Routing in Ad-Hoc Networks

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Abstract

In this paper, we deal with the basic concept of ad-hoc networks and the need for it. We present a classification of various routing protocols which have been proposed and some have been implemented. These protocols have been categorized as data centric, hierarchical and location based. We analyze the advantages and disadvantages of these routing protocols in this paper.

Introduction

Wireless computing is seen to undergo exponential growth in the coming years hence it is one of the hot topics in the research and development sector. An ad-hoc network is a collection of wireless mobile hosts forming a temporary network without the aid of any centralized administration or standard support services regularly available on the wide area network to which the hosts may normally be connected. The aim of Ad-hoc networking is to support robust and efficient operation in mobile wireless networks by incorporating routing functionality into mobile nodes. These mobile nodes are said to have dynamic, rapidly changing, random, multihop topologies which are composed of low bandwidth links. These two constraints make congestion a norm rather than an exception. The other problem being that the nodes are highly energy dependent. That is these nodes have limited battery power so utilization of these resources should be done prudently.

Routing in this network 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. Therefore, classical IP-based protocols cannot be applied to sensor networks. Second, in contrary to typical communication networks almost all applications of sensor networks require the flow of sensed data from multiple 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.

These constraints caused many new algorithms to be proposed for the problem of routing data in ad-hoc networks. Most of these algorithms have been classified as data centric, hierarchical or location based on network flow or quality of service. 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.

Conventional Routing Approach

Let us consider three mobile hosts A,B and C as shown in the figure below.

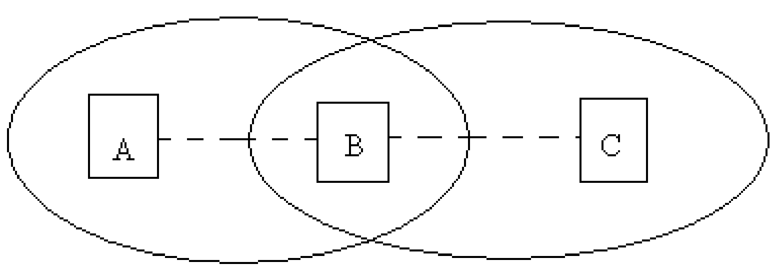

Figure 1

Host A and host C are not in the radio range of each other so whenever they want to communicate, they use node B which is in the range of both as a router which forwards information packets from A to C. Conventional routing protocols are based on either distance vector or link state algorithms. In distance vector routing, each router maintains a table giving the distance from itself to possible destinations. Each router broadcasts this information to each of its neighbors and hence the routing tables are updated. Updating the tables frequently results in decrease in the available bandwidth for data packets.

The other routing algorithm is the link state algorithm in which each router maintains a complete picture of the topology of the entire network. Each router monitors the cost of the link to each of its neighbors and periodically broadcasts an update of this information to all routers. Compared to the distance vector routing, this routing protocol converges to the correct path quicker.

The problem with these conventional routing protocols is that transmission between two hosts over a wireless network does not necessarily work equally well in both directions. Some routes determined by conventional routing protocols may not work in some environments. Also, many links between routers seen by the routing algorithms may be redundant. Rather than a single router between A and C, there may be many hosts within the range of a host. It has been found that conventional routing protocols are not designed for dynamic topology changes used in ad-hoc networks as convergence to new stable routes after dynamic changes will be very slow. The speed of convergence can be speed up by sending the routing updates more frequently at the cost of battery power and loss of bandwidth.

Data Centric Protocols

The large number of nodes makes it difficult for global identification of the nodes. Therefore, data is usually transmitted from every sensor node within the deployment region with some redundancy even though it results in inefficiency in bandwidth control and energy consumption. In data centric routing, the sink sends queries to certain regions and waits for data from the sensors located in the selected regions. The various types of data centric protocols are as follows

1. Flooding and Gossiping

In flooding, each node receiving a data packet broadcasts the packet to all the other nodes in its vicinity. This goes on until the packet has reached its destination. In gossiping, the receiving node sends the data packet to a randomly selected neighbor which in turn sends the data to another randomly selected node till it reaches its destination. Both these protocols have the disadvantage of resource contention despite being simple to implement.

2. Sensor protocols for information via negotiation (SPIN)

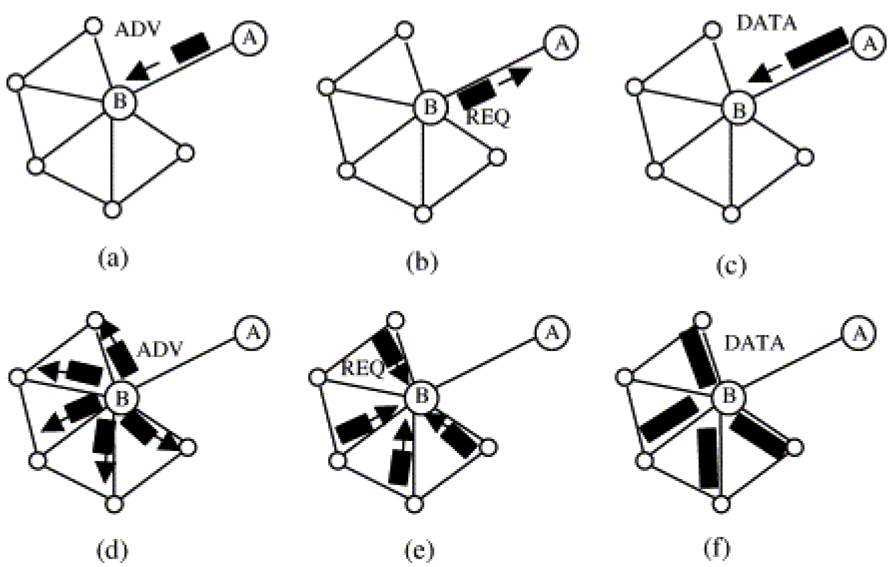

Figure 2) Node A starts by advertising its data to node B (a). Node B responds by sending a request to node A (b). After receiving the requested data (c), node B then sends out advertisements to its neighbors (d), who in turn send requests back to B (e–f).

The idea behind this protocol is that the data is named using high level descriptors called meta-data which are transmitted before the data is exchanged among the mobile nodes. This is done to eliminate the transmission of redundant data throughout the network. The exact format of the meta-data depends on the application. The meta-data is a data advertisement mechanism. Each node upon receiving new data, advertises it to its neighbors and interested neighbors, that is those who do not have the data, retrieve the data by sending a request message. Spin's meta-data negotiation solves the problems of flooding such as redundant information passes and resource blindness thus, achieving a lot of energy efficiency. The mobile nodes use three kinds of messages to communicate. They are 1) ADV which is a new data advertisement. When a node has data to share, it can advertise this fact by transmitting an ADV message containing meta-data. 2) REQ which stands for request for data. A SPIN node sends an REQ message when it wishes to receive actual data. 3) DATA which is the actual data message. Compared to flooding and gossiping, this protocol is much more energy efficient. However, Spin's data advertisement mechanism cannot guarantee the delivery of data. For instance, if the nodes that are interested in the data are far away from the source node and the nodes between source and destination are not interested in that data, such data will not be delivered to the destination at all.

3. Directed Diffusion

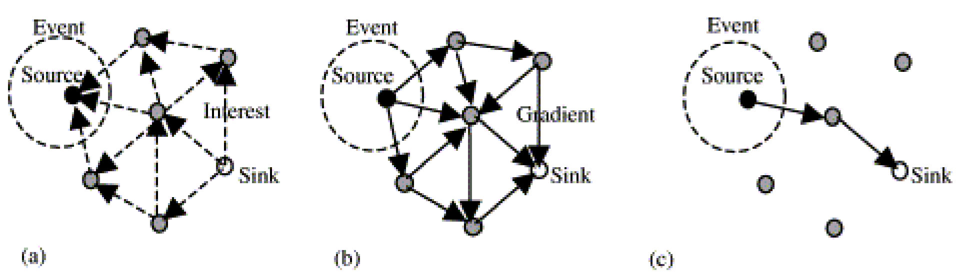

Figure 3) (a) Interest propagation, (b) initial gradients setup, (c) data delivery along reinforced.

In this routing protocol, data generated by mobile nodes is named by attribute value pairs. A node requests data by sending interests for named data. The interest is broadcast by a sink through its neighbors. Each node receiving the interest can do caching for later use. The nodes also have the ability to do in-network data aggregation. The interests in the caches are then used to compare the received data with the values in the interests. The interest entry also contains several gradient fields. A gradient is a reply link to a neighbor from which the interest was received. It is characterized by the data rate, duration and expiration time derived from the received interest's fields. 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. The sink resends the original interest message through the selected path with a smaller interval hence reinforces the source node on that path to send data more frequently. Direct Diffusion has the potential for significant energy efficiency. Even with relatively non-optimized path selection, it outperforms an idealized traditional data dissemination scheme. Secondly fusion mechanisms are stable under a range of network dynamics. However directed diffusion cannot be applied to all sensor network applications since it is based on a query driven data delivery model. Therefore, Directed Diffusion is not a good choice as a routing protocol for the applications such as environmental monitoring. In addition, the naming schemes used in Directed Diffusion are application dependent and each time should be defined a priori. Moreover, the matching process for data and queries might require some extra overhead at the sensors.

4. Energy aware routing

The potential problem in current protocols is that they find the lowest energy route and use that for every communication. However, that is not the best thing to do for network lifetime. Using a low energy path frequently leads to energy depletion of the nodes along that path and in the worst case may lead to network partition. To counteract this problem, we propose a new protocol that we call energy aware routing. The basic idea is that to increase the survivability of networks, it may be necessary to use sub-optimal paths occasionally. This ensures that the optimal path does not get depleted and the network degrades gracefully as a whole rather than getting partitioned. To achieve this, multiple paths are found between source and destinations, and each path is assigned a probability of being chosen, depending on the energy metric. Every time data is to be sent from the source to destination, one of the paths is randomly chosen depending on the probabilities. This means that none of the paths is used all the time, preventing energy depletion. Also different paths are tried continuously, improving tolerance to nodes moving around the network. Energy aware routing is also a reactive routing protocol. It is a destination-initiated protocol where the consumer of data initiates the route request and maintains the route subsequently. Thus, it is similar to diffusion in certain ways. Multiple paths are maintained from source to destination. However, diffusion sends data along all the paths at regular intervals, while energy aware routing uses only one path at all times. But due to the probabilistic choice of routes, it can continuously evaluate different routes and choose the probabilities accordingly. The protocol has three phases: 1) Setup phase or interest propagation – Localized flooding occurs to find all the routes from source to destination and their energy costs. This is when routing tables are built up.2) Data Communication phase or data propagation – Data is sent from source to destination, using the information from the earlier phase. This is when paths are chosen probabilistically according to the energy costs that were calculated earlier.3) Route maintenance – Route maintenance is minimal. Localized flooding is performed infrequently from destination to source to keep all the paths alive.

Hierarchical Protocols

Hierarchical techniques are commonly used in wired network for scalability. For wireless networks, a hierarchical clustering and routing scheme based upon physical location management was recently proposed. This scheme, however, creates implementation problems which are potentially complex to resolve. First, it does allocate Cluster IDs dynamically. This allocation must be unique - not an easy task in multi-hop mobile environment, where the hierarchical topology must be often reconfigured. Second, each cluster can dynamically merge and split, based on the number of nodes in the cluster. Frequent cluster changes may degrade the network performance significantly.
Another approach to scalability is On-demand routing. On-demand routing is the most recent entry in the class of wireless routing schemes. It is based on a query-reply approach. Typically, on-demand routing aims at providing solutions for networks with fast changing topologies. MANET working group is also focusing on the on demand routing solution for an Ad Hoc Network Standard. On-demand routing does scale well to large population as it does not regularly maintain a routing table for all destinations.

Instead, as the name suggests, a route to a destination is computed only when there is a need. Thus, routing table storage is greatly reduced, if the traffic pattern is sparse. However, on-demand routing introduces the less desirable initial latency which makes it not very efficient for interactive traffic. It is also impossible to know in advance the quality of paths to all destinations- a feature which can be very effective in call acceptance and path selection of QoS oriented connections. Zone routing can be viewed an extension of on-demand routing, since it is based on a hybrid of on-demand routing and conventional routing . In fact, zone routing represents a first step towards hierarchical on-demand routing. For a routing inside of a zone, any routing scheme, including Distributed Bellman-Ford routing or Link State routing, can be applied. For an inter zone routing, on-demand routing is used. The advantage of zone routing is its scalability, as it reduces the need for routing table storage. At the same time, the efficiency of global routing is preserved within each zone. However, for the inter zone routing, the on-demand solution poses the usual problems of connection latency and QoS reporting.

1. Low-energy adaptive clustering hierarchy

Low-energy adaptive clustering hierarchy or LEACH is one of the most popular hierarchical routing algorithms for sensor networks. The idea is to form clusters of the sensor nodes based on the received signal strength and use local cluster heads as routers to the sink. This will save energy since the transmissions will only be done by such cluster heads rather than all sensor nodes. Optimal number of cluster heads is estimated to be 5% of the total number of nodes.

All the data processing such as data fusion and aggregation are local to the cluster. Cluster heads change randomly over time in order to balance the energy dissipation of nodes. This decision is made by the node choosing a random number between 0 and 1. The node becomes a cluster head for the current round if the number is less than the following threshold.

$$T(n) = \begin{cases} \frac{p}{1-p*(r \bmod 1/p)} & \text{if } n \in G, \\ 0 & \text{otherwise,} \end{cases}$$

Where p is the desired percentage of cluster heads (e.g. 0.05), r is the current round, and G is the set of nodes that have not been cluster heads in the last $1/p$ rounds

The nodes die randomly and dynamic clustering increases lifetime of the system. LEACH is completely distributed and requires no global knowledge of network. However, LEACH uses single-hop routing where each node can transmit directly to the cluster-head and the sink. Therefore, it is not applicable to networks deployed in large regions. Furthermore, the idea of dynamic clustering brings extra overhead, e.g. head changes, advertisements etc., which may diminish the gain in energy consumption.

2. Wireless Hierarchical Routing Protocol

In WHIRL, the entire network is divided into logical subnets. Each subnet has one primary Home Agent (HA). It can have several secondary HAs from which, in the case of primary HA failure, a new primary HA will be selected. Each node has a unique identifier Node ID. The address of the node consists of two parts: logical subnet ID and Node ID. The subnet ID is used to identify the logical subnet to which each node belongs and the Node ID is used in physical routing. In our study, we use the Link State (LS) physical routing scheme which is on the top of MAC layer clustering described in [7, 4] as the physical routing infrastructure for WHIRL. However, the concept of WHIRL can be built upon any routing scheme using Node ID as the physical routing address. The key responsibility of the HA is to maintain the physical clustering information of its logical subnet members. HA also needs updates its own clustering information to the entire cluster heads. There are two phases in the WHIRL. The packet is routed first from the source to destination HA. Then it is routed from the destination HA to the final destination. The header of the packet contains the Node ID of the destination cluster head DestCH. Initially the DestCH is set to unknown. The source sends the packet to its cluster head. The cluster head will look up it's HA clustering table. The cluster head will set the

DestCH to be the Node ID of the destination cluster head of the destination HA in the packet header according to the table. If the destination HA has more than one cluster heads, it will choose the one that has the minimum distance. All the intermediate gateways and cluster heads will route the packet according to the DestCH in the packet header using the physical routing scheme. Once the destination cluster head gets the packet, it will send the packet to the HA. The HA scans its subnet member clustering table, finds out the cluster head for the destination node and sets the DestCH with it. The HA will then send the packet to its cluster head and the packet will be on the journey to its final destination cluster head. The destination cluster head will pass the packet to destination node.

Location Based Protocols

Most of the routing protocols for sensor networks require location information for sensor nodes. In most cases location information is needed in order to calculate the distance between two particular nodes so that energy consumption can be estimated. Since, there is no addressing scheme for sensor networks like IP-addresses and they are spatially deployed on a region, location information can be utilized in routing data in an energy efficient way. For instance, if the region to be sensed is known, using the location of sensors, the query can be diffused only to that particular region which will eliminate the number of transmission significantly. Some of the protocols discussed here are designed primarily for mobile ad hoc networks and consider the mobility of nodes during the design. However, they are also well applicable to sensor networks where there is less or no mobility.

Minimum energy communication network

Minimum energy communication network (MECN) sets up and maintains a minimum energy network for wireless networks by utilizing low power GPS. Although, the protocol assumes a mobile network, it is best applicable to sensor networks, which are not mobile. A minimum power topology for stationary nodes including a master node is found. MECN assumes a master-site as the information sink, which is always the case for sensor networks.

MECN identifies a relay region for every node. The relay region consists of nodes in a surrounding area where transmitting through those nodes is more energy efficient than direct transmission. The enclosure of a node i is then created by taking the union of all relay regions that node i can reach. The main idea of MECN is to find a sub-network, which will have less number of nodes and require less power for transmission between any two particular nodes. In this way, global minimum power paths are found without considering all the nodes in the network. This is performed using a localized search for each node considering its relay region. The protocol has two phases:

1. It takes the positions of a two-dimensional plane and constructs a sparse graph, which consists of all the enclosures of each transmit node in the graph. This construction requires local computations in the nodes. The enclose graph contains globally optimal links in terms of energy consumption.

2. Finds optimal links on the enclosure graph. It uses distributed Bellmen–Ford shortest path algorithm with power consumption as the cost metric. In case of mobility the position coordinates are updated using GPS.

The small minimum energy communication network (SMECN) is an extension to MECN. In MECN, it is assumed that every node can transmit to every other node, which is not possible every time. In SMECN possible obstacles between any pair of nodes are considered. However, the network is still assumed to be fully connected as in the case of MECN. The sub-network constructed by SMECN for minimum energy relaying is provably smaller (in terms of number of edges) than the one constructed in MECN if broadcasts are able to reach to all nodes in a circular region around the broadcaster. As a result, the number of hops for transmissions will decrease. Simulation results show that

SMECN uses less energy than MECN and maintenance cost of the links is less. However, finding a sub-network with smaller number of edges introduces more overhead in the algorithm.

Conclusion

Routing in sensor networks has attracted a lot of attention in the recent years and introduced unique challenges compared to traditional data routing in wired networks. In this paper, we have summarized recent research results on data routing in sensor networks and classified the approaches into three main categories, namely data-centric, hierarchical and location-based.

Although the performance of these protocols is promising in terms of energy efficiency, further research would be needed to address issues such as quality of service posed by video and imaging sensors and real-time applications. Energy-aware QoS routing in sensor networks will ensure guaranteed bandwidth through the duration of connection as well as providing the use of most energy efficient path

Other possible future research for routing protocols includes the integration of sensor networks with wired networks (i.e. Internet). Most of the applications in security and environmental monitoring require the data collected from the sensor nodes to be transmitted to a server so that further analysis can be done. On the other hand, the requests from the user should be made to the sink through Internet. Further research in these topics is going on in the topic of routing in Ad- hoc networks. The scope of research is very vast and yet unexplored.

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