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Survey on Energy Efficient Routing Protocols in Mobile Ad Hoc Networks

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Abstract**—**Mobile Ad-Hoc Network (MANET) is a network without infrastructure dynamically formed by autonomous system of mobile nodes that are connected via wireless links. Mobile nodes communicate with each other on the fly. In this network each node also acts as a router. The battery power and the bandwidth are very scarce resources in this network. The network lifetime and connectivity of nodes depend on battery power. Therefore, energy is a valuable constraint which should be efficiently used. In this paper we survey various energy efficient routing protocols. The energy efficient routing protocols are classified on the basis of approaches they use to minimize the energy consumption. The purpose of this paper is to facilitate the research work and combine the existing solution and to develop a more energy efficient routing mechanism.

Keywords**—**Delaunay Triangulation, deployment, energy efficiency, MANET.

I. Introduction

MOBILE AD-HOC NETWORK (MANET) is a self-configuring network. Mobile nodes communicate with each other directly or indirectly via other nodes. These nodes employ one or the other protocol to find route from the source to the destination, transfer data packets and also employ route maintenance in case of link failure due to dynamic nature of nodes. The nodes in this network are also resource constrained. Battery depletion not only affects the nodes but also can cause performance degradation of the network which may lead to network failure. In such scenario, efficient utilization of battery power is an issue of high concern. Many algorithms have been proposed to maximize the network lifetime. Mobile nodes not only consume energy when it actively sends or receives packet but also when it stays idle, listening to the wireless medium for any possible communication from other nodes. Thus, many mechanisms have been proposed that minimizes the energy consumption either during active session or during the inactive time period of nodes. The reduction of energy during the active session is achieved through mainly two approaches: - (a) Transmission power control approaches, (b) Load balancing approaches.

The first approach determines the optimal routing path that minimizes the total transmission energy required to deliver the data packets to the destination. The second approach increases the lifetime of network by distributing the load equally among all the nodes so that a single node does not get overloaded and hence, depletes its energy causing performance degradation of the network. During inactive session of the nodes Sleep/Power down mode is used to minimize energy consumption of the nodes. In this approach each node can save the energy by switching its mode of operation into sleep/power down mode or simply turns it off when there is no data to transmit or receive.

The remainder of this paper is organized as follows: Section II provides a general discussion on MANET routing protocol. Section III comprises of energy efficient routing protocol based on different approaches to minimize the energy consumption and goals of different approaches followed by the conclusion.

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II. Routing Protocols in Mobile Ad-hoc Network

MANET routing protocols are mainly categorized into four parts:

a) Routing Information update mechanism.
b) Use of temporal information for routing.
c) Routing Topology.
d) Utilization of specific resources.

A. Based on Routing Information Update Mechanism

Based on Routing Information update mechanism routing protocol can be classified in three major categories:

1. Table-Driven Routing Protocols

These protocols are extension of the wired network the routing protocols. They maintain the global topology information in the form of tables at every node. These tables are updated frequently in order to maintain consistent and accurate network state information. Some of the table driven routing protocols are mentioned below:

a) Destination Sequence Distance Vector Routing Protocol [1]
b) Wireless Routing Protocol [2].
c) Cluster-head Gateway Switch Routing Protocol [3].
d) Source-Tree Adaptive Routing Protocol [4].

2. On-Demand Routing Protocols

On-demand routing protocols execute the path-finding process and exchange routing information only when a path is required by a node to communicate with a destination. Some of the existing on-demand routing protocols are mentioned below:

a) Dynamic Source Routing Protocol [5].
b) Ad-hoc On Demand Distance Vector Routing Protocol [6].
c) Temporally Ordered Routing Algorithm [7].

d) Location Aided Routing [8].
e) Associatively Based Routing [9].
f) Signal Stability-Based Adaptive Routing Protocol [10].
g) Flow-Oriented Routing Protocol [11].

3. Hybrid Routing Protocol

Protocols belonging to this category combine the best features of above two categories. For routing within this zone, a table driven approach is used. For nodes that are located beyond this zone an on-demand approach is used. The protocol belonging to this category is mentioned below:
a) Core Extraction Distributed Ad Hoc Routing Protocol [12].
b) Zone Routing Protocol [13].
c) Zone-Based Hierarchical Link State Routing Protocol [14].

B. Based On the Use of Temporal Information for Routing

This classification of routing protocol is based on the use of temporal information used for routing. The protocols that falls under this category can be classified into two types:

1. Routing Protocols Using Past Information

These routing protocol use information about the past status of the links or the status of links at the time of routing to make routing decisions. The protocol belonging to this category is mentioned below:
a) Destination Sequence Distance Vector Routing Protocol.
b) Wireless Routing Protocol.
c) Source-Tree Adaptive Routing Protocol.
d) Dynamic Source Routing Protocol.
e) Ad-hoc On Demand Distance Vector Routing Protocol.

2. Routing Protocols Using Future Temporal Information

In this, the protocols use the information about the future status of the wireless link to make approximate routing decisions. The protocol belonging to this category is mentioned below:
a) Flow Oriented Routing Protocol
b) LBR [15].
c) RABR [16].

C. Based On Routing Topology

Routing topology being used in hierarchal in order to reduce the state information maintained at the core routers. It can be further divided into two categories:

1. Flat Topology Routing Protocols

Protocols that fall under this category make use of flat addressing scheme similar to the one used in IEEE 802.3 LANs. The protocol belonging to this category is mentioned below:
a) Dynamic Source Routing Protocol.
b) Ad-hoc On Demand Distance Vector Routing Protocol.
c) Flow Oriented Routing Protocol.

2. Hierarchal Topology Routing Protocols

Protocols belonging to this category make use of logical hierarchy in the network and an associated addressing mechanism. The protocol belonging to this category is mentioned below:
a) Cluster-Head Gateway Switch Routing Protocol
b) Fisheye State Routing Protocol (FSR) [17]
c) Hierarchical State Routing Protocol (HSR) [17]

D. Based On the Utilization of Specific Resources

1. Power-Aware Routing

This category of routing protocols aims at minimizing the consumption of a very important resource in the ad-hoc wireless networks: the battery power. The protocol belonging to this category is mentioned below:-
a) Power-aware Localized Routing [18].

2. Geographical Information Assisted Routing

Protocols belonging to this category improve the performance of routing and reduce the control overhead by effectively utilizing the geographical information available. The protocol belonging to this category is mentioned below:
a) Load-aware Routing.

III. Energy Efficient Routing Protocols

There are many different routing protocols which are used to establish a correct and efficient route between a pair of nodes. Since, each node has limited power due to which the selected route cannot remain for a long time so that the source-destination pair can use it for its successful communication. To achieve the goal of getting longer lifetime and successful communication for a network, we should minimize nodes energy not only during active communication but also when they are in inactive state. There are three approaches to minimize energy in which two approaches to minimize the active communication energy are:
a) Transmission power control approach
b) Load distribution approach.

One approach to minimize energy during inactivity [19] is
c) Sleep/Power-down mode.

Before presenting protocols that belong to each of the three approaches, energy-related metrics that have been used to determine energy efficient routing path instead of the shortest one are discussed. They are [20]
i. energy consumed/packet,
ii. time to network partition,
iii. variance in node power levels,
iv. cost/packet, and
v. maximum node cost.

The overall energy consumption for delivering a packet is minimized if we choose a min-power path. The metric, energy consumed/packet is useful to provide min-power path. However, a routing algorithm which uses this metric may result in unbalanced energy spending among mobile nodes. The nodes which are unfairly burdened to support many packet-relaying functions, they consume more battery energy and stop running earlier than other nodes and cause bottleneck for overall functionality of the ad hoc network. Thus, the second metric time to network partition is main goal of an energy efficient routing.

However, it is difficult to calculate the future lifetime of a network, the next three metrics is proposed to achieve the goal of energy efficiency. Variance of residual battery energies of mobile nodes is a simple indication of energy balance and may be used to increase the lifetime of the network. Cost-per-packet metric includes each node's residual battery life with transmission energy. In the last metric, each path candidate is assigned with the maximum node cost among the intermediate nodes and the path with the minimum path cost, min-max path, is selected.

A. Transmission Power Control Approach

The essential work of a routing algorithm is to find an optimal route on a given network graph where a mobile node is represented by a vertex and an edge represents a wireless link between two end nodes that are within each other's radio transmission range. The adjustment of direct communication range and the no. of immediate neighbors depend upon the radio transmission power when a node's radio transmission power is controllable, their direct communication ranges as well as the number of its immediate neighbors are also adjustable. With stronger transmission power, the transmission range increases and the hop count to the destination is reduced. Weaker transmission power makes the topology sparse which may result in network partitioning and high end-to-end delay due to a larger hop count. There has been active research on topology control of a MANET via transmission power adjustment [21]-[23] and the main motto is to maintain a connected topology using the minimal power. Energy efficient routing protocols which are based on transmission power control find the best route so that the total transmission power between a source-destination pair is reduced. 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 energy efficient (min-power) route from S to D is equivalent to finding the least cost path in the weighted graph.

In this category, the following protocols are categorized:-

a) Flow Augmentation Routing (FAR) .
b) Online Max-Min Routing (OMM) .
c) Power aware Localized Routing (PLR).
d) Common Power Protocol (COMPOW).
e) PEER
f) Energy Efficient Location Aided Routing (EELAR).
g) Minimum Energy routing (MER).
h) Lifetime-aware Multicast Tree (LMT) Protocol
i) Lifetime-aware Refining Energy Efficiency of Multicast Trees (L-REMIT).

Since each node runs the routing algorithm, equivalently the graph optimization algorithm, in a distributed way, it must be supplied with information such as the transmission energy over the wireless link (link cost) and the residual battery energy of the node (reciprocal of node cost). The latter is used to balance the energy consumption by avoiding low energy nodes when selecting a route. The main goal of Minimum Energy Routing (MER) protocol [24] is not to provide energy efficient paths but to make the given path energy efficient by adjusting the transmission power just enough to reach to the next hop node. Smallest Common Power (COMPOW) protocol [25] presents one simple solution to maintain bi-directionality between any pair of communicating nodes in a MANET.

1. Flow Augmentation Routing (FAR)

The FAR [26] protocol assumes a static network and finds the optimal routing path for a given source-destination pair that minimizes the sum of link costs along the path. The traffic balance, in turn, can be achieved by selecting the optimal transmission power levels and the optimal route. Given a static network topology, the selection problem turns out to be a conventional maximum flow optimization problem on a graph, where the transmission energy between two neighboring nodes corresponds to the link cost between them. Since there are multiple source-destination pairs with different data generation rates at each source, the solution can be obtained step-by-step with incremental data generation or data traffic. Here, the link cost for link (i,j) is expressed as e_{ij}^x_1E_i^x_2R_i^x_3. where e_{ij} is the energy cost for a unit flow transmission over the link and E_i and R_i are the initial and residual energy at the transmitting node i, respectively, and x_1, x_2, and x_3 are nonnegative weighting factors. A link requiring less transmission energy is preferred. At the same time, a transmitting node with high residual energy that leads to better energy balance is also preferred. Depending on the parameters x_1, x_2, and x_3, the corresponding routing algorithm achieves a different goal. While e_{ij} and E_i are constant for a wireless link (i, j), R_i continues to drop as communication traffic moves on. An optimal solution at one moment may not be optimal at a later time because R_i's and the corresponding links costs have changed. For this reason, FAR solves the overall optimal solution in an iterative fashion: It expends energy of the corresponding intermediate nodes. Then, it augments data traffic at each source and solves the same problem again with the reduced energy reserves. The final and overall routing decision is obtained by repeatedly solving the optimization problem until any node runs out of its initial energy reserves.

2. Online Max-Min Routing (OMM) Protocol

Li et al. proposed the Online Max-Min (OMM) power-aware routing protocol [27] for wireless ad-hoc networks dispersed over large geographical areas to support applications where the message sequence is not known. This protocol optimizes the lifetime of the network as well as the lifetime of individual nodes by maximizing the minimal residual power, which helps to prevent the occurrence of overloaded nodes. The OMM protocol achieves the same goal without knowing the data generation rate in advance. Without requiring that information, the OMM protocol makes a routing decision. It optimizes two different metrics of the nodes in the network: Minimizing power consumption (min-power) and maximizing the minimal residual power (max-min). The second metric is helpful in preventing the occurrence of overloaded nodes. Given the power level information of all nodes and the power cost between two neighboring nodes, this algorithm first finds the path that minimizes the power consumption (P_{min}) by using the Dijkstra algorithm (single-source shortest-path algorithm). This min- power path consumes the minimal power (P_{min}) but it is not necessarily the max-min path. 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}) and selects the best path that optimizes the max-min metric. Among the next power efficient paths with some tolerance (less than zP_{min}, where $z \geq 1$), it selects the best path that optimizes the second metric by iterative application of the Dijkastra algorithm with edge removals.

The parameter z measures the tradeoff between the max-min path and the minimum power path. When z=1, the algorithm optimizes only the first metric and thus provides the minimal power consumed path. When $z=\infty$, it optimizes only the second metric and thus provides the max-min path. Thus, the proper selection of the parameter z is important in determining the overall performance. A perturbation method is used to compute z adaptively. First, it randomly chooses an initial value of z, and estimates the lifetime of the most overloaded node. Then, z is increased by a small constant, and the lifetime is estimated again. The two estimates are compared and the parameter z is increased or decreased accordingly. Since the two successive estimates are calculated during two different time periods, the whole process is based on the assumption that the message distributions are similar as time elapses. Algorithm steps are given below:-

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

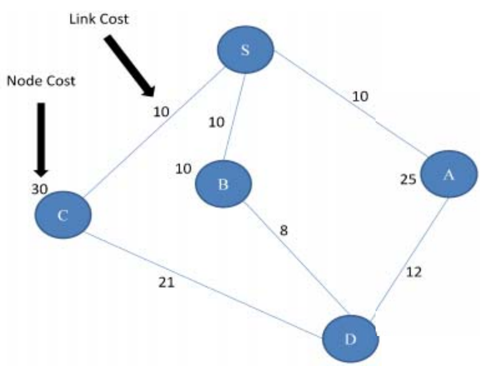

Fig. 1 (a) Min-power path in OMM protocol

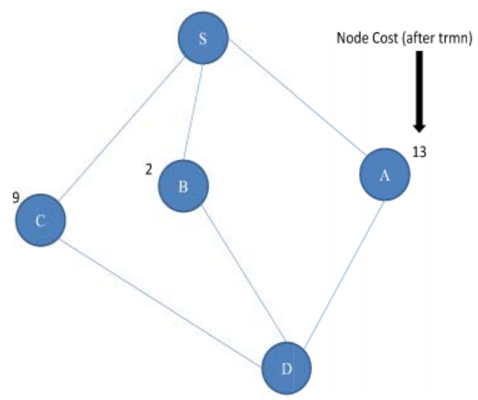

Fig. 1 (b) Max-power path in OMM protocol

OMM requires information about the power levels of all mobile nodes. In large networks, this requirement is not trivial. To improve the scalability, zone-based hierarchical routing mechanism is used. In this routing mechanism the area is divided into a small number of zones. A routing path usually consists of a global path from zone to zone and a local path (just a few hops) within the zone. With the extended OMM protocol, a node estimates the power level of each zone, computes a path across zones, and computes the best path within each zone.

3. Power Aware Localized Routing (PLR) Protocol

Routing algorithms based on global information, such as data generation rate or power level information of all nodes (node costs), may not be practical because each node is provided with only the local information. The PLR protocol [28] is a localized, fully distributed energy aware routing algorithm. The PLR protocol is an algorithm but it assumes that a source node has the location information of its neighbors and the destination. It is equivalent to knowing the link costs from itself to its neighbors and to the destination. Based on this information, the source cannot find the optimal path but selects the next hop through which the overall transmission power to the destination is minimized. A direct communication may consume more energy than an indirect communication via intermediate nodes due to the super-linear relationship between transmission energy and distance. Since the transmission power needed for direct communication between two nodes has super-linear dependence on distance, it is usually energy efficient to transmit packets via intermediate nodes. In Fig. 2, when node A has data packets to send to node D, it can either send them directly to D or via one of its neighbors (1, 2, or 3). Note that A to i is a direct transmission while i to D is an indirect transmission with some number of intermediate nodes between i and D. In order to select the optimal route, node A evaluates and compares the power consumption of each distance is known, i.e., p(d)=ad^ a +c, where a and c are constants, d is the distance between two nodes. It has been shown that power consumption of indirect transmission is minimized when (n-1) equally spaced intermediate nodes relay transmissions along the two end nodes, and the resultant minimum power consumption is q(d)^2. Therefore, the node (A), whether it is a source or an intermediate node, selects one of its neighbors (1, 2, or 3) as the next hop node which minimizes p(|Ai|) + q(|iD|).

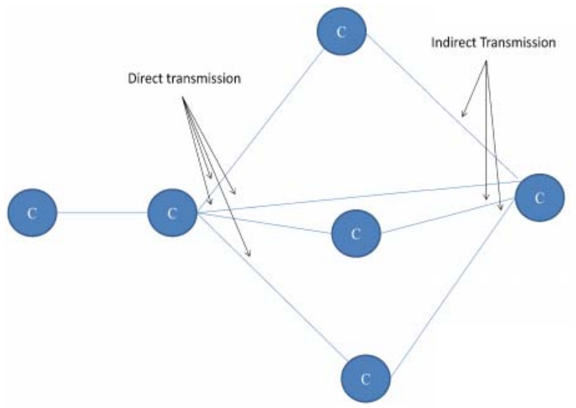

Fig. 2 Selection of the next hop node in the PLR protocol

4. Common Power (COMPOW) protocol

Smallest Common Power (COMPOW) protocol [25] presents one simple solution to maintain bi-directionality between any pair of communicating nodes in a MANET. This is achieved by having all the nodes in the MANET maintain a common transmission power level (Pi). If Pi is too low, a node can reach only a fraction of the nodes in the MANET as in Fig. 3 (a). If Pi is very high, a node can directly reach all other nodes as in Fig. 3 (b) but results in high energy consumption. In fact, a node can directly or indirectly reach the entire MANET with a smaller Pi as shown in Fig. 3 (c).

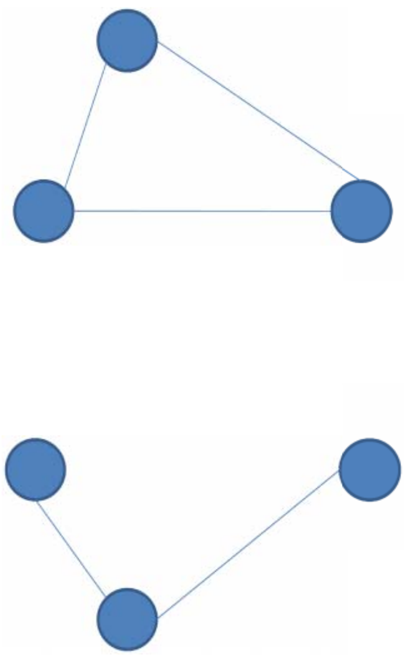

Fig. 3 (a) P_i is too low

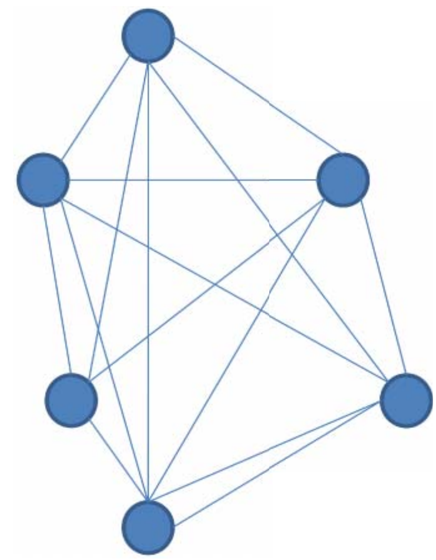

Fig. 3 (b) P_i is too high

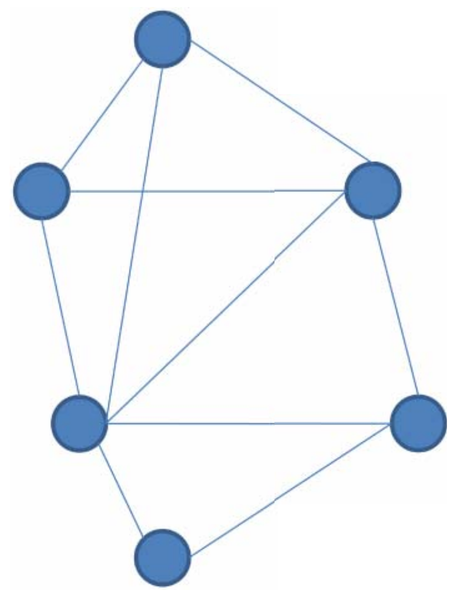

Fig. 3 (c) P_i is optimal

Therefore, the optimum power level (Pi) 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 different 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 power level (RTP_1, RTP_2... RTP_{max}). The number of entries in RTP_i, denoted as $|RTP_i|$, means the number of reachable nodes at Pi. This includes directly connected nodes as well as indirectly connected nodes via intermediate nodes. By exchanging these routing tables, nodes find the minimal Pi that satisfies $|RTP_i|=n$ for all nodes, where n is the total number of nodes in the MANET.

5. Peer Protocol

This protocol [29] proposes a fast route discovery method associated with progressive route maintenance scheme. PEER seeks for set of shortest hop paths available and picks the one implying lowest energy consumption. Packet forwarding is done based on a criterion that the packet comes from a shorter path and consumes least energy. A link cost table is implemented at each node such that a promiscuous node oversees the network transmissions to find a more energy efficient path that could be used. Apart from all other protocols, PEER assumes infinite retransmissions and also reduces the energy consumption overhead implied by the signaling packets sent at a higher power level. Problems associated are the provision for infinite retransmissions and chances of route overutilization resulting in the depletion of node batteries on a specific route. This protocol significantly reduces the average energy required per packet transmission. As the protocol assumes infinite retransmissions, the packet delivery ratio is very high. The best part of this protocol is the contemplation of routing overhead in the best manner and accordingly cutting down the same.

6. Energy Efficient Location Aided Routing (EELAR) Protocol

Energy Efficient Location Aided Routing (EELAR) Protocol [30] was developed on the basis of the Location Aided Routing (LAR) [8]. This is a peculiar approach trying to reduce energy consumption in MANETs. This protocol partitions the whole network area into six sectors assuming a circular space centered by a reference node (base station). Energy efficiency is achieved through the restriction of packet flooding for route discovery onto one sector containing the destination node. Positions of nodes are maintained in a position table. Despite the reduction in control packet overhead, feasibility of this protocol in mobile scenarios is questionable. The need to update position table can incur high energy consumption overheads. Both the average energy consumption and signaling overhead are acceptably reduced in this method. Increased mobility can decline the delivery ratio as packets are targeted for a particular sector of the whole network. In EELAR, a reference wireless base station is used and the network's circular area centered at the base station is divided into six equal sub-areas. During route discovery, instead of flooding control packets to the whole network area, they are flooded to only the sub-area of the destination mobile node. The base station stores locations of the mobile nodes in a position table.

7. Minimum Energy Routing (MER)

Minimum Energy Routing (MER) can be described as the routing of a data-packet on a route that consumes the minimum amount of energy to get the packet to the destination which requires the knowledge of the cost of a link in terms of the energy expanded to successfully transfer and receive data packet over the link, the energy to discover routes and the energy lost to maintain routes [24]. MER incurs higher routing overhead, but lower total energy and can bring down the energy consumed of the simulated network within range of the theoretical minimum the case of static and low mobility networks. However as the mobility increases, the minimum energy routing protocol's performance degrades although it still yields impressive reductions in energy as compared performance of minimum hop routing protocol [31].

8. Lifetime-aware Multicast Tree (LMT) Protocol

The Lifetime-aware multicast tree routing algorithm [32] maximizes the ad hoc network lifetime by finding routes that minimize the variance of the remaining energies of the nodes in the network. LMT maximizes the lifetime of a source based multicast tree, assuming that the energy required to transmit a packet is directly proportional to the forwarding distance. Hence, LMT is said to be biased towards the bottleneck node. Extensive simulation results were provided to evaluate the performance of LMT with respect to a number of different metrics (i.e., two definitions of the network lifetime, the root mean square value of remaining energy, the packet delivery ratio, and the energy consumption per transmitted packet) in comparison to a variety of existing multicast routing algorithms and Least-cost Path Tree (LPT) [33], [34]. These results clearly demonstrate the effectiveness of LMT over a wide range of simulated scenarios.

9. Lifetime-aware Refining Energy Efficiency of Multicast Trees (L-REMIT)

Lifetime of a multicast tree in terms of energy is the duration of the existence of the multicast service until a node dies due its lack of energy. L-REMIT [35] is a distributed protocol and is part of a group of protocols called REMIT (Refining Energy efficiency of Multicast Trees). It uses a minimum-weight spanning tree (MST) as the initial tree and improves its lifetime by switching children of a bottleneck node to another node in the tree. A multicast tree is obtained from the "refined" MST (after all possible refinements have been done) by pruning the tree to reach only multicast group nodes. L-REMIT is a distributed algorithm in the sense that each node gets only a local view of the tree and each node can independently switch its parent as long as the multicast tree remains connected that utilizes an energy consumption model for wireless communication. L-REMIT takes into account the energy losses due to radio transmission as well as transceiver electronics. L-REMIT adapts a given multicast tree to a wide range of wireless networks irrespective of whether they use long-range radios or short-range radios [35], [36].

B. Load Distribution Approach

The specific goal of the load distribution approach 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 (CMMBCR) protocols.

1. Localized Energy Aware Routing (LEAR) Protocol

Local Energy-Aware Routing (LEAR) [37] simultaneously optimizes trade-off between balanced energy consumption and minimum routing delay and also avoids the blocking and route cache problems. LEAR accomplishes balanced energy consumption based only on local information, thus removes the blocking property. Based on the simplicity of LEAR, it can be easily be integrated into existing ad hoc routing algorithms without affecting other layers of communication protocols. In comparison to APR, the LEAR protocol directly controls the energy consumption. The LEAR routing protocol is based on DSR, where the route discovery requires flooding of route-request messages but modifies the route discovery procedure for balanced energy consumption. 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 relay 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). The node forwards the route-request message only when E_r is higher than a threshold value (Th_r) 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 levels, and nodes with low battery levels can conserve their battery power [25]. Thus, the first arriving message is considered to follow an energy-efficient as well as a reasonably short path. Decision-making process in LEAR is distributed to all relevant nodes, and the destination node does not need wait or block itself in order to find the most energy efficient path.

If any of the intermediate nodes along every possible path drops route-request message, the source will not receive a single reply message even though one exists. To prevent this, the source will re-send the same route-request message, but this time with an increased sequence number. When an intermediate node receives the same request message again with a larger sequence number, it adjusts (lowers) its Th_r to allow forwarding to continue.

2. Conditional Max-Min Battery Capacity Routing (CMMBCR) Protocol

As in LEAR, the CMMBCR protocol uses the concept of a threshold to maximize the lifetime of each node and to use the battery fairly. The basic idea behind CMMBCR is that when all nodes in some possible routes between a source and a destination 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 [38] for most nodes will be reduced, and their lifetime will be extended. However, if all routes have nodes with low battery capacity (i.e., below a threshold), routes including nodes with the lowest battery capacity should be avoided to extend the lifetime of these nodes. The battery capacity Rc for route j at time t as

$$R_{j=}^{c} \min_{i \in route\_j} \quad c_i^t \qquad (1)$$

Let A be a set containing all possible routes between any two nodes at time t and satisfying the following equation:

$$R_j^c >= \gamma, \text{ for any route } j \in A \qquad (2)$$

γ is a threshold and ranges between 0 and 100. Let Q denote the set containing all possible paths between the specified source and destination nodes at time t. Then we arrive at:

- If A∩Q≠ ϕ, which implies that all nodes in some paths have remaining battery capacity higher than g, choose a path in A∩Q by applying the MTPR scheme.
- Otherwise, select route i with the maximum battery capacity: R_i^c = max{R_j^c for j∈Q}.

If γ = 0, (2) is always true, and this metric is identical to MTPR. If γ = 100, (2) is always false, and this metric is identical to MMBCR because at this time, routes with less battery capacity will always be avoided. g can be viewed as a protection margin. If some nodes' battery capacity goes below this value, they will be avoided to elongate lifetime. The performance of CMMBCR will therefore depend on the value of γ.

C. Sleep/Power-Down Mode Approach

In sleep/power-down mode approach the main focus is on inactive time of 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, if all the nodes in a MANET in sleep mode and do not listen, packets cannot be delivered to a destination node. The possible solution for this problem is to choose a special node, called a master, which coordinate the communication on behalf of its neighboring slave nodes. Thus, slave nodes can safely sleep most of time saving battery energy. Each slave node periodically wakes up and communicates with the master node to find out if it has data to receive or not but it sleeps again if it is not addressed. This subsection introduces three 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.

1. SPAN Protocol

Span [39] is a fully specified power-save protocol, based on a routing backbone that is a connected dominating set, whose members are called "coordinators". Coordinators are continually in the idle state, whereas non coordinator nodes wake up periodically to exchange traffic with the coordinator nodes and participate in coordinator election. The coordinators act as a low-latency routing backbone for the network and buffer traffic for sleeping destinations, in effect acting as base stations for the non coordinator nodes.

The coordinator election algorithm is structurally similar to the one described above, in that nodes provisionally join the dominating set, then eliminate themselves from it. Nodes periodically exchange HELLO messages to discover their two-hop neighborhood. A node marks itself eligible to be a coordinator if it discovers that two neighbors cannot communicate directly or via other coordinators. Each marked node schedules a back off interval, during which it listens for announcements from other nodes. If the node is still eligible after this interval (i.e., no other suitable coordinators have announced themselves), it sends its own coordinator announcement. The back off interval has both random and adaptive elements. Nodes with greater utility, that is, effectiveness at connecting new pairs of neighbors, and higher energy reserves announce themselves as coordinators more quickly than less effective ones, which volunteer later and only if they are still needed to complete the connected dominating set. After spending some time as a coordinator, a node withdraws as a coordinator, allowing other nodes to consider their eligibility and announce themselves as coordinators. Rotating the coordinator role in this way tends to balance nodes' energy reserves, even in the case of initially unequal distribution.

The coordinators buffer traffic for their sleeping neighbors, using the traffic announcement mechanism of IEEE 802.11. Because coordinators do not sleep, they have no need for the traffic announcement mechanism and a portion of each beacon interval is therefore reserved for traffic between coordinators. The routing protocol is integrated with the coordinator mechanism so that data is forwarded through the coordinator backbone with low latency until it is buffered by the appropriate coordinator for delivery to a sleeping destination.

Span is a synchronous power-save protocol for two reasons. First, nodes must be awake simultaneously to exchange traffic to determine their connectivity and participate in coordinator election—the topology cannot be determined solely by the coordinators. Second, the underlying buffering and traffic announcement mechanism is based on the synchronous IEEE 802.11 power-save mechanism. This is not integral to Span operation, however; some form of asynchronous polling is a possible alternative.

2. Geographic Adaptive Fidelity (GAF) Protocol

Geographic adaptive fidelity (GAF) [40] is a power-save protocol that selects its representative nodes based on position information rather than membership in a dominating set. As defined, GAF is primarily intended for sensor networking scenarios. Nodes that are data sources or sinks do not participate in the power-save protocol, and there is no concept of buffering pending traffic for a sleeping node.

GAF partitions the network using a geographic grid. The grid size is defined such that each node in a grid square is within transmission range of every node in each adjacent grid square, implying a grid size of $R/\sqrt{5}$, where R is the node transmission range. This grid structure ensures that all the nodes in a grid square are equivalent with respect to providing connectivity to any adjacent grid square. One non sleeping node in each grid square is sufficient to maintain the connectivity of the original network. Because connectivity is defined by the grid, selecting the active node for each grid square does not require explicit exchange of connectivity information. Each node transitions independently among three states: sleep, discovery, and active. Nodes periodically wake up from the sleep state and transition to the discovery state. In the discovery state, a node listens for other nodes' announcements and can announce its own grid position ID and residual energy status. If the node hears no "higher ranking" announcement, it transitions to the active state, otherwise it transitions back to the sleep state. A node in the active state is responsible for maintaining network connectivity on behalf of its grid square, periodically announcing its state. After spending some time in the active state, a node transitions back to the discovery state, allowing the active role to be rotated among the nodes in the grid square.

Master election rule in GAF is as follows. Initially, a node is in the discovery state and exchanges discovery messages including grid IDs to find other nodes within the same grid. A node becomes a master if it does not hear any other discovery message for a predefined duration T_d. If more than one node is in the discovery state, one with the longest expected lifetime becomes a master. The master node remains active to handle routing for T_a. After T_a, the node changes its state to discovery to give an opportunity to other nodes within the same grid to become a master. 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 nodes stays within the grid.

The ranking function and state timeouts can be used to tune GAF, trading energy consumption against the risk that there will be no active node in a grid square. The ranking function is used to balance energy consumption among nodes, by preferring nodes with the longest "expected node active time," which is based on the node's residual energy and the length of time it is projected to remain in its current grid square. The sleep intervals are calculated such that nodes are likely to transition from the sleep state to the discovery state in time to replace an active node, if needed.

Currently, the ad-hoc routing protocol operates independently of GAF. This makes it possible to isolate the impact of GAF power saving on routing-protocol performance. It imposes some burden on GAF, because when the active node in grid square changes, the routing protocol interprets this as a route failure from which it must recover. Alternatively, GAF might be more closely coupled with an ad hoc routing protocol by using preemptive route recovery or grid-based forwarding.

3. Prototype Embedded Network (PEN) Protocol

The PEN [41] protocol exploits the low duty cycle of communication activities and powers down the radio device when it is idle. However, unlike SPAN and GAF, nodes interact "asynchronously" without master nodes and thus, costly master selection procedure as well as the master overloading problem can be avoided. But in order for nodes to communicate without a central coordinator, each node has to periodically wake up, advertises its presence by broadcasting beacons, and listens briefly for any communication request before powering down again.

A transmitting source node waits until it hears a beacon signal from the intended receiver or server node. Then, it informs its intention of communication during the listening period of the server and starts the communication.

Route discovery and route maintenance procedures are similar to those in AODV, i.e., on-demand route search and routing table exchange between neighbor nodes. Due to its asynchronous operation, the PEN protocol minimizes the amount of active time and thus saves substantial energy. However, the PEN protocol is effective only when the rate of interaction is fairly low. It is thus more suited for applications involving simple command traffic rather than large data traffic [42].

4. PAMAS Protocol

The PAMAS [43] protocol is based on this principle. PAMAS uses an RTS/CTS-style mechanism with a separate control signaling channel. A node that is waiting to initiate a transmission or is in the process of receiving a transmission causes other nodes to defer their transmissions by generating a busy tone on the control channel. A PAMAS node turns itself off if a neighbor is transmitting and it has no packets to transmit or if it has a packet to transmit, but a neighbor is receiving. The node can determine the duration of the current transmission from information in the control traffic and sleep until the end of the transmission. When the node wakes up, however, it does not have information about the state of the channel. For example, another neighbor may have begun a transmission, in which case the node should go back to sleep. In order to determine the duration of the current transmission, the node transmits a sequence of probe messages and awaits a response on the control channel. Similarly, if the node wishes to transmit; but, another neighbor is now receiving; the node's RTS will evoke a busy tone response indicating the duration of the ongoing transmission. PAMAS is inherently conservative; a node sleeps only if it determines that it is possible to do so without affecting network capacity.

This technique is less applicable to network interfaces with high data transmission rates. If the time required for data transmission is short, then the time and energy required for the network interface to transition to the sleep state and back to the idle state outweigh the possible savings. Examples of low-power, low-data-rate transmitters are most often found in sensor network scenarios, where transmission rates of a few Kbps are not uncommon.

5. Protocol for Unified Multicast through Announcements (PUMA)

PUMA [44] is a protocol that uses simple multicast announcements to elect a core for the group and inform all routers of their distance and next-hops to the core, join, and leave the multicast group. PUMA provides the lowest and a very tight bound for the control overhead compared to ODMRP and MAODV. In other words, the control overhead of PUMA is almost constant node when mobility, number of senders, multicast group size or traffic load is changed. It also provides the highest packet delivery ratio for all scenarios [24]. The mesh constructed by PUMA provides redundancy to the region containing receivers, thus reducing unnecessary transmissions of multicast data packets. PUMA does not depend on the existence of any specific pre-assigned unicast protocol [36].

6. Predictive Energy-efficient Multicast Algorithm (PEMA)

The Predictive Energy-efficient Multicast Algorithm (PEMA) [45] exploits statistical properties of the network to solve scalability and overhead issues caused by large scale MANETs as opposed to relying on route details or network topology. The running time of PEMA depends on the multicast group size, not network size; this makes PEMA fast enough even for MANETs consisting of 1000 or more nodes. Simulation results show that PEMA not only results in significant energy savings compared to other existing algorithms, but also attains good packet delivery ratio in mobile environments. A distinct feature in PEMA is its speed; it is extremely fast because its running time is independent of its network size and the routing decision does not rely on the information about network topology or route details [43].

TABLE I
COMPARISON OF PROTOCOLS

Approach		Protocol	Goal
Minimize active communication energy	Transmission power control	• Flow Argumentation Routing (FAR) • Online Max-Min (OMM) • Power aware Localized Routing (PLR) • PEER • FLR • EELAR • MER • LMT • L-REMIT	Minimize the total transmission energy but avoid low energy nodes.
		• Smallest Common Power (COMPOW)	Minimize the total transmission energy while considering retransmission overhead
	Load distribution	• Localized Energy Aware Routing (LEAR) • Conditional Max-Min Battery Capacity Routing (CMMBCR)	Distribute load to energy rich nodes
Minimize inactive communication energy	Sleep/Power down mode	• SPAN Protocol • Geographic Adaptive Fidelity (GAF) • PEN • PAMAS • PUMA • PEMF	Minimize energy consumption during inactivity.

IV. CONCLUSION

In this paper, we survey the energy efficient routing protocols in MANET and classified them according to the approaches employed by each of them for minimizing the energy consumption. We have also listed and classified them on the basis of the goal to be achieved by each of the approaches. For example, the transmission control should be employed when the communication between the nodes take place at regular intervals whereas the load distribution approach is used where the node density or the traffic density is not uniform and hence we need to employ the equal distribution of load to minimize the energy consumption. The Sleep/Power down approach should be used where the communication between the nodes is low and hence, they can utilize their energy when there is energy imbalance problem. Since energy is a constrained resource in MANET, more research is to be done to find energy efficient protocols.

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