A SURVEY OF SENSOR NETWORK AND RELATED ROUTING PROTOCOLS

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Abstract: Recent advances in wireless sensor networks have led to many new protocols specifically designed for sensor networks where energy awareness is an essential consideration. Most of the attention, however, has been given to the routing protocols since they might differ depending on the application and network architecture. Tiny sensor nodes create sensor network. These nodes are severely constrained by energy, storage capacity and computing power. The prominent task of this network is to design proficient routing protocols for to make the node's life last longer. In this paper, we first analyze the requirements of sensor networks and its architecture. Then, we enlighten the existing routing protocols for sensor networks and present a critical analysis of these protocols. The paper concludes with open research issues. At the end of this paper, we compare and contrast these protocols.

1 INTRODUCTION

Recent advances in micro-electro-mechanical systems (MEMS) and low power and highly integrated digital electronics have led to the development of micro sensors. Such sensors are generally equipped with data processing and communication capabilities. The sensing circuitry measures ambient conditions related to the environment surrounding the sensor and transform them into an electric signal. Processing such a signal reveals some properties about objects located and/or events happening in the vicinity of the sensor. The sensor sends such collected data; usually via radio transmitter (1), to a command center (sink) either directly or through a data concentration center (a gateway). A natural architecture for such collaborative distributed sensors is a network with wireless links that can be formed among the sensors in an ad hoc manner.

Networking unattended sensor nodes are expected to have significant impact on the efficiency of many military and civil applications such as combat field surveillance, security and disaster management. These systems process data gathered from multiple sensors to monitor events in an area of interest. For example, in a disaster management setup, a large number of sensors can be dropped by a helicopter. Networking these sensors can assist rescue operations by locating survivors, identifying risky areas and making the rescue crew more aware of the overall situation. Such application of sensor networks not only can increase the efficiency of rescue operations but also ensure the safety of the rescue crew.

On the military side, applications of sensor networks are numerous. For example, the use of networked set of sensors can limit the need for personnel involvement in the usually dangerous reconnaissance missions. In addition, sensor networks can enable a more civic use of landmines by making them remotely controllable and target-specific in order to prevent harming civilians and animals. Security applications of sensor networks include intrusion detection and criminal hunting.

However, sensor nodes are constrained in energy supply and bandwidth. These challenges necessitate energy-awareness at all layers of networking protocol stack. The issues related to physical and link layers are generally common for all kind of

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sensor applications. At the network layer, the main aim is to find ways for energy efficient route setup and reliable relaying of data from the sensor nodes to the sink so that the lifetime of the network is maximized. Routing in sensor networks is very challenging due to several characteristics that distinguish them from contemporary communication and wireless ad-hoc networks. First of all, it is not possible to build a global addressing scheme for the deployment of sheer number of sensor nodes. Second, in contrary to typical communication networks almost all applications of sensor networks require the flow of sensed data from multiple regions (sources) to a particular sink. Third, generated data traffic has significant redundancy in it since multiple sensors may generate same data within the vicinity of a phenomenon. Such redundancy needs to be exploited by the routing protocols to improve energy and bandwidth utilization. Fourth, sensor nodes are tightly constrained in terms of transmission power, on-board energy, processing capacity and storage and thus require careful resource management. Due to such differences, many new algorithms have been proposed for the problem of routing data in sensor networks. These routing mechanisms have considered the characteristics of sensor nodes along with the application and architecture requirements. Almost all of the routing protocols can be classified as data-centric, hierarchical or location-based. Data-centric protocols are query-based and depend on the naming of desired data, which helps in eliminating many redundant transmissions. Hierarchical protocols aim at clustering the nodes so that cluster heads can do some aggregation and reduction of data in order to save energy. Location-based protocols utilize the position information to relay the data to the desired regions rather than the whole network. In this paper, we will explore the routing protocols for sensor networks developed in recent years. Each routing protocol is discussed under the proper category. Our aim is to help better understanding of the current routing protocols for wireless sensor networks and point out open issues that can be subject to further research. The paper is organized as follows. In the section 2, we will briefly summarize the system architecture design issues for sensor networks and their implications on data routing. We then set our work apart from prior surveys on sensor networks. In the section 3, explores some prominent routing protocols of sensor network. In the Section 4, comparison of the routing protocols with a comparative summary of the surveyed approaches and points out open research problems. Finally section 5, concludes this paper.

2 SENSOR NETWORK ARCHITECTURE AND REQUIREMENTS

Before we discuss the routing protocols, we present sensor network architecture (10) and requirements. A sensor network can, in practice, be composed of tens to thousands of sensor nodes, which are distributed in a wide area. These nodes form a network by communicating with each other either directly or through other nodes. One or more nodes among them will serve as sink(s) that are capable of communicating with the user either directly or through the existing wired networks.

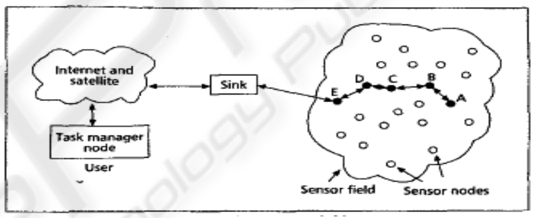

Figure 1: Sensor nodes scanered in a sensor field.

The sensor nodes are usually scattered in a sensor field as shown in above figure 1. Each of these sensor nodes has the capabilities to collect the data and route data back to the sink. Data are routed back to the sink by a multihop infrastructureless architecture through the sink as shown in above figure. The sink may communicate with the task manger node via Internet or satellite.

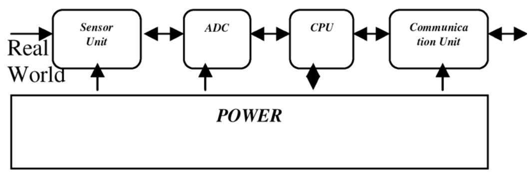

Figure 2: Components of Sensor Node.

Figure. 2 shows components of sensor node in which each node typically consist of the five components: sensor unit, analog unit, analog digital convector (ADC), central processing unit (CPU), power unit and communication unit. They are assigned with different tasks. The sensor unit is responsible for collecting information as the ADC requests, and returning the analog data it sensed. ADC is a

translator that tells the CPU what the sensor unit has sensed, and also informs the sensor unit what to do. Communication unit is tasked to receive command or query from, and transmit the data from CPU to the outside world. CPU is the most complex unit. IT interprets the command or query to ADC, monitors and controls power if necessary, processes received data, computes the next hop to the sink, etc. Many other units may be added for special usage, but the above five are the most important ones and are included in every sensor node.
Following are some of the features and requirements of a sensor network -

- Varying network size – The size of a sensor network can vary from one to thousands of nodes.
- Long lifetime network – An important characteristic of a sensor network is to design and implement efficient protocols so that the network can last as long as possible.
- Self – Organization – Sensor nodes should be able to form a network automatically without any external configuration.
- Query and re – tasking – The user should be able to query for special events in a specific area, or remove obsolete tasks from specific sensors and assign them with new tasks. This saves a lot of energy when the tasks change frequently.
- Cooperation/ Data aggregation – Sensor nodes should be able to work together and aggregate their data in a meaningful way. This could improve the network efficiency.
- Node Capabilities – In a sensor network, different functionalities can be associated with the sensor nodes. These special sensors either deployed independently or the functionality can be included on the normal sensors to be used on demand. Reading generated from these sensors can be at different rates, subject to diverse quality of service constraints and following multiple data delivery models, as explained earlier. Therefore, such a heterogeneous environment makes data routing more challenging.

3 ROUTING PROTOCOLS

In this section, we classify the routing protocols (9) for sensor networks first and then analyze the existing routing protocols.

A. Classification of the Routing Protocols

Depending on how the sender of a message gains a route to the receiver, routing protocol can be classified into three categories, namely, proactive, reactive and hybrid protocols. In proactive protocols, all routes are computed before they are really needed, while in reactive protocols routes are computed on demand. Hybrid protocols use a combination of these two ideas. Since sensor nodes are resource poor, and number of nodes in the network could be very large, sensor nodes cannot afford the storage space for "huge" routing tables. Therefore reactive and hybrid routing protocols are attractive in sensor networks. According to the participating style routing protocols can be classified into three categories, namely, direct communication, flat and clustering protocols.

B. Existing Routing Protocols

I. Low Energy Adaptive Clustering Hierarchy (LEACH)

LEACH is a clustering – based protocol that utilizes randomized rotation of the cluster – heads to evenly distribute the energy load among the sensor nodes in the sensor network. It assumes that the base station is fixed and located far from the sensors and all nodes in the network are homogenous and energy – constrained. The main energy saving of LEACH protocols comes from the combination of data compression and routing. It (i) employs localized coordination to improve the scalability and robustness, (ii) uses data fusion to reduce the amount of information transmitted between the sensor nodes and a given sink, and (iii) uses dynamic cluster – heads mechanism to avoid the energy depletion of selected cluster – heads.
LEACH provides sensor networks with many good features, such as clustering architecture, localized coordination and randomized rotation of cluster – heads; however, it suffers from the following problems:

- The nodes on the route from a hot spot to the base station might drain their battery soon, which is known as "hot spot" problem.

- It cannot be deployed in time critical applications.
- The assumption about the sink may not be practical.

II. Power – Efficient Gathering in Sensor Information Systems (PEGASIS)

PEGASIS (4) is a chain – based power efficient protocol based on LEACH. It is near optimal protocol under the following assumption about the network.

- All nodes have location information about all other nodes and each of them has the capability of transmitting data to the base station directly.
- Sensor nodes are immobile.

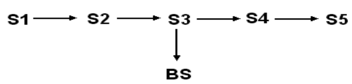

Figure 3: Token passing approach in PEGASIS.

Because each node has global knowledge of the network, the chain can be constructed easily by using a greedy algorithm. To balance the overhead involved in communication between the leaders (s3 is the leader in above figure) and sink, each node in the chain takes turn to be the leader. Nodes fuse the received data with their own data when data are transmitted in the chain.

PEGASIS outperforms LEACH by eliminating the overhead of dynamic cluster formation, minimizing the sum of distances that non – leader nodes must transmit and limiting the number of transmissions. However, PEGASIS has the same problem as LEACH does, (about the sink) because of their common assumptions. Furthermore, it requires global information of the network known by each sensor node. This does not scale well and is not suitable for sensor networks where such global knowledge is nit easy to obtain.

III. Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN)

TEEN (8) is a cluster- based routing protocol based on LEACH. Before we go into details of TEEN, let's have a look at the definition and assumptions used in TEEN –

Definition

- Hard Threshold (HT) – The absolute value of the attribute beyond which, the node sensing this value must switch on its transmitter and report it.
- Soft Threshold (ST) – A change in the value of the sensed attribute, which triggers the node, to switch on its transmitter and report sensed data.

Assumptions

- The network is composed of a base station and sensor nodes with the same initial energy.
- The base station has a constant power supply and can transmit with high power to all the nodes directly.

TEEN employs LEACH's strategy to form clusters, so all the issues that are un – addressed by LEACH are left un – addressed by TEEN as well. In addition to LEACH's drawbacks TEEN suffers from the following disadvantages:

- Cluster heads have to leave their transmitter on all the time and wait for data sent from other nodes.
- A node's time slot is wasted if it does not have data to send, while other nodes have to wait for their time slots.
- There is no mechanism to distinguish a node, which does not sense a "big" change from a dead or failed node.

IV. Sensor Protocols for Information Via Negotiation (SPIN)

SPIN (6) is family of protocols that efficiently disseminate information among sensor nodes in energy – constrained sensor network, assuming all of them are potential sink. Every node uses meta – data, i. e. high – level data descriptors, to name their data and uses negotiations to eliminate the redundant data transmissions throughout the network.

Conventional data dissemination approaches, e. g. classic flooding and gossiping, have three problems, namely, implosion, overlap, and resource blindness. SPIN solves these problems by using data negotiation and resource – adaptive algorithms. Before any data is really transmitted, a node performs meta – data negotiations. Exchanging ADV and REQ messages between the sender and receiver does the negotiations. In addition, SPIN checks the current energy level of nodes and adapts the protocol it is running based on how much energy remains. Simulation results show that SPIN is more

energy – efficient than flooding or gossiping while distributing data.
SPIN disadvantages are clear. First of all, it is not scalable. Secondly, the nodes around a sink could deplete their battery quickly if the sink is interested in too many events. Finally, events are always sent throughout the network.

V. Directed Diffusion

Directed Diffusion (5) is a data – centric routing algorithm in which all communication is for named data.. It consists of four elements – interests, data messages, gradients and reinforcements. An interest is a task description, which is named by, for instance a list of attribute – value pairs that describe a task. A gradient specifies both data rate and the direction along which events should be sent. Reinforcement is used to select a single path from multiple paths.
Although this protocol achieves some energy saving, it also has problems. For instance, to implement data aggregation, it employs time synchronization technique, which is not easy to realize in a sensor network. One other problem in data aggregation is the overhead involved in recording information.

VI. Flooding and Gossiping

Flooding and gossiping (15) are two classical mechanisms to relay data in sensor networks without the need for any routing algorithms and topology maintenance. 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. On the other hand, gossiping is a slightly enhanced version of flooding where the receiving node sends the packet to a randomly selected neighbor, which picks another random neighbor to forward the packet to and so on. Flooding has several drawbacks. Such drawbacks include implosion caused by duplicated messages sent to same node, overlap when two nodes sensing the same region send similar packets to the same neighbor and resource blindness by consuming large amount of energy without consideration for the energy constraints. Gossiping avoids the problem of implosion by just selecting a random node to send the packet rather than broadcasting. However, this cause delays in propagation of data through the nodes.

VII. Maximum Lifetime Energy Routing

Chang et al. (16) presents an interesting solution to the problem of routing in sensor networks based on a network flow approach. The main objective of the approach is to maximize the network lifetime by carefully defining link cost as a function of node remaining energy and the required transmission energy using that link. Finding traffic distribution is a possible solution to the routing problem in sensor networks and based on that, comes the name "maximum lifetime energy routing". The solution to this problem maximizes the feasible time the network lasts. In order to find out the best link metric for the stated maximization problem, two maximum residual energy path algorithms are presented and simulated. The two algorithms differ in their definition of link costs and the incorporation of nodes' residual energy.
By using Bellman-Ford shortest path algorithm for the above link costs, the least cost paths to the destination (gateway) are found. The least cost path obtained is the path whose residual energy is largest among all the paths. The algorithms utilizing these link costs are compared to Minimum transmitted energy (MTE) algorithm, which considers ij e as the link cost. Simulation results show that the proposed maximum residual energy path approach has better average lifetime than MTE for both link cost models. This is due to the absolute residual energy metric that MTE uses. The newly proposed metrics are concerned with relative residual energy that reflects the forecasted energy consumption rate.

4 COMPARISON

In this section, we compare and contrast the routing protocols for sensor networks, discussed above, with respect to a few metrics we identified.
As we observe LEACH, PEGASIS and TEEN are protocols with similar features designed with the similar idea. It is hard to say one protocol is better than another one because sensor network are application specific. For example, SPIN should be one of the best protocols for application deployed in a small sensor network in which no mobility is required and each node can serve as a sink.
Based on the analysis of the above protocols, we believe that some of the desirable features of a good routing algorithm for sensor networks are:

- Dynamic clustering architecture – It prevents cluster heads from depleting their power soon and hence extends the network's lifetime.
- Data fusion – If nodes could classify and aggregate data, it helps in efficient query

processing and decreases network overhead dramatically. This saves energy.

- Randomizing path choice – If a routing algorithm can support multiple paths to a destination with low overhead, it could help balancing the network load and tolerating the failure of nodes.
- Thresholds for sensor nodes to transfer sensed data – Given good threshold it may solve "hot spot" problem.
- Thresholds for sensor nodes to relay data – Determining appropriate thresholds of energy and time delay to relay data would help in elongating nodes' lifetime.

5 CONCLUSIONS

Sensor networks that are capable of sensing various physical phenomena will become ubiquitous in the near future. Hence, designing efficient routing protocols for sensor networks that suits sensor networks serving various applications is important. In this paper, we identified some of the important desired features of routing protocols for sensor networks and also compared and contrast the existing routing protocols.

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