ISSN: 2229-6948 (ONLINE)
DOI: 10.21917/ijct.2010.0006

EVALUATION AND COMPARISON OF EMERGING ENERGY EFFICIENT ROUTING PROTOCOLS IN MANET

Getsy S Sara[1], S.Neelavathy Pari[2], D. Sridharan[3]

Department of Electronics and Communication, CEG Campus, Anna University Chennai, India.
E-mail: getsysudhir@gmail.com[1], sridhar@annauniv.edu[3]
[2]Department of Information and Technology, MIT, Anna University Chennai, India.
E-mail: neela_pari@yahoo.com

Abstract
The routing in Mobile Ad Hoc Network (MANET) consumes huge amount of power and bandwidth and undergoes frequent topology changes to which it must adjust quickly. Energy efficient routing protocols have an important role in MANET. In this survey, few of the emerging energy efficient routing protocols for MANET are reviewed and their performance critically compared. The energy efficient protocols either minimize the active communication energy required to transmit or receive packets or minimize the inactive energy. The classification suggested here summarizes the chief distinctiveness of many published proposals for energy efficient routing. After getting insight into the different emerging energy efficient protocols, the enhancements that can be done to improvise the existing routing protocols are pointed out. The purpose of this paper is to facilitate the research efforts in combining the existing solutions to offer a more energy efficient routing mechanism.

Keywords:
Mobile Ad hoc network, Energy efficient routing, Energy balance, Transmission power control, Energy dissipation rate.

1. INTRODUCTION

Mobile Ad hoc Network (MANET) [1] is a dynamically reconfigurable wireless network with no fixed infrastructure. Each node acts as a router and host and it moves in an arbitrary manner [27]. MANET has recently been the topic of extensive research. The interest in such network stems from their ability to provide temporary and instant wireless networking solutions in situations where cellular infrastructures are lacking and are expensive or infeasible to deploy. Due to their inherently distributed nature, MANETs are more robust than their cellular counterparts against single-point failures and have flexibility to reroute around congested nodes [28]. In many ad hoc networks, each node is powered by a battery and has limited energy supply. Over time, various nodes will deplete their energy supplies and drop out of the network. Unless nodes are replaced or recharged, the network will eventually become partitioned. In a large network, relatively few nodes may be able to communicate directly with their intended destinations. Instead most nodes must rely on other nodes to forward their packets. Some nodes may be especially critical for forwarding these packets because they provide the only path between certain pair of nodes. Associated with each node that depletes its battery and stops operating, there may be number of other nodes that no longer communicate [11]. Energy is scarce by the fact that the devices are mobile *i.e.* they must be small and therefore cannot be fitted with large battery packs. For these reasons a number of researchers have focused on design of energy efficient routing protocols. This paper surveys few of the energy efficient routing protocols. The mechanisms are classified based on whether the routing protocols minimize the active communication energy required to transmit and receive data packets or minimize the energy during inactive periods.

This paper is distributed as follows – In section 2 we have discussed about previous such works. Section 3 gives details about current emerging energy efficient routing protocols. Section 4 analyses and compares the different energy efficient routing protocols. Section 5 summarizes this paper.

2. RELATED WORK

Several simulation based performance comparison have been done for energy efficient routing protocol for MANETs.

Dhiraj *et al.* [3] compared the energy consumption in DSR and AODV and concluded that DSR performed better than AODV if energy consumption only due to routing packets is considered. At low speed DSR performed better while at high speed AODV showed an improvement because at high speed the route cache becomes useless which results in more route discovery in DSR, hence it increases the overheads and energy consumption. Considering the total energy consumed by the nodes when varying the sources, DSR performed better than AODV due to cache. The increment in energy here is due to increase in routing packets which in turn increases with the increase in sources.

Ahvar *et al.* [4] simulated and compared the performance of LAR, DSR and AODV. The key findings from this experiment suggest that LAR is better in energy consumption in high density network. DSR resulted in best energy consumption for low density network. AODV generated higher amount of energy even than DSR in high density network.

Qingting *et al.* [5] suggests that the delivered data packet of AODV is much less than DSDV since nodes in AODV often needs rediscovery. So energy consumption of AODV is more. As the terrain size increases, the efficiency of AODV and DSDV routing protocol decreases. When the number of nodes is constant the cost of exchanging route information in DSDV is close to the cost of route discovery in AODV.

Fu *et al.* [6] describes that proactive protocols are better suited to CBR traffic. Source routing strategy combined with multicasting outperforms proactive and reactive routing strategy in terms of throughput and energy efficiency in mobility scenarios.

The most relevant energy aware routing metrics that are widely used are MTPR (Minimum Total Transmission Power Routing), MBCR (Minimum Battery Cost Routing), MMBCR (Min-Max Battery Cost Routing), CMMBCR (Conditional MMBCR) and MDR (Minimum Drain Rate) [19].

The MTPR and MBCR [2] mechanism uses a simple energy metric, represented by the total energy consumed to forward the information along the route. This way, MTPR reduces the overall transmission power consumed per packet, but it does not affect directly the lifetime of each node. Let $c_i(t)$ be the battery capacity of node n_i at time *t* and $f_i(t)$ be the battery cost function of node n_i. The less capacity a node has, the more reluctant it is to forward the packets. The proposed value is $f_i(t) = 1/c_i(t)$. The metric that minimizes this function to forward a packet is called MBCR. If only the summation of battery costs on a route is considered, a route containing nodes with little remaining battery capacity can be selected. MMBCR [2] defines the route cost as: $R(r_j) = \max_{n_i \in r_j} f_i(t)$ [19]. The desired route r_0 is obtained so that $R(r_0) = \min_{n_i \in r_j} R(r_j)$, where r_x is the set of all possible routes. Because MMBCR considers the weakest and crucial node over the path, a route with the best condition among paths impacted by each crucial node over each path is selected.

CMMBCR metric (Conditional MMBCR) [2] attempts to perform a hybrid approach between MTPR and MMBCR, using the former as long as all nodes in a route have sufficient remaining energy (over a threshold) and the latter when all routes to destination have at least a node with less energy than the threshold. Power saving mechanisms based only on the remaining power cannot be used to establish the best route between source and destination nodes. If a node is willing to accept all route requests only because it currently has enough residual battery capacity, too much traffic load will be injected through that node. In this sense, the actual drain rate of power consumption of the node will tend to be high, resulting in an unfair sharp reduction of battery power [19].

To address the above problem, the MDR [2] mechanism can be utilized with a cost function that takes into account the Drain Rate index (DR) and the Residual Battery Power (RBP) to measure the energy dissipation rate in a given node [19]. In this mechanism, the ratio RBP_i / DR_i, at node n_i, indicates when the remaining battery of node n_i will be exhausted, i.e., how long node n_i can keep up with the routing operations under current traffic conditions. The corresponding cost function can be defined as: $C_i = RBP_i / DR_i$. Therefore, the maximum lifetime of a given path r_P is determined by the minimum value of C_i over the path. Finally, the MDR mechanism is based on selecting the route r_M, contained in the set of all possible routes r_x between the destination, having the highest lifetime value [19].

3. EMERGING ENERGY EFFICIENT ROUTING PROTOCOLS IN MANET

3.1 SPAN-AFECA – AODV ROUTING PROTOCOL

Mads *et al.* suggests an energy efficient MANET routing using a combination of span and AFECA [7]. Span [8] is a power save approach based on the notion of Connected Dominating Sets (CDS). As illustrated in figure 1, the CDS is a connected set of nodes from which all other nodes in the network can be reached. The nodes in the CDS (also called as co-coordinators) are placed to act as routers for the entire network. Span merely provides an intelligent way of selecting a CDS of coordinators by running a Distributed Coordinator Selection Withdrawal algorithm. Coordinators are selected based on the utility and residual battery capacity of the node. Once the CDS have been found a power save algorithm must be utilized to do the actual conservation of power. The power save method called AFECA [9] is tailored here to work together with Span so that only non coordinator nodes participate in the power saving scheme [7]. Adaptive fidelity energy conserving Algorithm's (AFECA) approach entails dynamically switching the nodes between sleeping, listening and active states. The nodes switch between these states with fixed interval. In order to ensure successful forwarding of messages, the active nodes may have to retransmit messages a number of times before the receiving node is listening or active. AFECA takes node density into consideration when determining the length of the interval in which a node may sleep. Span – AFECA is a purely power saving algorithm and not routing protocol. So they have to be combined with some existing MANET routing protocol. A reactive routing protocol like AODV [10] is well suited for this purpose since the periodic control messages sent in a proactive protocol would keep the nodes awake even in low traffic scenario. AODV is modified here so that only the coordinators would forward the RREQ messages [7].

On simulation it is found that the nodes running the SPAN/AFECA power saving scheme on top of AODV used only 80% of energy reserve as compared with pure AODV. Thus energy saving is achieved here. The downside of this protocol is the packet loss incurred. Two reasons for packet loss are that the receiving node would be sleeping when the packet arrives and the packet collision occurs because a lot of extra packets are sent. High amount of traffic kills energy efficiency and hence degradation in performance occurs when traffic increases. The delivery ratio of SPAN/AFECA – AODV protocol was only 66.5% while that of AODV protocol was 76.5%.

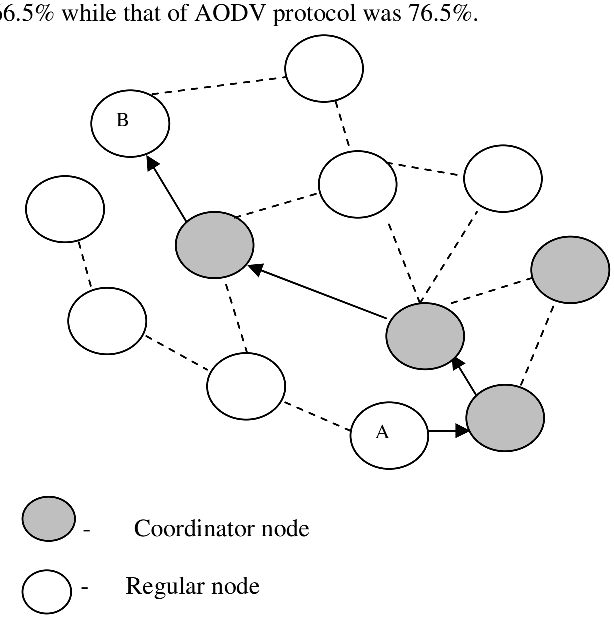

Fig.1. Span's routing backbone of coordinator nodes

Designing an adaptive routing protocol i.e. routing protocols that are able to switch energy efficiency on and off, depending on current network load could enhance the performance of this protocol.

3.2 MAXIMAL MINIMAL NODAL RESIDUAL ENERGY AD HOC ON DEMAND MULTIPATH DISTANCE VECTOR ROUTING PROTOCOL (MMRE–AOMDV)

Yumei *et al.* designed a multipath routing protocol [11] for node battery limited and highly dynamic ad hoc networks where link failures and route breaks occur frequently. When a single path on-demand routing protocol, such as AODV is used in such networks, a route rediscovery is needed in response to every route break. Each route discovery is associated with high overhead and latency. This inefficiency can be avoided by having multiple redundant paths [11]. Now, a new route discovery is needed only when all paths to the destination break. The main idea of MMRE-AOMDV is to balance nodal energy consumption in order to prevent the critical nodes depleting their energy supplies and dropping out from the network. If there are critical nodes which depletes their energy supplies, the network will eventually become partitioned, and there may be a number of energy available nodes that can no longer communicate.

The MMRE-AOMDV protocol uses routing information already available in the underlying AOMDV protocol. Thus little additional overhead is required for the computation of maximal minimal nodal residual energy in the route [11]. The two main components of this protocol are finding minimal nodal residual energy of each route in the route discovery process and sorting multi-route by descending nodal residual energy and using the route with maximal nodal residual energy to forward data packets.

MMRE-AOMDV outperforms AOMDV protocol in packet delivery ratio because it can balance the traffic load among different nodes depending on their nodal residual energy. MMRE-AOMDV gets nearly 20% higher lifetime than AOMDV. It has smaller number of nodes that die (nearly 40% shorter) than AOMDV. So MMRE-AOMDV performs better than AOMDV in balancing battery utilization to prolong nodal lifetime.

Implementing some power saving techniques to increase the residual energy can increase the performance of the protocol. Cooperating with MAC layer power control technique can decrease the network's energy consumption further.

3.3 MULTIPATH ENERGY AWARE DSR (MEA-DSR)

Florina *et al.* proposed the MEA-DSR protocol [12] as an extension to the DSR protocol. Here the Route Discovery mechanism of DSR (Dynamic Source Routing) [13] was modified to implement a multipath and energy aware routing. A caching update mechanism through probe packets was included to have 'always' updated information in routing cache and a simple round robin data scheduling among multiple selected routes was implemented in order to balance the traffic load and the energy consumption. With the purpose of having all possible paths between a source-destination pair, the destination replies to all RREQs that arrive and the source stores all the paths of received RREPs. Among all the stored paths only the node disjoint routes are considered [12]. The paths are ordered by an energetic metric. The energy metric used here is the cost function of the entire path. It is computed while the RREP crosses the network from source to destination and it is sorted in the routing table at the source. The value of this metric is updated for all stored path using cache mechanism. Two paths are considered disjoint if their intersection is empty. Spreading the traffic among multiple routes improves balancing, alleviates congestion, bottlenecks and prolongs connection's lifetime, thereby saving more energy. So multipath routing is utilized here.

It was observed that the MEA-DSR wastes less energy compared with MDSR (Modified DSR) and DSR due to round robin scheduling. The data packet delivery ratio is 90% for MEA-DSR, 85% for MDSR and 80% for DSR. The end to end delay is the least for MEA-DSR due to which it has prolonged connection lifetime.

The disadvantage of this protocol is that the overhead is big thereby increasing the energy consumption. MDSR outperforms MEA-DSR in terms of average energy and residual energy.

3.4 SCORE BASED CLUSTERING ALGORITHM (SBCA)

Sahar *et al.* proposed a new energy efficient clustering algorithm called SBCA [14] which is based on the score values. The score values are determined by considering battery remaining (Br), number of neighbors (Nn), number of members (Nm) and stability(S).The SBCA selects the cluster heads based on the information of the neighbor nodes and maintains clusters locally. The node with the highest score is chosen as the cluster head. The score is calculated using the formula:

$$\text{Score} = (Br*C1)+(Nn*C2)+(S*C3)+(Nm*C4) \quad (1)$$

Where C1, C2, C3, C4 are the score factors for the corresponding system parameters.

SBCA performed better than the other clustering methods when the node density and node mobility are made high. In the clustering methods defined earlier, as the mobility of node increases, the number of cluster increases and the nodes consume more battery power thereby minimizing the lifespan of nodes. In SBCA, even if the node density is increased, cluster size is not varied much. Thus the consumption of energy by SBCA is less.

The disadvantage of SBCA is that due to node mobility and node join and leave events, the network is subject to frequent topological reconfigurations. Thus links and clusters are continuously established and broken. This process results in excessive overhead and cluster head change which degrades the performance of the whole network.

The network dynamics and topography changes in physical layer can be fully subjugated in network layer cluster formation to achieve better energy efficiency and sturdiness against topological changes.

3.5 CROSS LAYER CLUSTER BASED ROUTING PROTOCOL (CBRP)

In the cross layer design approach [15] proposed by Arash Dana, cluster formation mechanism and cluster maintenance are considered with respect to the proportional mobility of the node with its neighbors. The aggregate local mobility value is considered as the metric. As per this scheme, a node with lowest mobility and movement in the pre-specified period of time will be named cluster head. Cluster head stabilization is achieved on using this protocol so that the network will not suffer from cluster tumbling and local destruction in addition to overheads caused by that. The aggregate local mobility value MY at any node Y is obtained by calculating the variance of the entire set of relative mobility samples (MYrel(Xi)), where Xi is a neighbor of Y. MYrel(Xi) is considered as a mobility characteristic of a node with respect to its neighbors. Every node is able to calculate MY just from comparison between received powers of 'hello' packets in successive periods of time as illustrated in figure 2 [15].

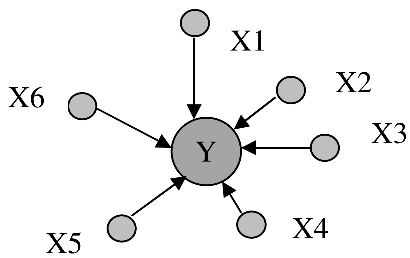

Fig. 2. 'HELLO' packet reception at Y from neighbor

Aggregate local mobility of nodes will be included in the advertising packets and broadcasted to neighbors in addition to node ID. This algorithm is distributed. Thus a node receives the MY values from its neighbors and then compares them with its own. If a node has the lowest value of MY amongst all its neighbors, it assumes the status of cluster head. Then this node broadcasts a 'hello' packet to introduce itself as cluster head. If in case the mobility metric of two cluster head nodes are the same, and they are in competition to retain the cluster head status, then the selection of the cluster head is based on the Lowest ID algorithm in which the node with the lowest ID gets the status of cluster head. If a node with cluster member status and low mobility moves into the range of another cluster head with higher mobility, re-clustering will not be triggered [15].

Simulation results have shown that packet delivery ratio of cross CBRP performs 9% better than the CBRP [16] because of cross layer adaptation technique. Protocol overhead is decreased here because the cluster reformation is decreased, thereby reducing energy consumption.

End to end delay is high. Energy saving techniques can be utilized here to reduce energy consumption. Other parameters from the physical layer such as channel state can be used to provide more reliable adaptive clustering protocols with lesser energy consumption.

3.6 EFFICIENT HYBRID ROUTING PROTOCOLS FOR MANET (MEHRP)

Subha *et al.* proposed the MEHRP [17] which is a modified version of Hybrid Adaptive Routing Protocol for MANET (MHARP) with zone radius selection extension and direction dependent border casting. In this protocol two modules are used; Local routing (Intra zone) and Global routing (Inter zone). It is assumed here that the largest part of the traffic is directed to nearby nodes and the reactive routing like AODV, DSR etc. are employed to route the packets to the nearby nodes. This achieves the Intra zone routing. For inter zone routing, MDREAM (Modified Distance Routing Effect Algorithm for mobility) [18] is used. In MDREAM the sender S of a packet with destination D will forward the packet to all one hop neighbors that lie in the distance'd'. In order to determine the direction, a node calculates the region that is likely to contain D, called expected region so that it will reduce the redundant data forwarding. By using the intrazone routing, packet delivery ratio is increased and flooding of data packets is avoided. The end to end delay for making long route in reactive routing is high. So it is better to confine reactive routing to small zone. Zones will be selected depending on the traffic and the mobility pattern of the mobile nodes to reduce the overhead. For routing nearby nodes using DREAM, frequent location update is needed, which is more power consuming than establishing a route in reactive routing. So the Intra zone module uses reactive routing due to which the transmission becomes easier and it will save power to a greater extent. MDREAM doesn't require appropriate location information of each node. This not only saves the power of mobile nodes but also other network resources. A combination of these two algorithms helps to save power to a greater extent. This protocol is scalable to network size as it divides the whole network into small zones and reacts accordingly. It reduces congestion and overhead related to hierarchical protocols. MEHRP reduces the traffic amount as compared to pure reactive routing protocols.

The constraint of having uniform zone radius (distance 'd') for all nodes may not be desirable. Having independently sized routing zones capability within the zone routing framework would allow nodes to dynamically and automatically configure their optimal zone radii in distributed fashion thus making the protocol more flexible.

3.7 ENERGY EFFICIENT OPTIMIZED LINK STATE ROUTING (EE-OLSR)

Floriano *et al.* proposed a modification in the Multipoint Relays (MPR) [19] selection mechanism of OLSR [20] in order to prolong the network lifetime without losses of performance.

The key concept used in OLSR is that of Multi Point Relays (MPRs). Figure 3 [19] shows the MPRs as selected nodes which forward broadcast messages during the flooding process. In OLSR, link state information is generated only by the nodes elected as MPRs. An MPR node may choose to report only links between itself and its MPR selectors. This information is used for route calculation. OLSR provides optimal routes in terms of number of hops [19].

The EE-OLSR used three mechanisms to achieve the energy efficiency: EA-Willingness Setting Mechanism, Overhearing exclusion and energy aware packet forwarding Minimum Drain Rate metric. The Energy Aware Willingness Setting is a mechanism to involve energetic considerations in MPR selection. Each node calculates its own energetic status and declares an appropriate willingness. Willingness selection depends on battery capacity and energy drain rate of a node. The heuristic used to associate a willingness i.e. 'default', 'low', or 'high' to a pair 'battery', 'lifetime' decides the MPR.

After the MPR election the next hop for data packet forwarding is selected using the Minimum Drain Rate metric. The next step is the overhearing exclusion which is turning off the device when a unicast message exchange happens in its neighborhood. This can save a large amount of energy.

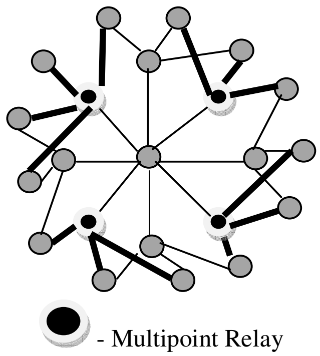

Fig.3. MPR election in EE-OLSR Protocol

The pros of this protocol are that the nodes with residual energy are not stressed. Usage of an energy aware willingness selection extends the lifetime of network. Without the overhearing energy consumption the energy in the network is consumed very slowly, allowing the nodes to send and receive the packets for a longer time. It was observed that EE-OSLR outperforms OSLR in terms of throughput, average nodes lifetime, connection expiration time and preserving the normalized control overhead. The higher bandwidth requirements and extra overhead due to constant route updates makes this method less efficient when compared with other reactive protocols.

3.8 E-AODV AND F-AODV: ENERGY BASED ROUTING OPTIMIZATION

3.8.1 E-AODV:

It [21] is an energy consumption rate–based mechanism that aims to maximize the network lifetime and enhance the performance obtained by the basic AODV routing algorithm. It routes the packets through nodes that is expected to have better residual lifetime among all possibilities. Lamia described a new framework to compute a novel metric called energy consumption rate which reflects how fast a node is consuming its remaining energy. This metric takes into account by nature the traffic load in the node and its contribution on the data forwarding process in the network. Few modifications are made in the AODV routing protocol in order to make it energy aware by considering the above given metric. This scheme is classified as source initiated and network assisted technique.

3.8.2 F-AODV:

It [21] is a cross-layer forwarding strategy, which is based on the cooperation between MAC and routing protocol. The proposal aims to minimize the number of Forwarding Nodes (FN) by hop, in the network. By this way, the contention amount is decreased and the medium utilization is improved. The selection of FN is based on maximum battery level and queue occupancy. This information is injected into routing requests and replies, across nodes in the network. Then each node is able to select the FN that will participate in path establishment. In order to maintain a fair node capability, the forwarding procedure is dynamically distributed and assigned to nodes in the network. This cross-layer mechanism demonstrates a good performance in terms of throughput that can be significantly improved. Moreover, it achieves a high degree of fairness among applications.

It is observed that F-AODV outperforms both AODV and E-AODV in high node density. The improvement achieved by F-AODV, compared to AODV, is about 9% at low node density and about 14% at high node density. Due to load balancing effect triggered by the features of the algorithm that uses E-AODV and F-AODV, their associated performance remains significantly high compared to AODV protocol. This indicates the robust nature of the protocols and their ability to adapt themselves to increasing load. F-AODV and E-AODV have a lower overhead in terms of bytes compared to AODV protocol. This is due to high reactiveness of F-AODV and E-AODV to link changes compared to AODV, induced by congestion and energy exhaustion. E-AODV has the minimum routing overhead. In terms of delay, E-AODV performs better. F-AODV and E-AODV shows significantly lower delay compared to the AODV at high congested network. Route failure due to power exhaustion and node congestion are avoided using F-AODV and E-AODV. When considering low loaded network and stable nodes, the basic AODV performs better than F-AODV and E-AODV. Complexity of the architecture makes this technique expensive and inefficient. Future work can be towards reducing the complexity of the architecture.

3.9 ENERGY LEVEL BASED ROUTING PROTOCOL (ELBRP)

La *et al.* proposed the Energy Level Based Routing Protocol [22] that is based on request delay mechanism and the node’s left out energy. The main idea of ELBRP is that during routing, forward decisions should be based on each node’s energy level. The idea of request-delay mechanism is as follows [22]: Consider a node that is not the destination node or which does not have the route to the destination in its route table or route cache. The node first holds the packet for a period of time which is inversely proportional to its current energy level, that is, the higher the energy levels of a node, the shorter delay time it holds. After this waiting period, the node then forwards the request packet to its neighbors. This delay mechanism is motivated by the fact that each node accepts only an earlier request packet and discards later duplicate requests.

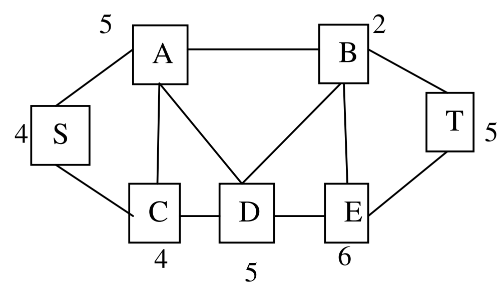

Fig.4. An Example network

With the delay mechanism, request packets from nodes with lower energy levels are being transmitted after a longer delay to the neighborhood, thus they are more likely to be discarded than the packets from nodes with higher energy. This route discovery procedure continues until a destination node receives the first request packet whose recorded routes may constitute nodes with higher energy levels. For example, consider an ad hoc network in Figure 4 [22], where the energy level of each node is shown with a number. The route for communication from node S to node T may be the path (S, A, D, E, T) if the request-delay mechanism is used instead of the shortest paths (S, A, B, T), since nodes may delay forwarding the packet more than others due to their low energy levels. The intuition behind this protocol is to enable those request packets that traverse nodes with higher energy levels to arrive at the destination earlier. It is not necessary to make delay function at every energy level. The node energy level is classified into four phases: $[0, \gamma]$, $[\gamma, \beta]$, $[\beta, \alpha]$, $[\alpha, 1]$, which map the four states: very danger, danger, sub safety and safety. The delay function is adopted in the sub safety state ($[\beta, \alpha]$) and make node sleep in the very danger state ($[0, \gamma]$), for the other two states there is no delay function as in the case of original forward strategies of AODV. The value of γ is chosen very small for a better loss ratio and routing load and the value of α is chosen relatively higher for a better load balance on energy consumption. The node is classified into five states: transmitting, receiving, listening, sleep and dead.

When the left out energy of a node is equal to zero, the node in the dead state is automated. The sleep nodes are wakened at the time when they are the destination nodes or there is only one route to the destination and the sleep nodes are just the middle nodes of the route [22].

ELBRP has lower energy consumption than AODV. The routing protocol not only makes the system energy consumption low but also prolongs the system lifetime and improves the delay characteristic. Extension of this work can be carried out to achieve QoS routing, energy aware multicast and any cast routing in mobile ad hoc networks

3.10 ENERGY EFFICIENT ROUTING BASED ON REINFORCEMENT LEARNING (RL)

Usaha *et al.* proposes an energy–efficient path selection algorithm [23] which aims at balancing the contrasting objectives of maximizing network lifetime and minimizing energy consumption routing in mobile ad hoc networks (MANETs). In this method, information on the residual battery and the energy consumption required to forward a packet are referred to as a state. Based on its current state, each source node acts as an agent which must make certain decisions (i.e. take actions), such as, which path it should select to achieve the best long-term performance. It is assumed that the future state (the energy consumption and the residual battery) depends only on the current state and not on its past and it is possible to roughly model the state transitions as a Markov process [23]. Therefore, the path selecting problem in MANET is modeled as a Markov Decision Process (MDP), whose goal is to optimize the performance criterion in finite horizon. Reinforcement Learning (RL) [24] is a computational approach used to solve MDPs by identifying how a system in a dynamic environment can learn to choose optimal actions to achieve a particular goal.

Due to the episodic nature of the MANET, reinforcement learning method based on sample episodes, called the On-policy Monte Carlo (ONMC) method is employed [24]. This method requires sample episodes to estimate the action-value functions ($Q(s, a)$, $\forall s \in S$, $\forall a \in A$) which quantizes the average amount of cost an agent can expect to accumulate in the long run from that state-action pair. These action-value functions are computed from average sample returns received from the environment operating within a fixed decision rule called policy ($\pi: S \rightarrow A$). The ONMC method learns incrementally on an episode-by-episode basis, meaning that the action-value functions are estimated and policies are improved after each episode.

Simulation results show that the proposed RL framework maintains a high ratio of successfully delivered packets using low network energy consumption over all other algorithms like MMBR, MTPR etc. The method also has the most alive nodes which prolongs the network connectivity in the long run. In terms of the long-term cost, which takes into account the network lifetime, ratio of successfully delivered packets, network energy consumption and the alive nodes, the RL outperforms other algorithms. These results suggest that the RL framework can learn to attain good energy-aware routing decisions [23].

3.11 MINIMIZING THE MAXIMUM USED POWER ROUTING METHOD (MMPR)

Kwang *et al.* proposes MMPR [25], a new energy aware routing method that can optimize two objectives, i.e. minimize the total energy consumption and fair distribution of using energy between nodes. The route metric of MMPR is used energy. If one node has multiple routes for a certain destination, MMPR evaluate a route cost as energy consumption of each path, and selects a route that minimizes route cost. The route cost evaluation of MMPR was applied to DSR in route search and selection procedures. A start node of DSR searches a route to a destination to communicate with a destination node. This route searching process is done by Route Request (RREQ) message. When a node receives RREQ message from others, it calculates the cost to communicate through that node. This cost of node is used in evaluating the cost of the route and expressed as the following equation [25].

$$\mathrm{Cost}(N_i) = (E_c + E_{tx} + E_{rx} + (N-1)E_o) + (T \max[0, E_c + E_{tx} + E_{rx} + (N-1)E_o - \alpha]) \quad (2)$$

where E_c is the used energy at current node, E_{tx} is the energy required for transmitting to the next node, E_{rx} is energy required for receiving from neighbor nodes, E_o is the energy used in overhearing, α is the used energy of a which has least remaining energy in certain route, and N is the number of neighbors at the current node.

The equation (2) optimizes two objectives concurrently. The first term, $(E_c + E_{tx} + E_{rx} + (N-1)E_o)$ expresses the increase of expected used energy by including the current node which has current used energy E_c. A route that has less expected used energy by this term is selected. So the first term achieves the optimization objective of minimizing the total energy. As the first term means the expected used energy, the second term of (2) can be expressed as $T \cdot \max[0, \text{Expected Used Energy} - \alpha]$. It represents the increase of the maximum used energy, α, by including current node. If the expected used energy is less than the current maximum used energy α, the second term goes to 0 and the route cost is only added by the first term. When the expected used energy is higher than α, the second term is added to the route cost by T times. It represents an optimization of route for minimizing the maximum used energy, and so one can avoid a node that is over exhausted by including the second term in route cost computation. Therefore, the second term fulfills the optimization objective of fair distribution of using energy to each node in a network. As a result, an optimized route that balances both optimization objectives can be selected. MMPR update a route cost for every packet transmission, but it uses the energy information included in RREP which was received in a route request and not the current energy state of intermediate nodes. The updated route cost is not an exact value, and some difference can exist. But MMPR does not require additional energy information to be delivered periodically. The procedures of updating a route cost for every packet transmission are only performed in a source node, and there is no overload in intermediate nodes and destination node. When MMPR is implemented with DSR, a source node saves used energy value and energy required to transmit once, collected from intermediate nodes in the received RREP, to a route cache.

MMPR provides the lower maximum used energy by all times, compared with CMMBCR [2]. The number of dead nodes in MMPR is noticeably less than CMMBCR. Using DSR as a routing protocol for MMPR makes the performance improvement by rerouting less effective because DSR returns an alternative route that contains duplicated nodes that were used in previous routes. For further study, it is required that an additional consideration about overhearing circumstance to improve overall performance of energy aware routing be done. And it is also required that further experiments can be done using other ad hoc routing protocols rather than DSR [25].

4. ANALYSIS AND COMPARISON

Energy Efficient Routing Protocols in MANET can be broadly categorized based on when the energy optimization is performed [26]. Table 1 gives the taxonomy of the emerging energy efficient routing protocols. A mobile node consumes its battery energy not only when it actively sends or receives packets but also when it stays idle listening to the wireless medium for any possible communication requests from other nodes. Thus, energy efficient routing protocols must minimize either the active communication energy required to transmit and receive data packets or the energy during inactive periods. For protocols that belong to the former category, the active communication energy can be reduced by adjusting each node's radio power just enough to reach the receiving node but not more than that. This transmission power control approach can be extended to determine the optimal routing path that minimizes the total transmission energy required to deliver data packets to the destination. For protocols that belong to the latter category power save approach can be used. Each node can save the inactive energy by switching its mode of operation into sleep/power-down mode or simply turn it off when there is no data to transmit or receive. This leads to considerable energy savings, especially when the network environment is characterized with low duty cycle of communication activities. However, it requires well-designed routing protocol to guarantee data delivery even if most of the nodes sleep and do not forward packets for other nodes. Another important approach to optimizing active communication energy is load distribution approach. While the primary focus of the above two approaches is to minimize energy consumption of individual nodes, the main goal of the load distribution method is to balance the energy usage among the nodes and to maximize the network lifetime by avoiding over-utilized nodes when selecting a routing path. Energy efficient design is a new area of research that is investigating approaches to save battery life [26].

The Energy efficiency analysis is done based on the following metrics:

- Packet Delivery Ratio: It is defined as the ratio of the data packets delivered to the destination to those generated by the source.

Table 1. Cataloging of the Emerging Energy Efficient Routing Protocols

APPROACH		PROTOCOLS	GOAL
Minimum active communication energy	Transmission power control	MEA-DSR [12] Cross layer CBRP [15]	Minimize the total transmission energy but avoid low energy nodes
	Load Distribution	MMRE-AOMDV [11] MEHRP [17] E-AODV & F-AODV [21] ELBRP [22] MMPR [25]	Balance the energy usage among the nodes and to maximize the network lifetime by avoiding over utilized nodes when selecting a routing path.
Minimum inactivity energy	Power save	SPAN-AFECA-AODV [7] EE-OLSR [19]	Save the inactivity energy by switching the nodes mode of operation into sleep and power down mode.
	Energy efficient design	SBCA [14] Reinforcement Learning [23]	Save the battery life via coding and modulation scheme

- Network Lifetime: It is defined as the duration from the beginning of the simulation to the first time a node runs out of energy.
- Routing Overhead Ratio: It is the ratio of the number of control bytes and the total number of bytes transmitted by the network.
- Energy Dissipation Rate: It determines how long a node can keep up with the routing operations with current traffic conditions based on residual energy.
- End to end delay: It is the average delay time of all successfully delivered packets.

Table 2 gives the comparison of few of the emerging energy efficient routing protocols. A combination of power saving method along with a reactive routing protocol [7] boosts the energy efficiency of a routing protocol but it is observed that at high traffic, this protocol degrades the performance of the network due to evident packet loss. If the routing protocols are able to switch on and off depending on the current network load, better performance could be achieved. Multipath routing is regarded as appealing for ad hoc networking because it can provide fault tolerance. The application of back-up routes reduces packet loss and guarantees longer duration of the communication session and provides robustness to mobility and fading. Moreover, dispatching the data packets of each flow through many network nodes along different paths can lead to better distribution of the traffic load as demonstrated [29] in the study of Florina et al. [12] and as a consequence to more even distribution of the residual energy. Although multipath routing can positively influence the energy consumption in the network, total overhead and packet disorder increases when load balancing is implemented in the mobile ad hoc network routing protocols.

Table 2. Comparison of the Various Emerging Energy Efficient Routing Protocol

Energy Efficient Routing Protocols	**Philosophy**	**Delivery Ratio**	**Life Time**	**Energy Dissipation Rate**	**Overhead Ratio**	**End to End Delay**	**Energy Reserve**	**Multipath**
SPAN-AFECA-AODV [7]	Flat Reactive Routing	Low	Good	High	Low	Less	Supplementary	No
MMRE-AOMDV [11]	Flat Reactive Routing	High	Very Good	High	Low	Less	Satisfactory	Yes
E-AODV & F-AODV [21]	Flat Reactive Routing	High	Good	Low	Very Low	Very Less	Satisfactory	No
MEA-DSR [12]	Flat Reactive Routing	Low	Good	Low	Low	Very Less	Less	Yes
MMPR [25]	Flat Reactive Routing	Low	Good	High	Low	Less	Supplementary	No
EE-OLSR [19]	Flat Proactive Routing protocol	High	Very Good	High	High	High	Satisfactory	No
SBCA [14]	Hierarchical Routing	Low	Good	Uniform	High	Less	Satisfactory	No
Cross layer CBRP [15]	Hierarchical Routing	High	Good	Uniform	Very Low	High	Satisfactory	No
MEHRP [17]	Geographic Position Assisted Routing	High	Very Good	Low	Low	Very Less	Supplementary	No
ELBRP [22]	Energy Aware Routing	Low	Good	Low	Low	Less	Satisfactory	No
Reinforce-ment Learning [23]	Energy Aware Routing	High	Good	Low	Low	Less	Satisfactory	No

Energy efficient clustering routing protocols [14] performs better than the clustering routing protocols when node density and node mobility are made high. Protocol overhead which is the main constraint of clustering routing methods could be minimized as seen in the work of Arash [15]. Introduction of zonal routing technique along with reactive routing by Subha *et. al.* [17] reduces traffic amount, congestion and overhead thereby saving power as compared to pure reactive routing protocols. Usage of energy aware willingness selection algorithm [19] to the existing proactive algorithm improves the throughput, average nodes lifetime and connection expiration time. Cross layer mechanism i.e. cooperation between MAC and routing protocol [21] when applied to the reactive routing protocol enables to achieve robust protocols that are able to adapt themselves to increasing load. But when considering low loaded network and stable nodes, the basic reactive routing protocol performs better. The protocols denominated as energy-aware usually take into account only energy-wise metrics and no other parameters. An improvement on this general approach is the inclusion of the speed with which the battery is burned. Energy level based routing protocols that is based on request delay mechanism [22] prolongs the network lifetime, improves delay characteristic and makes the system energy consumption low when compared with primitive routing protocols. Employing reinforcement learning method [23] helps to achieve good energy aware routing decision. Although the results in the consulted research papers always show an improvement of the energy efficiency, they can never be considered the most energy efficient routing protocol because they are usually compared with proposals that do not contemplate all energy metrics.

5. CONCLUSION

The recent research efforts have made a big progress on MANET routing, both in theory and practical implementation. Achieving energy efficiency is one of the main issues in MANET's routing protocols. In this article, a comprehensive survey of energy efficient routing techniques in MANET that have been presented in the literature is discussed. These routing protocols are modifications to the basic routing protocols like AODV, DSR and OLSR etc. They have the common objective of trying to reduce the energy consumption at each node and in increasing the battery lifetime, thereby extending the life time of MANET. 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.

The energy efficient routing are mainly classified based on transmission power control, load distribution, power saving and energy efficient design. The design tradeoffs between energy aware routing and energy save routing, as well as the advantages and disadvantages of the emerging energy efficient routing protocols in MANET are highlighted. Although many of these techniques look promising in terms of energy efficiency, there are still many challenges that need to be addressed such as security, quality of service etc.

REFERENCES

[1] Basagni, M. Conti, S. Giordano, I. Stojmenovic, "Mobile Ad Hoc Networking", IEEE Press, Piscataway, New Jersey, 2004.

[2] C.-K. Toh, "Maximum Battery Life Routing to Support Ubiquitous Mobile Computing in Wireless Ad Hoc Networks", in IEEE Communication Magazine, June 2001.

[3] Dhiraj Nitnaware, Ajay Verma, "Energy Evaluation Of Two On Demand Routing Protocol Under Stochastic Traffic" in the Proceedings of INDICON 2008, International Conference, Kanpur, Annual IEEE, December 11-13, 2008, pp-183 to187.

[4] E.Ahvar and M. Fathy, "Performance Evaluation Of Routing Protocols For High Density Ad Hoc Networks Based On Energy Consumption by GlomoSim Simulator" in the Proceedings Of World Academy Of Science, Engineering And Technology, Volume 23, August 2007.

[5] Qingting Wei And Hong Zou, "Efficiency Evaluation And Comparison Of Routing Protocols in MANET" in the Proceedings of ISISE 2008, International Symposium on Information Science and Engineering, IEEE Computer Society, pp-175 to177.

[6] Fu Yongsheng, Wang Xinyu, Li Shanping," Performance Comparison And Analysis Of Routing Strategies In Mobile Ad Hoc Networks" in the Proceedings of CSSE 2008, International Conference on Computer Science and Software Engineering, IEEE Computer Society, pp-505 to 510.

[7] Mads Daro Kristensen and Niels Olof Bouvin, " Energy Efficient MANET Routing Using a Combination of Span and BECA/AFECA" Journal of Networks, Vol 3, no.3, March 2008, pp-49 to56.

[8] B. Chen, K. Jamieson, H. Balakrishnan, and R. Morris, "Span: An Energyefficient Coordination Algorithm for Topology Maintenance In Ad Hoc Wireless Networks," ACM Wireless Networks Journal, 2002, vol. 8, no. 5, pp. 481–494.

[9] Y. Xu, J. Heidemann, and D. Estrin, "Adaptive Energy Conserving Routing For Multihop Ad Hoc Networks," USC/ISI, Research report 527, Oct. 2000.

[10] C.E. Perkins and E. M. Royer, "Adhoc on demand distance vector routing," in the proceedings of Mobile Computing Systems and Applications, WMCSA '99, Feb 1999, pp. 90–100.

[11] Yumei Liu, Lili Guo, Huizhu Ma, Tao Jiang, " Energy Efficient On Demand Multipath Routing Protocol for Multi-Hop Ad Hoc Networks ", in the Proceedings of ISSSTA-08, IEEE 10th International symposium on Spread spectrum and applications, Bologna, Italy, August 25-27, 2008, pp-592-597.

[12] Florino De Rango, Paola Lonetti, Salvatore Marano, " Energy Aware Metrics Impact On Multipath DSR In MANETs Environment", in the proceedings of SPECTS2008, IEEE Computer Society, June 2008, pp-130 to 137.

[13] J.-E. Garcia, A. Kallel, K. Kyamakya, K. Jobmann, J.-C. Cano, P. Monzoni, "A novel DSR-based energy-efficient routing algorithm for mobile ad-hoc networks ", in the proceedings of Vehicular Technology Conference (VTC'03), IEEE, Fall 2003.

[14] Adabi, S.; Jabbehdari, S.; Rahmani, A.M, "SBCA: Score Based Clustering Algorithm for Mobile AD-hoc Networks ", in the proceedings of ICYCS 2008, the 9th International Conference for Young Computer Scientists, 2008. , Nov 2008, pp-427 to 431,.

[15] Arash Dana, Amir Mansour, Marzieh Hajhosseini, Tina Mifakhraie, " A Robust Cross-Layer Design Of Clustering-Based Routing Protocol for MANET" in the proceedings of ICACT, 2008, Feb 17-20, 2008, pp-1055 to 1059.

[16] M.Jiang, J.Li, and Y.C Tay, "Cluster Based Routing Protocol" IETF Draft, August, 1999.

[17] Subha Sarkar, Bijan Bihari Bhaumik, " MEHRP: An efficient hybrid routing protocol for MANET using Direction dependent bordercasting" in the Proceedings of TENCON 2008, IEEE Region 10 conference, Hyderabad, 19-21 November 2008, pp-1 to 6.

[18] S. Basagni, I. Chlamtac, V.R. Syrotiuk, and B.A. Woodward, "A distance routing effect algorithm for mobility (DREAM)," in the Proceedings of the ACM/IEEE International Conference on Mobile Computing and Networking (Mobicom), 1998, pp.76–84,.

[19] Floriano De Rango, Marco Fotino, Salvatore Marano, " EE-OLSR:Energy Efficient OLSR Routing Protocol For Mobile Ad-Hoc Networks" in the Proceedings of MILCOM 2008, International Conference on Military Communications, IEEE, November 16-19 2008, pp-1 to 7.

[20] P. Jacquet, P. Muhlethaler, T. Clausen, A. Laouiti, A. Qayyum, and L. Viennot, "Optimized link state routing protocol for ad hoc networks," in the Proceedings of the 5th IEEE Multi Topic Conference (INMIC 2001).

[21] Lamia Romdhani and Christian Bonnet, "Energy-Based Routing Optimization in MANET: Cross-Layer Benefits" in the proceedings of the 9th International Conference on Mobile And Wireless Communications Networks, Cork, Ireland, September 19-21, 2007.

[22] La-Yuan Li, Feng Zheng, Chun-Lin Li, Pei-Yan Yuan, "An Energy Constrained Routing Protocol For MANETs" in the Proceedings of the 6th International Conference on Machine Learning And Cybernetics, Hong Kong, August 19-22, 2007.

[23] W.Naruphiphat, W. Usaha, "Balancing Tradeoffs for Energy- Efficient Routing In MANETs Based On Reinforcement Learning" in the proceedings of Vehicular Technology Conference, 2008, VTC Spring 2008. IEEE, 11-14 May 2000, pp: 2361-2365.

[24] Y.-H.Chang,T. Ho, L.P. Kaelbling., "Mobilized ad-hoc networks: a reinforcement learning approach," in the Proceedings of International Conference on Autonomic Computing, (ICAC'04), 2004, pp.240 247.

[25] Kwang-Ryoul Kim; Sung-Gi Min; Nam-Kyu Yu, "Maximizing the lifetime of wireless ad hoc networks using Minimizing the Maximum used Power Routing" in the proceedings of 3rd International Symposium on Wireless Pervasive Computing, 2008, ISWPC 2008, pp:557-561,7-9.

[26] Chansu Yu, Ben Lee, Hee Yong Youn "Energy Efficient Routing Protocols for Mobile Ad Hoc Networks" in the journal of Wireless Communications and Mobile Computing, Vol. 3, No. 8, 2003, pp. 959-973.

[27] Jin Lian "An Energy Based QOS Routing Protocol in Mobile Ad Hoc Network" in the proceedings of Pacific Asia Conference On Circuits , Communications & Systems 2009, pp-19-22

[28] Marwan Krunz and Alaa Muqattash "Transmission Power Control In Wireless Ad Hoc Networks: Challenges, Solutions And Open Issues" in the journal of IEEE Networks, September/ October, 2004, pp- 8 to 14.

[29] Natalia Vassileva, Franscisco Barcelo- Arroyo "A Survey of Routing Protocols For Energy Constrained Ad Hoc Wireless Networks" www.upcommons.upc.edu, 2007.