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Hierarchical Cluster Based Energy Efficient Routing Protocol for Wireless Sensor Networks: A Survey

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Abstract- **Wireless Sensor Networks are collection of number of small and spatially distributed autonomous devices called Sensor Nodes. These nodes are able to sense, can do computations and perform wireless communications but have limited resources available for their operation. Due to this, the routing protocol of wireless sensor network must minimize the energy consumption so as to increase the network lifetime. For this purpose, a number of routing techniques are employed. Here, we are mainly focusing on the hierarchical cluster based routing techniques. Many researchers have already proposed a number of distinct algorithms based on this technique. In this paper, we are providing an introduction to wireless sensor networks, the need for reducing the energy consumption in wireless sensor networks and some of the already implemented energy efficient routing protocols for wireless sensor networks.**

Keywords- **Wireless Sensor Networks, Clustering, Routing, Hierarchical Clustering, Energy Efficient Routing, etc.**

I. INTRODUCTION

Wireless Network is a type of Computer Network that provides communication between a numbers of nodes without having a Physical Connectivity between these nodes. No nodes are connected through a Physical Medium to communicate with each other. Rather they use wireless mediums such as air / atmosphere to transmit the data from one node to another. Commonly used wireless transmission mediums include Microwave Communication, Radio Wave Communication, Satellite Communication, etc.

Wireless Sensor Network (WSN) is a sub class of Wireless Networks that have the same operating principle but are slightly intelligent or better as compared to the traditional Wireless Networks. A Wireless Sensor Network consists of spatially distributed sensors called Sensor Nodes that senses and monitors the environmental conditions along with communicating with the other nodes or sharing the data between a number of nodes.

Wireless Sensor Networks (WSNs) consists of a set of sensor nodes that are deployed in a field and interconnected with a wireless communication network. Each of these scattered sensor nodes have the capabilities to collect data, fuse that data and route the data back to the sink/base station [1] [2]. To collect data, each of these sensor nodes makes decision based on its observation of a part of the environment and on partial a-priori information. As larger amount of sensors are deployed in harsher environment, it is important that the distributed computation should be robust and fault-tolerant. The identification of event in a wireless sensor network should be done as fast as possible, thus the computations are done in parallel. Here we investigate the problem of design of optimal parallel distributed computational architecture. In distributed system components located on networked computers communicate and coordinate by passing messages to perform the specified task. Similarly distributed computation is done on distributed nodes connected over the network with defined computational model. A model of computation is a formal description of a particular type of computational process. More details about computability theory can be found in [3]. This paper assumes the no memory computational model of sensor nodes in the architecture for primitive recursive functions. No memory computational model means the sensor node just has registers to store two values, whenever the sensor node receives any value from other sensor nodes, it simply computes the function with its own measured value and the received value and passes the results to the other sensor node(s).

Each sensing node has a Radio Transceiver for sending the Information (Transmitter) and receiving the Information (Receiver), an Antenna for providing connectivity to the Network, a Micro Controller for controlling the operation of the Sensor Node, an Electronic Circuit for interfacing with other Sensors and an Energy Source usually a Battery as each element utilizes some form of Energy to carry out its operation.

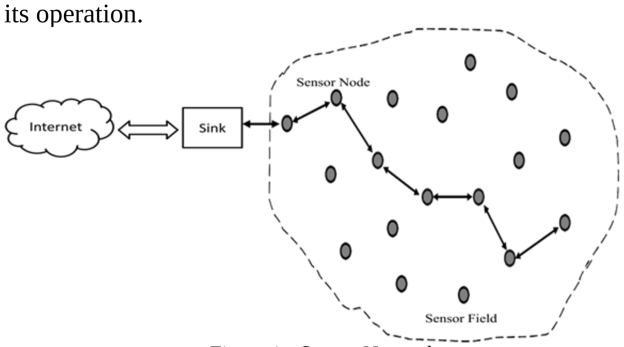

Figure 1:- Sensor Network

Sensor Nodes can be considered as small computers in terms of their interfaces and components. They usually have a Processing Unit with limited Computational Capabilities and limited Memory, Sensors, a Transceiver and a Power Source usually a Battery. These nodes can share the data either through Routing or through Flooding. The major characteristics of Wireless Sensor Networks are:

a. Power Consumption Constraints
b. Reliability / Resilience / Ability to cope with Node Failures
c. Mobility of Nodes
d. Heterogeneity of Nodes

e. Scalability
f. Ease of Use
g. Ability to withstand harsh environmental conditions
h. Cross Layer Design to improve Quality of Service (QoS)

II. Energy In Wireless Sensor Networks

Energy is the ability of an object to perform a task. Whenever an object, performs a task, the energy possessed by the object is converted from one form to another form. This is actually the first law of energy that "Energy can neither be Created nor be Destroyed, it can only be converted from one form to another". The second law of Energy is "The total energy of the Universe is constant".
Similarly, the Sensor Nodes also possess energy that has been utilized during their operation when they transmit some data to other sensing nodes or whenever they receive data from some other sensing nodes. The objective of our work is to implement an energy efficient routing algorithm in wireless sensor networks.
Energy consumption is the best way to determine the life span of a sensor network because sensor nodes operate by battery and have very low energy resources. This makes energy optimization more complex in sensor networks because it not only involves reducing the energy consumption but also increasing the life time of the network as much as possible. This can be accomplished by having energy awareness in every area of design and operation. This ensures that energy awareness is also taken into consideration for group of communicating sensor nodes and the overall network and not only in the individual nodes.

III. Routing Protocols For Manet

Routing in wireless sensor networks differs from conventional routing in fixed networks in various ways. There is no infrastructure, wireless links are unreliable, sensor nodes may fail, and routing protocols have to meet strict energy saving requirements. Many routing algorithms were proposed for wireless networks which can be divided into seven categories as:

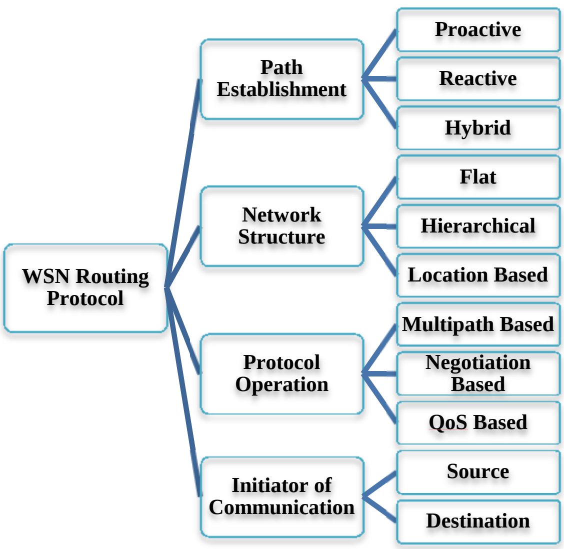

Figure 2: Routing Protocol Hierarchy of Sensor Network

This paper gives introduction over Hierarchical Routing Protocols.

A. *Hierarchical Routing Protocols*

Clustering is an energy-efficient communication protocol which can be used by the sensors to report their sensed data to the sink. In this section, we describe a layered protocol in which a network is composed of several clusters of sensors. Each cluster is managed by a special node, called cluster head, which is responsible for managing the data transmission activities of all sensors in its clump.
A hierarchical approach divides the network into layers. Nodes are grouped together to form the clusters and each cluster has a cluster head, responsible for routing inside the cluster as well as between different clusters. Clustering provides inherent optimization capabilities at the cluster heads. In this section, we provide a brief introduction to a number of hierarchical-based routing protocols for WSNs.

B. *Low-Energy Adaptive Clustering Hierarchy (LEACH)*

LEACH is the first and most common energy-efficient hierarchical clustering algorithm for WSNs that was developed for reducing power consumption. In LEACH, the clustering task is distributed among the nodes, based on duration. Direct communication is used by each cluster head (CH) to forward the data to the base station (BS). This is because the lifetime of the network has been improved due to the applicability of clustering approach. LEACH is based on an aggregation (or fusion) technique that combines or aggregates the original data into a smaller size of data that carry only meaningful information to all individual sensors.
LEACH divides entire network into several clusters, which are designed by using local coordination and control. This will not only to reduce the amount of data to be transmitted to the sink, but also to make routing and data distribution more extensible and robust. LEACH uses a randomize distribution of high-energy CH position rather than selecting in fixed manner, so that all sensors can get equal chance to act as CHs, thereby avoiding the battery consumption of an individual sensor and death, quickly.
The operation of LEACH is divided into rounds of two phases each namely (i) a setup phase to divide the network into clusters, CH advertisement and defining the scheduled plan for transmission and (ii) a steady-state phase for data collection, compression and transmission to the sink. LEACH is completely distributed and requires no global knowledge of network.
It reduces energy consumption by (a) decreasing the communication overheads between sensors and their cluster heads and (b) turning off non CH nodes as much as possible, if not in use. LEACH incorporates single-hop routing in which each node can communicate either with the cluster-head or with the sink. So, it cannot be applied to networks deployed in large regions.
Furthermore, the idea of dynamic clustering brings extra overheads, e.g. head changes, advertisements etc., which may reduce the gain in energy consumption. While LEACH helps the sensors within their cluster dissipate their energy slowly, the CHs utilizes more energy when they are

located farther away from the sink. Also, LEACH clustering terminates in a finite number of iterations, but does not guarantee good CH distribution and assumes uniform energy consumption for CHs.

C. Power-Efficient Gathering In Sensor Information Systems (PEGASIS)

PEGASIS is an improved version of the LEACH protocol, in which sensor nodes are arranged in the form of a chain, so that each node communicates only with neighbour and there is only one node in the chain that can communicate with the base station (sink). The data is collected and moved from sensor to sensor, combined and ultimately sent to the base station. The chain is constructed using greedy approach principle. Unlike LEACH, in PEGASIS, nodes are not distributed in clusters. Here, only one node in a chain can communicate with the BS (sink).

A sensor transmits to its local neighbours in the data fusion phase rather than sending directly to its CH as in the case of LEACH. In PEGASIS routing protocol, in the construction phase, it has been assumed that all the sensors have knowledge about the entire topology about the network, particularly, the location of the sensors and use a greedy approach. In case of sensor failure due to low battery power, the chain is constructed again using the same greedy approach by isolating the failed sensor from the network. In each round, a randomly selected sensor node from the chain will transmit the collected data to the BS, thus reducing the per round energy utilization as compared to LEACH.

Simulation results showed that PEGASIS will improve the life span of the network to a factor of two as compared to the life span of the network under the LEACH protocol. This improvement in the performance is achieved by eliminating the overheads due to dynamic cluster formation in LEACH and by reducing the number of transmissions and receptions by using data aggregation. Although the overheads due to cluster formation are avoided, PEGASIS still requires dynamic changes in network topology since a sensor node must have information about remaining energy status of its neighbours so as to identify the route to forward its data. Such topological adjustments can introduce high overheads mainly in highly utilized networks.

D. Hybrid, Energy-Efficient Distributed Clustering (HEED)

HEED modifies the basic scheme of LEACH by incorporating residual energy and node degree or density as parameters for cluster selection to accomplish power balancing. It operates in multi-hop networks, using an adaptive transmission power for inter-cluster communication. HEED was designed with four major goals namely (i) increasing the network lifetime by distributing energy utilization, (ii) terminating the clustering process after a fixed number of iterations, (iii) reducing control overheads, and (iv) designing equally-distributed CHs across the network and compact clusters.

In HEED, the selection of a CH is based on two parameters, viz. Residual Energy and Intra – Cluster Communication Cost. The first parameter is used to compute the probability of each node for becoming a CH and the second parameter is used as a function of node degree. The primary parameter is used to select an initial set of CHs while the secondary parameter is used as tie breaker.

The HEED clustering improves network lifetime over LEACH clustering because LEACH randomly selects CHs (and hence cluster size), which may result in reducing the lifetime of some nodes. The finally selected CHs in HEED are approximately equally distributed across the network and the communication cost is minimized. However, the cluster selection deals with only a subset of parameters, which can possibly apply certain constraints on the system. These techniques are suitable for increasing the network lifetime rather than for the entire needs of WSN.

E. Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN)

TEEN is a hierarchical clustering protocol, which divides sensors into clusters, each headed by a CH. The sensors inside a cluster report the sensed data to their CH. The CH combines the received data and forwards it to higher level CH until the data reaches the sink. Thus, the sensor network architecture in TEEN is based on a hierarchical grouping where nearby nodes form clusters and this process goes on the second level until the BS (sink) is reached. TEEN is useful for applications where the users can control a trade-off between energy efficiency, data accuracy, and response time dynamically.

TEEN uses a data-centric method with hierarchical approach. Important features of TEEN include its applicability for time critical sensing applications. Another advantage of TEEN is that more energy is consumed for message transmission as compared to data sensing, so this also reduces the energy utilization of the nodes and ultimately the entire network. However, TEEN is not suitable for sensing applications where timely reports are required since the user may not obtain any data if the thresholds are not achieved.

F. Adaptive Periodic Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN)

APTEEN is an improvement to TEEN to overcome its drawbacks and aims at both collecting the periodic data (LEACH) and also reacting to time-critical activities (TEEN). Thus, APTEEN is a hybrid clustering-based routing protocol that permits the sensor to send their sensed data on timely basis and also can react to any real time modification in the value of the sensed attribute by providing the modified data to their CHs.

The design of the network in APTEEN is same as TEEN, which incorporates the principle of hierarchical clustering for energy efficient communication between source sensors and the sink. APTEEN supports three different query types namely (i) historical query, to analyze old data values, (ii) one-time query, to get the current instance of the network; and (iii) persistent queries, to monitor an activity over a specified time duration. APTEEN ensures reduced energy utilization and the life span of the sensors also increases.

G. Energy Efficient Homogenous Clustering Algorithm For Wireless Sensor Networks

Singh et al. proposed homogeneous clustering algorithm for wireless sensor network that saves power and prolongs network life. The life span of the network is increased by ensuring a homogeneous distribution of nodes in the clusters. A new cluster head is selected on the basis of the residual energy of existing cluster heads, holdback value, and smallest hop distance of the node. The homogeneous algorithm makes sure that every node can be a cluster head or a member of one of the clusters in the wireless sensor network.

In the proposed clustering algorithm the cluster members are uniformly distributed, and thus, the life of the network is more extended. Further, in the proposed protocol, only cluster heads broadcast cluster formation message and not the every node. Hence, it increases the life span of the sensor networks. The emphasis of this approach is to increase the life span of the network by ensuring a homogeneous distribution of nodes in the clusters so that there is not much receiving and transmitting overheads on a Cluster Head.

IV. LITERATURE REVIEW

Maryam and Reza [1] in 2015 proposed “A de centralized Energy efficient hierarchical cluster based routing algorithm for wireless sensor networks”. In WSN, each sensor node reports occurred phenomena and perform local processing. These data are sent to the base station either directly or through some relay node. Finally, all data associated with a parameter will be processed and the ultimate result value is estimated fairly accurate. Here, failure of a node has almost no impact on estimated value but causes loss of coverage area and increases time for event diagnosis.

Their approach in based on concept of dividing the entire WSN into several clusters and each cluster has a cluster head for managing the operation of that cluster. Cluster head ensures proper distribution of load between nodes.

The energy for transmitting “L bit data” is given as

$$\mathbf{E_t(L, d) = L * E_{elec} + L * efs * d^2}$$

Where $\mathbf{d < d_0}$

$$\mathbf{E_t(L ,d) = L * E_{elec} + L * empf * d^4}$$

Where $\mathbf{d >= d_0}$

Where d is the transmission distance, E_{elec} is digital electronics, efs and empf are amplifier energy factors for free space and multi path fading channel models respectively. d_0 is the threshold distance that depends on the environment.

The energy for receiving data by sensor node is given by

$$\mathbf{E_r(L) = L * E_{elec}}$$

Their results show that the energy consumption has been reduced and the network lifetime has been improved significantly.

Abolfazli and Mahdavi [2] in 2014 proposed “A homogenous wireless sensor network routing algorithm: An energy aware cluster based approach”.The proposed algorithm consists of three phases as

1. Network leveling phase in which the nodes of the network are placed in the region and the network will be initialized.
2. Clustering phase in which the clusters are created and an election can be made for the selection of the cluster head for each cluster.
3. Data Transmission phase in which the nodes start communicating with each other and share their information and other information.

The energy consumption has been reduced to certain extent.

Zhao, Zhou and Gao [3] in 2012 proposed “Energy efficient and cluster based routing protocol for WSN”. Their work is based on the LEACH protocol. Low Energy Adaptive Clustering Hierarchy (LEACH) is the first routing protocol based on hierarchical clustering and a classical hierarchical routing protocol in WSN. It divides WSN in several clusters. The first step in this approach is the election for the selection of the cluster head. The second step is the transmission of data between sensor nodes in the network. This can be accomplished through clustering heads.The energy consumption has been reduced greatly and the network lifetime has been significantly improved.

Lee, Kong, Lee and Byeon[4] in 2005 proposed “Cluster Based Energy Efficient Routing Protocol without Location Information for Sensor Networks”. Their work is based on the LEACH protocol. They have proposed the use of Time Division Multiple Access (TDMA) for transmission of data and sharing of information between Cluster Nodes. The results show that there is a significant reduction in the energy consumption.

Nikolodakis, Kandris, Vergados and Douligeris[5] in 2013 proposed “Energy Efficient Routing in Wireless Sensor Networks through Balanced Clustering”. Their work is also based on the LEACH protocol and uses TDMA for transmission and sharing of data. For minimizing energy consumption, Gaussian elimination algorithm has been employed.The results show that the energy consumption has been reduced and network lifetime has been improved significantly.

Author Yi Sun and Can Cui present a dynamic clustering routing algorithm for WSN in [11]. In this paper, author proposed the algorithm comprised of three phases including cluster head (CH) selection, cluster setup and inter-cluster routing. Residual energy and node load are used for the cluster heads selection. Then the non-Cluster head nodes choose a cluster by comparing the cost function of its neighbor CHs. Multi-hop communication is used to communicate with cluster head and base station in the network.

Author Lingxia Liu and Qiang Song present a paper “A Kind of Energy-efficient Routing Algorithm for WSN Based on HQEA”[12]. In this paper author proposed a hybrid QEA-based energy efficient routing algorithm (HERA)was proposed. This algorithm is based on LEACH and PEGASIS algorithm which is used in the environment of wireless sensor networks .To minimize the distance between transmitter and receiver, this algorithm uses the hybrid quantum evolutionary algorithm (HQEA) to select the best cluster based multi-chain topology. To minimize the energy consumption, node’s maximum energy and its distance from the target is considered.

Author Liang Yuan and Chuan Cai proposed [13] load balanced routing algorithm based on uneven clustering to calculate optimal number of clusters and performing uneven clustering. Because of this, number of non CH nodes under some cluster head becomes too high which leads to death due to overload as compared to even node clustering. For this, an evaluation function will be developed, which can represent residual energy distribution of nodes and at the same time defines routing evaluation function between cluster heads in the wireless network.

Author Haifeng Jiang proposed a [14], single-hop forwarding scheme to proved the better way to consume less energy than multi-hop forwarding scheme within the communication range of the source sensor or a current forwarder. This algorithm uses free space energy consumption model. This algorithm applies the social welfare function to compute inequality of residual energy of neighbors after selecting different next hop nodes. Based on energy inequality, the method is designed to compute the degree of energy balance.

Author Xiao-Hui Li and Zhi-Hong Guan in the paper Energy-Aware Routing in “Wireless Sensor Networks Using Local Betweenness Centrality” [15], proposed an energy-aware dynamic routing strategy that provides balanced energy usage in wireless sensor networks to improve the lifetime of the network. Routing algorithm proposed by author uses local betweenness centrality to estimate the energy utilization of the nearby nodes around a given local sensing node without any need regarding global information about the network architecture or energy utilization of the entire network and in case of high traffic performs the functions like load balancing and congestion control. Because the distance between nodes are large, it centrality consumes energy more quickly, the network lifetime can be increased by redistributing energy consumption of nodes with smaller local between centrality.

Author Stefanos A. Nikolidakis in his paper [16] proposed, a new protocol called Equalized Cluster Head Election Routing Protocol (ECHERP), which perform energy conservation through balanced clustering. In his proposal, the network is modeled as a linear system that uses the Gaussian elimination algorithm to compute the set of nodes that can be selected as cluster heads in order to improve the life span of the network.

Author Yang Wang presents a paper “Distributed Energy Balance Clustering Algorithm in Wireless Sensor Networks” [17]. In this paper author focused to concentrate on the residual energy of every node including the cluster head, and every new round the cluster head will attend selecting a new cluster head. In real time applications, the atmosphere of each wireless sensor network node is unknown and may be quite different. After running some time, the residual energy of each node will goes in very much in the ideal state; that means the cluster head will remain the highest energy node in that particular cluster. To improve the life of the wireless network, the cluster head with the highest energy must be selected as the cluster head in the network again. Because of this mechanism, the message load can be reduced greatly during the process of cluster head selecting.

In Sensor Networks, the energy resources are limited because there is no external source available in network by which the nodes can retain their energy. It means that if the node has consumed its entire energy then the only option to retain the energy is the replacement of the battery for the node in network with full capability and another option is to use the energy of nodes efficiently. The efficient use of battery power means to reduce the number of packets lost and retransmissions. The routing protocol is not capable of reducing the mobility of nodes, which is the main reason for link breakdown and energy wastage. The energy efficient routing scheme utilizes the nodes power in communication.

5. CONCLUSION

Wireless sensor networks have been developed and applied to industrial, commercial, defence and civil sector applications. Energy is the main goal in sensor networks. Battery power consumption is a major issue in the sensor network environment. This article is a review of various issues of sensor network. Here sink relocation has also discussed by which such problem can be solve.

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