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A Survey of Hierarchical Routing Protocols in Wireless Sensor Networks

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Abstract:* Wireless sensor networks comprises of small size sensor nodes with sensing , computation and wireless communications capability. These sensor nodes have very limited power and their process and storage capacity as well as transmission range and energy resources are also limited. Efficient power management is utmost requirement for these sensor nodes to keep it operational by increasing its lifetime. Since sensor networks are application dependent so a single routing technique cannot cater to all necessities. There are various routing protocols like location-aided, multi-path, data centric, mobility-based, QoS based, heterogeneity-based, hierarchical routing, hybrid routing, etc., in which optimal routing can be achieved in the context of energy. As the data travels from one cluster level to another covering greater amount of distance in hierarchy based routing it improves the scalability and increases the lifetime of the wireless sensor network by distributing the power dissipation load evenly among all the sensor nodes within the network. In this paper focus is on hierachical energy aware available routings in wireless sensor networks.

***Keywords:* Routing, Cluster, Energy, Battery, Base Station.**

I INTRODUCTION

The technological advances in micro electronic mechanical systems (MEMS) have enabled the development of tiny, low-cost, low-power, and multifunctional smart sensor nodes in a wireless sensor network (WSN)[23]. Wireless Sensor Networks (WSNs) have been widely considered as one of the most important technologies for the present age. These smart sensor nodes are deployed and networked through internet and wireless links. A WSN typically consists of a large number of low-cost, low-power, and multifunctional sensor nodes that are deployed in a region of interest. These sensor nodes are small in size, but are equipped with embedded microprocessors, radio receivers, and power components to enable sensing, computation, communication, and actuation. These components are integrated on a single or multiple boards, and packaged in a few cubic inches. [22] These sensor nodes typically have several parts:
a) a radio transceiver,
b) a microcontroller,
c) electronic circuit interfacing with the nodes, and
d) a power source usually a battery .

The *main features of Wireless Sensor Networks* are as follows:

a) Dynamic Network Topology
b) Power constraint.
c) Do not have global identification.
d) Nodes are heterogeneous.
e) Nodes are prone to failures.
f) Communication failures.

Application of wireless sensor networks:

Sensor nodes are used in various application dependent events which requires constant monitoring and detection.[22][23]

Some of the applications are mentioned below:
a) Battlefield surveillances and monitoring.
b) forest fire and flood detection.
c) inventory control system.
d) green house monitoring.
e) commercial appliances at home and at industries.

f) agriculture.
g) personal heath monitoring.
h) detecting chemical, biological, radiological, nuclear, and explosive material etc.

II ROUTING IN WIRELESS SENSOR NETWORKS

Routing in sensor networks is very challenging due to several characteristics that distinguish them from contemporary communication and wireless ad-hoc networks. Wireless sensor networks are infrastructure less, wireless links are unreliable. The sensor nodes are tightly constrained in terms of transmission power, and thus require careful resource management. The sensor nodes are densely deployed either inside the sink or very close to it and have limited power, computational capacity and memory. Sensor nodes are very prone to failures. Sensor nodes may not have global identification (ID) because of the large amount of overhead. Sensor nodes are densely deployed in large numbers. Thus, the fundamental goal of a WSN is to produce information from sensed data by individual sensor mode by prolonging the life time of WSN The limited power of sensor nodes mandates the design of energy-efficient communication protocol. The traffic in wireless sensor networks causes redundancy and affects the energy and bandwidth utilization. Researchers have devised many protocols for communication, and security in wireless networks life infrastructure based networks, ad-hoc networks, mobile networks, etc.

Classification of Routing Protocols in Wireless Sensor Networks:

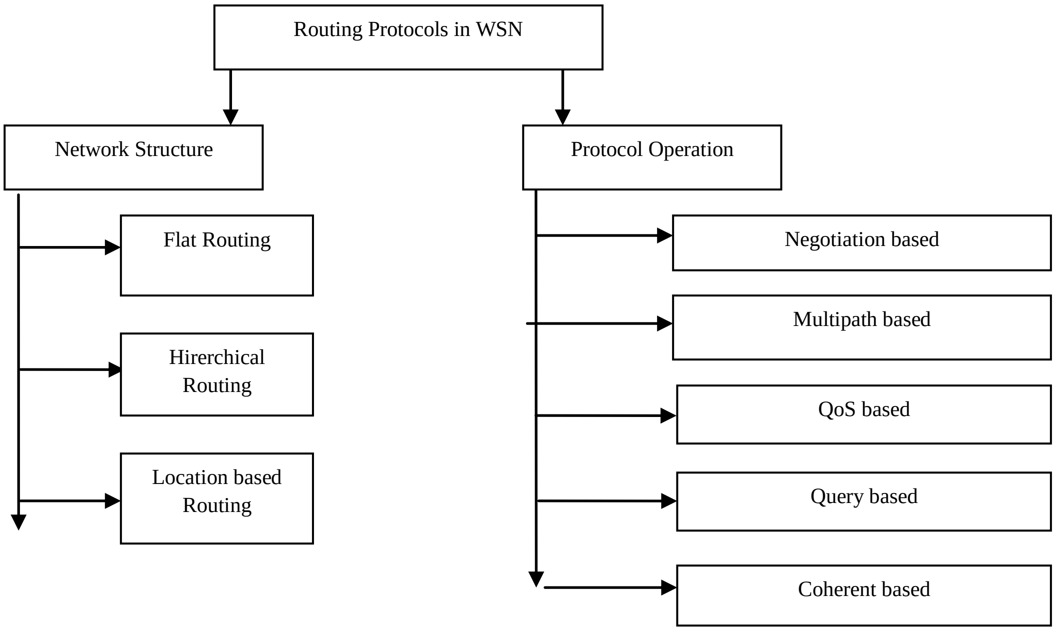

Fig 1: Taxonomy of routing protocols in WSN

In this paper energy aware hierarchical routing protocol for wireless sensor networks are discussed and compared. The paper is organized in the following way. In Section III, design issues of routing protocols. In section IV the energy-efficient hierarchical cluster routing protocols are discussed and compared. In section V literature review is done. Finally, Section VI concludes the survey.

III. DESIGN ISSUES OF ROUTING PROTOCOLS.

Initially WSNs was mainly motivated by military applications for battlefield surveillances. Civilian application domain of wireless sensor networks have been considered later, such as environmental ,production and healthcare, smart home etc. To meet this diversification, the following important design issues of the sensor network have to be considered:

a) **Fault Tolerance**: Fault tolerance is the ability to sustain sensor network functionalities without any interruption due to sensor node failures.
b) **Scalability**: Routing schemes must be scalable enough to respond to events.
c) **Operating Environment**: Sensor nodes may be deployed in any environment conditions.
d) **Power Consumption**: Sensor nodes are equipped with limited battery lifetime.
e) **Data delivery models**: Data delivery models determine when the data collected by the node has to be delivered.
f) **Data aggregation**: Data from the normal nodes are to be fused and transmitted to the cluster head of the cluster.
g) **Quality of Service**: The quality of service means the quality service required by the application.
h) **Network Dynamics**: Sensor nodes are mobile and therefore sensor network is not static.

IV ENERGY-EFFICIENT HIERARCHICAL CLUSTER ROUTING PROTOCOLS

A hierarchical approach breaks the network into clustered layers . Nodes are grouped into clusters with a cluster head that has the responsibility of routing from the cluster to the other cluster heads or base stations. Data travel from a lower clustered layer to a higher one. Clustering provides inherent optimization capabilities at the cluster heads. In the cluster-based hierarchical model, data is first aggregated in the cluster then sent to a higher-level cluster-head. As it moves from a lower level to a higher one, it travels greater distances, thus reducing the travel time and latency. This model is better than the one hop or multi-hop model.

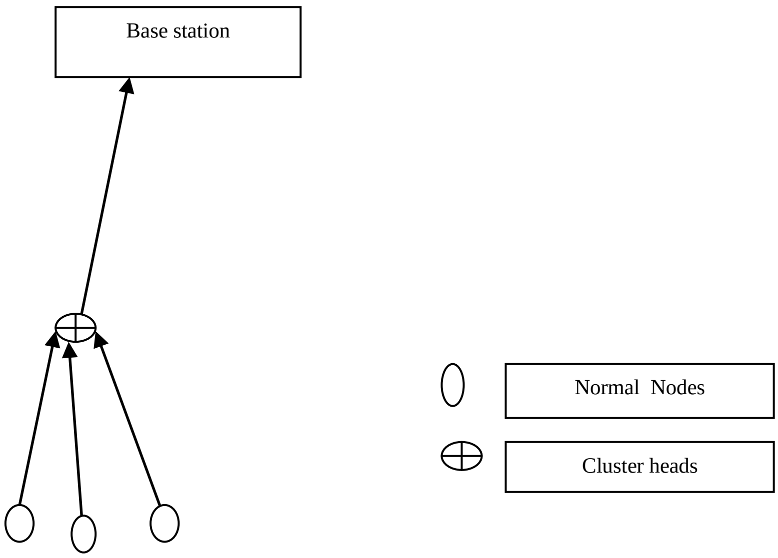

Fig 2. Cluster based hierarchical model.[7]

A cluster-based hierarchy moves the data faster to the base station thus reducing latency than in the multi-hop model.[34] Here only cluster-heads performs data aggregation whereas in the multi-hop model every intermediate node performs data aggregation. The cluster-based model is more suitable for time-critical applications than the multi-hop model. The main drawback is as the distance between clustering level increases, the energy spent is proportional to the square of the distance resulting energy overhead. Despite this drawback, a cluster-based hierarchical model offers a better approach to routing for WSNs.

The concept of hierarchical routing is to perform energy-efficient routing in WSNs and hence prolong the network lifetime. [23][33]. The creation of clusters and assigning tasks to cluster heads can contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster, performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other for routing.

V LITERATURE REVIEW

Heinzelman, *et al.* [2000] introduced a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH) [1]. LEACH is a cluster-based protocol, which includes distributed cluster formation. LEACH randomly selects a few sensor nodes as cluster heads (CHs) and rotates this role to evenly distribute the energy load among the sensors in the network. In LEACH, the CH nodes compress data arriving from nodes that belong to the respective cluster, and send an aggregated packet to the BS in order to reduce the amount of information that must be transmitted to the BS. LEACH uses a TDMA/code-division multiple access (CDMA) MAC to reduce inter-cluster and intra-cluster collisions. Data collection is centralized and performed periodically. Therefore, this protocol is most appropriate when there is a need for constant monitoring by the sensor network. The operation of LEACH is separated into two phases, the setup phase and the steady state phase. In the setup phase, the clusters are organized and CHs are selected. In the steady state phase, the actual data transfer to the BS takes place. During the setup phase, a predetermined fraction of nodes, p, elect themselves as CHs as follows. A sensor node chooses a random number, n, between 0 and 1. If this random number is less than a threshold value, $T(n)$, the node becomes a CH for the current round. The threshold value[1] is calculated based on an equation that incorporates the desired percentage to become a CH, the current round, and the set of nodes that have not been selected as a CH in the last ($1/P$) rounds, denoted G. It is denoted by

$$T(n)= \frac{P}{1-p(r \bmod (1 \div p))} \quad \text{if } n \in G$$

where G is the set of nodes that are involved in the CH election.[1]

Heinzelman in 2000 proposed LEACH-F a modified version of LEACH with fixed clusters and rotating cluster heads[24].Here clusters are formed once and are fixed, and the cluster head's position rotates among the nodes within the cluster.There is no set-up overhead as CHs are formed only once.

Savvides et al. in 2001 proposed Hierarchical-PEGASIS [26] is an extension to PEGASIS, which aims at decreasing the delay incurred for packets during transmission to the base station and proposes a solution to the data gathering problem by considering energy × delay metric. In order to reduce the delay in PEGASIS, simultaneous transmissions of data messages are transmitted. Avoidance of collisions and possible signal interference among the sensors,is done by signal coding, e.g. CDMA and in the second approach only spatially separated nodes are allowed to transmit at the same time. The chain-based protocol with CDMA capable nodes, constructs a chain of nodes, that forms a tree like hierarchy, and each selected node in a particular level transmits data to the node in the upper level of the hierarchy. This method ensures data transmitting in parallel and reduces the delay significantly. Such hierarchical extension has been shown to perform better than the regular PEGASIS scheme [26].

Manjeshwar et al. in 2001 proposed Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN). TEEN [7] is a hierarchical clustering protocol, which groups sensors into clusters with each led by a CH. The sensors within a cluster report their sensed data to their CH. The CH sends aggregated data to higher level CH until the data reaches the sink. TEEN uses a data-centric method with hierarchical approach. TEEN is a clustering communication protocol that targets a reactive network and enables CHs to impose a constraint on when the sensor should report their sensed data. After the clusters are formed, the CH broadcasts two thresholds to the nodes namely (i) hard threshold (*HT*), and (ii) soft threshold (*ST*) [7]. Hard threshold is the minimum possible value of an attribute, beyond which a sensor should turn its transmitter ON to report its sensed data to its CH. Thus, the hard threshold allows the nodes to transmit only when the sensed attribute is in the range of interest, thus reducing the number of transmissions significantly. Once a node senses a value at or beyond the hard threshold, it transmits data only when the value of that attribute changes by an amount equal to or greater than the soft threshold, which indicates a small change in the value of the sensed attribute and triggers a sensor to turn ON its transmitter and send its sensed data to the CH. As a consequence, soft threshold will further reduce the number of transmissions for sensed data if there is little or no change in the value of sensed attribute. Thus, the sensors will send only sensed data that are of interest to the end user based on the hard threshold value and the change with respect to the previously reported data, thus yielding more energy savings. Suitability for time critical sensing applications,less enegy consumption than proactive networks are important characteristics of TEEN. At every cluster change time, fresh parameters are broadcast and so, the user can change the soft threshold as required. The main drawback is that TEEN is not suitable for sensing applications where periodic reports are needed since the user may not get any data at all if the thresholds are not reached.

Heinzelman et al. in 2002 proposed application specific protocol architecture for WSN known as LEACH-C [25]. LEACH-C uses a centralised clustering algorithm and the same steady state phase as LEACH. LEACH-C is more efficient than LEACH because it delivers 40% more data per unit [25]energy than LEACH.

Manjeshwar et al. in 2002 proposed the Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN)[8]. APTEEN is an improvement to TEEN to overcome its shortcomings and aims at both capturing periodic data collections (LEACH) and reacting to time-critical events (TEEN). Thus, APTEEN is a hybrid clustering-based routing protocol that allows the sensor to send their sensed data periodically and react to any sudden change in the value of the sensed attribute by reporting the corresponding values to their CHs. The architecture of APTEEN is same as in TEEN, which uses the concept hierarchical clustering for energy efficient communication between source sensors and the sink. When the base station forms the clusters, the CHs broadcast the transmission schedule to all nodes, and a maximum time interval between two successive reports sent to a sensor, called count time (*TC*). CHs also perform data aggregation in order to save energy. APTEEN supports three different query types namely (i) analyzing past data values, (ii) one-time query, to take a snapshot view of the network; and (iii) persistent queries, to monitor an event for a period of time. APTEEN guarantees lower energy dissipation and a larger number of sensor alive.

Lindsey et al. in 2002 proposed Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [6], a near optimal chain-based protocol that is an improvement over LEACH. In PEGASIS, each node communicates only with a close neighbor and takes turns transmitting to the base station, thus reducing the amount of energy spent per round. PEGASIS, a greedy chain protocol that is near optimal for a data- gathering problem in sensor networks. PEGASIS outperforms LEACH by eliminating the overhead of dynamic cluster formation, minimizing the distance non leader-nodes must transmit, limiting the number of transmissions and receives among all nodes, and using only one transmission to the BS per round. Nodes take turns to transmit the fused data to the BS to balance the energy depletion in the network and preserves robustness of the sensor web as nodes die at random locations. Distributing the energy load among the nodes increases the lifetime and quality of the network.

An Energy Efficient Clustering Scheme (EECS)[27] [23] is a clustering algorithm in which cluster head candidates compete for the ability to elevate to cluster head for a given round. The candidates broadcast their residual energy to neighboring candidates and if a given node has higher residual energy in comparison to other candidate nodes , it becomes a cluster head. Dynamic sizing of clusters based on cluster distance from the base station determines the cluster heads. Clusters at a greater range from the base station requires more energy for transmission than those that are closer. The distribution of energy throughout the network is improved, resulting in better resource usage and extended network life time. EECS is a LEACH-like clustering scheme, where the network is partitioned into a set of clusters with one cluster head in each cluster. Communication between cluster head and BS is single-hop.In the network deployment phase, the BS broadcasts a "hello" message to all the nodes at a certain power level. Based on the received signal strength each node can compute the approximate distance to the BS. It helps nodes to select the proper power level to communicate with the BS and is used to balance the load among cluster heads. In cluster head election phase, well distributed cluster heads are elected with a little control overhead. And in cluster formation phase, a novel weighted function is introduced to form load balanced clusters.

Younis et al.(2004) proposed a Hybrid Energy efficient Distributed Clustering (HEED). HEED [12] protocol, which terminates in a constant number of iterations, independent of network diameter. Simulation results demonstrate that HEED prolongs network lifetime, and the clusters it produces exhibit several appealing characteristics. HEED parameters, such as the minimum selection probability and network operation interval, can be easily tuned to optimize resource usage according to the network density and application requirements. The main objectives of HEED are given below:

• To prolong network lifetime distribution of energy consumption is done.
• Minimize energy during the clusterhead selection phase
• Minimize the iterations in clustering process to control overhead of the network.

The most important aspect of HEED is the method of cluster-head selection. Cluster-heads are determined based on two important parameters[12] :

1)The residual energy of each node is used to choose the initial set of cluster-heads.

2) Intra-Cluster Communication Cost is used by nodes to determine the cluster to join. This is especially useful if a given node falls within the range of more than one cluster-head. The power level used by a node for intra-cluster announcements and during clustering is referred to as cluster power level. High cluster power levels are required for inter-cluster communication as they span more than one cluster areas. While choosing a cluster, a node will communicate with the cluster head that yields the lowest intra-cluster communication cost. The intra-cluster communication cost is measured using the Average Minimum Reachability Power (AMRP) measurement . The AMRP is the average of all minimum power levels required for each node within a cluster range R to communicate effectively with the cluster head . The AMRP [12][5] of a node then become a measure of the expected intra-cluster communication energy if this node is elevated to cluster head.

Yueyang et al. in 2006 proposed Energy Balancing PEGASIS (EB-PEGASIS): EB-PEGASIS [28] is an energy efficient chaining algorithm in which a node will consider average distance of formed chain. EB-PEGASIS can guarantee approximately the same in consumed energy of sensor nodes, and avoid the dying of some nodes early than other nodes to prolong the lifetime of sensor networks.

Xiangning et al. in 2007 improves the cluster head selection procedure in LEACH and proposed a protocol energy LEACH or E-LEACH [29] .It makes residual energy of the node as the main metric which decides whether the nodes turn into CH or not after the first round. The nodes are randomly selected as CHs, in the first round with the same probability, in the next round the residual energy of each nodes is different after one round communication and taken into account for the selection of the CHs. The nodes with more energy will become the CH rather than the nodes with less energy.

Loscri et al. proposed Two-Level Hierarchy LEACH (TL-LEACH) [21] is a proposed extension to the LEACH algorithm. It has two levels of cluster heads -primary and secondary. Here, the primary cluster head in each cluster communicates with the secondaries, and the corresponding secondaries in turn communicate with the nodes in their sub-cluster. Data fusion and communication within a cluster is scheduled using TDMA time-slots. The organization of a round will consist of first selecting the primary and secondary cluster heads using the same mechanism as LEACH, with the a priori probability of being elevated to a primary cluster head less than that of a secondary node. The communication of source to sink is done as follows: Secondary nodes collect data from nodes in their respective clusters. Primary nodes collect data from their respective secondary clusters. TL-LEACH reduces the amount total energy usage.

Yassien et al. in 2009 proposed V-LEACH, a new version which aims to reduce energy consumption within wireless networks.The main concept behind V-LEACH[30] is that besides having a CH in the cluster, there is a vice CH that takes the role of CH when the CH dies. Thus the Cluster node data will always reach the BS, no need to elect a new CH every time the CH dies which will extend the lifetime of the network and minimize the loss of data.

Richard Waiguru in 2009 proposed H-LEACH [31] by introduction of master cluster heads which is responsible of transmitting data to base station. It employs the same clustering scheme as LEACH during initial phases and later extends LEACH by further clustering the cluster heads, which then acts as master cluster head (MCH), to forward the data to the base station. The main drawback of this scheme is the central point of failure may occur when the MCH dies.

Kalpana Sharma et al. in 2010 proposed Power efficient Routing & Increased Yield Approach for WSNs (PRIYA) [33].It is a hierarchical cluster based routing protocol which improves the scalability as the data travels from one cluster level to another covering a greater amount of distance. It increases the lifetime of the wireless sensor network by distributing the power dissipation load evenly among all the sensor nodes within the network. Protocol facilitates the concept of Hierarchical Cluster-Based routing for efficient routing of data and the sensor nodes communicate directly with the BS minimizing the delay occurred in transmitting critical data. The evenly distribution of work load among the nodes ensure lesser power dissipation hence increasing the yield. The protocol is designed to fit for a particular environment by allowing the user to define the range of desired data resulting in greater and efficient yield along with power efficient routing of data.

Lee et al. proposed cluster based routing protocol [34]. The main strategy of the CBERP is to use a clustering approach to aggregate data and minimize on-demand route discovery traffic, reduce travel time and latency. Clustering mechanism of LEACH and the chaining mechanism of PEGASIS is used and it makes the lifetime of sensor networks longer than other protocols. CBERP divides nodes into clusters and selects the headers that gather and transmit the data from their member nodes as in LEACH-C. However, CBERP advances the header selection mechanism by utilizing a number of candidate nodes to reduce the overhead. After selecting the headers in this way, it forms a chain of the headers and send data through the chain as in PEGASIS.

Al-Refai et al. in 2011 proposed EFFICIENT ROUTING LEACH (ER-LEACH) [32] enhanced on leach protocol in wireless sensor networks . ER-LEACH proposes vital solutions to some shortcomings of the pure LEACH[1]. ER-LEACH is expected to perform well especially when the mobility is high and will prolong the overall network lifetime through load balancing.

There are three contributions which are:

(1)For CH selection the residual energy is the deciding criteria after the first round.

(2) Formation of A-CH which will act as a CH in the event if the CH dies.

(3) The concept of Zone Routing Protocol is used which attempts to balance the load over CHs evenly by permitting the CH to discover the optimal route to the BS with less cost messages update and then sends the fused data to the BS through many other CHs instead of direct sending to the BS.

VI CONCLUSION

In this paper recent research works focused mainly on the energy efficient hierarchical cluster-based routing protocols for WSN are discussed and summarized. As this is a broad area, this paper has covered only few sample of routing protocols. The protocols discussed in this paper have individual advantages and disadvantages. One of the major concern in WSN is energy efficiency due to resource and power constraints of the sensor nodes. Therefore main strategy behind developing a routing protocol in WSN is to be energy efficient and extended network lifetime. The factors affecting cluster formation and CH communication are open issues for future research. Moreover, the process of data aggregation and fusion among clusters is also an interesting problem to explore. Fault tolerance is a research issue for minimization of the problems faced by the failure of the cluster heads and master cluster heads which causes central point of failure in some instances.

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