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DATA-CENTRIC ROUTING PROTOCOLS IN WIRELESS SENSOR NETWORKS: A SURVEY

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Abstract: This survey paper is more focused and can serve those who like to overall concept about all data centric routing for wireless sensor networks. To the best of our knowledge, our paper is the first work to make a classification of routing protocols in sensor networks. Sensor networks are classified by considering several architectural factors such as network dynamics, data aggregations, node capabilities and the data delivery model. Such classification is helpful for a designer to select the appropriate infrastructure for his/her application. Our work is a dedicated study of different data centric routing protocol. Wireless sensor network (WSN) consists of small and low-cost sensor nodes with capability of sensing various types of physical and environmental conditions, data processing and wireless communication. Routing in sensor networks is very challenging, due to several characteristics that distinguish them from contemporary communication and wireless ad-hoc networks. Many new goal and data-oriented algorithms have been proposed for the problem of routing data in sensor networks. Most routing protocols can be classified as data-centric, hierarchical and location-based. Data-centric protocols are query-based and depend on the naming of desired data and also do some aggregation and reduction of data in order to save energy. Hierarchical protocols aim at clustering the nodes. Location-based protocols utilize the position information to relay the data to the desired regions. In this paper, we give a survey of data-centric routing protocols for Wireless Sensor Network and compare their strengths and limitations. We also highlight the advantages and performance issues of each routing technique.

Keywords: Wireless Sensor Networks, Routing Protocols, Cluster Head, Mobile Ad hoc Network.

I. INTRODUCTION

Wireless sensor network (WSN) is widely considered as one of the most important technologies for the twenty-first century [1]. In the past decades, it has received tremendous attention from both academia and industry all over the world. A WSN typically consists of a large number of low-cost, low-power, and multifunctional wireless sensor nodes, with sensing, wireless communications and computation capabilities [2,3]. These sensor nodes communicate over short distance via a wireless medium and collaborate to accomplish a common task, for example, environment monitoring, military surveillance, and industrial process control. The basic philosophy behind WSNs is that, while the capability of each individual sensor node is limited, the aggregate power of the entire network is sufficient for the required mission.

In many WSN applications, the deployment of sensor nodes is performed in an ad hoc fashion without careful planning and engineering. Once deployed, the sensor nodes must be able to autonomously organize themselves into a wireless communication network. Sensor nodes are battery-powered and are expected to operate without attendance for a relatively long period of time .In most cases it is very difficult and even impossible to change or recharge batteries for the sensor nodes. WSNs are characterized with denser levels of sensor node deployment, higher unreliability of sensor nodes, and sever power, computation, and memory constraints. Thus, the unique characteristics and constraints present many new challenges for the development and application of WSNs.

II. DESIGN ISSUES & CHALLENGES

Depending on the application, different architectures and design constraints have been considered for sensor networks. Since the performance of a routing protocol is depend on the architectural model, some design issues have been considered for sensor networks are as follows

1) Node Deployment:

In WSN the main consideration is the topological deployment of nodes. This is application dependent and affects the performance of the routing protocol. The deployment is either deterministic or self-organizing. In deterministic situations, the sensors are manually placed and data is routed through pre-determined paths. However in self-organizing systems, the sensor nodes are scattered randomly creating an infrastructure in an ad hoc manner.

2) Network Dynamics:

There are three main components in a sensor network. These are the sensor nodes, sink and monitored events. Routing messages from or to moving nodes is more challenging since route stability becomes an important optimization factor, in addition to energy, bandwidth etc. The sensed event can be either dynamic or static depending on the application [4]. For instance, in a target detection/tracking application, the event (phenomenon) is dynamic whereas forest monitoring for early fire prevention is an example of static events. Monitoring static events allows the network to work in a reactive mode, simply generating traffic when reporting. Dynamic events in most applications require periodic reporting and consequently generate significant traffic to be routed to the sink.

3) Data Delivery Models:

Depending on the application of the sensor network, the data delivery model to the sink can be continuous, event-driven, query-driven and hybrid [4].In the continuous delivery model, each sensor sends data periodically. In event-driven and query driven models, the transmission of data is triggered when an event occurs or a query is generated by the sink. Some networks apply a hybrid model using a combination of continuous, event driven and query-driven data delivery.

4) Node Capabilities:

In a sensor network, different functionalities can be associated with the sensor nodes. In earlier works [5][6], all sensor nodes are assumed to be homogenous, having equal capacity in terms of computation, communication and power. However, depending on the application a node can be dedicated to a particular special function such as relaying, sensing and aggregation since engaging the three functionalities at the same time on a node might quickly drain the energy of that node. Inclusion of heterogeneous set of sensors raises multiple technical issues related to data routing [7]. For instance, some applications might require a diverse mixture of sensors for monitoring temperature, pressure and humidity of the surrounding environment, detecting motion via acoustic signatures and capturing the image or video tracking of moving objects.

5) Energy Considerations:

During the creation of an infrastructure, the process of setting up the routes is greatly influenced by energy considerations. Since the transmission power of a wireless radio is proportional to distance squared, multihop routing will consume less energy than direct communication. Direct routing would perform well enough if all the nodes were very close to the sink.

6) Data Aggregation/Fusion:

Data aggregation is the combination of data from different sources by using functions such as suppression (eliminating duplicates), min, max and average [7]. Some of these functions can be performed either partially or fully in each sensor node, by allowing sensor nodes to conduct in-network data reduction. Data aggregation[7][8] is also feasible through signal processing techniques. In that case, it is referred as *data fusion* where a node is capable of producing a more accurate signal by reducing the noise.

7) Fault:

Tolerance:-Some sensor nodes may fail or be blocked due to lack of power, physical damage or environmental interference. The failure of sensor nodes should not affect the overall task of the sensor network. If many nodes fail, routing protocols must accommodate formation of new links and routes to the data collection BSs [8].

8) Energy consumption without losing accuracy:

Sensor nodes can use up their limited supply of energy performing computations and transmitting information in a wireless environment. As such, energy-conserving forms of communication and computation are essential. Sensor node lifetime shows a strong dependence on battery lifetime.

9) Scalability:

In sensor network routing protocols should be scalable [8] enough to respond to events in the environment. Until an event occurs, most sensors can remain in the sleep state, with data from the few remaining sensors providing coarse quality.

10) Transmission media:

In a multihop sensor network, communicating nodes are linked by a wireless medium. The traditional problems associated with a wireless channel may also affect the operation of the sensor network. In general, the required bandwidth of sensor data will be low, on the order of 1–100 kb/s. Bluetooth technology can also be used.

III. DATA-CENTRIC PROTOCOLS

In many WSN, it is not feasible to assign global identifiers or node addressing of each node due to the sheer number of nodes deployed. Such lack of global identification along with random deployment of sensor nodes makes it hard to select a specific set of sensor nodes to be queried. However, in *data-centric* protocols, when the source sensors send their data to the sink, intermediate sensors can perform some form of aggregation on the data originating from multiple source sensors and send the aggregated data toward the sink. This process can result in energy savings because of less transmission required to send the data from the sources to the sink. Here we review some of the data-centric routing protocols for WSNs.

A. *Flooding:*

In flooding, each sensor receiving a data packet broadcasts it to all of its neighbors and this process continues until the packet arrives at the destination or the maximum number of hops for the packet is reached. In fig-1[9] shows implementation of flooding. However it has three main drawbacks namely Implosion, Overlap and Resource blindness [7].

1) *Implosion:*

In flooding, a node always sends the data to its neighbors, without aware of whether or not the neighbors already receive the data from another source. In this figure node A start send the data (a) to both of its neighbor, B and C. Then, B and C are also received data from A and send the same copy of it to their neighbor D. The protocol therefore wastes resource by sending two copies of data to D.

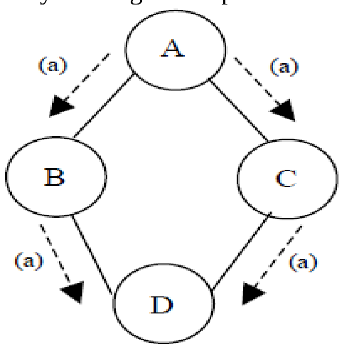

Fig-1: Implosion

2) *Overlap:*

This problem occurs when the nodes cover the same region's data. In Fig-2[9] two sensors cover an overlapping geographic region and C gets same copy of data from these sensors.

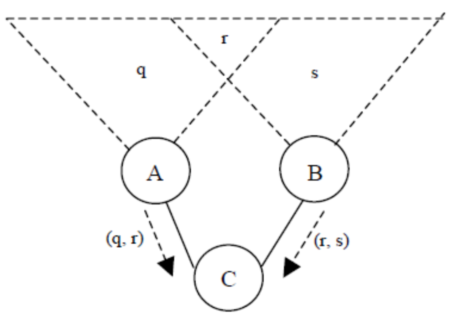

Fig-2: Overlap

3) *Resource Blindness:*

This is another drawback, when two nodes are covering the same region and broadcast same copy of data to their nearest neighbor that is the resources are more energy consuming. That is called Resource Blindness.

4) *Advantages and disadvantages of Flooding:*

The main advantage of flooding is the increased reliability provided by this routing method. Since the message will be sent at least once to every host it is almost guaranteed to reach its destination.

There are several disadvantages with this approach. It is very wasteful in terms of the networks total bandwidth. While a message may only have one destination it has to be sent to every host. This increases the maximum load placed upon the network. Messages can also become duplicated in the network further increasing the load on the networks bandwidth as well as requiring an increase in processing complexity to disregard duplicate messages.

B. *SPIN (Sensor Protocols for Information via Negotiation):*

The SPIN [7, 8] family of protocols uses data negotiation algorithm. Nodes running SPIN assign a high-level name to completely describe their collected data i.e. meta-data and perform metadata negotiations before any data is transmitted. This ensures that there is no redundant data sent throughout the network.

SPIN [9] is negotiation based data centric protocol suitable for wireless sensor networks. Every node uses meta-data to name their data. By using this metadata, each node can negotiate whether to deliver data or not to eliminate the redundant data transmission throughout the network. A sensor node performs negotiations by using its meta-data. These negotiations are done by exchanging a new data advertisement message (ADV) and a request for data message (REQ) between the sender and the receiver. After the negotiation, the sender transmits its data to the receiver (DATA).In Fig-3 SPIN Protocol. Node A starts by advertising its data to node B (a), Node B responds by sending a request to node A (b). After receiving the requested data (c), node B then sends out advertisements to its neighbors (d), who in turn send requests back to B (e-f).

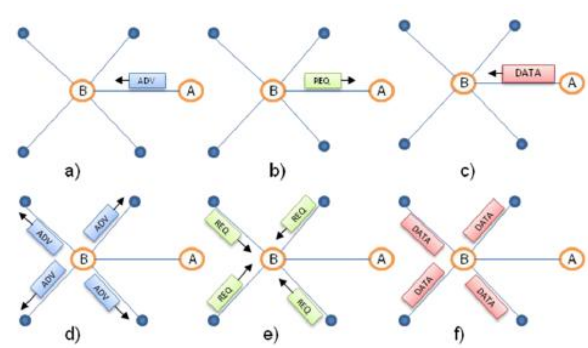

Fig-3: SPIN Protocol

Protocols of the SPIN family:

1) *SPIN-BC:*

This protocol is designed for broadcast channels.

2) *SPIN-PP:*
This protocol is designed for point to point communication (i.e., hop by-hop routing).

3) *SPIN-EC:*
This protocol works similar to SPIN-PP, but with an energy heuristic added to it.

4) *SPIN-RL:*
When a channel is lossy, a protocol called SPIN-RL is used where adjustments are added to the SPIN-PP protocol.

5) *Advantages and disadvantages of SPIN:*
One of the major advantages of SPIN is that topological changes are localized since each node need know only its single-hop neighbors and it provides more energy savings than flooding. SPIN's meta-data negotiation solves the classic problems of flooding such as redundant information passing, overlapping of sensing areas and resource blindness thus, achieving a lot of energy saving. Though this protocol has been designed for lossless networks, it can easily be adapted to work in lossy or mobile networks.

SPIN's data advertisement mechanism cannot guarantee delivery of data.

C. *Directed Diffusion:*

This is another data dissemination protocol in which the data generated by the nodes is diffusing through sensor nodes by using a naming scheme for the data. The main reason behind using such a scheme is to get rid of unnecessary operations of network layer routing in order to save energy. Direct Diffusion [11] suggests the use of attribute-value pairs for the data and queries the sensors in an on demand basis by using those pairs. Directed Diffusion is a data-centric routing and use attribute-value pairs scheme for data queries. In order to create a query, an *interest* is defined using a list of attribute-value pair such as objects, interval, duration, geographical area, etc.

The interest is broadcast by a sink through its neighbors. Each sensor receives the interest, setup a *gradient* toward the sensor nodes from which it receives the interest. This process continues until gradients are setup from the source back to the base station. Hence, by utilizing interest and gradients, paths are established between sink and sources. Several paths can be established so that one of them is selected by *reinforcement* in Fig.4.In this fig.4(a) sink broadcast an interest to all of its neighbors i.e. interest propagation. In fig.4 (b) an event occurs in source node and gradients are setup for all nodes to sink. In fig4(c) as well as source has encounter an event so data can be delivered from source to sink in multiple way. Then one of those path can be selected which has the lowest rate using reinforcement.

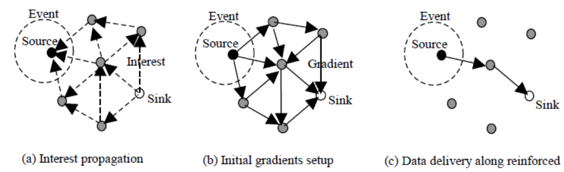

Fig-4: Directed diffusion's Phases

1) *Advantages and disadvantages:*
Direction Diffusion has noticeably better energy efficiency than flooding and spin, especially in highly dynamic network. It is because the data is transmitted from neighbor to neighbor, no data is propagated across the network.
There is limit memory storage for data caching inside the sensor node. Therefore, data aggregation may be affected. The matching process for data and queries might require some extra overhead at the sensors.

D. *Energy-aware routing:*

In Directed Diffusion, data is sent through multiple paths, one of them being reinforced to send at higher data rates. But Energy-aware routing [12] is similar to Directed Diffusion in the way potential paths from data sources to the sink are discovered. Energy-aware routing is to prolong the life time of the network. This protocol uses the metrics for cost and the energy metrics to identify an energy efficient path that minimizes the cost and more energy saving for increases the network lifetime.

The basic idea of Energy-aware routing is to increase the survivability of networks, it may be necessary to use sub-optimal paths occasionally. To achieve this, multiple paths are found between source and destinations, and each path has a cost, depending on the cost metric. And each node has a data transmitting and receiving energy to create energy metric. The approach argues that using the minimum energy path all the time will deplete the energy of nodes on that path. Instead, one of the multiple paths is used, so that the whole network lifetime increases.

We consider a network of static energy constrained sensors that means all the nodes, source, sink and event are static. Assume that all nodes in the network are assigned with a unique ID(i.e. node number, x and y location) and all nodes are participating in the network and forward the given data. Additionally, these sensor nodes have limited processing power, storage and energy, while the sink nodes have powerful resources to perform any tasks or communicate with the sensor nodes.

The protocol assumes that each node is addressable through a class-based addressing which includes the location and types of the nodes. There are 3 phases in the protocol:

1) *Setup phase or interest propagation:*
The interest is broadcast by a sink through its neighbors. This process continues until gradients are setup from the source back to the sink. An interest message is query or

which specifies what a user wants. Each interest's message contains a description of data interested by a user. Typically, data in sensor networks is collected or processed information of a phenomena which matches an interest or a request of a user. Such data can be an event which is a short description of the sensed phenomenon. Initially the "*Cost*" field is to zero before sending the request.

$$Cost(ND) = 0$$

Every intermediate node forwards the request only to the neighbors that are closer to the source node than oneself and farther away from the destination node. On receiving the request, the cost metric for the neighbor that sent the request is computed and is added to the total cost of the path. Thus, if the request is sent from node *Ni* to node *Nj*, *Nj* calculates the cost of the path as:

$$Cost(Nj, Ni) = Cost(Ni) + Metric(Nj, Ni)$$

In this way we calculate cost from source to sink.

2) Data Communication Phase:

After interest propagation, setup a *gradient* toward the sensor nodes from which it receives the interest. This process continues until gradients are setup from the source back to the base station. Hence, by utilizing interest and gradients, paths are established between sink and sources. Several paths can be established so that one of them is selected. After some time if a node die then it will be select another minimum energy saving path for data propagation.

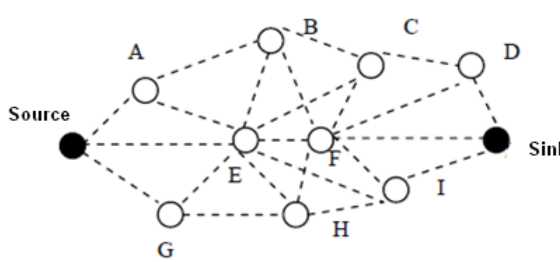

Fig-5: Data communication phase

As shown in Fig-5, there are many intermediate nodes, available in the network. When the source initially broadcast the message, the nodes A, E and G receive the message. Assume that the available energy at A is larger than at E and G, hence node A is selected to broadcast the message to the neighboring nodes. The process continues and node B which is selected sends out the broadcast message which is received by nodes F and C, it is found that both F and C have the same energy level, So both F and C start a back-off timer and if the back-off timer of node F ends before C an implicit acknowledgement is sent by node F which is also received by node C, and so node C stops its back-off timer as shown in Figure 6. When the broadcast message reaches the target sink, then this is the minimum energy saving path from source to sink. In this way we create an energy metric i.e. energy$Metric(Nj, Ni)$. $Energy(Nj, Ni)$ be the total energy.

$$Energy(Nj, Ni) = Energy(Ni) + \text{energy}Metric(Nj, Ni)$$

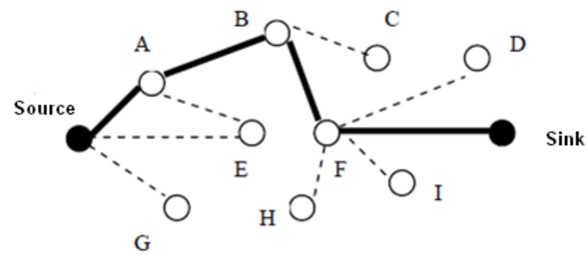

Fig-6: Minimum energy saving path

3) Route maintenance:

However, the route maintenance phase of energy efficient diffusion also same as in directed diffusion. It is also possible to local repair of failed or degraded paths. Causes for failure or degradation include node energy depletion and environmental factors affecting communication.

4) Advantages and disadvantages:

For sensor nodes to minimize energy consumption in data communication to extend the lifetime of sensor networks. The data delivery ratios increase as the node density increases. When node density is high, there are more nodes available for data forwarding, and this increases the delivery ratio.

There is limit memory storage for data caching inside the sensor node. It is more complex than directed diffusion.

E. Rumor Routing:

Rumor routing [10] is one type of Directed Diffusion and is mainly intended for contexts in which geographic routing criteria are not applicable. Generally Directed Diffusion floods the query to the entire network when there is no geographic criterion to diffuse tasks. However, in some cases there is only a little amount of data requested from the nodes and thus the use of flooding is unnecessary. An alternative approach is to flood the events if number of events is small and number of queries is large. Rumor routing is between event flooding and query flooding. The idea is to route the queries to the nodes that have observed a particular event rather than flooding the entire network to retrieve information about the occurring events.

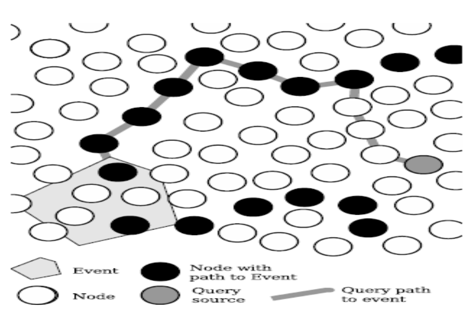

Fig-7: Query's path

The rumor routing algorithm uses a set of long-lived agents which create paths that are directed towards the events they encounter. Whenever an agent crosses path with a path leading to an event that it has not encountered, it adapts its behavior thus creating a path state which leads to both the events. When the agents come across shorter paths, they optimize the paths in the network by updating the routing tables to reflect the more efficient path. Each node maintains a list of its neighbors and an events table. When it encounters an event it adds it to its events table and might generate an agent in a probabilistic fashion. The agent also contains an events table like that of the nodes which it synchronizes with every node that it encounters. The agent has a lifetime of a certain number of hops after which it dies. Any node generating a query will transmit the query if it has a route to the event else it will transmit it in a random direction. If the node gets to know that the query did not reach the destination then it will flood the network. The lesser the number of queries which flood, the lesser the energy consumed.

1) Advantages and Disadvantages:

Rumor routing is a tunable and more energy-efficient algorithm than flooding-based ones in many situations, especially when geographic information is not available. It also handles node failures quite well. Rumor routing is a good choice also when events are not geographically locatable, like large concentrations of some chemical or looking for some acoustic pattern in a big network.

The amount of data flowing back from event node to query node is significant. In such cases it is not better to directed diffusion, the query messages through the network in order to find the shortest path between the query and event nodes. The amount of queries per event is high. In such cases it is usually better to flood messages from event nodes through the whole network.

IV. CONCLUSION AND FUTURE RESEARCH

In this paper, we have surveyed only data centric routing protocol and their design issues & challenges, advantages and disadvantages also including location information, network layering and in-network processing, data centricity, path redundancy, network dynamics etc. One of the main challenges in the design of routing protocols for WSNs is energy efficiency due to the scarce energy resources of sensors. The ultimate objective behind the routing protocol design is to keep the sensors operating for as long as possible, thus extending the network lifetime. The energy consumption of the sensors is dominated by data transmission and reception. Therefore, routing protocols designed for WSNs should be as energy efficient as possible to prolong the lifetime of individual sensors, and hence the network lifetime.

Sensor nodes are deployed in either deterministic or self-organizing, so the problem of estimating spatial-coordinates of the node is referred to as localization. Global Positioning System (GPS) cannot be used in WSNs as GPS can work only outdoors and cannot work in the presence of any obstruction. Moreover, GPS receivers are expensive and not suitable in the construction of small cheap sensor nodes. Hence, there is a need to develop other means of establishing a coordinate system without relying on an existing infrastructure. Overall, the routing techniques are classified based on the network structure into three categories: flat, hierarchical, and location-based routing protocols. In this paper we present a comprehensive survey of routing techniques in wireless sensor networks that have been presented in the literature. They have the common objective of trying to extend the lifetime of the sensor network.

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