for every cluster nodes but many existing algorithms transmits several messages for cluster-setup. The main activity in a WSN is to effectively select a CH. This is attained by using numerous techniques. In the proposed algorithm, CH selection is accomplished with the use of the following parameters.

A. Highest Coverage

In a network of N nodes, each node is assigned an exclusive Node Identity (NID) represented by n, where n=1, 2, 3…., N. The NID merely functions as recognition of the nodes and has no connection with location or clustering. The CH will be located at the center and the nodes will be systematized in to several layers around the CH and these layers are allotted with Layer Number (LN). LN is an integer number beginning from zero. CH gets LN0, nodes adjacent the CH in the next layer are assigned LN1, and so on. In LEACH, the coverage of a sensor node is not taken into account. This is basically significant when a sensor network is used for remote monitoring applications. The nodes with maximum coverage between the cluster nodes are given highest priority to become a CH. Basically HEED was proposed to avoid random selection of CHs. Although LEACH was more energy efficient, the foremost drawback is the arbitrary selection of CH. In HEED, the selection of CH is essentially based on residual energy and communication cost of the nodes. Here the lack of the parameter coverage leads to a main drawback. To overcome these problems, coverage among the nodes is considered to be one of the main parameter in the proposed CC-LEACH algorithm.

B. Highest Remaining Energy

Remaining energy is defined as to energy remaining within a particular node after some number of rounds. This is normally considered as one of the main parameter for CH selection in the proposed algorithm. LEACH uses much energy for communication among nodes and CHs. It attempts to distribute the loading of CHs to all nodes in the network by switching the cluster heads occasionally. Due to two-hop structure of the network, a node far from CH will have to consume additional energy than a node nearer to CH. This introduces an uneven distribution of energy among the cluster members, disturbing the total system energy and remaining energy. Node death rate is also directly proportional to the remaining energy. It is the measure of the number of nodes die over a time period, from the beginning of the process. When the data rate increases the node death rate also increases. The networks formed by LEACH show periodical variations in the data collection time. This is due to the selection function reliant on the number of data collection process. Since the CH selection of LEACH is a function of the number of completed data collection processes, the number of cluster varies periodically. The same process prevails also in HEED due to enlarged data collection. This increases the node death rate. Therefore, remaining energy is considered as one of the significant parameter for CH selection in the proposed CC-LEACH algorithm.

C. Highest Capacity

Capacity of a node is the measure of the amount of data processing it can handle compared to other nodes. A node with highest capacity is given priority to become a CH. LEACH uses more energy for communication between nodes and CHs. It tries to distribute the loading of CHs to all nodes in the network by swapping the cluster heads from time to time. The uneven distribution of energy among the cluster members is avoided in HEED as the CH selection is based on residual energy and communication cost. A node with highest residual energy and communication cost becomes a CH, thus the arbitrary selection of CH is avoided. But in the repetition phase, a number of iterations are carried out in order to find the communication cost and selecting a node with better communication cost. This is a peculiar drawback of HEED. In the proposed algorithm, fewer communication energy is necessary. It uses the concept of variable-transmission power in which the transmission power is variable from the lower edge to the higher edge based on the layers. Also in the proposed algorithm, separation among the layers is optimized to use optimum power for each layer. Hence the node with highest capacity is selected as a CH in the proposed CC-LEACH algorithm.

IV. PROPOSED INTEGRATED DISTRIBUTED CLUSTERING ALGORITHM (IDCA)

The proposed clustering algorithm, the Integrated Distributed Clustering Algorithm (IDCA) is well distributed, where the sensor nodes are deployed randomly to sense the target environment. The nodes are divided into clusters with each cluster having a CH. The nodes throw the information during their TDMA timeslot to their respective CH which fuses the data to avoid redundant information by the process of data aggregation. The aggregated data is forwarded to the BS. Compared to the existing algorithms, the proposed algorithm has three distinguishing features. First, the aggregated data is forwarded from the cluster head to the base station through cluster head of the next higher layer with shortest distance between the cluster heads. Second, cluster head is elected based on the clustering factor, which is the combination of residual energy and the number of neighbors of a particular node within a cluster. Third, each cluster has a crisis hindrance node, which does the function of cluster head when the cluster head fails to carry out its work in some conditions.

A. Aggregated Data Forwarding

In a network of N nodes, each node is assigned with an exclusive Node Identity (NID). The NID just serves as a recognition of the nodes and has no relationship with location or clustering. The CH will be placed at the center and the nodes will be organized in to several layers around the CH. Every clusters are arranged into hierarchical layers and layer numbers are assigned to each clusters. The cluster that is far away from the base station is designated as the lowest layer and the cluster nearer to the base station is designated as the highest layer. The main characteristic feature of the proposed algorithm is that the lowest layer cluster head forwards only its own aggregated data to the next layer cluster head but the highest layer forwards all the aggregated data from the preceding cluster heads to the base station.

Thus lower workload is assigned to the lower layers but the higher layers is assigned with greater workload. The workload assigned to a particular cluster head is directly proportional to the energy utilization of the cluster head. In order to balance the energy utilization among the cluster head, the concept of variable transmission power is employed, where the transmission power reduces with increase in layer numbers. In LEACH, each cluster head forwards the aggregated data to the base station directly which uses much energy. The proposed algorithm uses a multi-hop fashion of data forwarding from cluster head to the base station resulting in reduced energy utilization.

B. Cluster Head Selection

The cluster head is elected based on the clustering factor, which is the combination of residual energy and the number of neighbors of a particular node within a cluster. Residual energy is defined as the energy remaining within a particular node after some number of rounds. This is generally believed as one of the main parameter for CH selection in the proposed algorithm. A neighboring node is a node that remains closer to a particular node within one hop distance. LEACH selects cluster head only based on residual energy, but in the proposed algorithm an additional parameter is included basically to elect the cluster head properly, thereby to reduce the node death rate. The main characteristic feature of the proposed algorithm compared to LEACH is that, the base station does not involve in clustering process directly or indirectly. A node with highest clustering factor is selected as cluster head for the current round. This is generally significant in mobile environment, when the sensor nodes move, the number of neighbors vary which should be taken into account but it is barely not concentrated in the LEACH clustering mechanism.

C. Alternate Crisis Hindrance Node

In a cluster with large number of nodes, cluster crisis does not affect the overall performance of the wireless sensor system. But in the case of network with less number of nodes, cluster crisis greatly affects the wireless sensor system. Care should be done when cluster head selection process by applying alternate recovery mechanisms. In addition to the regular cluster head, additional cluster node is assigned the task of secondary cluster head, and the particular node is called as crisis hindrance node. Generally the cluster collapses when the cluster head fails.

In such situations, crisis hindrance node act as cluster head and recovers the cluster. The main characteristic feature of the proposed algorithm is that, the crisis hindrance node solely performs the function of recovery mechanism and does not involve in sensing process. In case of LEACH, the distribution and the loading of CHs to all nodes in the networks is not uniform by switching the cluster heads periodically. Hence, there is a maximum probability of a cluster to be collapsed easily, but it can be avoided in the proposed algorithm with the help of crisis hindrance node.

V. SIMULATION RESULTS AND COMPARISON

The sensor network is randomly organized over a 500 x 500 m^2 area. All the sensor nodes are expected to possess equal amount of initial energy. All the simulation mechanisms have been carried out using NS-2. The simulator contains of various components such as deployment component, topology construction component, mobility management component, medium access control component, routing component, energy expenditure computing component and throughput computing component.

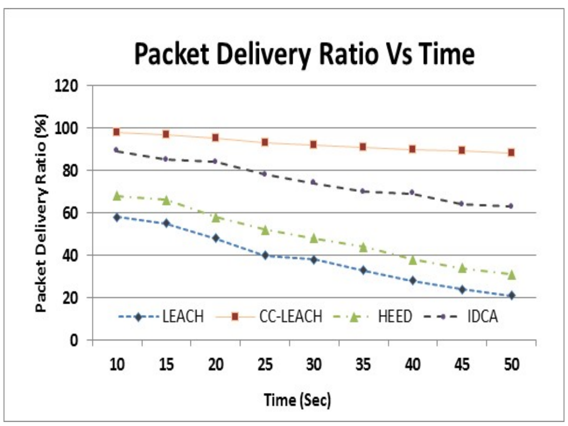

Figure 1: Comparison of Packet Delivery Ratio

Figure 1 shows the Comparison of Packet Delivery Ratio of LEACH, HEED, CC-LEACH and IDCA. The average packet delivery ratio of LEACH, HEED, CC-LEACH and IDCA are 38.33%, 48.77%, 92.55% and 75.11%. CC-LEACH shows 58.58% of improvement in packet delivery ratio over LEACH and 47.30% improvement over HEED. Similarly, IDCA shows 48.96% improvement in packet delivery ratio over LEACH and 35.06% improvement over HEED.

Figure 2 shows the Comparison of Packet loss of LEACH, HEED, CC-LEACH and IDCA. The average packet loss of LEACH, HEED, CC-LEACH and IDCA are 125 bytes, 103 bytes, 49.22 bytes and 41.11 bytes respectively. CC-LEACH shows 60.62% of reduction in packet loss over LEACH and 52.21% reduction over HEED. Similarly, IDCA shows 67.11% reduction in packet delivery ratio over LEACH and 60.08% reduction over HEED.

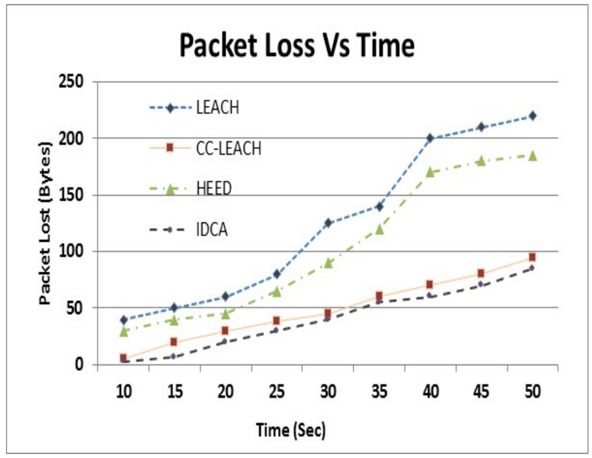

Figure 2: Comparison of Packet loss

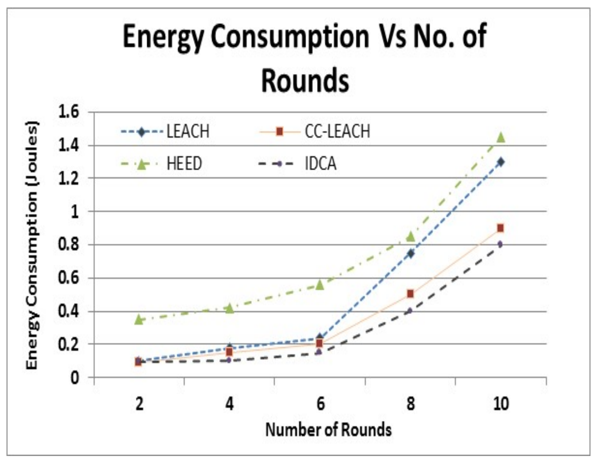

Figure 3: Comparison of Energy Consumption

Figure 3 shows the Comparison of Energy Consumption in LEACH, HEED, CC-LEACH and IDCA. The average energy consumption of LEACH, HEED, CC-LEACH and IDCA are 0.51 Joules, 0.73 Joules, 0.37 Joules and 0.31 Joules respectively. CC-LEACH shows 27.45% of reduction in energy consumption over LEACH and 49.32% reduction over HEED. Similarly, IDCA shows 39.22% reduction in energy consumption over LEACH and 57.53% reduction over HEED.

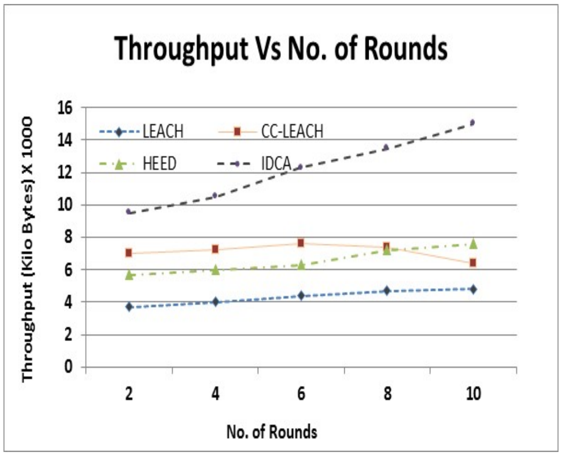

Figure 4: Comparison of Throughput

Figure 4 shows the Comparison of throughput of LEACH, HEED, CC-LEACH and IDCA. The average throughput of LEACH, HEED, CC-LEACH and IDCA are 4.32 kilobytes, 6.56 kilobytes, 7.12 kilobytes and 12.16 kilobytes respectively. CC-LEACH shows 39.32% of improvement in throughput over LEACH and 7.80% improvement over HEED. Similarly, IDCA shows 64.47% improvement in throughput over LEACH and 46.05% improvement over HEED.

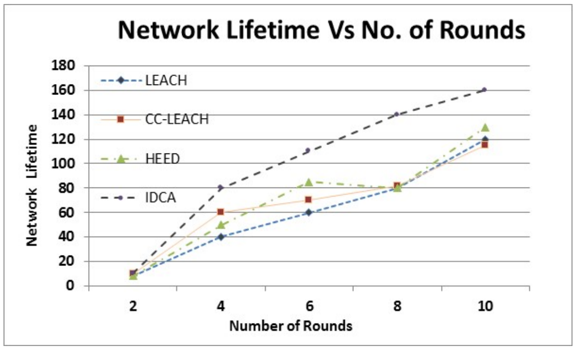

Figure 5: Comparison of Network Lifetime

Figure 5 shows the Comparison of network lifetime of LEACH, HEED, CC-LEACH and IDCA. The average network lifetime of LEACH, HEED, CC-LEACH and IDCA are 61.6 seconds, 67.4 seconds, 70.06 seconds and 100 seconds respectively. CC-LEACH shows 8.60% of improvement in network lifetime over LEACH and 3.79% improvement over HEED. Similarly, IDCA shows 38.10% improvement in network lifetime over LEACH and 29.94% improvement over HEED.

VI. CONCLUSION

In this paper, the results of Capacity based Clustering Low Energy Adaptive Clustering Hierarchy (CC-LEACH) and Integrated Distributed Clustering Algorithm (IDCA) has been compared with Low Energy Adaptive Clustering Hierarchy (LEACH) and Hybrid Energy-Efficient Distributed Clustering (HEED). It could be concluded that the outcomes of CC-LEACH and IDCA are better in terms of Packet Delivery Ratio, Packet loss, Energy Consumption, Throughput and Network Lifetime when compared to LEACH and HEED.

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