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A Review of Energy Conservation Issues and Routing Protocols in Mobile Ad Hoc Networks

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Abstract - Mobile Ad hoc Network (MANET) is a self-establishing and self-organizing network that facilitates communication among the nodes independent of a fixed infrastructure. Therefore, it can be deployed quickly and with fewer efforts. Some of the major applications of MANETs are emergency rescue operations, battle field communication, and information exchange at conference or classroom. MANETs are extremely dynamic and dispersed in nature. Also, MANET has battery operated nodes. The network can get partitioned due to draining out of a node which decreases packet delivery as well as network lifetime. This imposes a serious constraint on the routing process in MANET. At the same time, energy conservation issues require special attention so as to keep the nodes alive for a longer time. Hence there is earnest need of modifying the conventional routing protocols and make them energy efficient. This paper reviews different energy conservation issues and energy efficient routing protocols, along with the survey of work done by other researchers.

Keywords - *MANET, Energy Conservation, Energy Efficient Routing, Residual Battery, Network Lifetime.*

1. Introduction

In infrastructure wireless networks, the nodes use base station to communicate with each other as well as to access services of the network. The mobile nodes may be battery constrained but there is no such limitation at the base station [1]. So energy management schemes spend more energy at the base station and conserve it at mobile nodes. The whole network may fail, even if one of the mobile nodes move out of transmission range, as MANET lacks centralized administration. The nodes should be able to enter or leave the network at any time is one of the important requirements of MANET. Multi-hop communication is required in MANET because the nodes have very short transmission range. Thus every node in an ad-hoc network needs to forward packets for other nodes. Hence each node plays both the roles, as a host and as a router. When a node exits the network making the links to break then ad-hoc networks can handle topology changes by requesting new routes. The nodes in ad hoc networks, being highly dependent must cooperate in the routing process, making it essential to maximize network lifetime.

2. Energy Conservative Designs

Energy conservative designs can be categorized as,

1. Transmitter power control techniques [2]
2. Power management algorithms [2]

2.1 Transmitter Power Control Techniques

Power control is the technique of tuning hosts' transmission powers to the proper range [2]. The topology of the wireless network can be changed by changing antenna direction and tuning the transmission powers. Battery conservation and increase in spatial reuse of bandwidth are the main advantages of power control. If it is considered that the transmission power is constant and same for all the nodes in the network, then the minimum hops route is the minimum energy route. The minimum energy routing protocols should transmit the data packets at variable power instead of transmitting them at fixed power in order to gain maximum energy savings. To achieve this, dynamic transmission power control can be employed on the link. Now the energy cost of each link can be calculated using variable power as well as other factors.

The conventional on-demand protocols do not have any mechanism to calculate and transmit the parameters necessary to calculate the energy cost per packet. Hence they cannot support the dynamic transmission power control feature. The dynamic transmission power also helps in the efficient utilization of the network resources. This kind of power control increases the total network capacity, by allowing a larger number of simultaneous transmissions.

2.2 Power Management Algorithms

Power management algorithms are further classified into three layers, depending upon their implementation. Thus they are classified into MAC layer, network layer, and higher layer implementations [2].

Power Management at MAC-Layer

The MAC policy strongly influences a device's power consumption. As ad-hoc networks lack central coordination, designing of power-efficient algorithms becomes more difficult.

In the Distributed Contention Control (DCC) protocol, the probability of successful transmission is estimated before actual transmission of each frame. If the probability of success is high, the frame is transmitted immediately. Else, the transmission is delayed to reduce the probable retransmission overhead. The packet loss probability increases if the channel congestion level is high. This leads to unnecessary retransmission which further consumes battery. Hence it is necessary to observe the channel congestion level to optimize battery energy.

Power Management at Network-Layer

The function of the network layer is to route the packets towards the destination. In wireless networks, mobile devices can move freely, enter or leave the network at any time. This causes frequent breaking of routing paths, in contrast to wired networks, where routing paths are fixed. In an ad hoc network, a packet is transmitted through multiple nodes or hops before it reaches its final destination. Route selection in traditional ad hoc routing protocols considers metrics like, the number of hops, quality of the link, and stability of location. As battery power conditions are not taken into account, improper energy expenditure will lead to reduced network lifetime. Therefore the focus is on the design of power-aware routing protocols and conserving total power consumption as well as equally balancing the energy expenditure among mobile nodes.

Higher-Layer Power Management: Transport Layer

Transport layer resides above network layer and provides the functionality of end to end communication. Transmission Control Protocol (TCP) was initially designed for wired networks. Packet loss because of fading or interference or handoff is an unusual or rare phenomenon in wired networks. TCP considers channel congestion as the reason for the packet losses and applies congestion control algorithms to decrease the transmission and retransmission rate. This further reduces the throughput and increases delays. In wireless networks, there are frequent link breakages which will initiate many unnecessary retransmissions and energy will be wasted. To avoid this queuing of data is done till the congestion is over and delivered later. Thus the energy-efficient transport protocols aim at reducing delays and redundant retransmissions, which are the main factors that consume energy.

In this paper energy conservative designs using different power management routing algorithms have been discussed. Section 3 discusses basics of the MANET routing protocols. The metrics used for maximum lifetime routing are discussed in section 4 while survey on work done by various researchers is discussed in section 5. Section 6 concludes the paper.

3. Routing Protocols in MANET

The key aim of routing in MANET is to find a route from the source to the destination which is shortest as well as optimized. For this, many researchers have developed different protocols. These protocols must be capable of handling the typical limitations of MANETs, which include large power consumption, less bandwidth, and high error rates. Dynamic topology of nodes in the network makes MANET significantly different from other existing networks. All the nodes in the network may not be in the direct transmission range of each other and will require multi-hop transmission. Therefore these networks require dedicated routing protocols which are self-initiating and self-organized. These protocols are broadly classified into two types viz.

1. Proactive (Table-Driven) Routing Protocols

2. Reactive (On-Demand) Routing Protocols

3.1 Proactive (Table-Driven) Routing Protocols

In this type of routing, one or more tables containing the up-to-date information of the routes to other nodes in the network are maintained by every node. Every node knows the cost of this route as well as its next hop neighbor to reach to a destination node. The way in which the information about the change in topology is forwarded through all nodes in the network is different for different table-driven protocols. Destination-Sequenced Distance-Vector (DSDV)[3] and Optimized Link State Routing (OLSR) protocols are some of the examples of proactive routing protocols.

Drawbacks of proactive routing:

- Wastage of power and bandwidth because of the periodic broadcasting to update the routing tables/s.
- The table size will increase with an increase in the number of nodes in the MANET.
- Also, proactive routing protocol needs to control traffic in order to update stale route entries frequently. Unlike the wired network, nodes may be mobile in MANET wherein links are frequently disconnected and reestablished.

3.2 Reactive (On-Demand) Routing Protocols

Reactive routing protocols initiate route discovery only when the source needs to start communication with the destination. With the change in network or route topology, route tables are not maintained or frequently updated by these protocols. A source broadcasts a request into the network for destination route discovery whenever it wants to transmit a message. This process is known as Route Discovery and the packet broadcasted for route discovery is known as Route Request (RREQ) packet. In response to RREQ, the destination sends a Route Reply (RREP) packet. Thus the source dynamically discovers the route/path to the destination. The route thus discovered is maintained till the destination node is accessible or until the end of communication. Reactive protocols are generally considered more energy efficient as they do not have periodic broadcasting to update the routing tables/s. Ad Hoc on-demand Distance Vector Routing (AODV) [4] Dynamic Source Routing (DSR) [5] are the some of the examples of reactive routing protocols. The only limitation of reactive protocols is the increased latency period, as the route discovery will be done just before the start of communication.

4. Maximum Lifetime Routing

All the nodes in ad hoc network cooperate in forwarding the data traffic from source to destination. A node that acts as a router may drain its energy and cannot participate in the network any more.

This makes it necessary for an algorithm to select a route in such a way that it will maximize the network lifetime. To increase the lifetime of the network it is extremely important to balance the energy consumption throughout the network. There are three metrics [1], commonly used for selection of energy aware route. These are,

1. **Minimum - energy routing**
2. **Max - min routing**
3. **Minimum - cost routing**

4.1 Minimum - Energy Routing

Here the total energy consumed is minimized when a packet is being forwarded on the selected route [1]. The minimum – energy routing does not consider the residual energy of a node. This will make the nodes on minimum – energy routes to die prematurely due to heavy load on these routes. Thus minimum – energy routing does not help to maximum the network lifetime.

4.2 Max - Min Routing

The max–min metric selects the route that has more number of nodes with higher residual energy. These selected routes may not be the shortest path and can also have the total energy consumption higher than the minimum-energy route. Even though max–min routing normally performs better than minimum- energy routing [1], the network lifetime is likely to decrease due to increase in per-packet energy consumption.

4.3 Minimum - Cost Routing

A monotonically increasing cost function that tells unwillingness of a node to forward the data if it has less residual energy is considered by the minimum-cost routing. Thus the minimum-cost routing minimizes the total cost of forwarding the packet at each node that deflects the traffic from the routes with nodes having low residual energy. This helps to increase the network lifetime. Researchers have worked on algorithm modifications [6] to [17] based on any of these three metrics. The following section gives the overview of the related work done.

5. Related Work

The authors in [6] propose a system that has two phases: i) Lead Node (LN) Selection and ii) Energy Aware Route Selection. A lead node which will calculate, maintain and coordinate the energy levels of all the nodes is selected by LN selection phase. In energy aware route selection, all the network traffic is directed via the minimum energy route and energy consumption per flow is not considered. The proposed method here focuses on the consumption of energy by each node because the nodes on the route in the former approach will be drained rapidly which results in reduced network lifetime and increased performance overhead. The proposed power aware route selection leads to enhanced load balancing and reduced congestion. But the authors have not studied the effect of an increase in a number of nodes, and change in speed, on Packet Delivery Ratio (PDR), energy consumption and network lifetime.

A new routing protocol called as Energy-balanced Dynamic Source Routing (EB-DSR) is proposed in [7]. Here the conventional DSR protocol is enhanced by using an energy balanced metric to extend the lifetime of the network. For this EB-DSR protocol proposes a new energy-balanced metric, '*LP/EP',* where *LP* is the number of links on path *P* and *EP* is the minimum energy of node on path *P*. During process of route discovery, the remaining energy of all nodes along the possible paths should be provided in order to implement the proposed energy-balanced metric effectively. It is also required to incorporate a process to refresh this information recurrently to assure multiple path energy balanced routing on the fly. For the exchanging the information of residual node energies among different nodes on the path between source transmitter and destination receiver, additional node energy fields are provided in the route header of the source in EB-DSR. Each intermediate node on the path will add its residual energy to this field while forwarding the packets. Thus the residual node energy is passed in the route request and route reply messages during route discovery process. The source node will have adequate updated data of remaining node energies along all possible paths to select a route based on the energy-balanced metric. The simulations results have shown that EB-DSR can efficiently extend the lifetime of the network by excluding the low-energy nodes from forwarding the data, without compromising the PDR. EB-DSR shows much better performance of in terms of load balancing than the other protocols in the study. During the simulation of proposed algorithm, the considered nodes are static and fixed in number. Thus the effect of change in number of nodes and change in speed on network lifetime has not been discussed.

A multicast algorithm is presented in [8] to increase the lifetime of node and network in the MANET. The authors propose two metrics namely, remaining battery capacity and relay or transmission capacity of the node to do multicasting from the first transmitter to intended receiver i.e. destination nodes. The algorithm tries to balance the energy consumption and load to increase the network lifetime. The proposed algorithm uses three tables to forward data packets from one node to another. These are group table, routing table, and neighbouring node table.

Neighbouring Node Table: Every node collects and regularly updates information of the nodes which are in its range of transmission. This information consists of relay capacity, battery lifetime, node position, and node-id.

Routing Table: This table consists of source number, destination number, sequence number, and route expire-time. Also, it maintains the current route used by the node to forward packets to the destination. The destination-sequence number is used to ensure that the route to intended receiver is not stale. The source node first checks its routing table for a suitable route when it wants to send a message. If no useful route is found, then *the* source broadcasts route request (RREQ) packet. The node that has a path to the destination sends a Route Reply (RREP) packet to the source, on receiving RREQ packet. Else RREQ packet is broadcasted by the source node to its neighbours. The source node selects the direct shortest path among all the possible paths after receiving RREP and makes its entry into the routing table.

Group Table: It maintains a list of nodes in the group. Every entry in the group table consists of the group-sequence number, group-leader address, group address, next hop and hop count.

The results of simulation show that the network lifetime has been increased by 20% on the implementation of the proposed model. But the effect of variation in speed of nodes on the Quality of Service (QoS) parameters like PDR, network lifetime, energy consumption and average delay has not been considered. Also, the number of nodes considered for calculating all the QoS parameters is not uniform.

Maddhi Sunitha et al proposed Maximal Power Conserved and Battery Life Aware Routing (MPC-BLAR) approach in [9]. Here a routing table is maintained by each node of the network to store the remaining battery capacity of its hop level neighbor nodes. A periodic procedure that makes the nodes to communicate their residual battery among the neighbor nodes is instigated here.

During route discovery process conditional broadcasting is done by the source node. The source node will compare the required battery capacity and the existing battery level of its neighboring nodes within the immediate hop to select the nodes to flood a route request. Firstly the source node calculates the minimum required battery capacity 'mbc' by determining the mean energy consumption per data bit, that is transmitted to its immediate hop neighbor nodes. Then the minimum required battery capacity along with route request, RREQ is transmitted by the source node. Every node upon receiving RREQ from the source first checks whether it has received that route request earlier, if yes, then it is rejected. If not then the node confirms if that node itself is destination node. Else the RREQ is not intended for that node then it starts flooding the route request to immediate hop level neighboring nodes. Thus the source node always chooses its immediate hop neighboring nodes that have remaining battery level greater than the required minimum battery capacity threshold. This process is carried on till the route request reaches the destination node.

From simulations, it was seen that the Packet Delivery Fraction for MPC-BLAR is 1.5% more than that of MMBCR. Here the MPC-BLAR avoids the confirmation of battery level while electing the best path from all possible paths selected during the process of route discovery. Although the proposed algorithm is for enhancing the network lifetime but the results do not show any considerations or calculations of energy consumption and node or network lifetime.

A Delay-Sensitive and Power-Aware routing protocol (DSPA) are proposed in [10]. Power control and delay are the two metrics added to the on-demand routing protocol, AODV to implement DSPA protocol. To transmit control packets and data packets of MAC layer and network layer, different power control policies used by DSPA. This paper compares DSPA with LAPC, CLUSTERPOW, and AODV protocols and shows improvements in node residual energy, lifetime of the network, end to end delay and PDR. DSPA shows 5% to 12% savings in energy than CLUSTERPOW, thus extending the lifetime of the network. DSPA shows 9 msec. to 23 msec. enhancement in the lifetime of network and 8.6% saving in the remaining energy than LAPC.

The scheme called Minimum Power Route/Maximum Battery Lifetime (MPR/MBL) is proposed in [11] that extends the time for which nodes in the network are alive. It considers the power consumption which is the sum of the power necessary for signal processing and RF transmission at each node and the weighing factor to represent remaining battery of each node on the route to calculate a 'cost' for all possible routes between source to destination nodes. The proposed scheme selects the minimum power route with higher battery levels on that route. When any of the nodes on the selected route is depleted of the residual battery charge, then the lowest power route excluding that node is selected. Uniform utilization all the nodes to avoid premature death of any of the nodes is the major aim of this scheme.

With the help of simulation results, it is seen that the MPR/MBL scheme increases the time to first node failure by 18% than the MPR scheme, thus increasing the node lifetime. It is necessary to check the effect of proposed algorithm on PDR and average end to end to ensure that these QoS parameters are not degraded, which has not been done here.

The authors in [12] propose Directly Node Lifetime Based Routing (DNLBR) algorithm to find the route with maximum lifetime. Node lifetime is directly used as cost metric by DNLBR protocol whereas most of the current protocols for maximum-lifetime routing, use remaining battery capacity as their cost metric. In wireless ad hoc networks, the energy depletion of even a single node on the path will make the whole path down. Thus the node with the minimal lifetime determines the lifetime of the whole path. The network with longer lifetime is capable of transmitting more packets. So here the lifetime of the network is proportional to the number of successfully transmitted packets in energy-constraint networks. Though DNLBR enhances the network lifetime but the average delay is increased at the same time.

In [13] authors propose a Co-operAtive Multi-criteria Energy-aware Routing Algorithm (CAMERA). Here the remaining energy of nodes along with their transmission power is considered as path metric. There are two phases of CAMERA algorithm. In the first phase, it calculates all possible paths between a source and destination, and secondly, it chooses the route that minimizes a required optimization function. The main goal of this algorithm is to reduce the total energy consumption and maximize the minimum of the residual energies of the nodes in the network. To operate the network efficiently it is necessary to minimize total energy consumption as well as distribute it uniformly among the nodes. It is possible that the network will get partitioned even if the battery of a single node is depleted, in spite of the availability of other nodes with enough remaining energy.

The performance of the proposed CAMERA algorithm in a network shows substantial energy savings, enhanced network lifetime and higher PDR than without application of cooperation.

A new power-aware routing protocol, Efficient Power Aware Routing (EPAR) which increases the network lifetime of MANET is proposed in [14]. EPAR recognizes the node capacity by considering two parameters viz. remaining battery level and the probable energy spent in faithfully forwarding data packets on a specified path. Using a mini-max formulation, a path selected by EPAR that uses the smallest residual packet transmission energy for largest packet delivery ratio. The evaluation results show more than 20 % reduction in total energy consumption and decrease in the mean delay, specifically, for high load networks for attaining a good packet delivery ratio.
Authors in [15] propose two algorithms called Maximized Energy Efficient Routing (MEER) and Energy Efficient Delay Time Routing (EEDTR), to enhance the effective lifetime of MANETs. Both these algorithms are implemented by modifying the conventional DSR protocol. The main objective of these algorithms is to balance the power consumption of the entire network by selecting distributed routes. The route request packet of MEER algorithm includes energy information of the nodes on the route and selects the route based on this energy information. Thus the energy information is made accessible to the destination node so that it is capable of selecting an energy efficient route among all the possible routes. EEDTR algorithm introduces a delay based on the residual energy level of the node while sending the packets forward. Every node forwards the route request packet after this delay which is inversely proportional to its existing energy level. The request packet received first will be accepted by the destination node discarding all other duplicate requests. Thus nodes with lesser energy levels will transmit the route request packets after a higher delay and vice versa.

Authors in [16] consider the reliability of selected route and remaining battery level of nodes in networks to prolong network lifetime in their proposed algorithm. To select routes, two schemes viz. minimum cost routing and reputation routing are used by the proposed routing mechanism. These algorithms also consider the effect of malicious nodes present in the network whose residual battery level will remain high as it is assumed that they will just discard received data packets. Energy is consumed by cooperative node while forwarding data packets to its neighboring nodes. Due to this the cooperative node's battery level reduces and goes below to that of the malicious node. The algorithms here consider a different network scenario when malicious nodes are present. But it doesn't consider the effect of mobility and speed of non-malicious nodes on the QoS parameters.

In [17] two new energy-aware routing algorithms, called reliable minimum energy cost routing (RMECR) and reliable minimum energy routing (RMER) are proposed by authors. RMER algorithm selects the route which minimizes the total energy required for end-to-end transmission of the packet. Energy-efficiency, reliability, and extending network lifetime are the three important requirements of ad hoc networks addressed by RMECR protocol. Along with the parameters like consumption of energy and the remaining battery of nodes, it also considers the quality of links to find reliable as well as energy-efficient routes that will increase the lifetime of the network. Simulation studies show that RMECR increases trustworthiness, lifetime of networks, and energy-efficiency. In RMECR, the authors have also considered other smaller details such as packet sizes the impact of acknowledgment packets, limited number of retransmissions allowed per packet, and energy consumed by processing elements of transceivers.

5. Conclusion

As battery power is one of the major constraints in MANET, it is necessary to consider different techniques to reduce the energy consumption of the nodes in the network. Researchers are working on the ways to reduce energy consumption at various levels like physical level, MAC level, operating system level as well as routing level. This paper discusses the review of maximum lifetime routing algorithms based on three metrics viz. minimum - energy routing, max - min routing and minimum - cost routing. In order to balance the network load, the routes with nodes having less residual energy should be avoided during the route selection. This will avoid the premature dying of the nodes, thus extending the network lifetime.

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