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Open Issues using LEACH Algorithm in Sensor Networks

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Abstract: Ad hoc sensor networks are ad hoc networks that are characterized by decentralized structure and ad hoc deployment. Sensor networks have all the basic features of ad hoc networks but to different degrees – for example, much lower mobility and much more stringent energy requirements. We analyze the current state of research and evaluate open issues in development of routing techniques in wireless sensor networks.

Keywords: General Sensor Network, MANETs, PODS

Introduction

Consider a wireless network made up of units that perform both measurements and communications. These units are totally independent and are capable of recording data from sensors. The mobility of these units is very low but the data forwarding strategy is robust enough to be fault tolerant and to allow occasional mobility among units.

For example, we consider the sensor network being developed for the PODS project at UH Manoa [9]. One of the major objectives of the project is to implement a sensor network to study endangered plants such as "Silene Hawaiiensis", in order to determine what is essential for the plant's survival in its native habitat. The challenge is to implement an ad hoc network comprised of hundreds of small sensors or pods, which monitor wind, rain, temperature, light and moisture, and which are used for determining spatial or temporal patterns in the environment of the plant being studied.

Such a real life sensor network is comprised of hundreds of sensors. The nodes are battery powered, so the first networking challenge is getting data back with minimal energy expenditure, by choosing energy-efficient paths and by minimizing the routing overhead. The second challenge is to maintain connectivity in case some pods are moved to a different location or fail to participate due to lack of power, though overall mobility is likely to be more limited than in a network of laptops. The third challenge is that sensor networks can be expected to grow to many thousands of nodes, so any algorithms used in these networks must be scalable. Finally, these networks should use multiple paths whenever possible, both for redundancy and to distribute the energy expenditure of forwarding packets. These requirements distinguish ad-hoc wireless sensor networks from mobile ad-hoc networks (MANETs). Table 2 compares MANETs with ad hoc sensor networks.

A sensor network such as the PODS network also differs from many of the wireless sensor networks considered in the literature. Though some data can be combined and summarized, other data, for example camera images, must be delivered unchanged to a base station. The PODS network is designed to have multiple base stations if possible. In addition, communication is not limited to sending data to base stations: interaction between individual sensor nodes may be needed to allow distributed computation among nodes in close geographic proximity, to support occasional communication from the base stations to the individual nodes, and for a variety of reasons including fault-tolerance. These requirements mean that a PODS-style network needs to be able to support any-to-any communication, though the common mode of communication is from nodes to one or more base stations.

There has been a lot of research in wireless routing protocols. Existing protocols provide different tradeoffs among the following desirable characteristics: fault tolerance, distributed computation, robustness, scalability, and reliability. Wireless protocols proposed so far for wireless sensor networks are very limited, generally focusing on communication to a single base station or on merging sensor data. While these protocols are suitable for their intended purposes, in this paper we explore the use of protocols developed for MANETs to provide more general communication among nodes in a sensor network.

Low Energy Consumption

Protocols for MANETs are designed for communication among laptops. Even though laptops are battery-powered, their power budget far exceeds that of a node in a wireless sensor network. Such nodes are often deployed in remote locations. Whether powered by batteries, solar energy, or some other method, reducing energy consumption lessens the weight or extends the lifetime of the package and makes the sensor easier to conceal. Each node in a wireless sensor network only needs to record, transmit, and forward data, unlike a laptop which might have to perform much more complex tasks. As a result, the computational engine in a sensor node consumes significantly less energy than a laptop, and communications must likewise use less energy.

Many routing techniques have been proposed for both MANETs and wireless sensor networks [3,11,7,12,18,21,22,26,27,28], including protocols that focus on “minimum energy” routing [21,23,24,25,27,29]. For example, [23] notes that a route with more, shorter hops often requires less total energy than a route using fewer, but longer, hops. Other papers focus on developing generalized power aware/energy aware routing schemes, designing power aware cost metrics [23], using transmit power adjustment to control the network topology [19], or using the location information to minimize the power relay route, thus minimizing the total energy consumption [24]. However, none of these studies focus on practical issues such as the overhead of computing such minimum-energy routes. Doshi et al., [21] list the following reasons why minimum energy routing is hard to implement in practice. Minimum energy routing introduces an overhead cost, the additional routing information is not free, current protocols fail to provide sufficient information for making power level decisions, lower power routes leave less margin for channel fluctuations or measurement errors, minimum energy routes are difficult to discover, and minimum energy routes are difficult to maintain. Because of these issues, it is not currently clear that such “minimum energy” routing is in practice any better than other methods which have lower theoretical efficiency but provide other practical advantages. Because of these limitations, we consider a variety of protocols, not only those which claim to use "minimal" energy.

The SensIT program at DARPA notes that many MANET protocols focus on fast topology changes, and that a focus on power-aware metrics, location information, and the energy usage of each node can lead to more power-aware routing. Location information is used by some MANET protocols [2, 5, 20, 25, 28, 29] both to improve scalability and, in some cases, also to minimize energy consumption [14, 27, 29]. Some authors [29] point out that an optimal geographic route may provide power savings and network lifetime extension compared to a similar route that does not use location information. However, at least for the GEAR protocol this has only been tested under a very limited number of relatively favorable network configurations.

LEACH [27] proposes a clustering based protocol that utilizes randomized rotation of local cluster heads to evenly distribute energy load among the sensors in the network. In LEACH each local cluster head performs "local data fusion" to compress the information. It is a single path routing technique whose scalability is provided by its hierarchical nature. However, some of their assumptions may not be true when compared to general sensor networks like PODS. LEACH requires a fixed base station to which data needs to be routed. Leach only supports sensors which do not move and send data at fixed rate, with symmetric radio channels, and adjustable transmit power. Leach also assumes that the cluster heads can talk directly to the gateway node. LEACH may be a good solution for a smaller subset of the problem but for a general sensor network like PODS, it does not address the situation when more than one fixed base station is present, where sensors are not static, and where a node can communicate to another node in an arbitrary fashion.

GEAR [29] presented an alternative to this by incorporating the technique of data diffusion and using geographic computations to find low energy paths. They propose that if the destination is quite far from the packet then the path found by geographic routing may be nearly as energy efficient as an optimal route. Some of their techniques that are not useful for the more general sensor networks we are interested in, include the use of data diffusion, which is only useful to deliver the data to a single or a few base stations, and does not support communication between arbitrary nodes. The paper by Doshi et al. [21] showed that a path which is primarily discovered using location information may not be the most energy efficient path.

Low mobility

Sensor networks differ from MANETs in a very important way and that is in mobility. A MANET is a more general case where the participating laptops can either be stationary or move randomly with a random speed. As nodes within a MANET move, they move out of range of their neighbors and hence are no longer able to communicate with the old neighboring nodes and come within range of new nodes. Hence the mobility introduces the problem of fault tolerance. An ideal routing protocol for MANET should be able to deliver data packets from source to destination even when some of the intermediate nodes move away from their neighbors range. This complicates the design of the routing protocol as this introduces additional routing overhead. In previous work [17], one of the authors related the speed of the movement of the nodes to the packet delivery ratio and routing overhead. The packet delivery ratio worsens as speed is increased for DSR [8], whereas AODV [6] does not degrade as rapidly when mobility increases. Nodes in a sensor network most of the time are static and with an occasional breaking of a link as the node runs out of its energy or is relocated. Sensor networks need the ability to re-configure automatically in case links disappear or new nodes appear. Protocols such as GEAR and LEACH assume that the nodes in a sensor network are static where as in PODS at least some of the nodes (e.g. a hand-held base station) may be mobile.

Self-configuring nature

Ad hoc wireless sensor networks are self-configuring in nature. This can be considered an added feature to the existing ad hoc nature of the network. The network is adaptable to the changing requirements and is able to diagnose when a link / sensor node goes down and when it comes up. There are two main schemes to design a wireless sensor network, the address centric scheme and the data centric scheme. The address centric scheme has been used by various routing protocols such as LAR, GSPR, and DREAM etc. In this scheme we assign IP addresses to each sensor node, simplifying the process of routing. This concept is similar to that of normal wired networks. A unique IP address will help the source sensor node to know the sensor node to which data must be routed. However in [5] a new concept of data centric model is presented which is not address oriented. The mechanism and goal of self-configuration in these networks is different from those of the address centric scheme.

Multipath desirable

Macker and Corson [13] listed qualitative and quantitative independent metrics for judging the performance of mobile ad hoc network routing protocols. One of these qualitative metrics was path strategy. There are a number of different path strategies. One that is very common is shortest path [2, 8, 21, and 28] where one copy of the message is in the network at any time. At the other extreme is the flooding based approach [10, 20] where the message is flooded through the whole network area. A good example of this approach is the Multi-path On-demand Routing (MOR) Protocol [10] which is a on-demand, load balancing routing protocol designed for the PODS project at the University of Hawaii at Manoa. MOR may require as little as one network flood to establish necessary routes and its energy efficient and robust in low mobility and low energy networks such as PODS. Broadcasting usually solves the routing in highly mobile conditions but considering our requirement for a general sensor network for PODS this is undesirable. The compromise between these two approaches is a multipath strategy, where data packets are routed through a few distinct paths and successive packets follow different paths whenever possible. This not only provides robustness to the network using multiple paths but also helps in distribution of the energy requirement of the network evenly across the network. In [1] A.Nasipuri et al., prove that the use of multiple paths in DSR can keep correct end to end connections, but they did not study the performance improvement on network load balancing. M.R Perlman et al., demonstrate [16] that multipath routing can balance loads. They propose a diversity injection method to find more node-disjoint paths compared to DSR. However, their work is based on multiple channel networks, which are contention free but may not be available in some applications. [14] applies the multipath strategy to DSR's source routing technique and achieves some scalability under mobile conditions. However the energy distribution component of the multipath strategy has not been adequately explored in the paper.

Scalability

An ideal routing protocol for a MANET should be scalable. This means that as the size of the network increases or the number of nodes increases the routing protocol should be able to adapt to the changes and provide consistent performance based on the parameters that we have discussed earlier. [2] describes three methods, which have been used by researchers to provide scalability to a routing protocol for MANETs. The first method uses hierarchy to provide scalability. The second way to provide scalability is caching. The third way to provide scalability is using geographic information. Using hierarchy to provide scalability is the most widely deployed approach to scale routing as the number of destinations increases. Two main strategies used to combine nodes location and hierarchical network structures are the Zone Based Routing and the Dominating Set Routing. Online power-aware routing routing [28] schemes are example of Zone Based Routing and GRID is an example of dominating set routing.

Caching is becoming a widely deployed technique for scaling ad hoc routing protocols in MANET [6, 8]. Caching reduces the routing protocols message load in two ways: It avoids pushing topological information where the forwarding load does not require it (like ideal routers) and it often reduces the number of hops between the router that has topological information and the router that requires it. However, Doshi et al.,[21] demonstrated with their implementation of energy aware DSR protocol using old routes from the cache does not necessarily mean that a low energy route is selected every time.

The last and most frequently used technique to provide scalability to ad hoc routing protocols is to use the geographic location information. This technique assumes that all wireless nodes know their positions and links are bi-directional. This approach has been adapted in GPSR, GEAR and gradient routing.

For a general sensor network a combination of the above-mentioned strategies would be sufficient to provide scalability, as mobility is limited in these networks.

Conclusion

In this paper we have evaluated the necessary features of the routing protocols for general wireless sensor network like PODS [9]. Current research into routing protocols for MANETs and ad hoc sensor networks tend to make many tradeoffs in various features and are generally tested in a much regulated environment. As seen from the paper that the needs and requirements of routing protocols for general ad hoc sensor networks is very unique compared to routing protocols for MANETs and other sensor networks. Hence, there is a need for further research into this new field as it poses some of its unique challenges and we would be continuing our research in this area in future.

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Table 1: Comparison of three different energy efficient routing protocols for ad hoc sensor networks

Method	Distributed	Metrics	Scalability	Comm. Without merging	Multiple base stations	Mobility	Fault Tolerance	Robustness
New DSR [4]	No	Shortest path	Caching	Yes	Yes	Sufficient	Single path	Yes: Limited
LEACH [19]	Yes : Location aware: clustering	Location,	Hierarchical	No	No	No	Single path	No
GEAR [28]	Yes: Location aware	Shortest Path, Location	Geographic	No	Yes	Not tested	Single path	No

Table 2: Comparison of features of MANETs and Ad Hoc Sensor Networks.

Features	**MANET**	**Ad Hoc Sensor Networks**
Decentralized control	Yes	Yes
Bandwidth deficient	Yes	Sometimes
Energy deficient	Yes. But this is of secondary importance as battery packs can be replaced	Yes, it is of primary importance
Mobility	Varies (slow to fast)	Limited
Traffic	Multimedia rich	Statistical and Multimedia
Data rate	High	Low [1-1000 Kbps]
Flow of data	Bi-directional	Mostly uni-directional [sensor to sink]
Redundancy in data	No	Sometimes

Main Goal	To optimize QoS and high bandwidth efficiency	Prolonging the life of the network through aggressive energy management, to prevent connectivity degradation.
Fault tolerance	Needed as mobility increases	Needed only if nodes exhaust available energy or are moved
Basic features of routing protocol	Loop free, energy and bandwidth efficient, secure, provides QoS, fault tolerant and reactive instead of proactive, and distributed in nature	Most of the same features as for MANETs, but with less emphasis on mobility and more emphasis on energy efficiency, scalability, and multipath connectivity.