Chapter 1

INTRODUCTION

1.1. Wireless networks

A computer network is an interconnected collection of independent computers which aids communication in many ways. Apart from providing a good communication medium, sharing of available resources, improved reliability of services and cost-effectiveness are some of the advantages of computer networking. A modern day computer network consists of two major components, namely, distributed applications and networking infrastructure. The distributed applications provide services to users located distant computers. Common distributed applications are electronic mail, air/train reservation system, credit card authentication system etc. The networking infrastructure provides support for data transfer among the interconnected computers where the applications reside. Several physical media such as copper cable, optic fiber, and wireless radio waves are used in the present day communication infrastructure.

Over the last several years the wireless world has seen a great development with new generation of radio frequency (RF) networking products [T.S. Rapport, 2011]. Advancements in wireless communication technologies together with the availability of wireless communication devices with increased processing capabilities have enabled wireless connectivity of mobile users to global Internet. At the same time, the proliferation of mobile computing devices (e.g., laptops, handheld digital devices, personal digital assistants (PDAs), and wearable computers) have brought about a revolution in the computing world. Not only the general-purpose computers but also the handheld terminals designed for specific tasks (store management, hospital data logger, and so forth) are available at modest prices. Technology trends have thus evolved rapidly from the personal computer (PC) age to ubiquitous computing age [R. G. T. Anderson et al., 2000], in which, individual users simultaneously use several electronic platforms through which they can access all the required information anytime, anywhere.
Due to basic difference in the physical layer (ISO/OSI model), the wireless devices and networks show distinct characteristics from their wired counterparts, such as:

i. Higher interference results in lower reliability.
ii. Low bandwidth and much slower data transfer rate.
iii. Highly variable network conditions.
iv. Limited computing and energy resources.
v. Device size limitation, and
vi. Weaker security.

In spite of these limitations the wireless networks are immensely popular because of the benefits of using wireless technologies, such as:

- **Access to more than one technology** - Users can use more than one access technology to service various parts of their network and during the migration phase of their networks, when upgrading occurs on a scheduled basis. It enables a fully comprehensive access technology portfolio to work with existing technologies.

- **Minimal cost** - The inherent nature of wireless network is that it doesn’t require wires or lines to accommodate the data/voice/video pipeline. Although paying fees for access to elevated areas such as masts, towers, and building tops is not unusual but the associated logistics, and contractual agreements are often minimal as compared to the costs of trenching a cable.

- **Reduced time to revenue** - Companies can generate revenue in less time through the deployment of wireless solutions than with comparable access technologies, because a wireless system can be assembled and brought online in a very short span of time.

- **Provides broadband access extension** - Wireless commonly competes and complements existing broadband access. Wireless technologies play a key role in extending the reach of cable, fiber, and Digital Subscriber Line (DSL) markets, and it does so quickly and reliably.
1.1.1. Wireless LANs

To do away with wiring associated with the interconnection of PCs in LANs, researchers have explored the possible usage of radio waves and infrared light for interconnection. This has resulted in the emergence of Wireless LAN (WLANs), where wireless transmission is used at physical layer of the network.

**Design goals**

The following are some of the goals which have to be achieved while designing WLANs:

- **Operational simplicity**: Design of wireless LANs must incorporate features to enable a mobile user to quickly set up and access network services in a simple and efficient manner.
- **Power-efficient operation**: The power constrained nature of mobile computing devices necessitates the important requirement of WLANs operating with minimal power consumption.
- **License free operation**: One of the major factors that affects the cost of wireless access is the license fee for the spectrum in which a particular wireless access technology operates. Hence design of WLAN should consider the parts of frequency spectrum for its operation which do not require an explicit licensing.
- **Tolerance to interference**: The proliferation of different wireless technologies have led to a significant increase in the interference level across the radio spectrum. The WLAN design should account for this and take appropriate measures by way of selecting technologies and protocols to operate in the presence of interference.
- **Global usability**: The design of WLAN should take into the prevailing spectrum restrictions in countries across the world.
- **Security**: The inherent broadcast nature of wireless medium adds to the requirement of security features to be included in the design of WLANs.
- **Safety requirements**: The design of WLAN technology should follow the safety requirements that can be classified into the following: (i) interference
to medical and other instrumentation devices and (ii) increase in power level of transmitters that can lead to health hazards.

- **Quality of service requirements**: Quality of service (QoS) refers to the provisioning of designated levels of performance for multimedia traffic. The design of WLAN should take into consideration the possibility of supporting a wide variety of traffic, including multimedia traffic.

- **Compatibility with other technologies and applications**: The interoperability among different LANs is important for efficient communication between hosts operating with different LAN technologies.

*Infrastructure based versus infrastructureless LANs*

The WLANs can be classified into two types, infrastructure networks and infrastructureless network. The infrastructureless networks are also referred as Ad-hoc networks. As shown in Figure 1.1, the infrastructure network contain special nodes called access points (APs), which are connected via existing networks. The APs are special in the sense that they can interact with wireless nodes as well as with the existing wired network. The other wireless nodes, also known as mobile stations, communicate via APs. The APs also act as bridges with other nodes.

![Figure 1.1 Infrastructure based network](image-url)
Chapter 1

Figure 1.2 Infrastructureless network

The ad-hoc LANs do not need any fixed infrastructure. These networks can be set up on the fly at any place. As shown in Figure 1.2, the nodes in ad-hoc networks communicate directly with each other or forward messages through other nodes that are directly accessible.

The design objectives of an ad-hoc wireless network are the speed of connection setup, the ease of control over services, users and the anytime, anywhere network service access. In this regard, mobile professionals consider the introduction of ad-hoc networking technologies into local mobility scenarios as the buzzword for tomorrow’s mobile wireless communication systems. There are few factors that turn the wireless ad-hoc networking technology to a special case of adapting to specific network and application peculiarities as technology evolves, is developed, and deployed. These include:

- Wireless ad hoc networks are particularly tailored for operation in situations where wireless communication range of a single base-station is not sufficient to cover a given area of mobile terminals. In addition to coverage limitations, a malfunctioning of a serving base-station would impair the communication of all mobile nodes in a given area. A malfunctioning of a base-station, however, can be easily overcome through network self-configuration and re-routing of original calls to neighbor base-station via mobile-to-mobile or multi-hop relaying.
- Ad hoc networks are easily setup in a wireless environment. If a company moves to a new location, the wireless system is much easier to move than ripping up all the cables that a wired system would have snaked throughout the building.
• There are many applications that can benefit from the ad-hoc networks, especially where base-stations cannot be deployed or are destroyed/malfunctioning.

Thus, the adoption of ad-hoc networking principles enables engineers to build local area networks (as well as wide area networks) using modest expenditures while keeping network administrative costs at a minimum.

In recent years, more and more communication environments have become wireless oriented. Unlike traditional wired networks, in which end hosts are fixed in location, wireless networks include a variety of mobile terminals, such as notebooks, personal digital assistants (PDAs), cellular phones, etc.

1.1.2. Applications of wireless networks

A wireless network is a flexible data communication system implemented as an extension to a wired LAN. The electromagnetic waves transmit and receive data over the air, minimizing the need for wired connections. It has got variety of applications.

Retailers use wireless terminals and WLANs to order, sell, and keep inventories of merchandise. Warehouse staff can use the technology to manage goods, conduct inventory, and ship goods to customers. Once items are received for storage in a warehouse, a clerk scans bar-code numbers into the database via a handheld device. In today’s healthcare environment, wireless networks provide fast and accurate transmission of patient information and can send timely alarms to key personnel for the patients' well-being. The use of pen-based computers enables the input of electronic patient records and drug transactions, updating data from anywhere in the hospital, and increases the accuracy and speed of healthcare. Using a handheld device, a doctor can order a blood test and the lab technician can perform the necessary tests, store the results, and send a message to the doctor. With the help of WLANs, corporations and students at universities can use wireless connectivity to facilitate laptops to access necessary information. Hospitality establishments check customers in and out and keep track of room service orders and laundry requests. Restaurants can track the names and
number of people waiting for entry, table status, and drink and food orders. State and provincial government officials can use WLANs to effectively and efficiently deal with legislature, constituent offices, and other government officials at municipal and federal levels. Global Positioning Systems (GPS) [JeongyeupPaek et al., 2010] are space-based radio positioning systems that provide 24-hour, 3D position, velocity, and time information to suitably equipped users anywhere on the surface of the Earth. The NAVSTAR system, operated by the U.S. Department of Defense, is the first GPS system that allows intelligent vehicle location and navigation. It has many military applications such as intelligence and target location, command and control, mine laying and detection, testing combat aircraft, missile guidance, and artillery pointing, to name a few. GPS can be used for surveying and can be done in almost all weather conditions. GPSs are useful in agriculture for precision farming as well as for search and rescue operations.

Automobile manufacturers have introduced GPS-based navigation in cars, with a four-inch monitor asking travelers their destination, displaying a color map of the area and scrolling down a list of preselected points of interest, such as hotels, convention centers, or a specific street address. Another example of GPS-based applications is the use of mobile notebooks in sporting competitions, including sailboat races, where progress is recorded and communicated wirelessly to servers.

1.1.3. **Challenges in wireless networks**

The challenge of a wireless network is to overcome the harsh reality of wireless transmission and provide mobility and multimedia services. Some of the challenging issues in wireless network are:

*Traffic and resource allocation*: Each accepted connection has a certain traffic contract that describes the traffic type and resource requirement. Wireless network has to meet these requirements without compromising on the quality of service.

*Flow control*: A connection involves buffering at several places on the path between the sender and the receiver. Flow control mechanisms are needed not only prevent
buffer overflows, but also to discard packets that have exceeded the allowable transfer time.

*Error control:* Error and packet loss are the common features in case of wireless networks. Proper error control mechanisms and mechanisms to overcome packet loss are needed.

*Security and privacy:* Wireless networks are very much vulnerable to security attacks. Eavesdropper can easily have access to the traffic in real time and record it for future cryptanalysis. Proper authentication and access control mechanisms are needed to overcome such attacks.

*Mobility:* In a wireless environment, the mobility of the wireless nodes enforces handover procedures when nodes move from one area to another.

### 1.2. Mobile ad hoc networks

The definition of a mobile ad-hoc network, as quoted from the charter of the corresponding Internet Engineering Task Force (IETF) is:

“A ‘mobile ad-hoc network’ (MANET) is an autonomous system of mobile routers (and associated hosts) connected by wireless link, the union of which forms an arbitrary graph. The routers are free to move randomly and organize themselves arbitrarily; thus, the network’s wireless topology may change rapidly and unpredictably. Such a network may operate in a standalone fashion, or may be connected to the larger Internet”.

Thus, a mobile ad-hoc network (MANET) is a special type of wireless network in which a collection of mobile network interfaces (Figure 1.3) may form a temporary network without the aid of any established infrastructure or centralized administration. Ad-hoc wireless network has applications in emergency search-and-rescue operations, decision making in the battlefield, data acquisition operations in hostile terrain, etc. It is featured by dynamic topology (infrastructureless), multi-hop communication, limited resources (bandwidth, CPU, battery, etc.) and limited security. The basic principle behind ad-hoc networking is the multi-hop relaying [C. Murthy et al., 2005], which traces its root
back to 500 B.C. Darius I (522-486 B.C.), the king of Persia, devised an innovative communication system that was used to send messages and news from his capital to the remote provinces of his empire by means of a line of shouting men positioned on the tall structures. The system was faster than normal method of sending the message/news through a messenger. The use of ad-hoc voice communication was used in many tribal societies with a string of repeaters of drums, trumpets or horns. In recent times, it was the Department of Defense (DoD), in 1972, initiated a new program on Packet Radio Networks (PRNET) [A. Ephremides et al., 1987] with the intention to create technologies for the battlefield that did not employ the previously deployed infrastructure but were highly survivable.

![Figure 1.3 A typical mobile ad-hoc network](image)

These characteristics put special challenges in the design of routing protocols for MANETs. The primary objectives of MANET routing protocols are to maximize network throughput, network lifetime, and to minimize delay. Developing routing protocols for MANETs has been an extensive research area in recent years, and many proactive, reactive and hybrid protocols have been proposed from a variety of perspectives. These protocols try to satisfy various properties, like: distributed implementation, efficient utilization of bandwidth and battery capacity, optimization of metrics, fast route convergence and freedom from loops, etc. The mobile/portable devices which form a MANET are
invariably battery powered, and thus battery lifetime becomes crucial for wireless communications and mobile computing. The Table 1.1 summarizes the evolution of MANETs [Bdale Garbee, 1987].

Table 1.1. Evolution of MANETs

<table>
<thead>
<tr>
<th>Date</th>
<th>Generations</th>
<th>Developments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>First generation</td>
<td>• PRNET (Packet Radio Networks)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ALOHA (Aerial Locations of Hazardous Atmospheres)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• CSMA (Carrier Sense Medium Access)</td>
</tr>
<tr>
<td>1980</td>
<td>Second Generation</td>
<td>• SURAN (Survivable Adaptive Radio Networks)</td>
</tr>
<tr>
<td>Early 1990</td>
<td>Third generation</td>
<td>• GloMo (Global Mobile Information Systems)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• NTDR (Near-term Digital Radio)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Mobile Ad-Hoc Networking Working group was established, 1991.</td>
</tr>
<tr>
<td>Mid and Late</td>
<td></td>
<td>• JTRS (Joint Tactical Radio System), 1996.</td>
</tr>
<tr>
<td>1990</td>
<td></td>
<td>• IETF published several drafts about Routing protocol of MANET, 2000.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• IEEE Workshop on Mobile Ad Hoc Networking and Computing was established, 2000.</td>
</tr>
<tr>
<td>Future</td>
<td>Fourth generation</td>
<td>• Use of mobile adhoc routers to provide Internet connectivity to mobile users.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Distributive collaborative computing.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Distributed sensing networks.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Disaster recovery networks.</td>
</tr>
</tbody>
</table>

1.2.1. Challenges in MANETs

Ad hoc networks have to suffer many challenges. Dynamically changing topology (due to Brownian motion of the nodes of the network) and absence of centralized infrastructure are the biggest challenges in the designing of an ad-hoc network. The position of the nodes in an ad-hoc network continuously varies, due to which, it is very difficult to say that any particular protocol will give the best performance in each and every case. Since topology varies very frequently, one has to select a protocol which dynamically adapts to the situation. Another challenge in MANET is limited bandwidth. As compared to the wired network, wireless network has less but more varying bandwidth. So, bandwidth efficiency is also a major concern in ad-hoc network routing protocol designing because, sometimes
data has to be transmitted within real time constraints. Limited power supply is the biggest challenge in an ad-hoc network. If it is desired to increase the network lifetime (duration of time when the first node of the network runs out of energy) as well the node lifetime, then a proper energy efficient routing protocol has to be used. So, a MANET routing protocol must meet all these challenges to give the average performance in every case. The main challenges in mobile ad-hoc networks are as follows:

- **Vulnerabilities**: The lack of physical security and the ease of eavesdropping and spoofing leaves much desired gap between the security in wireless communication and the security in standard wired communication.
- **Lack of a priori trust**: A MANET consists of set of nodes, which are not part of any organization, therefore the classical security paradigm based on pre-established trust among the parties are not applicable.
- **Lack of infrastructure**: Security solutions comprising of dedicated secure components with predefined roles (such as trusted third party and key servers) cannot be used in this environment.
- **Requirement for cooperation**: Due to lack of dedicated components, such as routers and servers, the basic network functions and services need to be carried out by a set of ordinary nodes in a distributed fashion. Thus, the routing is affected by the presence of malicious node or the absence of cooperation among the nodes.
- **Limited power supply**: The MANETs inherently imply an underlying reliance on portable, finite power sources. Thus, the basic components of any MANET are mostly battery-operated portable devices.
- **Dynamically changing topology**: Nodes are free to move arbitrarily; thus, the network topology may change randomly and rapidly at unpredictable times.
- **Limited and varying bandwidth**: This is caused by the limits of the air interface. Furthermore, multiple access, multipath fading, noise and signal interference decrease the limited capacity available at the allocated frequency rate.
1.2.2. Applications of MANETs

The benefits of ad hoc networks appeal to applications like conferences, meetings, disaster relief, rescue missions, and battlefield operation. Such scenarios typically lack a central administration or wired infrastructure. Some of the application areas are listed in Table 1.2 [C. K. Toh, 1996].

Table 1.2 Applications of MANETs

<table>
<thead>
<tr>
<th>Applications</th>
<th>Descriptions/Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tactical networks</td>
<td>Military communication and operations, Automated Battlefields.</td>
</tr>
<tr>
<td>Sensor networks</td>
<td>Collection of embedded sensor devices used to collect real-time data to automate everyday timetions. Data highly correlated in time and space, e.g., remote sensors for weather, earth activities; sensors for manufacturing equipment. Can have between 1000–100,000 nodes, each node collecting sample data, then forwarding data to centralized host for processing using low homogeneous rates.</td>
</tr>
<tr>
<td>Emergency services</td>
<td>Search-and-rescue operations as well as disaster recovery; e.g., early retrieval and transmission of patient data (record, status, diagnosis) from/to the hospital, replacement of a fixed infrastructure in case of earthquakes, hurricanes, fire, etc.</td>
</tr>
<tr>
<td>Commercial</td>
<td>E-Commerce, e.g., electronic payments from anywhere (i.e., in a taxi) Dynamic Business environment; access to customer files stored in a central location on the fly provide consistent databases for all agents mobile office, Transmission of news, road conditions, weather, music local ad hoc network with nearby vehicles for road/accident guidance.</td>
</tr>
<tr>
<td>Home and enterprise</td>
<td>Home/office wireless networking (WLAN), e.g., shared whiteboard-networking application, use PDA to print anywhere, trade shows Personal Area Network (PAN), Body Area Network (BAN).</td>
</tr>
<tr>
<td>Educational</td>
<td>Set up virtual classrooms or conference rooms applications Set up ad hoc communication during conferences, meetings, or lectures.</td>
</tr>
<tr>
<td>Entertainment</td>
<td>Multiuse games, Robotic pets, Outdoor Internet access.</td>
</tr>
<tr>
<td>Location-aware</td>
<td>Follow-on services, e.g., automatic call forwarding, transmission of the actual workspace to the current location Information services Push, e.g., advertise location-specific service, like- gas stations; Pull, e.g., location-dependent travel guide; Services (printer, fax, phone) availability information; etc.</td>
</tr>
<tr>
<td>services</td>
<td></td>
</tr>
</tbody>
</table>
1.3. **Routing protocols for MANETs**

The heart of any routing protocol is the routing algorithm that determines the path for a packet. The purpose of routing algorithm is simple – given a set of routers, with links connecting them, it finds a “good” path between a pair of nodes. Routing protocols [S. Corson et al., 1999] base their calculations on the available routing information for the network connectivity. Reachability information of remote stations is maintained in the routing cache (also called routing tables). To guarantee that the routing tables are up-to-date and reflect the actual network topology, nodes should continuously broadcast route updates and recalculate paths. Routing is one of the key issues in MANETs due to their highly dynamic and distributed nature. Routing in a MANET is intrinsically different from traditional routing found in infrastructure networks. Routing in a MANET depends on many factors including topology, selection of routers, initiation of request, and specific underlying characteristic that could serve as a heuristic in finding the path quickly and efficiently. The low resource availability in these networks demands efficient utilization and hence the motivation for optimal routing in ad-hoc networks. Also, the highly dynamic nature of these networks imposes severe restrictions on routing protocols specifically designed for them, thus motivating the study of protocols which aims at achieving routing stability. One of the major challenges in designing a routing protocol for ad-hoc networks stems from the fact that, on one hand, a node needs to know at least the reachability information to its neighbors for determining a packet route and, on the other hand, the network topology can change quite often in an ad-hoc network. Furthermore, as the number of network nodes can be large, finding route to the destinations also requires large and frequent exchange of routing control information among the nodes. Thus, the amount of update traffic can be quite high, and it is even higher when high mobility nodes are present. High mobility nodes can impact route maintenance overhead of routing protocols in such a way that no bandwidth might remain leftover for the transmission of data packets.

A routing protocol [Marco Fotino et al., 2011] is the mechanism by which user traffic is directed and transported through the network from the source node to the destination node. Objectives include maximizing network performance from
the application point of view, i.e. application requirements, while minimizing the cost of network itself in accordance with its capacity. The application requirements are hop count, delay, throughput, loss rate, stability, jitter, cost and the network capacity is a function of available resources that reside at each node and number of nodes in the network as well as its density, frequency of end-to-end connection (i.e. number of communications), frequency of topology changes (mobility rate).

The four core basic routing functionality for mobile ad-hoc networks are:

- **Path generation**: Generates paths according to the assembled and distributed state information of the network and of the application; assembling and distributing network and user traffic state information.
- **Path selection**: Selects appropriate paths based on network and application state information.
- **Data forwarding**: Forwards user traffic along the select route forwarding user traffic along the selected route.
- **Path maintenance**: Maintenance of the selected route.

### 1.3.1. Classification of routing protocols

Ad-hoc routing protocols can be broadly classified as being Proactive (or table-driven) routing protocols, Reactive (on-demand) routing protocols and Hybrid routing protocols (Figure 1.4).

![Figure 1.4. Classification of routing protocols](image-url)
Proactive routing protocols mandate that nodes in a MANET should keep track of routes to all possible destinations, so that, when a packet needs to be forwarded, the route is already known and can be immediately used. On the other hand, reactive protocols employ a lazy approach whereby nodes only discover routes to destinations on demand, i.e., a node does not need a route to a destination until that destination is to be the sink of data packets sent by the node. Proactive protocols have the advantage that a node experiences minimal delay whenever a route is needed as a route is immediately selected from the routing table. However, proactive protocols may not always be appropriate as they continuously use a substantial fraction of the network capacity to maintain the routing information current. To cope up with this shortcoming, reactive protocols adopt the inverse approach by finding a route to a destination only when needed. Reactive protocols often consume much less bandwidth than proactive protocols, but the delay to determine a route can be significantly high and they will typically experience a long delay for discovering a route to a destination prior to the actual communication. In brief, one can conclude that no protocol is suited for all possible environments, while some proposals using a hybrid approach have been suggested.

1.3.1.1. **Proactive routing protocols**

*Destination sequenced distance vector protocol:*

The destination sequenced distance vector (DSDV) is a proactive hop-by-hop distance vector routing protocol, requiring each node to periodically broadcast routing updates. Here, every mobile node in the network maintains a routing table for all possible destinations within the network and the number of hops to each destination. Each entry is marked with a sequence number assigned by the destination node. The sequence numbers enable the mobile nodes to distinguish stale routes from new ones, thereby avoiding the formation of routing loops. Routing table updates are periodically transmitted throughout the network in order to maintain consistency in the table. To alleviate the potentially large amount of network update traffic, route updates can employ two possible types of packets: full dumps or small increment packets. A full dump type of packet carries all available routing information and can require multiple network protocol data
units (NPDUs). These packets are transmitted infrequently during periods of occasional movement. Smaller incremental packets are used to relay only the information that has changed since the last full dump. Each of these broadcasts should fit into a standard-size NDU, thereby decreasing the amount of traffic generated. The mobile nodes maintain an additional table where they store the data sent in the incremental routing information packets. New route broadcasts contain the address of the destination, the number of hops to reach the destination, the sequence number of the information received regarding the destination, as well as a new sequence number unique to the broadcast. The route labeled with the most recent sequence number is always used. In the event that two updates have the same sequence number, the route with the smaller metric is used in order to optimize (shorten) the path.

Mobiles also keep track of settling time of the routes, or the weighted average time that routes to a destination could fluctuate before the route with the best metric is received. By delaying the broadcast of a routing update by the length of the settling time, mobiles can reduce network traffic and optimize routes by eliminating those broadcasts that would occur if a better route could be discovered in the very near future. Note that each node in the network advertises a monotonically increasing sequence number for itself. The consequence of doing it so is that, when a node B decides that its route to a destination D is broken, it advertises the route to D with an infinite metric and a sequence number one greater than its sequence number for the route that has broken (making an odd sequence number). This causes any node A routing packets through B to incorporate the infinite-metric route into its routing table until node A hears a route to D with a higher sequence number.

The Wireless routing protocol:

The wireless routing protocol (WRP) is a table-based protocol with the goal of maintaining routing information among all nodes in the network. Each node in the network is responsible for maintaining four tables: Distance table, Routing table, Link-cost table, and the Message Retransmission List (MRL) table. Each entry of the MRL contains the sequence number of the update message, a re-
transmission counter, an acknowledgment-required flag vector with one entry per neighbor, and a list of updates sent in the update message. The MRL records which updates in an update message need to be retransmitted and neighbors should acknowledge the retransmission. Mobiles inform each other of link changes through the use of update messages. An update message is sent only between neighboring nodes and contains a list of updates (the destination, the distance to the destination, and the predecessor of the destination), as well as a list of responses indicating which mobiles should acknowledge (ACK) the update.

After processing updates from neighbors or detecting a change in a link, mobiles send update messages to a neighbor. In the event of the loss of a link between two nodes, the nodes send update messages to their neighbors. The neighbors then modify their distance table entries and check for new possible paths through other nodes. Any new paths are relayed back to the original nodes so that they can update their tables accordingly. Nodes learn about the existence of their neighbors from the receipt of acknowledgments and other messages. If a node is not sending messages, it must send a hello message within a specified time period to ensure connectivity. Otherwise, the lack of messages from the node indicates the failure of that link; this may cause a false alarm. When a mobile receives a hello message from a new node, that new node is added to the mobile’s routing table, and the mobile sends the new node a copy of its routing table information. Part of the novelty of WRP stems from the way in which it achieves freedom from loops. In WRP, routing nodes communicate the distance and second-to-last hop information for each destination in the wireless networks. The WRP belongs to the class of path-finding algorithms with an important exception. It avoids the “count-to-infinity” problem by forcing each node to perform consistency checks of predecessor information reported by all its neighbors. This ultimately (although not instantaneously) eliminates looping situations and provides faster route convergence when a link failure occurs.

*The Fisheye state routing (FSR):*

The fisheye state routing (FSR) is a proactive unicast routing protocol based on Link State routing algorithm with effectively reduced overhead to maintain network topology information. As indicated in its name, FSR utilizes a function
similar to a fish eye. The eyes of fishes catch the pixels near the focal with high detail, and the detail decreases as the distance from the focal point increases. Similar to fish eyes, FSR maintains the accurate distance and path quality information about the immediate neighboring nodes, and progressively reduces detail as the distance increases. In Link State routing algorithm used for wired networks, link state updates are generated and flooded through the network whenever a node detects a topology change. In FSR, however, nodes exchange link state information only with the neighboring nodes to maintain up-to-date topology information. Link state updates are exchanged periodically in FSR, and each node keeps a full topology map of the network. To reduce the size of link state update messages, the key improvement in FSR is to use different update periods for different entries in the routing table. Link state updates corresponding to the nodes within a smaller scope are propagated with higher frequency. FSR exhibits a better scalability concerning the network size compared to other link state protocols because it doesn’t strive for keeping all nodes in the network on the same knowledge level about link states. Instead, the accuracy of topology information is reverse proportional to the distance. This reduces the traffic overhead caused by exchanging link state information because this information is exchanged more frequently with node nearby than with nodes far away.

1.3.1.2. Reactive routing protocols

The Dynamic source routing (DSR) Protocol:

The dynamic source routing (DSR) is a reactive unicast routing protocol that utilizes source routing algorithm. In source routing algorithm, each data packet contains complete routing information to reach its destination. Additionally, in DSR each node uses caching technology to maintain route information that it has learnt. There are two major phases in DSR, the route discovery phase and the route maintenance phase. When a source node wants to send a packet, it firstly consults its route cache. If the required route is available, the source node includes the routing information inside the data packet before sending it. Otherwise, the source node initiates a route discovery operation by broadcasting route request packets. A route request packet contains addresses of both the source and the destination and a unique number to identify the request.
Receiving a route request packet, a node checks its route cache. If the node doesn’t have routing information for the requested destination, it appends its own address to the route record field of the route request packet. Then, the request packet is forwarded to its neighbors. If the route request packet reaches the destination or an intermediate node has routing information to the destination, a route reply packet is generated. When the route reply packet is generated by the destination, it comprises addresses of nodes that have been traversed by the route request packet. Otherwise, the route reply packet comprises the addresses of nodes the route request packet has traversed concatenated with the route in the intermediate node’s route cache.

After being created, either by the destination or an intermediate node, a route reply packet needs a route back to the source. There are three possibilities to get a backward route. The first one is that the node already has a route to the source. The second possibility is that the network has symmetric (bi-directional) links. The route reply packet is sent using the collected routing information in the route record field, but in a reverse order. In the last case, there exists asymmetric (unidirectional) links and a new route discovery procedure is initiated to the source. The discovered route is piggybacked in the route request packet. In DSR, when the data link layer detects a link disconnection, a ROUTE_ERROR packet is sent backward to the source. After receiving the ROUTE_ERROR packet, the source node initiates another route discovery operation. Additionally, all routes containing the broken link should be removed from the route caches of the immediate nodes when the ROUTE_ERROR packet is transmitted to the source. DSR has increased traffic overhead by containing complete routing information into each data packet, which degrades its routing performance.

*The Ad hoc on demand distance vector routing (AODV) protocol:*

The ad hoc on demand distance vector routing (AODV) protocol is a reactive unicast routing protocol for mobile ad-hoc networks. As a reactive routing protocol, AODV only needs to maintain the routing information about the active paths. In AODV, routing information is maintained in routing tables at nodes. Every mobile node keeps a next-hop routing table, which contains the destinations to which it currently has a route. A routing table entry expires if it has not been
used or reactivated for a pre-specified expiration time. Moreover, AODV adopts the destination sequence number technique used by DSDV in an on-demand way. In AODV, when a source node wants to send packets to the destination but no route is available, it initiates a route discovery operation. In the route discovery operation, the source broadcasts route request (RREQ) packets. A RREQ includes addresses of the source and the destination, the broadcast ID, which is used as its identifier, the last seen sequence number of the destination as well as the source node’s sequence number. Sequence numbers are important to ensure loop-free and up-to-date routes. To reduce the flooding overhead, a node discards RREQs that it has seen before and the expanding ring search algorithm is used in route discovery operation. The RREQ starts with a small TTL (Time-To-Live) value. If the destination is not found, the TTL is increased in following RREQs. In AODV, each node maintains a cache to keep track of RREQs it has received. The cache also stores the path back to each RREQ originator. When the destination or a node that has a route to the destination receives the RREQ, it checks the destination sequence numbers it currently knows and the one specified in the RREQ. To guarantee the freshness of the routing information, a route reply (RREP) packet is created and forwarded back to the source only if the destination sequence number is equal to or greater than the one specified in RREQ. The AODV uses only symmetric links and a RREP follows the reverse path of the respective RREP. Upon receiving the RREP packet, each intermediate node along the route updates its next-hop table entries with respect to the destination node. The redundant RREP packets or RREP packets with lower destination sequence number will be dropped. In AODV, a node uses hello messages to notify its existence to its neighbors. Therefore, the link status to the next hop in an active route can be monitored. When a node discovers a link disconnection, it broadcasts a route error (RERR) packet to its neighbors, which in turn propagates the RERR packet towards nodes whose routes may be affected by the disconnected link. Then, the affected source can re-initiate a route discovery operation if the route is still needed.

**The Temporally ordered routing algorithm (TORA):**

The temporally ordered routing algorithm (TORA) is a reactive routing algorithm based on the concept of link reversal. TORA improves the partial link
reversal method by detecting partitions and stopping non-productive link reversals. The TORA can be used for highly dynamic mobile ad-hoc networks. In TORA, the network topology is regarded as a directed graph. A Directional Acyclic Graph (DAG) is accomplished for the network by assigning each node $i$ a height metric $h_i$. A link directional from $i$ to $j$ means $h_i > h_j$. In TORA, the height of a node is defined as a quintuple, which includes the logical time of a link failure, the unique ID of the node that defines the new reference level, a reflection indicator bit, a propagation ordering parameter and a unique ID of the node. The first three elements collectively represent the reference level. The last two values define an offset with respect to the reference level. A packet always goes from upstream to downstream according the height difference between nodes. The DAG provides TORA the capability that many nodes can send packets to a given destination and guarantees that all routes are loop-free. The TORA has three basic operations: route creation, route maintenance and route erasure. A route creation operation starts with setting the height (propagation ordering parameter in the quintuple) of the destination to 0 and heights of all other nodes to NULL (i.e., undefined). The source broadcasts a QRY packet containing the destination’s ID. A node with a non-NULL height responds by broadcasting a UPD packet containing the height of its own. On receiving a UPD packet, a node sets its height to one more than that of the UPD generator. A node with higher height is considered as upstream and the node with lower height is considered as downstream. In this way, a directed acyclic graph is constructed from the source to the destination and multiple paths route may exist. The DAG in TORA may be disconnected because of node mobility. So, route maintenance operation is an important part of TORA. The TORA has the unique feature that control messages are localized into a small set of nodes near the occurrence of topology changes. After a node loses its last downstream link, it generates a new reference level and broadcasts the reference to its neighbors. Therefore, links are reversed to reflect the topology change and adapt to the new reference level. The erase operation in TORA floods CLR packets through the network and erase invalid routes.
1.3.1.3. Hybrid routing protocols

*The Zone routing protocol (ZRP):*

The ZRP is a hybrid routing protocol for mobile ad-hoc networks. The hybrid protocols are proposed to reduce the control overhead of proactive routing approaches and decrease the latency caused by route search operations in reactive routing approaches. In ZRP, the network is divided into routing zones according to distances between mobile nodes. Given a hop distance $d$ and a node $N$, all nodes within hop distance at most $d$ from $N$ belong to the routing zone of $N$. Peripheral nodes of $N$ are $N$'s neighboring nodes in its routing zone which are exactly $d$ hops away from $N$. In ZRP, different routing approaches are exploited for inter-zone and intra-zone packets. The proactive routing approach, i.e., the Intra-zone Routing protocol (IARP), is used inside routing zones and the reactive Inter-zone Routing Protocol (IERP) is used between routing zones, respectively. The IARP maintains link state information for nodes within specified distance $d$. Therefore, if the source and destination nodes are in the same routing zone, a route can be available immediately. Most of the existing proactive routing schemes can be used as the IARP for ZRP. The IERP reactively initiates a route discovery when the source node and the destination are residing in different zones. The route discovery in IERP is similar to DSR with the exception that route requests are propagated via peripheral nodes.

*The Hybrid ad hoc routing protocol (HARP):*

The HARP is a hybrid routing scheme, which exploits a two-level zone based hierarchical network structure. Different routing approaches are utilized in two levels, for intra-zone routing and inter-zone routing, respectively. The Distributed Dynamic Routing (DDR) algorithm is exploited by HARP to provide underlying supports. In DDR, nodes periodically exchange topology messages with their neighbors. A forest is constructed from the network topology by DDR in a distributed way. Each tree of the forest forms a zone. Therefore, the network is divided into a set of non-overlapping dynamic zones. A mobile node keeps routing information for all other nodes in the same zone. The nodes belonging to different zones but are within the direct transmission range are defined as gateway nodes.
Gateway nodes have the responsibility forwarding packets to neighboring zones. In addition to routing information for nodes in the local zone, each node also maintains those of neighboring zones. As in ZRP, the intra-zone routing of HARP relies on an existing proactive scheme and a reactive scheme is used for inter-zone communication. Depending on whether the forwarding and the destination node are inside the same zone, the respective

1.3.1.4. **Routing protocols using location information**

*Location aided routing (LAR)*:

The location aided routing (LAR) [Young-BaeKo et al., 2000] is a reactive unicast routing scheme. The LAR exploits position information and improves the efficiency of the route discovery procedure by limiting the scope of route request flooding. In LAR, a source node estimates the current location range of the destination based on information of the last reported location and mobility pattern of the destination. In LAR, an expected zone is defined as a region that is expected to hold the current location of the destination node. During route discovery procedure, the route request flooding is limited to a request zone, which contains the expected zone and location of the sender node. There are two different schemes in LAR. In the scheme 1, the source node calculates the expected zone and defines a request zone in request packets, and then initiates a route discovery. Receiving the route request, a node forwards the request if it falls inside the request zone; otherwise it discards the request. When the destination receives the request, it replies with a route reply that contains its current location, time and average speed. The size of a request zone can be adjusted according to the mobility pattern of the destination. When speed of the destination is low, the request zone is small; and when it moves fast, the request zone is large. In the scheme 2, a source node \( S \) with coordinate \((x_s, y_s)\) calculates the distance \(\text{Dist}_s\) to the destination \( D \), whose coordinate is \((x_d, y_d)\) before it initiates a route discovery operation. Receiving a route request, a node \( I \) with coordinate \((x, y)\) calculates its distance \(\text{Dist}_i\) to the destination \( D \) and forwards the request only if \(\text{Dist}_i \leq \text{Dist}_s + \delta\), otherwise it discards the request. Before
forwarding the request, node $I$ replaces $\text{Dist}_s$ with $\text{Dist}_i$. The non-zero $\delta$ increases the success probability of the route discovery procedure.

The Distance Routing Effect Algorithm for Mobility (DREAM):

The Distance Routing Effect Algorithm for Mobility (DREAM) [Basagni et al., 1998] exploits location and speed information of mobile nodes for data packet routing. In DREAM, geographical information is used to limit the flooding of data packets to a small region, rather than to merely provide assistance during the route discovery phase in LAR. DREAM is a proactive routing scheme. In DREAM, the routing table of a node contains location information of all other nodes in the network. When a source wants to send a packet, firstly it checks its routing table and gets the respective location information of the destination. Then, the source forwards the packet to a neighbor in the direction towards the destination. Therefore, the most substantial issue in DREAM is disseminating the location information through the network. To do that, every mobile node sends location updates comprising its location. The frequency of the location update is determined by the distance and node mobility. Considering the distance effect, nodes departing far away normally have a more stable relative location relationship. Consequently, when a node maintains the location information of another one that is far away, less frequent updates are used. Additionally, each location update is tagged with the "life time" which limits the transmission range of the update. Mobile nodes are allowed to adjust transmission frequencies of their location updates according to their mobility patterns.

1.4. Energy aware routing

Most of the routing protocols for ad-hoc networks were adopted from existing wired–network routing which need not consider power consumption since its nodes are usually powered by an energy network or from cellular wireless networks whose base stations (i.e. routers) are also powered not by batteries, but infinite power sources. Therefore, these protocols do not account for power consumption of the routing process. However, ad-hoc nodes generally run on limited battery power. A node is completely lost and wasted as soon as it depletes its energy supply. So, energy–awareness is an important aspect of ad-hoc routing.
That is, energy efficient routing is the most important design criteria for MANETs. Power failure of a mobile node not only affects the node itself but also its ability to forward packets on behalf of others and thus the overall network lifetime. For this reason, many research efforts have been devoted to developing energy-aware routing protocols.

1.4.1. Major sources of energy consumption

The major sources of power consumption in mobile computing devices include radio communication and data processing, with radio communication often being the dominant source of energy consumption. Data processing involves the usage of CPU, memory, hard drive, etc. Its energy consumption is relatively negligible compared with that of the radios. The energy expenditure in radio communication includes the power consumed by transmitting and receiving devices of all nodes along the path from source to destination, together with their neighbors that can overhear the transmission. Actually, there is a tradeoff on energy consumption between data processing and radio communication, the two energy consuming factors. For example, data compression techniques are introduced to reduce packet length and therefore achieve energy saving in radio communication, but the cost of computation is increased. In mobile ad-hoc networks, communication related energy consumption includes the power consumed by the radios at the sender, receiver and intermediate nodes in the route from the source to the destination. Actually, at any time a mobile node in MANETs must be in one of the following four modes: transmit, receive, idle listening, and sleep. When a node is in transmit or receive mode, it is transmitting or receiving a packet. Idle listening mode means the node is neither transmitting nor receiving a packet, but is doing channel monitoring. This mode also consumes power because the node has to listen to the wireless medium continuously in order to detect the arrival of the packet that it should receive, so that the node can switch to receive mode. When in the sleep mode, nodes do not communicate at all. Receive and idle mode consume similar amount of power, while transmit mode requires slightly larger amount. Nodes in sleep mode consume extremely low power. The estimated power consumption of each state is as presented in the Table 1.3.
The mobile ad-hoc nodes must keep on monitoring the media for possible data transmission. Thus most of the time nodes must be in idle listening mode instead of sleeping. Actually, a network interface operating in ad-hoc status has a constant idle power consumption, which rejects the cost of listening to the wireless channel. Many measured results have shown that the energy spent by idle listening is 50% to 100% of that by receiving. In other words, idle listening consumes only slightly less energy than actually receiving traffic. Thus, significant energy is consumed even when there is no traffic in the MANETs. Further, the energy expenditure for the radio interface to transit from one mode to another is not negligible, because, the transition time cannot be infinitesimally short. For example, the transition between transmit and receive modes typically takes 6 to 30 µs, while the transition from sleep to transmit or receive generally takes even more time (250 µs). Mode transitions have significant impact on energy consumption of wireless nodes. Besides the power consumption in transmit, receive and idle listening, there exists other significant energy expenditure in packet retransmission, node overhearing and protocol overhead. Retransmission is caused by collision. When a packet is corrupted, it must be discarded and transmitted again. Retransmission increases energy consumption. In fact, due to the lack of a centralized authority in mobile ad hoc networks, transmissions of packets from distinct mobile terminals are more prone to overlap, resulting in more serious packet collisions and energy loss. Overhearing means a node picks up packets that are destined for other nodes. Wireless nodes will consume power unnecessarily due to overhearing transmissions of their neighboring nodes. Protocol overhead is generated by packets dedicated for network control and header bits of data packets. It should be reduced as much as possible because transmitting data packet headers or control packets also consumes energy, which results in the transmission of fewer amounts of useful data packets.

Table 1.3. Power consumption of network interface (Cisco AIR-PCM350, Cisco Systems, Inc., Milpitas, CA).

<table>
<thead>
<tr>
<th>Status</th>
<th>Transmit</th>
<th>Receive</th>
<th>Idle</th>
<th>Sleep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power consumption (W)</td>
<td>1.875</td>
<td>1.3</td>
<td>1.08</td>
<td>0.045</td>
</tr>
</tbody>
</table>
1.4.2. Energy consumption model

The sources of energy consumption, with regard to network operations, can be classified into two types: communication related and computation related. Communication involves usage of the transceiver at the source, intermediate (in the case of ad-hoc networks), and destination nodes. The transmitter is used for sending control, route request and response, as well as data packets originating at or routed through the transmitting node. The receiver is used to receive data and control packets – some of which are destined for the receiving node and some are forwarded. Understanding the power characteristics of the mobile radio used in wireless devices is important for the efficient design of communication protocols. As shown in the Figure 1.5 [Marco Fotino et al., 2011], a typical mobile radio may exist in one of the following four modes. Each mode represents a different level of energy consumption.

- **Transmit**: node is transmitting a frame with transmission power $P_{tx}$.
- **Receive**: node is receiving a frame with reception power $P_{rx}$. The energy is consumed even if the frame is discarded by the node (because it was intended for another destination, or it was not correctly decoded).
- **Idle (listening)**: even when no messages are being transmitted over the medium, the nodes stay idle and keep listening the medium with $P_{idle}$.
- **Sleep**: when the radio is turned off and the node is not capable of detecting signals, no communication is possible. The node uses power $P_{sleep}$ that is negligibly small.

The energy dissipated in transmitting ($E_{tx}$) or receiving ($E_{rx}$) one packet can be calculated as:

$$E_{tx} = P_{tx} \cdot duration$$

$$E_{rx} = P_{rx} \cdot duration$$

where, *duration* denotes the transmission duration of the packet. When a transmitter transmits a packet to the next hop, because of the shared nature of wireless medium, all its neighbors receive this packet, even though it is intended to only one of them.
Moreover, each node situated between transmitter range and interference range receives this packet but it cannot decode it. These two problems generate loss of energy. So to compute the energy dissipated by one transmission, we must take into account these losses as follows:

\[ \text{Cost}_{tx} = E_{tx} + n \cdot E_{rx} \]

where \( n \) represents the number of non-sleeping nodes belonging to the interference zone of the transmitter \( i \).

Figure 1.5. Energy consumption in a MANET

1.4.3. Energy related metrics

The aim of energy-aware routing protocols is to reduce energy consumption in transmission of packets between a source and a destination, to avoid routing of packets through nodes with low residual energy, to optimize flooding of routing information over the network and to avoid interference and medium collisions. Thus, the main focus is on designing routing protocols to reduce energy consumption and to increase the lifetime of each mobile node, increasing network life as well. To measure the performance of MANET routing protocol in terms of energy savings, the following five different metrics are defined:

- **Energy consumed per packet.** It is easy to observe that if energy consumed per packet is minimized then the total energy consumed is also minimized. Under light loads, this metric will most likely result in the shortest-hop path. As network load increases, this is not necessarily the case because
the metric will tend to route packets around areas of congestion in the network.

- *Time to network partition.* Given a network topology, a minimal set of mobiles exist such that their removal will cause the network to partition. Routes between the two partitions must go through one of the “critical” mobiles; therefore a routing algorithm should divide the work among these mobiles in such a way that the mobiles drain their power at equal rates.

- *Variance in power levels across mobiles.* The idea behind this metric is that all mobiles in a network operate at the same priority level. In this way, all mobiles are equal and no one mobile is penalized or privileged over any other. This metric ensures that all mobiles in the network remain powered-on together for as long as possible.

- *Cost per packet.* In order to maximize the life of all mobiles in the network, metrics other than energy consumed per packet need to be used. When using these metrics, routes should be created such that mobiles with depleted energy reserves do not lie on many routes. Together, these metrics become the “cost” of a packet, which needs to be minimized.

- *Maximum mobile node cost.* This metric attempts to minimize the cost experienced by a mobile node when routing a packet through it. By minimizing the cost per mobile, significant reductions in the maximum mobile cost result. Also, mobile failure is delayed and variance in mobile power levels is reduced due to this metric. In order to conserve energy, the goal is to minimize all the metrics except for the second which should be maximized.

As a result, a shortest-hop routing protocol may no longer be applicable; rather, a shortest-cost routing protocol with respect to the five energy efficiency metrics would be pertinent. For example, a cost function may be adapted to accurately reflect a battery’s remaining lifetime. The premise behind this approach is that although packets may be routed through longer paths, the paths contain mobile nodes that have greater amounts of energy reserves. Also, energy can be conserved by routing traffic through lightly loaded mobiles, because the energy expended in contention and retransmission is minimized.
1.4.4. **Energy awareness in different layers of protocol**

The software components used in wireless data network systems. Application programs using the network do not interact directly with the network hardware. Instead, an application interacts with the protocol software. The notion of protocol layering provides a conceptual basis for understanding how a complex set of protocols work together with the hardware to provide a powerful communication system. The Figure 1.6 shows how energy conservation can be achieved at different layers in the network protocol stack. Different studies suggest different techniques to handle energy issues in different ways.

**Physical layer**: The physical layer consists of radio frequency (RF) circuits, modulation, and channel coding systems. From an energy efficient perspective, considerable attention has already been given to the design of this layer.

**Data link layer**: The data link layer is responsible for establishing a reliable and secure logical link over the unreliable wire-less link. The data link layer is thus responsible for wireless link error control, security (encryption/decryption), mapping network layer packets into frames, and packet retransmission. A sub-layer of the data link layer, the media access control (MAC) protocol layer is responsible for allocating the time-frequency or code space among mobiles sharing wire-less channels in a region.

**Network layer**: The network layer is responsible for routing packets, establishing the network service type (connection-less versus connection-oriented), and transferring packets between the transport and link layers. In a mobile environment this layer has the added responsibility of rerouting packets and mobility management.

**Transport layer**: The transport layer is responsible for providing efficient and reliable data transport between network end-points independent of the physical network(s) in use.

**OS and Middleware**: The operating system and middleware layer handles disconnection, adaptivity support, and power and quality of service (QoS) management within wireless devices. This is in addition to the conventional tasks such as process scheduling and file system management.

**Application layer**: The application and services layer deals with partitioning of tasks between fixed and mobile hosts, source coding, digital signal processing, and
context adaptation in a mobile environment. Services provided at this layer are varied and application specific.

Each of these layers of protocol stack consume considerable amount of energy, which needs to be minimized for energy efficiency in a MANET. Several research works in this direction have been reported in the literature.

![Protocol stack of a generic wireless network](image)

**Figure 1.6.** Protocol stack of a generic wireless network [Christine E. J. et al., 2001].

### 1.5. Literature review

Mobile computing [S. Narayanaswamy et al., 1996] is proliferating as devices are becoming smaller, cheaper, and more powerful. By combining mobile devices with wireless communication abilities, the vision of being connected anytime, anywhere, anyhow will soon be a reality. New applications arise from mobile entities interacting and collaborating towards a common goal. With cellular phones being widely employed [Bin Xie et al., 2006] and the mobile Internet emerging into the market place, concepts of dynamic wireless networks that do not depend on expensive infrastructure draws attention to the area of ad hoc networks. The ultimate goal of MANETs is to provide efficient routing of data resources to mobile users at anytime and from anywhere. The traditional routing algorithms used for routing in MANETs, namely, DSDV, AODV, DSR etc. do not consider energy as one of the routing metric. The protocol layering
J. et al., 2001] provided in the Figure 1.6 shows how energy conservation can be achieved at different layers in the network protocol stack. The details of different researcher works on energy conservation at different layers is presented below.

**Physical layer.**

Designing electronic circuits to be energy-efficient is technically challenging. The current commercial radio transceivers, such as those proposed for the Bluetooth standard [L. Nord et al., 2000], are not ideal for mobile network applications, since the energy over-head of turning them on and off is high. Thus, innovative solutions in transceiver and protocol design are required to achieve efficient transmission of short packets over short distances. Another challenge arises due to the remote placement of these nodes and the high cost of communication. Since mobile nodes are remotely deployed, transmitting to another mobile node has high energy cost. Thus, the use of data aggregation schemes to reduce the amount of redundant data in the network will be beneficial [A. Wang et al., 1999]. Thus, wireless networks must allow adaptation of underlying hardware by higher level algorithms. By giving upper layers the opportunity to adapt the hardware in response to changes in system state, the environment and the user’s quality constraints, the energy consumption of the node can be better controlled. Thus, reducing energy consumption to extend system life-time is a primary concern in mobile ad-hoc networks. Hence, protocols and algorithms should be designed with saving energy in mind. Unfortunately, without the knowledge of the underlying computation and communication hardware, performing intelligent power management can be difficult. If system designers want to create energy-efficient algorithms and protocols, correct and accurate modeling of the underlying hardware is critical. If physical parameters are ignored, one could end up with an energy inefficient solution that only survives a short time. Due to recent advances in integrated circuit and MEMS technology, it is clear that small, low power sensing devices will be ready to be deployed in sensor networks in the near future.

Many research groups are exploring the issues related to the design of nodes for deployment in MANETs. The WINS [G. Asada et al., 1998] and PicoRadio [J. Rabaey et al., 2000] projects are seeking ways to integrate sensing, signal
processing, and radio elements onto a single integrated circuit. Meanwhile, researchers involved in SmartDust [J. Kahn et al., 1999] aim to design particle-sized nodes for wide-area distributed sensing. The modulation scheme used by the radio is another important factor which can strongly impact the energy consumption of the node. One way to increase the energy efficiency of communication is to reduce the transmission time of the radio. This can be accomplished by sending multiple bits per symbol, that is, by using M-ary modulation. Using M-ary modulation, however, will increase the circuit complexity and power consumption of the radio. In addition, when M-ary modulation is used, the efficiency of the power amplifier is also reduced. This implies that more power will be needed to obtain reasonable levels of transmit output power. The energy consumption of static CMOS-based processors designed in the past couple of decades has been primarily due to switching energy. As circuit designers become more concerned with reducing power consumption, switching energy will become less dominant. Supply voltages are constantly being lowered as an effective way to reduce power consumption. At the lowest level, individual circuits and components are designed for low power. Many special techniques for minimizing power consumption in CMOS circuits, applicable across all of the digital hardware shown in the figure, including DSPs, modems, and processors are discussed in [A.P. Chandrakasan et al., 1995]. Shrinking threshold voltages along with the use of techniques such as parallelism and pipelining continue to reduce power consumption while maintaining performance. New display technologies and improved means of mass storage have brought additional benefits. At the same time, to satisfy ever demanding performance requirements, the threshold voltage is also scaled proportionately to provide sufficient current drive and reduce the propagation delay of signals in an integrated circuit. Thus, processor leakage energy is an important parameter to model when designing a wireless micro sensor network because energy is wasted while no work is done [A. Sinha et al., 2000].

Data Link Layer

The data link layer comprises logical link layer and medium access control (MAC) sublayer, in which the energy consumption needs to be optimized during network operations.
(i) **Logical link layer**

The data link layer's task is to structure each frame, i.e., the atomic unit which passes through the medium, in a way that is most energy efficient given the existing channel conditions. Wireless links are known to experience widely varying channel conditions as compared to their wired counterparts. Effects such as path loss and multipath fading, compounded by device mobility, result in a channel that can experience bit error rates varying over orders of magnitude with bursty bit error characteristics. At the same time, the Quality of Service (QoS) guarantees of the higher layer protocols should still be supported. Toward this end, one may alter the error control strategy and the frame size on a frame by frame basis to keep up with changing conditions while simultaneously minimizing energy consumption. With energy consumption kept as our most important metric in this work, it is important to have an intuitive feel for why a dynamic link layer might be a valuable tool in achieving low power operation. There are a large variety of error control strategies, each with its own advantages and disadvantages in terms of latency, throughput, and ultimately energy efficiency. Broadly, the available schemes fall into the categories of Automatic Repeat reQuest (ARQ), Forward Error Correction (FEC), and hybrids of the two. Within each category, there are numerous options to choose from, for example in terms of the protocol used and scaling of protection. Error control is clearly an old area with the literature dating back to Shannon and Hamming in the context of FEC, and to early work on packet networks in case of ARQ. Books on error control, such as [S. Lin et al., 1983], cover the basic FEC and ARQ schemes well. Much work has been focused on error control in wireless channels. The delay and throughput performance of various FEC and ARQ schemes over ATM wireless links is presented in [S. Yajnik et al., 1995], while hybrid FEC/ARQ scheme for wireless networks are described in [E. Ayanoglu et al., 1995] and [H. Zhao et al., 1996]. An adaptive hybrid error control scheme which makes use of incremental redundancy to improve through-put on a wireless ATM link is discussed in [I. Joe, 1997]. Most relevant is the analytic work on an energy efficient probing ARQ protocol that slows down retransmissions during fades is done in [M. Zorzi, 1997]. Also relevant is the work on AIRMAIL wireless link-layer protocol [E. Ayanoglu et al., 1995]. While not quantifying the impact of various error control options on battery power consumption, the hybrid
ARQ/FEC design of AIRMAIL strived to put the bulk of the complexity at the base station via an asymmetric ARQ protocol instead of equally dividing the complexity between the mobile and the base station. The relative complexity of implementation in terms of code size and processing time is measured in [E. Ayanoglu et al., 1995]. Optimizing frame size for a variety of factors, including the number of hops in a multihop link is discussed in [J.D. Spragins et al., 1991]. Calculating this optimal frame size in the presence of several ARQ schemes based on formulae for packet error rates given bit error rates is also discussed. A simulation based study of throughput improvements with a stop-and-wait ARQ protocol with adaptive packet length chosen according to channel condition estimate is presented in [S. Hara et al., 1996]. A simulation study of potential wireless link throughput improvements using ARQ protocols with adaptive packet lengths is discussed in [J.Y. Park et al., 1995].

(ii) **Medium access control sub layer**

The MAC layer, a sub-layer of the data link layer, is responsible for providing reliability to upper layers for the point-to-point connections established by the physical layer. The MAC sub layer interfaces with the physical layer and is represented by protocols that define how the shared wireless channels are to be allocated among a number of mobile nodes. To design a good MAC protocol for the wireless ad-hoc networks, the following attributes must be considered. The first attribute is the energy efficiency. We have to define energy efficient protocols in order to prolong the network lifetime. Other important attributes are scalability and adaptability to changes. Changes in network size, node density and topology should be handled rapidly and effectively for a successful adaptation. As far as energy efficiency is concerned, the major energy waste comes from idle listening, retransmission, overhearing and protocol overhead. The different techniques of power-aware MAC protocols that reduce energy waste from one or all of the above sources are discussed below.

(a) **Minimize random access collision and the consequent retransmission:**

Collisions should be avoided as far as possible otherwise; the following retransmission will lead to unnecessary energy consumption and longer time delay. One of the fundamental tasks of any MAC protocol is to avoid collisions so
that two interfering nodes do not transmit at the same time. The simplest ways for collision avoidance in a general network include code division multiple access (CDMA), time division multiple access (TDMA), and frequency division multiple access (FDMA). The collision can also be avoided by using control packets and carrier sensing. Carrier sense multiple access with collision detection (CSMA/CD) method widely used in amateur packet radio on shared simplex packet radio channels frequently suffers from "hidden terminal problem" and "exposed terminal problem". The Multiple Access with collision avoidance (MACA) protocol [P. Karn, 1990] greatly solves these problems. MACA can also be easily extended to provide automatic transmitter power control. This could increase the carrying capacity of a channel substantially. The PAMAS protocol [S. Singh et al., 1998], modifies the MACA protocol described in [P. Karn, 1990] by providing separate channels for RTS/CTS control packets and data packets. In PAMAS, a mobile with a packet to transmit sends a RTS (request-to-send) message over the control channel, and awaits the CTS (clear-to-send) reply message from the receiving mobile. Carrier sense multiple access with collision avoidance (CSMA/CA) is a network multiple access method in which carrier sensing is used, but nodes attempt to avoid collisions by transmitting only when the channel is sensed to be "idle".

(b) Minimize idle listening:

In typical MANET systems, receivers have to be powered on all the time. This results in serious energy waste. Since the power consumed in idle listening is significant, attention should be paid to the energy conservation in nodes other than the source and destination. Ideally the radio should be powered on only when it needs to transmit or receive packets, thus remove the unnecessary monitoring of the media. Measurements have shown that idle listening consumes 50-100% of the energy required for receiving. Based on this observation, a new kind of power conservation mechanism is proposed in which some nodes are allowed to stay in doze/sleep state when they are not actively transmitting, receiving, or waiting for a channel ([J.C. Chen et al., 1999], [ETSI TC-RES, 1996], [C.-H. Hwang, 1997]). Obviously, this power off mechanism can save battery power. Thus, it helps prolong the lifetime of hosts and the whole network system. The Power-aware Multi-access Protocol with Signaling (PAMAS) [S. Singh et al., 1998] is proposed to conserve battery power by powering off nodes that are not
transmitting or receiving. This is a combination of the original MACA protocol [P. Karn, 1990], and the use of a separate signal channel - the "busy tone" channel [28]. The SPAN protocol [Chen B et al., 2001] and the Geographic Adaptive Fidelity (GAF) protocol [Xu Y et al., 2001] employ the master-slave architecture and put slave nodes in low power states to save energy. Unlike SPAN and GAF, Prototype Embedded Network (PEN) protocol [Girling G et al., 1997] practices the sleep period operation in an asynchronous way without involving master nodes. A new power conservation scheme for multi-hop ad hoc networks is proposed in [Selma Ikiz et al., 2002]. A virtual backbone consisting of special nodes (coordinators) is used for the power saving algorithm and routing. It is based on distributed algorithm for constructing a connected dominating set (CDS) that is used to construct and maintain the virtual backbone of the network. The scheme includes a message history based variable sleeping time for the non-coordinators. A scheme for prolonging the lifetime of dense sensor networks that selects a set of active nodes to be used for sensing and communication activities is proposed in [Sharad Kumar Verma, 2011]. This scheme maintains the total sensing coverage achieved by the initially deployed nodes. It reconfigures the network periodically and distributes the energy consumption load more evenly among the nodes. An adaptive scheduler for determining an effective sampling schedule, given dynamic system conditions is presented. An Energy based Ad-Hoc on-Demand Routing algorithm that balances energy among nodes so that a minimum energy level is maintained among nodes and the life of network is increased is discussed in [MortezaMaleki et al., 2002]. Minimum energy threshold limit is set for a mobile node, when a node reaches this threshold limit, it goes to sleep mode. This makes the nodes to conserve their energy and extend the lifetime of the MANET. An Energy based Ad hoc on-Demand Routing algorithm that balances energy among nodes so that a minimum energy level is maintained among nodes and the life of network is increased is proposed in [Ramakant S. Komali et al., 2006]. It sets the minimum energy threshold limit of a mobile node, when a node reached up to the threshold limit the node goes to sleep mode, save energy and join in the event as long as possible.
(c) Minimize overhearing:

Wireless nodes consume power unnecessarily due to overhearing the transmissions of their neighbors. This is often the case in a typical broadcast environment. One solution to this problem is the introduction of a control channel for the transmission of control signals that will wake up the nodes only when needed. Another solution for overhearing avoidance is to power off interfering nodes after they hear an RTS or CTS packet [Y. Wei Ye et al., 2002]. A mechanism based on broadcast schedule that contains the data transmission starting times for each mobile node is proposed in [K.M. Sivalingam et al., 2000].

(d) Minimize control overhead:

Protocol overhead should be reduced as much as possible, especially for transmitting short packets. Due to the large channel acquisition overhead, small packets have disproportionately high energy costs. Header compression can be used to reduce packet length, thus achieving energy savings. Since significant energy is consumed by the mobile radio when switching between transmit and receive modes, packet aggregation for header overhead reduction will be useful. When mobile nodes request multiple transmission slots with a single reservation packet, the control overhead for reservation can be reduced. Allocating contiguous slots for transmission or reception to reduce the turnaround also helps to achieve low power consumption [J.C. Chen et al., 1999].

(e) Control transmission power:

The transmission power determines the range over which the signal can be coherently received, and is therefore crucial in determining the performance of the network (throughput, delay, and energy consumption). The selection of the “best” transmission range has been investigated extensively in the literature. It has been shown that a higher network capacity can be achieved by transmitting packets to the nearest neighbor in the forward progress direction. The intuition behind this is that halving the transmission range increases the number of hops by two but decreases the area of the reserved floor to one fourth of its original value, hence allowing for more concurrent transmissions to take place in the same
neighborhood. When a node’s radio transmission power is controllable, its direct communication range as well as the number of its immediate neighbors is also adjustable. While stronger transmission power increases the transmission range and reduces the hop count to the destination, 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 an MANET via transmission power adjustment and the primary objective is to maintain a connected topology using the minimal power. Flow augmentation routing (FAR) [Chang J.H et al., 2000], Online max-min routing (OMM) [Li Q et al., 2001] and power aware localized routing (PLR) [Stojmenovic I et al., 2001] protocols fall into this category.

The main goal of minimum energy routing (MER) protocol [Doshi S et al., 2002] 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. Transmission power control provides an opportunity to save energy by utilizing intermediate nodes between two distant nodes. However, the resultant path with many short-range links may perform worse than a path with fewer long-range links in terms of latency as well as energy consumption. This is because the path with many short-range links would cause more link errors that would result in more retransmissions [Banerjee S et al., 2002]. To deliver packets with minimum energy, the transmission power control approach adjusts each node’s radio power and allows different transmission power levels at different nodes. However, in order for the link-level connectivity of a MANET to work correctly, any pair of communicating nodes must share a bidirectional link [Narayanaswamy S et al., 2002]. The DPAECR [U.Raghavendra et al., 2011], uses per packet power calculation of the links and updates the sender, the required transmission power. Thus the sender updates its transmission power and sends the data packets using that power. After each node receives the data packet they calculate the required transmission power and update the sender by sending a reply packet. As the sender updates the required transmission power the energy utilization will be reduced. The impact of individual variable-range power control on the physical and network connectivity, network capacity, and power savings of wireless
multihop networks such as ad hoc and sensor networks has been investigated in [Javier Gomez et al., 2007].

A new protocol which considers both areas of routing and energy has been proposed in [Jangsu Lee et al., 2010]. It proposes a more efficient routing method which minimizes the spread of unnecessary control messages. And also, an energy aware method is proposed to select proper transmission power by the distance between nodes. And finally, a new function to select next hop which considers both of distance and energy is proposed. A novel algorithm based on-demand energy-aware routing protocol, UBPCR [utility-based power control routing is proposed in [Chan-ho Min et al., 2007]. It reduces the trade-offs that arise in the energy-aware route selection mechanisms that have recently been proposed for mobile ad hoc networks. This approach is based on an economic framework that represents the degree of link’s satisfaction (utility). With UBPCR, the utility function for any transmitter-receiver pair is defined as a measure of the link’s preference regarding the signal-to-interference-and-noise ratio (SINR), the transmit power, and the transmitter’s residual battery capacity. During a route-searching process, each intermediate node between the source and the destination is executed via two consecutive phases: the scheduling phase and the transmit power control phase. The scheduling algorithm finds the proper qualified data slot for the receiving channel so that the transmissions of independent transmitters can be coordinated. The transmit power control determines the optimal power, if one exists, that maximizes the corresponding link’s utility.

A novel energy efficient route discovery scheme with transmission power control for ad-hoc networks has been proposed in [Masaki Bandai et al., 2008]. It improves energy efficiency without any information about neighboring nodes. When a node receives RREQ packet, it calculates the routing level back-off time as being inversely proportional to the received power of RREQ. After the route discovery, source and intermediate nodes transmit packets by using power controlled MAC protocol. A novel algorithm for clustering of nodes by transmission range based clustering (TRBC) is introduced in [S.Muthuramalingam et al., 2010]. This algorithm does topology management by the usage of coverage area of each node and power management based on mean
transmission power within the context of wireless ad-hoc networks. By reducing the transmission range of the nodes, energy consumed by each node is decreased and topology is changed. Formation of cluster and selection of optimal cluster head and thus forming the optimal cluster taking weighted metrics like battery life, distance, position and mobility is done based on the factors such as node density, coverage area, contention index, required and current node degree of the nodes in the clusters. This algorithm helps in reducing the system power consumption and prolonging the battery life of mobile nodes. A distributed power control protocol [Pierpaolo Bergamo et al., 2004] is proposed as a means to improve the energy efficiency of routing algorithms in ad-hoc networks. Each node in the network estimates the power necessary to reach its own neighbors, and this power estimate is used both for tuning the transmit power (thereby reducing interference and energy consumption) and as the link cost for minimum energy routing. The purpose of topology control is to assign per-node optimal transmission power such that the resulting topology satisfies certain global properties such as connectivity. Due to the multi-hop nature of ad-hoc networks, establishing network connectivity may require nodes to use their power resources to service other nodes. Since nodes have limited power they may act selfishly in order to minimize their power (energy) consumption.

Game theory is a suitable tool to analyze the conflicting objectives of nodes seeking to achieve an energy-efficient and connected network in the presence of selfish nodes. A very general game theoretic framework of topology control that provides incentives to nodes in a manner so that a global objective such as connectivity can be realized is presented in [Maurizio D'Arienzo et al., 2011]. A distributed power control algorithm with power restrictions originated from a game theoretical frame work is presented in [Ramakant S. Komali et al., 2006]. This algorithm (GT-DPC) is developed over a continuous transmit power domain unlike general power controlled systems which work with discrete power sets. The performance of the algorithm is evaluated as a static, multi-stage nonzero-sum, non-cooperative game. The principles of power control, which form the basis for the design of power aware routing protocols, have been discussed in [S.-M. Senouci et al., 2004]. The designs of a sequence of increasingly complex protocols, which address the multidimensional ramifications of the power control problem,
have also been discussed. Energy Efficient Routing in Mobile Ad hoc Networks based on AODV Protocol [Jing et al., 2004] modifies the popular on demand routing protocol AODV to make it energy aware. The proposed algorithm also varies the transmission power between two nodes as per their distance.

**Network layer**

The main functions of the network layer are routing packets and congestion control. In wireless mobile networks, the network layer has an added functionality of routing under mobility, power constraints and mobility management including user location, update, etc. In a multi-hop routing, if the same nodes are used frequently for routing as they happen to be part of the shortest path, such nodes lose their battery power sooner than other nodes. This leads to network partitioning. To avoid this, the traditional MANET routing protocols are modified so that the load of routing is to be shared among all the nodes. Thus the 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, ensure longer network lifetime. The LEAR routing protocol [Woo K et al., 2001] based on DSR, 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 relays messages if the corresponding route is selected. However, in LEAR, a node determines whether to forward the route-request message or not depending on its residual battery power (RE). When RE is higher than its threshold value \( \text{RE}_{\text{TH}} \) the node forwards the route-request message; otherwise, it drops the message and refuses to participate in relaying packets. Therefore, the destination node will receive a route-request message only when all intermediate nodes along a route have good battery levels, and nodes with low-battery levels can conserve their battery power. LEAR is a distributed algorithm where each node makes its routing decision based only on local information such as \( \text{RE} \) and \( \text{RE}_{\text{TH}} \). As \( \text{RE} \) decreases with the passing of time, the
value of $RE_{TH}$ must also be decreased adaptively in order to identify energy-rich and energy-hungry nodes in a relative sense. For example, if the source node does not receive any reply for a route-request message, the source re-sends the same route-request message. If an intermediate node receives the duplicate request message, it adjusts (i.e. lowers) it’s $RE_{TH}$ to allow forwarding to continue. A sequence number is used to distinguish between the original and the re-sent route-request message.

As in LEAR, the CMMBCR protocol [Toh C.K et al., 2001] uses the concept of a threshold to maximize the lifetime of each node and to use the battery fairly. If all nodes in some possible routes between a source–destination pair have larger remaining battery energy than the threshold, the min-power route among those routes is selected. An energy saving routing protocol named ECAODV based on AODV is proposed in [Yonghuichen et al., 2010]. During route discovery, the source node not only takes the residual energy of the intermediate nodes and hops, but also considers the influence of motivation of those nodes imposed on the topology of network. A new energy and delay aware protocol called energy and delay aware TORA (EDITORA) based on extension of Temporally Ordered Routing Protocol (TORA) is proposed in [R. Asokan et al., 2008].

At query phase, nodes that do not have required energy and delay are eliminated. Each node upon receipt of the query packet, determines whether to forward this request based on its energy level and delay or not. At the destination, update packet is generated. Energy-aware Node-disjoint Multipath Routing (ENDMR) protocol, which balances node energy utilization to increase the network lifetime is proposed in [M. Bheemalingaiah et al. 2009]. It takes network congestion into account to reduce the routing delay and increases the reliability of the packets reaching the destination. A new protocol with global path energy as an additional metric for route selection is proposed in [Qutaiba A. Razouqi et al., 2006]. This protocol, referred to as maximum energy path routing based on AODV (MEP-AODV), studies the impact of the added metric in improving the lifespan of the MANET. In Hint Based Routing Protocol (HBP), the nodes discover an active path to the destination exploiting a set of routing meta-information (called hints). The active paths based on hint computation is alone not sufficient for nodes
in the ad hoc network for which there may be energy loss during packet transfer leading to disconnection. To avoid path loss a new energy efficient hint based routing approach [B. Manasa et al., 2010] has been proposed. It outperforms the existing HBP protocol by inheriting the node handoff strategy into the HBP protocol which finds the active shortest path based on hint computation followed by route maintenance based on power of the nodes in the active route.

A novel approach to modify route request broadcast based on node caching is proposed in [Nisar Hundewale et al., 2010]. The intuition behind node caching is that the nodes involved in recent data packet forwarding have more reliable information about its neighbors and have better locations (e.g., on the intersection of several data routes) than other nodes. Nodes which are recently involved in data packet forwarding are cached, and used to forward route a request which makes the protocol more energy efficient. The Ad-hoc On-Demand Distance Vector (AODV) protocol performs routing based on the metric of least number of hops. To extend the lifetime of the ad-hoc networks, AODV energy aware routing protocol (AODVEA) [Radhika D.Joshi et al., 2007] is used, which performs routing based on the metric of minimum remaining energy. In this paper, an efficient modified AODV (AODVM) routing protocol is proposed which performs routing based on the combination of least hops and minimum remaining energy. An Energy Efficient Location Aided Routing (EELAR) protocol for MANETs that is based on the Location Aided Routing (LAR) has been introduced in [Mohammad A. Mikki, 2010]. EELAR makes significant reduction in the energy consumption of the mobile nodes batteries by limiting the area of discovering a new route to a smaller zone. Thus, a control packet overhead is significantly reduced. 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. At 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. A Routing Protocol based on AODV for extending network life time through the residual battery and link stability (EBL) in MANET is proposed in [Gun Woo Park et al.,2008] The EBL considers distance among neighbor nodes, residual battery capacity and link stability. It minimizes energy consumption and
allows balanced energy consumption in MANET. An energy-efficient routing protocol for MANETs that minimizes energy consumption and increases the network’s consistency has been proposed in [Sanjay Kumar Dhurandher et al., 2009]. The protocol, energy-efficient ad hoc on-demand routing protocol (EEAODR) focuses on increasing the network longevity by distributing energy consumption in the network.

A new minimum energy routing scheme based on a newly developed energy consumption models for common wireless ad-hoc networks that take the energy consumption in sending control packets into account has been proposed in [Jinhua Zhu et al., 2004]. A lifetime prediction routing protocol for MANETs that maximizes the network lifetime by finding routing solutions that minimize the variance of the remaining energies of the nodes in the network has been presented in [MortezaMaleki et al., 2003]. It achieves this by doing local decisions with minimum overhead. A game theoretic approach to conserve energy in MANET routing is developed in [Borges.V et al., 2010]. An ad-hoc network model is defined and the conditions under which the nodes participating in the communication can form Nash equilibrium is identified. It follows a distributed approach in calculating the routes to a destination depending on the individual battery energy of each of the nodes in that route. For this Nash Equilibrium is used as a greedy algorithm, dynamically, to determine whether a node will use its battery power for routing packets through it. An overview of game-theoretic approaches to energy-efficient resource allocation in wireless networks is presented in [FarhadMeshkatti et al., 2007]. Game theory can be used as an effective tool to study resource allocation in wireless networks with quality-of-service (QoS) constraints. A family of non-cooperative (distributed) games in which each user seeks to choose a strategy that maximizes its own utility while satisfying its QoS requirements is presented. The utility function considered here measures the number of reliable bits that are transmitted per joule of energy consumed and, hence, is particularly suitable for energy-constrained networks. Cooperation among mobile nodes can improve the overall energy efficiency of an ad hoc network has been demonstrated in [He et al., 2010]. By exploiting a behavior-tracking algorithm inspired by the results of game theory and allowing traffic to be forwarded only towards cooperative nodes, can dramatically reduce power wastage, at the same time maximizing the delivery rate.
Under this perspective, cooperation can definitely be seen as an incentive for all nodes, since it allows optimizing one of the most crucial parameters impacting the performance of ad hoc networks. A novel approach called ant-based energy-aware disjoint multipath routing algorithm (AEADMRA) is proposed in [Wu et al., 2010]. AEADMRA is based on swarm intelligence and especially on the ant colony-based meta-heuristic. AEADMRA can discover multiple energy-aware node-disjoint routing paths with a low routing overhead. A new power-aware source-initiated (on demand) routing protocol for mobile ad hoc networks that increase the network lifetime is presented in [Zheng Shi et al., 2010]. It adopts a greedy policy to fetch paths from the cache to make sure no path would be overused and also to make sure that each selected path has minimum battery cost among all possible path between two nodes.

A novel energy based local maintenance protocol EBLM is introduced in [Shilpi Jain K et al., 2012]. In routing discovery mechanism, relevant algorithm is adopted according to the different levels of node’s remaining energy. This hybrid routing protocol considers not only power conservation, but also protecting nodes with scarce battery. The EEMLAR (Energy Efficient Maximum Lifetime Ad-Hoc Routing) algorithm to improve the networks lifetime in MANET is proposed in [Sowmya K S F et al., 2012]. It considers residual node energy, previously used paths, and also the message overhead into account while establishing the energy efficient path. A load balancing using clustering technique is proposed in [ShwaitaKodesia et al., 2012]. The entire region is divided into clusters and the cluster leader and cluster sub leaders are identified. To provide better QoS for real time traffic in MANETs, clustering technique is used along with multicasting/broadcasting. Ant Colony Optimization (ACO) along with the rule based approach is used to balance load of a mobile node to achieve QoS. An approach to utilize location information using Geographical Routing Protocol (GRP) to improve performance of Dynamic Source routing protocols for mobile ad hoc networks is proposed in [Naigende Duncan et al., 2012]. By using location information, the proposed GRP with Location Aware Routing (LAR) protocols limits the search for a new route to a smaller request zone of the mobile ad hoc network. EEDSR, an extension of DSR that reduces routing overhead by limiting the number of route discovery and maintenance packets in the MANET is discussed.
in [SeemaVerma et al., 2012]. The scheme involves use of bigger packet headers for the source route discovery packets since they contain information about the energy levels of the nodes in the route cache. In EEDSR, since the RREQ packets are flooded once for each communication period, routing overhead is minimized.

**Transport layer**

The transport layer provides a reliable end-to-end data delivery service to applications running at the end points of a network. The most commonly used transport protocol for wired networks, where underlying physical links are fairly reliable and packet loss is random in nature, is the Transmission Control Protocol (TCP). However, due to inherent wireless link properties, the performance of traditional transport protocols such as TCP degrades significantly over a wireless link. TCP and similar transport protocols resort to a larger number of retransmissions and frequently invoke congestion control measures, confusing wireless link errors and loss due to handoff as channel congestion. This can significantly reduce throughput and introduce unacceptable delays [R. Cáceres et al., 1995]. As stated earlier, increased retransmissions unnecessarily consume battery energy and limited bandwidth. Various schemes have been proposed to alleviate the effects of non-congestion-related losses on TCP performance over networks with wireless links. These schemes, which attempt to reduce retransmissions, are classified into three basic groups: (i) split connection protocols, (ii) link-layer protocols, and (iii) end-to-end protocols. Split connection protocols completely hide the wireless link from the wired network by terminating the TCP connections at the base station. This is accomplished by splitting each TCP connection between the source and destination into two separate connections at the base station. The result is one TCP connection between the wired network and the base station and a second TCP connection between the base station and the mobile. The second connection over the wireless link may use modified versions of TCP that enhance performance over the wireless channel. Examples of split connection protocols include Indirect-TCP [A. Bakre et al., 1995], Berkeley Snoop Module [H. Balakrishnan et al., 1995], and M-TCP [K. Brown et al., 1997]. The link layer approach which attempts to hide link related losses from the TCP source by using a combination of local retransmissions and forward error
correction over the wireless link. Local retransmissions use techniques that are
tuned to the characteristics of the wireless channel to provide significant increase
in performance.

The protocols described previously generally achieve higher throughput
rates over the wireless channel than standard TCP because the protocols are
better able to adapt to the dynamic mobile environment. However, the
performance of a particular protocol is largely dependent upon various factors
such as mobility handling, amount of overhead costs incurred, frequency and
handling of disconnections, etc. Therefore, performance and energy conservation
may range widely for these protocols depending upon both internal algorithm and
external environmental factors. Although the above protocols, along with many
others proposed in re-search, have addressed the unique needs of designing trans-
port protocols in the wireless environment which may or may not lead to greater
energy efficiency, they have not directly addressed the idea of a low-power
transport protocol. The energy consumption of Tahoe, Reno, and New Reno
versions of TCP is analyzed in [M. Zorzi et al., 2000]. Energy consumption is the
main parameter studied with the objective of measuring the effect of TCP
transmission policies on energy performance. The energy efficiency of a protocol is
defined as the average number of successful transmissions per energy unit, which
can be computed as the average number of successes per transmission attempt. A
two-state Markov packet error process is used in the performance evaluation of a
single transceiver running the various versions of TCP on a dedicated wireless
link. Results of the study demonstrate that error correlation significantly affects
the energy performance of TCP and that congestion control algorithms of TCP
actually allow for greater energy savings by backing off and waiting during error
bursts. It is also seen that energy efficiency may be quite sensitive to the version of
TCP implemented and the choice of protocol parameters.

The same versions of TCP were studied in [V. Tsaoussidis et al., 2000] in
terms of energy/throughput tradeoffs. Simulation results show that no single TCP
version is most appropriate within wired/wireless heterogeneous networks, and
that the key to balancing energy and throughput performance is through the error
control mechanism. Using these results, the authors propose a modified version of
TCP, referred to as TCP-Probing, in [V. Tsaoussidis et al., 2000]. In TCP-Probing, data transmission is suspended and a probe cycle is initiated when a data segment is delayed or lost, rather than immediately invoking congestion control. A probe cycle consists of an exchange of probe segments between sender and receiver. Probe segments are implemented as extensions to the TCP header and carry no payload. The TCP sender monitors the network through the probe cycle which terminates when two consecutive round-trip-times (RTT) are successfully measured. The sender invokes standard TCP congestion control if persistent error conditions are detected. However, if monitored conditions indicate transient random error, then the sender resumes transmission according to available network bandwidth. Simulation results provided in [V. Tsaoussidis et al., 2000] indicate that TCP-Probing achieves higher throughput rates while consuming less energy. Therefore, the authors believe that TCP-Probing provides a universal error control mechanism for heterogeneous wired/wireless networks. The authors also present in [V. Tsaoussidis et al., 2000] an experimental transport protocol, called Wave and Wait Protocol (WWP), developed specifically for a wireless environment with limited power.

**OS/middleware**

The design of operating systems, middleware, files systems etc. is directly or indirectly influenced by mobility. It also presents a new set of challenges that result from power constraints and voluntary disconnections. The majority of the techniques used in the design of today’s applications to conserve bandwidth and battery life. The main function of an operating system is to manage access to physical resources like CPU, memory, and disk space from the applications running on the host. To reduce power dissipation, CPUs used in the design of portable devices can be operated at lower speeds by scaling down the supply voltage [A. Chandrakasan et al., 1995]. Due to the quadratic relationship between power and supply voltage, halving the supply voltage results in one fourth of the power being consumed. To maintain the same throughput, the reduction in circuit speed can be compensated by architectural techniques like pipelining and parallelism. These techniques increase throughput resulting in an energy efficient system operating at a lower voltage but with the same throughput. The operating system is active in relating scheduling and delay to speed changes.
Another technique of power management at this layer is predictive shutdown [A. Chandrakasan et al., 1995]. A study of different page placement algorithms that exploit the new power management features of memory technology is presented in [A.R. Lebeck et al., 2000]. CPU scheduling techniques that attempt to minimize power consumption are presented in [J. Lorch et al., 1997, M. Weiser et al., 1994]. The impact of software architecture on power consumption is studied in [H. Mehta et al., 1997, V. Tiwari et al., 1994].

**Application layer**

The application layer in a wireless system is responsible for such things as partitioning of tasks between the fixed and mobile hosts, audio and video source encoding/decoding, and context adaptation in a mobile environment. Energy efficiency at the application layer is becoming an important area of research as is indicated by industry. APIs such as Advanced Configuration and Power Interface [Intel Corporation, 2000] and power management analysis tools such as Power Monitor [Intel Corporation, 2000] are being developed to assist software developers in creating programs that are more power conserving. Another power management tool developed at Carnegie Mellon University is PowerScope [J. Flinn et al., 1999]. PowerScope maps energy consumption to program structure, producing a profile of energy usage by process and procedure. Nearly 46% reduction in energy consumption is observed of an adaptive video playing application by taking advantage of the information provided by PowerScope. Challenged by power and bandwidth constraints, applications may be selectively partitioned between the mobile and base station [M. Weiser et al., 1994, S. Narayanaswamy et al., 1996]. Thus, most of the power intensive computations of an application are executed at the base station, and the mobile host plays the role of an intelligent terminal for displaying and acquiring multimedia data [S. Narayanaswamy et al., 1996]. Another means of managing energy and bandwidth for applications on mobile clients is to use proxies. Proxies are middleware that automatically adapt the applications to changes in battery power and bandwidth.

**1.6. Motivation**

Wireless network devices, especially in ad hoc networks, are typically battery-powered. The growing need for energy efficiency in wireless networks, in
general, and in mobile ad hoc networks (MANETs), in particular, calls for power enhancement features. A layered approach for energy efficient routing protocols used for mobile ad-hoc networks. It broadly classifies different energy efficient routing protocols based on the technique/approach they use. It is found that each protocol has a different technique, different objective with different assumptions and employs different means to achieve the objective. When the transmission power is controllable, the optimal adjustment of the power level is essential not only for energy conservation but also for the interference control. When node density or traffic density is far from uniform, a load distribution approach must be employed to alleviate the energy imbalance problem. The sleep/power-down mode approach is essentially independent of the other two approaches because it focuses on inactivity energy. These issues provide motivation for development of more energy efficient routing protocols possibly by combining multiple approaches that exist at different layers which results in a cross-layer design approach.

1.7. Objectives of the thesis

The objective of present research is to study the existing algorithms for routing in MANETs especially, energy aware routing algorithms, and to design and develop better, energy efficient routing algorithms for MANETs. The proposed research is to develop routing protocols for MANETs which provide higher network lifetime with minimum energy consumption. The simulation experiments for performance analysis of proposed algorithms is done using NS2 simulator. Thus, the following objectives are set:

- To study and compare the existing routing algorithms for MANETs and compare their performance in terms of energy efficiency apart from other performance parameters.
- To apply load balanced routing technique based on threshold battery residual energy, to the MANETs, so that, same nodes are repeatedly not used for routing.
- To apply fuzzy technique to determine threshold value for load balanced routing in MANETs.
• To explore the impact of selfish nodes on the lifetime of the MANETs and also the impact of application of fuzzy based load balancing technique on the network with selfish nodes.
• To develop adaptive transmission power control technique along with fuzzy based load balancing technique.
• To design a routing protocol based on cross layer design approach with fuzzy based load balanced routing at network layer and fuzzy based adaptive transmission power control at MAC layer.

1.8. Organization of the thesis

The thesis is organized into nine chapters. In Chapter 1, wireless networks, wireless LANs and their applications, and challenges are discussed. An introduction to MANETs, their applications and their challenges are presented.

In the Chapter 2, the impact of the variations in the different performance measures due to varying transmission range for different number of nodes, namely, 10, 50 and 100 and the different energy models, on the routing protocols AODV, DSR, DSDV are analyzed in terms of system performance metrics, namely, packet delivery fraction (PDF), throughput, end to end delay and energy consumption.

In the Chapter 3, a new protocol that conserves energy of mobile nodes is proposed, which enhances the lifetime of the MANET. It is an on-demand routing protocol that is based on load balancing scheme. The proposed load aware energy efficient routing protocol (LAEE), which is a modified AODV routing protocol, uses adaptive threshold energy, which is the average residual energy of all the neighboring nodes at each hop.

In the Chapter 4, an on-demand routing protocol based on adaptive fuzzy threshold energy (AFTE) is proposed. The energy of a mobile node is conserved by employing fuzzy based threshold energy for each node which is a function of the residual energy of neighbors of that node.

In the Chapter 5, a new power efficient routing protocol, namely, fuzzy thresholded power aware location aided routing (FTPALAR) is proposed. In this
In case, routing is based on the location of the node and also on its residual energy. The nodes that are nearer to the baseline and whose residual energy is greater than adaptive fuzzy based threshold energy are considered for routing. Thus, the routing takes place in the direction towards the destination.

In the Chapter 6, the impact of selfish nodes on the lifetime of the MANET is investigated. This study is done for different node densities and different selfish node concentrations.

In the Chapter 7, a comprehensive energy optimized cross layer routing algorithm based on adaptive transmission range (ATR) and adaptive fuzzy threshold energy (AFTE) is proposed using ad-hoc on demand distance vector routing (AODV) and a position based routing protocol, namely, Location Aided Routing (LAR). Transmission power is varied in accordance with the required transmission range ensuring sufficient number of mobile nodes to maintain network connectivity.

In the Chapter 8, a novel cross layer design approach based on fuzzy adaptive transmission range and a power aware routing based on fuzzy threshold energy is proposed and as applied to AODV and LAR. The performance comparison of the proposed method is done to demonstrate its superiority over other methods.

Finally, the conclusions and future directions of the present research work are discussed in the Chapter 9.