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A Brief Review on Hierarchical Routing in Wireless Sensor Networks

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Abstract: *Wireless Sensor Network (WSN) is an emerging research field in the scientific world. Sensor nodes are power limited main components of WSNs which are scattered in the sensor field. Basically sensor nodes are small tiny devices that have responsibilities of sensing the surrounding, computation and communication of sensed data. To enhance the durability of sensor network and to make energy efficient routing protocol, are two special needs of WSN. This paper gives a brief introduction about the WSNs including its routing issues and limitations. In hierarchical routing, nodes are organized in the form of cluster. Each cluster has a special node called cluster head to perform data transmission from all its members to the base station. This paper provides a brief review of hierarchical routing protocols and compared them on various parameters such as architecture, cluster head election criteria, number of hops, heterogeneity level etc.*

Keywords: Hierarchical Routing, Energy Efficiency, Routing Protocols, Wireless Sensor Networks

1. INTRODUCTION

A Wireless Sensor Network (WSN) is defined as a collection of low-power, short-lived, multi-functional sensor nodes which are restricted in memory capacity and radio range [1]. These sensors are provided with wireless interfaces with which they can communicate with one another to form a network. A very important and of course a basic function of WSN is to monitor the target area for a long period of time. These sensors are deployed in unreachable areas where refilling the sensor energy is usually impossible, a key issue in wireless sensor network applications is conserving sensor energy and prolonging the network lifetime [2]. Figure 1 shows the widely adopted architecture of WSNs. Sensor nodes are usually scattered in a sensor field, which is an area where the sensor nodes are deployed. When a large number of nodes are present to monitor a phenomenon in an area, great amount of accuracy is obtained.

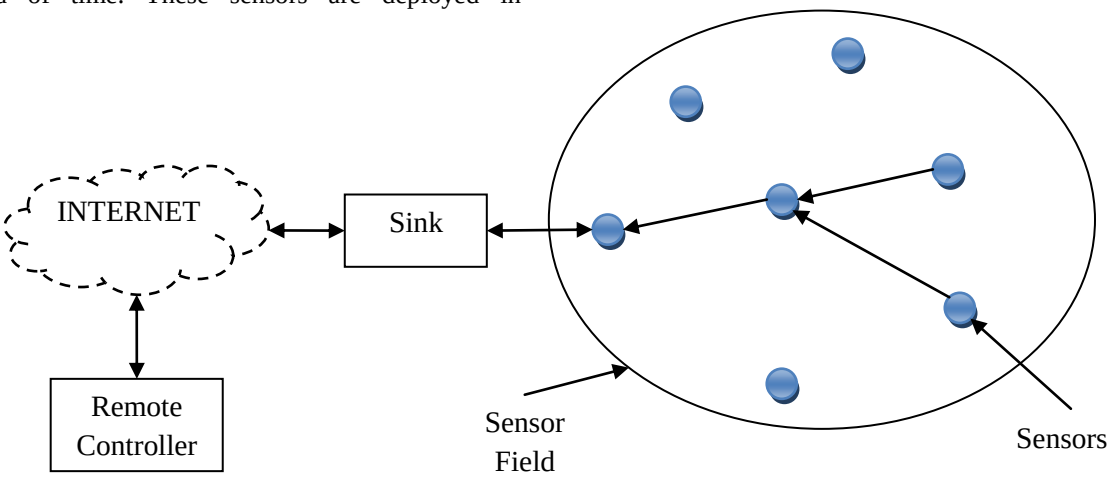

Figure 1: Architecture of Wireless Sensor Networks [2]

Basically, a sensor node comprises of three basic components as illustrated in figure 2 i.e. Sensing subsystem, Processing subsystem and Radio subsystem. These components are used for data acquisition, local data processing and for wireless communication [3]. In addition, a mobilizer - to change the location or configuration and a location finding subsystem - to find the location of sensors are also present. A power unit is also attached. Sensor nodes coordinate among themselves to produce high-quality information about the physical environment. The decision of the sensor nodes for transmitting the data is based on the information it currently has and also on the knowledge of the computing capacity, energy resources and communication. Each of these sprinkled sensor nodes, has the capacity to collect and route data either to other sensors or back to an external base station (BS).

2. CRITICAL ISSUES OF WSNs

The main design goal of WSN is not only to transmit the data between source and destination but is also to increase the network lifetime; which can achieved by applying an energy efficient protocol. The task of the protocol is not only to choose a path having lower energy consumption between sources to destination, but also to find an efficient approach to prolong the network lifetime.

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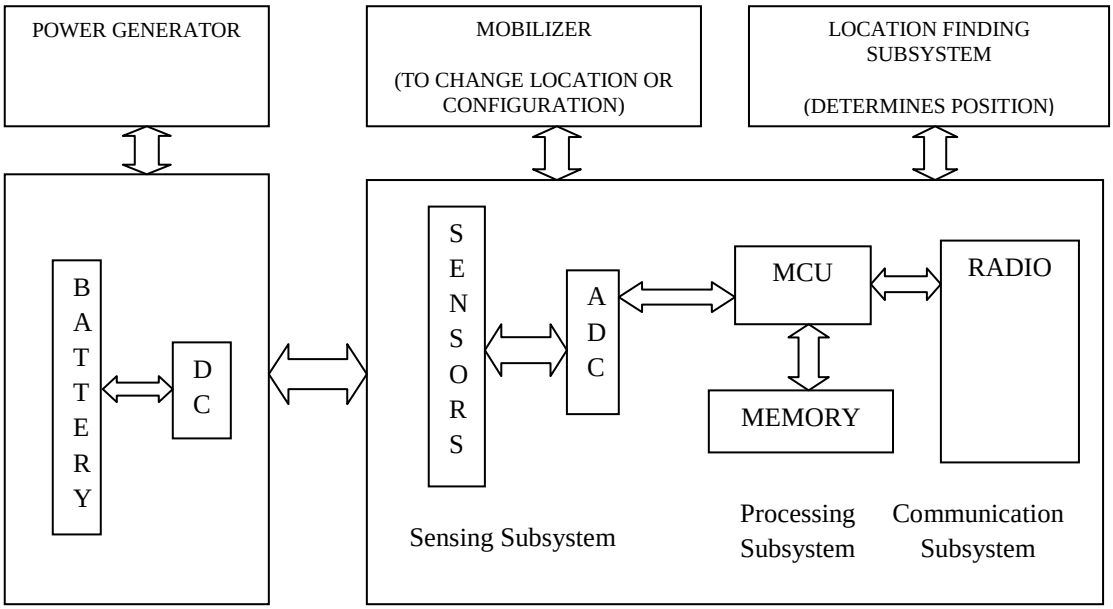

Figure 2: Architecture of a Sensor Node [4]

But sometimes continuous use of low energy path may lead to energy depletion of sensor nodes in that path leading to network partition.

Performance of the routing protocol is calculated based on some terms which includes [1]:-

a) Energy per Packet:- The amount of energy required for sending a packet from source to destination safely.

b) Low Energy Consumption: - It includes such protocols that consider the remaining energy level of nodes and selects route accordingly for longevity of the network.

c) Total Number of Nodes Alive: - It gives an idea of the area coverage of the network over time. This metric is related to network lifetime.

d) Average Packet Delay: - This metric measures the accuracy of packet. This metrics is calculated as one way latency which is observed between transmission and reception of data packet at the sink.

e) Time until the First Node Dies: - This metric indicates the duration for which all the sensor nodes on the network are alive. There are protocols in which the first node on the network runs out of energy earlier than in other protocols, but manages to keep the network operational much longer.

f) Energy Spent per Round. This metric is related to the total amount of energy spent in routing messages in a round. It is a short-term measure designed to provide an idea of the energy efficiency of any proposed method in a particular round.

g) Packet Size: - The lifetime of the network also depends on the packet size; it determines the time for which a transmission will last. As it is effective in energy consumption so packet size should be reduced by combining large number of packets.

h) Distance: - The distance between the transmitter and receiver can affect the power that is required to send and receive packets. The routing protocols can select the shortest paths between nodes and reduce energy consumption.

3. LIMITATIONS OF WSNs

Whether the WSNs have unlimited applications and starting to become a reality in this world, but WSNs have some limitations such as:-

- Low Energy
- Durability of Network
- Dynamic Topology
- Application-specific Dependency
- Low Power
- Limited Computational Resources
- Cluster Formation and Cluster Head Selection
- Security Issues
- Synchronization
- Data Aggregation
- Repair Mechanisms
- Quality of Service (QoS)

To make network stability long last it is required that the sensor nodes should consume less energy and become available in the network for long time. Thus energy consumption is an important issue of WSNs. [4]

4. ROUTING PROTOCOLS IN WSNs

Routing in WSNs is more difficult these days due to following reasons [1]. First, Sensor nodes require careful supervision of resources. Second, WSNs are quite operation specific. Third, position of sensor nodes should be known at the time of data collection. Fourth, Data collected at the base station has higher possibility of redundancy. Due to such disparities, various routing algorithms have been developed. It has been said that the protocols having higher energy efficiency will improve the longevity of network.

The routing protocols can be classified into four main schemes [5]:

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Network Structure Scheme - the protocols are classified on the basis of uniformity amongst nodes. Communication Model Scheme - the protocols are classified on the basis of how the data is routed towards the base station in packets.
Topology Based Scheme - the sensor nodes have to maintain the topological information of sensor topology.
Reliable Routing Scheme - the protocols are here classified as how reliable a protocol is in terms of route failures.
Network Structure Scheme: - The protocols based on network structure can be classified on the basis of node uniformity. The nodes when are deployed uniformly over an area to form a network. It depends on networks whether they consider that all the nodes are equal to each other, while some other networks make distinction between different nodes of the network. More specifically, the main characteristic of the routing protocols that fit in to this category, it is the way that the nodes are connected and they route the information based on the networks architecture. This class includes flat and hierarchical protocols.
a. Flat Protocols: - All the nodes in the network play the similar role. Flat network architecture presents several advantages, including minimum overhead to preserve the infrastructure between communicating nodes. It is divided into Pro-active and Re-active protocols.
1. Pro-active Protocols:- The nodes periodically exchanges data between themselves and generate a routing table which is used to find the path to destination. These tables respond to the changes in the network by sending updates throughout the network. The route is discovered initially; thus no extra delay due to route discovery at the time of packet forwarding.
2. Re-active Protocols: - (On Demand) the protocols in this category start route discovery procedure when required. When a route from source to destination is needed then a global search procedure starts, this process causes delay as the routes are not available and need to be found. Sometimes routes are found in caches maintained by the sensor nodes.
b. Hierarchical Protocols: - It is also called Cluster Based Routing [6]. The routing protocols in this category force a structure on the WSNs to provide energy efficient communication and scalability to the network. The network nodes are organized into clusters and based on some criteria a cluster head for each cluster is selected i.e. higher energy nodes are used to route the data and lower energy nodes are used to sense the area. Figure 3 illustrates the clustering based scheme of WSNs. The cluster heads are then responsible for organizing the activities within the cluster. In hierarchical routing, the numbers of messages that are transferred to the base-station are decreased due to fusion and data aggregation thus it lowers the energy consumption and hence helps to improve the lifetime of the network. In such protocols, the nodes around the base station and cluster head will exhaust their energy faster than all the other nodes.

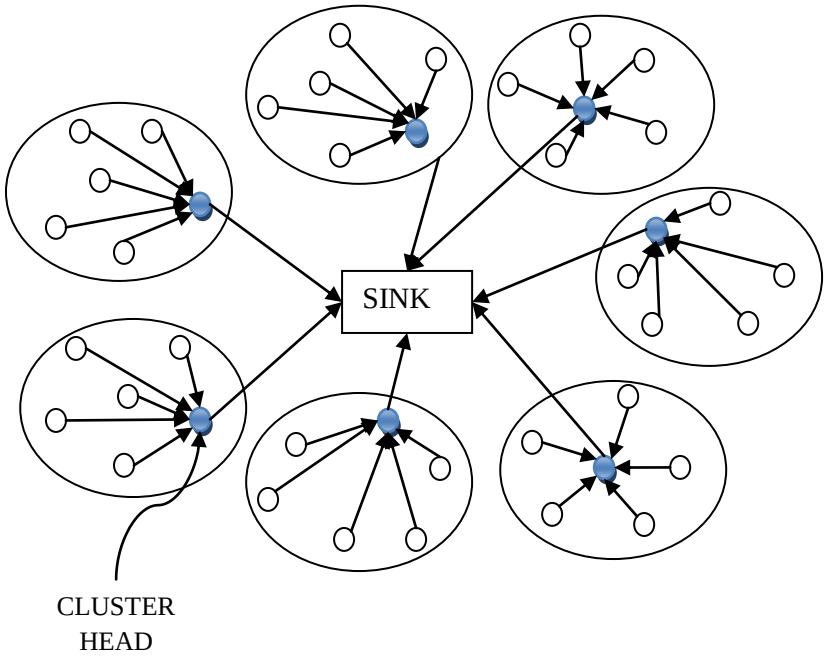

Figure 3: Clustering Schema for Wireless Sensor Networks [5]

Some of the well known protocols under this section are: -
A. LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY - CENTRALIZED (LEACH-C): -
Since LEACH has a problem of determining the number of cluster heads in every round. For the formation of clusters LEACH-C utilizes the base-station [7]. In LEACH the nodes configure themselves to form clusters, but in LEACH-C at each iteration or round the base-station first receives the information about location, state and the energy level of the nodes. This information is used then to calculate the mean value of network node energy; and base-station finds predetermined number of cluster heads and hence configures the network into clusters. The nodes that are selected as cluster head have higher energy level that the mean energy value. LEACH-C is an improvement over LEACH by the following points: First, to produce clusters that require less

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energy for transmission Base-Station utilizes it global knowledge of the network, Second, unlike LEACH where the number of cluster head varies from round to round due to lack of global coordination amongst nodes, in LEACH-C the number of cluster heads in each round equals a predetermined optimal value [8].

B. TEEN Protocol

Threshold sensitive Energy Efficient sensor Network protocol (TEEN) [9] is also a cluster-based hierarchical routing protocol like LEACH i.e. the nodes form clusters and selection of CH for transmission of data to BS. It uses both hierarchical technique and data-centric approach. Transmission of data is done less frequently so it saves energy efficiently. It is reactive protocol in which nodes are sensitive to certain activities like temperature weather etc. so reactive protocols are best suited for time critical activities. While inside LEACH, absolutely no certain action are generally driven therefore it is a proactive protocol. The actual nodes behave instantly for immediate and also for extreme changes in the value of a sensed attribute. A pair of Thresholds is employed to check sensing changes:

(1) Hard threshold: This threshold value is assigned by the CH to the sensed attribute. When sensor node's sensed value is larger than the hard threshold value then this is the sign for nodes to switching on its transmitter and inform to its CH.

(2) Soft threshold: This is the value of the sensed attribute if this value has some small change then it imply the node to switch on its transmitter and transmit. So, data transmission happen only in two conditions either the sensed data value is larger than the hard threshold value or changes in the value of sensed attribute is greater than/ equal to the soft threshold value.

C. SEP Protocol

A network which consist number of nodes with same level of energy means all sensor nodes are equipped with significantly equal amount of energy then such networks are known as Homogeneous sensor network. Discussed routing schemes LEACH, LEACH C, TEEN are advisable only for homogenous sensor network. So for heterogeneous purpose in terms of energy, Stable election protocol (SEP) [10] was proposed which carried two level heterogeneity for sensor network. Here two-level heterogeneous sensor network means out of the total population of sensor nodes, some nodes are having significant more battery power (energy) then the remaining nodes in the sensor network.

D. DEEC Protocol

In Distributed Energy Efficient Clustering (DEEC) [11], selection of CHs is not only based on the election probability. In addition DEEC protocol merges a ratio of residual energy of each node and the average energy of network to the election probability. The nodes with high initial and residual energy will have more chances to become the CH than the other nodes with low energy. In DEEC protocol election probability of each node include residual energy and average energy of network. Table 1 shows the comparison of various hierarchical routing protocols in WSNs.

LEACH, LEACH-C, TEEN, SEP and DEEC is compared based on various performance criteria such as architecture, cluster stability, cluster head selection criteria, heterogeneity level, number of hops and network global knowledge. TEEN shows very high cluster stability as compared to other protocol and it does not require any global knowledge.

Table 1: Comparison of various Routing Protocols

Performance Criteria	**LEACH**	**LEACH-C**	**TEEN**	**SEP**	**DEEC**
Architecture	Distributed	Centralized	Distributed	Distributed	Distributed
Cluster Stability	Lower	Higher than LEACH	Very High	Moderate	High
CH Selection Criterion	Probabilistic Approach	Nodes Energy and Distance	Randomly	Based on Initial and Residual Energy	Initial , Residual and Average Energy
Heterogeneity Level	Not present	Not present	Not present	Two-level	Multilevel
Number of Hops	Single Hop	Single Hop	Multi-Hop	Multi-Hop	Multi-Hop
Network Global Knowledge	Not Required	Required	Not Required	Not Required	Not Required

5. CONCLUSION AND FUTURE SCOPE

This paper gives a brief introduction about the wireless sensor network including its routing issues, limitation and review of various hierarchical routing protocols. Hierarchical routing protocols such as LEACH, LEACH-C, TEEN, SEP and DEEC is compared based on various performance criteria such as architecture, cluster stability, cluster head selection criteria, heterogeneity level, number of hops and network global knowledge. TEEN shows very high cluster stability as compared to other protocol and it does not require any global knowledge. In future, we will consider TEEN protocol and try to increase the network lifetime of wireless sensor network.

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