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A Comprehensive Review on Cluster based Energy Efficient Routing Protocols in Wireless Sensor Networks

A. Gopi Saminathan[1], V. Nivedhitha[2*]

[1] Department of ECE, NPR College of Engineering and Technology, Natham, Dindigul, India
[2] SSM Institute of Engineering and Technology, Dindigul, India

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Abstract – Recent **t**echnological advancements like internet of things, home automation, disaster management etc shed light on wireless sensor networks. Thousands of micro sensor nodes are geographically located to capture a remote environment. The communication and computing process consume more energy from the nodes. Prolong usage of same path to transfer data may lead to decrease of the residual energy in the sensor nodes, thus causes the node to death. Power conservation in the nodes is the major concern in hostile environments. Clustering is an energy saving scheme that enables the nodes to communicate data to the nominated cluster heads, from where the cluster heads communicate the gathered data to the sink. This gain focus on two factors of increasing the node life time, namely - the selection of cluster head that has more residual energy and the periodic change of cluster heads. This paper surveys on various energy-aware clustering schemes involved in routing data from the sensor nodes to sink.

Keywords- Wireless Sensor Networks, Energy Consumption, Clustering, Cluster head selection, Routing protocols.

I. INTRODUCTION

Wireless Sensor Network (WSN) is a network of nodes with each node connected to several autonomous sensors that are distributed spatially over a geographic area. They work cooperatively to sense the real world parameters spontaneously, measure and organize the acquired data. The collected data are transferred from the node through wireless medium to a central gateway that is linked to an external network [1].

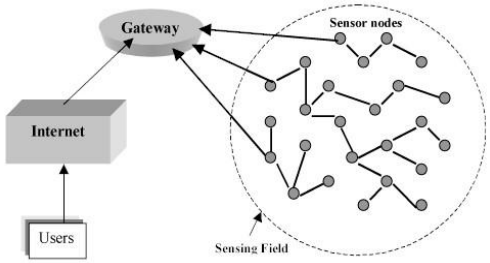

Figure. 1 Wireless Sensor Network

II. COMPONENTS OF WSN

A typical WSN consist of five main components, namely – sensors, nodes, transmission medium, gateway, and base station. Sensors collect information from the physical environment and transmit them to the node which is connected by wired/wireless medium.

Sensors are low cost, low power and have very short transmission range. They are used in a wide range of applications to measure temperature, humidity, sound and so on. They transmit data by hoping to the nearest neighbors and the process continues until it reaches the destination node, known as sink.

Nodes collect the data from sensors and processes, analyze and organize the data using software. A sensor node that performs both sensing and processing of measured data and is also known as a mote. The data is transferred by wireless links using infra red or radio interface. Gateway acts as an interface between the wireless sensor network and the device that requires the data. It possesses protocols to transfer data between heterogeneous networks [2].

Each sensor has mainly four parts, namely – the sensing unit, processing unit, communication unit and the power unit. The sensing unit is comprised of sensor and analog to digital converter. The sensor captures physical environment and converts it into electrical signal. The ADC converts the electrical signals into of digital form of the signal.

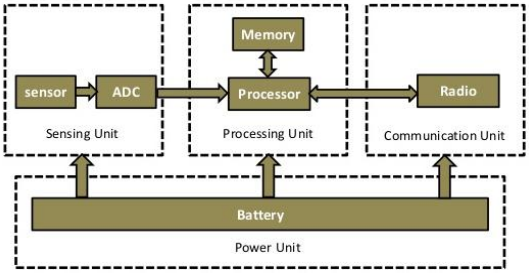

Figure. 2 Components of a sensor node

The processing unit has the microprocessor circuit extract information from the captured signal and store it using the inbuilt memory. The radio transceiver acts as the communication unit to send and receive signals to and from other networks. The power unit is an energy source that usually has a battery to supply energy to the components [2, 3].

III. CHARACTERISTICS OF WSN

The key characteristics of wireless sensor networks include,

Small sized sensors: The nodes should be designed as small as possible so as deploy them in any kind of environments especially in military for enemy intrusion detection, habitat monitoring in forests etc.

Low Cost Sensors: Thousands of sensor nodes will be deployed in a monitoring environment. The entire network cost should be kept minimal by using low cost nodes.

Distributed sensing and computation: WSN components capture the features of the environment uniformly in distributed manner, process them, communicate with each other, and store data in memory. The aggregated data collected from multiple sources are distributed to neighboring nodes to reach the sink node.

Energy Efficiency: The nodes transmit data by multi-hop communication that sends the data from the captured node to the sink using intermediate nodes. The repeatedly chosen path for transmission may consume more power and the nodes may soon run out of energy and become dead. Energy efficient routing algorithms, dynamic topologies, and transmission policies are to be used to utilize energy efficiently.

Low range Communication medium: The sensor nodes in a WSN environment use radio waves, infrared or optical medium to transmit the signal in wireless media. Radio frequencies are capable of transmitting signal over short range while IR and optical medium transmit signal over long range and are robust comparatively.

Secure Transmission: Each sensor node mush have security and privacy preservation mechanism in order to prevent unauthorized access of data causing damage.

Self-organization: The sensor nodes should possess the capability of automatic self-organizing and work collaboratively that enables the nodes to create a network by themselves.

Application oriented: WSN is highly dependent on the application chosen to deploy the network. The applications include Area monitoring (Enemy intrusion detection in military, geo-fencing of gas lines), Health care monitoring(body area networks), Environmental or Earth monitoring (Air pollution monitoring, Forest fire detection, Landslide detection, Water quality monitoring, Natural disaster prevention like Earth quakes and Tsunami), Industrial monitoring (Machine health monitoring, Data center, Data logging, Water/waste water monitoring, Structural health monitoring), Smart Home, Intelligent buildings etc. The nodes are deployed randomly and spanned depending on the type of application [1, 2].

IV. CLUSTERING

In a typical WSN environment, the nodes capture the physical environment. The captured data is processed and collectively sent to the base station (BS) for transmission to the destination. The aggregation of data can be done using the clustering concept. Clustering allows the grouping of nodes based on some mechanism, thus dividing the entire network into small set of clusters [5].

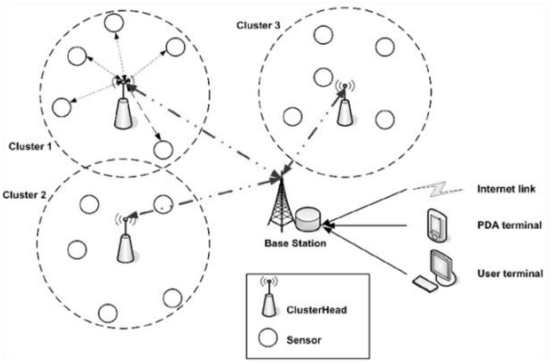

Figure. 3Clustering in WSN

Clustering is the process of choosing up of a particular leader node as cluster head (CH) that serves other neighboring nodes to send data to the gateway in the network [6]. When this level of hierarchy is extended it becomes hierarchical clustering, thus enforcing an improved network lifetime. The CH is responsible for processing the raw data, aggregate data from multiple sources and transmits them to the BS. All other nodes in the cluster shall sense and capture the data from external environment and forward it to the CH for further processing. These nodes are said to be member nodes.

Clustering Properties

The important factors that are to be noticed in clustering process are

(i) The number of clusters in a network
(ii) Uniformity in the size of clusters
(iii) Inter – cluster Routing
(iv) Intra - cluster Routing

(i) The number of clusters in a network
The number of clusters is dependent upon the number of nodes in the network. It shall be either fixed where the number of clusters to be formed in a network is preset or can be of variable type where the cluster count is not preset.

(ii) Uniformity in the size of clusters
The number of member nodes in a cluster shall be either even or odd. If the cluster size is even, the number of nodes in each cluster is unvarying and if the cluster size is odd, then the node count in each cluster is of varying type.

(iii) Inter-cluster Routing
Inter-cluster Routing deals with the communication between one cluster and other. It can be either single-hop or multi-hop. Single-hop routing involves direct communication between CH and BS. Multi-hop Routing requires communication from one CH and BS using intermediate CHs.

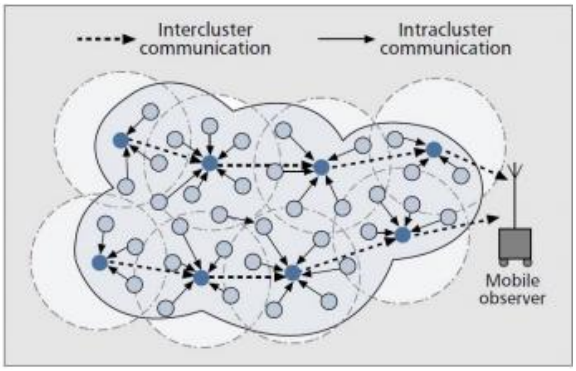

Figure. 4 Inter- and Intra- Cluster Communication

(iv) Intra-cluster Routing
Intra-cluster routing deals with the communication between the nodes within a cluster and the CH. It can be either single hop where the member node directly communicates with the CH or can be multi-hop that requires intermediate member nodes to communicate from one member node to CH.

V. SELECTION OF CH BASED CLUSTERING ALGORITHMS

The clustering algorithms enable grouping of nodes under a cluster head there by enabling (i) reduction of routing table size, (ii) reduction of the redundancy of exchanged messages, (iii) reduction in the energy consumption, and (iv) provision of extended network lifetime.

There are two types of clustering algorithms for selecting the CHs, namely – centralized and distributed types. Distributed clustering algorithms [7] are classified into four types – Identity (ID) based, Neighborhood information based, Probabilistic type and Iterative type. The centralized clustering algorithms [8] include LEACH – C, BCDCP, DMSTRP, and LEACH – F and so on.

(i) ID based clustering algorithm: Each node in the network is assigned with a unique identification number (ID). A typical node broadcasts its own ID and the IDs of its neighboring nodes. The CH is selected based on two approaches. First, the node that receives IDs that is greater than itself shall be selected as CH. Second, the CH is selected as a node that receives IDs that are lesser than it [9]. A node that receives more than one CH is considered to be the gateway node. All other nodes are considered to be member nodes.

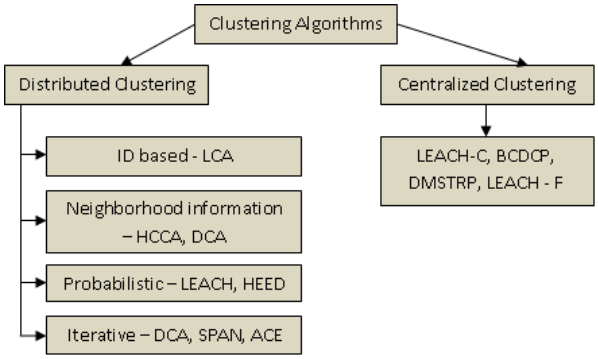

Figure. 4 Classification of Clustering algorithms based on CH selection

Linked Cluster Algorithm version 1 (LCA) [10] is ID based on Identity based algorithm that considers ID of the node as a distinct factor in choosing the CH [11].

A variation of LCA is **Linked Cluster Algorithm version 2 (LCA2)** [12] that discard the selection of numerous CHs. The algorithm works with a principle that the node with least ID is chosen as CH if it follows that following rules. First, the lowest ID node is not a CH. Second, the lowest ID is within one-hop of the previously chosen CHs. A node is said to be covered if one of its neighbor is a CH and else it is said to be non-covered where the CH is elected that has lowest ID.

(iii) The neighborhood information algorithm: The CHs are elected based on the number of neighbors to the elected node.

Highest Connectivity Cluster Algorithm (HCCA) chooses a node as CH that follows two requirements. First, if the node possesses highest number of one-hop distance neighbors. That is, a node is selected as CH if a node is connected to most number of nodes. Second, the nodes under the elected CH follow strict clock synchronization [13].

Min-Max D-Cluster Algorithm (DCA) selects a node as CH if none of its neighbors are d-hop away from it. The algorithm sets off 2d rounds of flooding through a set of simple rules. The first d-rounds of flooding is said to be "flood-max" does propagate the largest node IDs. The second d-rounds of flooding is said to be "flood-min" that that propagates the nodes with smallest IDs. If a node has received its own ID after the second d-rounds of flooding, then it declares itself as CH. Else, there exists a set of node pairs, then the minimum node pair is chosen as CH. Thus, the schemeprovides better load balancing without clock synchronization requirements.

(iii) The probabilistic clustering algorithm: The algorithm selects the CH in a random manner and enables the rotation of selecting the CH based in the residual energy possessed by every node.

The **Low Energy Adaptive Clustering Hierarchy (LEACH)** algorithm is the most popular distributed probabilistic clustering algorithm that follows hierarchical routing. It selects the CH that has the highest energy remaining as the CH needs more energy than the member nodes [14].

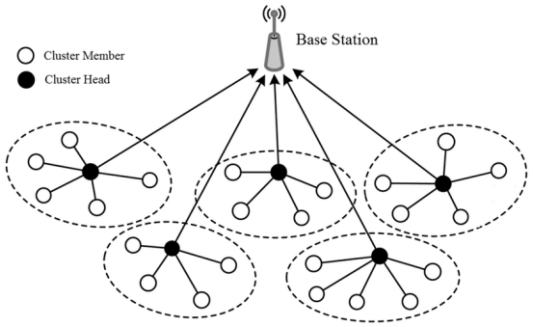

Figure. 5 General view of LEACH Algorithm

LEACH engrosses two phases of operations, namely- (i) set-up phase and (ii) steady state phase. In Set-up phase, clusters are made and a cluster head is selected for each cluster. Cluster head is selected based upon a probabilistic factor. Initially the CH is selected based on the energy of nodes. The nodes with the higher energy are selected as CHs. Each sensor nodes generates a randomnumber, n between 0 and 1 and compares it to a pre-defined threshold T_n. The probability of a node to become a cluster head is calculated on the basis of two factors, namely – (i) Number of times a particular node has been a CH. (ii) Suggested total number of CHs for a network. If the probabilistic factor of a node, $n<T_n$, the corresponding node becomes CH in that round, otherwise it becomes a member node. The CH is selected based on the advertisement packet by the cluster nodes by calculating T(n) which is given as,

$$T(n) = \frac{P}{1 - P\ x\ (r\ mod\ P^{-1})} \qquad for\ all, n \in G$$

$$T(n) = 0 \qquad for\ all, n \notin G$$

where, n is a random number between 0 and 1, P is the CH probability and G is the set of nodes that weren't CHs in the previous rounds. Steady state phase involves the transfer of data collected by cluster heads to base station. Thus, every node in the network gets a chance to become a CH in a randomized manner, and so fading up of lifetime of the nodes is eliminated and even load balancing take place.

Two-Level LEACH Algorithm (TL-LEACH) is an extension to LEACH that provides two levels of CH selection, namely - primary and secondary level so as to minimize energy utilization [14]. The CHs are selected as per LEACH protocol. A head for all CHs is selected to be the father of CHs. The data transferred are sent to the base station through the father node.

Energy Efficient Clustering Scheme (EECS) is a dynamic, non-iterative algorithm for selection of cluster heads based on residual energy of sensor nodes, distance and data overhead. It provides lower message overhead and uniform distribution of cluster heads [15].

The **Hybrid Energy Efficient Distributed clustering algorithm (HEED)** is one of the most effective cluster-based routing protocols. It selects a node as CH only if the particular node has relatively high residual energy than its member nodes. The algorithm mainly considers two factors to decide whether to make a node cluster head or not, namely – (i) Residual Energy of the sensor node and (ii) Intra-cluster communication cost.

The main goal of this distributed clustering algorithm is that all the cluster heads in the network get uniformly distributed. It has manly three phases of operation, namely – (i) Initialization Phase, (ii) Processing phase and (iii) Finalization phase. The initialization phase involves all the sensor nodes to compete with their probabilities to become CHs.

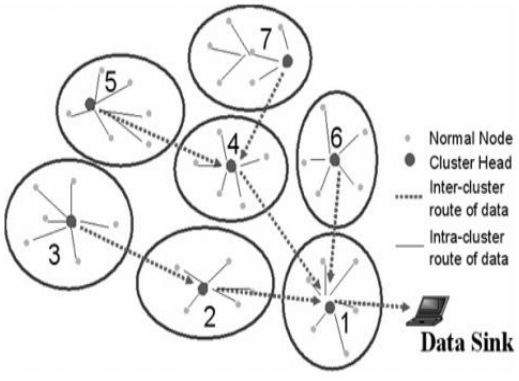

Figure. 6 General view of HEED Algorithm

The processing phase enables the nodes go through several steps to elect the CHs. The finalization phase involves each sensor node, join the least communication-cost CH or announce itself as a CH [16].

The probability of CH is found using,

$$CH_{prob} = C_{prob} * \frac{E_{residual}}{E_{max}}.$$

After which, the data collected by individual member nodes are sent to the base station in a multi-hop fashion. This enables more conservation of energy than LEACH algorithm, which involves single-hop communication.

(iv) Iterative Clustering Algorithm: It includes Distributed Clustering Algorithm (DCA), SPAN and Algorithm for Cluster Establishment (ACE).

The **Distributed Clustering Algorithm (DCA)** protocol uses delayed willingness announcement technique that provides a better mechanism for any sensor node to become a CH. It provides an optimized way of giving chance for other higher-weighted neighbor sensor nodes to become CHs.

SPAN selects CHs in a randomized manner with localized decision making which is based on number of sensor nodes being benefitted and its own energy levels for a sensor node that is likely to become cluster head.

Algorithm for Cluster Establishment involves two phases of cluster head selection, namely - spawning phase and migration phase for existing clusters. It is used to achieve non-overlapping, uniform cluster formation.

(v) Centralized Clustering: Distributed clustering algorithms selects CHs based on some parameters like ID of the node, neighborhood distance, probability value etc in each cluster independent of any other nodes in the network. These algorithms select a CH at a particular time and then select some other node that is eligible to become CH.There is dynamic CH election and thus each node gets an equal chance to become the CH.

In centralized clustering technique, the selection of CH in each cluster is done by the central base station, BS. BS selects CHs based on certain parameters like node type, residual energy, hop count, minimal distance from the BS etc. The node that becomes CH is static throughout the entire lifetime of the network. Few algorithms like LEACH-C, LEACH-F, DMSTRP, and BCDCP are discussed below.

Low-Energy Adaptive Clustering Hierarchy-Centralized (LEACH-C): LEACH-C is a centralized and improved algorithm over LEACH protocol. Here, the CHs are randomly selected by BS by two phases, namely - setup phase and steady state phase. In setup phase of each round, every node competes and sends its energy information and ID to the BS. The BS selects the CH based on three parameters, namely - average node energy, location of the node and energy level to the BS. The BS then broadcast the IDs of the selected CHs to all member nodes.After selecting the CH, the transmission of message takes place between nodes which contains the cluster ID. Whereas, the steady state phase of LEACH-C is similar to LEACH protocol [14] .

To transmit k-bit data a distance d, the energy consumption for sending the k-bit data is given by the following model.

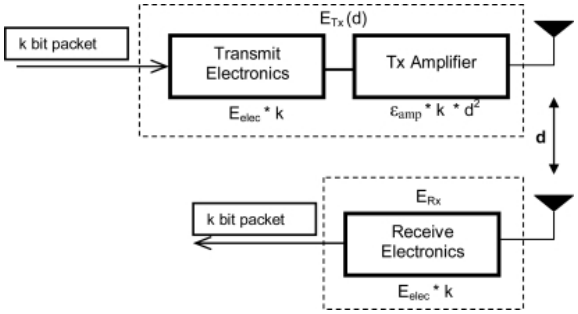

Figure. 7 Radio energy dissipation model in LEACH-*C*

The relationship between distance from the node to BS and energy is given as,

$$E_{trans}(k,d) = \begin{cases} kE_{elec} + k\varepsilon_{fs}d^2 (d < d_0), \\ kE_{elec} + k\varepsilon_{amp}d^4 (d \geq d_0). \end{cases}$$

where, E_{elec} is electronics energy, amp ε is magnification times of amplifier, d_0 is the threshold level. The protocol chooses channel mode on the basis of distance between the transmitters and receivers. From the above model, if the distance between nodes, d is less than threshold d_0, free space attenuation channel model is proper, otherwise multipath fading channel model.

Power-Efficient GAthering in Sensor Information Systems (PEGASIS): PEGASIS is a near-optimal chain-based protocol that minimizes energy usage by the nodes. The basic idea followed here is greedy chain approach that forms a chain among the sensor nodes so that each node will receive from and transmit to a close neighbor. The gathered data move from node to node, get combined, and, eventually transmits to the BS. Nodes take turns transmitting to the BS thus reducing the average energy spent by each node per round.

Base-Station Controlled Dynamic Clustering Protocol (BCDCP): BCDCP is a wireless sensor routing protocol where the BS performs energy intensive computation

decisions. The BS is assumed to be non-energy constrained and it is fully aware of the location of all the other nodes in the network. The protocol carries outa balanced cluster formation by balancing the size of the clusters. BCDCP operates in two major phases: setup and data communication. During data-communication phase, each CH receives signals from the member nodes, and combines them.A CH-to-CH routing path is constructed using minimum spanning tree algorithm that connects all CHs on the basis of their spatial separation and the signals are sent in a multi-hop routing path. The protocol randomly selects one of the CHs to forward the data to the BS. The death of one CH would have a considerate effect on partitioning the network and causing other CHs to be virtually dead.

Low-Energy Adaptive Clustering Hierarchy – Fixed cluster (LEACH-F): LEACH-F is similar to LEACH-C protocol that uses centralized approach for cluster formation. No re-clustering phase takes place when the cluster formation process is done. The clusters are fixed and only rotation of cluster head nodes within its clusters take place. The set-up overhead at the beginning of each round due to re-clustering in LEACH is removed by LEACH-F protocol. But this protocol does not provide any flexibility in adding or removing the nodes once when the clusters are formed and nodes cannot adjust their behavior on node dying.

Dynamic Minimal Spanning Tree Routing Protocol (DMSTRP): This protocol is an extended type of BCDCP protocol and is applied when the network size is larger. Protocol uses MSTs to create two layers of the network: intra-cluster and inter-cluster. In each cluster, all nodes including CH are connected by a MST. CH being the leader then collects data from the whole tree. All CHs are connected by another MST and go on route towards BS. The MSTs produce lesser delay than LEACH-C and BCDCP, thus extending network lifetime.

VI. CONCLUSION AND SCOPE FOR FUTURE WORK

Clustering of nodes in WSN environment is very useful in communicating the signals through reduced overhead. In this paper we have only focused on the components, characteristics of WSN in Chapters 2 and 3, various clustering properties, techniques and energy efficient protocols for WSN in Chapters 4 and 5. There are many challenges to be focused upon, like CH rotation and replacement, inter-cluster and intra-cluster communication to enhance the lifetime of the network. The further research shall be based on the clustering algorithms in heterogeneous and mobility based environments.

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Authors Profile

Dr. A. Gopi Saminathan pursued his Bachelor's Degree in Electronics and Communication Engineering from MK University, Madurai in the year 1995. He received his Master's Degree in Applied Electronics in the year 2006 from Anna University, Chennai.

He has obtained Ph.D. degree in the Faculty of Information and Communication Engineering, Anna University, Chennai, Tamilnadu, India in the year 2013. He started his career as an Assistant Professor in the year 1999. He has worked in various reputed colleges in Tamilnadu and has 19 years of service in teaching. He also holds 3 years of service in industry.

His research interest includes Wireless Sensor Networks and Signal Processing. Presently he is working as professor and Head in the department of ECE at NPR College of Engineering and Technology, Natham, Dindigul, Tamilnadu.

He is a life member of Indian Society for Technical Education (MISTE) and life time fellow of Institute of Electronics and Telecommunication Engineering (FIETE). He has published his research articles in more than ten international journals and presented many papers in National and International conferences.

Mrs. V. Nivedhitha pursued her Bachelor's Degree in Information Technology from Anna University, Chennai in the year 2008. She received her Master's Degree in Computer Science and Engineering in the year 2011 from Karpagam University, Coimbatore.

She is currently pursuing her Ph.D. degree in the Faculty of Information and Communication Engineering, Anna University, Chennai. She has 7 years of Experience in reputed Engineering colleges. She is presently working as an Assistant Professor in Department of CSE, SSM Institute of Engineering and Technology, Dindigul, Tamilnadu, India.

She is a life member of Indian Society for Technical Education (MISTE). She has presented five papers in International and National Conferences.

