Hierarchical Routing Protocol in Wireless Sensor Network – A Survey

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Abstract—The area of Wireless Sensor Networks (WSN) is one of the most emerging and fast growing fields in the scientific world. It consists of a collection of sensing devices and these sensing devices are known as sensor nodes. Each sensor nodes are deployed into the network to monitor the physical or environmental condition such as temperature, sound, vibration at different location. The data is transfer over the network and each sensor node consumes some energy in sending data and receiving data. In WSN, the lifetime of the network depend how much energy spent in each transmission. The efficient use of energy source in a sensor node is most desirable criteria for prolong the life time of wireless sensor network. So designing efficient routing protocol for reducing energy consumption is the important issue in the network. A large number of routing protocol has been proposed since few decades. Some of the most popular routing protocols are LEACH, PEGASIS, TEEN, APTEEN and HEED. This paper reviews each hierarchical routing protocol for wireless sensor networks and describe under the appropriate category. We also highlight the advantage, disadvantage and area of application of each routing technique. Finally, we provide a comparative study on these various hierarchical routing protocols in wireless sensor network.

Index Terms— Wireless network, sensor devices, routing protocol, energy efficiency.

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1 INTRODUCTION

A wireless sensor network (WSN) is a group of specialized transducers with a communications infrastructure that uses radio to monitor and record physical or environmental conditions. It is a self-organized network composed by a large number of micro sensors that are randomly deployed in monitoring regional through wireless communication [1]. Each of the sensor nodes are scattered in the sensor field which is situated far away from the user [2]. These sensors nodes have gained more importance due to the advancement of Micro-Electro-Mechanical Systems (MEMS) [3]. In computer science and telecommunications, wireless sensor networks are an active research area with numerous workshops and conferences arranged each year .The basic goals of WSNs are as follows

I.   Determine the value of physical variables at a given location.
II.   Detect the occurrence of events of interest, and estimate parameters of the detected event or events
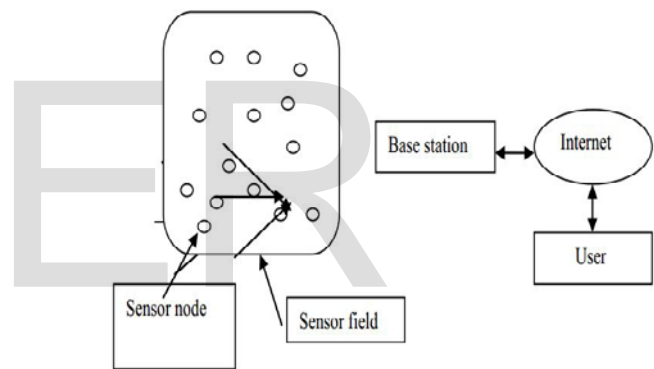III.   Classify a detected object and also track an object.

Fig. 1: An Example Wireless Sensor Network

The main aim of Wireless sensor network routing protocol approaches is to find routes that result in prolonged lifetime of the entire sensor network. The most important applications of WSN include military applications like battlefield, environmental applications, health applications, home applications, other commercial applications [4]. In WSN smart sensors nodes are used extensively used in tele-monitoring, tracking moving objects, home automation, telemedicine and industrial applications [5]. The WSN consists of sensor nodes which are resource constrained and these sensor nodes are deployed for collecting information from the various sensor field.

Hierarchical cluster-based routing protocols are well-known techniques with special advantages related to scalability and efficient communication in wireless sensor network. The concept of hierarchical routing protocol is also utilized to perform

energy-efficient routing in sensor network. In a hierarchical architecture, higher energy sensor nodes can be used to process and send the information while low energy sensor nodes can be used to perform the sensing in the proximity of the target efficiently.

There are two types of sensor networks homogeneous sensor networks and heterogeneous sensor networks. In homogeneous sensor networks all sensor nodes are equipped same quantity of links, computational resource and energy. This type of network cannot be assumed because different sensor nodes do not always have the same communication and sensing capabilities. The fact that sensor nodes use the same platform does not guarantee that they will have exactly the same physical properties [6].

A heterogeneous sensor node in wireless sensor network is an effective way to increase network lifetime and reliability. There are three common types of resource heterogeneity in sensor node: computational heterogeneity, link heterogeneity, and energy heterogeneity [7]. Computational heterogeneity means that the heterogeneous node has a more powerful microprocessor and larger memory than the normal sensor node. With the powerful computational resources, the heterogeneous sensor nodes can provide complex data processing and longer-term storage. Link heterogeneity means that the heterogeneous sensor node has high-bandwidth and long-distance network transceiver than the normal sensor node. Link heterogeneity can provide more reliable data transmission. Energy heterogeneity means that the heterogeneous node is line powered and its battery is replaceable. Among above three types, the most important heterogeneity is the energy heterogeneity because both computational heterogeneity and link heterogeneity will consume more energy resource. If there is no energy heterogeneity, computational heterogeneity and link heterogeneity will bring negative impact to the whole network, i.e., decreasing the network lifetime [8]. Heterogeneous nodes in the sensor network can bring following three main benefits are prolonging network lifetime, improving reliability of data transmission, decreasing latency of data transportation.

2 APPLICATION OF WIRELESS SENSOR NETWORK

2.1 Process Management

Area monitoring is a common application of wireless sensor network. In area monitoring, the WSN is deployed over a region where some phenomenon is to be monitored. A military example is the use of sensors detects enemy intrusion; a civilian example is the geo-fencing of gas or oil pipelines.

2.2 Health Care Monitoring

The medical applications can be of two types: wearable and implanted. Wearable devices are used on the body surface of a human or just at close proximity of the user and implantable medical devices are those that are inserted inside human body. There are many other applications too e.g. body position measurement and location of the person, overall monitoring of ill patients in hospitals and at homes. Body-area networks can collect information about an individual's health, fitness, and energy expenditure [9].

2.3 Air Polution

Wireless sensor networks have been deployed in several cities to monitor the concentration of dangerous gases for citizens. These can take advantage of the ad hoc wireless network links rather than wired installations, which also make them more mobile for testing readings in different areas.

2.4 Forest Firest Detection

A network of Sensor Nodes can be installed in a forest to detect when a fire has started. The sensor nodes can be equipped with sensors to measure temperature, humidity and gases which are produced by fire in the trees or vegetation. The early detection is crucial for a successful action of the firefighters.

2.5 Water Quality Monitoring

Water quality monitoring involves analyzing water properties in dams, rivers, lakes & oceans. The use of many wireless distributed sensors enables the creation of a more accurate map of the water status. It allows the permanent deployment of monitoring stations in locations of difficult access, without the need of manual data retrieval [10].

2.6 Data Logging

Wireless sensor networks are also used for the collection of data for monitoring of environmental information. This can be as simple as the monitoring of the temperature in a fridge to the level of water in overflow tanks in nuclear power plants.

2.7 Landslide Detection

A landslide detection system makes use of a WSN to detect the slight movements of soil and changes in various parameters that may occur before or during a landslide. Through the data gathered it may be possible to know the occurrence of landslides long before it actually happens.

2.8 Structural Health Monitoring

Wireless sensor networks can be used to monitor the condition of civil infrastructure and related geo-physical processes close

to real time using appropriately interfaced sensors nodes.

3 CHARACTERISTICS OF WIRELESS SENSOR NETWORK

The main characteristics of a WSN include:

- ❖ Power consumption constraints for nodes using batteries or energy harvesting
- ❖ Ability to cope with node failures
- ❖ Mobility of nodes
- ❖ Heterogeneity of nodes
- ❖ Scalability to large scale of deployment
- ❖ Ability to withstand harsh environmental conditions
- ❖ Ease of use
- ❖ Cross-layer design.

4 .HIERARCHICAL PROTOCOLS

A single-tier network can cause the gateway to overload with the increase in sensors density. Such overload might cause latency in communication and inadequate tracking of events and the single-gateway architecture is not scalable for a larger set of sensors covering a wider area of interest since the sensors are typically not capable of long-haul communication. The main goal of hierarchical routing protocol is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink nodes.

4.1 Low-Energy Addaptive Clustering Hierarchy

Low-energy adaptive clustering hierarchy (LEACH) [11, 12] is the first and most popular energy efficient hierarchical clustering algorithm for WSNs that was proposed for reducing power consumption. LEACH is one of the most popular distributed cluster-based routing protocols in wireless sensor network. It uses localized coordination to enable scalability and robustness for dynamic networks, and incorporates data fusion into the routing protocol to reduce the amount of information that must be transmitted to the base station [11]. The main goal of the LEACH protocol is to consume lower energy that are required to create and maintain clusters in order to improve the life time of a wireless sensor network. LEACH is a hierarchical protocol in which most nodes transmit to cluster heads, and the cluster heads aggregate and compress the data and forward it to the base station (sink) and each node uses a stochas-

tic algorithm at each round to determine whether it will become a cluster head in this round. Duce the number of transmission and reception operations. The key features of LEACH are randomized rotation of the CH and corresponding clusters, local compression to reduce global communication, and localized coordination and control for cluster set-up and operation.

4.1.1 Advantages of Leach Protocol
- ❖ It provides scalability in the wireless network by means of limiting most of the communication inside the different clusters of the network.
- ❖ The cluster heads aggregates or fuses the information that is been collected by the sensor nodes and reduce amount of traffic generated within the network.
- ❖ Single-hop routing is possible from sensor node to cluster head
- ❖ Distributiveness property within the cluster
- ❖ LEACH increases the lifetime of network in three phases.
- ❖ It does not require the information of location of the sensor nodes in the network to create the clusters in the whole network.
- ❖ LEACH gives the dynamic clustering approach

4.1.1 Disadvantages of Leach Protocol
- ❖ It significantly relies on cluster heads to communicate the sink. Due to this it incurs robustness issues like failure of the cluster heads.
- ❖ There is no inter-cluster communication in the network to communicate the sink and requires high range of transmission power in the network.
- ❖ LEACH cluster heads are not uniformly distributed within the cluster
- ❖ It does not work well with the applications that require large area coverage along with multi-hop inter-cluster communication in the network.

4.2 Power-efficient Gathering in Sensor Information Systems (PEGASIS)

Power-efficient Gathering in Sensor Information Systems (PEGASIS) [13] is an improvement of the LEACH protocol. Rather than forming multiple clusters, PEGASIS forms chains structure and every chain have only one cluster head. This approach will distribute the energy load evenly among the sensor nodes in the network. This protocol saves the battery

for wireless sensor network and increase the lifetime of the network by sending data to it the closet neighbor sensor nodes. Sensor nodes are deployed in harsh physical environment. Gathered data moves from node to node, aggregated and eventually sent to the base station. The chain construction is performed in a greedy way [14] .Sensor nodes have very limited computation capability because they are limited by the battery.

Hierarchical-PEGASIS is an extension to PEGASIS, which aims to decrease 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 efficiently. For reducing the delay in PEGASIS, simultaneous transmissions of data messages are pursued. In order to avoid collisions and possible signal interference among the sensors nodes, two approaches have been investigated. The first approach incorporates signal coding, e.g. CDMA and the second approach is only spatially separated nodes are allowed to transmit at the same time.

4.2.1 Advantages of PEGASIS Protocol

❖ It avoids the cluster formation and uses only one node in a chain to transmit to the base station instead of multiple nodes.

❖ It increases the lifetime of each sensor node by using collaborative techniques.

❖ PEGASIS reduces the power required to transmit data per round as the power draining is spread uniformly over all the sensor nodes.

4.2.2 Disadvantages of PEGASIS Protocol

❖ It assumes that each node is able to communicate with the base station directly. In practical cases, sensor nodes use multi-hop communication to reach the base station.

❖ PEGASIS assumes that all nodes have the same level of energy and are likely to die at the same time.

❖ It introduces excessive delay for distant sensor nodes on the chain.

❖ The single leader can become a bottleneck.

4.3 Thereshold-Sensitive Energy Efficient Sensor Network Protocol (TEEN)

Threshold sensitive Energy Efficient sensor Network protocol (TEEN) [15] is a hierarchical protocol designed to be responsive to sudden changes in the sensed attributes such as tem-

perature. It is a hybrid of hierarchical clustering and data-centric protocols, which groups sensors into clusters with each led by a cluster head. The sensor network architecture in TEEN is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until the base station is reached. In this protocol, sensor nodes sense the medium continuously, but the data transmission is done less frequently. The whole network consists of simple nodes are first-level cluster heads and second-level cluster heads. It uses LEACH's strategy to form cluster. First level cluster heads are formed away from the base stations and second level cluster heads are formed near to the base station [16].

4.3.1 Advantages of TEEN Protocol

❖ Time critical data reaches the user almost instantaneously.

❖ The soft threshold can be varied, depending on the criticality of the sensed attribute and the target application.

❖ A smaller value of the soft threshold gives a more accurate picture of the network.

4.3.2 Disadvantages of TEEN Protocol

❖ A sensor node may wait for their time slot for data transmission. Again time slot may be wasted if a sensor node has no data for transmission.

❖ Cluster heads always wait for data from nodes by keeping its transmitter on.

4.4 Adaptive Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN)

Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN) [17] is an extension to TEEN protocol and aims at both capturing periodic data collections and reacting to time critical events. The architecture is same as in TEEN protocol. It is a hybrid clustering-based routing protocol. APTEEN allows the sensor nodes 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 cluster heads [16]. It uses modified TDMA schedule to implement the hybrid network model. It also supports three different types query namely Historical query (to analyze past data values), One-time query (to take a snapshot view of the network) cand Persistent queries (to monitor an event for a period of time). It is best suited for both periodic sensing & reacting to time critical events.

4.4.1 Advantages of APTEEN Protocol

- ❖ APTEEN combines both proactive and reactive policies.
- ❖ It offers a lot of flexibility by allowing the user to set the count-time interval (CT) and the threshold values for energy consumption in sensor network.
- ❖ Energy consumption controlled by changing the count time as well as the threshold values

4.4.2 Disadvantages of APTEEN Protocol

- ❖ The overhead and complexity of forming clusters in multiple levels.
- ❖ The complexity increases to implementing threshold based functions, Count Time (CT) and dealing with attribute-based naming of queries

4.5 Hybrid, Energy-Efficient Distributed Clustering (HEED)

Hybrid, Energy-Efficient Distributed Clustering (HEED) periodically selects cluster heads according to a hybrid of the node residual energy and a secondary parameter, such as node proximity to its neighbors or node degree. In HEED, the proposed algorithm periodically selects cluster head according to a combination of two clustering parameters. The primary parameter is their residual energy of each node and the secondary parameter is the intra-cluster communication cost as a function of cluster density. Therefore primary parameter is used to probabilistically select initial set of cluster head while the secondary parameter is used for breaking ties efficiently. It proposed four primary goals

- ❖ Prolonging whole network lifetime by distributing energy consumption efficiently
- ❖ breaking the clustering process within a constant number of iterations
- ❖ reducing control overhead
- ❖ Producing well-distributed cluster head and compact clusters.

In HEED, the clustering process at each node requires several rounds and each round is long enough to receive messages from any neighbor within the cluster range. This protocol is most suitable for prolonging the network lifetime rather than for the entire needs of wireless sensor network.

4.5.1 Advantages of HEED Protocol

- ❖ Distribution of energy in HEED extends the lifetime of the sensor nodes within the network and stabilizing the neighboring sensor nodes
- ❖ It operates correctly even when nodes are not synchronized.
- ❖ Each sensor nodes require only local (neighborhood) information to form the clusters.
- ❖ It does not require special node capabilities, such as location-awareness.

4.5.2 Disadvantages of HEED Protocol

- ❖ The random selection of the cluster heads, may cause higher communication overhead for: The ordinary member nodes in communicating with their corresponding cluster head and the cluster heads in establishing the communication among them, or between a cluster head and a base station.
- ❖ The periodic cluster head rotation or election needs extra energy to reconstruct clusters.

5 CONCLUSIONS

The wireless sensor networks have been envisioned to help in numerous monitoring applications. Routing in sensor networks has attracted a lot of attention in the recent years and introduced unique challenges compared to traditional data routing in wired networks. Energy efficient routing is paramount to extend the stability and lifetime of the system. Energy efficiency is one of the main challenges in the design of protocols for wireless sensor network for the scarce energy resources of sensors. The main goal behind the protocol design is to keep the sensor nodes operating for as long as possible, thus extending the network lifetime. In this paper, a survey of the current state-of-the-art in energy efficiency for various types of nodes clustering algorithms, mainly focus on the energy efficient hierarchical cluster-based routing protocol has been discussed. We also discussed advantage and disadvantage of each hierarchical cluster-based routing protocol. The energy efficiency can be optimized by various optimization techniques such as genetic algorithms and anti-colony algorithms. For realization of wireless sensor networks, it is needed to satisfy the constraints introduced by various factors i.e. fault tolerance, scalability, cost, topology change, environment, and power consumption. Our future work will focus on Quality of Service (QoS) of each routing protocol.

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