Chapter 2

Literature Survey

In this section we present exhaustive review of issues related to power consumption in MANETs with the corresponding literature in which they are reported. Existing power saving techniques are studied to explore various causes of energy consumption. Due to limited battery capacity and mobility of nodes, routing in MANETs requires special attention. Routing issues, classification of routing protocols, various existing protocols are discussed along with related literature survey. Energy efficient routing protocols are studied. Route Selection algorithms for optimal path selection in MANET are also explored.

2.1 Power requirement in MANET

Power conservation within the wireless protocol stack remains a very crucial research area for the viability of wireless services in the future. In order to make wireless communication energy efficient, a need is felt to propose a scheme to optimize the performance with respect to a parameter. The network performance can be optimized with respect to one of the metrics like maximum end to end throughput, minimum end to end delay, shortest path or minimum hops, minimum total power, load balancing and minimum overhead. Efforts are made towards minimizing the energy consumption of the network. Any such effort should not affect other parameter to a great extent.
2.2 Power consumption in network

Energy consumed by each node at the end of each simulation time slot is power consumption. The power consumption of a mobile host is classified in two categories:

1. Communication related power \((Power_{CR})\) or active communication energy: - Processing power and transceiver power

2. Non-communication related power \((Power_{NCR})\) or inactive energy.

It is necessary to reduce total power requirement of the node and thereby that of the network. Total power is summation of \(Power_{CR}\) and \(Power_{NCR}\). According to different types of networks for different applications, the ratio of the power used for these two parts can be quite different [6]. The ratio is defined by,

\[
\sigma = \frac{Power_{CR}}{Power_{NCR}}
\] (2.1)

According to different types of networks for different applications the ratio differs.

Transmission Power control (TPC) and load distribution approaches are used for controlling communication related power. Transmission Power Control adjusts the transmission power according to the propagation and interference characteristics of the surrounding. It is important to decide the correct power level of mobile host for retransmission. Retransmission power can be increased which will reduce transmission error possibility but this increases signal to interference ratio (SIR) of the network.

By carefully separating potentially conflicting transmissions in time and frequency or code space, reduction in number of wasted retransmissions is possible. Additional energy saving can be obtained by routing packets over energy-efficient paths in Power-Aware Routing (PAR). Load distribution approach assumes that nodes are distributed evenly in the network. Node characteristic like residual battery is considered in addition to usual shortest hop approach.

Sleep mode or power down mode approach [3] is suitable for non communication related power. The power consumption of the node’s wireless interface can be greatly reduced by putting the interface into sleep mode when no communication is needed as in Power-Saving Modes (PSM). In order to reduce power consumption, a node’s transceiver should be powered off (snooze or not listening) when not in use. One important issue in PSM is when to enter the sleep state and for how long to stay in this mode. At data link layer (DLL), energy conservation can be achieved by using effective retransmission request schemes and sleep mode operations.
2.3 Power saving, need for MANET

Power conservation is one of the central issues in MANETs as they use components that are mostly battery-operated portable devices. Without central coordination facilities, power-conservative design for ad hoc networks poses many challenges. One of the major challenges in MANET is how to provide high throughput and low-energy wireless access to mobile nodes. Hence routing plays important role in MANET study.

There is a need to combine routing protocols based on conventional routing metrics like minimum hops and delay, fast adaptability and new routing metrics such as stability, load balancing and power consumption in order to meet the requirement of any desired application. Power aware algorithms and protocols should conserve the node’s energy. Majority of these power saving techniques try to improve energy efficiency of certain protocol layer such as MAC or network layer.

Power efficient routing protocols should select the best path to minimize the total power needed to route the packets on the network and maximize the lifetime of nodes [5, 1]. Energy efficient routing is expected to minimize energy consumed per packet, maximize time for partition of network, minimize the variation of hosts’ power levels, minimize cost per packet and minimize maximum node cost.

Energy cost is considered to be important parameter for effective message delivery and is defined as the average energy consumption required delivering a unit message,

\[
\text{Energy cost} = \frac{\text{Total energy consumption}}{\text{Number of delivered messages}}
\]  

Suresh Singh, Mike Woo et al. [9] demonstrated that significant reductions in cost can be obtained by using shortest-cost routing as opposed to shortest-hop routing.

2.3.1 Energy saving techniques based on Power\textsubscript{CR}

Several route-selection algorithms, that use residual energy, transmission power or link distance as the metrics to select an optimal path are proposed in literature. They try to achieve energy aware goals. In order to reduce energy consumption and increase the lifespan of the network, Power aware alteration (PAA) was proposed in [10]. The scheme needs traffic overhead to maintain the network connectivity and to assume data transmission in spite of congestion. This power aware routing protocol for mobile ad hoc networks can be incorporated in existing routing protocol [9].
In Energy Efficient Coordination Algorithm, proposed by Chen B, Morris R etc [11], a distributed coordination technique reduces energy consumption without significantly diminishing the capacity or connectivity of network. It adaptively elects coordinators and rotates them in time.

Technique suggested by Ahmed Safwat et al. in paper titled, “Power - Aware Fair Infrastructure Formation for Wireless Mobile Ad Hoc Communications” [12], uses battery capacity as a basis for developing a wireless mobile infrastructure for achieving load balancing and fair clustering. Selection of best neighbor is also a critical issue in ad hoc networks. High mobility of nodes results in rapid changes in the route. A K Sharma and A Goel in [13] proposed an algorithm called, “Best neighbor node selection algorithm”, (BNNSA) which is designed for choosing the next best mobile node in a manner that reduces the number of packets transmitted on network.

Geographical Adaptive Fidelity (GAF) [14] is an example of adaptive fidelity to extend the lifetime of self configuring systems by exploiting redundancy to conserve energy while maintaining application fidelity. Narayanaswamy S, Kawadia V. et al. [15] have suggested a protocol that satisfies three objectives those are, maximizing the traffic carrying capacity, extending battery life through providing low power routes and reducing contention at the MAC layer. The power control can be achieved by using new route selection mechanisms like Energy Based Time Delay Routing (EBTDR) and Highest Energy Routing (HER) [16].

### 2.3.2 Energy saving techniques based on $Power_{NCR}$

Saving of power is achieved in a simple manner by keeping the node in sleep mode for some time. Sleep mode is controlled carefully so that throughput is not affected and there is an improvement in communication latency and capacity.

Requirements of effective network design in this case are:

- Minimizing the energy cost
- Necessity to keep node in inactive state
- Observing impact of traffic load and node mobility
- Deciding various time intervals (wake up, beacon interval) for active window size
PAMAS - Power Aware Multi-Access Protocol with Signalling for Ad Hoc Networks [17] suggested by S. Singh and C. S. Raghavendra achieves power saving up to 10% to 70% by turning off radios under certain conditions. They have proposed applicability of this technique to other multi-access protocols without affecting their delay and throughput performance. There is another energy saving scheme proposed in [18], termed as Gossip-based Sleep protocol (GSP). With GSP, each node randomly goes to sleep for some time with gossip sleep probability ‘p’ which in turn decides network connectivity. Choice of ‘p’ should be proper to avoid network partition.

The use of Message Ferrying (MF) routing scheme to save energy while trading off delay is possible [19]. In this method, nodes switch among different power management modes according to the knowledge of ferry location. In MF, special nodes called ferries move around the deployment area to deliver messages for nodes. The MAC layer power management can minimize the standby power of the network by putting the radio in sleep mode when nonactive, thus powering down most if the functions [20]. A MAC protocol requirement is that it lets radios sleep most of the time and yet lets them awaken precisely when they need to transmit or receive data.

A low power ad hoc protocol stack uses a Rendezvous protocol [21] that enables Prototype Embedded Network (PEN) nodes to remain asleep for much of their duty cycle and switch on the transceivers only when required using routing information. A distributed low power algorithm [22] is used to do dynamic channel assignment. In this, a novel wake up radio scheme is incorporated resulting in higher power efficiency by reducing network maintenance overhead.

In another method a node can enter in a sleep mode under following conditions [9]:

- If it is overhearing a transmission and does not have a packet to transmit
- If at least one neighbor is transmitting and at least one neighbor is receiving
- If all neighbors of a node are transmitting and the node is not a receiver

2.4 Routing issue in MANET

Routing is one of the important issues in MANET due to its highly dynamic and distributed nature. Majority of routing protocols in mobile ad hoc networks use shortest path length routing [23] where the number of hops is the path length. Conventional routing protocols for ad hoc
networks select the routes under the metric of the minimum hop count. Such min-hop routing protocols can use energy unevenly among the nodes and thus it can cause some nodes to quickly spend their whole energy.

In mobile environment, the problem of routing is essentially the distributed version of the shortest path problem. The next-hop routing methods can be categorized into two primary classes, link-state and distance-vector.

- **Link-State**: In this approach each node maintains a view of the network topology with a cost for each link.

- **Distance-Vector**: In distance-vector algorithms, every node maintains for each destination a set of distances. The succession of next hops chosen in this manner leads to the destination along the shortest path. The above distance-vector algorithm is the classical Distributed Bellman-Ford (DBF) algorithm.

Ad hoc routing protocols are classified based on the manner in which route tables are constructed, maintained, and updated.

### 2.5 Mobile network scenario

In MANET, network scenario is based on application such as emergency rescue operations or data sharing during conference. Different factors influencing the application under consideration are, number of users, area under considerations, mobility, data transfer rate and type of network i.e. flat or hierarchical.

Authors in [24] have proposed MANET protocol testing for parameters like packet delivery and throughput. New routing algorithms are needed in order to handle the overhead of mobility and topology changes in such energy constrained environment [25]. Most of previous work on routing in wireless ad hoc networks deals with the problem of finding and maintaining correct routes to the destination during mobility and changing topology. The performance of ad hoc routing protocols greatly depends on the mobility model it runs over [26]. In [27] the authors developed a dynamic routing algorithm for establishing and maintaining connection-oriented sessions, which uses the idea of predictive re-routing to cope up with the unpredictable topology changes.
2.6 Classification of Routing Protocols in MANETs

Routing protocols in MANETs can be classified in many ways. This is mostly done on the basis of routing strategy and network structure [2]. Routing strategy categorizes protocols as table-driven (Proactive) or on demand (Reactive) that is source initiated. Depending on the network structure, routing protocols are classified as flat routing, hierarchical routing and geographic position assisted routing.

Proactive protocols are based on routing tables, which store paths to all possible destinations i.e. they maintain consistent, up-to-date routing information from each node to every other node in the network. These protocols enjoy the advantage that the path to the destination is immediately available, so no delay is experienced when an application needs to send packets. However they incur significantly high routing overhead and hence tend to increase the energy consumption. Examples of such protocols are Destination Sequenced Distance Vector (DSDV) protocol [28, 29], and Optimized Link State Routing (OLSR) protocol [30]. Mobility of nodes demands route updates in order to know the current status of the node position in the network. Table driven protocols are preferred for such applications.

Source initiated on-demand routing creates routes only when desired by the source node. Reactive routing protocols execute the path finding process and exchange routing information only when a path is required by a node to communicate with destination. In case of on demand protocol, transfer of control information is limited and is not as frequently updated as in table driven protocols. This leads to less routing overheads and in turn more energy saving. The disadvantage of the protocol is high average end to end delay as compared to table driven protocols, as no periodic route updates are available. Examples of such protocols are Ad Hoc On-Demand Distance Vector (AODV) protocol [31] and Dynamic Source Routing (DSR) protocol [28]. In situations where nodes move in groups, source initiated protocol perform better than table driven protocols in terms of energy consumption.

There are two approaches in providing ad hoc network connectivity; flat routed network architecture and hierarchical network architectures. In flat routed network architecture, all the nodes are equal and packet routing is done based on peer-to-peer connections. However in hierarchical network architecture, at least one node in each lower layer is designated to serve as a gateway or coordinator to higher layers [6]. Both, the table-driven and on demand protocols come under Flat routing.
When wireless network becomes larger, it is complex to design routing protocols. All nodes in the network are separated into groups, called clusters. All clusters form a hierarchical infrastructure. In such network, hybrid routing protocols, i.e., combining proactive and reactive routing protocols, are used in order to take advantages of these two routing protocols. Here, proactive protocol maintains route in a cluster and reactive protocol maintains route between clusters. Several hybrid routing protocols have been proposed such as Zone Routing Protocol (ZRP), Zone-based Hierarchical Link State (ZHLS) protocol. The Zone Routing Protocol is targeted for large networks [32]. In ZHLS protocol, hierarchical routing approach is used for peer to peer nodes of large mobile networks [33].

Most of the ad hoc routing protocols focus only on single path routing and do not provide the possibility to convey the load during route establishment and therefore cannot balance the load on different routes. The development of multimedia service brings new opportunities and challenges to the wireless network technologies. Multipath routing fits the serious time-varying characteristic of the mobile wireless network, which means, it can provide effective bandwidth, respond to congestion and bursty traffic, and increase delivery reliability. Because the classic AODV and DSR perform better than DSDV, most of multipath algorithms are On-Demand based. Despite the fact that On-Demand routing can set up path faster, it needs to flood the network with route request. Furthermore, the disjoint path problem and feedback information increase the overhead [34]. Another problem is the routing rediscovery. In multipath approach, alternate paths are available. If the major path was broken, the alternate one always could not fulfill the QoS requirement. Hence the transmitter may have to start the whole route discovery process again. Some well known examples of multi-path routing protocols are Dynamic MANET On-demand (DYMO) and Ad hoc On-demand Multipath Distance Vector (AOMDV) [35].

The DYMO protocol is a reactive protocol that resembles AODV. However, it adopts some techniques found in source routing protocols (such as DSR), under the optional path accumulation method described in the protocol. The DYMO is intended for use by mobile nodes in wireless, multi hop networks [36]. DYMO determines unicast routes between DYMO routers within a network in an on demand fashion, offering improved convergence in dynamic topologies.

S. Chettibi and M. Benmohamed proposed MEA-DSR (Multipath Energy Aware an Demand Source Routing) protocol that uses load distribution policy in order to maximize network
lifetime [37]. Instead of splitting traffic on several routes only one route is used in MEA-DSR during communication session until its breakage. RREQ format has been slightly modified. MEA-DSR utilizes three data structures: routes cache, route requests table and routes table. Route request table has additional fields. A field called ‘\text{min\_bat\_lev}’ is added to RREQ packets. Additional fields are defined in routes request table while routes table is a new data structure specific to MEA-DSR.

Minimum drain rate (MDR) metric is selected as energy metric to integrate in multipath DSR protocol in [38]. The proposed algorithm DSR-MDR (DSR with Minimum Drain Rate) is compared with MDSR-MDR (Multipath DSR with MDR), MEA-DSR-MDR (Minimum Energy Aware DSR with MDR).

An energy aware multipath routing protocol (EMRP) is proposed in [39]. EMRP is a multipath routing protocol which uses information from the physical layer and MAC layer in choosing routes, focusing on the energy efficiency and the overall network performance. EMRP inherits the basic framework of DSR but makes some changes in route reply, route selection and route maintenance. Simulation results show that EMRP outperforms the traditional single path routing protocol providing longer network lifetime and lower energy consumption. Also multipath routing provides reduction in end-to-end delay and improved PDF.

2.7 Overview of energy efficient routing protocols

The aim of power-aware routing is to equally balance energy expenditure among mobile hosts to prolong network lifetime, while at the same time conserving overall power consumption as much as possible. We can distinguish three families of energy efficient routing protocols [40],

- The protocols which select the path consuming the minimum energy:

  Each transmission of a packet from its source to its destination minimizes the energy consumed. This is called as, ‘Power aware routing’ - trying to minimize total power consumption by choosing well-positioned neighbors for relaying packets. However, such protocols use always the same nodes (those minimizing the energy consumed) without considering their residual energy. Consequently, these nodes will exhaust their battery more quickly than the others and the network lifetime is not maximized.

- The protocols which select the path by visiting the nodes with the highest residual energy:
Each flow is ensured to have enough energy on the selected path and depleted nodes are avoided. This is termed as, Cost aware routing - attempting to increase host’s lifetimes by favoring hosts with more remaining battery power. However, the path selected does not minimize the energy needed to transmit a flow packet from its source to its destination. Hence, the network lifetime may not be maximized.

- The hybrid protocols which select the path with the minimum cost:
  
  Cost takes into account the residual energy of each visited node (and possibly its neighbors) and the energy consumption of a packet on this path. This is known as Power-cost routing - which combines above two methods for selecting paths. These protocols minimize overall power needed and also avoid hosts with low power levels. These protocols avoid the problems encountered by the protocols of the two previous categories by weighing the factors used in the cost computation.

Power-conservative protocols are divided into two categories [41]:

- Transmitter power control mechanisms:

  By adjustment of antenna directions and tuning, transmission powers can be adjusted. ‘Power control’ refers to the technique of tuning host’s transmission powers to proper range.

  Power control can conserve battery energy and it can reduce radio interference and thus increase spatial reuse of wireless bandwidth. The drawbacks include lower reliability, higher error rate, and weaker network connectivity. Balancing these factors is an important design issue.

- Power management algorithms:

  Power conservation techniques are implemented using various algorithms at different layers in OSI model. These algorithms are classified into MAC-layer and network-layer power management algorithms.

  - MAC-Layer Power Management: The MAC layer is mainly responsible for access scheduling of shared medium. Power consumption of a device strongly depends on the policy that MAC has adopted. Battery energy is saved as many unnecessary retransmissions, which consume significant power, are avoided.
- Network-Layer Power Management: The network layer is responsible for routing packets towards destinations. The wireless network layer takes care of mobility management by location tracking. Network-layer power-aware routing is thus a unique issue for ad hoc networks.

One of the examples of energy efficient protocol is AODV Energy Aware (AODVEA). In order to extend the lifetime of the ad-hoc networks, AODVEA performs routing based on the metric of minimum remaining energy of nodes. The node with minimum remaining energy in the route is marked and the route having maximum of minimum remaining energy is selected. Unbalanced node energy consumption in AODV is overcome by AODVEA.

To reduce overheads and power consumption in DSR, efficient energy management is proposed in [42]. In this work, modifications are proposed in route reply process which limits the number of route replies to one whereas in DSR, route reply is sent through all the available routes.

### 2.8 Route Selection algorithms for optimal path selection in MANET

Several route-selection algorithms that use residual energy, transmission power or link distance as the metric to select an optimal path, with energy aware goals are mentioned in [6].

1. **Minimum Total Transmission Power-Routing (MTPR) Algorithm:**

   The MTPR selects the route that uses the minimum total energy consumed in transmission along the route. More specifically, based on the algorithm for each route ‘l’ the total energy consumed over the route $P_l$ is computed as:

   $\[ P_l = \sum_{i=0}^{D-1} P(n_i, n_{i+1}) \] \quad (2.3)$

   where $n_0$, and $n_D$ are the source and the destination nodes respectively, while $P(n_i, n_j)$ denotes the transmission power between two nodes. The selected route $P_k$ is the one that satisfies the following property:

   $\[ P_k = \min(P_l : l \in A) \] \quad (2.4)$
where A is the set of all the possible routes. MTPR may achieve the total power consumption of the overall network. However, since it does not take into consideration the residual energy of each node, it fails to prolong the lifetime of each host.

2. **Minimum Battery Cost Routing (MBCR) Algorithm:**

The MBCR algorithm selects the route that minimizes the battery cost function. More specifically, for each node it assigns a battery cost function that is given by:

\[ f(n_i) = \frac{1}{c(n_i)} \]  \hspace{1cm} \text{(2.5)}

where \( c(n_i) \) denotes the residual energy of node \( n_i \). Therefore, the battery cost for a route \( l \), length \( D \), is given by:

\[ P_l = D - 1 \sum_{i=0}^{D-1} f(n_i) \]  \hspace{1cm} \text{(2.6)}

The selected route \( P_k \) is the one that satisfies the following property:

\[ P_k = \min(P_l : l \in A) \]  \hspace{1cm} \text{(2.7)}

where A is the set of all the possible routes. The main disadvantage of the MBCR is that the selection is based only on the battery cost; this will lead to increased fairness among nodes, since one node may be overused.

3. **Min-Max Battery Cost Routing (MMBCR) Algorithm:**

The MMBCR algorithm selects the route with the maximum values of the minimum residual energies of the nodes. Therefore, the Equation 2.6 is modified to

\[ P_l = \max_{i \in \text{route } l} f(n_i) \]  \hspace{1cm} \text{(2.8)}

The selected route \( P_k \) is the one that satisfies the following property:

\[ P_k = \min(P_l : l \in A) \]  \hspace{1cm} \text{(2.9)}
where \( A \) is the set of all the possible routes. The main disadvantage of the MMCBCR is that it does not guarantee that the total transmission power per packet is minimized over a chosen route.

4. **Conditional Max Min Battery Capacity Routing (CMMBCR):**

This mechanism considers both the total transmission energy consumption of routes and the remaining power of nodes. When all nodes in some possible routes have sufficient remaining battery capacity, i.e. above a threshold, a route with minimum total transmission power among the routes is chosen. Since smaller total power is required to forward packets for each connection, the relaying load for most of the nodes is reduced, and thereby lifetime gets extended. But, if all routes have nodes with low battery capacity i.e. below the defined threshold, a route including nodes with lowest battery capacity must be avoided to extend the lifetime of these nodes when MMBCR technique applied. The performance totally depends on value selected as threshold.

5. **Minimum Drain Rate (MDR):**

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 accepts 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. To address the above problem, the Minimum Drain Rate (MDR) 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 [43]. In this mechanism, the ratio of RBP\(_i\) to DR\(_i\), at node Ni, indicates when the remaining battery of node Ni will be exhausted. In other words, this ratio represents how long the remaining energy can maintain the connections with current traffic condition. The corresponding cost function is defined as,

\[
C_i = \frac{RBP_i}{DR_i}.
\]  

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’ between the source and the destination, having the highest maximum lifetime value.

6. **Low Cost Min-Max Energy Routing (LCMMER) Algorithm:** Even though the MMBCR strategy prevents the lowest-energy nodes from forwarding packets and further reducing their energy, it presents the disadvantage of not considering the cost of the path used when transmitting the information. This strategy may lead to excessively long paths, which will consume large amounts of energy.

The LCMMER strategy tries to avoid the least-energy nodes, and at the same time maintains low energy consumption for each transmission [6]. This is realized by applying the MMBCR strategy for all paths that have the minimum cost. That is, from all the admissible paths returned by the routing algorithm, the LCMMER selection strategy filters all the paths with delay larger than a minimum, and keeps all paths that have the minimum possible cost. From these paths, the path containing the least energy nodes is rejected and path with the highest energy nodes is selected. This route selection scheme avoids the least-energy nodes, while at the same time maintaining the cost of the path low, ensuring limited power consumption for each transmission.

### 2.9 Summary

Providing effective wireless services with low power remains an important design aspect. Communication related and non communication related powers and ways for power reduction are studied. Different techniques such as monitoring the battery capacity, searching multipath option for data transfer or turning node into sleep mode when not in use are used for power saving in the literature. MANET routing is important due to limited resources and mobility. In order to suit ad hoc network situations, existing routing protocols and energy efficient routing techniques are studied. For energy efficient routing, cost per packet and maximum node cost are found to be suitable parameters for route selection. Both criteria, being functions of remaining battery power, are preferred over conventional hop-count and delay as metrics for route selection.