IRACST – International Journal of Computer Networks and Wireless Communications (IJCNWC), ISSN: 2250-3501
Vol.3, No4, August 2013

Energy Efficient Routing Protocols in Wireless Sensor Networks

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***Abstract*-Wireless Sensor Networks are networks of tiny, battery powered sensor nodes with limited on-board processing, storage and radio capabilities. The sensor nodes which are powered by limited capacity battery sources are difficult to be replaced or recharged. The main motive here is to reduce the energy consumption and increase the network lifetime. Therefore design of energy efficient protocols are being focused to a larger extent which results in a number of approaches to save the limited energy of the sensor nodes. The energy efficient routing protocols have received more attention because they differ depending on the network architecture and application. This paper provides a survey of the various energy efficient routing protocols based on the network structure and also highlights the advantages and performance issues of each routing protocol.**

Keywords- Wireless Sensor Network, energy efficiency, routing protocol

I. INTRODUCTION

A Wireless Sensor Network is composed of a large number of sensor nodes distributed over a certain region. These sensor nodes are characterized by their low power, small size and cheap price. They actually transform the data into electric signals, which are then processed to reveal some of the characteristics about the phenomena located in the area around the sensors. The data collected by the sensors are transmitted to the sink directly or indirectly via other sensor nodes. The unique nature of sensor networks is the cooperative effort of sensor nodes. The small size and cheap price of the sensors has increased the usage of large number of disposable and unattended sensors.

The applications of WSNs are quite numerous. Some of the application areas include health, military and home. For example, WSNs have profound effects on military and civil applications such as target field imaging, intrusion detection, weather monitoring, security and tactical surveillance, distributed computing, detecting ambient conditions such as temperature, movement, sound, light, or the presence of certain objects, inventory control, and disaster management. Deployment of a sensor network in these applications can be in random fashion (e.g., dropped from an airplane in a disaster management application) or manual (e.g., fire alarm sensors in a facility or sensors planted underground for precision agriculture). Creating a network of these sensors can assist rescue operations by locating survivors, identifying the risky areas and making the rescue team more aware of the overall situation in a disaster area.

II. SENSOR NETWORK COMMUNICATION ARCHITECTURE

Wireless Sensor Networks contain hundreds or thousands of sensor nodes, and these sensors have the ability to communicate either among each other or directly to an external base station (BS). A greater number of sensors allow sensing over larger geographical regions with greater accuracy. The communication architecture gives the various sensor node components. Figure 1 shows a schematic diagram of sensor node components which shows the communication architecture of a WSN. Sensor nodes are usually scattered in a sensor field, which is an area where the sensor nodes are deployed. Sensor nodes coordinate among themselves to produce high-quality information about the physical environment. Each sensor node makes decisions based on its mission, the information it currently has, and the knowledge of its computing, communication and energy resources. Each scattered sensor node has the capability to collect and route data to other sensors or back to an external BS. A BS may be a fixed or mobile node which connects the sensor network to an existing communication infrastructure or to the Internet where user can have access to the data [1].

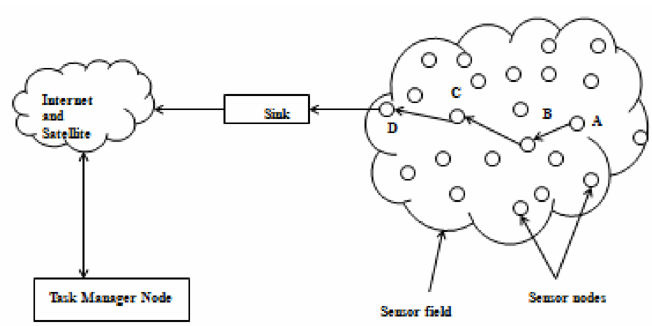

Figure1 Sensor nodes scattered in a sensor field

The design of the sensor networks is influenced by the following factors: fault tolerance, scalability, production costs, hardware constraints, sensor network topology, transmission media, node heterogeneity, Quality of Service and power consumption. A sensor node is made up of four basic components namely the sensing unit, processing unit, transceiver unit and a power unit [1]. The power consumption in a sensor can be divided into three domains: sensing, data processing and communication. The sensor node, a microelectronic device is equipped with a limited power source and the lifetime of the node is dependent on the battery lifetime. The lifetime of a sensor and the lifetime of the network, which directly determines the duration of the sensing task, are limited by the amount of energy each sensor has. Hence designing energy efficient algorithms is a primary concern. The energy efficient algorithms can be developed at all layers of the networking protocol stack.

This paper gives a survey of the network layer routing protocols. Wireless sensor network can be used in a large number of applications and so a one-thing-fits all solution cannot be used. So designing a network routing protocol differs with the application requirements. The routing protocols can be classified into three categories based on the network structure: flat, hierarchical, and location-based routing. Furthermore, these protocols can be classified into multipath-based, query-based, negotiation-based, QoS-based, and coherent based depending on the protocol operation. The advantages and performance issues of routing techniques based on network structure has been highlighted.

III. FLAT ROUTING PROTOCOLS

In flat networks, each and every node plays the same role and the nodes collaborate together to perform the sensing task. There are a large number of nodes and so it is not feasible to assign a global identifier to each node. Hence this has led to data centric routing, where the sink sends the query to the sensor nodes, the nodes having the appropriate data sends the data to the sink. The intermediate nodes along the route perform data aggregation thereby saving energy which is not done in the address-centric routing. In this section some of the protocols that employ the data-centric approach have been described.

A. Flooding

Flooding is one of the routing protocols where each node broadcasts the data it has sensed or received. This process is repeated until the maximum hop for the packet has reached. The advantages of this protocol are that there are no costly topology maintenance requirement and complex route discovery algorithms.

The drawbacks are implosion, overlap and resource blindness. The implosion problem where duplicated messages are sent to the same node can be overcome by sending the packets only to selected nodes [1].

B. Gossiping

In this protocol the nodes do not broadcast the packet but they send the packets to only one randomly selected neighbor. The implosion problem is avoided using this mechanism. But this protocol consumes more time to propagate the message to all sensor nodes. So latency is a major problem in this protocol.

C. SPIN

Sensor Protocols for Information via Negotiation uses the data centric routing mechanism. In this protocol instead of sending the whole data, the node sends the data that describes the sensor data. The data descriptor called the meta-data is exchanged among the sensors using an advertisement mechanism. The nodes interested in the data send a request message and gets the data. The process continues and the nodes in the entire sensor network that are interested in the data get a copy. The three types of messages used are: ADV message to advertise the meta-data, REQ message to request the data and DATA message carries the actual data along with the meta-data header [2].

The advantages of this protocol are that it is more efficient than the standard flooding, relatively quick convergence in terms of latency, it works well for mobile sensors and users. But there are some drawbacks like the nodes are always active thereby the energy gets wasted and the SPIN’s data advertisement mechanism does not guarantee the delivery of data.

D. Directed Diffusion

Directed diffusion is a novel data centric, data dissemination protocol which has the following features: data-centric dissemination, reinforcement based adaptation, in-network aggregation and caching [3]. The data is identified using sets of attribute value pair which resembles database query. The next hop along the route is decided by matching the data with the established gradients in the network. The data is cached at intermediate nodes for aggregation and loop prevention. The idea of path reinforcement is used to identify the best route for two nodes. First, the sink requests data by broadcasting interests. As the interest is propagated throughout the network, gradients are setup. Finally, the best paths are reinforced and data is disseminated. Directed diffusion uses query-response model.

The various advantages of directed diffusion are that it consumes much less energy due to less traffic compared to flooding, handles simultaneous queries inside a single network, uses data aggregation thereby reduces energy consumption , does not require addressing because the communication is neighbor-to-neighbor and is robust because of retransmission of interest and low data rate gradients. There are some drawbacks like gradient setup phase is expensive, the periodic broadcast of the interest reduces the network lifetime. It may not work well for certain applications where continuous data transfers are required like environmental monitoring applications.

IV. HIERARCHICAL ROUTING PROTOCOLS

The data-centric routing protocols work well for small scale sensor networks but are not suitable for large scale networks because of the transmission delay. This happens because when the number of nodes increases, the data has to be propagated via long multi-hop paths. Some of the data-centric protocols deal with request and advertisement packet transmissions which introduces communication overheads. So as to overcome the above mentioned drawbacks Hierarchical Routing Protocols have been developed. It is an efficient way to reduce the energy consumption by employing the clustering concept which includes data aggregation and fusion in order to decrease the number of transmitted messages to the BS. Few of the hierarchical routing protocols have been discussed in this section.

A. LEACH

Low Energy Adaptive Clustering Hierarchy protocol is the first well known clustering routing protocol. Here the nodes organize themselves into local clusters, with one node acting as the cluster head. The non-cluster head nodes transmit their data to the cluster head, while the cluster head node which receives data, performs data aggregation, and transmits data to the remote BS. Therefore, being a cluster head node is much more energy intensive than being a non-cluster head node. If the cluster heads were chosen a priori and fixed throughout the system lifetime, these nodes would quickly use up their limited energy. If the cluster head is depleted of its energy, it is no longer operational, and so the whole cluster gets cut off. Therefore LEACH incorporates randomized rotation of the high-energy cluster head position among the sensors to avoid draining the battery of any one sensor in the network. So the energy load of being a cluster head is evenly distributed among the nodes. The operation of LEACH consists of two stages, the set-up phase and the steady phase. During the set-up phase, a sensor node chooses a random number between 0 and 1. If this random number is less than the threshold *T*(*n*), the sensor node is a cluster-head. *T*(*n*) is calculated as

$$T(n) = \begin{cases} \dfrac{p}{1 - p\left[r \bmod \left(\frac{1}{p}\right)\right]} & if\ n \in G \\ 0 & otherwise \end{cases} \quad \ldots\ldots..(1)$$

where p is the desired percentage to become a cluster-head; *r* is the current round; and *G* is the set of nodes that have not been selected as a cluster-head in the last $\frac{1}{p}$ rounds [4,5].

The advantages of this protocol are: it is completely distributed and the global knowledge of the network is not required. The network lifetime is increased when compared to the direct communication and Minimum Transmission Routing. Some of the disadvantages of this routing protocol are single-hop communication between the cluster head and base station which is not suitable for large sized networks and the overhead incurred due to the dynamic clustering.

B. PEGASIS

PEGASIS (Power – Efficient gathering in Sensor Information Systems) protocol is an improvement of LEACH protocol. It allows only one node to transmit to the BS in each round and makes nodes transmit to their close neighbors. This protocol basically employs two ideas namely chaining and data fusion. The nodes employ the greedy algorithm for the construction of a chain which starts with the farthest node from the BS. In each round, a node is chosen randomly to be a leader. This leader node initiates a control token to start data transmission from the ends of the chain. Each node fuses its neighbor's data packet with its own to generate a single packet of the same length and then transmits it to the neighbors. This is repeated till all the sensed data are collected at the leader node, which then transmits one data packet to the BS through direct communication. The main idea in PEGASIS is that each node can receive from and transmit to its close neighbors and it takes turns for being the leader. This approach leads to the even distribution of energy among the sensor nodes.

The strengths of this protocol is that it increases the network lifetime by employing data aggregation and also outperforms LEACH by eliminating the overhead involved in clustering [6]. This protocol also has the disadvantages that it does not scale well for the sensor networks where global knowledge is not easy to get and the single leader concept gives rise to bottleneck scenario also.

C. SEP

The Stable Election protocol is a heterogeneous protocol for clustered wireless sensor networks [7]. The source of heterogeneity employed here is based on the energy of nodes and the types of nodes are advanced nodes and normal nodes. The assumption made in this routing protocol is that a percentage of nodes in the total node population have more energy than the other nodes present in the same network. The other assumptions are that the nodes are immobile and are uniformly distributed, the dimensions of the sensor field are known and the position of the sink is also known. The heterogeneity of the sensors is being utilized to improve the stability period, which is the time interval before the first node dies. The cluster heads are elected in a distributed fashion for a 2 level hierarchical sensor network. The weighted election probabilities of each sensor node are being employed to elect the cluster head based on the remaining energy in the node.

V. LOCATION BASED ROUTING

Location-based protocols use position information to send the data only to the desired regions rather than to the whole network thereby reducing the number of data transmissions which results in prolonging the network lifetime. Few of the energy aware location based routing protocols like GEAR and GAF have been explained.

A. GEAR

Geographic Energy Aware Routing Protocol is an energy efficient routing protocol for routing queries [7]. It efficiently routes a message to a region keeping in mind the load balancing of nodes so that energy is not depleted soon. Each node contains an estimated cost and a learning cost for reaching the destination through its neighbors. The estimated cost is a combination of residual energy and distance to destination. The learned cost is a refinement of the estimated cost that considers routing around holes in the network. A hole occurs when a node does not have any closer neighbor to the target region than itself. The estimated cost is equal to the learned cost if there are no holes. This protocol involves two phases namely delivery phase and distribution phase.

In the delivery phase the packet is routed to a node in the target region. During this phase GEAR protocol acts like a unicast protocol but keeps the energy resources of the nodes in mind using the learned and estimated costs. In the distribution phase the packet that has been received by a node present in the target region distributes the packet to all other nodes present in that region. It employs recursive forwarding technique or restricted flooding to forward the packets within the target region. GEAR reduces the energy consumption and also performs better than GPSR in terms of packet delivery.

B. GAF

Geographic Adaptive Fidelity is an energy aware protocol which was designed primarily for the mobile ad hoc networks but is found to be suitable for wireless sensor networks also [8]. In this protocol the area is divided into square grids and each node uses the location information based on GPS to associate itself with a virtual grid. The node with the highest residual energy becomes the master of the grid. If there are equivalent nodes within a grid then some of the nodes can be put into the sleep state to save energy which in turn increases the network lifetime. The three states in this protocol are: discovery state: to determine the neighbors in the grid, active state: participation of the node in routing and sleep state: where the radio is turned off. The protocol tries to keep the network connected by having a representative node in each grid which is always in the active state. This protocol results in energy saving and also performs well in terms of latency and packet loss when compared to ad hoc networks. It resembles a hierarchical routing protocol where the grids are acting as clusters but does not employ the data aggregation technique.

VI. CONCLUSION

One of the main challenges of Wireless Sensor Network is the network lifetime which is due to the scarce energy resources of the sensors. To combat this challenge designing energy efficient routing protocols for WSN is very important. This paper gives a comprehensive survey of the routing protocols depending on the network structure. They are classified into three categories namely flat, hierarchical and location based routing. The sensor networks are application specific and so it cannot be declared that a particular protocol is the best. The protocols can be compared with respect to some parameters only. Future direction of this work is to modify one of the above routing protocols such that the modified protocol increases the network lifetime.

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