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Energy Efficient Hierarchy Based Routing Algorithms with Mobile Sink in Wireless Sensor Networks: A Survey

Ajay Kumar Singh, Kanika Sharma

***Abstract*— In wireless sensor networks recent developments have enabled the development of low power, low cost, multifunctional sensor nodes that are small in size and communicate over the network. The main aim of the data aggregation technique is to collect and aggregate data in an energy efficient manner so that the network lifetime is enhanced. Sensor nodes are powered by limited capacities of batteries and because of this limitation the energy consumption of sensor nodes must be controlled. One of the mechanisms used to enhance the lifetime of the wireless sensor networks (WSNs) is hierarchical routing. Hierarchical routing in the network provides better aggregation and scalability for the sensor network with conserving energy of sensor nodes. In this paper we present a survey on energy efficient hierarchical routing with sink mobility to make the energy efficient and improved lifetime of the network.**

***Index Terms*— cluster routing, Energy efficiency, mobile sink, sensor node, wireless sensor networks.**

I. INTRODUCTION

A wireless sensor network is composed of a large number of sensor nodes which consist of sensing, data processing, power unit and communication capabilities. In wireless sensor network the sensor nodes distributed over a particular area to cooperatively monitor physical or environmental conditions such as temperature, pressure, humidity, sound, vibration, motion and pollutants at different locations. Data are collected from many sensor nodes by the base station which is the goal of the network. Data centric, self-organizing, application specific and scalability are the main characteristics of the wireless sensor network. Another unique feature of sensor network is the cooperation effort of sensor nodes. Large numbers of sensor nodes are densely employed; neighbour nodes may be very close to each other. Hence multi-hop communication in wireless sensor network is expected to consume less power than the traditional single hop communication. Multi-hop communication can also effectively overcome some of the signal propagation effects experienced in long distance wireless communication.

Recent advancement in wireless communication the battery operated technologies have enabled the development of low power, small size and multifunction sensor nodes with sensing, processing and communicating properties [1]. Many routing, power management and data dissemination protocols have been specifically designed for wireless sensor networks where energy awareness is an essential design issue. The major components of the wireless sensor network include the sensing, processing, communication and power unit [2]. Large quantities sensor nodes are typically deployed in high-density manner, a wireless sensor network consists of high densely distributed nodes that support sensing, data processing and communication. Sensor nodes are logically linked by self organizing manner in short-hop point-to-point master–slave pair arrangements. The typical wireless sensor network in a monitoring and data collection environment has a number of components as depicted in Fig.1.

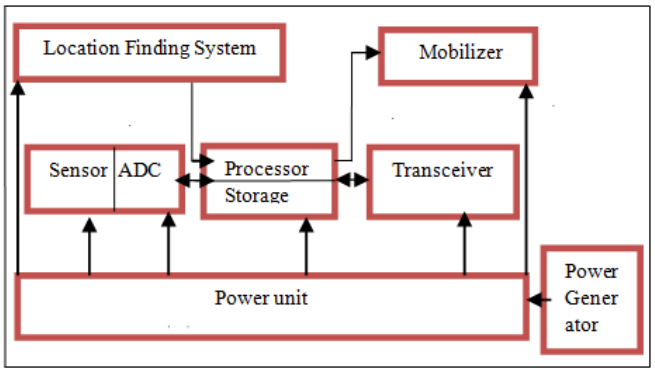

Fig.1. Components of a sensor node.

Sensing Unit- In this unit sensor node which physically reads and collects data from its surroundings, there are two categories of sensor unit such as active and passive sensor. The sensing units consist of sensor and analog to digital converter, sensor reads and collects data from the environment and analog to digital converter change the received analog input into digital signal for the processing unit.

Processing Unit- The processing unit is a small unit of sensor which consist of processor and memory devices that are responsible for computation and storage of received data from the environment. Energy consumed in the processing unit can be divided into switching and leakage energy. Energy is consumed during switching when software instructions are executed. Leakage energy is related with the nominal consumption of energy when no computation is performed. The output of the processing unit is fed to the communication unit for the transmission of received data from the sensing unit.

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Ajay Kumar Singh, Department of Electronics and Communication Engineering, National Institute of Technical Teacher's Training and Research (NITTTR), Chandigarh, India.

Kanika Sharma, Department of Electronics and Communication Engineering, National Institute of Technical Teacher's Training and Research (NITTTR), Chandigarh, India

Communication Unit- Communication unit is the most demanding component of a sensor node. The transceiver unit form a major part of the communication unit and are tasked with the transmission and reception of data. The more energy is consumed in the transmission of data from sensor node to the base station as compared to the processing, computing and reception of data. Approximately energy consumed in transmitting a single bit of data is equal to the energy spent in processing of one thousand operations in typical sensor nodes.

Power Unit- This unit is required to maintain all sensing, processing computational and communication operations from a few hours to several years depending on the applications. In this unit Primary and secondary batteries are used. The non-rechargeable batteries are Primary batteries and rechargeable batteries are secondary batteries.

A sensor node has some application dependent additional components such as location finding components, mobilizer and power generator. Sensors and analog to digital converters are the parts of sensing unit. Analog to digital converter convert the analog signals produced by the sensor nodes into the digital signal. These digital signals are fed to the next unit (processing unit), the processing unit consists of a small storage unit to store the data received by sensor nodes. A transceiver unit is made up of two main sub units that are transmitter and receiver units. Power unit is the most important component of a sensor node. A mobilizer is used to move the sensor node from one place to another to perform necessary tasks and a location finding system is used to find the location of the sensor node in the network.

II. CONCEPT OF MOBILE SINK

Mobile sink is a node which collects the data from the sensor nodes and sends the collected data to the end user through the internet or satellite communication system. Data gathering is a fundamental task of wireless sensor network. Research has shown that sensors near the sink deplete their battery power faster than those far apart due to their heavy overhead of forwarding messages. Non-uniform energy consumption causes reduced lifetime of the network. Sink mobility is used to reduce and balance energy expenditure among sensor nodes. Sink mobility can effectively improve network lifetime without bringing above mentioned negative impacts on the network. The reason is evident as sinks move the role of "hot spot" (i.e., heavily loaded nodes around sink) rotates among sensors, resulting in balanced energy consumption. Sink should move toward data sources so as to shorten path length and thus reduce energy consumption in wireless sensor network and enhance the lifetime of the WSNs.

If the sensor field is a small area only one mobile sink is used to collect the data from the sensor nodes. If the sensor field increases to a large area, there are large numbers of source nodes to transmit the data to the single mobile sink. The data transmitted from the end point of the sensor field to the mobile sink, Cooperative data processing being done. In this process the source nodes spent more energy to transmit the data of other source nodes and itself also. Cooperative data processing by sensor nodes reduces the energy of individual node. To make the energy efficient routing between the source nodes and sink in a large sensor field the multiple mobile Sinks are used to improve the energy consumption and lifetime of the wireless sensor network. If the sensor field area is large, clustering of sensor nodes is very useful to make the system energy efficient.

Depending on the applications and deployment area the sink may follow different mobility patterns. The sink mobility could be viewed in the perspective of sink and the sensors deployment. The sink's perspective reflects the true motion pattern of the sink and the sensors' perspective reflects the estimate of sink's mobility through the limited knowledge of the sensors. Sink mobility can be classified into three categories are random, predictable and controllable mobility.

III. OVERVIEW OF HIERARCHICAL ROUTING

In hierarchical routing higher energy nodes are used to process and send the message, while low energy nodes are used to detect the data in the network. The purpose of hierarchical routing approach to decreases the load of advertising the sink's location to the network by establishing a virtual hierarchy of nodes which imposes different dynamic roles on the sensors. The constructed hierarchy may be composed of two or more tiers. The hierarchical approaches is further classified as grid based, tree based, area based and cluster based approach.

(A) Grid-based Structure- In this approach grid structure provides the higher level of the virtual hierarchy for the data transmission in the network. The crossing-points of the grid are constituted by the selected high-tier nodes in the network. The number of shapes make up the grid i.e. squares, rectangles, triangles, hexagons etc. For this structure geographic coordinates of the sensors are required, hence location-aware sensors are preferred in the structure.

(B) Tree-based Structure- In this approach tree based structure is virtual hierarchical, the sink advertisement is usually dissipated from the root towards the leaves.

(C) Area-based Structure- In this approach the sensor nodes are designated in a specific region as high-tier nodes. The construction cost of this hierarchy is minimum. To solve the hotspot problem, large size of the area is specified to reduce the extra load on the high- tier sensor nodes in the network.

(D) Cluster-based Structure- In this approach clustering technique is used to partition the sensor network and employ the cluster head nodes as the high-tier nodes. Clustering is a topology-aware mechanism which considers the distribution of nodes in the network, with this approach an efficient virtual hierarchy is achieved. The creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, energy efficiency and lifetime of the network. Hierarchical routing is an efficient routing to reduce the energy consumption of sensor nodes within a cluster, performing data aggregation in order to decrease the number of transmitted messages to the sink in the

wireless sensor network. In this section, we describe the basic concept of clustering and components of a cluster in wireless sensor networks. In studies where clustering technique were primarily proposed for energy efficiency purposes [3] - [5].

➢ **Basic Concept of Clustering:** The basic concept of clustering play an important role to improve the network performance. To fulfil the requirements such as lifetime improvement, aggregation of data, quality of service and coverage, it is necessary to design an efficient network layer routing protocol. There exist a number of routing protocols in wireless sensor network such as Hierarchal routing protocols, Location based routing protocols and Flat routing protocols . Researchers and Engineers moved to routing protocols in recent years.

➢ **Components of a Cluster**

- **Cluster member:** A cluster member is the most important component of the wireless sensor network, cluster member nodes are scattered in the sensor field to detect events from the environment and perform local data processing for the transmission of data to the base station.

- **Cluster Head:** In each cluster one node is elected as cluster head (CH). Each cluster head is responsible for aggregating sensed data from its cluster member nodes that is sensor nodes and propagate it to the base station or the next CH. The phenomenon of CH selection is periodically divided in rounds. In each round new CH is selected randomly or based on parameters like residual energy of the sensor nodes, distance between sensor nodes and base station, connected nodes and topology of the networks etc.

➢ **Advantages of Clustering**

- **Scalability:** Among the nodes transmission numbers are limited, the number of deployed sensor nodes in the network could be high, the density of sensor nodes can range from few sensor nodes to few hundred nodes in a region. the number of nodes in a region of the network indicate the density of the nodes. The deployment of nodes in the region of network depends on the application in which the sensor nodes are deployed to sense the data.

- **Data Aggregation:** Data aggregation eradicates the duplication of data. In a large wireless sensor network there are often multiple nodes sensing similar information. In the clustering approach data aggregation allows to make difference between sensed data and useful data.

- **Energy Efficiency:** The energy limitation of the sensor nodes in the sensor network results in a limited network lifetime for the nodes in the network. Clustering process help to prolong the network lifetime of the WSN.

- **Collision Reduction:** In a large wireless sensor network cluster heads work as a coordinator between sensor nodes and sink, number of nodes that access the channel is limited. Cluster helps avoiding collisions between the sensor inside the cluster, because they don't have to share the communication channel with the nodes in other clusters.

IV. EXISTING HIERARCHICAL ROUTING PROTOCOLS WITH MOBILE SINK IN WSNs

Depending on the structure of the wireless sensor networks, there are three main categories of the data collecting protocols in WSNs. Flat-based routing, hierarchical routing and location based routing [6]-[7]. A mobile sink routing algorithm mitigates the hotspot problem and improves the lifetime of the sensor network. There are various hierarchical routing protocols with mobile sink in many contexts have been existed.

MSRP: It is a Mobile Sink based Routing Protocol for prolonging the network lifetime in clustered wireless sensor networks. In this protocol mobile sink moves in the clustered network to collect the sensed data from the cluster heads (CHs) within its vicinity. At a particular instant of time CHs in the neighbourhood of the mobile sink forward their data to the sink. The rest of the nodes in the network wait for their turn to become mobile sink neighbourhood. In this way, during sink movement all the nodes in the network forward their data to the mobile sink, when mobile sink comes in their neighbourhood during data gathering mobile sink also maintains information about the residual energy of the CHs. Consequently, the hot spot problem is minimized as the immediate neighbour of the sink is high energy node and it changes because of regular movement of the sink. It is a balanced use of network energy and improves network lifetime [8].

MECA: It is a Mobile-sink based Energy-efficient Clustering Algorithm. In this algorithm minimizing and balancing energy consumption for all sensor nodes. The network is divided into several equal clusters and the intra-cluster routing exploits multi-hop routing to save energy of the sensor nodes. In this approach the mobile sink deployment helps to solve the hotspot problem. The mobile sink moves around the edge of the sensing field. Clustering technique and multi-hop intra cluster routing algorithm ensures less energy consumptions [9].

GBEER: It is a Grid-Based Energy-Efficient Routing, it constructs a single combined grid structure for all possible sources. Location-awareness of sensor nodes is necessary to build the grid structure, data requests originated from the sink and data announcements originated from the source are propagated through the grid structure. While data requests are propagated vertically data announcements are propagated horizontally along the grid to ensure that these packets intersect at a crossing point. The location of the sink is send to the source node, and data is delivered directly to the sink. This routing is to eliminate the high overhead of constructing separate grids for each source by establishing and maintaining a common grid structure [10].

EEMSRA: It is an Energy-Efficient Mobile Sink Routing Algorithm. In this algorithm the number of hops, amount of data in the transmission, the lifetime of sensor nodes can be

prolonged and the communication is guaranteed. This algorithm uses cluster-based network structure to implement the mobile sink routing protocol, and the sink movement depends on the average energy in each cluster of the network. The mobile sink compares the average energy of the present cluster with the other clusters received from other cluster-heads, if the average energy is more than any of the received average energy from other cluster-heads, the mobile sink will not move from its present position. Otherwise the mobile sink will move to the cluster which has the maximum average energy in the network [11].

OAR: This is an Optimized Agent-based Routing protocol; it provides efficient data delivery to the mobile sink and reduces the delay in data transmission. This algorithm minimizes signalling overhead and improve degraded route called triangular routing problem. All sensor nodes can transmit data to the sinks without delay or additional overhead, by maintaining paths between all source nodes and sink pairs. This feature enables OAR to cover a wide range of applications [12].

TTDD: It is a Two-Tier Data Dissemination protocol used in in large scale wireless sensor networks. This protocol solves the hierarchical routing problems in a sensor network with mobile sinks. Source node uses an algorithm to construct a grid structure in the network for itself as a crossing node. The crossing node maintains events and source node information. The cluster node sends flooding request message to neighbour nodes for searching the data. The data would be sent in reverse direction. The cluster nodes can move and guarantee data delivery correctly by agent policy, this algorithm is a hierarchical routing algorithm which solves the nodes motion issues by agent policy. The algorithms have saved the energy cost and improve the lifetime of the wireless sensor network [13].

HCDD: This is a hierarchical Cluster-based Data Dissemination protocol. In this approach clustering is used to determine the second-tier nodes. A combined hierarchical structure for all data sources is constructed. The cluster heads are responsible for propagation of data requests called Routing Agents. The advantage of this routing algorithm is its ability to operate without location information of sensor nodes [14].

MSDG: This protocol is a Mobile Sink-based Data Gathering protocol. In mobile wireless sensor network model for high efficient data gathering it adopts a joint strategy of sink mobility and routing based on the nodes which are divided into certain number of clusters. For data gathering when sink nodes move along the path the minimum energy consumption of the network is used. In this protocol sink approaches the closest fixed nodes along the path as roots to build a routing tree, cluster-heads gather the data of all common nodes within cluster and perform data aggregation. The aggregated data is sent to the sink in reverse direction by tree. This protocol is better than other data gathering protocols in terms of average energy consumption and lifetime of the network. The sensing data of each mobile node is aggregated and calculated by cluster-head, and then reversely forwards to sink hop-by-hop by tree structure. MSDG is a distributed clustering data gathering protocol based on mobile sink [15].

DHA- It is a Data Dissemination Protocol Based on Home Agent and Access Node. It is a progressive footprint chaining mechanism to handle both sink position advertisement and data dissemination. DHA selects home agents a data aggregation and dissemination point. The load on the home agent is more and changing the home agent requires global flooding in the network. The access node represents the mobile sink to the home agent and home agent represents the mobile sink to the sensor nodes, movement of the sink is transparent to the sensor network. The home agent and the access node are affected by the movement of the sink. When sink moves it selects new access nodes which inform the home agent of their new roles. The home agent is changed occasionally to avoid hotspot problem and the location of the new home agent is flooded across the sensor network. The source nodes are only need to know the location of the home agent to disseminate the data in the network [16].

CMR: It is a Coordinate Magnetic Routing that constructs a virtual rectangular grid in the network. Magnetic diffusion strategy is used to create a magnetic field over the nodes where the nodes knowing about the source nodes have positive polarity and nodes knowing the sink's position have negative polarity. The sensor data are sent in the vertical direction and the sink position advertisements are sent in the horizontal direction along the grid. When a data packet is received by a node with negative polarity it is the awareness of the sink's position in the network [17].

Ring Routing- It is a Ring Routing structure which is a closed loop of single-node width. Ring routing is considered to be an area-based approach. In this approach the sink advertises its position to the ring by forwarding packets towards the network centre via geographic routing. Hence the ring nodes maintain the fresh position of the sink at all the times. In this routing to mitigate the hotspots on the ring a local structure change mechanism is used. Ring Routing is an efficient routing to mitigate the hotspot problem [18].

SEAD: It is a Minimum-Energy Asynchronous Dissemination protocol to mobile sinks in wireless sensor networks. In this protocol Steiner trees are used as the high-tier structure with minimum cost. To make the sink mobility transparent to the overlaying structure, this protocol uses progressive chaining. For construction of the Steiner tree and data dissemination the location-awareness of the sensor nodes is required .This protocol establishes a more intelligent second-tier structure i.e. Steiner tree for efficient data delivery in the network [19].

On the basis of existing hierarchical routing algorithms with mobile sink a comparison of hierarchical routing protocols with mobile sink in wireless sensor networks as shown in Fig.2

Protocol	Location awareness	Sink mobility	Hierarchical structure	Data aggregation	Multiple sink support	Protocol overhead	Hotspot mitigation
MSRP	Yes	Controlled	Cluster	Yes	Yes	Medium	Medium
MECA	Yes	Controlled	Cluster	Yes	No	Medium	Medium
GBEER	Yes	Random	Rectangular Grid	No	Yes	Medium	Medium
EEMSRA	Yes	Controlled	TDMA Cluster	Yes	No	Medium	High
OAR	Yes	Random	Single Agent	No	Yes	Low	Low
TTDD	Yes	Random	Rectangular Grid	Yes	Yes	High	High
HCDD	No	Random	Max-Min D-Cluster	No	No	High	Low
MSDG	Yes	Random	Square grid	Yes	No	Medium	Medium
DHA	Yes	Random	Two Agent	Yes	No	Low	Low
CMR	Yes	Random	Rectangular Grid	No	Yes	Medium	medium
Ring Routing	Yes	Random	Area	No	No	Low	High
SEAD	Yes	Random	Stainer tree	No	Yes	High	High

Fig.2. Comparison of Hierarchical routing protocols in wireless sensor networks.

V. CONCLUSION

In wireless sensor networks routing is a leading area of research. In this paper we present a comprehensive survey of hierarchical routing schemes in wireless sensor networks that have been presented in the literature. They have the common objective to extend the lifetime of the sensor network. Hierarchical routing technique is most suitable for large scale WSNs and a useful technology management approach to reduce the communication overhead in sensor networks. In wireless sensor networks many hierarchical routing protocols have been reviewed. In this paper, the main concern of this survey is to examine the energy efficiency and network lifetime enhancement of these routing protocols.

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