A Survey on Power Aware Routing Protocols for Mobile Ad-Hoc Network

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Abstract. The Mobile Ad-Hoc network is a growing type of wireless network characterized by decentralized and dynamic topology. One of the main challenges in Mobile Ad-Hoc networks (MANETs) is that it has very limited power supply. To overcome the challenge, there are several power-aware routing protocols that have been developed in recent years. This paper describes a survey on some of those energy aware routing protocols for Mobile Ad-Hoc networks. The first category of power aware protocol schemes minimizes the total transmission power and the second category of schemes tries to increase the remaining battery level of every individual node to increase the lifetime of the entire network. The optimizations between these two objectives are important issues in power aware routing. This discussion focuses on different power saving algorithms and their development and modifications. After analyzing the existing works it has been seen that there are still several fields (using a dual threshold, passive energy saving etc) where we can give more focus in the future.

Keywords: Power Aware, Mobile Ad-Hoc Network, Routing Protocol.

1 Introduction

A network can be defined as a collection of different interconnected nodes that can be wired or wireless. A Mobile Ad-Hoc Network [1] is composed of a group of autonomous mobile wireless nodes without any centralized administration in which they forward the packets to each other in a multi-hop manner. Wireless multi hop Mobile Ad-Hoc networks offer communication facilities in areas where it is impossible for wired cable networks to reach. Mobile Ad-Hoc networks have proved to be useful in different areas like battlefield scenarios, in case of disaster recovery, cell phone, laptop, traffic control, space and astronomy.

MANET is infrastructure less, so the network topology may change very fast and unpredictably at any time. In MANETs there is limited bandwidth compared to the wired network. Another important issue in the Mobile Ad-Hoc network is power optimization as the network lifetime needs to be increased.

Most of the ad-hoc mobile devices today use lithium batteries. Usually the average lifetime of batteries in an idle phone is one day. A single node in the routing path going to 'dead' condition can cause the entire network to fail.

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A large number of researchers are trying to solve the problem of energy-efficient data transfer in the context mobile ad hoc networks [2]. The different existing protocols can be classified in the following two categories:

The first category of protocols deals with minimizing the total power requirements for the end to end transmission. The main advantage of this kind of protocol is that it always selects a minimum cost route very quickly. But the main disadvantage is that the nodes on that selected route are overused. So, critical nodes will 'die' soon by exhausting their battery life causing network failure.

The second category of protocols is based on battery aware routing algorithms that take care of battery life of individual nodes. In such manner, this category of protocols increases the battery lifetime of each node as well as the overall lifetime of the entire network.

2 Review of Existing Power Aware Protocol

2.1 Minimum Total Transmission Power Routing (MTTPR)

The Minimum Total Transmission Power Routing Protocol [3] is a basic power aware routing protocol that always tries to minimize the total transmission power of the entire network by selecting the minimum hop count route. This actually implements the metric 'minimize the energy consumed per packet' proposed in [3]. MTTPR, first calculates the total transmission power for all possible routes between source and destination. The total transmission power $P(n_i, n_j)$ between two hosts n_i and n_j for route l can be calculated from the following equation, $P_l = \sum_{i=0}^{D-1} P(n_i, n_{(i+1)})$

Where *0* is source node and *D* is destination node.

Finally it selects the route with minimum total transmission power. Using this metric the minimum route *k* can be obtained from the following equation where *A* is the set containing all possible routes. $P_k = \min_{l \in A} p_l$

2.2 Minimum Battery Cost Routing (MBCR)

The MTTPR algorithm does not take care of battery life of every individual node, so MBCR algorithm is proposed by introducing an extra battery cost function [3] that is the inverse of remaining battery capacity. That means if the remaining battery power decreases the cost function will increase. This algorithm first finds the battery cost for each node of the network and finds the battery cost function. Let c_i^t is the remaining battery capacity of a host n_i at time t and let $f_i(c_i^t)$ is a battery cost function of node n_i. The cost function is the inverse of battery capacity that can be achieved from the following equation. $f_i(c_i^t) = \left(\frac{1}{c_i^t}\right)$

Now the total battery cost R_j for the route *i* with *D* nodes will be, $R_j = \sum_{i=0}^{D_{j-1}} f_i(c_i^t)$

From this equation we can find a route with the maximum remaining battery capacity by selecting a route *i* with having minimum battery cost.

$$R_i = \min \{R_j \mid j \in A\}$$

Here *A* is the set of all possible routes from source to destination.

The cost function is calculated based on the battery life remaining of individual nodes, so it takes care about individual battery life of nodes. If all nodes in the network have same battery charge remaining, it will choose the shortest hop.

2.3 Min-Max Battery Cost Routing (MMBCR)

MMBCR [3] is a modification of the MBCR algorithm in such a way that no critical node will be overused. Without summing the battery cost function of all nodes of every individual route, MMBCR finds the maximum battery cost among all nodes of different routes to find the critical nodes. The algorithm first finds the battery cost for each node and then finds the battery cost function. For every route, it selects maximum battery cost function among all nodes in that particular route. To find the battery cost *R* for route *j* the following equation is used, $R_j = \max_{i \in \text{route } j} f_i(c_i^t)$.

After finding the battery cost the desired route i can be obtained from the equation

$$R_i = \min\{ R_j \mid j \in A\}$$

The algorithm selects the route avoiding critical battery node, so the battery will be used more fairly to avoid network failure.

2.4 Conditional Max-Min Battery Capacity Routing (CMMBCR)

A hybrid approach CMMBCR was devised by C.K Toh [4] that gives a better routing algorithm based on the battery life. CMMBCR tries to minimize the total transmission power and also avoid the battery having low remaining capacity by adding an extra threshold to each battery node. This algorithm first finds the minimum battery capacity (R_i) for all nodes of each route. If $R_i \geq Y$ (chosen threshold value) is true for some or all routes between a source and destination, then the MTPR scheme is applied to select the route among all possible paths which satisfy the previous condition. If any path does not satisfy the condition then the route j is selected with the help of maximum battery remaining capacity by using the protocol MMBCR.

The battery capacity R_j^c for route j at time t can be defined by the following equation, $R_j^c = \min_{i \in \text{route } j} c_i^t$

The threshold ranges between 0 and 100. Now let *Q* is the set containing all possible paths between source and destination at time *t*. Now, if *A* is the set of all routes between any two nodes at time *t* satisfying the following equation, $R_j^c \geq \gamma$. $A \cap Q \neq \emptyset$ that means all nodes in some paths has remaining battery capacity higher than given threshold, and then it is needed to find a route by MTTPR scheme. Otherwise the route selection is done by MMBCR algorithm, CMMBCR algorithm always depends upon the value of threshold γ chosen. If the value of the threshold is 0 it is identical to MTPR, because it will select shortest route. If the value of threshold is 100, then the condition $R_j^c \geq \gamma$ will never satisfy. So it is identical to MMBCR.

2.5 Power-Aware Multiple Access Protocol with Signaling (PAMAS)

Suresh Singh, Mike Woo and C. S. Raghavendra [3, 5] proposed a new algorithm for power saving in Mobile Ad-Hoc network using passive energy saving techniques. They presented five different metrics based on battery power that can reduce the routing cost from 5 to 30% over short-hop routing. PAMAS is a MAC-level protocol that is used to control the power off mechanism of that mobile node. The main idea behind PAMAS is that as maximum energy is wasted in overhearing, so PAMAS can save 40 to 70 % of battery power by turning off the node's radios, when they are not transmitting or receiving.

To save the power of a node the node can power off if any of the following conditions satisfies.

1. A node can power itself off if it is overhearing a transmission and does not have any packet to send.
2. A node can power off if at least one of its neighbor nodes is transmitting and at least one neighbor node is receiving a transmission.
3. The node can power off if all neighbors of a node are transmitting and the node is not a receiver.

In PAMAS the nodes attempt to capture the communication channel by exchanging RTS/CTS packets. This packet contains all the details about the transmission like duration, distance etc. A node can know this timing before going to the sleep mode. The RTS/CTS packet transmission is done on different signaling channel so it doesn't interfere with the ongoing transmission. The problem comes when a node is needed to transmit a data and it is in sleeping mode, so it cannot know about the time duration until it wakes up. To solve this problem, another protocol runs in the signaling channel that allows nodes to find the duration of remaining transmission.

2.6 Power Aware Ad-Hoc On-Demand Multipath Distance Vector (PAAOMDV)

Dr. A. Rajaram and J. Sugesh proposed a routing protocol named Power Aware Ad-hoc On-Demand Multipath Distance Vector (PAAOMDV) [6] that gives an optimum path between the power saving path and shortest path. The main Idea behind PAAOMDV is each node maintains an *Energy Reservation Table* (ERT) where each item is mapped with a route with all its details like destination id, amount of energy reserved, last operation time, route, and their functions. PAAOMDV applies a threshold value based on the remaining battery level at the time of route discovery to remove the very low remaining battery node. The operations of PAAOMDV include three steps.

The route discovery of PAAOMDV is based on the energy, *E,* that is defined as the minimum residual energy over its entire link.

$$E \equiv \min_{1 \le h \le H} \text{resudial energy}_h$$

Where h is the link number and H is the number of links or hops in the path. For calculating the residual energy all the information needed is available via the RREQ. The minimum residual energy in the entire path between two nodes *i* and *d* is used for the cost estimation. That is $E_{\min}^{i,d} \equiv \min_{c \in path\_list_i^d} E_c$

All the paths between nodes n_i and n_d is denoted by $path\_list^d_i$. The route discovery of PAAOMDV is based on the RREQ or RREP packet. In case of a node n_d, if the neighbor node has a higher destination sequence number or shorter hop-count than the existing route for n_d, it updates the packet. Now if the destination sequence number and hop-count is equal with the existing route but with a greater E_i, E_{min}, the list of paths in node *i* and *d*'s routing table is updated. So the path selection is dependent on both E_i, E_{min} as well as the destination sequence number and hop count. After Route establishment the data are sent from source to destination via that selected path. After each transmission the table is updated by subtracting the used energy for every used node. When an error occurs, the detected node sends a route error packet (RERR) to every node and they remove the corresponding item from their routing table and select an alternative path.

2.7 Energy Aware Ad-Hoc Routing (EAAR)

Another proposed energy aware routing algorithm is EAAR [7] that is based on naturally occurring ant's foraging behavior. This will not only optimize the effect of power consumption, but will also exploit the multi-path transmission properties of ant swarms. When a source node has some data to send, it broadcasts a ant (control packet) say F_s^d. Each intermediate nodes receive the replica of F_s^d that will be $F_s^d k$. Next will be $F_s^d KL$ (where k, L, … are integers). All the journey information of the packet is stored in an array called j. Now when a node receives several ant of same generation it compares those ants. If the new arrived ant is a subset of previous one, then it is dropped. If the older received ant is a subset of younger received ant, then it is accepted. Else if, the new received ant is not any superset of any previous received ant then it is only accepted if the condition satisfies. $N \leftarrow \lambda * M$.

Where *N* is the hop count of previously received ant and *M* is the hop count of newly received ant. λ is a factor of taking decisions. After receiving the ant in a specific time, the ant travel backward to the source. At the time of moving backward each ant updates an entry in neighbors table $T^i_{n,d}$, where $T^i_{n,d} = \frac{MBR}{H}$

That is the inverse of the number of hops (*H*) multiplied by a minimum residual battery energy traveled by current backward node.

After completing path discovery the data session starts. When the first proactive backward ant is received by the host, it again sends another forward proactive ant to the first one. This always leads to a better path selection.

When a link failure occurs the node sends a control packet to all the neighbor nodes to remove the data from their entry.

3 Comparative Study of Power Aware Routing Protocols

These protocols have different goals, assumption and different mechanisms to achieve the goal. The basic protocol MTTPR always gives minimum total transmission power but it cannot satisfy the second goal of increasing network lifetime. The battery aware

	Advantages	Disadvantages
Minimum Total Transmission Power Routing (MTTPR)	It guarantees the minimum total transmission power of the network. This takes the least number of hops.	It does not deal with lifetime of each battery. The selected node on a specific route is exhausted quickly.
Minimum Battery Cost Routing (MBCR)	The routing is based on the remaining battery capacity of individual nodes. MBCR tries to minimize the total transmission power.	It does not assure that the selected route will be the shortest path. If a very low remaining battery lies on that specific route it will be exhausted quickly.
Min-Max Battery Cost Routing (MMBCR):	The battery of each node will be used in more efficient manner. Extends network lifetime by avoiding overuse of the most critical nodes.	There is no guarantee that minimum total energy path will be selected. Lifetime of all nodes decreases as it takes more power to deliver a packet.
Conditional Max-Min Battery Capacity Routing (CMMBCR)	CMMBCR can fulfill both goals of maximizing network and battery lifetime of each node. The threshold helps to avoid the critical node.	It takes more power to deliver a packet. Route selections take more time.
Power-Aware Multiple Access Protocol with Signaling (PAMAS)	Battery consumption minimizes by turning off the radio when nodes are not transmitting or receiving. This protocol saves 40-70% of battery life.	When a node is in sleep mode, it cannot hear about a new ongoing transmission. There is no proper wake up algorithm.

Power Aware Ad-hoc On-Demand Multipath Distance Vector (PAAOMDV):	Energy reservation table (ERT) is used instead of route cache. It not only deals with energy required in future.	Update in the table requires extra overhead. The average energy per packet is increased.
Energy Aware Ad-hoc Routing (EAAR)	EAAR is better compared to AODV and MMBCR in terms of energy conservation. This algorithm exploits the multi-path transmission properties of ant swarms.	The average energy per packet in high mobile conditions is not so good. In EAAR the packet delivery rate is high because time to judge the best route is high.

routing algorithms like MBCR, MMBCR, and CMMBCR take care of battery life of every individual node, but in some case the total transmission cost increases. The protocol PAAOMDV and CMMBCR use a special threshold function to filter the critical node for avoiding the network partition. A good approach is proposed by PAMAS, which use a passive power saving algorithm. Maximum energy is reduced in overhearing of others node's transmission, so idle node can put themselves off for a limited period of time. This protocol is very useful where the nodes are idle most of the time. PAAOMDV and EAAR use special packets like RERP, Ant for route discovery. The route is calculated based on different table and the cost is calculated by the Route discovery packets. PAAOMDV also deals with the energy required in the transmissions that give the cost function more accuracy.

4 Scopes for Improvement and Future Work

After surveying different power aware routing protocols it is seen that still there are future scopes in many directions that can solve the power aware problem more accurately.

The threshold can be used to remove critical nodes at the time of route discovery. Using dual threshold can help in routing when all nodes are below the first threshold. Secondly, the route discovery packet is transmitted to all the nodes in flooding manner that increases network traffic, cost, delay, and congregation. So, the routing algorithms can be designed in such a way that the routing decisions are taken locally with a limited number of nodes. Thirdly, link error is another problem in Mobile Ad-Hoc network. If any link error occurs when the data is transmitting; it needs to retransmit the entire data. So the link error should be taken into consideration to build the protocol with proper error control mechanism. Fourth, the transmission cost not only depends on the distance between two nodes but also on the load of the selected path. If the selected path is too congested, then the transmission cost increases. Hence, an alternate approach can be incorporated such that the route through lightly-loaded nodes is selected. This will result in less number of collisions thereby minimizing the energy required for the transmission. Fifthly, the optimal route from the battery life point of view will be such a route that ensures the even dissipation of energy by all the nodes in order to increase the overall network lifetime. Therefore, to build such a protocol for power aware routing, the formulation of the standard deviation can be taken into consideration by taking different node's battery cost as population set.

5 Conclusion

In this article we have made a survey on several power-aware routing protocols. As the nodes in Mobile Ad-Hoc network are free to move, so, a proper algorithm is needed for route selection. There should be a balance between the two goals of maintaining the minimum transmission power and increasing the network lifetime. We have carried out a detailed comparative analysis based on the advantages and disadvantages of those protocols. As a result we can conclude that the different protocols are suitable for different situations. MTTPR is useful when every node has enough battery power remaining, as it gives the shortest transmission cost. Among the basic battery aware protocols, CMMBCR and PAAOMDV give the best output as they always avoid the critical node. In case of multipath and congested scenario, EAAR give the better result because it has multicasting and congestion control algorithm. PAMAS can be used in that situation where maximum energy is wasted in overhearing.

As the mobile hosts have limited battery life so battery power should be used more efficiently to maximize the network life. More focus should be given to error control, power saving by switching of the node and congestion control. Although several researches have been done on power aware routing in these days, but this field is still in its infancy. More research on this work can lead to an appropriate route selection mechanism to extend the lifetime of both the nodes and the network.

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