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POWER AWARE ROUTING IN MOBILE AD HOC NETWORKS: A SURVEY

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ABSTRACT

Power consumption is a crucial design concern in Wireless ad hoc networks since wireless nodes are typically battery limited. Power consumption can occur due to receiving the data, transmitting the data traffic, mobility etc. Power failure of mobile node not only affects the node itself but also its ability to forward packets on behalf of others and hence overall network lifetime. It might not be possible to replace/recharge a mobile node that is powered by batteries. To take full advantage of life time of nodes, traffic should be routed in a way that power consumption is minimized. Power Aware Routing is a consideration in a way that it minimizes the energy consumption while routing the traffic, aims at minimizing the total power consumption of all the nodes in the network, minimizing the overhead etc and thus, at maximizing the lifespan of the network using some Power Aware Routing Protocols. Although establishing correct and efficient routes is an important design issue in mobile ad hoc networks (MANETs), a more challenging goal is to provide power efficient routes because mobile nodes operation time is the most critical limiting factor. This paper surveys and classifies the power aware routing protocols proposed for MANETs. They minimize either the active communication energy required to transmit or receive packets or the inactive energy consumed when a mobile node stays idle but listens to the wireless medium for any possible communication requests from other nodes. Transmission power control, load distribution and power management approaches are used to minimize active communication energy while sleep/power-down mode approach is used to minimize inactive communication energy using some power aware metrics like energy consumed per packet, time to network partition, variance in node power levels, cost per packet, throughput, end-to-end delay, packet delivery ratio etc. Each protocol has definite advantages/disadvantages and is well suited for certain situations. The purpose of this paper is to facilitate the research efforts in combining the existing solutions to offer a more power efficient routing mechanism.

Keywords: power aware routing, transmission power control approach, load distribution approach, power management approach, sleep/power down mode approach, power aware metrics.

1. INTRODUCTION

1.1. Ad-hoc networks

The computer network can be classified into two types (Figure-1): Wired or wireless. In wired network, data travels as electrical signals through wires, but in wireless medium, no wires are used and signals travel as electromagnetic waves through the air. With a wirelessly connected device, anyone can move around and still stay connected providing the person to be in range. This is great for office users or even students. In wired network, speed is fixed, where one will get the speed wire is capable of but in wireless network, speed is fluctuating and depends on the distance between nearest access point and whatever happens to be in between wireless device and access point itself. Further, the wireless network can be classified into two types: Infrastructure based [1] or Infrastructure less [2]. In Infrastructure based wireless networks the mobile nodes can move while communicating with the base stations being fixed and as the node goes out of the range of a base station, it gets into the range of another base station. In Infrastructure less or Ad Hoc wireless networks the existing wireless infrastructure is expensive and inconvenient to use. An ad hoc network consists of a collection of autonomous mobile nodes formed by means of multi-hop wireless communication without using any pre-existing fixed network infrastructure. Ad-hoc networks can be classified into three categories based on applications; Mobile Ad-hoc Networks (MANETs), Wireless Mesh Networks (WMNs) [3] and Wireless Sensor Networks (WSN) [4]. Mobile Ad hoc Networks (MANETs) are becoming more popular these days in a wide spectrum of applications.

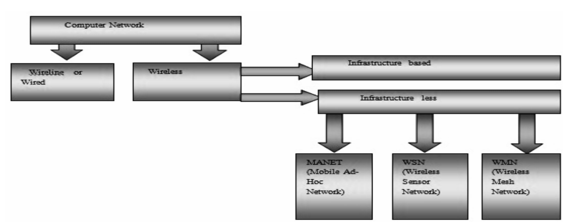

Figure-1. Classification of computer network.

Mobile nodes self-organize to form a network over radio links. All nodes in a MANET [5] basically function as mobile routers using some routing protocol required for deciding and maintaining the routes. Since MANETs are infrastructure-less, self-organizing, rapidly deployable wireless networks, they are highly suitable for applications involving special outdoor events, communications in regions with no wireless infrastructure, emergencies and natural disasters, military operations, mine site operations, urgent business meetings and robot data acquisition. An ad hoc routing is challenged by power and bandwidth constraints as well as by frequent changes in topology, to which it must adapt and converge quickly. This paper presents a wide literature survey on power aware routing protocols which can be very well applied to reactive, proactive and hybrid protocols like DSR,AODV,OLSR and ZRP [6, 7, 8] which are based on either transmission power control approach, load balancing approach or sleep/power down approach. The protocols under review are intended for general-purpose Mobile ad-hoc Networks (MANETs).

1.2. Design issues and challenges of MANET

Ad hoc wireless networks inherit the traditional problems of wireless communications, such as bandwidth optimization, power control, and transmission quality enhancement, while, in addition, their mobility, multi-hop nature, and the lack of fixed infrastructure create a number of complexities and design constraints that are new to mobile ad hoc networks.

a) **Infrastructure-less networks:** The most fundamental aspect of an ad hoc wireless network is its lack of infrastructure, and most design issues and challenges stem from this characteristic. Also, lack of centralized mechanism brings added difficulty in fault detection and correction.
b) **Dynamic topology:** The dynamically changing nature of mobile nodes causes to the formation of an unpredicted topology [9]. This topology change causes frequent route change, network partitioning and packet dropping.
c) **Limited link bandwidth and quality:** Because mobile nodes communicate each other via bandwidth-constrained, variable capacity, error-prone, and insecure wireless channels, wireless links will continue to have significantly lower capacity than wired links, and hence, more problematic network congestion.
d) **Power constrained operation:** Power constraints are another big challenge in ad hoc wireless network design [10]. These constraints in a wireless network arise due to battery powered nodes which cannot be recharged on line. This becomes a bigger issue in mobile ad hoc networks as each node is acting as both an end system and a router at the same time, and for the purpose, additional energy is required to forward packets.
e) **Robustness and reliability:** Misbehaving nodes and unreliable links can have a severe impact on overall network performance. Due to the lack of centralized monitoring and management mechanisms, these types of misbehaviors cannot be detected and isolated quickly and easily. This increases the design complexity significantly.
f) **Network security:** Mobile wireless networks are more vulnerable to information and physical security threats than fixed-wired networks. Use of open and shared broadcast wireless channels results in nodes with inadequate physical protection that are prone to security threats. In addition, because a mobile ad hoc network is a distributed infrastructure-less network, it mainly relies on individual security solution from each mobile node, as centralized security control is hard to implement.
g) **Quality of service:** Quality of Service (QoS) [11, 12, 13, 14, 15, 16, 17, 18, 19] guarantee is very much essential for the successful communication of nodes in the network. As QoS provisioning is an important aspect for mobile ad hoc networks, similarly power conservation is a critical issue in ad-hoc wireless networks for node and network life, as nodes are battery powered only. Therefore, power consumption must also be treated as an indirect measure of QoS. The key factor is to maximize the time for network partition and reduces variations in power levels of nodes. The QoS metrics are throughput, packet loss, delay, jitter and error rate. It is hard to use these metrics directly in a network without any centralized control the dynamically changing topology, limited bandwidth and quality impose difficulty in achieving the desired QoS guarantee for the network. Quality of service is more difficult to guarantee in ad-hoc networks than in most other types of networks, because the wireless channel bandwidth is shared among adjacent nodes and the network topology changes as the nodes move.
h) **Delay tolerance:** One of the challenges associated with supporting communication in disconnected MANETs with such a sparse population of nodes and so little or no fixed infrastructure that the network graph is rarely, if ever, connected. The networks considered are autonomous and do not depend on established infrastructure. The disconnected nature and lack of end-to-end connectivity between nodes mean that the communication must be delay-tolerant. Such networks are referred as Disconnected Delay-Tolerant MANETs (DDTMs). The challenges associated with mobile computing are not new. However, issues in wireless communication such as low bandwidth, disconnections and high bandwidth variability are problematic and further exacerbated in DDTMs by little or no infrastructure, variable node population and lossy links. Delay Tolerant MANETs additionally face challenges of mobility which is frequent and uncontrolled resulting in a highly dynamic topology and disconnected network graph. In these challenging environments, popular ad hoc routing protocols such as AODV and DSR fail to establish routes. This occurs as a consequence of the fact that these protocols attempt to first establish a complete route and then, forward the actual data after the route has been established.

1.3. Objective

The main objective of power aware routing protocols is to minimize the power consumption and maximize the network lifetime. The network lifetime is defined up to the moment when a node runs out of its own battery power for the first time. If a node stops its operation, it can result in network partitioning and interrupt communication. The main objective of this paper is to make an explicit literature survey on power aware routing protocols based on transmission power control approach, load distribution approach and sleep/power down approach.

Objectives can be summarized as:

a) To get a general understanding of ad hoc networks;
b) To get a general understanding of challenges of mobile ad hoc networks;
c) To gather knowledge on power aware metrics in ad hoc networks;
d) To survey on power aware routing protocols based on transmission power control, load distribution, sleep/power down mode approaches;
e) To investigate on the existing routing protocols based on power conservation and selects one where specific work has not been done and further enhancement can be incorporated.

2. POWER AWARE ROUTING

2.1. Power aware model

The mobile nodes in MANET are connected to other mobile nodes. These mobile nodes are free to transmit, i.e. send or receive the data packets to or from other nodes respectively, and require power for such activities. There are 4 important power components [20]: (1) Transmission Power (2) Reception Power (3) Idle Power and (4) Overhearing Power.

Transmission power: Whenever a node sends data packet to other nodes in the network, some amount of energy is required for transmission and such energy is called Transmission Energy (T_x) of that node and this energy is dependent on size of the data packet. On sending the data packet, some amount of power is consumed. The transmission energy is formulated as:

$$T_x = (330*Plength)/2*10^6$$

And

$$P_t = T_x / T_t$$

Where T_x is transmission energy, P_T is Transmission Power, T_t is the time taken to transmit a data packet and Plength is the length of data packet in bits.

Reception power: Whenever a node receives data packet from other nodes then some amount of energy is taken by the node to receive data packet, which is called Reception Energy(R_x). On receiving the data packet, some amount of power is consumed. Reception Energy is formulated as:

$$R_x = (230*Plength)/ 2*10^6 \text{ and } P_R = R_x / T_r,$$

Where R_x is the Reception Energy, P_R is the Reception Power, T_r is a time taken to receive data packet, and Plength is the length of data packet in bits.

Idle power: In this situation, node neither transmits nor receives any data packets. Power is consumed because it needs to listen to the wireless medium continuously in order to detect a packet that it should receive, so that the node can then switch into receiving mode from idle mode. Idle power is a wasted power that should be eliminated or reduced to a minimum. Thus, Idle Power is:

$$P_I = P_R,$$

Where P_I is Idle Power and P_R is Reception Power.

Overhearing power: In this case a node picks up the data packets that are destined to other nodes and this is called overhearing and it may consume power. This power is called overhearing power. Unnecessarily receiving such data packets will cause power consumption.

Then power consumed in overhearing is:

$$P_{over} = P_R,$$

Where P_{over} is Overhearing Power and P_R is Reception Power.

2.2. Power aware metrics

The main objective of power aware metrics is to carefully share the cost of routing which will ensure that node and network life is increased. These power aware metrics [21] result in power efficient routes, which are detailed below.

Minimize energy consumed per packet

This is one of the most obvious metrics that conserves power efficiently. Assume that some packet j traverses $n_1,.....,n_k$ nodes where n_1 is the source and n_k the destination. Let T (a, b) denote the energy consumed in transmitting and receiving one packet over one hop from a to b. Then the energy consumed for packet j is,

$$e_j = \sum_{i=1}^{k-1} T\left(n_i, n_{i+1}\right)$$

Thus, the goal of this metric is to minimize e_j, for all j [Figure-2]. It is easy to see that this metric will minimize the average energy consumed per packet. In fact it is interesting to observe that, under light loads, the routes selected using this metric will be identical to routes selected by shortest-hop routing. This is not a surprising observation because, if we assume that T (a, b) = T = Constant, for all (a, b) $\in$ E, where E is the set of all edges, then the power consumed is (k - 1) T. To minimize this value, we simply need to minimize k which is equivalent to finding the shortest-hop path. This metric will tend to route packets around congested areas (possibly increasing hop-count). One serious drawback of this metric is that nodes will tend to have widely differing energy consumption profiles resulting in early death of some of the nodes. Consider the network illustrated in Figure-2.3. Here, node 6 will be selected as the route for packets going from 0-3, 1-4 and 2-5. As a result, node 6 will spend its battery resources at a faster rate than the other nodes in the network and will be the first to die.

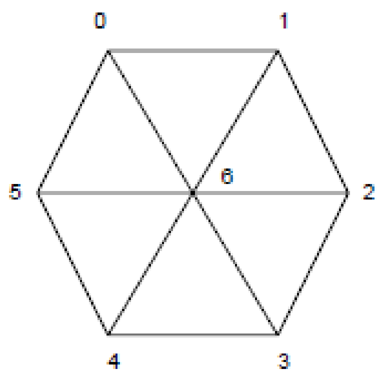

Figure-2. Energy packet as a metric.

Maximize time to network partition

One of the difficulties in implementing this metric is that given a network topology, using the max-flow-min-cut theorem, we can find a minimal set of nodes (the cut-set) the removal of which will cause the network to partition. The routes between these two partitions must go through one of these critical nodes. A routing procedure therefore must divide the work among these nodes to maximize the life of the network. If we don't ensure that these nodes use up their power at equal rates, then we will observe that delays will increase as soon as one of these nodes dies. Problem is similar to the load balancing problem where tasks need to be sent to one of the many servers available so that the response time is minimized. This is known to be an NP-complete problem.

Minimize variance in node power levels

This metric ensures that all the nodes in the network remain up and running together for as long as possible. This problem is similar to load sharing in distributed systems where the objective is to minimize response time while keeping the amount of unfinished work in all nodes the same. This is an intractable problem, because the execution times of future arrivals are not known. Join the Shortest Queue (JSQ) policy can be used to achieve this goal. Here each node sends traffic through a neighbor with the least amount of data waiting to be transmitted. If all packets are of same length, then we can achieve the equal power drain rate by choosing next hop in a round-robin fashion so that on the average, all nodes process equal number of packets.

Minimize cost per packet

This metric is used to maximize the life of all nodes in the network. The path selected using this metric should be such that nodes with depleted power reserves do not lie on many paths. Let $f_i(x_i)$ be a function that denotes the node cost or weight of node I, where x_i represents the total energy spent by node i. The total cost of sending a packet along some path is the sum of costs at individual nodes from n_1 to n_k via intermediate nodes $n_2, \ldots, n_{k-1}$ and can be represented as:

$$c_j = \sum_{i=1}^{k-1} f_i(x_i)$$

The goal of this metric is to Minimize c_j, for all packets j. If f_i is a monotonically increasing function, then nodes will not be overused thus increasing their life, where f_i can be tailored to reflect a battery's remaining life time.

$$f_i(x_i) = (1/(1 - g(x_i))\ ,$$

Where $g(x_i)$ is the normalized battery capacity.

3. LITERATURE REVIEW

Routing is one of the key issues in MANETs due to their highly dynamic and distributed nature. In particular, power aware routing may be the most important design criteria for MANETs since mobile nodes are powered by batteries with limited capacity. Power failure of a mobile node affects the ability of a node to forward packets on behalf of others and thus the overall network lifetime. For this reason, many research efforts have been devoted to developing power aware routing protocols [22]. One important goal of a routing protocol is to keep the network functioning as long as possible. This goal can be accomplished by minimizing mobile nodes' energy not only during active communication but also when they are inactive. Three approaches to minimize the active communication energy are: 1) Transmission Power Control Approach; 2) Load Distribution Approach; and 3) Power Management Approach. And to minimize energy during inactivity, the Sleep/Power-Down Mode approach is used. Table-1 lists each of the above approaches along with respective protocols under each approach and their objectives.

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Table-1. Taxonomy of power aware routing protocols.

Approach	Protocols	Objective
	OMM PLR MER COMPOW PAAODV	1st 3 protocols minimize the total transmission power by avoiding; low energy nodes and the last 2 protocols minimize thetotal transmission energy while considering retransmission overhead
Load distribution	LEAR CMMBCR	Distribute load to energy rich nodes
Power management	PAMAS PDTORA	Minimize the power consumption by using separate channels for data and control
Sleep/Power-Down mode	SPAN GAF	Minimize power consumption when node in an idle state

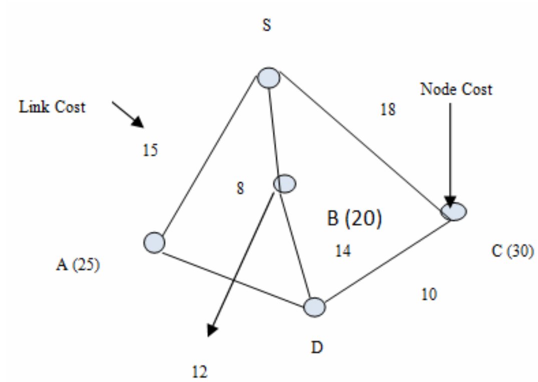
3.1. Transmission power control approach

Transmission power control approach can be achieved with the help of topology control of a MANET [23]. The transmission power determines the range over which the signal can be coherently received, and is therefore crucial in determining the performance of the network (throughput, delay, and power consumption) [24]. Power aware routing protocols based on transmission power control finds the best route that minimizes the total transmission power between a source and destination. It is equivalent to a graph optimization problem, where each link is weighted with the link cost corresponding to the required transmission power. Finding the most power efficient (min-power) route from source to destination is equivalent to finding the least cost path in the weighted graph. A routing algorithm essentially involves finding an optimal route on a given network graph where a vertex represents a mobile node and an edge represents a wireless link between two end nodes that are within each other's radio transmission range. In this paper, we reviewed various power aware routing protocols explained each one of them by taking our own examples and also introduced the new power aware routing protocol i.e. PADSR.

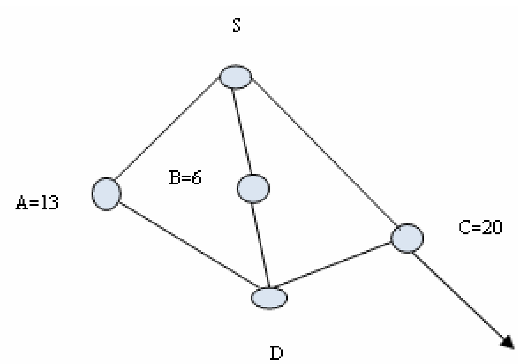
3.1.1. OMM (online max-min)

OMM [25] protocol uses two different metrics of the nodes in the network: Minimizing power consumption (min-power) and maximizing the minimal residual power (max-min). Max-min metric is helpful in preventing the occurrence of overloaded nodes. OMM protocol uses Dijkstra's algorithm to find the optimal path between source-destination pair. This min-power path consumes the minimal power (P_{min}).

In order to optimize the second metric, the OMM protocol obtains multiple near-optimal min-power paths that do not deviate much from the optimal value (i.e., less than zP_{min} where $z \geq 1$) and selects the best path that optimizes the max-min metric. Figure-3 shows an example of the algorithm for a given source and destination pair. In Figure-3 (a), S $\rightarrow B \rightarrow D$ is the min-power path as it consumes the minimal energy (P_{min}=22) i.e. path cost is 22. If z = 2, alternative paths S$\rightarrow A \rightarrow D$ (path cost=27) and S $\rightarrow C \rightarrow D$ (path cost=28) can be considered since their path costs are within the tolerance range ($zP_{min} = 44$).



(a) Min-power path



(b) Max-min path

Figure-3. Min-power path and max-min path in the OMM protocol

In order to obtain the max- min path among those three path candidates, the node with the minimal residual power in each path must be compared. In Figure-3(b), node A has the residual energy of 25 but it will drop to 13 if that path is used to transfer the data packets from S to D. Similarly, nodes B and C will have residual energy of 6 and 20 respectively. Therefore, the max-min path among the three min-power paths is $S \rightarrow C \rightarrow D$. The parameter z measures the tradeoff between the max-min path and the min-power path. The proper selection of the parameter z is important in determining the overall energy performance. At first, an initial value of z is randomly chosen, and the residual energy of the most overloaded node, called a lifetime, is estimated based on the measurement during a fixed time period of MANET operation. Then, z is increased by a small constant, and the lifetime is estimated again after the next time period. If the newly estimated lifetime is longer than the older one, the parameter z is increased accordingly; otherwise, z is decreased. Algorithm steps are given below:

(i) Find the path with the least power consumption, P_{min} using the Dijkstra algorithm.
(ii) Find the path with the least power consumption in the graph. If the power consumption > zP_{min} or no path is found, then the shortest path is the solution, stop.
(iii) Find the minimal residual power fraction on that path, and let it be r_{min}.
(iv) Find all the edges whose residual power fraction is smaller than r_{min}, remove them from graph.
(v) Go to step 2.

The major advantages of OMM protocol is that without requiring the information regarding the data transmission sequence or data generation rate the protocol makes a routing decision that optimizes the two different metrics in the nodes of the network. The max-min metric is useful in preventing the occurrence of overloaded nodes. It minimizes the power consumption by finding the optimal path using Dijkstra algorithm. Disadvantage is that data transmission sequence or data generation rate is not usually known in advance. This graph optimization algorithm based on global information such as data generation rate may not be practical because each node is provided with only the local information.

3.1.2. PLR (power-aware localized routing) protocol

The PLR [26] protocol implements a localized, fully distributed power aware routing algorithm, but it assumes that a source node has the location information of its neighbors as well as the destination. It is equivalent to knowing the link costs from itself to its neighbors and to the destination as well. In Figure-4, when node A has data packets to send to node D, it can either send them directly to D or through one of its neighbors (N_1, N_2 or N_3). A to N_i is a direct transmission while N_i to D is an indirect transmission with some number of intermediate nodes between N_i and D. Therefore node A, whether it is a source or an intermediate node, selects one of its neighbors (N_1, N_2 or N_3) as the next hop node which minimizes p (|AN_i|) + q (|N_i D|), where p and q are the respective path costs. Advantage of PLR protocol is that the source cannot find the optimal path but selects the next hop through which the overall transmission power to the destination is minimized. Disadvantage of PLR protocol is that the direct transmission consumes more power as compared to the indirect transmission via intermediate nodes. The path with direct transmission link may perform worse than a path with indirect transmission links in terms of latency as well as power consumption because the path with direct transmission would cause link errors that would result in more retransmissions.

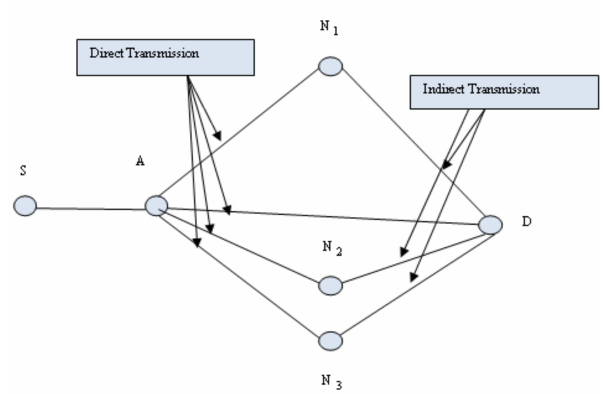


Figure-4. Selection of the next hop node in the PLR protocol.

3.1.3. MER (minimum energy routing)

The transmission power control approach requires power information such as link costs and node costs. In practice, the following issues need to be addressed: (1) how to obtain accurate power information; (2) how much overhead is associated with the energy aware routing; and (3) how to maintain the minimum energy routes in the presence of mobility. Minimum Energy Routing (MER) [27] protocol addresses these issues and implements the transmission power control mechanism in DSR and IEEE 802.11 MAC protocol with eight selectable options as shown in Table-2. Option A modifies the header of a route-request packet to include the power used by the sender to transmit the packet. The receiving node uses this information as well as radio power level used to receive the packet to calculate the minimum power required for the successful transmission from the sender to itself. Option B explains the minimum energy aware version of DSR using the energy aware link cache with energy aware route discovery and maintenance. If the source has multiple route candidates in its cache, it calculates the total transmission energy for each possible route based on the power level information obtained via applying Option A and chooses the minimum energy route. Option C which is Cache replies off explains the effect of on-demand behavior in ad-hoc routing protocols

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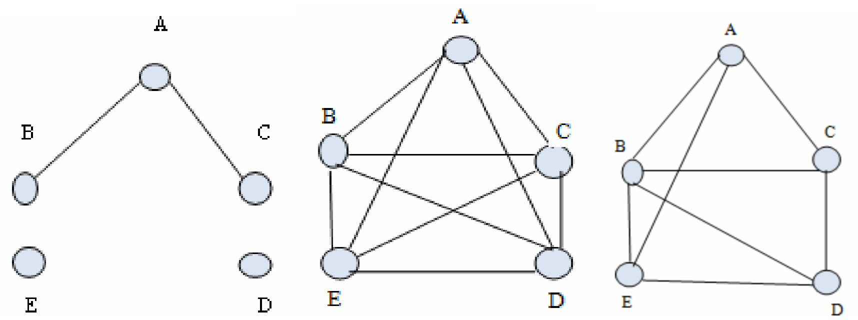
and state in their results that in a typical simulation scenario, the majority of the route reply packets are based on cached data and 59% of those replies carry valid routes. Option D i.e. internal cache timeouts is related to route-cache maintained in the DSR routing algorithm. Option E explains that the route request that is to be sent and replying back through the route reply request this route discovery procedure is carried out in a multi-hop manner. Option F applies the same power control mechanism on the MAC layer's ACK packets. In order to reduce the signaling cost per hop, transmit power control can be applied to the MAC ACK packets on the link. In Option G low energy routes are dynamically adjusted when the required transmission power changes due to node mobility. Option H allows non-participating nodes to snoop on packet exchange and to suggest the sender a more energy efficient route at the routing and the MAC layer respectively. The minimum energy routing has been implemented on laptops running Linux using Wireless Ethernet cards that support the transmit power control feature that sends the packets out at the minimum transmit power. Advantage of MER (Minimum Energy Routing) protocol is that this protocol maximizes the life time of the network and routing with maximum lifetime balances all the routes and nodes globally so that the network maintains certain performance level for a longer time. Disadvantage of MER protocol is that minimum energy routes sometimes attract more flows and the nodes in these routes exhaust their energy very soon hence the whole network cannot perform any task due to failure of these nodes. So there is a chance that node may fail.

Table-2. Eight options in MER protocol.

Options	**Implementation level**
A: Routing packet-based power control	Routing software/802.11 firmware
B: Minimum energy routing	Routing software
C: Cache replies off	Routing software
D: Internal cache timeouts	Routing software
E: Multi-hop route discovery	Routing software
F: MAC layer ACK power control	802.11 firmware
G: Route maintenance using power sensing of data packets	Routing software
H: MAC level DATA/ACK snooping /gratuitous replies	802.11 firmware

3.1.4. COMPOW (common power)

Common Power Protocol provides architecture for a modular implementation, guarantees bi-directionality of links, connectivity of the network, asymptotically maximizes the traffic carrying capacity, provides power aware routes, reduces MAC contention, and can even be used with any routing Table driven protocol. Common power protocol [28] mantains bidirectionality between any pair of communicating nodes in a MANET. This is achieved by having all the nodes in the MANET maintaining a common transmision power level (P_i). If P_i is too low, a node can reach only a fraction of the nodes in the MANET. If P_i is very high, a node can directly reach all other nodes but results in high power consumption.Infact, a node can directly or indirectly reach the entire MANET with a smaller P_i. Therefore the optimum power level is the smallest power level at which the entire network is connected. In COMPOW, it is assumed that the transmission power levels cannot be arbitrarily adjusted but instead it must be selected among a small number of discrete power levels(P_1,P_2,…,P_{max}). Different power levels result in dfferent node connectivity since they cover different radio transmission ranges. Each node maintains a routing Table as in Table driven routing mechanism, but one for each value of power,means the number of reachable nodes at P_i. This includes directly connected nodes as well as indirectly connected nodes through intermediate nodes. By exchanging these routing Tables, nodes find the minimal P_i that satisfies $|RT_{pi}|$=n for all nodes, where n is the total number of nodes in the MANET. In Figure-5(a), the network results from using too low a power level. The network is disconneceted. As the power level is too low, the network is partitioned into two disconneced components {A, B, C} and {D, E}. But in Figure-5(b), the power level is higher and it results in a set of links adequate to provide a connected network. Thus, the larger power level results in a connected network. In Figure-5(c) a node can directly or indirectly reach the entire MANET with a smaller P_i. Therefore, the optimum power level is the smallest power level at which the entire network is connected. So the optimum power level is the best one among the three and provides the best result.

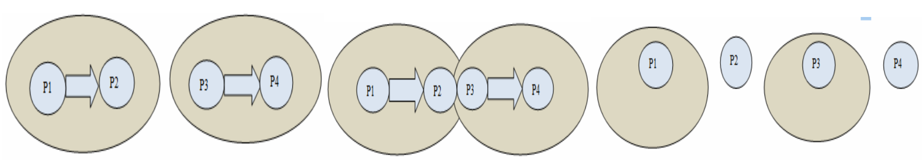


a) P_i is too low b) P_i is too high (c) P_i is optimal

Figure-5. Proper Selection of the common transmission.

3.1.5. PAAODV (power aware ad hoc on-demand distance vector routing) protocol

Power Aware AODV (PAAODV) protocol for ad hoc networks is an enhancement of existing AODV ad hoc routing protocol. The main objective of PAAODV is to optimally reduce power consumption to a minimum power level in MANET without disruption of network connectivity. As a result of it, the overall power consumed in transmission of overhead packets is significantly reduced. The control messages used in AODV protocol is modified. PAAODV [29] works in two phases that is route-discovery and link-by-link power adjustment. In the route discovery process, different power levels are used to determine a route consuming minimum power for transmission of packets. In this case, a source node attempts first to discover a path with a low power level. If it is unable to find a path with this power level, then it attempts further with a higher power level. Using two different power levels in the route discovery phase reduces route discovery time and at the same time reduces the overhead too as compared to that in COMPOW.



(a) Minimum transmit power (b) High transmit power (c) Low transmit power

Figure-6. Effect of transmit power control on network connectivity.

Transmit power levels of nodes in an ad hoc network using PAAODV is controlled to minimum levels. Controlling the transmit power level is performed due to two reasons: (i) transmit power level is directly related to the available power at the node and (ii) network connectivity is significantly affected by transmit power. The basic principle of PAAODV is that nodes in the network should control the transmit power in order to maintain the network connectivity. As shown in Figure-6, node p1 is transmitting a packet to node p2 and node p3 is transmitting a packet to node p4. In Figure-6(a), both transmissions are successful since they do not interfere with each other. In Figure-6(b), communications interfere with each other due to high transmit power level and hence, cannot be successful. In Figure-6(c), as the transmit power is too low, the network connectivity fails and the communications fail too. Thus, for the communication to take place, the power level should be as low as possible, but at the same time, the connectivity should be maintained. This transmit power, regarded as minimum transmit power level, i.e. $P_{\min}$, can be calculated

$$P_{\min}(d) = p_{th} d^{\gamma} / K$$

Where d is the distance between two nodes, γ is the path loss component and 'K' is constant. Authors have assumed $\gamma = 4$ during implementation, which is the path loss component for a two-ray ground model. The value of P_{th} for IEEE based network is 3.653×10^{10} mW. So the minimum power consumption is calculated as:

$$E_{\min} = K_3 D d^4 + K_2$$

Where $K_3 = 2.8 \times 10^{-10}\ \mu$ J/byte. The equation reveals that $E_{\min}$ depends upon d, the distance between two nodes. Otherwise for a fixed transmit power level, the power consumption can be calculated as:

$$E_{\max} = K_4 D + K_2$$

Where $K_4 = 1.62\ \mu$ J/byte. Thus the amount of power saved can be obtained as:

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$S(D, d) = E_{max} - E_{min}$

Advantages of COMPOW protocol is that this protocol increases the traffic carrying capacity, reduces the battery consumption i.e. increases the battery life, reduces the latency, reduces interference, guarantees bidirectional links, provides power aware routes and can be used with any proactive routing protocol. Another feature of COMPOW protocol is the plug and play capability. It is among the very few protocols that has been implemented and tested in a real wireless test bed. Limitations of COMPOW protocol is that when the nodes in a network are clustered the COMPOW protocol may settle for an unnecessarily high power level. Even a single node outside the cluster may result in a high power level selection for the whole network. Compow protocol works only for homogeneous networks.

Figure-7. COMPOW protocol is not appropriate for non homogeneous networks.

In Figure-7 there is a cluster in which the nodes transmit at 1 mW power level. The node N outside the cluster needs a power level of 100 mW for transmission. So the single node N outside the cluster can force the common power level for the network to a high value. Hence COMPOW is not suitable for clusters.

3.2. Load distribution approach

The specific objective of load distribution approach [30] is to balance the energy usage of all mobile nodes by selecting a route with underutilized nodes rather than the shortest route. This may result in longer routes, but packets are routed only through energy rich intermediate nodes. Protocols based on this approach do not necessarily provide the lowest energy route, but prevent certain nodes from being overloaded and thus, ensures longer network lifetime. This subsection discusses two such protocols: Localized Energy-Aware Routing (LEAR) and Conditional Max-Min Battery Capacity Routing protocols.

3.2.1. Localized energy aware routing (LEAR) protocol

The LEAR [31] routing protocol is based on DSR which modifies the route discovery procedure for balanced energy consumption. LEAR [Table-3.] is a distributed algorithm where each node makes its routing decisions based on local information such as E_r and Th_r. In DSR, when a node receives a route-request message, it appends its identity in the message's header and forwards it toward the destination. Thus, an intermediate node always relays messages if the corresponding route is selected. However, in LEAR, a node determines whether to forward the route-request message or not depending on its residual battery Power (E_r). When E_r is higher than a threshold value Th_r, the node forwards the Route-request message; otherwise, it drops the message and refuses to participate in relaying packets. Therefore, the destination node will receive a route-request message only when all intermediate nodes along a route have good battery power levels, and nodes with low battery levels can conserve their battery power. LEAR is a distributed algorithm where each node makes its routing decision based only on local information, such as E_r and T_r. As E_r decreases in time, the value of Th_r must also be decreased adaptively in order to identify energy-rich and energy-hungry nodes in a relative sense.

Table-3. The basic LEAR algorithm.

Node	Steps
Source node	Broadcast a ROUTE_REQ; Wait for the first arriving ROUTE_REPLY; Select the source route contained in the message; Ignore all later replies.
Intermediate node	If the message is not the first trial and $E_r < Th_r$ adjust Th_r by d; If $E_r > Th_r$, broadcast the ROUTE_REQ and ignore all later requests Otherwise, drop the message.
Destination node	Upon receipt the first arriving ROUTE_REQ send a ROUTE_REPLY to the source with the source route contained in the message.

The problems in LEAR algorithm are that it cannot utilize route cache in the basic form since upstream nodes cannot freely decide on behalf of downstream nodes and it may incur repeated route request messages due to dropping of requests by intermediate nodes in cascade. Thus, as a solution to this problem, 4 additional routing control messages are used [Table-3]:1) DROP_ROUTE_REQ; 2) ROUTE_CACHE; 3)

DROP_ROUTE_CACHE and 4) CANCEL_ROUTE_CACHE.

DROP_ROUTE_REQ: There is the cascading effect in LEAR algorithm, if the path is A→B→C1→C2→D. The intermediate nodes B, C1, C2 have low energy. On 1st request from A to D, B will drop request and adjust threshold. On 2nd request from A to D, C1 will drop and adjust, and so on. D will finally get the request on 4th attempt. Hence, in DROP_ROUTE_REQ, on 1[st] attempt from A to D, B drops and adjusts it and also forwards DROP_ROUTE_REQ along the path to D. This causes C1 and C2 to adjust their threshold. D will receive the request on the 2[nd] attempt.

LEAR-ROUTE_CACHE: Source node sends ROUTE_REQ message to the intermediate node B. Paths of all the intermediate nodes (B, C1 and C2) are stored in a cache and are routed towards the destination D [Figure-8]. Node B knows a path to D in its route cache. So the routes to the destination are present in the cache. Destination may receive multiple ROUTE_REQ and ROUTE_CACHE messages [32]. It replies to only the first one. If $E_r > Th_r$ ROUTE_CACHE is forwarded and all later requests are ignored.

DROP_ROUTE_CACHE and CANCEL_ROUTE_CACHE: If the route to the destination is present in the cache and if $E_r < Th_r$ then DROP_ROUTE_CACHE [33] is forwarded and all later requests are ignored [Figure-9].

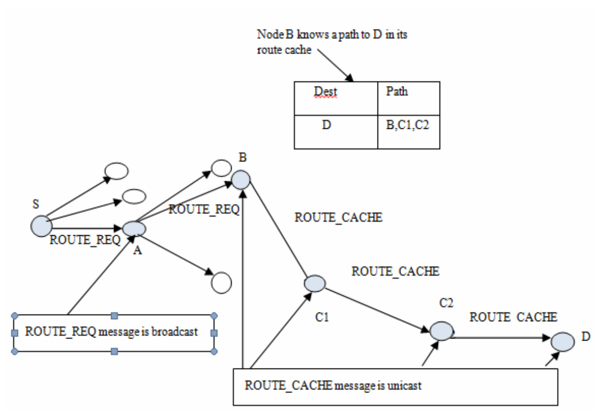

Figure-8. LEAR ROUTE_CACHE.

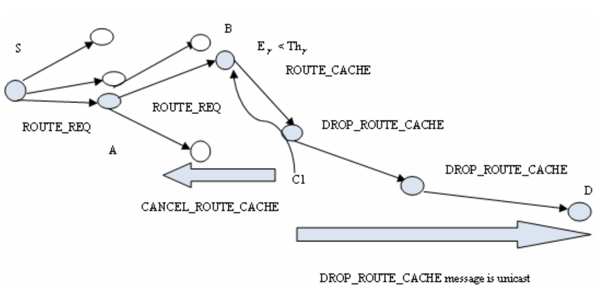

Figure-9. LEAR DROP_ROUTE_CACHE and CANCEL_ROUTE_CACHE.

Upon receipt of a ROUTE_CACHE, if $E_r < Th_r$ then forward DROP_ROUTE_REQ and ignore all later requests and send backward CANCEL_ROUTE_CACHE [34]. Advantages of LEAR protocol as compared to transmission power control approach is that it is the first protocol to explore balanced power consumption in a pragmatic environment where routing algorithm, mobility and radio propagation models are considered. It optimizes tradeoff between balanced power consumption and minimum routing delay and also avoids the blocking problem as it accomplishes the balanced power consumption based only on local information. It can be easily integrated into existing ad hoc routing algorithms without affecting other layers of communication protocols. The power usage is better distributed as compared to DSR algorithm. Disadvantage of LEAR protocol is that the threshold value is not fixed for which the design is considered to be complicated.

3.2.2. CMMBCR (conditional max-min battery capacity routing)

This protocol utilizes the idea of a threshold to maximize the lifetime of each node and to fairly use the battery. When all nodes in some possible routes have sufficient remaining battery capacity (i.e. above a threshold), a route with minimum total transmission power among these routes is chosen. Since less total power is required to forward packets for each connection, the relaying load for most nodes can be reduced, and their lifetime will be extended. However, if all routes have nodes with low battery capacity (i.e. below the threshold Y), a route including nodes with the lowest battery capacity must be avoided to extend the lifetime of these nodes. CMMBCR [35] protocol utilizes the idea of a threshold to maximize the lifetime of each node and to fairly use the battery. If all nodes in some possible routes between a source-destination pair have larger remaining battery energy than the threshold Y, the min power route among those routes is chosen. If all possible routes have nodes with lower battery capacity than the threshold, the max-min route is chosen. This protocol selects the shortest path, if all nodes in all possible routes have adequate battery capacity. If some nodes go below a predefined threshold, routes going through these nodes will be avoided. By adjusting the value of the threshold, the time when the 1[st] node powers down or lifetime of most nodes in the network can be maximized. For CMMBCR protocol an interesting performance metric has been proposed for measuring the energy balance i.e. expiration sequence which is defined as the sequence of times when mobile nodes exhaust their battery capacity. This metric is better than other power aware metrics i.e. time to network Partition, variance in node power levels, network lifetime etc. Since traditional metrics provides limited information on energy balance, the expiration sequence gives more accurate information on how fairly power is expended.

Algorithm for CMMBCR protocol:

a) For each route 'j' find the minimum capacity R_j among all nodes in that route

b) If $R_j >= Y$ is true for some or all routes between a source and destination

Apply Minimum Total Transmission Power Routing (MTPR) scheme to select path among all routes satisfying above condition

c) ELSE

Select the route 'i' with the maximum battery capacity

Advantages of CMMBCR protocol is that it uses a battery capacity i.e. "threshold" instead of cost function as a route selection metrics. Since less total power is required to forward packets for each route, the relaying load for most nodes will be reduced and their life time will be extended. So CMMBCR protocol increases the life time of each node use the battery fairly and guarantees that minimum total transmission path will be selected.

3.3. Power management approach

Power management approach [36] helps in reducing the system power consumption and hence prolonging the battery life of mobile nodes. Furthermore, it improves the end-to-end network throughput as compared to other ad-hoc networks in which all mobile nodes use the same transmit power. The improvement is due to the achievement of a tradeoff between minimizing interference ranges, reduction in the average number of hops to reach a destination, the probability of having isolated clusters, and the average number of transmissions (including retransmissions due to collisions) and also due to the fact that as the power gets higher, and the connectivity range increases, each node would reach almost all other nodes in a single hop. The protocols would dynamically determine first an optimal connectivity range wherein they adapt their transmit powers so as to only reach a subset of the nodes in the network. The connectivity range would then be dynamically changed in a distributed manner so as to achieve the near optimal throughput. Minimal power routing is used to further enhance performance. As power management approach increases the throughput of the network this approach is better in terms of throughput as compared to the previous 2 approaches.

3.3.1. PAMAS (power aware multi-access)

PAMAS [37] saves energy by turning off radios when the nodes are not in use. It uses a new routing cost model to discourage the use of nodes running low on battery power. The lifetime of the network is improved significantly. There is a trivial negative effect on packet delivery fraction and delay, except at high traffic scenarios, where both actually improve due to reduced congestion. Routing load, however, is consistently high, more at low traffic scenarios. For the most part, PAMAS demonstrates significant benefits at high traffic and not-so-high mobility scenarios. Although, it was implemented on the AODV [38] protocol, the technique used is very standard and can be used with any on-demand protocol. The energy-aware protocol works only in the routing layer and exploits only routing-specific information.

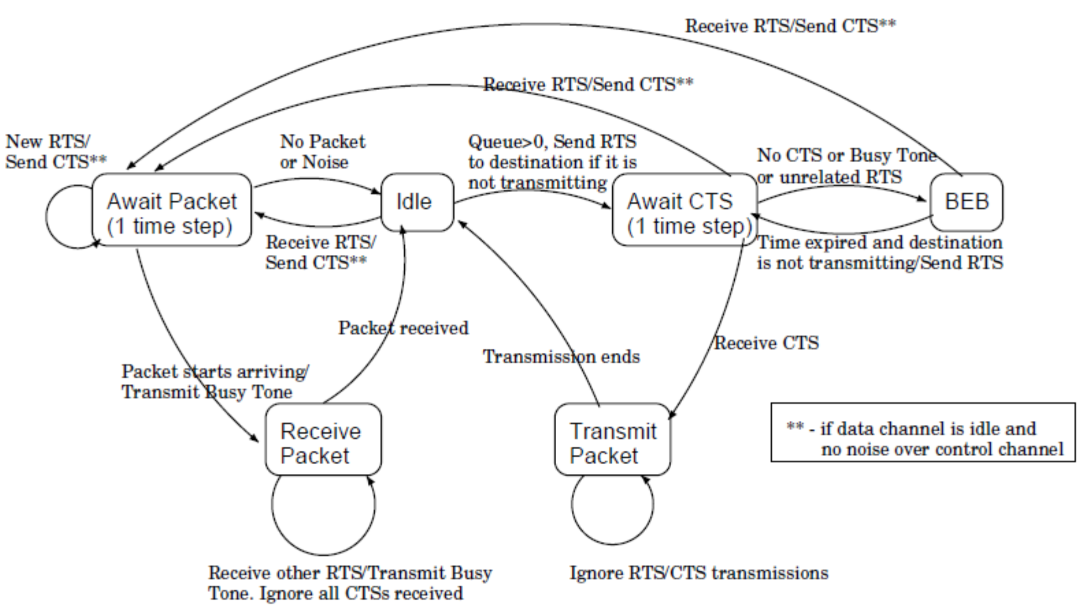

Figure-10. The pamas protocol.

Figure-10 is the state diagram which describes the behaviour of PAMAS protocol. As indicated in the diagram a node may be in any one of six states i.e. idle, AwaitCTS, BEB(Binary Exponential Backoff), Transmit Packet state, Await Packet and Receive Packet. The states are described as follows:

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i. Idle state - A node goes to idle state if it is not transmitting or receiving a packet or does not have any packets to transmit or does have packets to transmit but cannot transmit because a neighbor is receiving a transmission.
ii. Await CTS state - Whenever a node gets a packet to transmit it transmits a RTS and enters the Await CTS state.
iii. BEB(Binary Exponential Backoff) state-If the awaited CTS state does not arrive the node goes into BEB(Binary Exponential Backoff) state.
iv. Transmit Packet state-If a CTS arrives it begins transmitting the packet and enters the Transmit Packet state.
v. Await Packet state-This state comes into picture when the intended receiver transmits the CTS.
vi. Receive Packet state-If the packet begins arriving, it transmits a busy tone over the signalling channel and enters the Receive Packet state otherwise enters to the idle state.

Advantages of PAMAS protocol are this protocol saves 40-70 percentage of battery power by intelligently turning off radios when they cannot transmit or cannot receive packets. The specific conditions for nodes with power off in PAMAS are: 1) a node powers off, if it is overhearing a transmission and does not have a packet to transmit; 2) if at least one neighbor is transmitting and at least one neighbor is receiving a transmission, a node may power off; 3) if all of a node's neighbors are transmitting (and the node is not a receiver), it powers itself off. This protocol tends to increase the throughput of the network as compared to other power aware routing protocols. One of the drawbacks of PAMAS protocol is broadcasting problem. In this protocol a broadcast may collide with another transmission at some receiver. Another drawback is that here mobile hosts manage the communication device through suspension of the device during idle periods. Suspending the communication device causes its one-hop neighbors isolation which leads to buffer overflow.

3.3.2. PDTORA (power and delay aware on-demand routing for ad hoc networks)

In PDTORA [40], a node maintains the topology information involving its one-hop neighbors. During a reconfiguration process following a path break, TORA has the unique property to limit the control packets to a small region. The metrics such as delay, power and distance used in TORA, are depicted in Figure-11 for a given node n, H (n) denotes its height from the destination node. Three major functions performed by TORA are: establishing, maintaining and erasing routes. Route establishment function is initiated, when a source node requires a path to a specific destination, to which it does not possess a directed link. During this process, a destination oriented Directed Acyclic Graph (DAG) is established using a query / update mechanism. Prior to a communication, a source node sends a query packet to the destination, which incorporates the information regarding source address, destination address, minimum power level, maximum permissible delay (QRY (<source address>, <destination address>, <minimum power level>, <maximum delay>). The power extension in the query packet indicates the minimum power required to be available along the path during the communication. In addition, the delay extension specifies the maximum delay allowed between the source and destination.

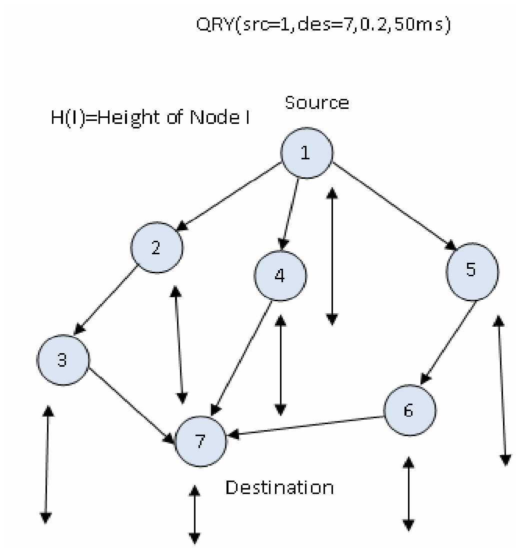

Figure-11. Power and delay extension in TORA.

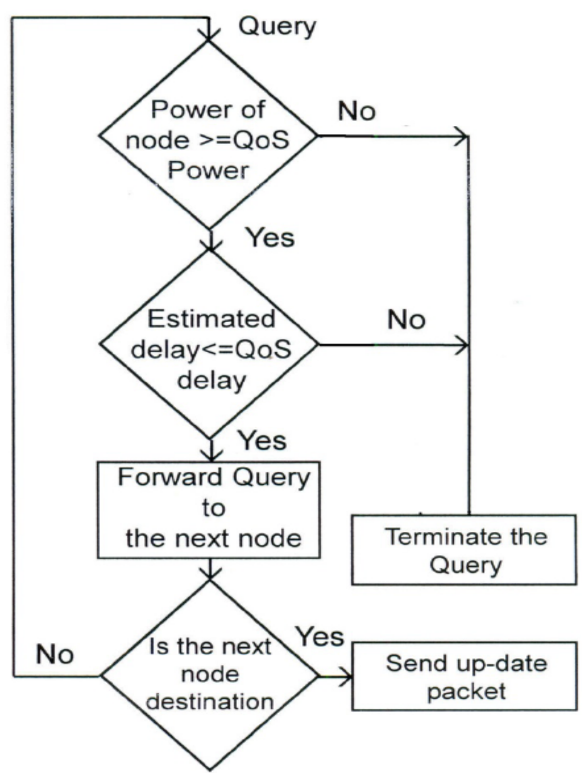

Figure-12. Algorithm of PDTORA.

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QoS power extension 0.2 indicates that a minimum of 20% initial power level be available with each of the nodes along the path and a maximum allowable delay of 50 milliseconds (ms). The verification for specified QoS power and QoS delay is made at each node as the query packet traverses the path from source to destination. A query packet is dropped if at least one of the constraints is not satisfied at any point of time. As the query packet traverses the network, each node compares its available power level with the power level, mentioned in the query packet. If the available power level at a node is found to be less than the power level specified in the query packet, then the query packet is dropped. In case the QoS power holds perfect, then the delay to destination is estimated, and if the estimate exceeds the QoS delay as mentioned in the query packet, then the packet is dropped. If the delay constraint is satisfied, the node subtracts its Node Traverse Time (NTT) from the delay bound provided in the extension and the query packet is forwarded to next hop along the route. Advantages of PDTORA as compared to TORA and other previous power aware routing protocols is that it works very well with more number of mobile nodes by taking into consideration different performance metrics like end-to-end-delay, packet delivery ratio, node lifetime etc. Figure-12 describes the sequence of operations during traversal of a query packet, which is forwarded by nodes 2, 3, 4, 5, 6 between node 1 (source) and node 7 (destination). Each node that terminates the query packet, replies with an update packet back to the source, indicating its distance from the destination and delay.

3.4. Sleep/power-down mode approach

The sleep/power-down mode [41] approach focuses on inactive time during communication. Since most radio hardware supports a number of low power states, it is desirable to put the radio subsystem into the sleep state or simply turn it off to save energy. However, when all the nodes in a MANET sleep and do not listen, packets cannot be delivered to a destination node. One possible solution is to elect a special node, called a master, and let it coordinate the communication on behalf of its neighboring slave nodes. Now, slave nodes can safely sleep most of time thereby saving battery power. Each slave node periodically wakes up and communicates with the master node to find out if it has data to receive or not and it sleeps again if it is not addressed. This subsection introduces two routing algorithms that exploit the radio hardware's low power states. The SPAN protocol and the Geographic Adaptive Fidelity (GAF) protocol employ the master-slave architecture and put slave nodes in low power states to save energy.

3.4.1. SPAN protocol

SPAN protocol is a power saving mechanism that reduces power consumption of nodes by retaining the capacity and coordinating with the underlying MAC layer. Figure-13 describes that the SPAN protocol operates between the routing layer and the MAC layer. SPAN tries to exploit MAC layers power saving features. The routing layer uses information SPAN provides for power aware routing. Advantages of the SPAN protocol is that the master nodes play an important role in routing by providing a routing backbone and control traffic as well as channel contention is reduced because the routing backbone helps to avoid the broadcast flooding of route-request messages. Other benefits of SPAN protocol are that this technique not only preserves network connectivity, it also preserves capacity, decreases latency and provides significant power savings. Drawback of SPAN protocol is that the amount of power saving increases slightly as density decreases.

Network Layer	DSR	AODV
SPAN		
Data Link Layer	802.11	

Figure-13. SPAN provides interface between network and data link layer.

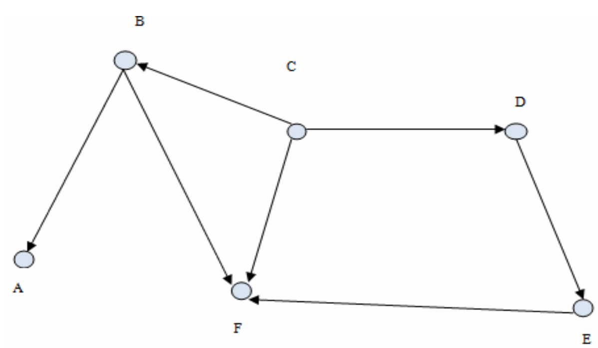

Figure-14. Master eligibility rule in the SPAN protocol.

To select master nodes in a dynamic configuration, the SPAN [42] protocol employs a distributed master eligibility rule [43] so that each node independently checks if it should become a master or not. The rule is that if two of its neighbors cannot reach each other either directly or via one or two masters, it should become a master. Non-master nodes also periodically determine if they should become a master or not based on the master eligibility rule. In Figure-14, nodes B, C and D become masters. Node B is eligible to become master since its two neighbors A and F cannot communicate directly. Node D is eligible to become master since its two neighbors C and E cannot communicate directly. Node C is not eligible to become master since its neighbors B and F can communicate with each other directly. Node C is also eligible to become master since its neighbors B and D cannot communicate directly. So, if any one of the nodes B and D do not elect itself as a master, node C is eligible to be the master. Thus, the master selection process is not deterministic. This rule does not yield the minimum number of master nodes, but it provides robust connectivity with substantial energy savings. However, the master nodes are easily overloaded. To prevent this and to

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ensure fairness, each master periodically checks if it should withdraw as a master and gives other neighbor nodes a chance to become a master. Non-master nodes also periodically determine if they should become a master or not based on the master eligibility rule.

3.4.2. GAF (geographic adaptive fidelity) protocol

In GAF [44] protocol, each node uses location information based on GPS to associate itself with a "virtual grid" so that the entire area is divided into several square grids, and the node with the highest residual energy within each grid becomes the master of the grid. Other nodes in the same grid can be regarded as redundant with respect to forwarding packets, and thus, they can be safely put to sleep without sacrificing the "routing fidelity" (or routing efficiency). The slave nodes switch between off listening with the guarantee that one master node in each grid will stay awake to route packets. For example, nodes 2, 3 and 4 in the virtual grid B in Figure-15 are equivalent in the sense that one of them can forward packets between nodes 1 and 5 while the other two can sleep to conserve energy. R is the radio range and the grid size can be derived from the relationship between grid size r and the radio range R as $r^2 + (2r)^2 \leq R^2$ or $r \leq R/\sqrt{5}$. Master election rule in GAF is as follows. Nodes are in one of three states as shown in Figure-16 i.e. sleeping, discovering and active. Initially nodes start out in the discovery state.

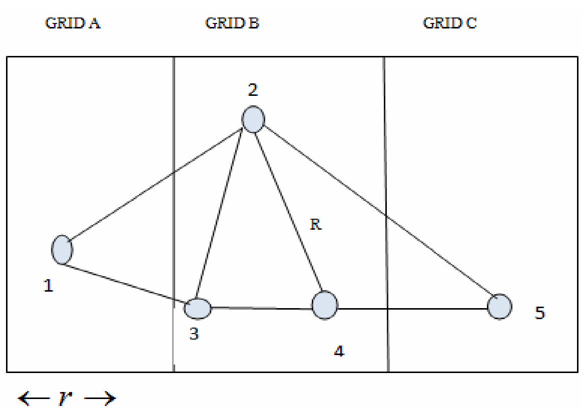

Figure-15. Virtual grid.

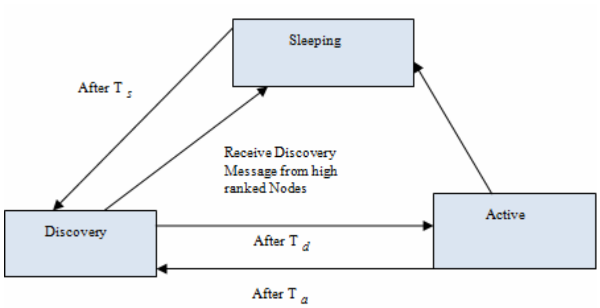

Figure-16. State transition in the GAF Structure in the GAF protocol.

When in state discovery, a node turns on its radio and exchanges discovery messages to find other nodes within the same grid. The discovery message is a tuple of node id, grid id, estimated node active time (enat), and node state. A node uses its location and grid size to determine the grid id. Initially, a node is in the discovery state and exchanges discovery messages including grid IDs to find other nodes within the same grid. When a node enters discovery state, it sets a timer for T_d seconds. When the timer fires, the node broadcasts its discovery message and enters state active. The timer can also be suppressed by other discovery messages. This timer reduces the probability of discovery message collision. When a node enters active, it sets a timeout value T_a to define how long this node can stay in active state. After T_a, the node will return to discovery state. While active, the node periodically re-broadcasts its discovery message at intervals T_d. A node in discovery or active states can change state to sleeping when it can determine some other equivalent node will handle routing. When transitioning to sleeping, a node cancels all pending timers and powers down its radio. A node in the sleeping state wakes up after an application-dependent sleep time T_s and transitions back to discovery. In scenarios with high mobility, sleeping nodes should wake up earlier to take over the role of a master node, where the sleeping time T_S is calculated based on the estimated time the node stays within the grid. Advantage of GAF protocol over other power aware routing protocol is that it conserves power by identifying nodes that are equivalent from a routing perspective and then turning off unnecessary nodes, keeping a constant level of routing fidelity and extends the lifetime of the network by exploiting redundancy to conserve power while maintaining application fidelity. Disadvantage of GAF protocol is that master selection procedure is very costly and causes master overloading problem.

4. CONCLUSIONS AND FUTURE WORK

A MANET consists of autonomous, self-organizing and self-operating nodes, each of which communicates directly with the nodes within its wireless range or indirectly with other nodes via a dynamically computed, multi-hop route. Due to its many advantages and different application areas, the field of MANETs is rapidly growing and changing, while there are still many challenges that need to be met. It is likely that MANETs will see wide-spread use within the next few years. In order to facilitate communication within a MANET, an efficient routing protocol required to discover routes between mobile nodes. Energy efficiency is one of the main problems in a MANET, especially in designing a routing protocol. In this paper, we performed an exclusive survey and classified a number of power-aware routing schemes. In many cases, it is difficult to compare them directly since each method has a different goal with different assumptions and employs different means to achieve the goal. For example, when the transmission power is controllable, the optimal adjustment of the power level is essential not only for energy conservation but also for the interference control. When node density or traffic density is far from uniform, a load distribution approach must be employed to alleviate the energy imbalance problem. The sleep/power-down mode approach is essentially independent of the other two approaches because it focuses on energy during inactivity. Therefore, more research is needed to combine and integrate some of the protocols presented in this paper to keep MANETs functioning for a longer duration. We will enhance existing DSR algorithm using transmission power control approach to make efficient communication in DSR protocol in order to minimize the energy consumption as much as possible, increase the lifetime of the node and network, and make the routing efficient based on mechanisms of DSR protocol i.e. Route Discovery and Route Maintenance.

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