Wireless Sensor Networks: Routing Protocol Comparison

CpE/CS /Sys Eng 443 - Wireless Ad Hoc and Sensor Networks

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A Literature Survey

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# Abstract

Wireless Sensor Networks (WSNs) have been around for decades. I have just become familiar with WSNs since starting this class. This undertaking is a timely topic; it is possible our analysis team may need to do some modeling in this area. The purpose of the paper will be to examine some of the important considerations in the design of the routing protocols for WSNs. This paper will be a literature survey from journals and papers found during my research on the topic. The routing protocols that are available for WSNs can be classified as data-centric, location based, quality of service (QOS) aware, flat and hierarchical. The focus of this survey will be on a few WSN protocols based on the network topologies flat and hierarchical. We will examine their composition, operation, and use. The paper will examine how the protocols are classified and best used. Finally, it will take a brief look at the future of the technology. [2}

# Introduction

The origin of the research and development on WSNs dates back to the early 80s and the Defense Advanced Research Projects Agency (DARPA) and were known as Distributed Sensor Networks (DSNs) at the time. Around that time Advanced Research Projects Agency Network (ARPANET) had been operational with around 200 nodes at various universities. They were assumed to have many low cost sensing nodes and operated autonomously. The program was a bit ahead of its time as there were still no personal computers and work stations, the internet was in its infancy, and Ethernet was beginning to become popular. One of the early demonstrated sensor applications was a helicopter tracking system. This system used a distributed array of acoustic microphones by doing signal abstraction and matching techniques that were developed by Massachusetts Institute of Technology (MIT). Even though the early researchers had a grand vision for the DSNs, the technology was not quite there yet. In addition, the sensors were rather large which limited their application. The DSNs were not well integrated with wireless technology either. Some of the recent advances in wireless technology particularly the advent of 802.11 have made the original visions of the early engineers and scientists of DSNs become a reality. [1]

Around the time frame of 1998 advances in computer and network technology began a shift toward more research and investment in WSNs both nationally and internationally. The now much smaller sensors enabled their use in many more applications such as environment monitoring, vehicular sensor networks, and even body sensor networks. Once again, DARPA lead the way in research of WSNs with its new program called SensIT. There development contributed to some of the current capabilities like ad hoc networking, dynamic querying and tasking, reprogramming and multi-tasking.

WSNs typically consist of spatially distributed sensor nodes. Each sensor will have a particular function/application and can independently do processing and sensing tasks. The nodes can process the raw data collected or sensed in place or pass it along for processing. The sensor nodes can communicate amongst themselves and will usually send the processed data on to another node to be routed to a base station. The base station provides the connectivity to transmit the data greater distances to a central processing and reporting unit. The sensor nodes themselves will have a wireless transceiver, memory, power source, sensors, and its own operating system that runs on the embedded processor. [1]

The sensor networks can be manually placed in the environment it is intended to service or can be dropped out of aircraft as well. The networks can be set up with a hierarchical structure or on a flat basis. These networks are used by commercial applications for assessment of the environment in the case of fires, floods, and other natural disasters to name a few. The WSNs can also be leveraged in military applications during times of peace and war.

# Background

Routing in a wireless sensor network is much different than traditional fixed terrestrial networks. Although they share some of the same characteristics as wireless mobile networks, the challenges are still greater due to the adhoc nature, limited energy sources and bandwidth the sensors must operate under. Energy awareness must be considered at all layers of the OSI, but particularly the network layer. A simple network can sometimes include thousands of nodes that need to get information to a base station so that the data can be utilized by computers and humans. One of the biggest challenges at the network layer is there is typically no global addressing scheme like there are on fixed networks. The sensor nodes might be set up in flat or hierarchical topologies. The sensor nodes need to be self organizing as they are typically placed in an adhoc style and need to create on the fly connections to their neighbors. The sensors are also limited in storage capacity and the ability to resupply their energy. Sensor nodes usually have low to no mobility, as they are sensing data for a particular area. Depending on the particular sensor application, a different set of requirements and challenges are encountered. Although GPS can be used for location information, it is not always desirable. To meet the special routing challenges posed by the resource limitations, the sensor routing protocols although different seem to employ some of the same basic functions. Energy conservation, data aggregation, and some type of topological hierarchy are used by the routing protocols. [2]

# Methodology

The approach used for this paper was to select a few wireless sensor routing protocols of interest. They were not selected for their topological characteristics or particular algorithm behavior. Next an attempt to find at least five journal articles that gave some sort of overview of the protocols was attempted.. After examining the articles, an attempt to review/describe their basic functionality was attempted. Any additional variants or hybrids were briefly presented as well. A comparison and contrast of the covered protocols is then given. Finally a conclusion is given based on what was learned from this survey.

# Results and Discussion

This section will cover the folowing routing protocols Temporarily-Ordered Routing Algorithm Protocol (TORA), Threshold-sensitive Energy Efficient sensor Network protocol (TEEN), Low-Energy Adaptive Clustering Hierarchy (LEACH), and the Sensor Protocol for Information via Negotiation (SPIN). These particular routing protocols were chosen based on any particular criteria, but will be examined and classified according to the characteristics they exhibit.

Temporally-Ordered Routing Algorithm Protocol or TORA is a hybrid, distributed, highly adaptive protocol. TORA is an on demand routing protocol that is based on a directed acyclic graph (DAG). [5] It is also known as a link reversal protocol. TORA uses an arbitrary height metric to establish a graph and length to the destination. TORA keeps track of the direction to forward the packets to the closest nodes. It may have more than one path to the same route but the one selected may not be the shortest. The protocol has reduced control messages because it only queries when it has packets to send.[6]

TORA’s three basic functions are creating routes, maintaining routes, and erasing routes. TORA maintains state on a per destination basis and keeps a separate instance for each destination. The destinations are assigned heights. The packets are only permitted to flow from higher to lower heights or downstream to its destination. The prevention of packet flows from downstream to upstream keep the topology loop free. [5].

TORA uses three types of control packets, query (QRY), update (UPD) and clear (CLR). Each node is required to maintain the following information: an ordered quintuple- packet direction, a set of neighbor nodes, a height array entry for each neighbor, a route required flag, and a link-state array.[5], [9] This is what conventional internet routers would call the routing table or topology table.

One of TORA’s advantages is that it can maintain multiple routes to the same destination. This enables the rerouting over an alternate path without intervention. This also would cut down on the need to do a query as in reactive routing protocols. The reduced overhead helps to conserve the limited energy of the sensors. It can also perform link status sensing, neighbor delivery, and security authentication. [6] The link sensing would detect when links are available and the authentication would allow for route exchange only between wanted routers.

There have been modifications for the purpose of enhancing TORA. One of the drawbacks of TORA is it will continue to send traffic over the same paths whether heavily utilized or not. This causes the sensors to use more energy faster. In order to prolong the life of the sensors the concept of E-TORA was introduced. It uses an energy parameter in addition to the height and state to calculate a route that presents the maximal path. Now the sensor can take advantage of additional routes to the same path without overburdening the same sensor. Another modification known as Hi-TORA is a bit of a clustering scheme. Each sensor node is assigned a role in the cluster it belongs to known as control node, border node, or ordinary node. The cluster id and state are changed according to the nodes mobility throughout the network. Nodes belong to a control node for a particular cluster and the height is then set to the control node instead of individual nodes. This cuts down on the need for every node to maintain a path to each node. This can conserve energy in the sensor nodes. The final modification to TORA is known as INORA which allows for quality of service (QOS) for traffic. [5], [8], [10]

The next routing protocol is called Threshold sensitive Energy Efficient sensor Network protocol (TEEN). It was designed for reactive networks and is one of the first reactive protocols for wireless sensor networks. TEEN uses the clustering concept where there is a cluster head for each cluster. During cluster change time the cluster head broadcast to the members and broadcast its attributes. There is a hard threshold (HT) and soft threshold (ST). The HT is the absolute value of the sensed attribute for which the transmitter must switch on and send that attribute value. The ST is a small change in value for which the sensor must switch on and transmit. The sensor nodes sense their environment continuously and store the attribute values in the sensed value (SV). The sensor nodes will only transmit in the current cluster period when the current value is greater than HT and the current value of the sensed attribute is different from SV. The HT is designed to reduce the number of transmissions because it should only transmit when it is in the range of interest.

The important features of TEEN are the time critical data reaches the user almost instantaneously. Energy consumption should be a lot less than proactive networks since the data is sent less often. The soft threshold can be varied which gives the ability to balance between accuracy and energy consumption. The attributes thresholds can be changed at every cluster change time if necessary. One of the major drawbacks is that the user would not receive any data if the thresholds are not reached. The nodes could be dead or out of service and it would not be known. Another issue is there is no collision avoidance mechanism in the clusters. [3], [4]

Low-Energy Adaptive Clustering Hierarchy (LEACH) is a routing protocol for sensor networks that focuses on energy conservation. LEACH also uses a clustering algorithm to limit the amount of sensor nodes that the data needs to pass through to get to the base station. It randomly rotates the selection of cluster heads to allow for even energy usage amongst the sensor nodes. The adaptive and self organizing refers to the fact that the nodes determine which one is the cluster head. The cluster head will in turn create a schedule for all the nodes so that their transmitters can remain off until necessary. The LEACH cluster head also performs local data fusion which compresses the data before it is transmitted up to the base station. This increases the overall sensor network lifetime. [13]

LEACH is considered to be one of the classic cluster head routing protocols which is a base for variants such as LEACH-C, LEACH-F, DCHS, PEGASIS, and TEEN. The random election of the cluster head within LEACH could possibly allow a sensor node with low energy become the cluster head. LEACH-C and LEACH-F use centralized algorithms to elect the cluster head. Although those two algorithms would eliminate the possibility of a low energy sensor becoming cluster head, they require more communication within the cluster to do so. This in turn burns more energy in all the nodes. DCHS does consider the cluster energy when electing the cluster head also but still isn’t ideal. PEGASIS takes a shorter transmission distance over a longer distance , but it still requires dynamic topology adjustment. As one can see there are various tradeoffs in the use of the LEACH variants as well. [12]

Another variant of the LEACH protocol is Stable Cluster Head Election (SCHE) which is suppose to optimize the selection of the cluster head so communication energy is reduced by 95% when compared to LEACH. SCHE minimizes energy dissipation of the sensor nodes by limiting the number of transmit/receive messages and by minimizing the distance between the base station and cluster head. In addition, it uses a fixed location for the cluster head and base station so that the protocol becomes more computationally simple. It only sends data out when it has it and uses data aggregation which are both similar to LEACH. [11]

Finally there are two other LEACH variants that will be briefly touched on. The first is a highly available sensor network protocol for differentiated services (HADS) which is a combination of Directed Diffusion and LEACH. HADS computes and then constructs a table based on best-effort service and real time service. There was a gateway node introduced for connecting cluster heads together. HADS is supposed to provide a reliable service and be energy efficient as well. This was based on a lab simulation, so the field viability was unknown at least in this paper. [14] Still another protocol that is supposed to add an element of security is Efficiency Security Model of Routing (ESMR). EMMSR only uses public key cryptography when a new sensor enters the network. This protocol was found resistant to outside attacks, but not resistant to inside attacks. EMSR still doesn’t perform as well as LEACH. [15]

Sensor Protocols for Information via Negotiation (SPIN) is a family of protocols. SPIN-1 and SPIN-2 are considered energy aware; they use negotiation and resource adaptation to overcome traditional flooding approaches. The nodes negotiate amongst themselves to make sure that they are transmitting the pertinent data. This eliminates the overlap and data duplication which is obviously wasted energy. By naming the data descriptors, which is called meta-data helps to eliminate implosion and overlap. The formats are specific to the sensor application. Each node has a resource manager which keeps track of consumption which is polled by the other nodes. The SPIN-1 protocol has three stages which use advertisements (ADV), requests for data (REQ), and the actual message (DATA). There are other types of SPIN known as SPIN-PP, SPIN-EC, SPIN-BC, and SPIN-RL. The SPIN-PP is the same as SPIN-1. SPIN will broadcast the type of data it has and if the neighbor is interested it sends a REQ for the data. [19], [16]

There are several variants of the SPIN family of protocols. The first is Secure-SPIN which uses three phases according to SPIN’s three messages. It uses a system of private pre-shared keys amongst the nodes, cluster head, and sink communicator to secure the data. [18] Another version of SPIN is cluster based SPIN or (CBS). The idea uses clustering to limit sending only the data that is needed to where it is required. The network is divided up similar to LEACH where each cluster is managed by a selected cluster head. Still another variant known as MS-SPIN uses secure multicast to limit the data to only where it is needed and in a secure manner. [20] The final SPIN variant covered is Centralized Sensor Protocol for Information via Negotiation (CSPIN). This approach combines the advertise-request-transfer process and the route distribution method. [17] All of these variants have only been simulated or tried in a lab environment; they have not been tried and proved in the field yet.

# Comparison and Contrast

The comparison used is based on simple attributes such as whether they are proactive, reactive, or hybrid when it comes to establishing connectivity and routing data or if they are flat, multihop or hierarchical. TORA, TEEN, and LEACH are all hierarchical in their approach to topology while SPIN uses a flat multihop topology. TEEN and TORA are reactive with SPIN being a bit of a hybrid. LEACH is more of a proactive protocol. All of the protocols or their variants seemed to have energy aware features built in. Although they may flood data out, only the required data sets were sent. All of the protocols examined have much more room for improvement as evidenced by the variants and hybrid protocols that took the best features and enhanced or changed those that were undesirable. Another area of concern was the security of the data exchange or compromise between the sensors. The most glaring attribute they all lacked was the physical security due to the nature of some of their application in open sensing environments. They are all heavily dependent on self organization and management. This is in great contrast to the terrestrial and cellular networks.

One area I originally wanted to cover was a comparison of WSN routing protocols to that of the traditional routing protocols I have worked with. Once I began to examine the WSN requirements, their application, and their need for low energy use, it was immediately obvious there was no real comparison to make. The distance vector routing protocols such as RIP, EIGRP, and IGRP would require much more processing power and operating systems than available in the WSNs. The link state protocols like IS-IS and OSPF while only sending changes in their networks, they too would require much more processing power, memory, etc. then the WSNs are capable of supporting. In addition all the conventional routing protocols wouldn’t work without some type of layer 3 addressing scheme. The conventional routing protocols couldn’t be used on WSNs.

As the area of wireless adhoc and sensor networks are vast, there were a number of areas I am interested exploring for future projects or reviews. Wireless sensor networks were expected to top a 21 billion dollar market in 2010 and a world wide deployment rate of 216%. That is incredible to me, especially since I knew very little about WSNs coming into this semester. [21] Some of the other interesting areas are for medical use. I have seen firsthand the use of wireless sensor system that relayed the vital signs for my father’s heart back to the office of his cardiologist. Home automation and smart grid technology are other areas where WSNs are making a huge impact. There are numerous security implications and problems that still need to be examined and solved just because of their physical exposure in some applications. In most traditional networks, wired and wireless, are secured from unwanted physical access. Finally there are methods being examined to allow web access to some of these WSNs. The thought would be to offload some of the processing from the resource constrained sensor nodes. [22], [23], [24]. [25]

# Conclusion

The WSN protocols examined in this paper were just a few of many in use and under development. It was clear that whatever the routing protocol used need to be energy conservative, have a light foot print, and require little to no real time administration. The processing power, memory, storage, and power resources are limited in the wireless sensor nodes. There are additional requirements, such as reactive or proactive routing which is driven by the application needs. The applications for WSNs are many and will continue to grow.

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